Spatial–temporal succession of the vegetation in Xishuangbanna, China during 1976–2010: A case study based on RS technology and implications for eco-restoration

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ABSTRACT

The spatial-temporal succession of regional vegetation in Xishuangbanna, China from 1976 to 2010 was studied based on RS technology. The results showed the area fluctuation of main vegetation types in the study area during the research period. There was no great change in the total area of main vegetation, with the fluctuation area ranging from 12,579.84 to 14,698.75 km², averaging 13,664.48 km² annually, and with the fluctuation ratio between −7.94% and 7.57%. The area of natural vegetation (tropical rainforest, tropical seasonal moist forest, tropical seasonal rainforest, and tropical mountainous evergreen broad-leaved forests) increased at first and gradually decreased afterwards, and the ratio of its distribution area to the total area of main vegetation was featured with an annual decrease, especially in 2005 and 2010. Both the distribution area and ratio of artificial vegetation (Rubber plantation) to the total area of main vegetation were characterized with the tendency of a gradual increase, especially in 2005 and 2010. Thus, the establishment of artificial vegetation (Rubber plantation) not only led to the decrease in natural vegetation (3641.16 km²) but also covered 343.66 km² of lands for other uses. The results also showed the distribution succession of main vegetation types in the study area during the research period. In the later research period (after 1999), compared with the early research period (before 1999), the distribution range of natural vegetation was characterized with a certain decrease in the following aspects as at different altitudes (<600 m, 600–800 m, 800–1000 m, 1000–1200 m, 1200–1400 m, and >1400 m), and on different slopes (0–5°, 5–8°, 8–15°, 15–25°, 25–35°, and >35°). By contrast, the artificial vegetation was just the opposite whose distribution range was characterized with a tendency of a rapid growth at different altitudes, and on different slopes. It indicated that the establishment of artificial vegetation had broken the original ecological pattern in Xishuangbanna, which would bring direct threats to the regional ecological security and environment healthy development, thus countermeasures were urgent to be taken in order to prevent it from worsening.

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1. Introduction

Since 2010, the frequent seasonal drought in Southwest China had not only brought serious impacts on the social economy and people's living in the drought-stricken areas, but also left endless afterthoughts and warnings for people, which had become a major scientific issue with considerable concerns for further exploration (Qiu, 2010; Stone, 2010), especially in 2010, the unprecedented consecutive trans-seasonal drought in Yunnan, Guizhou, Guangxi, Chongqing and Sichuan brought great shocks to China, even to the
world. Thus, the discussion and controversial argument related to the cause of it never ceased before, in the midst and after the drought, among all the controversies, the argument whether the drought was a natural or a human disaster was especially heated. Among those in favor of the human disaster, some scholars (Du, 2010; Zhang, 2010) pointed out that the plantation of Hevea sp. and Eucalyptus sp. directly led to the drought. In fact, before the drought, some scholars (Li et al., 2007; Li et al., 2008; Hu et al., 2008; Qiu, 2009; Robinson et al., 2006; Espinosa-García et al., 2008) had questioned the ecological benefits of these plantations, and for many years there spread one idea among the civilian population that Hevea sp. and Eucalyptus sp. were “water pumps”. However, such idea was rather than a perceptual cognition or a personal view of some experts and scholars, which lacked abundant evidence from experiments and statistics (Yu et al., 2013b). Thus does the cause derived from the idea of “water pumps” have enough scientific evidence? In addition, both H. sp. and E. sp. are fast-growing economic tree species, characterized with such biological quality as great demand for water. Therefore, it’s not difficult to raise such a scientific question: will the plantation of H. sp. and E. sp. which consume much water break the balance between regional ecological water supply and demand, further lead to regional droughts (Yu et al., 2013b)? In other words, to what extent will the plantation of H. sp. and E. sp. break the balance between income and expense of regional ecological water and further cause regional droughts? Based on such a scientific issue, a series of researches related to regional vegetation types and the succession of its ecological water demand were launched by us recently (Yu et al., 2013b). In this paper, the succession of regional vegetation in Xishuangbanna, China from 1976 to 2010 was reported. It was expected to provide basic statistic supports for further study on ecological water demand from regional vegetation afterwards.

2. Research methods

2.1. Introduction to the study area

The study area is located at the Autonomous Prefecture of Dai People in Xishuangbanna, China (Fig. 1), covering 87.5% of the total prefecture, approximately 16,773.03 km². Xishuangbanna lies with the latitudes around 21° 10’ N, and longitudes between 99° 55’ and 101° 50’ E, in the southernmost of Yunnan province, China, with the total area around 19,162.37 km². In this prefecture, geographically speaking, the northwest is the highest and the southeast lowest in altitudes, and the highest and lowest altitude is 2429.7 m, and 477.0 m, respectively, with the height difference of 1952.7 m. It lies to the south of the Tropic of Cancer, belonging to the tropical monsoon climate, with sufficient sunlight (the annual sunlight hours between 1700 and 2300 h, with total annual radiation up to 547.1 KJ/cm²) and abundant rainfall (the annual amount of rainfall between 1138.6 and 2431.5 mm) and rich biodiversities, known as “the kingdom of plants” and “the kingdom of animals”. It falls into two seasons—dry season and wet season, the dry season lasts from November to April of the next year, while the wet season May to October. During the whole year, the rainsfalls are characterized with unevenness. In the wet season, it covers over 80% of annual rainsfalls. The annual average temperature is around 21°C, without frost or snow all year round, with foggy days between 108 and 146 d. In this prefecture, Xishuangbanna National Nature Reserve (approved by the Chinese government in 1986) is located, which has been defined as International Biosphere Reserve (approved by UNESCO in 1993). Such natural vegetation as tropical rain forest (TRF), tropical seasonal moist forest (TSMF), tropical seasonal rain forest (TSRF) and tropical montane evergreen broad-leaved forest (TMEBF) are the dominant natural vegetation (Zhu, 2007), as well as such widespread typical artificial vegetation as rubber plantation (RP) (Qiu, 2009).

2.2. Major research methods

2.2.1. Data selection and its pretreatment

MSS/TM/ETM images (Track No. 130/45, covering 87.5% of the total prefecture of Xishuangbanna) in different years (1976, 1988, 1992, 1995, 2001, 2005 and 2010), DEM data and derived slope data, field GPS data, partial Google Earth images with high spatial resolution were selected in this study. Considering the accessibility to the satellite images and phonological laws of related vegetation, the time phase of the MSS/TM/ETM used in this study were mainly from January and February, with few from June and December (Table 1).

Most TM images are stored individually according to waves, thus a file of waves is generated from Layer Stack selected in ENVI in advance, further to rectify its radiation and geometry in each time phase, so as to eliminate (correct) the impact of atmosphere radiation and the geometrical aberration of images, respectively. The geometrical aberrations of images include the inner aberration due to the performance difference of sensors and external aberration from the attitude changes of carriages and from objects. The inner system error of sensors and the aberration from satellite attitude have been rectified before data distribution, thus Polynomial Method (Mei et al., 2001) is adopted to conduct geometrical rectification of external aberration from objects according to topographic map and GPS ground control point, the accuracy of 0.5 pixel will meet the demand. Next, two-scenery MSS images will be inlaid. Finally, images for each year will be cut according to the border of the study area.

2.2.2. RS classification system in the study area

RS three-grade classification system (Table 2) in the study area has been established, according to data of forest resource inventory and planning in Xishuangbanna and ground investigation statistics together with recognizable ground object types from TM RS images.

| Image phase | Satellite | Sensor types |
|-------------|-----------|--------------|
| 19750425/19760224 | Landsat 2 | MSS |
| 19880202 | Landsat 5 | TM |
| 19921111 | Landsat 5 | TM |
| 19991225 | Landsat 7 | ETM |
| 20010112 | Landsat 7 | ETM |
| 20050216 | Landsat 5 | TM |
| 20100224 | Landsat 5 | TM |

Notes: The data set is provided by International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn).

2.2.3. Image interpretation and ground objects classification

Visual interpretation signal and interpretation characters of the different surface objects (omitted) were determined, according to the vegetation shown in the colorful RS images (generated with RGB543) and ground sample points from practical investigation together with high-resolution images from Google Earth. Based on image interpretation, Random Forests (Breiman, 2001) was adopted to classify images (surface objects) in different years in the study area, totally up to three-grade types. Finally, a distribution map was drawn, following the determination of distribution ranges of natural vegetation (combined with TRF, TSMF, TSRF and TMEBF) and artificial vegetation (RP, combined with adult RP and young RP) in different years in the study area.
2.2.4. Analysis on vegetation spatial pattern

Altitude and slope factors were derived from DEM after topographical analysis, and then each topographical factor was graded to obtain altitude-grading maps (omitted) and slope-grading maps (omitted). On such basis and through spatial statistical function of GIS, the typical vegetation distribution map was overlapped with the administration division map, the altitude-grading map and the slope-grading map, respectively, in the study area for each year, then each vegetation patch matched with administration division, altitude grading and slope grading was summed, finally the spatial distribution laws of main vegetation (natural vegetation and artificial vegetation) in the study area in each year were determined.

3. Results

3.1. The area fluctuation of main vegetation types in the past different years in the study area

The distribution area of main vegetation types in the past different years in the study area was listed in Table 3. It showed:

i) There was no sharp change in the total area of main vegetation in the study area during the research period, with a fluctuation area ranging between 12,579.84 and 14,698.75 km², averaging 13,664.48 km² annually, and with the fluctuation ratio between −7.94% and 7.57%. With the year 1976 as a check sample, only in 2001, the total area of main vegetation in the study area decreased by 1.89% of that in 1976; while in 1988, 1992, 1999, 2005 and 2010, the total area of main vegetation there increased by 11.93%, 14.63%, 9.93%, 8.67% and 2.68% of that in 1976, respectively (Table 3).

ii) The distribution area of natural vegetation in the study area during the research period increased first and then decreased gradually, and its ratio to the total vegetation decreased year by year, especially the sharp decrease in the recent 2 years (2005, 2010). e.g., in 1992, the distribution area of natural vegetation increased to 14,174.37 km² from 12,795.96 km² in 1976, and then decreased to 9,154.79 km² in 2010, and the ratio decreased from 99.79% in 1976 to 80.87% in 2005 and further to 69.53% in 2010 (Table 3).

iii) Both the distribution area of artificial vegetation (RP) and its ratio to the total area of main vegetation were characterized with the tendency of a gradual increase, especially in 2005 and 2010, it increased greatly. e.g., the distribution area of RP increased from 26.79 km² in 1976 to 2665.29 km² in 2005 and further to 9154.79 km² in 2010, and its ratio increased from 0.21% to 19.13% and further to 30.47%, respectively (Table 3).

Table 2
Three-grade classification of land cover in the study area based on remote sense.

| Grade I           | Grade II          | Grade III         | Vegetation types |
|-------------------|-------------------|-------------------|------------------|
| Forest land       | Arbor forest      | Natural broad-leaved forest | TRF |
|                   |                   |                   | TSMF             |
|                   | Sparse woodland   | Artificial broad-leaved forest | TSRF |
|                   | Bamboo forest     | Young RP          | TMEBF            |
| Non-forest land   | Farmland          | Shrub wood        | Adult RP         |
|                   | Construction land | Bamboo forest     | Young RP         |
|                   | Water area        | Farmland          | Shrub wood       |
|                   |                   | Construction land | Bamboo forest    |
|                   |                   |                   | Others           |
|                   |                   |                   | -                |
iv) During the research period, the increased RP area totaled 3984.83 km², while the decreased area of natural vegetation totaled 3641.16 km² (Table 3). It showed the establishment of RP not only led to the sharp decrease in area of natural vegetation, but also covered a considerable area (343.66 km²) of lands for other uses.

3.2. The distribution succession of main vegetation types in the past different years

The statistic data shown in Fig. 2 indicated that during the research period there was a certain change in the distribution range of each vegetation type in the study area. Take artificial vegetation (RP) for instance, in 1976, there was only scattered distribution in such counties as Menhai or so (Fig. 2(a)), it expanded gradually to a few parts of north Menla County in 1988 (Fig. 2(b)) and further to central Menla County in 1992 (Fig. 2(c)), in 1999 and in 2005, it formed into a whole patch in northern and some central parts in Menla County to a certain scale (Fig. 2(d) and (e)), and in 2005 and in 2010, it rapidly expanded to southeast Jinghong City, and further to its west and north part (Fig. 2(f) and (g)), at the same period, there were some small scattered patches in Menhai County (Fig. 2(g)). In such areas with rapid growth and scaled development of artificial vegetation (RP), the distribution range of natural vegetation decreased and shrunk continually.

3.2.1. The altitude distribution of main vegetation types in the past different years in the study area

As is shown in Table 4, in the later research period (after 1999), the distribution range of natural vegetation at different altitudes (<600 m, 600–800 m, 800–1000 m, 1000–1200 m, 1200–1400 m and >1400 m) in the study area all shrunk compared to the early research period (before 1999), e.g., the area of natural vegetation at 600–800 m altitude was 1883.64 km², 1990.26 km² and 1850.94 km² in 1976, 1988 and 1992, respectively, while in 2001, 2005 and 2010 it decreased to 1240.07 km², 1104.40 km² and 661.20 km², respectively. By contrast, the distribution area of artificial vegetation was just the opposite at all altitude levels, characterized with a constant growth, e.g., the area of RP at 600–800 m altitude went up from 21.05 km² in 1976 to 681.53 km² in 1999 and further to 1622.71 km² in 2010.

3.2.2. The slope distribution of main vegetation types in the past different years in the study area

The statistic result shown in Table 5 indicated that in the later research period (after 1999) the area of natural vegetation of different slopes (0–5°, 5–8°, 8–15°, 15–25°, 25–35° and >35°) all showed a shrink compared to the early research period (before 1999), e.g., there was 3746.29 km², 4044.57 km² and 4152.44 km² of natural vegetation on 8–15° slope in 1976, 1988 and 1992, respectively, while it decreased to 3269.37 km², 3124.84 km² and 2467.27 km² in 2001, 2005 and 2010, respectively. On the contrary, the area of artificial vegetation on different slopes was just the opposite, characterized with the tendency of a rapid growth, e.g., the area of RP on 8–15° slope grew from 11.43 km² in 1976 to 147.59 km² in 1988, 205.19 km² in 1992, 348.25 km² in 1999, 386.21 km² in 2001, 971.50 km² in 2005 and further to 1392.71 km² in 2010.

4. Discussions

i) The research on vegetation ecological water demand based on vegetation succession. Recently, a considerable concern and extensive controversies had been raised about the ecological and hydrological effects of such regional typical artificial vegetation as H. plantation and E. plantation again due to the frequent seasonal drought in Southwest China (Mu et al., 2010; Zhang, 2012). The controversial focus was on whether the drought was closely related to the establishment of such artificial vegetation. However, both sides of controversies had no scientific or sufficient statistic evidence to fully support their ideas. In this paper, it must be pointed out that the solution to this controversy could eventually be found, only through the prior master of the relation between physiological water consumption and ecological water demand of vegetation, through the further analysis on the ratio of vegetation ecological water demand to regional ecological water demand and its impact on the regional ecological water demand, and through the final ascertainment on the extent to which ecological water demand of regional typical vegetation was related to statistic index of regional drought. Thus three basic researches should be conducted, namely, (a) the spatial-temporal succession of regional typical vegetation; (b) physiological water consumption (water consumption from transpiration) of regional typical vegetation; and (c) ecological water demand (physiological water consumption) of regional typical vegetation and its impacts on regional ecological water use (Yu et al., 2013b). Undoubtedly, the results from this study would provide basic statistic supports for the research on vegetation ecological water demand in the study area.

ii) The ecological risks and warnings of the unordered establishment of artificial vegetation. Natural vegetation is a major component of...
Fig. 2. Spatial distribution of main vegetation types in the study area in past different years.
### Table 4
Statistics on main vegetation types at different altitudes in the study area in past different years.

| Classification unit | Year  | Total area (km²) | Altitude <600 m | Altitude 600–800 m | Altitude 800–1000 m | Altitude 1000–1200 m | Altitude 1200–1400 m | Altitude >1400 m |
|---------------------|-------|------------------|-----------------|-------------------|-------------------|-------------------|-------------------|-----------------|
|                     |       |                  | Area (km²)      | Area (km²)        | Area (km²)        | Area (km²)        | Area (km²)        | Area (km²)    |
| The natural vegetation (4 vegetation types) | 1976 | 12795.96         | 186.67          | 1883.64          | 2835.77          | 3117.31          | 2377.33          | 2395.23       |
|                     |       |                  | 1.46            | 14.72            | 22.16            | 24.36            | 18.58            | 18.72         |
|                     | 1988 | 13981.51         | 150.75          | 1990.26          | 3319.30          | 3417.04          | 2526.70          | 2577.46       |
|                     | 1992 | 14174.37         | 173.16          | 1850.94          | 3187.40          | 3487.94          | 2706.28          | 2768.66       |
|                     | 1999 | 13134.06         | 152.83          | 1710.82          | 3011.83          | 3333.72          | 2418.18          | 2506.68       |
|                     | 2001 | 11679.91         | 83.67           | 1240.07          | 2359.80          | 3040.44          | 2314.58          | 2458.62       |
|                     | 2005 | 11269.72         | 108.05          | 1104.30          | 2524.59          | 3056.64          | 2214.02          | 2262.12       |
|                     | 2010 | 9154.79          | 25.24           | 661.20           | 1787.36          | 2569.50          | 1997.58          | 2113.91       |
|                    | 1976 | 26.79            | 3.51            | 21.05            | 66.26            | 1.79             | 0.00             | 0.00           |
|                    |      |                  | 13.10           | 78.55            | 12.64            | 0.00             | 0.00             | 0.00           |
|                    | 1988 | 371.12           | 37.20           | 302.73           | 30.45            | 0.74             | 0.00             | 0.00           |
|                    | 1992 | 524.38           | 44.90           | 411.43           | 66.26            | 1.79             | 0.00             | 0.00           |
|                    | 1999 | 961.91           | 66.71           | 681.53           | 198.72           | 14.48            | 0.46             | 0.00           |
|                    | 2001 | 1082.66          | 71.07           | 738.95           | 72.83            | 2.18             | 0.13             | 0.00           |
|                    | 2005 | 2665.29          | 168.23          | 1392.71          | 571.46           | 225.95           | 180.76           | 126.18        |
| Notes               |      |                  |                |                  |                  |                  |                  |                |

### Table 5
Statistics on main vegetation types on different slopes in the study area in past different years.

| Classification unit | Year  | Total area (km²) | Slope 0–5° | Slope 5–8° | Slope 8–15° | Slope 15–25° | Slope 25–35° | Slope >35° |
|---------------------|-------|------------------|-----------|----------|-----------|-----------|-----------|----------|
|                     |       |                  | Area (km²) | Area (km²) | Area (km²) | Area (km²) | Area (km²) | Area (km²) |
| The natural vegetation (4 vegetation types) | 1976 | 12795.96         | 782.63    | 1085.91  | 3746.29   | 5162.72   | 1745.17   | 273.23   |
|                     |       |                  | 6.12      | 8.49     | 29.28     | 40.35     | 13.64     | 2.14     |
|                     | 1976 | 13981.51         | 719.24    | 1092.75  | 4044.57   | 5833.57   | 1982.67   | 308.70   |
|                     | 1999 | 11334.06         | 652.93    | 1005.47  | 3754.07   | 5494.98   | 1918.96   | 307.64   |
|                     | 2001 | 11679.91         | 535.76    | 850.59   | 3269.37   | 4859.10   | 1707.06   | 275.30   |
|                     | 2005 | 11269.72         | 589.44    | 843.42   | 3124.84   | 4701.43   | 1726.17   | 284.42   |
|                    | 1999 | 961.91           | 43.79     | 612.31   | 2467.27   | 3942.68   | 1503.91   | 251.44   |
|                    | 2001 | 1082.66          | 43.79     | 612.31   | 2467.27   | 3942.68   | 1503.91   | 251.44   |
| Notes               |      |                  |           |           |           |           |           |           |

Notes: The percentage (%) refers to the ratio of the area of a vegetation type on a specific slope to the total area of such vegetation type.
forest ecological system, playing a significant and irreplaceable role in preserving ecosystem health and regional ecological security. However, in some countries and regions, natural vegetation was often confronted with destroy or degradation because of natural disaster or human disturbance (Hinojosa-Huerta et al., 2013; Cui et al., 2012; Miettinen et al., 2011; Rastmanesh et al., 2010; Hreško et al., 2009); by contrast, artificial vegetation was characterized with unordered establishment and rapid expansion without restraint (Senf et al., 2013; Koh et al., 2011; Oballa et al., 2010; Wei and Xu, 2003), which not only led to the sharp change in land use pattern (Uriarte et al., 2010; Li et al., 2008; Lambin and Geist, 2006), further to a series of ecological environment problems (Stanturf et al., 2013; Carlson et al., 2012; Liu and Li, 2010; Qiu, 2009), such as decrease in biodiversity (Wang et al., 2014; Hosoi et al., 2013; Qiu, 2009; Li et al., 2007; Beukema et al., 2007; Zhu et al., 2004; Estetu and Olavi, 2003), invasion of alien species (Yu et al., 2013a, 2014; Li et al., 2013; Moreira et al., 2013; Zuo et al., 2012; Richardson et al., 2007), and loss of soil and water resources (Briggs et al., 2013; Singwane and Malinga, 2012; Joshi and Palanisami, 2011; Robinson et al., 2006; Zheng, 2006; Yang et al., 2004; Behera and Sahani, 2003), etc., but also brought unprecedented difficulties and challenges to regional ecological construction and environment protection (Chen and Cao, 2013; Ma et al., 2013; Oliveira et al., 2013). This study indicated that the establishment of RP had broken the original ecological pattern in Xishuangbanna, which had brought direct threats to regional ecological security and environment healthy development. Thus, it requires not only great concerns from all social levels but also some practical countermeasures to prevent its further worsening and expansion.

5. Conclusions

From the analysis above, it can be concluded as below.

(i) The area fluctuation of main vegetation types in the study area during the research period. There was no sharp change in the total area of main vegetation, with a fluctuation area ranging between 12,579.84 and 14,698.75 km², averaging 13,664.48 km² annually, with a fluctuation ratio between 7.94% and 7.57%. The area of natural vegetation (TRF, TSMF, TSRF, and TMEBF) increased first gradually and then decreased gradually, and its ratio to the total vegetation area decreased year by year, especially in 2005 and 2010, the ratio decreased greatly; by contrast, both the distribution area and the ratio of the artificial vegetation (RP) to the total vegetation were featured with the tendency of an annual growth, especially in 2005 and 2010, its area and ratio increased sharply; thus the establishment of artificial vegetation (RP) not only led to the loss of 3641.16 km² of natural vegetation, but also covered 343.66 km² of lands for other uses.

(ii) The distribution succession of main vegetation types in the study area during the research period. During the later research period (after 1999), compared with the early research period (before 1999), the distribution range of nature vegetation shrank at different altitudes (<600 m, 600–800 m, 800–1000 m, 1000–1200 m, 1200–1400 m, and >1400 m), and on different slopes (0°–5°, 5°–8°, 8°–15°, 15°–25°, 25°–35° and >35°): on the contrary, the distribution range of artificial vegetation (RP) had the tendency of a rapid growth at different altitudes, and on different slopes.

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