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Significant trade-off for the impact of Grain-for-Green Programme on ecosystem services in North-western Yunnan, China

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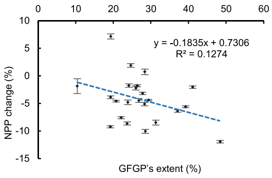
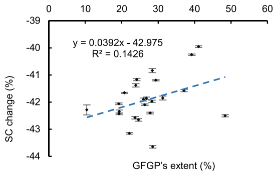
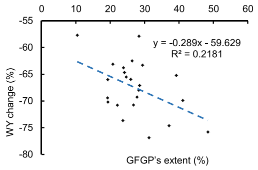
HIGHLIGHTS

- Ecosystem services trade-offs due to GFGP are assessed.
- Soil conservation was potentially increased with the implementation of GFGP.
- Increasing extent of GFGP implementation led to the decrease of NPP and water yield at sub-watershed scale.
- Recovery of soil conservation lagged behind recovery of net primary production.

GRAPHICAL ABSTRACT







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ABSTRACT

Ecological restoration can mitigate human disturbance to the natural environment and restore ecosystem functions. China's Grain-for-Green Programme (GFGP) has been widely adopted in the last 15 years and exerted significant impact on land-use and ecosystem services. North-western Yunnan is one of the key areas of GFGP implementation in the upper Yangtze River. Promotion of ecosystem services in this region is of great importance to the ecological sustainability of Yangtze River watershed. In this study, remote sensing and modelling techniques are applied to analyse the impact of GFGP on ecosystem services. Results show that the transformation from non-irrigated farmland to forestland could potentially improve soil conservation by 24.89%. Soil conservation of restored forest was 78.17% of retained forest while net primary production (NPP) already reached 88.65%, which suggested different recovery rates of NPP and soil conservation. Increasing extent of GFGP implementation improved soil conservation but decreased NPP and water yield at sub-watershed scale, which revealed trade-offs between ecosystem services under ecological restoration. Future ecosystem management and GFGP policy-making should consider trade-offs of ecosystem services in order to achieve sustainable provision of ecosystem services.

1. Introduction

Human activities have led to global environmental destruction and ecological degradation (Foley et al., 2005). Loss of biodiversity and decreased provision of ecosystem services impair ecosystem health and resilience, which in turn threatens human well-being (Parr et al., 2003). To address the problem and maintain environmental sustainability, ecological restoration programmes have been implemented worldwide in order to increase the provision of ecosystem services and thus promote human well-being (Carpenter et al., 2009). Restoration programmes have significantly enhanced biodiversity and ecosystem services in various ecosystems throughout the globe (Benayas et al., 2009). Assessment of ecosystem services under restoration could reveal the benefits and deficiencies of ecological policy and provide insights into future design and implementation of restoration programmes (Tallis et al., 2008).

China's Grain-for-Green Programme (GFGP) has received global attention due to its ambitious goal and wide spatial range of implementation (Liu et al., 2008). GFGP aims to transfer farmland on steep slopes to forestland or grassland to increase vegetation coverage and reduce soil

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erosion, and thus to restore regional ecosystems (Zhang et al., 2016a; Li et al., 2016). According to the data from the State Forestry Administration of China, 9.27 million ha of farmland were converted to forestland or grassland from 1999 to 2013, which accounted for 6.86% of China's total area of farmland in 2013. GFGP has significantly altered ecosystem services. Researches indicate that GFGP has reduced soil erosion (Deng et al., 2012; Zhou et al., 2009), and increased carbon sequestration (Liu et al., 2014; Persson et al., 2013) and soil organic carbon (Deng et al., 2014; Zhang et al., 2010). However, increased forestland might lead to reduction of water yield, especially in semi-arid regions (Cao et al., 2009; Cao et al., 2010; Sun et al., 2006).

Trade-off relationships exist between multiple ecosystem services; therefore, the implementation of ecological restoration could result in different ecosystem services changing in opposite directions with different scales (Bennett et al., 2009). Enhancing one or a few ecosystem services does not mean that other ecosystem services would increase simultaneously (Egoh et al., 2008). The research of Lü et al. (2012b) shows that while GFGP decreases soil erosion in Loess Plateau, water yield is also reduced. Su and Fu (2013) find that water yield has trade-offs with sediment control and net primary production. Jia et al. (2014) discover the synergy between NPP and soil conservation and the trade-off between NPP and water yield in Loess Plateau. However, these researches focus mainly on the overall trends of ecosystem services change of the whole region with the implementation of GFGP, but fail to specifically contrast ecosystem services change between GFGP areas and non-GFGP areas. In addition, the extent of GFGP implementation is different between various sub-regions due to spatial heterogeneity in GFGP-associated natural and socio-economic factors. It is necessary to analyse the influence of GFGP's extent on the change of various ecosystem services.

At the end of 2015, China's central government announced to increase the extent of the new round of GFGP. The impact assessment of last round's GFGP on ecosystem services could provide insights into future ecological restoration. North-western Yunnan is located at the transition zone among East Asian Monsoon Region, South Asian Sub-tropical Monsoon Region and Qinghai-Tibetan Plateau. Complex and diverse landforms, climate types and hydrological systems make the region a global bio-diversity hotspot (Peng et al., 2016a; Xu and Wilkes, 2004). North-western Yunnan is the main GFGP area in the watershed of upper Yangtze River. Therefore, Dali Bai Autonomous Prefecture in North-western Yunnan as the study area (Fig. 1), the objectives of this study are: (1) to quantify land-use and ecosystem services change after the implementation of GFGP; (2) to contrast ecosystem services change in GFGP and non-GFGP areas; and (3) to analyse the influence of GFGP's extent on ecosystem services change.

2. Material and methods

2.1. Study area

Dali Bai Autonomous Prefecture (24°41′–26°42′N, 98°52′–101°03′E) is located in North-western Yunnan Province, China. Mountainous region accounts for 83.7% of Dali Prefecture's total area. Main mountains are of a north–south trend and are part of Yunling and Nushan mountain ranges. Rivers belong to four major rivers: the Jinsha River (the upper reach of the Yangtze River), the Lancang River (the upper reach of the Mekong River), the Nujiang River (the upper reach of the Salween River), and the Yuan River (the upper reach of the Red River), with > 160 branches forming a pinnate drainage pattern. The regional climate is low-latitude plateau monsoon climate, with an average annual temperature of 15.8 °C and precipitation of 836 mm (Peng et al., 2016b).

2.2. Land-use change detection

Landsat TM images of 2001 and Landsat OLI images of 2013 are used to interpret land-use before and after GFGP was implemented in Dali Prefecture with a resolution of 30 m. FLAASH module in ENVI 5.1 is applied for atmospheric correction. Remote sensing images are classified to six land-use types (forestland, grassland, construction land, waterbody, non-irrigated farmland and irrigated farmland) with ISODATA algorithm. The overall producer's accuracy for land-use in 2013 is 76.07%. Land-use data of the two times are used to detect GFGP area and generate land-use transformation matrix.

2.3. Ecosystem services quantification

NPP is estimated by the process-based Carnegie-Ames-Stanford Approach (CASA) (Potter et al., 1993), which has been widely adopted in

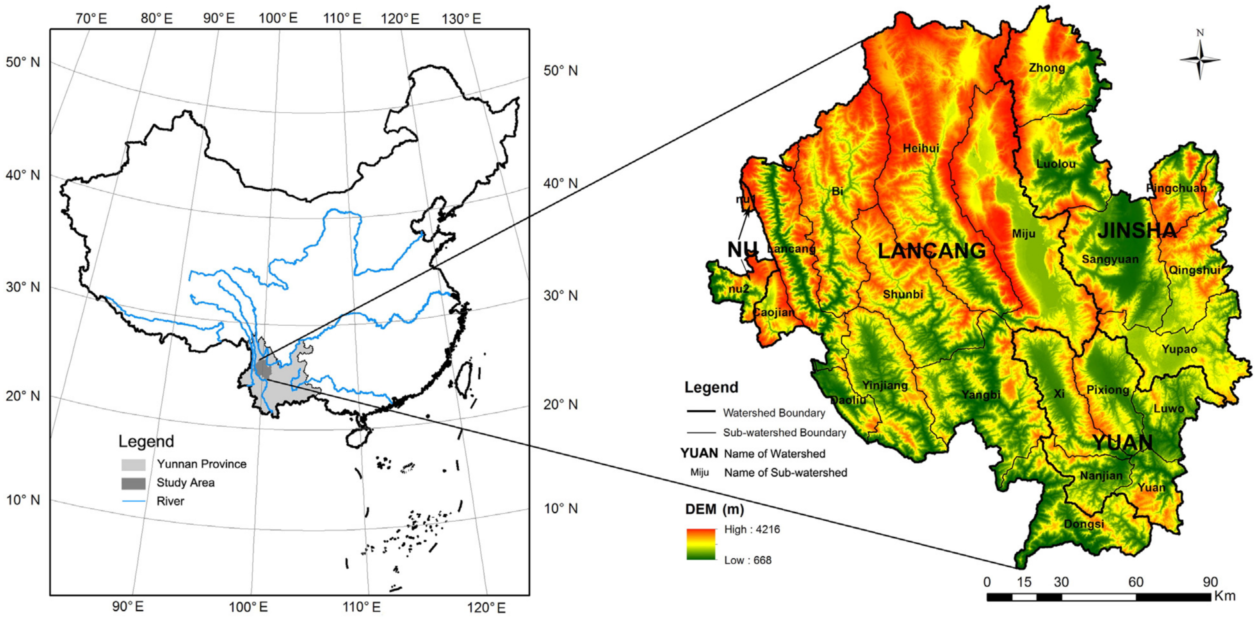

Fig. 1. Location, terrain and watersheds of the study area.

NPP estimation and global carbon cycle (Crabtree et al., 2009). In the model, NPP is determined by absorbed photosynthetic active radiation (APAR) and light utilisation efficiency (ε):

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

APAR is affected by total solar radiation and absorption ratio of active radiation which is calculated by normalised difference vegetation index (NDVI). MODIS NDVI product with 250 m resolution is used in this study. The method of nearest neighbour resampling is applied to match the resolution of interpreted land-use data and NDVI data. ε describes the efficiency of vegetation to transfer APAR to organic carbon, and is influenced by temperature stress, water stress and maximal light utilisation efficiency of the vegetation (Dong and Ni, 2011; Zhu et al., 2007).

Soil conservation (SC) is evaluated by Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991), which has been widely applied in various mountainous landscapes (Mallick et al., 2014). Soil erosion is determined by rainfall-runoff erosivity (R), and is affected by soil erodibility (K), slope length and steepness (LS), cover-management (C) and support practice (P). Potential soil erosion refers to the quantity of soil erosion without any cover-management and support practice, with C and P both equal to 1. Soil conservation is the difference between potential and actual soil erosion. Thus, soil conservation is calculated as:

$$\mathrm{SC}(x) = \mathrm{R}\cdot\mathrm{K}\cdot\mathrm{LS}\cdot(1-\mathrm{C}\cdot\mathrm{P}) \tag{2}$$

In this study, R and LS factor are calculated by empirical equations from soil erosion experiments in Yunnan Province (Yang, 2002). K factor is obtained using EPIC model (Williams, 1990). C and P factor are derived by their relationship with NDVI (Lin et al., 2002).

Water yield (WY) is modelled by Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) (Sharp et al., 2014). Based on the water balance method, water yield is calculated as the difference between precipitation (P) and actual evapotranspiration (AET):

$$\mathrm{WY}(x) = \left(1-\frac{\mathrm{AET}(x)}{\mathrm{P}(x)}\right)\cdot \mathrm{P}(x) \tag{3}$$

Evapotranspiration portion is the ratio of AET on P, and is determined by potential evapotranspiration and a climatic-soil parameter, which are further affected by factors including plant available water capacity and climate seasonality. As the model is based on understanding of hydrological processes at sub-watershed and watershed scale, the water yield data generated are the total amount and depth of water yield at sub-watershed scale.

2.4. Comparison of ecosystem services between different land-use types

Welch's *t*-test is applied to compare the quantity of ecosystem services of different land-use types. Welch's *t*-test is used to compare the means between variables with unequal variances and sample sizes, and is more robust than Student's *t*-test (Ruxton, 2006). As the quantities of soil conservation in flat areas are zero no matter GFGP has been implemented or not, all zero values of soil conservation are excluded from the samples. Quantities of water yield of different land-use types are not compared as reliable results of water yield generated by InVEST are at sub-watershed scale.

2.5. Correlation between GFGP's extent and ecosystem services change

Twenty-three sub-watersheds as units, ordinary least squares regression is conducted to analyse the impact of GFGP's extent on ecosystem services change. GFGP's extent is defined as the ratio of the area of GFGP zones to the total area of forestland and grassland in 2013. Average percentage change and its 95% confidence level of NPP and soil conservation of a sub-watershed is calculated according to the percentage change of ecosystem services of all the grids in the sub-watershed. As water yield at sub-watershed scale is generated directly by InVEST, confidence level could not be calculated based on grids. Since the overall level of ecosystem services in 2013 was lower than the level in 2001, it is reasonable to infer that sub-watersheds with less decrease of ecosystem services have higher capacity for the provision of ecosystem services.

3. Results

3.1. Land-use change

GFGP exerted a significant impact on land-use of Dali Prefecture during 2001 and 2013. The land-use transformation matrix (Table 1) indicates that the transformation from non-irrigated farmland to forestland and grassland was the major type of land-use change, with an area of 4296.47 km^2 and 1795.49 km^2 respectively. Land-use change caused by the implementation of GFGP accounted for 44.08% of overall land-use change, leading to a 36.74% increase in the area of forestland and grassland. GFGP areas were not evenly distributed across the region. Northern and eastern parts of the region had larger areas of farmland transferred to forestland and grassland. Mountainous regions with slope degree ranging from 6° to 15° and from 15° to 25° were influenced mostly, which accounted for 42.10% and 31.22% of the total GFGP area (Fig. 2). It could be concluded that non-irrigated farmland on steep slopes was the focus of GFGP implementation in the study area.

3.2. Ecosystem services change

Change of land-use and climatic conditions drives the change of ecosystem services. The total amount of the three ecosystem services, net primary production (NPP), soil conservation (SC) and water yield (WY), decreased 10.32%, 41.50%, and 66.49% respectively. The dramatic decline attributed to the large impact of precipitation on the three ecosystem services. In details, primary production is constrained by water availability, which is reflected in the water stress part of CASA. Precipitation determines erosivity, namely the R factor in RUSLE; therefore, low precipitation reduces the quantity of soil conservation. Low precipitation reduces water yield which equals the difference between precipitation and actual evapotranspiration. The precipitation of Dali Prefecture in 2013 was 693 mm, 17.1% less than the multi-year average and 39.2% less than the precipitation in 2001. As a result, the total amount of NPP, soil conservation and water yield in 2013 decreased compared with the amount in 2001.

Central and north-western areas had high NPP due to the cool temperate climate with sufficient sunlight and precipitation. River valleys in north-eastern and south-eastern parts of the region had low NPP because of the climate with high temperature and limited precipitation (Fig. 3). The implementation of GFGP led to a higher proportion of forestland and grassland in the total amount of NPP. Grassland accounted for 14.83% of total NPP in 2013, a significant increase from 0.76% in 2001. The percentage that forest represented increased from 60.97% to 74.44%, while the percentage of non-irrigated farmland decreased sharply from 33.80% to 8.35% (Table 2).

Forestland and grassland were also more crucial in regional soil conservation. The percentage of total soil conservation that forestland constituted increased largely to 81.50% in 2013 from 69.12% in 2001. The percentage of grassland also expanded from 3.15% to 9.95%. For non-irrigated farmlands, the percentage declined markedly from 25.30% to 7.54% (Table 2). Mountainous areas had high level of soil conservation, especially central and western mountain ranges (Fig. 3). Potential soil erosion was high in central and western mountains due to high precipitation and steep slopes; however, the dense forest cover significantly reduced soil erosion. Therefore, soil conservation was of high level in these mountainous areas.

Table 1
Land-use transformation matrix of Dali Prefecture during 2001–2013 (km^2).

2013	2001					
	Waterbody	Construction land	Non-irrigated farmland	Irrigated farmland	Grassland	Forestland
Waterbody	339.42	23.17	32.31	1.62	17.9	96.13
Construction land	6.82	159.03	786.92	157.38	7.36	377.92
Non-irrigated farmland	4.31	83.18	1378.38	69.55	3.65	558.81
Irrigated farmland	9.58	236.88	289.65	106.62	26.32	217.33
Grassland	4.76	264.87	**1795.49**	142.64	21.64	1290.06
Forestland	49.82	507.1	**4296.47**	510.56	610.86	13,826.24

Water yield in central and western Dali Prefecture was substantial while north-eastern and south-eastern parts of the region had low level of water yield (Fig. 3). Central and western areas belong to Nu River watershed and Lancang River watershed with a cool and humid climate where relatively high precipitation and low transpiration led to high water yield. With low-altitude river valleys and a semi-arid climate, north-eastern and south-eastern areas which mainly belong to Jinsha River watershed and Yuan River watershed had low water yield due to low precipitation and high transpiration. As water yield generated by InVEST was at sub-watershed scale, water yield of different land-use types was not analysed.

3.3. Ecosystem services comparison between GFGP areas and non-GFGP areas

Land-use change and climate change together drive the change of ecosystem services (Turner et al., 2007). Thus, it is necessary to exclude the influence of climate change in order to precisely analyse the impact of ecological restoration on ecosystem services. All ecosystems experienced the influence of decreased precipitation in 2013, but GFGP only affected new vegetation in GFGP areas. Therefore, ecosystem services of restored vegetation (GFGP areas) and retained non-irrigated farmland (non-GFGP areas) in 2013 were compared to analyse the impact of GFGP on ecosystem services.

Welch's *t*-test was applied to analyse whether the quantity of ecosystem services of restored forest converted from non-irrigated farmland (sample denoted as A) was significantly larger than the quantity of ecosystem services of retained non-irrigated farmland (sample denoted as B). The *t*-test is as follows:

$H_0: \mu_A = \mu_B \quad H_1: \mu_A > \mu_B \quad \alpha = 0.05$

Results showed that neither NPP nor SC passed the *t*-test (NPP: $T = -82.07$; SC: $T = -4.06$). Therefore, restored forest did not had higher level of NPP and soil conservation than non-irrigated farmland, which meant that the implementation of GFGP did not increase the provision of ecosystem services. There might be two reasons:

Assumption 1. The restored forest of young tree-age was still in growing stage and had not attained the maximum level of ecosystem services;

and

Assumption 2. After sufficient time of growth, the restored forest could supply higher level of ecosystem services than non-irrigated farmland.

To test Assumption 1, *t*-test was conducted to verify whether the quantity of ecosystem services of restored forest (sample A) was less than the quantity of ecosystem services of retained forest (sample denoted as C) which was already forest in 2001 and was conserved between 2001 and 2013. The *t*-test is as follows:

$$H_0: \mu_A = \mu_C \quad H_1: \mu_A < \mu_C \quad \alpha = 0.05$$

Both NPP and SC passed the *t*-test (NPP: $T = -147.32$, $P < 0.001$; SC: $T = -77.57$, $P < 0.001$). Assumption 1 was proved, indicating that

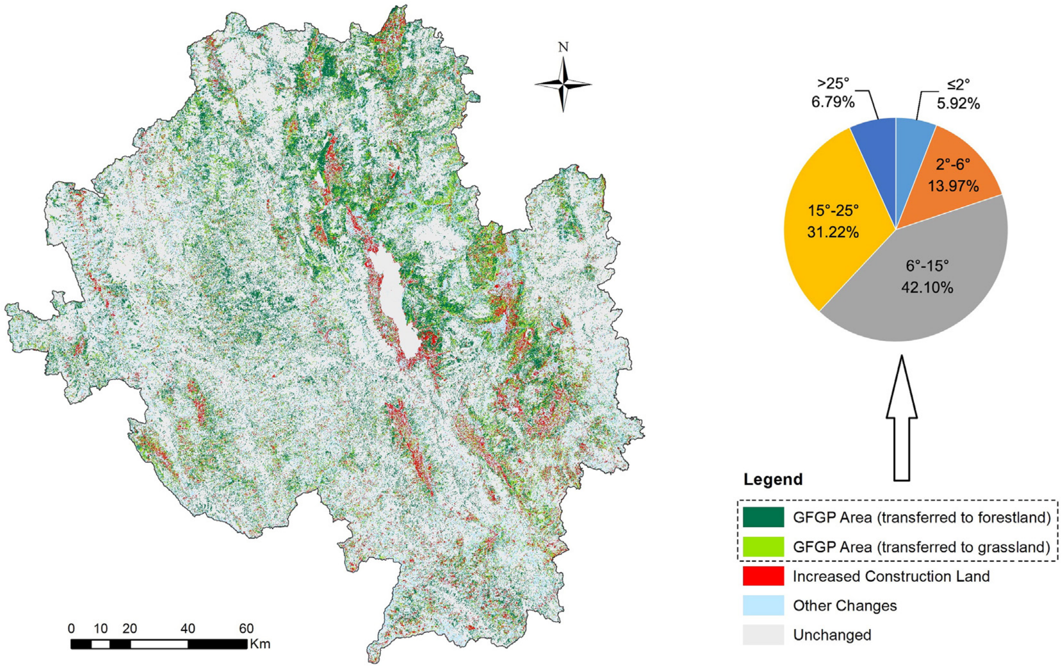

Fig. 2. Land-use change of Dali Prefecture during 2001–2013 and slope distribution of GFGP area.

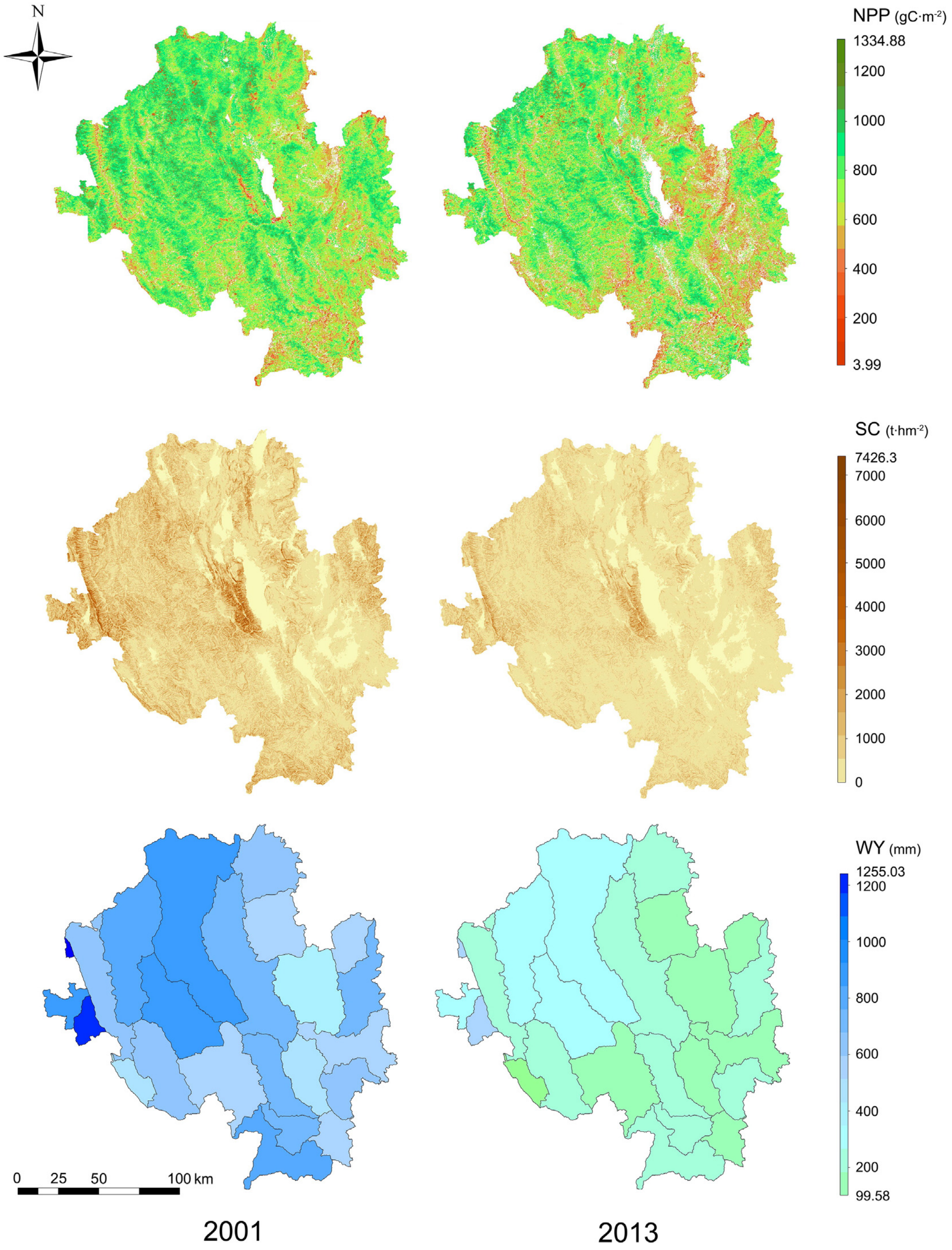

Fig. 3. Ecosystem services of Dali Prefecture in 2001 and 2013.

Table 2
Ecosystem services of different land-use types of Dali Prefecture in 2001 and 2013.

	NPP_2001		NPP_2013		SC_2001		SC_2013	
	Total amount (GgC)	Percent (%)	Total amount (GgC)	Percent (%)	Total amount (Mt)	Percent %	Total amount (Mt)	Percent %
Forestland	12,068.74	60.97	13,214.23	**74.44**	1291.41	69.12	890.85	**81.50**
Grassland	149.91	0.76	2632.31	14.83	58.79	3.15	108.73	9.95
Irrigated farmland	885.65	4.47	422.65	2.38	45.50	2.43	11.00	1.01
Non-irrigated farmland	6691.42	33.80	1483.30	**8.35**	472.70	25.30	82.44	**7.54**
Sum	19,795.72	100.00	17,752.49	100.00	1868.40	100.00	1093.02	100.00

restored forest needed time to grow to a mature stage to supply more ecosystem services. Average NPP of restored forest was 640.86 $gC\cdot m^{-2}$, 88.65% of retained forest; average soil conservation of restored forest was 382.73 $t\cdot hm^{-2}$, 78.17% of retained forest (Table 3).

To test Assumption 2, *t*-test was conducted to verify whether the quantity of ecosystem services of retained forest (sample C) was larger than the quantity of ecosystem services of retained non-irrigated farmland (sample B). The *t*-test is as follows:

$$H_0: \ \mu_C = \mu_B \quad H_1: \ \mu_C > \mu_B \quad \alpha = 0.05$$

NPP did not pass the *t*-test, but SC passed the *t*-test (NPP: $T = -2.26$; SC: $T = 45.63$, $P < 0.001$). The average amount of soil conservation of retained forest was 489.64 $t\cdot hm^{-2}$, 24.89% more than the amount of retained non-irrigated farmland (Table 3). Forest has much higher level of soil conservation than non-irrigated farmland. Therefore, it could be inferred that GFGP areas would perform better effect of soil retention in the future.

4. Discussion

4.1. Recovery rates difference between NPP and soil conservation

The average quantity of soil conservation of restored forest in GFGP areas was 78.17% of the quantity of mature forest, while NPP already reached 88.65% of mature forest. This suggested that the recovery rate of NPP was faster than the rate of soil conservation taking all GFGP areas as a whole. Yet it remains untested whether this characteristic of ecosystem services recovery is applied in every single GFGP area. Namely, it is necessary to figure out whether soil conservation recoveries slower than NPP at grid-cell level in a statistically significant manner. Therefore, the amount of the two ecosystem services of restored forest as the sample, a paired *t*-test is applied to verify whether the recovery percentage of NPP is higher than the recovery percentage of soil conservation. Recovery percentage (RP) is calculated as the ratio of ecosystem services amount of restored forest on the average amount of retained forest in 2013. The *t*-test is as follows:

$$H_0: \ RP_{NPP} = RP_{SC} \quad H_1: \ RP_{NPP} > RP_{SC} \quad \alpha = 0.05$$

The *t*-test passed ($T = 49.61$, $P < 0.001$), which suggested that the recovery rate of NPP was higher than the recovery rate of soil conservation at grid-cell level.

A number of researches have demonstrated different recovery trends of ecosystem services in disturbed forest ecosystems (e.g. Beier et al., 2015; Sutherland et al., 2016). This study shows that the recovery of soil conservation significantly lags behind the recovery of NPP. Soil retention of forests lies in the overall effect of canopy, groundcover and roots, which is affected by the trees' biomass (Hartanto et al., 2003). This means that high NPP of forests is a premise to better effect of soil conservation. Researches in south-western China indicate that biomass and soil carbon storage of new stands in GFGP areas would rise with increasing tree age (Chen et al., 2009; Cheng et al., 2015). Huang et al. (2012) discover that under the scenario of high survival and low harvest, forestation could lead to higher carbon sequestration. Therefore, to obtain more benefits of soil conservation in the long term, proper management of forests to achieve higher NPP should be a precondition.

4.2. Impact of GFGP's extent on ecosystem services change

The effect of ecological restoration is largely influenced by ecosystem characteristics and restoration measures (Wiens and Hobbs, 2015). The extent of GFGP implementation had distinct spatial heterogeneity in Dali Prefecture as shown in Fig. 2. Ecosystem services change might vary as GFGP's extent increased. With spatially explicit boundaries, watershed is regarded as a relatively independent unit of ecosystem processes with ecological integrity (Flotemersch et al., 2015). Thus, sub-watersheds are used as spatial units to analyse the variation of ecosystem services change within the region and its relationship with the extent of GFGP implementation.

GFGP's extent negatively affected NPP ($P < 0.1$) (Fig. 4). The larger proportion new vegetation constituted in total vegetation, the lower average level of NPP. This was related to the low NPP of restored forest with young tree-age. GFGP's extent was positively correlated with soil conservation change ($P < 0.1$) (Fig. 4), which meant that GFGP contributed to the enhancement of sub-watersheds' soil retention. Forest canopies could intercept precipitation and decrease velocity of rains, which reduces rainfall erosivity. Groundcover could slow down the rate of water flow and increase infiltration, further reducing soil erosion (Geißler et al., 2012). As GFGP's extent increased, water yield significantly declined ($P < 0.05$) (Fig. 4). Evapotranspiration of forest consumes large portion of precipitation, while interception and evaporation of the canopy also use up water, therefore reducing sub-watershed's water yield (Farley et al., 2005).

Increasing GFGP's extent enhanced soil conservation but reduced NPP and water yield at sub-watershed scale. The conversion of farmland to forestland and grassland could not lead to increase in all ecosystem services at the same time. Hence, trade-offs exist between ecosystem services under the scenario of ecological restoration. Comparison between the slope coefficients of the three regression functions demonstrated that as GFGP's extent increased, the rate of NPP decrease was 4.68 times of the rate of SC increase; the decrease rate of WY was even higher, 1.57 times of the rate of NPP. Therefore, to set proper and realistic goals of ecosystem services improvement, the characteristic curves of various ecosystem services change should be taken into account. It is important to choose appropriate extent of GFGP implementation in order to mitigate the side-effect resulting from trade-offs between ecosystem services and thus to achieve maximal ecological benefits of restoration.

4.3. Implications for future GFGP implementation and ecosystem management

Forest ecosystems could provide many sorts of ecosystem services with various human benefits. Through supplying supporting services including refugia provision and nutrient cycling and regulating services such as climate regulation and natural hazard regulation, forest ecosystems play an important role in maintaining biodiversity and ecosystem functioning. However, farmland ecosystems provide limited supporting and regulating services due to harvesting of primary products and intensive human disturbance. Thus, forest ecosystems could contribute largely to reducing ecological risk and enhancing ecological resilience in the region. Furthermore, ecological restoration could provide

Table 3
Ecosystem services of different land-use change zones of Dali Prefecture in 2013.

Land-use change zones	NPP			SC		
	Mean ($gC\cdot m^{-2}$)	Standard deviation	Sample size	Mean ($t\cdot hm^{-2}$)	Standard deviation	Sample size
Restored forest	640.86	139.94	79,793	382.73	314.04	74,338
Retained non-irrigated farmland	725.03	144.14	25,755	392.06	304.36	23,170
Retained forest	722.92	129.26	257,673	489.64	380.74	252,915

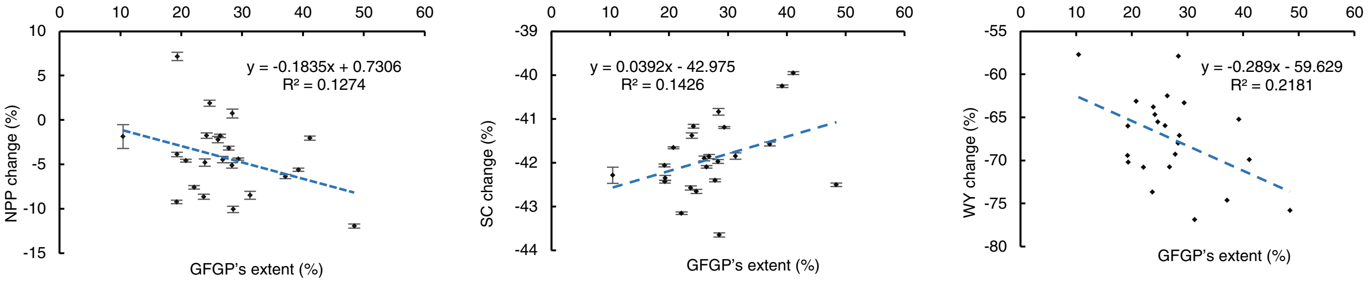

Fig. 4. Correlations between GFGP's extent and ecosystem services change (error bar shows 95% confidence level).

substantial benefits to areas outside the region through ecosystem services flows (Wolff et al., 2015). For instance, the increase supply of soil conservation could reduce the sediments entering into the watercourse and thus mitigate the damage of downstream sediment erosion and accumulation. Therefore, the impact of GFGP on ecosystem services exceeds the scope of the specific three ecosystem services focused in this study and extends in spatial scales.

Understanding how GFGP alters ecosystem services helps to provide implications for future ecosystem management and GFGP implementation (Lü et al., 2012a). There is a significant recovery rate difference between NPP and soil conservation under Grain-for-Green Programme. The average quantity of soil conservation of restored forest was 78.17% of the quantity of mature forest, while NPP already reached 88.65%. In addition, both ecosystem services that the restored forest ecosystem supplied had not reached its potential maximum. Therefore, in order to achieve high and long-term ecological benefits of GFGP, apart from reforestation, more attention should be paid to ecosystem management of artificial forests. Technical methods such as forest nursery and reproduction improvement could be adopted to enhance forest survival and growth (Ciccarese et al., 2012), while institutional arrangements should be applied at the same time to build incentives mechanisms to motivate human behaviour for conservation and restoration (Fremier et al., 2013; Petursson et al., 2013; de Juan et al., 2015). In this way, sustainable provision of ecosystem services could be achieved in the long term.

Trade-offs between ecosystem services render it difficult for various kinds of ecosystem services to increase simultaneously with the implementation of ecological restoration. This makes ecological policy-making and ecosystem management more complicated. For forests in GFGP areas, appropriate technological methods should be applied to mitigate the effect of the trade-off relationships. For instance, through investigating site quality and stand structure and identifying main functions of the forest, multifunctional forest management could be carried out to balance the positive and negative effects of restoration (Wang et al., 2015). In future GFGP policy formation and implementation, both recovery rate difference and trade-off relationships of ecosystem services should be carefully and completely considered. Appropriate goals, extent, and approaches of ecological restoration are suggested to be set according to regional ecological needs and characteristics of geographic factors, in order to achieve sustainable provision of ecosystem services.

Apart from the ecological impact, the effects of restoration programmes should also be evaluated from a cost-benefit perspective (Birch et al., 2010; Jellinek et al., 2014). Ecological restoration exerts influence on both natural environment and human society in the context of a closely-interacted socio-ecological system (Budiharta et al., 2016; Cao et al., 2014). The implementation of restoration programmes requires extensive human efforts in both physical and monetary terms. Also, utilisation of certain resources may incur substantial opportunity cost (Cao et al., 2016). For example, Zhang et al. (2016b) estimate that afforestation in China leads to an opportunity cost of water allocation which accounts for 18.9% of forest's ecosystem services value. Therefore, it is necessary to measure trade-offs among various ecological and socio-economic benefits of different restoration alternatives (Cao et al., 2016), so as to formulate restoration policies that promote both ecological and socio-economic sustainability in the long term (Feng et al., 2016).

5. Conclusions

This study evaluates how China's Grain-for-Green Programme alters ecosystem services in a mountainous area with critical ecological importance. Ecosystem services between GFGP areas and non-GFGP areas are contrasted to analyse the response of ecosystem services to GFGP. The influence of the extent of GFGP implementation on ecosystem services change is assessed at sub-watershed level. Results show that transformation from non-irrigated farmland on steep slopes to forestland and grassland led to a significant increase in vegetation coverage. At grid-cell level, the recovery of soil conservation lagged behind the recovery of NPP: the level of soil conservation of restored forest was 78.17% of retained forest while NPP already reached 88.65%. At sub-watershed level, increasing extent of GFGP implementation improved soil conservation but decreased NPP and water yield. This suggested trade-offs between ecosystem services under ecological restoration. These features of ecosystem services' response to Grain-for-Grain Programme provide valuable implications for future policy formation and implementation. The recovery rate difference and trade-off relationships of ecosystem services should be considered together with regional ecological needs and geographic factors in order to achieve sustainable provision of ecosystem services.

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