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Spatial-temporal vegetation succession in Yao'an County, Yunnan Province, Southwest China during 1976–2014: A case survey based on RS technology for mountains eco-engineering

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ABSTRACT

The remote sense (RS) technology was adopted to explore the vegetation succession from 1976 to 2014 in Yao'an County, Yunnan Province, Southwest China. The results showed: (i) the changes in the distribution range of major vegetation types in the study area. In the 6 statistic years after 1976, in the study area, the distribution range of the secondary vegetation shrank greatly in 4 different subareas (northeast, southeast, northwest and northwest subarea), at 4 different altitudes (1500–1800 m, 1800–2100 m, 2100–2400 m and 2400–2700 m), on 4 different gradients (0–8°, 8–15°, 15–25°, 25–35°) and on 4 different aspects but the flat land (sunny slope, semi-sunny slope, semi-shadowy slope, and shadowy slope); by contrast, in the study area, the distribution range of artificial vegetation expanded greatly in all the subareas, at 2 different altitudes (1800–2100 m and 2100–2400 m), on 3 different gradients (0–8°, 8–15°, 15–25°), and on the 4 different aspects but the flat land. (ii) The increase and decrease in distribution area of major vegetation types in the study area. During the research period, the total area of major vegetation fluctuated between 1471.92 and 1196.94 km^2, averaging 1255.52 km^2 annually, with the fluctuation rate between −4.67% and 17.24%. In the second statistic year (1989), the total area of major vegetation decreased sharply, and then remained relatively stable afterward. During the research period, the distribution area of the secondary vegetation decreased sharply in the 6 statistic years after 1976, in contrast to the sharp increase in the distribution area of artificial vegetation in such 6 years. During the research period, the total area of major vegetation decreased by 258.73 km^2 in total, among which the total area of the secondary vegetation decreased by 342.52 km^2 in contrast to the increase in artificial vegetation by 83.78 km^2 in total. Thus, it indicated that the secondary vegetation in the study area had been damaged seriously, and the construction of artificial vegetation lagged behind, so there was a potential danger in ecological safety, which should be concerned and precautioned.

1. Introduction

Since 2010, the consecutive seasonal droughts in Southwest China has brought serious impacts on socio-economy and people's life, and left people with endless afterthoughts and inspirations, which has been a major scientific issue in the academia with considerable concerns and restless exploration (Qiu, 2010; Stone, 2010; Laura et al., 2014). Especially in 2010, the trans-seasonal continuous drought hit 5 provinces (municipalities), Yunnan, Guizhou, Guangxi, Chongqing, and Sichuan, which was rarely seen in history and had raised great shocks at home and abroad. The discussions and controversies over the reason for the drought were not ceased during the period of its occurrence and development, even to its ending. Among all the arguments, whether the drought was a "natural disaster" or a "man-made disaster" was the most serious. In the argument for a "man-made disaster", some scholars (Du, 2010; Zhang, 2010) pointed out the plantation of *Eucalyptus* spp. and *Hevea* spp. was the key reason for the drought. As a matter of fact, before the drought, some scholars (Robinson et al., 2006; Espinosa-García et al., 2008; Li et al., 2007; Li et al., 2008; Hu et al.,

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2008; Qiu, 2009; Mao et al., 2014) had realized some negative side-effects of the plantation of *E*. spp. and *H*. spp. on eco-environment, and such idea as that *E*. spp. and *H*. spp. were "a water pump" was very popular among the local people. However, such ideas were more a perceptual recognition or a personal view of some experts or scholars, which lacked strong evidence from the perspective of experiments and statistics (Yu et al., 2014; William, 2014). Thus, was the reason for the drought which was generated from the idea of "a water pump" scientifically sufficient enough? In addition, both *E*. spp. and *H*. spp. are fast-growing economic plant species, characterized with such a biological trait as a large demand for water. Consequently, such a scientific issue is not hard to find whether the plantation of *E*. spp. and *H*. spp. characterized with a large demand for water consumption would break the balance between the regional ecological water supply and demand, and further lead to regional drought (Yu et al., 2014). In other words, to what extent could the plantation of *E*. spp. and *H*. spp. break the regional water balance between supply and demand, and further bring up drought? Based on such a scientific issue, a series researches on types of regional vegetation and the succession of ecological water demand have been conducted by the authors (Yu et al., 2014). In this paper, the vegetation succession in Yao'an County, Yunnan Province, China from 1976 to 2014 was mainly reported for a basic statistic support for later researches on ecological water demand of vegetation in this region.

2. Methods

2.1. An introduction to the study area

Yao'an County, Chuxiong Yi Autonomous Prefecture, Yunnan Province, Southwest China was selected as the study area, which is located in the middle north of Yunnan, and in the northwest of the prefecture (Fig. 1), at latitudes of 100°56′–101°34′E and longitudes of 23°13′–24°45′N, with a total area of 1803 km^2. The topography in Yao'an were featured with rather high south, mountain surroundings, and flat central areas, the area of flat land and mountains covers 20.4%, 79.6% of the total area of the county, respectively, and the highest and lowest altitude is 2898 m and 1519 m, respectively. The climate features sub-tropical monsoon and mild seasons, with an annual average temperature of 15.4 °C, an annual average precipitation of 790.0 mm, an annual sunshine duration of 2500 h and a frost-free season of 285 days. There are just two seasons, dry season and rainy season; the former begins from November to April the next year, with 9% of the annual precipitation; the later from May to October, with 91% of the annual precipitation. In the county, a few secondary vegetation coexists with a large amount of artificial forests, the former consists mainly of broad-leaved forest (BF), evergreen coniferous forest (ECF), mixed broadleaf-conifer forest (MBF) and shrub forest (SF), and the latter refers to the area of *E*. plantation (EP), other plantation (OP) (*Acacia mearnsii* plantation, etc.).

In order to meet statistical demand, the whole study area was divided into 4 study subareas with the center of Yao'an County (E 101.202929, N 25.513862) as the base point, namely, the northeast subarea, southeast subarea, southwest subarea, and northwest subarea (Fig. 1), with an area of 377.86 km^2, 395.16 km^2, 447.24 km^2, and 480.23 km^2, respectively.

2.2. Methods

2.2.1. Data selection and its pretreatment

The basic data selected in this study includes the following 4 aspects: (1) statistic satellite images for different years (1976, 1989, 1995, 1999, 2005, 2009, 2014) (Table 1); (2) DEM data in the study area and its derived data for altitude, gradient, and aspects; (3) spatial high-resolution images partially from Google Earth; (4) a 1:50000 topographic map for the study area, data of Forest Resource Inventory and Planning (2006).

Table 1
Data of MSS/TM/ETM images.

Image phase	Track No.	Satellite	Sensor types
19760314	140/42	Landsat 2	MSS
19890111	130/42	Landsat 4	TM
19950731	130/42	Landsat 5	TM
19991123	130/42	Landsat7	ETM
20050131	130/42	Landsat 5	TM
20091212	130/42	Landsat 5	TM
20140225	130/42	Landsat 8	OLI_TIRS

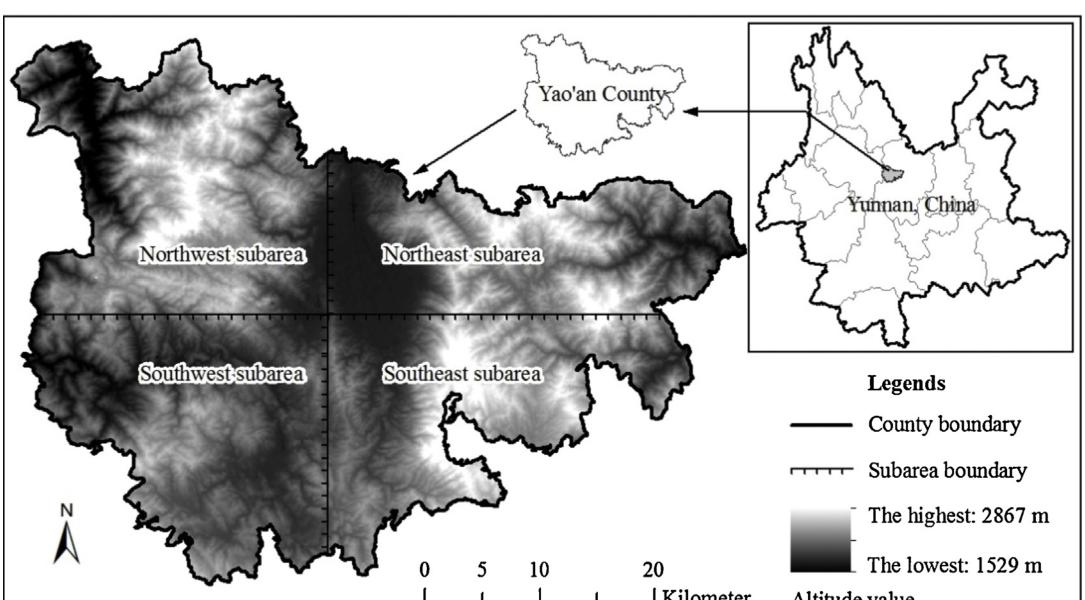

Fig. 1. Geographical position of the study area.

Table 2
Classification of land cover in the study area based on remote sense.

Classification	Vegetation types
The secondary vegetation	Broad-leaved forest (BF) Evergreen coniferous forest (ECF) Mixed broadleaf-conifer forest (MBF) Shrub forest (SF)
The artificial vegetation	*Eucalyptus* plantation (EP) Other plantation (OP)

In regard to image data for each statistic year, a multi-wave file was generated with Layer Stack in ENVI, followed by radiation correction and geometric correction; finally, according to the boundary of the study area, the image data for each statistic year was cut. For data correction, the approach of dark pixels (Song et al., 2001) was adopted for radiation correction, and polynomial method (Mei et al., 2001) for geometric correction.

2.2.2. RS classification system in the study area

According to the data of Forest Resource Inventory and Planning in Yao'an County, together with recognizable ground object types, a RS classification system in the study area (Table 2) has been established.

2.2.3. Visual interpretation and classification of ground objects

Visual interpretation signal and interpretation characters of 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 (Table 3). The distribution range for each typical vegetation type in different statistic years was analyzed and determined, and its distribution map was drawn afterward.

2.2.4. Analysis on the spatial distribution pattern of vegetation

After the topographical analysis on DEM data, factors such as altitude, slope and aspect were obtained, and then after grading each topographical factor, altitude-grading maps (omitted), slope-grading maps (omitted) and aspect-grading maps (omitted) were obtained. Based on it, aided by GIS to conduct spatial analysis, the typical vegetation distribution map was overlapped with the subarea division map, the altitude-grading map, the slope-grading map and the aspect-grading map, respectively, in the study area for each year, then each vegetation patch which was matched with its subarea division, altitude, slope and aspect grading was summed, finally the spatial distribution laws of main vegetation in the study area in each year were summed.

3. Results and analysis

3.1. Changes in distribution range of major vegetation types in the study area

As shown in Fig. 2, during the research period, there was a great change in the distribution range of major vegetation types in the study area. Take artificial vegetation as an example, in 1976, it was scattered only in part of the central and northern section in Yao'an County, with an area of only 1.65 km^2 (Fig. 2(a)); while in 1989 and 1995, in the interlace district between forest and non-forest in quite a few central and northern section in the study area, it expanded in a multi-fold way, with an area up to 7.24 km^2 (Fig. 2(b)), 18.96 km^2 (Fig. 2(c)), respectively; in 1999 and 2005, it expanded at a rather rapid speed eastward, southward and westward, with an area up to 54.78 km^2 (Fig. 2(d)), 80.67 km^2 (Fig. 2(e)), respectively; while in 2009, it shrank partially, with an area down to 75.81 km^2 (Fig. 2(f)); but in 2014, it expanded again, with the area up to 85.44 km^2 (Fig. 2(g)). By contrast, the distribution range of secondary vegetation shrank greatly in 1989, and in the statistic years afterward its distribution range remained below 1200.00 km^2 and never reached the high level of 1976 (1470.27 km^2).

3.1.1. Distribution of major vegetation types in different subareas of the study area

Statistics results (Table 3) showed: around 60% of secondary vegetation was distributed in northwest subarea and southwest subarea, the rest about 40% in southeast subarea and northeast subarea; there was a certain change (shrink or expansion) in the distribution range of secondary vegetation in 4 subareas, but compared to 1976, the distribution range in 4 subareas all shrank greatly in the 6 statistic years afterward. For instance, in 1976, the distribution range of secondary vegetation in northeast subarea covered 280.81 km^2, but in 1989, 1999, 2009, and 2014, it decreased to 231.27 km^2, 223.26 km^2, 220.77 km^2 and 209.68 km^2, respectively. Over 60% of artificial vegetation was distributed in southeast subarea and northeast subarea, the rest less than 40% in northwest subarea and southwest subarea; compared to 1976, the distribution range of artificial vegetation expanded greatly in the 6 statistic years afterward. For instance, in 1976, the distribution range of artificial vegetation was 0.00 km^2, in 1989, 1999, 2009 and 2014, it increased up to 3.22 km^2, 18.36 km^2, 23.89 km^2 and 27.34 km^2, respectively.

Table 3
Statistics on main vegetation types in different subareas in the study area in different years.

Classification unit	Year	Total area (km^2)	Northeast Subarea		Southeast Subarea		Southwest Subarea		Northwest Subarea	
			Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)
The secondary vegetation (4 vegetation types)	1976	1470.27	280.81	19.10	334.71	22.77	394.69	26.84	460.06	31.29
	1989	1189.70	231.27	19.44	251.21	21.12	329.10	27.66	378.12	31.78
	1995	1192.09	232.39	19.49	256.57	21.52	329.02	27.60	374.10	31.38
	1999	1183.23	223.26	18.87	252.97	21.38	332.28	28.08	374.71	31.67
	2005	1147.97	216.17	18.83	242.76	21.15	327.23	28.51	361.80	31.52
	2009	1153.11	220.77	19.15	241.62	20.95	326.54	28.32	364.19	31.58
	2014	1127.76	209.68	18.59	239.57	21.24	323.44	28.68	355.07	31.48
The artificial vegetation (*E.* and other plantation)	1976	1.65	0.00	0.00	0.00	0.00	0.98	59.65	0.67	40.35
	1989	7.24	3.22	44.43	1.86	25.70	0.80	11.01	1.37	18.86
	1995	18.96	8.56	45.16	5.22	27.52	2.86	15.10	2.32	12.22
	1999	54.78	18.36	33.52	18.46	33.70	9.26	16.91	8.69	15.86
	2005	80.67	25.70	31.86	25.78	31.95	11.36	14.08	17.84	22.11
	2009	75.81	23.89	31.51	22.45	29.62	11.18	14.75	18.29	24.12
	2014	85.44	27.34	32.01	26.55	31.07	12.03	14.08	19.51	22.84

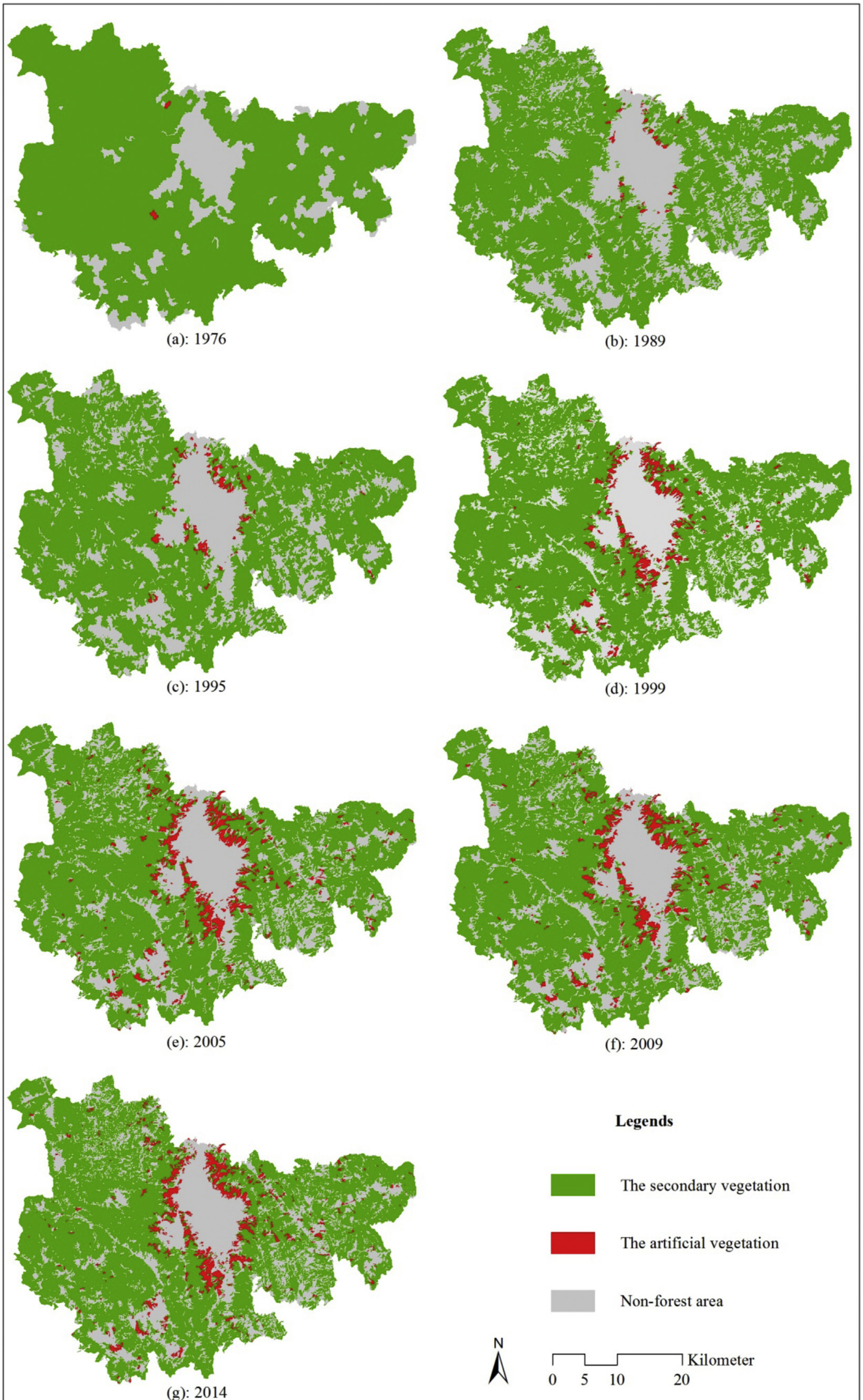

Fig. 2. Spatial distribution of main vegetation types in the study area in different statistics years.

Table 4
Statistics on main vegetation types at different altitudes in the study area in different years.

Classification unit	Year	Total area (km^2)	1500 m < A ≤ 1800 m		1800 m < A ≤ 2100 m		2100 m < A ≤ 2400 m		2400 m < A ≤ 2700 m		A > 2700 m	
			Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)
The secondary vegetation (4 vegetation types)	1976	1470.27	32.45	2.21	465.91	31.69	697.37	47.43	265.84	18.08	8.70	0.59
	1989	1189.70	19.99	1.68	310.72	26.12	619.44	52.07	231.65	19.47	7.89	0.66
	1995	1192.09	19.33	1.62	309.95	26.00	623.34	52.29	231.61	19.43	7.86	0.66
	1999	1183.23	20.52	1.73	302.51	25.57	618.66	52.29	233.75	19.76	7.78	0.66
	2005	1147.97	19.92	1.74	295.69	25.76	601.17	52.37	223.72	19.49	7.47	0.65
	2009	1153.11	20.12	1.74	296.26	25.69	602.87	52.28	226.37	19.63	7.50	0.65
	2014	1127.76	18.58	1.65	288.81	25.61	592.74	52.56	220.11	19.52	7.52	0.67
The artificial vegetation (*E.* and other plantation)	1976	1.65	0.00	0.00	0.98	59.65	0.67	40.35	0.00	0.00	0.00	0.00
	1989	7.24	0.00	0.00	6.30	86.98	0.94	13.02	0.00	0.00	0.00	0.00
	1995	18.96	0.00	0.00	14.82	78.15	3.82	20.17	0.32	1.68	0.00	0.00
	1999	54.78	0.06	0.12	40.09	73.19	13.72	25.06	0.90	1.64	0.00	0.00
	2005	80.67	0.17	0.21	50.89	63.08	26.18	32.46	3.43	4.25	0.00	0.00
	2009	75.81	0.18	0.24	46.91	61.88	25.11	33.12	3.61	4.76	0.00	0.00
	2014	85.44	0.24	0.28	53.30	62.39	28.36	33.20	3.52	4.12	0.00	0.00

3.1.2. The distribution of major vegetation types at different altitudes in the study area

As shown in Table 4, over 97% of secondary vegetation was distributed at the altitude of 2100–2400 m, 1800–2100 m, and 2400–2700 m; compared to 1976, the distribution range at such 3 altitudes shrank greatly in the 6 statistic years afterward. For example, in 1976, at the altitude of 2100–2400 m, there was 697.37 km^2 of secondary vegetation, while in 1995, 2005, and 2014, it decreased to 623.34 km^2, 601.17 km^2, and 592.74 km^2, respectively. In the study area, 95% or more artificial vegetation was distributed at the altitude of 1800–2100 m and 2100–2400 m; compared to 1976, there was a great increase in the distribution range of artificial vegetation in the 6 statistic years afterward. For instance, in 1976, there was 0.67 km^2 of artificial vegetation at the altitude of 2100–2400 m, but in 1995, 2005 and 2014, it expanded to 3.82 km^2, 26.18 km^2, and 28.36 km^2, respectively.

3.1.3. The distribution of major vegetation types on different slopes in the study area

According to the statistic results (Table 5), over 96% of secondary vegetation was distributed on the slope of ≤8°, 8–15°, 15–25°, and 25–35°; compared to 1976, there was a great decrease in distribution range on such 4 slopes. For instance, in 1976, there was 588.17 km^2 of secondary vegetation on the slope of 15–25°, by contrast, in 1989, 1999, 2009 and 2014, it decreased to 499.33 km^2, 498.24 km^2, 484.25 km^2, and 474.82 km^2, respectively. Over 91% of artificial vegetation was distributed on the slope of ≤8°, 8–15°, and 15–25°; compared to 1976, the distribution range of artificial vegetation on such 3 slopes increased greatly. For example, in 1976, only 0.45 km^2 of artificial vegetation was on the slope of 15–25°, by contrast, in 1989, 1999, 2009 and 2014, it increased to 3.08 km^2, 21.04 km^2, 28.70 km^2, and 33.27 km^2, respectively on such slope.

3.1.4. The distribution of major vegetation types on different aspects in the study area

From the statistic results (Table 6), it showed that over 50% of secondary vegetation in the study area was distributed on the shadowy slope and semi-sunny slope, the rest on the sunny slope and semi-shadowy slope; compared to 1976, the distribution range of secondary vegetation on all aspects except flat ground was characterized with a sharp decrease in the 6 statistic years afterward. For example, in 1976, there was 370.86 km^2 of secondary vegetation on the shadowy slope, by contrast, in 1989, 1999, 2009 and 2014, it

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

Classification unit	Year	Total area (km^2)	S ≤ 8°		8° < S ≤ 15°		15° < S ≤ 25°		25° < S ≤ 35°		S > 35°	
			Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)
The secondary vegetation (4 vegetation types)	1976	1470.27	207.90	14.14	413.26	28.11	588.17	40.00	222.53	15.14	38.41	2.61
	1989	1189.70	134.52	11.31	319.46	26.85	499.33	41.97	200.32	16.84	36.08	3.03
	1995	1192.09	135.07	11.33	320.80	26.91	500.17	41.96	200.11	16.79	35.94	3.01
	1999	1183.23	131.21	11.09	315.99	26.71	498.24	42.11	201.40	17.02	36.39	3.08
	2005	1147.97	129.04	11.24	306.55	26.70	481.15	41.91	195.64	17.04	35.59	3.10
	2009	1153.11	128.81	11.17	307.60	26.68	484.25	42.00	196.87	17.07	35.58	3.09
	2014	1127.76	123.34	10.94	298.78	26.49	474.82	42.10	195.23	17.31	35.59	3.16
The artificial vegetation (*E.* and other plantation)	1976	1.65	0.84	50.95	0.30	18.29	0.45	26.97	0.06	3.79	0.00	0.00
	1989	7.25	1.05	14.44	2.67	36.82	3.08	42.56	0.38	5.26	0.07	0.93
	1995	18.96	3.30	17.40	6.86	36.19	7.52	39.64	1.21	6.36	0.08	0.40
	1999	54.78	9.67	17.66	19.90	36.34	21.04	38.41	3.82	6.97	0.34	0.63
	2005	80.67	14.92	18.50	28.77	35.67	30.30	37.56	6.18	7.66	0.50	0.61
	2009	75.81	13.88	18.31	26.81	35.36	28.70	37.86	5.96	7.86	0.46	0.61
	2014	85.44	14.75	17.26	30.04	35.17	33.27	38.94	6.79	7.95	0.58	0.68

Table 6
Statistics on main vegetation types in different aspects in the study area in different years.

Classification unit	Year	Total area (km^2)	Flatland		Sunny slope		Semi-sunny slope		Semi-shady slope		Shady slope	
			Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)
The secondary vegetation (4 vegetation types)	1976	1470.27	0.20	0.01	375.94	25.57	373.91	25.43	349.37	23.76	370.86	25.22
	1989	1189.70	0.11	0.01	280.31	23.56	310.04	26.06	276.93	23.28	322.32	27.09
	1995	1192.09	0.11	0.01	289.81	24.31	311.17	26.10	281.81	23.64	309.18	25.94
	1999	1183.23	0.10	0.01	277.15	23.42	304.55	25.74	280.61	23.72	320.81	27.11
	2005	1147.97	0.10	0.01	264.75	23.06	302.31	26.33	265.10	23.09	315.72	27.50
	2009	1153.11	0.10	0.01	263.93	22.89	303.00	26.28	266.83	23.14	319.24	27.69
	2014	1127.76	0.10	0.01	261.20	23.16	298.21	26.44	260.99	23.14	307.27	27.25
The artificial vegetation (*E.* and other plantation)	1976	1.65	0.00	0.22	0.26	15.67	0.41	24.74	0.52	31.68	0.46	27.69
	1989	7.24	0.00	0.01	1.80	24.81	2.98	41.11	1.40	19.33	1.07	14.74
	1995	18.96	0.00	0.01	5.46	28.79	5.82	30.67	3.78	19.94	3.90	20.58
	1999	54.78	0.01	0.01	14.34	26.17	16.68	30.45	11.42	20.85	12.33	22.51
	2005	80.67	0.01	0.02	22.93	28.43	22.09	27.38	18.85	23.37	16.79	20.81
	2009	75.81	0.01	0.01	22.13	29.20	19.20	25.33	19.09	25.19	15.37	20.27
	2014	85.44	0.01	0.01	23.29	27.26	24.13	28.25	18.99	22.22	19.02	22.26

Table 7
Summary statistics on distribution of main vegetation types in the study area in different years.

Year	The main vegetation				The secondary vegetation			The artificial vegetation		
	Area (km^2)	Net var. (km^2)	Ratio[a] (%)	Ratio[b] (%)	Area (km^2)	Net var. (km^2)	Ratio[c] (%)	Area (km^2)	Net var. (km^2)	Ratio[c] (%)
1976	1471.92	–	117.24	100.00	1470.27	–	99.89	1.65	–	0.11
1989	1196.94	−274.98	95.33	81.32	1189.70	−280.58	99.39	7.24	5.59	0.61
1995	1211.05	14.11	96.46	82.28	1192.09	2.39	98.43	18.96	11.72	1.57
1999	1238.00	26.95	98.60	84.11	1183.23	−8.86	95.58	54.78	35.81	4.42
2005	1228.64	−9.36	97.86	83.47	1147.97	−35.26	93.43	80.67	25.90	6.57
2009	1228.92	0.28	97.88	83.49	1153.11	5.14	93.83	75.81	−4.87	6.17
2014	1213.19	−15.73	96.63	82.42	1127.76	−25.36	92.96	85.44	9.63	7.04
Mean	1255.52	−43.12	100.00	85.30	1209.16	−57.09	–	46.36	13.96	–
Sum	–	−258.73	–	–	–	−342.52	–	–	83.78	–

i) The area of main vegetation includes the area of secondary vegetation and that of artificial vegetation, the former includes the area of broad-leaved forest (BF), evergreen coniferous forest (ECF), mixed broadleaf-conifer forest (MBF) and shrub forest (SF), and the latter refers to the area of E. plantation (EP) and other plantation (OP). ii) Net var. refers to the difference between the index value (area) of the following statistic year and the previous statistic year, Ratio[a] (%) refers to the ratio between the total area of main vegetation in a specific statistic year and average value of the total area of main vegetation in 7 statistic years, Ratio[b] (%) refers to the ratio of the total area of main vegetation in a specific statistic year to that in 1976; Ratio[c] (%) refers to the ratio of the total area of secondary vegetation (or artificial vegetation) in a specific statistic year to that of main vegetation in the same statistic year.

decreased to 322.32 km^2, 320.81 km^2, 319.24 km^2, and 307.27 km^2, respectively. By contrast, around 55% of artificial vegetation was distributed on sunny slope and semi-sunny slope, the rest on shadowy slope and semi-shadowy slope (except 1976); compared to 1976, the distribution range of artificial vegetation was characterized with a rapid growth in the 6 statistic years afterward. For instance, in 1976, there was 0.41 km^2 of artificial vegetation on the semi-sunny slope, by contrast, in 1989, 1999, 2009 and 2014, it increased to 2.98 km^2, 16.68 km^2, 19.20 km^2, and 24.13 km^2, respectively.

3.2. Changes in distribution area of major vegetation types in the study area

The statistic results (Table 7) for distribution area of major vegetation types in the study area showed the following characteristics:

i) The total area of major vegetation types in the study area fluctuated between 1471.92 and 1196.94 km^2, averaging 1255.52 km^2 annually, with a fluctuation ratio between −4.67% and 17.24%. In the second statistic year (1989), the total area of the major vegetation decreased sharply in the study area, and then remained relatively steady afterward. With the total area in 1976 as a control group, the total area of major vegetation in 1989, 1995, 1999, 2005, 2009 and 2014 decreased by 18.68%, 17.72%, 15.89%, 16.53%, 16.51%, and 17.58%, respectively (Table 7).

ii) With the total area of secondary vegetation in 1976 as a control group, the distribution area of secondary vegetation in the 6 statistic years afterward all decreased sharply in the study area. For instance, the area of secondary vegetation decreased from 1470.27 km^2 (1976) to 1189.70 km^2 (1989), 1183.23 km^2 (1999), 1153.11 km^2 (2009), and further to 1127.76 km^2 (2014), and its ratio to the total area of major vegetation also went down from 99.89% (1976) to 99.39% (1989), 95.58% (1999), 93.43% (2009), and further to 93.83% (2014) (Table 7).

iii) With the total area of artificial vegetation in 1976 as a control group, the distribution area of artificial vegetation in the 6 statistic years afterward all increased sharply in the study area. For instance, the area of artificial vegetation increased from 1.65 km^2 (1976) to 7.24 km^2 (1989), 54.78 km^2 (1999), 75.81 km^2 (2009), and further to 85.44 km^2 (2014), and its ratio to the total area of major vegetation also went up from 0.11% (1976) to 0.61% (1989), 4.42% (1999), 6.17% (2009), and further to 7.04% (2014) (Table 7).

iv) During the research period, the total area of major vegetation totally decreased by 258.73 km^2, among which the area of secondary vegetation decreased by 342.52 km^2, by contrast, the area of artificial vegetation increased by 83.78 km^2 (Table 7). Thus, it is obvious that the vegetation construction in the study area was faced with double pressure, on the one hand, secondary vegetation was destroyed in a large scale, on the other hand, the construction of artificial vegetation lagged far behind. Such status quo for vegetation would easily lead to eco-safety problems, which should be of great precaution.

4. Discussions

4.1. Changes in distribution range of major vegetation types in the study area

During the 6 statistic years since 1976, in the study area, the distribution range of secondary vegetation shrank sharply in 4 different subareas (northeast, southeast, southwest and northwest subarea), at 4 different altitudes (500–1800 m, 1800–2100 m, 2100–2400 m, and 2400–2700 m), on 4 different slopes (0–8°, 8–15°, 15–25°, and 25–35°), and on 4 different aspects (sunny slope, semi-sunny slope, semi-shadowy slope and shadowy slope) except the flat land, by contrast, the distribution range of artificial vegetation expanded greatly in 4 different subareas, at 2 different altitudes (1800–2100 m, 2100–2400 m), on 3 different slopes (0–8°, 8–15°, and 15–25°), and on 4 different aspects except the flat land.

4.2. Ups and downs in the distribution area of major vegetation types in the study area

During the research period, the total area of major vegetation fluctuated between 1471.92 and 1196.94 km^2, averaging 1255.52 km^2 annually, with a fluctuation ratio between −4.67% and 17.24%. Though in the 2nd statistic year (1989), the total area of major vegetation decreased sharply and then stayed relatively steady afterward. During the research period, the distribution area of secondary vegetation decreased sharply in all the 6 statistic years since 1976, while the distribution area of artificial vegetation increased greatly in all the 6 statistic years since 1976; the total area of major vegetation decreased by 258.73 km^2, among which the total area of the secondary vegetation decreased by 342.52 km^2 in contrast to the total increase in artificial vegetation by 83.78 km^2. Consequently, it indicated the serious damage in secondary vegetation and backwardness in the construction of artificial vegetation, as well as a certain eco-safety hidden problems, which should be of great precaution.

4.3. Human economic activities and regional vegetation destruction

Since the late 20th century, in search of rapid socio-economic growth, many countries and regions developed at the cost of natural resources and eco-environment, leading to shocking eco-environment problems, among which there were quite a few typical examples for vegetation destruction (Richardson et al., 2007; Hreško et al., 2009; Rastmanesh et al., 2010; Miettinen et al., 2011; Koh et al., 2011; Cui et al., 2012; Hinojosa-Huerta et al., 2013; Senf et al., 2013; Mao et al., 2014; William, 2014; Zhou et al., 2014). AO (1995) reported that during 1980–1990 there was 9.95×10^4 km^2 of forest lost annually, almost equivalent to the area of South Korea. Statistics from Center for International Forestry Research (CIFOR) (2004) showed that from 1990 to 2000, the destructed area of Amazon rain forest went up from 41.50×10^4 km^2 to 58.70×10^4 km^2, most of which had been changed into pasture; figures by National Institute for Space Research in Brazil (INPE) (2008) suggested that by 2005 Amazon rain forest in Brazil had decreased to 340×10^4 km^2, the destroying ratio is 17.08% of its original area (410×10^4 km^2). In this study, during the 38 years from 1976 to 2014, in Yao'an County with a land surface of 1803 km^2, the destructed secondary vegetation reached 342.52 km^2, accounting for 23.16% of the total area of secondary vegetation (1470.27 km^2) in an early period (1976). Obviously, the vegetation destruction intensity in Yao'an County was not lower than that in the typical examples in the world. Meanwhile, vegetation destruction can bring about a series of ecological consequences (Yang et al., 2004; Zheng, 2006; Chen and Cao, 2013; Ma et al., 2013), such as increase in CO_2 emissions and abnormal changes in temperature, species extinction and decrease in biodiversity, soil erosion and land degradation, frequent flood, and shortage in water resources, etc. Such consequences have occurred in Yao'an County to a certain degree, and lead to some threats in regional eco-safety and environment sustainable development, which should be tracked, monitored and scientifically prevented.

4.4. Eco-risk assessment and management of artificial vegetation

Recently, with the rise of global movement on environment protection, people came to realize the heavy cost of ecological destruction, and tried to restore degraded eco-system via the construction of artificial vegetation. However, it is proven that there was a lack of scientific assessment and effective management on the eco-risk of artificial vegetation in many regions (Wei and Xu, 2003; Lambin and Geist, 2006; Uriarte et al., 2010; Carlson et al., 2012). Take *E.* spp. as an example, it has been introduced into and planted in many countries such as China, India, and Brazil, which has arisen a variety of problems in ecological degradation (Behera and Sahani, 2003; Eshetu and Olavi, 2003; Oballa et al., 2010; Joshi and Palanisami, 2011; Singwane and Malinga, 2012; Stanturf et al., 2013; Yu et al., 2013), such as degradation in soil quality and land productivity, shortage in water resources, decrease in biodiversity, and ecological invasion of alien species. The same story once happened in China that *A. mearnsii* was introduced to make a mixed plantation with *E.* spp., and there were reports saying that such mixed pattern could relieve ecological degradation by pure *E.* plantation and further realize its sustainable development (Liu and Li, 2010; William, 2014), *A. mearnsii* is one of the 100 most invasive species in the world, which has imposed a serious impact on the survival of local species and biodiversity, and its risk in invasiveness outweighs its role in ecological restoration. The results in this study showed that during the period from 1976 to 2014, the constructed artificial vegetation totaled 83.78 km^2, among which *E.* plantation and *A. mearnsii* plantation covered 50% or even more. The ecological impacts of such artificial vegetation had been recognized by the local people and were considered as "a water pump", "a fertilizer pump" and "an ecological killer". Such ideas are constantly proven correct afterwards. In fact, with the help of modern technology, the eco-risk of artificial vegetation would not be difficult to be prevented in advance and avoided scientifically. Therefore, eco-risk assessment mechanism and scientific management mechanism should be integrated into the construction and management of artificial vegetation in the future.

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