

How ecological restoration alters ecosystem services: an analysis of vegetation carbon sequestration in the karst area of northwest Guangxi, China

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Abstract Ecological restoration, which aims to restore disturbed ecosystems, has been an important approach to mitigate human pressures on natural ecosystems and to improve ecosystem services. Determination of the vegetation carbon effect requires the assessment of ecological restoration measures. In this study, the temporal-spatial characteristics of vegetation carbon services were analyzed using remote sensing data and weather parameters by using geographic information system in northwest Guangxi, China, a typical karst area covered by the ongoing China's Grain-to-Green Program and eco-environment immigration during 2000–2010. The results showed that ecosystem services of vegetation carbon sequestration showed an upward trend during the 11 years; approximately 21.14 and 18.09 % of the karst area showed significant changes in the net primary productivity (NPP) and net ecosystem productivity (NEP; $P < 0.05$), respectively. With regard to spatial distribution, NPP and NEP were higher for the western non-karst areas, and the greatest increase in these parameters was recorded in the eastern part of the restoration area of karst rocky desertification. Vegetation carbon sequestration was significantly affected by the impacts of vegetation coverage, vegetation species, and forest

type. The results of this study suggested that rocky desertification control measures have positive impacts on the spatial distribution of vegetation carbon services in the typical karst area of northwest Guangxi, China.

Keywords Environmental immigration · China's grain-to-green program · Karst region · Temporal-spatial characteristics · Vegetation carbon

Introduction

Carbon cycle is a link among major global change issues, because it is a complex process of material circulation and energy flow in the earth system (Bolin et al. 1977; Tian et al. 1998; Pan et al. 2011). The climate convention held in Kyoto Protocol and the Copenhagen conference has made the issue of carbon reduction and performance to have a far-reaching impact on the economic and political decisions worldwide (Wang et al. 2012). Vegetation carbon, an important component of the carbon cycle, plays an important role in carbon balance, because it is one of the important factors that determine the ecosystem carbon source/sink and regulate ecological processes (Dixon et al. 1994; Manzoni et al. 2011).

Ecological restoration, which aims to restore disturbed ecosystems, has been an important approach to mitigate human pressures on natural ecosystems and to improve ecosystem services (Holl et al. 2003; Doren et al. 2009; Feng et al. 2013). China's grain-to-green program (GTGP) is one such national ecological restoration program. For instance, the GTGP has helped re-establish semi-natural vegetation on previously cultivated slopes (14.7 million hectares) and abandoned agricultural lands (17.3 million hectares; Chen et al. 2009). This continuous increase in

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vegetation cover is expected to change ecosystem services, including the potential to sequester greenhouse gases. Furthermore, the effectiveness of ecological restoration as well as the consequence of carbon sequestration can be highly variable across climatic gradients (Piao et al. 2009; Valentini et al. 2000). Therefore, assessing the spatial and regional variances in ecosystem services caused by large-scale restoration programs is important. Such information is particularly important for adjusting current and planning for future restoration programs in a more effective and efficient way.

Numerous studies have assessed various aspects of ecosystem services (Daily 1997; Chazdon 2008; Li et al. 2008; Bergstrom et al. 2009; Brown et al. 2011) by using different methods. Their findings indicated that a local management authority can establish guidelines to limit human activities associated with landscape changes. Further, the management of study areas as a part of a network of natural parks seemed to be an effective measure for maintaining the natural capital flow. However, these studies have mainly focused on forests, wetlands, and grasslands; studies on karst areas are limited (Wu et al. 2008; Zhang et al. 2011; Richards et al. 2012; Thevs et al. 2013). Karst regions account for about 15 % of land area globally (about 2.2 million km²) and house approximately 1 billion people (17 % of the world's population; Yuan and Cai 1988). These areas are the most fragile systems (Parise et al. 2008) and are characterized by poor soil formation ability, thin soil depth (generally below 10 cm), and poor surface water retention (i.e., infiltration coefficient of 0.3–0.6; Yuan and Cai 1988). Therefore, the recovery of degraded karst ecosystems is slow and difficult.

One of the most harmful consequences of ecosystem degradation in karst regions is rocky desertification—development of a desert-like landscape with high percentage of bedrock due to severe human disturbances (Yuan 1993). Since the bedrock is widely exposed, land productivity declines and cropland distribution becomes more scattered, which is an important index of environmental capacity for humans. Therefore, the karst region in southwest China has been severely affected by poverty and environmental degradation (Cai 1996; Cao et al. 2008). This situation has been addressed by applying countermeasures, including GTGP and environmental (ecological) migration, to alleviate poverty and control rocky desertification (Zhang et al. 2011). However, the efficiency of these ecological projects on the karst ecosystem services has not yet been investigated.

This study aimed to quantitatively evaluate the efficiency of GTGP in improving carbon sequestration. This evaluation has been speculated to assist in ecosystem management to achieve sustainable development in fragile

environments. The ecosystem carbon sequestration in the typical karst area of northwest Guangxi, China, a prioritized pilot region covered by the ongoing GTGP, was investigated between 2000 and 2010. Satellite data, climate data, and ecosystem modeling data were used to determine the changes in net primary productivity (NPP) and net ecosystem productivity (NEP) in this region since the implementation of GTGP. Finally, the correlation of vegetation carbon with environmental factors was assessed using canonical correspondence analysis (CCA; TerBraak 1986) to obtain some useful information for policy makers to effectively plan ecological restoration.

Materials and methods

Study area

The study region of northwest Guangxi, China, includes 16 counties that cover an area of 50,700 km² (104°29'–109°09'E, 23°33'–25°37'N; Fig. 1). The region has a subtropical wet climate, with annual mean temperature and precipitation of 19.5 °C and about 1000 mm, respectively. The elevation in this hilly region varies from 100 to 2000 m. Vegetation communities mainly include mixed subtropical evergreen and deciduous forests. There are all kinds of karst landforms in this region, such as towers, poljes, cockpits, and dolines. There is mountainous agricultural region with infertile cropland due to the influence of geological conditions; the ratio of high productivity is only 53.58 %, which is mainly found in flat areas located in closed depressions that have major settlements. Therefore, conflicts always exist between agricultural development and ecosystem conservation.

Data description

Enhanced thematic mapper plus (ETM+) imaging (7 bands, with a resolution of 30 m × 30 m) and a digital elevation model (DEM, with a resolution of 100 m × 100 m) were selected; they were provided by the Data-sharing Network of Earth System Science, China (<http://www.geodata.cn>). The daily meteorological data (solar radiation, temperature, and precipitation) for 2000–2010 were obtained from 97 stations within and near the study area of northwest Guangxi, China, from the China Meteorological Data-sharing Service System (cdc.cma.gov.cn). They were interpolated to 100-m resolution on a 100-m resolution digital elevation model layer by using the thin-plate smoothing spline method. Carbon sequestration rates were calculated on a monthly basis.

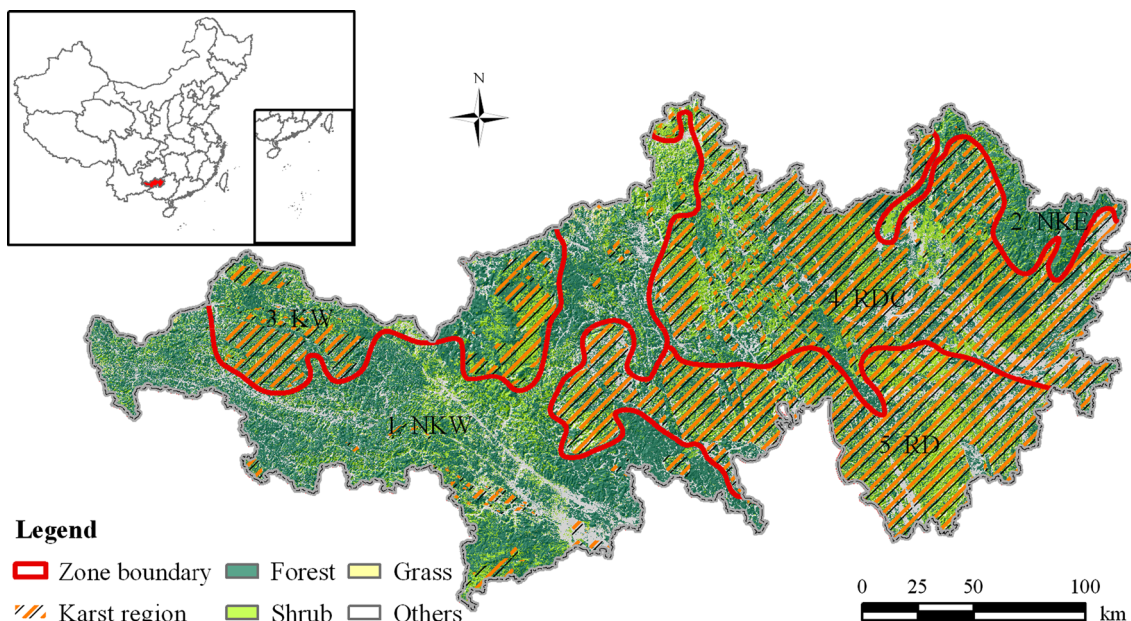


Fig. 1 Sketch map of location in the study area, a typical karst area by the ongoing Grain-to-Green Program of northwest Guangxi China, divided into five zones according to the geographical condition and the intensity of human disturbance: zone 1 (NKW, Western non-karst

area), zone 2 (NKE, Eastern non-karst area), zone 3 (KW, Western karst area), zone 4 (RDC, Restoration area of karst rocky desertification) and zone 5 (RD, Area of karst rocky desertification)

Vegetation type was extracted from the ETM+ images by using ArcGIS 10.0 (Environment Systems Research Institute) and ERDAS IMAGINE 9.1 software (Leica) by using the normalized difference vegetation index (NDVI). The classifications were validated using the color infrared aerial photographs and in situ data collected during 2000–2010. The accuracies of the classifications were 80.54 %, with Kappa coefficients of 0.63. In addition, meteorological data (solar radiation, temperature, and precipitation) for 2000–2010 were obtained from 97 stations within and near this study area and interpolated to a 250-m resolution by using the thin-plate smoothing spline method. All data were projected to the same level (Albers Conical Equal Area, Krasovsky Spheroid) and sampled to the same pixel spacing (250 m × 250 m).

Estimating NPP from the remotely sensed data

The terrestrial Carnegie–Ames–Stanford Approach (CASA) ecosystem model was used to estimate ecosystem NPP from satellite data (Field et al. 1995; Zhu et al. 2006; Xing et al. 2010). The following models were used to calculate NPP:

$$NPP(x, t) = \varepsilon(x, t) \times APAR(x, t) \tag{1}$$

where $\varepsilon(x, t)$ is light energy utilization, and $APAR(x, t)$ is absorbed photosynthesis availability radiation.

$$APAR(x, t) = SOL(x, t) \times FPAR(x, t) \times 0.5 \tag{2}$$

where $FPAR(x, t)$ is the fraction of photosynthesis active radiation, and $SOL(x, t)$ is solar radiation.

$$\varepsilon(x, t) = T_{\varepsilon 1}(x, t) \times W_{\varepsilon}(x, t) \times \varepsilon_{\max} \tag{3}$$

where $T_{\varepsilon 1}(x, t)$ is the effect of temperature, and $W_{\varepsilon}(x, t)$ is the effect of water on light energy utilization. ε_{\max} is the maximum light energy utilization, using the eco-physiological process model (BIOME-BGC) as revealed by Running and Coughlan (1988).

$$T_{\varepsilon 1}(x, t) = 0.8 + 0.02 \times T_{\text{opt}}(x, t) - 0.0005 \times [T_{\text{opt}}(x, t)]^2 \tag{4}$$

where $T_{\text{opt}}(x, t)$ is the mean annual temperature.

$$W_{\varepsilon}(x, t) = 0.5 + 0.5 \times \frac{E(x, t)}{E_p(x, t)} \tag{5}$$

$$E(x, t) = \frac{P(x, t) \times R_n(x, t) \times [(P(x, t))^2 + (R_n(x, t))^2 + P(x, t) \times R_n(x, t)]}{[P(x, t) + R_n(x, t)] \times [(P(x, t))^2 + (R_n(x, t))^2]} \tag{6}$$

$$E_{\rho}(x, t) = (E(x, t) + E_{\rho 0}(x, t))/2 \tag{7}$$

where $E(x, t)$, $E_{\rho}(x, t)$, $p(x, t)$, and $R_n(x, t)$ are the actual evapotranspiration, potential evapotranspiration, rainfall, and radiation, respectively. $E_{\rho 0}(x, t)$ is the local available

evapotranspiration, which is calculated using the vegetation-climate model of Thomthwaite (1948).

Estimating NEP from NPP and environmental conditions

In an ecosystem, when the fixed carbon is more than the discharged carbon, the ecosystem becomes a sink of atmospheric CO₂ (carbon sequestration). NEP is one of the most important indexes to identify the carbon source (sink). Vegetation carbon sequestration can be expressed as the difference between vegetation NPP and soil microbial respiration carbon (RH) emissions (Zhao et al. 2005; Pei et al. 2010).

$$\text{NEP} = \text{NPP} - \text{RH} \quad (8)$$

$$\text{RH} = 0.22 \times (\text{Exp}(0.0913T) + \text{Ln}(0.3145R + 1))30 \times 46.5\% \quad (9)$$

where T is temperature, and R is precipitation. When $\text{NEP} > 0$, the carbon of vegetation fixed is more than that of soil discharged (Fang et al. 2007; Tang et al. 2013).

Factors influencing the spatial distributions of vegetation carbon density determined using CCA

CCA is a robust method that has been widely used in ecology and can be used to directly relate community data to environmental variables by constraining species ordination to a pattern correlated with environmental variables. It allows the measurement of the linear relationship between two multi-dimensional variables and can be used to evaluate the relationship between two group variables (TerBraak 1994).

In this analysis, vegetation carbon is treated as samples, and environmental variables such as land type (LT), forest type (FT), vegetation species (VS), vegetation type (VT), degree of rocky desertification (DR), humus layer (HL), area grad, vegetation coverage (VC), soil thickness (ST), slope position (SP), slope (S), aspect (AS), and altitude are treated as environmental factors. CCA was performed using CANOCO for Windows (TerBraak 1994). All variables were standardized using SPSS 11.0 (International Business Machines Corporation, IBM) before applying CCA.

Results

Annual NPP increased in the typical karst area of northwest Guangxi, China, since the implementation of the GTGP

First, the changes in annual NPP, which showed an increasing trend during 2000–2010, over the typical karst

area were investigated. The total annual NPP increased from 191.66 Tg C in 2000 to 201.08 Tg C in 2010 with a significance rate of $13.20 \text{ g C m}^{-2} \text{ year}^{-1}$ ($P < 0.05$). Annual NPP also significantly increased ($P < 0.05$) by 21.14 % in the study area, with the mean annual NPP accumulation rate of $58.00 \text{ g C m}^{-2} \text{ year}^{-1}$ (Fig. 2a). The study area can be divided into five zones according to the geographical condition and intensity of human disturbance: zone 1 (NKW, western non-karst area), zone 2 (NKE, eastern non-karst area), zone 3 (KW, western karst area), zone 4 (RDC, restoration area of karst rocky desertification), and zone 5 (RD, area of karst rocky desertification; Fig. 1). The annual NPP increased during 2000–2010 in all the five zones. The greatest increase was found in zone 4 ($34.20 \text{ g C m}^{-2} \text{ year}^{-1}$, $P < 0.05$), followed by those in zone 2 ($23.90 \text{ g C m}^{-2} \text{ year}^{-1}$, $P < 0.05$), zone 3 ($5.30 \text{ g C m}^{-2} \text{ year}^{-1}$, $P < 0.05$), and zone 5 ($2.40 \text{ g C m}^{-2} \text{ year}^{-1}$, $P < 0.05$). The change was slight in zone 1 ($1.70 \text{ g C m}^{-2} \text{ year}^{-1}$; Fig. 2).

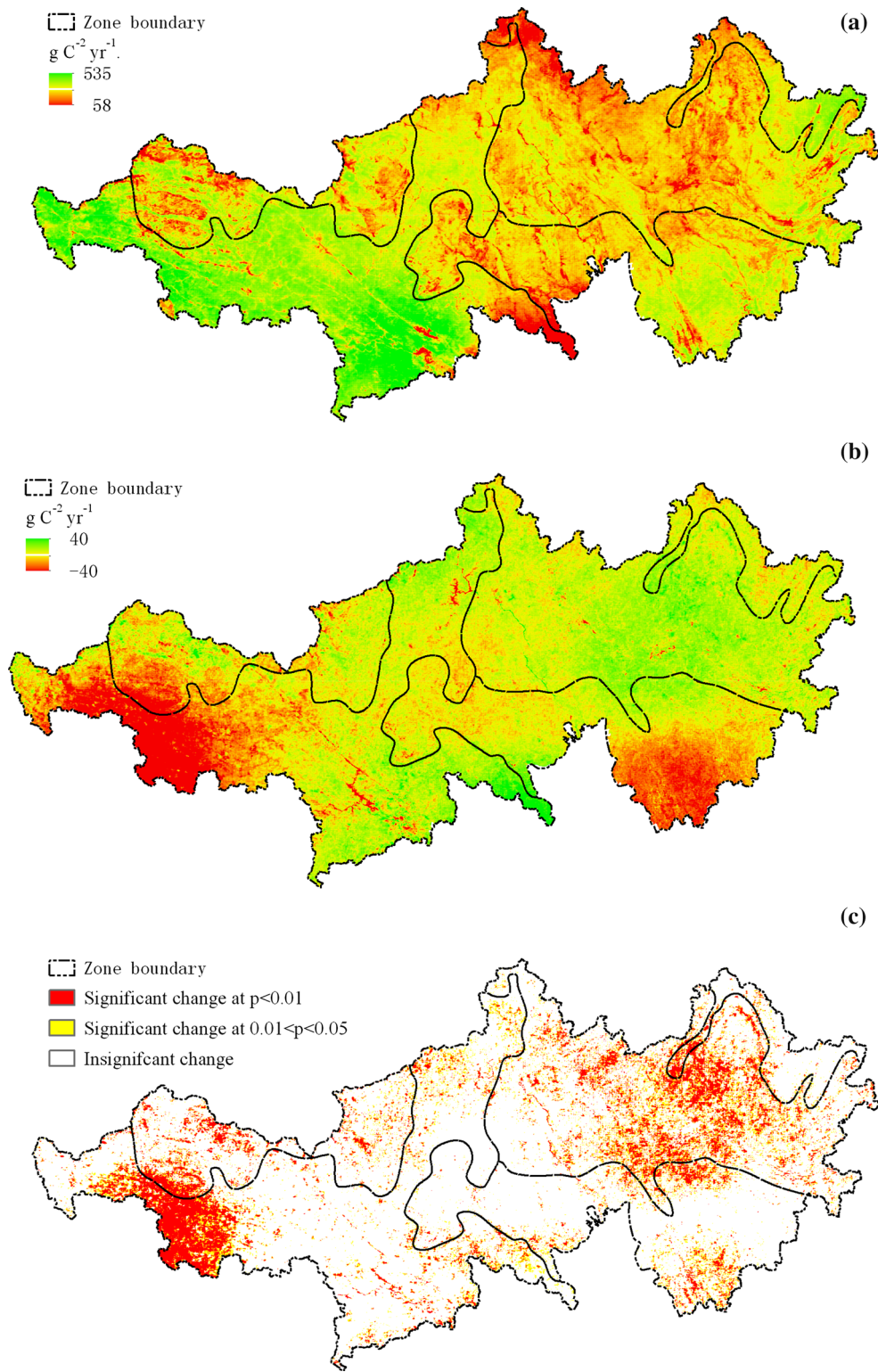
Increased annual NEP in the typical karst area during 2000–2010

NEP of the typical karst area also significantly increased from 179.58 Tg C in 2000 to a carbon sink of 182.54 Tg C in 2010, with a rate of $9.00 \text{ g C m}^{-2} \text{ year}^{-1}$ ($P < 0.05$). Zones 1–5 functioned as net carbon sinks in 2010, with an annual NEP of 10.94 Tg C (36.43 % of the total annual NEP), 4.12 Tg C (4.12 %), 3.36 Tg C (11.19 %), 8.73 Tg C (29.06 %), and 5.77 Tg C (19.19 %), respectively (Fig. 3). NEP also tended to significantly increase in each zone during 2000–2010. Zone 4 (RDC) showed the highest annual NEP ($30.30 \text{ g C m}^{-2} \text{ year}^{-1}$, $P < 0.05$), followed by zone 2 ($19.70 \text{ g C m}^{-2} \text{ year}^{-1}$, $P < 0.05$), zone 3 ($0.90 \text{ g C m}^{-2} \text{ year}^{-1}$, $P < 0.05$), zone 5 ($-1.60 \text{ g C m}^{-2} \text{ year}^{-1}$, $P < 0.05$), and zone 1 ($-2.70 \text{ g C m}^{-2} \text{ year}^{-1}$, $P < 0.05$; Fig. 3).

Carbon sequestration increased mostly due to the implementation of the ecological restoration program

Besides the improvements afforded by the implementation of the GTGP, changes in climate might have also contributed to the significant ecosystem carbon sequestration in the typical karst area. Thus, the changes in annual precipitation and mean annual temperature over 2000–2010 were also assessed. However, there was no significant change in precipitation or temperature in either the entire region or any of the separate zones (Fig. 4). Statistical analysis also showed no significant correlations between NPP or NEP and the climate variables ($P = 0.45$). Hence, the observed significant increases in NPP and NEP in the

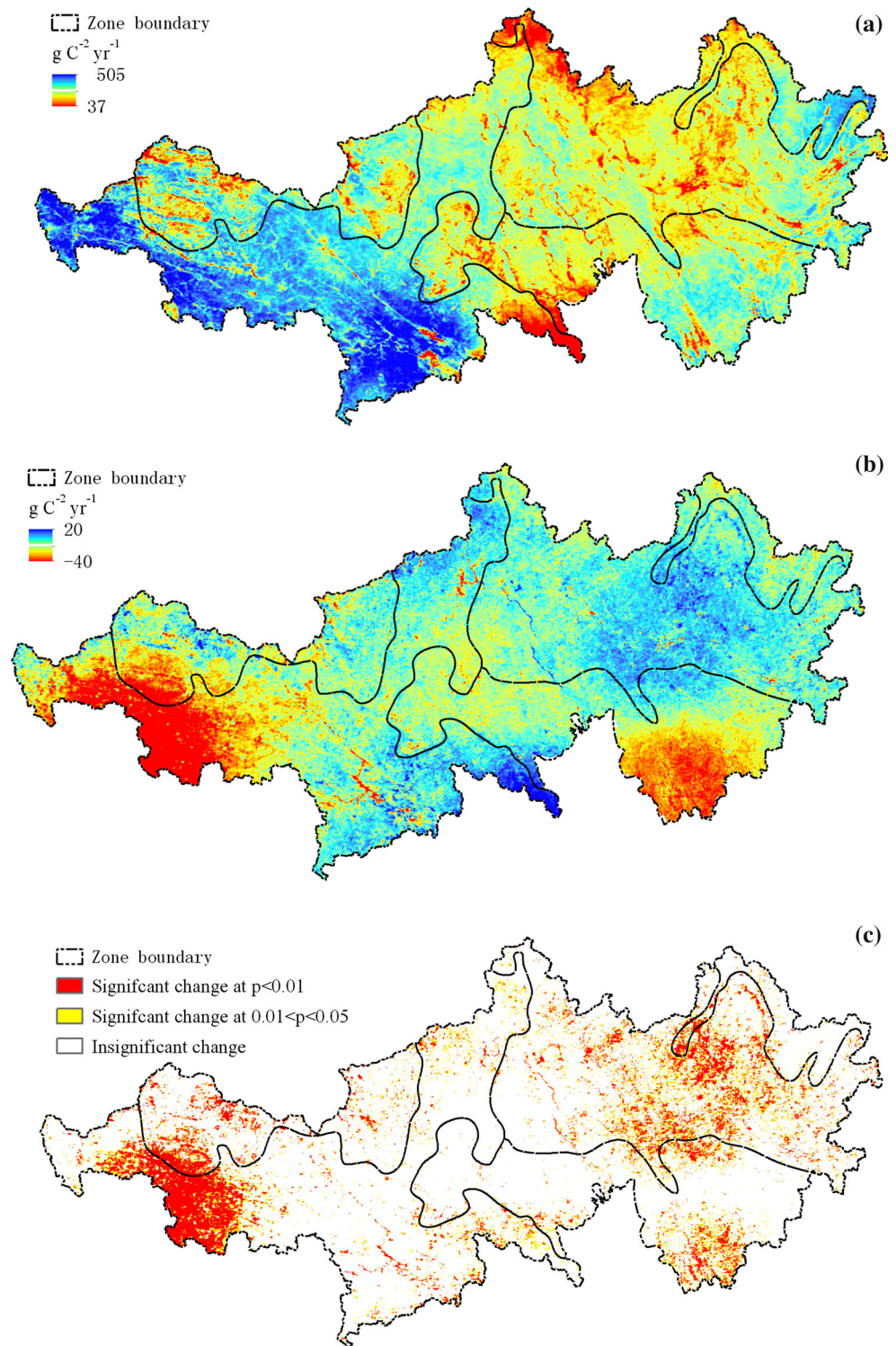
Fig. 2 Distribution of **a** annual NPP, **b** the increment of annual NPP and **c** the significant level of the increment of annual NPP during 2000–2010



study area were unlikely to have been caused by climate changes. Correlation analysis of each pixel variation showed that the changes in NPP were less affected by those in precipitation and temperature ($P > 0.05$; Fig. 5). The

changes in NPP were positively correlated with the changes in precipitation and negatively correlated with those in temperature (Fig. 5), whereas regions where the GTGP was implemented showed a significant increase in annual NPP

Fig. 3 Distribution of **a** annual NEP, **b** the increment of annual NEP and **c** the significant level of the increment of annual NEP in the karst area of northwest Guangxi, China during 2000–2008



(compare Figs. 1, 2). These results suggested that the increased annual NPP and net ecosystem sequestration in the typical karst area during the study period were mostly due to the implemented ecological restoration program.

Although the changes in climate might not be responsible for the significantly increased NPP in the study area,

the carbon sequestration efficiency of the GTGP was still limited by precipitation. Precipitation can have a direct effect on plant characteristics such as size, plant structure, and plant density of the restored vegetation. Grass, shrubs, and forests showed the highest trends of NPP and NEP increase for zones 1 and 3, zone 2, and zones 4 and 5,

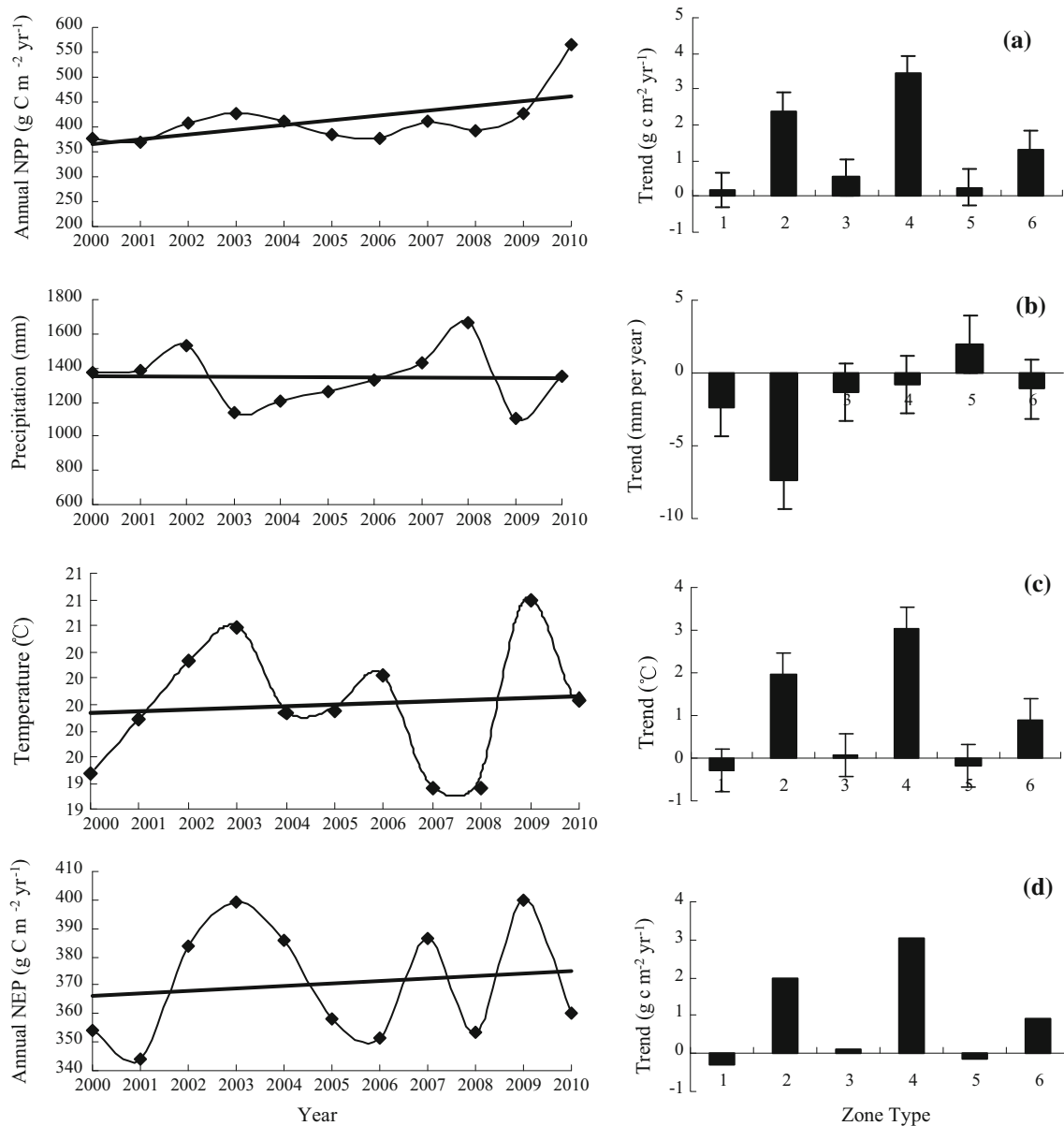


Fig. 4 Time series of **a** annual NPP, **b** annual precipitation, **c** temperature and **d** annual NEP during 2000–2010 across the karst area of northwest Guangxi, China. 1 Western non-karst area. 2

Eastern non-karst area. 3 Western karst area. 4 Restoration area of karst rocky desertification. 5 Area of karst rocky desertification. 6 The study area of northwest Guangxi, China

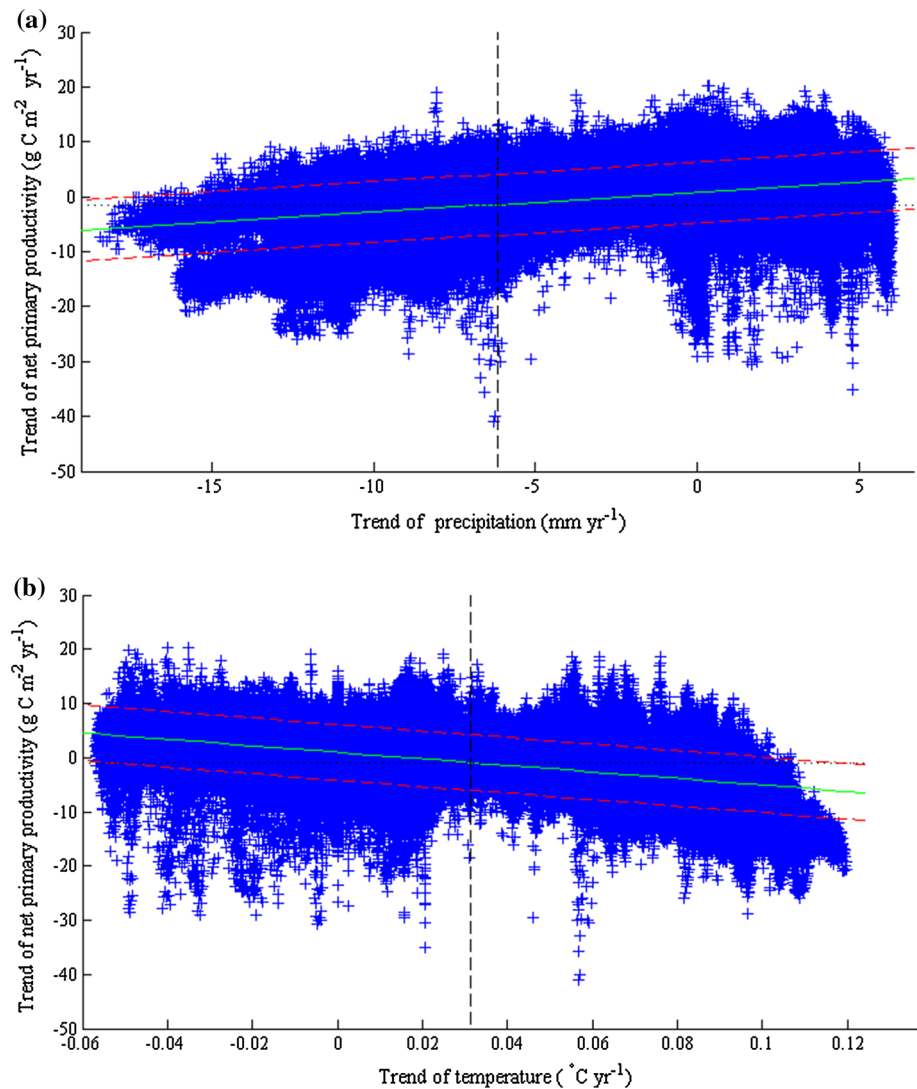
respectively (Table 1). There was also a certain correlation between the NPP and NEP of different vegetation types, especially between forests and shrubs. Forests and shrubs might thus have associated characteristics. Human activities affected carbon sequestration by alternating land use change and could play either positive or negative roles in generating stressors. Population growth and agriculture generated stressors, whereas ecosystem restoration programs intended to reduce stressors, but these programs feedback to human activities. These results suggest that appropriate restoration programs should be implemented in

accordance with the local climate of regions in order to achieve the best efficiency.

Vegetation carbon density is closely related with human activity

The results of CCA are shown in figures as t horizontal, vertical axes, and some vectors. The angle of the vector and axis indicated the size of correlation (smaller the angle size, larger the power of correlation). The length of the vector indicated the strength of environmental impacts, and

Fig. 5 The relativity analysis of trend of NPP, vegetation fractional cover, precipitation and temperature based on pixel



its direction and axis express a positive or negative correlation.

There were significant correlations between vegetation carbon and environmental factors. The correlation coefficients of the first and second axes of the vegetation carbon matrix and that of environmental factor matrix were 0.915 and 0.868, respectively. This suggested that most correlation information was located in the first two axes, and various line segments emerged in the graph. The length of the line segments and the angle between them and the axes represented the relationship between environmental factors and vegetation carbon (the longer the line, the stronger is the influence).

Axis 1 was closely correlated with AG, HL, ST, VC, VS, and FT. The first axis increased with all the six factors. The second axis increased with SP and AS. DR increased when

axis 1 increased (Fig. 6). High elevation and slope were found in the upper part of the ordination. Vegetation carbon was closely related with AG, HL, ST, VC, VS, and FT. High vegetation carbon was mainly found in areas with fertile soil and high vegetation coverage. Vegetation carbon was highly correlated with slope and elevation, and higher carbon was typically found at higher slope and elevation positions (the average NPP was $380.59 \text{ g C m}^{-2}$ below the elevation of 200 m and $406.40 \text{ g C m}^{-2}$ above the elevation of 1000 m in the study area between 2000 and 2010). There was generally good vegetation coverage at high elevation because of little disturbance by human activities, especially by the implementation of hill closing for forestation. At low elevations, such correlations were not found due to the strong rocky desertification.

Table 1 Time series of annual NPP, NEP and trend of NPP, NEP with different vegetation types

Vegetation type	Zone 1 NKW	Zone 2 NKE	Zone 3 KW	Zone 4 RDC	Zone 5 RD	Northwest Guangxi, China
Annual NPP (g C m ⁻² year ⁻¹)						
Forest	429.44	405.85	396.06	383.22	392.19	405.16
Shrub	422.04	385.68	386.16	379.04	394.92	394.31
Grass	404.02	373.45	383.68	345.25	387.42	388.30
Trend of NPP (g C m ⁻² year ⁻¹)						
Forest	0.37	2.30	0.76	3.54	0.72	1.47
Shrub	0.67	2.62	0.80	3.49	-0.51	1.46
Grass	1.93	1.92	1.74	2.90	-0.66	1.53
Annual NEP (g C m ⁻² year ⁻¹)						
Forest	403.89	380.14	371.96	356.99	364.32	379.22
Shrub	396.53	360.42	361.82	353.16	366.71	368.08
Grass	378.86	344.24	360.14	320.96	359.19	363.05
Trend of NEP (g C m ⁻² year ⁻¹)						
Forest	-0.09	1.88	0.33	3.15	0.31	1.04
Shrub	0.24	2.23	0.36	3.10	-0.90	1.05
Grass	1.52	1.29	1.31	2.23	-1.04	1.09

NPP Net primary productivity, NEP Net ecosystem productivity. zone 1 NKW: western non-karst area, zone 2 NKE: eastern non-karst area, zone 3 KW: western karst area, zone 4 RDC: restoration area of karst rocky desertification, zone 5 RD: area of karst rocky desertification

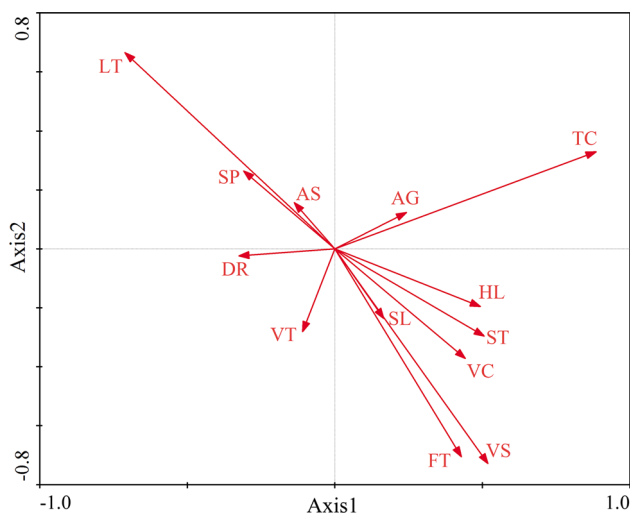


Fig. 6 The ordination diagram of impact factors through the method of CCA (canonical correspondence analysis). *LT* Land type, *FT* forest type, *VS* vegetation species, *VT* vegetation type, *DR* degree of rocky desertification, *HL* humus layer, *AG* area grade, *VC* vegetation coverage, *ST* soil thickness, *SP* slope position, *SL* slope, *AS* aspect and *AL* altitude

Discussion and conclusions

Our results showed a significantly increasing trend in ecosystem carbon sequestration in the typical fragile karst area of northwest Guangxi, China (13.20 g C m⁻² year⁻¹ on average) since the implementation of the GTGP, which

resulted in the fixation of 2.96 Tg C in this land. Because of the widely distributed rocky desertification, the density of vegetation carbon in the study area was relatively low compared with that in the other areas. Regarding the distribution of the NEP in different zones, zone 1 had high and zone 4 had relatively low contribution, although the increase in NEP in zone 4 was significant and that in zone 1 was slight. Moreover, the CCA analysis showed that the most significant factors that influenced vegetation carbon in the study area were AG, HL, ST, VC, VS, and FT. Our study results indicated that karst ecosystem had improved because of the rocky desertification control measures, including ecological migration, and the GTGP. About 0.53 % of the total area covered by the GTGP was restored in this typical karst area. Therefore, the GTGP substantially contributed to the mitigation of China’s anthropogenic CO₂ emission.

Unlike in other study areas (Tian et al. 1998; Piao et al. 2009; Pan et al. 2011; Harris et al. 2012; Feng et al. 2013), the per unit area NEP in the present study area was fairly high primarily because of the higher temperature, ample precipitation, and dominant mixed forests. The ecosystem conditions improved with the implementation of measures to overcome rocky desertification during 2000–2010 (Yang 2003). The focus of environmental migration is to help people move to places with better ecosystem conditions, and 49,133 families (232,705 persons) were relocated in northwest Guangxi, China. The total area of GTGP was up to 1278.67 km² in Baise, which included farmland to forest

(605.33 km²) and barren hills to reforestation (673.33 km²).

Results of the CCA showed that the impact of VC, VS, and FT on vegetation carbon was significant and positive. The results indicated that environmental migration and GTGP were the main impact factors on land use changes, and thus landscape pattern modifications, leading to the changes in NEP. Controlling karst rocky desertification requires the optimization of land use structure.

Obtaining a balance between development and protection is a common problem and is also noted in rocky desertification in karst areas (Brown et al. 2011). The environmental quality is known to be poor in karst areas. Therefore, conservation of karst ecosystem should take precedence over economic purposes in future land use. Although discontinuing all reclamation activities in the karst areas might not be possible, future land reclamation projects need to be controlled and should be implemented after rigorous environmental impact analysis. Therefore, more studies investigating the impacts on ecosystem services are necessary in the karst region of southwest China.

This study analyzed the spatiotemporal variations in vegetation carbon in the typical karst area of northwest Guangxi, China, based on previously reported findings and field verification. However, the estimated results were not completely consistent with the actual carbon density due to the complexity and dynamics of the ecosystems themselves (Costanza 2008; Li et al. 2010; Zhao et al. 2010; Ngugi et al. 2011) and the problems in identifying appropriate scales (Bengtsson et al. 2005; Hein et al. 2006; Petrosillo et al. 2009). Consequently, the multi-scale and spatial analyses of vegetation carbon are necessary in the future. Unlike most other ecosystems, the karst ecosystem is fragile and heterogeneous. Therefore, the spatial scale and image resolution need to be taken into account in future assessments of ecosystem services in this or similar karst regions.

Our analysis showed that the current increase in NEP was mainly because of enhanced NPP, and that environmental conditions such as precipitation and temperature had insignificant contributions. This is because of the fact that human activities have a remarkable impact on NPP. The present results also revealed the rates of different restoration types that are required to increase the annual NPP across different zones. In terms of carbon sequestration potential, the present results showed that there is no universally best restoration for all zones. In conclusion, the vegetation restoration in the typical karst area of northwest Guangxi, China, is especially limited by the intensity of human activities.

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