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Rubber plantation and its relationship with topographical factors in the border region of China, Laos and Myanmar

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Abstract: Rubber plantation is the major land use type in Southeast Asia. Monitoring the spatial-temporal pattern of rubber plantation is significant for regional land resource development, eco-environmental protection, and maintaining border security. With remote sensing technologies, we analyzed the rubber distribution pattern and spatial-temporal dynamic; with GIS and a newly proposed index of Planted Intensity (PI), we further quantified the impacts and limits of topographical factors on rubber plantation in the border region of China, Laos and Myanmar (BRCLM) between 1980 and 2010. The results showed that: (1) As the dominant land use type in this border region, the acreage of rubber plantation was 6014 km^2 in 2010, accounting for 8.17% of the total area. Viewing from the rubber plantation structure, the ratio of mature- (≥10 year) and young rubber plantation (<10 year) was 5:7. (2) From 1980 to 2010, rubber plantation expanded significantly in BRCLM, from 705 km^2 to 6014 km^2, nearly nine times. The distribution characteristics of rubber plantation varied from concentrated toward dispersed, from border inside to outside, and expanded further in all directions with Jinghong City as the center. (3) Restricted by the topographical factors, more than 4/5 proportion of rubber plantation concentrated in the appropriate elevation gradients between 600 and 1000 m, rarely occurred in elevations beyond 1200 m in BRCLM. Nearly 2/3 of rubber plantation concentrated on slopes of 8°–25°, rarely distributed on slopes above 35°. Rubber plantation was primarily distributed in south and east aspects, relatively few in north and west aspects. Rubber planted intensity displayed the similar distribution trend. (4) Comparative studies of rubber plantation in different countries showed that there was a remarkable increase in area at higher elevations and steeper slopes in China, while there were large appropriate topographical gradients for rubber plantation in Laos and Myanmar which benefited China for rubber trans-boundary expansion. (5) Rubber plantation in BRCLM will definitely expend cross borders of China to the territories of Laos and Myanmar, and the continuous expansion in the border region of China will be inevitable.

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1 Introduction

With the deepening of economic globalization and regional economic integration, natural rubber becomes increasingly important in the global, and the pattern of supply and demand has changed significantly. According to the International Rubber Study Group, China has become the world's largest rubber consumer and importer since 2001 with an increasing demand of natural rubber. Up to over 97% of natural rubber exporters to China are countries in Southeast Asia (IRSG, 2011). Cultivated area of natural rubber in China reached 10,140 km^2 in 2010, accounting for 8.6% of the global rubber planted areas. The natural rubber production in China is only 6.3% of global share, while the consumption reached 33.4% of global consumption. The degree of external dependence on rubber import in China is more than 80%, which indicates future supply and demand situation is not optimistic (Mo *et al*., 2011). Acreage of rubber plantation in Yunnan Province accounts for 48.0% of that in China, and the natural rubber yield is 47.9% of the total output in China. Meanwhile, in Xishuangbanna, the rubber acreage accounts for 55.7% of Yunnan Province, and production is 77.2% of Yunnan. Rubber plantation has become the pillar agricultural industry with the largest planting scale, the widest business scope, the best overall benefit, the highest marketing level, and the most participants (YBS *et al*., 2011). Xishuangbanna is the most appropriate region for rubber plantation with the suitable climate, soil, and water conditions, and is the perfect place for developing the rubber manufacturing industry in China. To be sure, northern Laos and northeastern Myanmar have the similar natural environment with Xishuangbanna in China, which indicates BRCLM is suitable for planting similar crops. Therefore, the BRCLM becomes the optimal rubber planting area for Chinese investment.

BRCLM has attracted much international attention due to the special geo-economics and geo-politics characteristics, as well as being the hinterland of the world's famous "Golden Triangle". United Nations Office on Drugs and Crime (UNODC) reported that opium poppy cultivation in Laos and Myanmar continuously reduced before 2006 and increased significantly after 2006 in those two countries. In 2010, the area of opium poppy in Myanmar reached 381 km^2, with East Shan State accounting for 32% of the country. Meanwhile, Laos had 30 km^2 of opium poppy plantations which mainly distributed in the northern mountainous areas (UNODC, 2011). With the "Opium Poppy Substitution Planting" (OPSP) being the crucial field of cooperation in the neighboring countries of "Golden Triangle" and vital project supported by national and international organizations, rubber tree becomes one of the most important substitution planting crops. China has implemented the OPSP projects abroad and given priority to rubber plantation (including other 41 alternative crop types) since 1990 throughout seven provinces of Laos in the northern mountainous areas and Shan State and Kachin State of Myanmar in the northern highland (DCY, 2009).

Ziegler *et al*. (2009) pointed out that there were more than 5000 km^2 natural forest lands converting into rubber plantations in China, Laos, Myanmar, Thailand, Cambodia, Vietnam and other countries in Southeast Asia. And the most obvious land use and land cover changes in BRCLM were the decreasing natural forest lands and the increasing rubber plantations. Fox *et al*. (2005) and Kummer *et al*. (2007) considered the global demands for natural rubber and the benefits for the investors from China, Thailand and Vietnam as the main driving forces for rubber planting in the mountainous areas. Rubber tree had become another commercial substitution planting crop of opium poppy in the traditional illegal crops cultivated area (Manivong *et al*., 2007; Paul, 2009). Fox (2009) found that about 50 years ago, the landscape of the "Golden Triangle" was very similar. Yet, in recent decades, land use patterns have changed rapidly, with forest coverage declined and rubber plantation expanded after opening up the border area since the early 1990s, especially in the areas near villages, small towns and roads. Li *et al*. (2007) got the same conclusion that most tropical forest land was converted into rubber plantation in Xishuangbanna. Thongmanivong *et al*. (2006; 2009) held that the rise of rubber plantation in Luang Namtha Province was due to the local government required to clear natural forest in the border near China for border security on one side, and on the other side, being considered as the most potential commercial crop, rubber tree can reduce farmers' dependence on swidden cultivation. Liu *et al*. (2010) found that the area of opium poppy decreased or even eliminated in the alternative planting areas in the northern part of Laos, and rubber plantation was the largest alternative land use type, accounting for 64% of substitution planting crops. Mon *et al*. (2012) discovered that the border region with Xishuangbanna in northern Myanmar (Shan State Special Region 4) had become a successful model of alternative cultivation for opium poppy, and rubber plantation became the dominated land use type in this border region of Myanmar.

Accurate and up-to-date monitoring and mapping of rubber plantation rapidly by means of remote sensing has important scientific value and guiding significance for rational distribution of rubber plantation, eco-environmental protection, and planning decision support of the department concerned. Currently, the majority extraction of rubber plantation using remote sensing was in the exploratory stage. The mainstream approach was pixel-based Maximum Likelihood Classification with accuracy of 80% approximately (Li *et al.*, 2007; Li *et al.*, 2008; Zhang *et al.*, 2010; Li *et al.*, 2011). Object-oriented classification method has gradually been applied with general accuracy of 85%, which indicated that this method was better than the previous method (Ekadinata *et al.*, 2004; Liu *et al.*, 2010; Liu *et al.*, 2012). Although these methods had the high classification accuracy, yet all of them concerned about immature or mature rubber forest. Indeed, rubber tree belongs to the perennial deciduous vegetation type, which means that there are significant spectral differences between rubber forest at different growth stages. Extraction area of rubber plantation is always smaller than the actual value because of lack of young rubber forest. Some scholars tried to extract rubber plantation according to the spectral differences in three stages and achieved higher classification accuracy. Ekadinata *et al.* (2004) discriminated rubber plantation into three classes which implies differences in complexity: young rubber forest (<10 years), mature rubber forest (10–30 years) and old rubber forest (>30 years) using Landsat ETM images based on object-oriented classification method in Bungo district of Indonesia. Li *et al.* (2012) extracted rubber plantation covering the whole Southeast Asia from rubber trees (≥ 4 years) and rubber trees (< 4 years) using MODIS images based on Mahalanobis typicality method. Liu *et al*. (2012) discriminated rubber plantation from young rubber forest (<10 years) and mature rubber forest (≥ 10 years) using Landsat TM based on object-oriented classification method in Xishuangbanna. Compared with 4-year intervals, 10-year intervals were more suitable for rubber plantation extraction in BRCLM according to the growth rules of rubber trees.

Rubber plantation distribution has obvious geographical features because it requires specific water and heat conditions. The decisive factor for rubber plantation is climate, but in regions with complicated topography, geomorphic features are the decisive factors to determine the reallocation of climatic elements (TBRCSY, 1960). Topographic factors, such as elevation, slope and aspect, are the background factors of land use and land cover types, and the restricted factors of land use intensity in heterogeneous landscape. The relationship between spatial-temporal land use change and topographic features is the important field of land use and land cover change research, because those factors not only reallocated regional water, heat and nutrient, but also influenced human activities on land use ways and degrees (Turner *et al*., 1996; Zhou, 2001). Altitude changes have a major impact on the growth and physiological metabolism of rubber forests, which ultimately affect biomass accumulation (Jia *et al*., 2006). The upper limit of elevation suitable for rubber plantation varies with different latitude and topographic features. In light of light condition differences resulted from aspects, rubber trees grow better in south aspect than north aspect, and in southeast aspect than northwest aspect (XDAPLMAZO, 1986). Rubber plantation mainly distributed in the intermontane basin and hilly regions with elevations below 1000 m in Jinghong City and Mengla County (Zhang *et al*., 2006). The maximum altitude of rubber plantation can be increased in hilly regions, but the planting elevation should not be too high for the sake of economic interest (Wang, 1982). Meanwhile, rubber trees would be better to plant in the places with slopes less than 35° (Zhou, 2008). Overall, topographic features are not only the important parameters for mapping rubber plantation using remote sensing data, but also the critical indicators for selecting land for planting rubber trees, which have significant influence on spatial distribution of rubber plantation.

Driven by natural rubber prices and OPSP policy, rubber plantation will undoubtedly expand in future in the border region of China, Laos and Myanmar. Therefore, this study selected four important periods in BRCLM, namely the 1980s for the opening up of the border in Yunnan Province, China; 1990s for the opening up of the border in northern Laos and establishing the "Golden Economic Quadrangle Region" in the border of China, Laos, Myanmar and Thailand; 2000s for the cooperating between China and ASEAN (Association of Southeast Asian Nations); 2010s for officially launching the China-ASEAN Free Trade Area. Based on the four periods of rubber plantation distribution maps extracting from Landsat MSS/TM/ETM imagery data according to the previous research (Liu *et al.*, 2012), this study analyzed the spatial-temporal patterns and distribution characteristics of rubber plantation in BRCLM systematically. Topographic features, such as elevation, slope and aspect were extracted from DEM with a 30-m resolution using geographic information system technology. Relationship between spatial-temporal changes of rubber plantation and topographic factors was analyzed respectively. The purpose of this study was to provide scientific basis and decision support for rational distributions of rubber plantation and regional sustainable development in the border region of China, Laos and Myanmar.

2 Materials and methods

2.1 Study area

BRCLM (19°48′–22°36′N, 98°56′–103°00′E) is the border region of southwest China, northern Laos and northeast Myanmar, and is located in the middle and lower reaches of the Mekong River Basin. The borderline length of China-Laos, China-Myanmar, and Laos-Myanmar is 714 km, 542 km, and 238 km, respectively. Located to the south of the Tropic of Cancer, this region has a tropical and sub-tropical monsoon climate. The annual mean temperature is 10℃ to 22℃, and its annual precipitation ranges from 1000 to 2400 mm. The year is divided into dry season from November to April of the following year and rainy season from May to October which accounts for more than 80% of the annual precipitation. The region has mountain-valley topography with altitude ranging from 267 m to 2555 m above the sea level. With the landforms of highland or plateau, the terrain of this region is higher in the west and north, and lower in east and south. BRCLM is one of the places with the world richest biodiversity and tropical rainforest, and with three typical vegetation types, namely subalpine vegetation, low mountain vegetation and monsoon forests. BRCLM includes three regions in southwest China (Jinghong City, Menghai County, and Mengla County), three provinces in northern Laos (Luang Namtha Province, Phongsaly Province, and Oudomxay Province), and two districts in northeast Myanmar (Kengtung District and Mongphat District) (Figure 1). The region covers nearly 74 000 km^2 with a population of

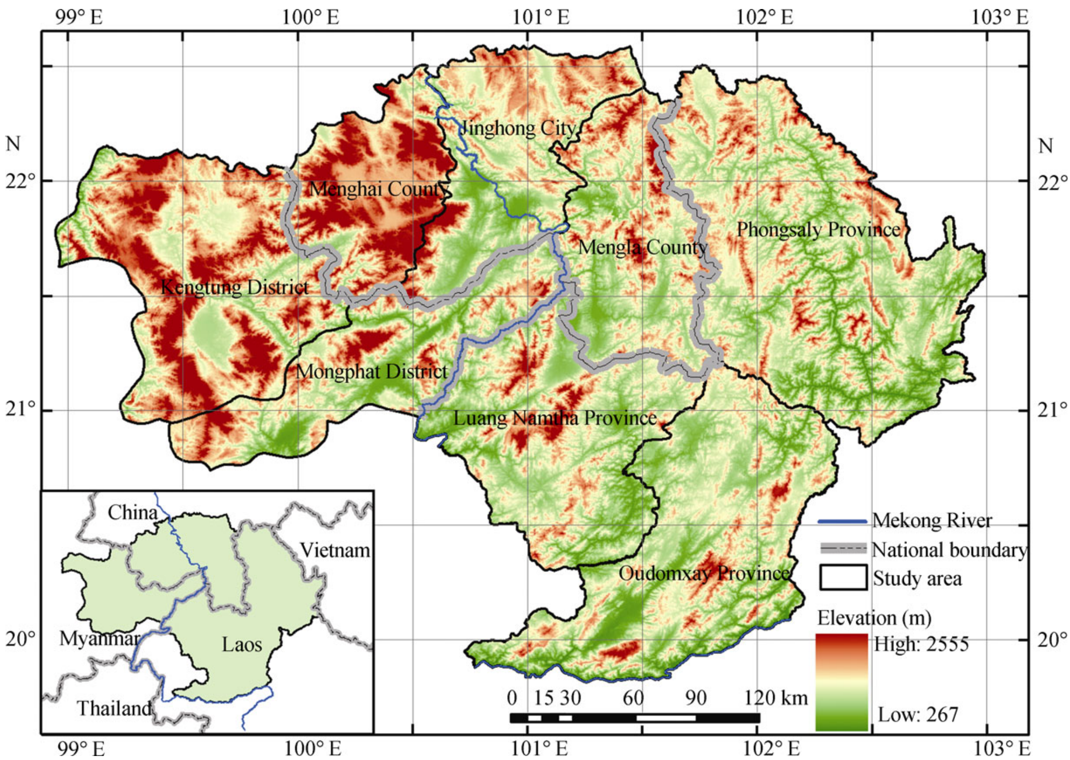

Figure 1 The location and topography of the study area
Note: The administrative maps are from Global Administrative Areas (GADM) database, and special region 4 of Myanmar is not included in the GADM Version 2 in January 2012

2 million in 2010. BRCLM is a multi-ethnic region with more than 20 ethnic groups living across borders, including Dai, Kachin, Shan, Wa, Miao, Yao, Hani, Lisu and other ethnics (Chen *et al*., 2000).

Agriculture plays an important role in Xishuangbanna, and rubber plantation has become the pillar industry of the state economy. The three provinces in northern Laos (Luang Namtha, Phongsaly, and Oudomxay) have cultivated opium poppy traditionally, and are the parts of drugs sources of the "Golden Triangle" and the major investment areas for China's OPSP policy implementation. East Shan State in Myanmar is the world-known best opium poppy cultivated place, and opium poppy is regarded as the special economic crop in this place. In 2010, the acreage of opium poppy cultivation in East Shan State is 121 km^2, accounting for 32% of poppy cultivation in Myanmar, which indicates that the situation of drug control is still not optimistic. BRCLM will be the opium poppy substitution planting region under international cooperation, and rubber trees will be the dominate alternative crops.

2.2 Data sources and data preprocessing

Two types of satellite data were used in this study, namely Landsat Multispectral Scanner (MSS)/Thematic Mapper (TM)/Enhanced Thematic Mapper Plus (ETM) and Moderate Resolution Imaging Spectroradiometer (MODIS). Four periods of Landsat images were selected, namely 1980s, 1990s, 2000s, and 2010s. For the sake of comparing and analyzing, this study used the year of 1980, 1990, 2000 and 2010 for short. In this study, MODIS Terra 8-day composite 250 m time-series products (MOD09Q1) from January to December in 2010 were used to generate MODIS-NDVI data through band math. According to the MODIS-NDVI time series analyses of different land use types, all Landsat images were acquired during the dry season between January and April for rubber plantation extraction (Table 1).

Global Digital Elevation Model (GDEM) with a 30-m resolution and topographic maps

Table 1 List of remote sensing images of Landsat MSS/ETM/TM

Datasets	Path	Row	Date	Datasets	Path	Row	Date
1980	138	45	1973-01-24	1990	130	46	1989-02-03
	138	46	1976-02-23		131	45	1989-02-03
	139	44	1976-04-18	2000	129	45	2000-03-23
	139	46	1976-02-23		129	46	2000-03-07
	139	45	1980-03-01		130	44	2000-03-14
	139	46	1980-03-19		130	45	2000-03-14
	140	44	1976-03-14		130	46	2000-03-14
	140	45	1980-03-02		131	45	2000-03-21
	140	46	1976-02-25	2010	129	45	2009-03-08
	141	45	1980-02-14		129	46	2011-04-15
1990	129	45	1989-03-25		130	44	2010-05-05
	129	46	1989-03-25		130	45	2010-02-14
	130	44	1989-01-11		130	46	2011-04-22
	130	45	1989-01-27		131	45	2011-02-16

(1:100000) are obtained respectively from Computer Network Information Center, Chinese Academy of Sciences (CAS) and library of Institute of Geographic Sciences and Natural Resources Research, CAS (Figure 2a). Based on ArcGIS software, exceptional value and nodata value of DEM data were dealt with Nibble tool (Spatial Analyst Tools/ Generalization/ Nibble) and Raster Calculator (con(isnull([DEM]), focalmean([DEM], [DEM])). Field survey samples were acquired in Xishuangbanna from November 3rd to 25th in 2010 and in Laos from February 24th to March 18th in 2013 (Figure 2b). Two types of land use/land cover maps can be used as references for remote sensing interpretation. Land use maps of Xishuangbanna with a scale of 1:100000 in the 1980s, the 1990s and 2000 were developed from Data Center for Resources and Environmental Sciences, CAS (RESDC), and GlobCover2009 datasets of Laos and Myanmar with a 300-m resolution in 2009 were developed from European Space Agency (ESA).

Based on the topographic maps, and field survey samples (Figure 2), the TM satellite images were rectified to Albers Conical Equal Area projection system in 2010. The process adopted Cubic Convolution resampling method and Polynomial transform geometric correction method. The ETM and MSS images were registered to the TM images using an image-to-image registration technique with 30 m pixel size: rectification RMS errors were controlled less than 0.5 pixels. Some remote sensing images with small acreage in the study area were clipped by vector map of study region and mosaicked with neighbouring remote sensing images with large acreage.

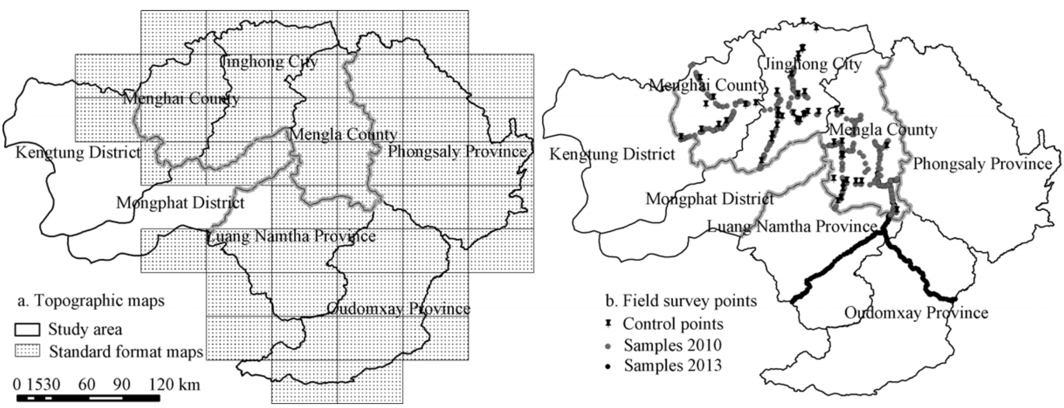

Figure 2 Topographic maps with 1:100000 scale (a) and field survey samples (b)

2.3 Methodology

The conceptual framework of this study was very clear and feasible as shown in Figure 3. According to spectral differences between rubber forests at different growth stages and existed research results, we divided rubber plantation into young rubber forest (< 10 years old) and mature rubber forest (⩾ 10 years old) (Liu *et al*., 2012). Firstly, rubber plantation was extracted using TM images in 2010, with overall classification accuracy of mature rubber forest (91.07%), and young rubber forest (77.06%). Secondly, based on the general rule of rubber tree growth, the mature rubber forest grow from the young rubber forest. Therefore, rubber plantation was obtained in 1980, 1990 and 2000 based on the distribution maps of mature- and young rubber forests in 2010. The total classification accuracy of rubber plantation from 1980 to 2010 was 82.3%, 84.7%, 86.9% and 85.2%, which can meet the demand of spatial-temporal analysis and practical application. Spatial-temporal distribution characteristics and national differences of rubber plantation in BRCLM were analyzed during 1980–2010. The relationship between topographic factors (elevation, slope and aspect) and spatial-temporal pattern changes of rubber plantation were analyzed respectively.

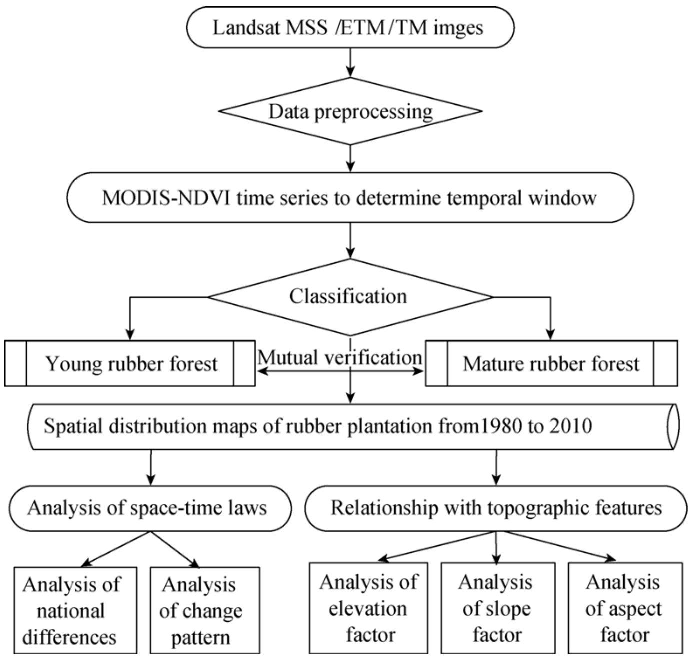

Figure 3 The conceptual framework

In order to analyze the spatial-temporal change patterns of rubber plantation in different topographic factors, this study constructed the index of planted intensity (*PI*). Formula is as follows:

$$PI_i = PA_i / OA_i \quad (1)$$

where PI_i is the proportion of rubber planted area with total area under *i* (the gradients of elevation, slope and aspect) topographic factor (%), PA_i is the planted area of rubber forest under *i* topographic factor (km^2), and OA_i is the total area under *i* topographic factor (km^2).

3 Results and analyses

3.1 Spatial-temporal pattern analysis of rubber plantation

In 2010, the area of rubber plantation in BRCLM was 6014 km^2, accounting for 8.17% of the total area. Rubber plantation was the dominant land use type influenced by human activities in this study area. Rubber plantation was mainly distributed in Jinghong City and Mengla County of Xishuangbanna in China, and also in Kengtung District and Mongphat District of Myanmar, and Luang Namtha Province and Phongsaly Province of Laos. The areas of mature- and young rubber forests were 2502 km^2 and 3512 km^2, with a ratio of 5:7. In terms of spatial pattern, both types of rubber plantation have a hugh difference. Mature rubber forest showed aggregated distributions and the circle-layer expansions with the intermontane basins as centers, mainly distributed in Jinghong City, Mengla County, the border region of Mengla County and Phongsaly Province, and the border region of Menghai County and Kengtung District. Young rubber forest showed dispersed distributions and the circle-layer expansions with mature rubber forest as centers, mainly distributed in the border region of northern part of Mengla County and Phongsaly Province, the border region of Jinghong City and Mongphat District, the border region of Menghai County and Kengtung District, and the intermontane basin of Luang Namtha Province (Figure 4d).

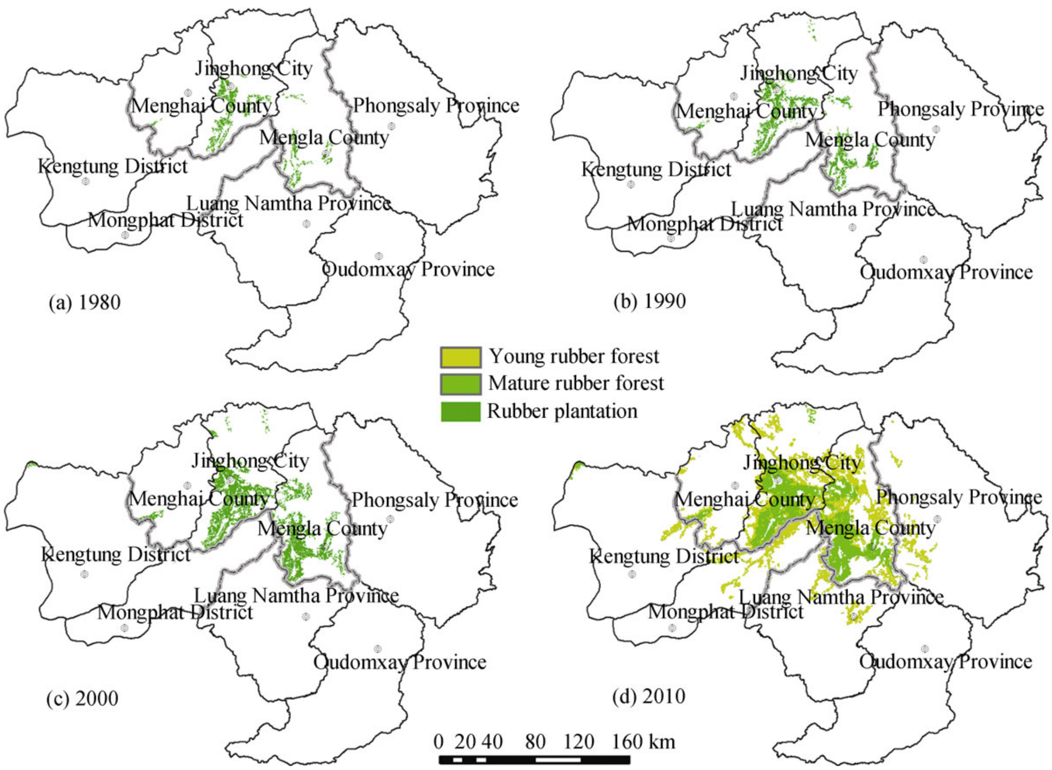

Figure 4 Spatial distributions of rubber plantation in BRCLM from 1980 to 2010

3.1.1 National differences of rubber plantation distribution

In 2010, nearly 83.31% of rubber plantation was distributed in China, and over half of them was mature rubber forest. The proportion of rubber plantation area was only 6.60% in Laos, and almost all was young rubber forest. Rubber plantation in Myanmar accounted for 10.09% and 7.30% of which was mature rubber forest.

There were significant national differences in planted area between countries. Rubber plantation area in China was 5010 km^2, accounting for 83.31% of the total rubber plantation. Some 77.27% of rubber plantation was distributed in Jinghong City and Mengla County, while only 6.04% occurred in Menghai County. Mature rubber forest accounted for 49.02% of the total planted areas in Xishuangbanna, and were concentrated in Jinghong City and Mengla County, and a few distributed in Daluo Town of Menghai County. Young rubber forest accounted for 50.98% of the total planted areas in Xishuangbanna, which indicated that rubber plantation expanded rapidly in the recent decade. The expansion of rubber plantation mainly occurred in the northeast of Mengla County, the border region of Laos, and the northern part of Jihong City at high latitudes.

Rubber plantation area in Laos was 397 km^2, accounting for 6.60% of the total planted areas. Apart from Oudomxay Province, both Luang Namtha and Phongsaly Provinces had rubber plantation, especially in the border region with China, namely the western Phongsaly Province and northeast of Luang Namtha Province. Phongsaly Province had 174 km^2 of rubber plantation, while Luang Namtha Province had 223 km^2. There were small mature rubber forests with an area of 2 km^2 accounting for 0.50% in Laos, which was distributed in the northern part of Luang Namtha Province. Young rubber forest accounted for 99.50% of the total planted areas in Laos, and was concentrated in the border regions of northeast Luang Namtha Province and western Phongsaly Province. In Laos, rubber trees were planted in the recent 10 years, mainly in the border region neighboring with China.

Rubber plantation area in Myanmar was 607 km^2, accounting for 10.09% of the total planted areas. Most of rubber plantation distributed in the eastern Kengtung District and northern Mongphat District. The area of rubber plantation in Mongphat District was 450 km^2, which was the major planted area in the border region of China and Myanmar. Mature rubber forest accounted for 7.30% of the total planted areas in Myanmar, mainly distributed in the border between Mongphat District and Jinghong City, the border between Kengtung Disrict and Menghai County and the northwest of Kengtung District. Mongphat District had nearly twice as much as mature rubber forest as Kengtung District. Young rubber forest accounted for 92.70% of the total planted areas of Myanmar, and was concentrated in Mongphat District near the border of Jinghong City in China and Kengtung District near the border of intermontane basin of Menghai County in China.

3.1.2 Distribution changes of rubber plantation

Spatial-temporal change pattern analysis of rubber plantation in BRCLM showed that the distribution characteristics of rubber plantation varied from concentrated to dispersed, from border inside to outside, and expanded further in all directions with Jinghong City as an expanding center from 1980 to 2010 (Figure 5 and Table 2).

During 1980–1990, rubber plantation area in BRCLM expanded from 705 km^2 to 1286 km^2 with an increment of 581 km^2 and a growth rate of 58 km^2/a. Rubber plantation in this period was mainly distributed in the following intermontane basins, like Jinghong, Menglong and Ganlan in Jinghong City (64.82%) as well as Mengla and Mengman in Mengla County (32.62%), showing a radiation expansion model from the original distribution center. Rubber plantation area in Jinghong City, Mengla County and Menghai County increased by 302 km^2, 259 km^2 and 18 km^2, respectively. Rubber plantation showed a trend of expansion across borders. Kengtung District was the first place to plant rubber forest with an increase of 2.18 km^2 located in the border region of Daluo Town in Menghai County of China and the northwest border with Shan State Special Region 2. There was a notable rubber expansion trend in the border region of China and Myanmar. With the implementation of the reform and opening up policy of China, border trades were developed in Yunnan Province actively due to frontier advantages, and the cross-border business in the border region of China and Myanmar was given high priority for development by government of Yunnan Province in

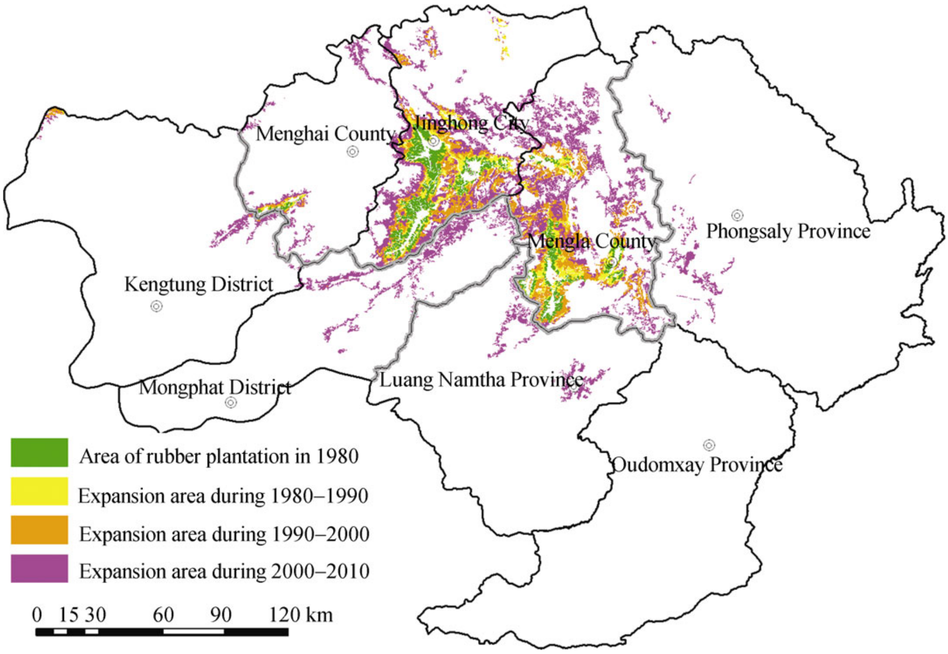

Figure 5 Spatial expansion of rubber plantation in BRCLM from 1980 to 2010

Table 2 Annual and inter-annual area change of rubber plantation in BRCLM from 1980 to 2010

Region	Annual area (km^2)				Area of inter-annual changes (km^2)			
	1980	1990	2000	2010	1980–1990	1990–2000	2000–2010	1980–2010
Within China	705	1284	2580	5010	579	1296	2430	4305
Jinghong City	457	759	1316	2288	302	557	972	1831
Menghai County	18	36	69	363	18	33	294	345
Mengla County	230	489	1195	2359	259	706	1164	2129
Within Laos			2	397		2	395	397
Luang Namtha Province			2	223		2	221	223
Phongsaly Province				174			174	174
Within Myanmar		2	33	607	2	31	574	607
Kengtung District		2	29	157	2	27	128	157
Mongphat District			4	450		4	446	450
BRCLM	705	1286	2615	6014	581	1329	3399	5309

1980. In 1985, *Temporary Provisions on Border Trade of Yunnan Province* was issued in order to further relax the policies of border trades. Daluo border port in Menghai County has a long history of cross-border trade. Since the 14th century, Daluo port has been an important channel for tea trade in southern Yunnan Province and post for cross-border trade of Southeast countries. Therefore, the border region of Menghai County in China and Kengtung District in Myanmar becomes an important breakthrough for rubber plantation expansion from China to Myanmar in BRCLM.

During 1990–2000, rubber plantation in BRCLM rose from 1286 km^2 to 2615 km^2 with an increase of 1329 km^2 and a growth rate of 133 km^2/a. The planting area of rubber plantation has been continuously expanding, with Jinghong City, Mengla County and Menghai County increased by 557 km^2, 706 km^2 and 33 km^2, respectively. Meanwhile, in Kengtung District of Myanmar, rubber plantation also increased by 29.05 km^2, while Mongphat District started to plant rubber forest with an area of 4.06 km^2 which became another border region for rubber plantation expansion. Additionally, rubber plantation emerged in Luang Namtha Province of Laos along the border with Mengrun Town of Mengla County in China, with an area of 2 km^2. Rubber plantation crossed the border of China and Laos, expanded further in Laos. In the early 1990s, based on its own regional advantages, Yunnan Province promoted OPSP abroad in the "Golden Triangle" region. Rubber forest planted prosperously in the neighboring border region of Laos and Myanmar driven by the OPSP policy. The border ports of Mohan in Mengla County of China and Moten in Luang Namtha Province of Laos were opened in 1993, while the "Golden Economic Quadrangle Region" was established in the same year. The border regions of China with Laos and Myanmar has turned into the preferred substitution planting areas and also the spearhead region of cross-border rubber plantation owing to those policies and economic and international cooperation mechanisms.

During 2000–2010, rubber plantation in BRCLM went up from 2615 km^2 to 6014 km^2 with an increase of 3399 km^2, a growth rate of 340 km^2/a faster compared with other periods. The expansion proportion of rubber plantation in China dropped to 71.49%, while increased to 11.62% and 16.89% respectively in Laos and Myanmar. The main rubber planting expansion in China occurred in Jinghong City and Mengla County. The increased area of rubber plantation in Mengla County, Jinghong City and Menghai County was namely 1164 km^2, 972 km^2 and 294 km^2, which was much larger compared with the last decade. As in Laos, rubber plantation expanded in Luang Namtha Province, meanwhile appeared in Phongsaly Province with an area of 174 km^2. In Phongsaly Province, rubber plantation was mainly distributed in Boon Neua District near Mengla Town in Mengla County and Nhot Ou District near Jiangcheng County in Pu'er City of China. The bilateral border crossing between Mengkang in Jiangcheng County and Sobhun in Nhot Ou District was opened officially in July 2011, and the border crossing between Manzhuang in Mengla County and Pakhar in Boon Neua District will be opened in the future (MFA of PRC, 2011). The opening up of border crossings will undoubtedly encourage the expansion of rubber plantation in the border region of China and Laos. Rubber plantation expansion was also found in Myanmar. Rubber expansion in Mongphat District was much faster than that in Kengtung District, with an expansion area of 446 km^2, accounting for 77.70% of the total expansion area in Myanmar. Since 2000, the cooperations between China and ASEAN countries have become more closely. OPSP cooperation was intensified and the results were even more significant because of the establishment of the China-ASEAN Free Trade Area in 2010 as well as the further rise of international rubber price, both will serve as important driving forces to promote rubber plantation expansion in BRCLM. It can be predicted that future expansion of rubber plantation will take place in BRCLM, especially in Laos and Myanmar.

3.2 Relationship between rubber plantation distribution and topographic factors

Based on the distribution maps of rubber plantation in four periods of 1980, 1990, 2000 and 2010 and the DEM data with a 30-m resolution of the same remote sensing images used, this study analyzed the relationship between the expansion of rubber plantation and topographic features including elevation, slope and aspect. Holding the inner relationship between rubber plantation and topographic factors, the results can provide the scientific basis and decision support for land suitability evaluation, eco-environmental impact assessment, and planning guide of rubber plantation and regional sustainable development.

3.2.1 Relationship with elevation factor

The original elevation structure of BRCLM was analyzed in 200 m intervals (Table 3). The elevation between 400 m and 1600 m is the main range in the study area, accounting for nearly 95%, which indicates that the landforms of BRCLM are primarily hills and mountains. The leading elevation is from 600 m to 1200 m, accounting for 70% of the total area, and the area ranges from 1200 m to 1600 m, accounting for 22% of the total area. Except for Menghai County and Kengtung District, other regions show the similar elevation structure with the study area.

Table 3 The original elevation structure in BRCLM (%)

Elevation (m)	BR CLM	Jinghong City	Menghai County	Mengla County	Luang Namtha Province	Pongsaly Province	Oudomxay Province	Kengtung District	Mongphat District
267–400	0.08			0.00	0.00	0.32	0.90	0.01	0.00
400–600	5.43	4.50	0.12	3.52	8.85	7.39	10.86	0.71	10.70
600–800	18.89	19.35	3.40	21.98	29.70	23.50	27.49	7.00	20.76
800–1000	25.89	26.31	8.75	27.95	30.85	32.87	35.04	19.11	24.80
1000–1200	22.56	26.37	20.61	25.39	17.70	22.28	17.34	24.16	22.26
1200–1400	14.91	16.26	27.83	13.80	8.25	10.26	5.94	22.07	13.04
1400–1600	7.30	4.60	20.36	5.21	3.17	2.94	2.01	15.26	5.01
1600–1800	3.45	1.80	13.12	1.90	1.27	0.41	0.41	7.92	1.97
1800–2000	1.10	0.59	4.53	0.25	0.21	0.02	0.01	2.78	0.80
2000–2555	0.38	0.22	1.28	0.00	0.00			0.98	0.66

Based on structure analysis above, the distribution characteristics and planted intensity of rubber plantation in different elevation gradients in 1980, 1990, 2000, and 2010 were discussed in BRCLM (Table 4 and Figure 6a). The results showed that rubber plantation was mainly distributed in elevations ranging from 400 to 1200 m, and more than 4/5 concentrated in the appropriate elevation gradients between 600 and 1000 m, rarely occurred in elevations beyond 1200 m. For the period from 1980 to 2010, the proportion of rubber plantation area decreased between 600 and 800 m, while increased in the range of 800–1000 m. Rubber plantation expanded to the areas below 600 m, and especially the regions above 1000 m, which indicated that there was a remarkable increase in areas at higher elevations. Meanwhile, the planted intensity of rubber plantation gradually increased in the elevation gradients between 400 and 1200 m. Although the proportion of rubber planted area decreased from 96.26% to 51.24% in the elevations below 800 m, the planted intensity increased from 6.64% to 29.05% during the past 30 years. Thus, it was obvious to find that rubber plantation was primarily limited to the elevations below 1200 m in BRCLM. Rubber plantation had achieved great planted intensity in the appropriate elevation gradients of China, and expanded in areas at higher elevations in China and across the border in the appropriate elevations in Laos and Myanmar.

Table 4 The area proportion of rubber plantation in different elevation gradients (%)

Elevation (m)	1980	1990			2000				2010			
	BR CLM/CN	BR CLM	CN	MMR	BR CLM	CN	LAO	MMR	BR CLM	CN	LAO	MMR
400–600	15.08	11.49	11.51		7.53	7.18	3.84	12.10	5.64	3.71	10.51	19.06
600–800	80.18	78.06	78.07	80.74	65.82	66.04	73.27	84.04	45.60	42.86	67.91	54.18
800–1000	4.73	10.30	10.30	19.26	25.07	25.20	22.89	3.86	34.59	37.20	19.00	22.53
1000–1200	0.01	0.15	0.12		1.57	1.57			11.79	13.46	2.58	3.28
1200–1400					0.01	0.01			1.90	2.20		0.89
1400–1600									0.33	0.39		0.06
1600–1800									0.13	0.15		
1800–2000									0.02	0.03		

Note: CN=Within China; MMR=Within Myanmar; LAO=Within Laos

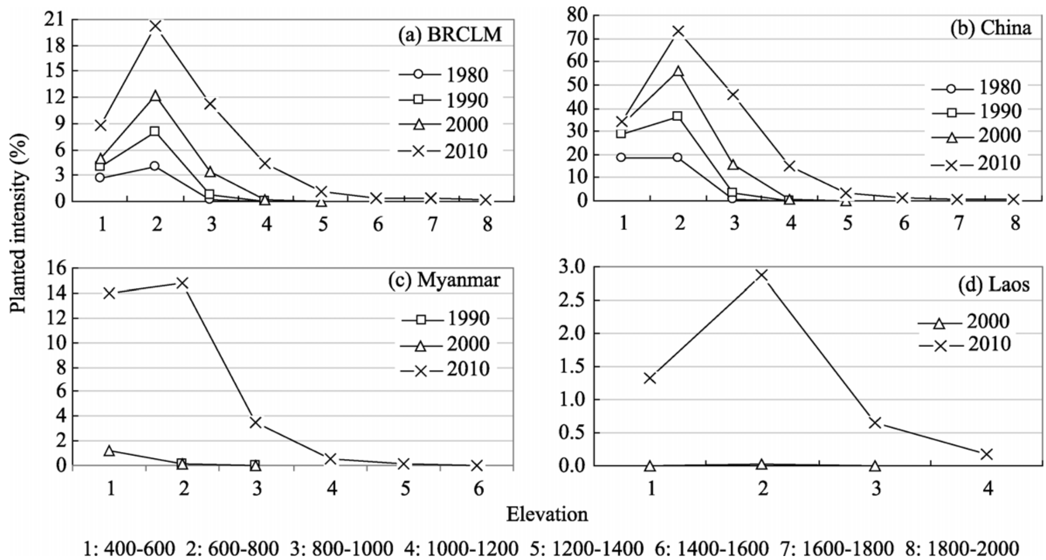

Figure 6 The planted intensity of rubber plantation in different elevation gradients

During 1980–2010, rubber plantation expanded to areas at higher elevations with wider range of expansion in China, and gradually increased the planted intensity (Table 4 and Figure 6b). The highest elevation for rubber planted was in Jinghong City, rising from 1044 to 1998 m, while the lowest elevation was 453 m in Mengla County with the range rising from 591 to 1545 m. Rubber plantation mainly occurred between 600 and 800 m, and gradually expanded to the gradients of 800–1000 m and 1000–1200 m, even higher elevations. The planted intensity of rubber plantation in the gradients of 600–800 m increased from 18.36% to 73.21% with an increase of 54.85%, while in the gradients of 800–1000 m rose from 0.78% to 45.76% with an increase of 44.98%. Rubber plantation had reached strict high intensity in those two gradients. Without counting natural forest reserves, the planted intensity of rubber plantation had reached 80% and 60% respectively in that two mentioned elevation gradients, which indicated that there was a limited potential for rubber expansion in the elevations between 600 and 1000 m in the future, and rubber plantation expansion will occur in areas with elevations above 1000 m or below 600 m. It is inevitable for rubber expansion crossing border of China into Laos and Myanmar.

During 1990–2010, rubber plantation expanded fluctuating around the appropriate elevation gradients between 600 and 800 m with a wider elevation range in Myanmar, and increased continually the planted intensity (Table 4 and Figure 6c). The highest elevation for rubber forest increased from 843 m in Kengtung District to 1580 m in Mongphat District, while the lowest decreased from 622 m in Kengtung District to 427 m in Mongphat District, with nearly five times range increasing from 221 to 1163 m. Rubber plantation was mainly distributed in elevations between 400 and 1000 m, more than half concentrated in the most appropriate gradients of 600–800 m, rarely in areas above 1000 m. Rubber planted intensity went up obviously in the gradients of 400–600 m and 600–800 m, nearly 14%–15% in 2010. Compared with China, the territory of Myanmar still has a wide space for rubber planting with great potential in the future.

During 2000–2010, rubber plantation showed an obvious characteristic of expending to higher and lower elevations surrounding the most appropriate gradients of 600–800 m with a wider elevation range in Laos with the planted intensity increasing gradually (Table 4 and Figure 6d). The highest elevation for rubber plantation increased from 931 m in Luang Namtha Province to 1200 m in Phongsaly Province, while the lowest fell from 573 to 423 m in Luang Namtha Province. The elevation range for rubber planting increased more than twice, namely from 358 to 777 m. Rubber plantation was mainly distributed in elevations between 400 and 1000 m, more than 2/3 concentrated in the most appropriate gradients of 600–800 m, rarely in areas above 1000 m, which was similar with the distribution characteristics of rubber plantation in Myanmar. Rubber plantation had a powerful expansion trend in gradients of 600–800 m with planted intensity close to 3%, which was similar with the original elevation structure in Laos. Compared with China, Laos still has huge development space for rubber plantation because of the extremely low planted intensity in the appropriate elevation gradients.

3.2.2 Relationship with slope factor

The slope gradients are divided into 6 types according to the industrial standard issued by The Ministry of Water Resource of the People's Republic of China in 1997, namely slight slope (<5°), gentler slope (5°–8°), gentle slope (8°–15°), sharp slope (15°–25°), steep slope (25°–35°), and abrupt slope (>35°) (MWR of PRC, 1997). The slope structure in BRCLM is dominated by gentle and sharp slopes with proportion 61.25%, and gentler and steep slopes of 24.78%. The proportion of slopes below 35°, which are suitable for rubber plantation (Zhou, 2008), accounts for 96% in BRCLM. Similar slope structures show in the sub-regions with BRCLM (Table 5).

Based on the analysis above, the distribution characteristics and planted intensity of rubber plantation in different slope gradients in 1980, 1990, 2000, and 2010 were discussed in BRCLM (Table 6 and Figure 7a). The results showed that 90% of rubber plantation was mainly distributed in slopes below 25°, nearly 2/3 concentrated in the appropriate slope gradients between 8° and 25°, rarely in slopes above 35°. From 1980 to 2010, the area proportion of rubber plantation in slopes below 15° declined, while in slopes above 15° increased. The expansion of rubber plantation mainly occurred between 15° and 35° and gradually extended in steep and abrupt slopes. Meanwhile, the planted intensity of rubber plantation

Table 5 The original slope structure in BRCLM (%)

Slope (°)	BR CLM	Jinghong City	Menghai County	Mengla County	Luang Namtha Province	Pongsaly Province	Oudomxay Province	Kengtung District	Mongphat District
<5	10.02	12.32	12.48	8.39	9.25	6.04	14.06	9.59	11.15
5–8	10.17	11.55	11.07	9.15	10.36	8.20	11.40	10.22	11.12
8–15	28.16	30.27	29.40	27.21	29.65	26.99	26.04	28.50	29.70
15–25	33.09	31.87	32.19	34.06	33.95	36.73	28.59	33.03	32.47
25–35	14.61	11.52	12.12	16.08	13.58	17.52	14.99	14.53	12.59
>35	3.95	2.47	2.74	5.11	3.21	4.52	4.92	4.13	2.97

Table 6 The area proportion of rubber plantation in different slope gradients (%)

Slope (°)	1980	1990			2000				2010			
	BR CLM/CN	BR CLM	CN	MMR	BR CLM	CN	LAO	MMR	BR CLM	CN	LAO	MMR
<5	19.02	16.16	16.17	8.10	12.32	12.30	12.50	15.69	10.26	9.41	17.14	12.92
5–8	18.86	16.89	16.89	11.93	13.94	13.92	12.50	17.65	12.17	11.52	17.09	14.38
8–15	37.00	36.25	36.25	47.36	34.18	34.17	37.50	35.29	32.32	31.96	34.93	33.65
15–25	21.23	24.87	24.86	25.60	29.86	29.88	25.00	25.49	32.49	33.51	24.19	29.27
25–35	3.57	5.23	5.23	7.01	8.44	8.46	12.50	5.88	10.82	11.50	5.83	8.53
>35	0.32	0.60	0.60		1.26	1.27			1.94	2.10	0.82	1.25

Note: CN=Within China; MMR=Within Myanmar; LAO=Within Laos.

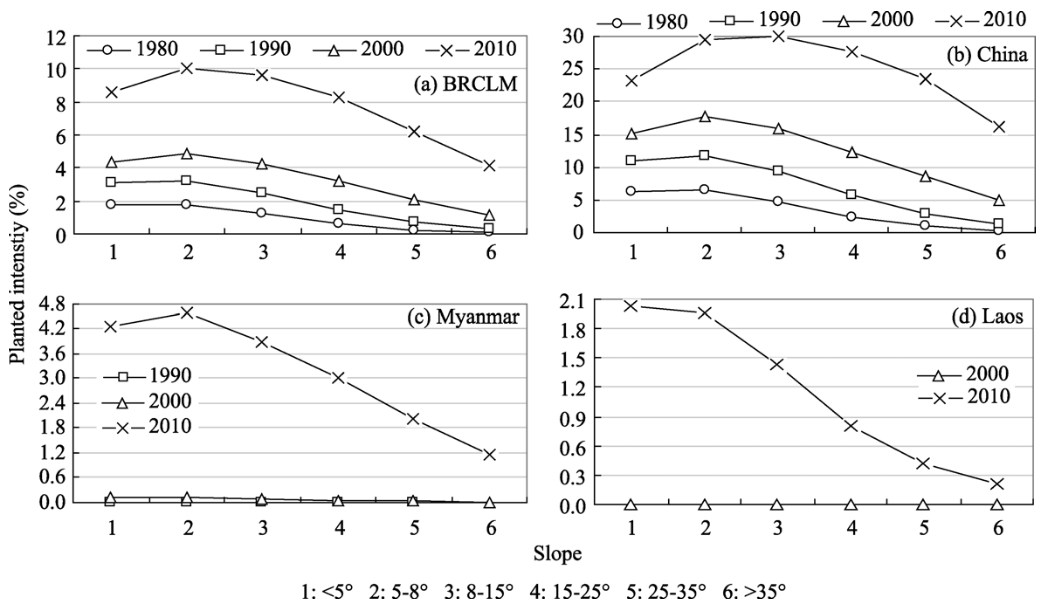

Figure 7 The planted intensity of rubber plantation in different slope gradients

gradually increased at all slopes with an increase of 6.83% in gentle slope and 4.06% in abrupt slope. In Xishuangbanna with high planted intensity in the appropriate slopes, rubber plantation gradually occupied the areas at lower slopes, and had to spread toward higher slopes which were not suitable for rubber planting.

During 1980–2010, rubber plantation gradually expanded to areas at higher slopes from mainly occurring in slope gradients of 5°–15° with 55.86% to distributed in slope gradients of 15°–35° with 45.01% in China (Table 6), and had the highest planted intensity and increased gradually in different slope gradients (Figure 7b). Among them, the highest planted intensity in gentler and gentle slopes were close to 30%, and in abrupt slope was more than 15% with area proportion above 2.10%. No doubt about the land resource restriction for rubber plantation in China.

During 1990–2010, rubber plantation extended significantly in different slope gradients in Myanmar with the planted intensity increasing continually, especially in the recent decade of obvious growth (Table 6 and Figure 7c). At present, rubber plantation was mainly distributed in gentler, gentle and sharp slopes with area proportion more than 3/4 in 2010. Meanwhile, the rubber planted intensity was less than 5% in gentler slopes which had the highest planted intensity in Myanmar, which meant that there was a great potential development space for rubber planting in the future.

During 2000–2010, rubber plantation expanded obviously to higher (>35°) and lower slopes (<5°) with wider slope range in Laos, and the planted intensity rose gradually in different slope gradients in spite of owning the lowest rubber planted intensity in BRCLM (Table 6 and Figure 7d). Nearly 3/5 of rubber plantation was mainly distributed in the slope gradients of 8°–25°, about 1/3 in slopes below 8°, rarely occurred in slopes more than 25°. In Laos, there was enough appropriate space for rubber planting because the planted intensity only accounted for less than 2% in slight and gentler slopes which owned the highest planted intensity in Myanmar.

3.2.3 Relationship with aspect factor

Aspects are divided into 5 gradients in this research, namely flat aspect (0°), north aspect (0–45° and 315°–360°), east aspect (45°–135°), south aspect (135°–225°), and west aspect (225°–315°). Firstly, the original aspect structure in BRCLM was discussed. The results showed that the proportions of four aspects were similar, with the south aspect ranking the highest (25.75%) and the east aspect ranking the lowest (23.95%). South aspect was dominated in BRCLM except Oudomxay Province, and north aspect followed. Meanwhile, the proportion of west aspect was more than east aspect in all regions except Jinghong City, Phongsaly Province and Mongphat District in BRCLM (Table 7).

Table 7 The original aspect structure in BRCLM (%)

Aspect	BR CLM	Jinghong City	Menghai County	Mengla County	Luang Namtha Province	Pongsaly Province	Oudomxay Province	Kengtung District	Mongphat District
Flat	1.42	1.22	1.15	0.96	1.12	1.01	3.23	1.08	1.03
North	24.73	24.39	25.87	25.44	25.58	24.60	23.68	24.93	24.10
East	23.95	25.11	22.80	22.80	23.06	24.76	23.43	24.04	24.90
South	25.75	26.36	26.01	25.60	25.38	25.62	25.46	25.78	26.38
West	24.15	22.92	24.17	25.20	24.86	24.01	24.20	24.17	23.59

Based on analysis above, the distribution characteristics and planted intensity of rubber plantation in different aspect gradients in 1980, 1990, 2000, and 2010 were discussed in BRCLM (Table 8 and Figure 8a). The results showed that rubber plantation was rarely distributed on flat aspect, while meanly distributed on other 4 aspects, and the planted intensity increased gradually in different aspect gradients. Comparatively speaking, rubber plantation was distributed more on south and east aspects than north and west aspects, so was the planted intensity. During the period from 1980 to 2010, the proportion of rubber plantation gradually declined on the flat and north aspects, while rose continually on the south aspect, and decreased firstly then increased on the east aspect which was opposite with the west aspect. The change pattern in different aspect gradients revealed that the expansion of rubber plantation mainly occurred on south aspect. The area of rubber plantation continued to expand on east aspect, while declined on north and west aspects.

Table 8 The area proportion of rubber plantation in different aspect gradients (%)

Aspect	1980	1990			2000				2010			
	BR CLM/CN	BR CLM	CN	MMR	BR CLM	CN	LAO	MMR	BR CLM	CN	LAO	MMR
Flat	1.24	1.16	1.16	4.05	1.00	1.00	0.97	0.69	0.99	0.94	1.51	1.05
North	23.45	23.52	23.54	11.42	23.00	23.01	22.15	21.93	22.96	23.08	22.51	22.24
East	23.21	23.02	23.02	50.83	23.11	23.12	23.59	21.18	24.47	24.52	24.48	24.05
South	26.68	27.27	27.24	33.69	28.14	28.08	34.97	38.85	28.31	27.95	28.80	31.44
West	25.42	25.03	25.04	0.01	24.75	24.79	18.32	17.35	23.27	23.51	22.70	21.22

Note: CN=Within China; MMR=Within Myanmar; LAO=Within Laos.

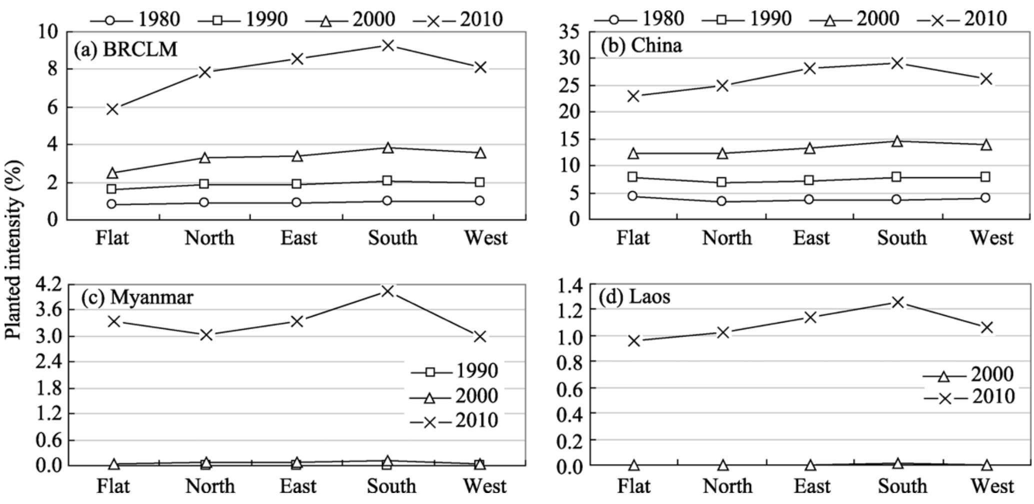

Figure 8 The plantation intensity of rubber plantation in different aspect gradients

During 1980–2010, rubber plantation expanded continually on south and east aspects, and the rubber planted intensity increased at all aspects in China (Table 8 and Figure 8b). The south aspect had the highest rubber planted intensity and the largest increment, but the area proportion increased firstly then decreased influenced by land resource limitation. East aspect had the secondary increment of rubber planted intensity, and the proportion has been increasing. The planted intensity of rubber plantation on west aspect was similar with north aspect, but the proportion on west aspect declined annually, while on north aspect declined firstly then increased. South and east aspects had more advantages for rubber plantation.

During 1990–2010, rubber plantation in Myanmar was mainly distributed on south and east aspects with expansion on south and west aspects, and the planted intensity increased in all aspect gradients (Table 8 and Figure 8c). The south aspect had the highest planted intensity of rubber plantation, but the proportion was in downtrend. East and north aspects had similar planted intensity with an increasing area proportion. West aspect had the lowest planted intensity with limited planting area.

During 2000–2010, rubber plantation in Laos was mainly distributed on south and east aspects with expansion on east and west aspects, and the planted intensity rose in all aspect gradients (Table 8 and Figure 8d). Apart from south aspect, the proportion of rubber plantation in other aspects showed an obvious upward trend. Therefore, aspect is not the limiting factor for rubber plantation within the appropriate range of elevations and slopes.

4 Conclusions

BRCLM is one of the typical regions of the world's tropical rainforest, and the main area of rubber plantation and opium poppy substitution planting as well. This study analyzed the distribution characteristics and the spatial-temporal change pattern of rubber plantation in BRCLM using remote sensing technology and quantitatively revealed the relationships with topographical factors between 1980 and 2010.

(1) Rubber plantation was the dominant land use type in BRCLM with an acreage of 6014 km^2 in 2010 accounting for 8.17% of the study area. Viewing from the rubber forest structure, the area of mature rubber forest (≥10 years) and young rubber forest (<10 years) were 2502 km^2 and 3512 km^2, with a ratio of 5:7 which indicated the expansion of rubber plantation was significant in the past decade, and far exceeded the development in the past 30 years. As for national differences in the BRCLM, 83.31% of rubber plantation was distributed in China, and nearly half was mature rubber forest. Rubber plantation in Laos accounted for only 6.60% and almost all was young rubber forest. Rubber plantation in Myanmar was 10.09% with mature rubber forest 7.30% as well. The national differences of rubber plantation in the BRCLM were significant, and the cross-border plantation developed quickly in the recent 10 years.

(2) From 1980 to 2010, rubber plantation in the BRCLM increased nearly nine times, from 705 km^2 to 6014 km^2. The distribution characteristics of rubber plantation varied from concentrated to dispersed, from border inside to outside, and expanded further in all directions with Jinghong City as the center. From the aspect of initial planting time, China was the first place to cultivate rubber and had large area of rubber forests since 1980. With the opening up of national borders and development of border trades as well as implement of the OPSP policy, Myanmar and Laos began to plant rubber trees in 1990 and 2000 respectively. From the distribution pattern aspect, rubber plantation in BRCLM was mainly influenced by China, and concentrated in the border region close to Xishuangbanna. Rubber plantation was distributed in the northeast of Luang Namtha Province and western Phongsaly Province of Laos, and the eastern Kengtung District and northern Mongphat District of Myanmar.

(3) The analyses on relationship between rubber plantation and topographical factors showed that the distribution of rubber plantation was impacted by topographical factors. Viewing from the elevation, rubber plantation was mainly distributed in elevation ranging from 400 to 1200 m. Among them, over 4/5 concentrated in the appropriate elevation gradi-

ents between 600 and 1000 m, rarely occurred in elevations beyond 1200 m. For the period from 1980 to 2010, the proportion of rubber plantation area in the elevation of 600–800 m decreased, while increased in the gradients of 800–1000 m. Rubber plantation showed an obvious characteristic of expanding to higher (especially above 1000 m) and lower (below 600 m) elevations. Viewing from the slope factor, 90% of rubber plantation was mainly distributed in slopes below 25°. Among them, nearly 2/3 concentrated in the appropriate slope gradients between 8° and 25°, rarely in slopes above 35°. During the period of 1980 to 2010, the area proportion of rubber plantation in slopes below 15° declined, while those in slopes beyond 15° increased. The expansion of rubber plantation mainly occurred between 15° and 35° and gradually extended to steep and abrupt slopes. Viewing from the aspect factor, rubber plantation was mainly distributed on south and east aspects, and the corresponding planted intensity showed a similar trend. During the period of 1980 to 2010, the expansion of rubber plantation mainly occurred on south aspect. The area of rubber plantation continued to expand on east aspect, while declined on north and west aspects.

(4) Comparative studies on rubber plantation of different countries showed that rubber plantation expanded to the areas with higher elevations and steeper slopes in China. There were huge appropriate topographical area for cross-border rubber planting in Laos and Myanmar. As for Xishuangbanna in China, rubber plantation had occurred in the topographical gradients of 600–1000 m and 5°–25° which were appropriate for rubber planting, and further expanded to the areas with elevations above 1000 m (even 1200 m) and slopes more than 25° (even 35°). The rubber planted intensity generally ranged from 20% to 30%. Regardless of national nature reserves, the planted intensity of rubber plantation reached 80% and 60% in the elevation gradients of 600–800 m and 800–1000 m, respectively, which indicated that there is a limited potential for rubber expansion due to land resource endowment. As for Laos and Myanmar, rubber plantation was concentrated in the elevation gradients of 600–1000 m and the slope gradients of 5°–25°, rarely distributed in the areas with elevations more than 1000 m and slopes beyond 25°. The highest planted intensity of rubber plantation was 14%–15% in Myanmar and 3%–5% in Laos which indicated that these two countries had enough areas for rubber expansion topographically.

In conclusion, the area of rubber plantation continued to expand rapidly between 1980 and 2010 in BRCLM. The expansion of rubber plantation mainly occurred in areas at higher elevations, steeper slopes and adverse aspects within China, and such a trend has no benefits for the environmental protection and improvement of natural rubber quality and production (Wang, 1982). Topographical features, especially elevation and slope, exerted significant influence on the rubber plantation distribution (Li *et al.*, 2007; Li *et al.*, 2008). Rubber plantation in China was restricted by land resource limitation and had limited potential for further expansion. Meanwhile, rubber plantation within Laos and Myanmar close to the border with China still have suitable conditions of elevations, slopes and aspects for rubber development. The advantages will provide favorable conditions for the cross-border expansion of rubber plantation from China. Therefore, it is necessary for Chinese government to provide a reasonable planning in the border regions for both rubber expansion and opium poppy substitution planting, according to the current pattern of rubber plantation and topographical conditions appropriate for rubber planting, and provide funds and technical assistances for rubber plantation appropriately. Those will not only benefit for rational land resource exploitation, but also for poverty reduction and economic development in BRCLM.

This study analyzed the distribution characteristics and the relationships with topographical factors of rubber plantation using the classification results extracted from remote sensing images directly. In fact, the identification and mapping of rubber plantation was significant and fundamental for this research while we did not pay more attention to that process for existing related studies of our group (Liu *et al.*, 2012). However, the classification method and accuracy should be improved for further study and yield survey validation using more multi-source data and multiple classifiers. Topographical features are important for rubber plantation distribution in BRCLM, so are the socio-economy factors and land use and land cover change. It is not surprising that current land use changes involving replacement of tropical forest with rubber plantation will negatively impact flora, fauna, and some ecosystem services (Li *et al.*, 2007). Therefore, more studies on the driving forces of rubber plantation should be strengthened, especially the relation of land use and land cover change. Apparently, distribution of rubber plantation is influenced by a number of factors, such as climate, topography, soil, hydrologic, and socio-economy conditions. It is necessary to execute comprehensive land suitability evaluation with integrated factors for rubber plantation in BRCLM in the future for the purpose of balancing the economic and social needs with the habitat requirements of ecological security. With the continually increasing demands and price of natural rubber, rubber plantation in BRCLM will definitely expand cross borders of China and be planted into the territories of Laos and Myanmar, and the continuous expansion of rubber plantation in regions near the border of China will be inevitable. Thus, rubber plantation and distribution in BRCLM will become the important ecological, economic and political issues which are worthy of sustained attention for taking into account the ecological and social interests on the basis of ensuring economic benefits.

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