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Effects of agricultural land consolidation on ecosystem services: Trade-offs and synergies

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ABSTRACT

Agricultural land consolidation (ALC) has been used as an important and efficient development tool to improve agricultural production worldwide for decades, with numerous impacts on the ecological environment. How to coordinate the tradeoff relationships of agricultural production and other ecosystem services is a great challenge. Taking Jianxi Watershed in Fujian Province as an example, it was estimated three ecosystem services (crop production capacity, carbon storage, and soil conservation) and quantified the synergies and trade-offs among these three ecosystem services. Twenty-three factors were used to evaluate the influential mechanism of ALC on synergies and trade-offs between ecosystem services. The results demonstrated that (1) from 2010 to 2016, the relationship between crop production capacity and carbon storage evolved from a synergistic to a trade-off relationship, while that between crop production capacity and soil conservation developed from a trade-off to a synergistic relationship; (2) after ALC, the strength of trade-offs between crop production capacity and soil conservation decreased from 0.354 to 0.198. However, the strength of trade-offs between soil conservation and carbon storage and that between crop production capacity and carbon storage increased from 0.302 to 0.322; and (3) the trade-offs and synergies among ecosystem services changed due to changes in ALC measures. Finally, some suggestions of ALC measures were put forward to promote balanced and efficient development of various ecosystem services. ALC, considering trade-offs and synergies among ecosystem services, and if applied sensitively, may be an instrument for delivering sustainable rural development in a wider context.

1. Introduction

Ecosystem services are the benefits that humans obtain directly or indirectly from ecosystems (Costanza et al., 1997) and provide a foundation for improving the well-being of mankind and achieving regional sustainable development (Li et al., 2013a; Azam et al., 2019). The Millennium Ecosystem Assessment (2005) classified ecosystem services into four major categories: provisioning, supporting, regulating, and cultural services. Three possible mutual relationships, known as synergy, independence, and trade-off, exist among these services. An improvement in the provisioning ability is often accompanied by the sacrificing of other ecosystem services (Qiu and Turner, 2013; Raudsepp-Hearne et al., 2010; Rodríguez et al., 2006). Overlooking the trade-off/synergistic relationships among ecosystem services may lead to a reduction in the provisioning abilities of certain ecosystem services and may even threaten the stability and security of an entire ecosystem (Wu, 2013). Knowledge of trade-offs and synergies among ecosystem services is crucial for the design of land use strategies that optimize ecosystem service delivery (Landuyt et al., 2016), and ecosystem management must balance and consider different ecosystem services to optimize their integrated effects (Li et al., 2013b; Zheng et al., 2013).

As a tool to promote regional sustainable development, land consolidation has been applied in many countries around the world. Many Western European countries, such as England and Denmark, have a long tradition of land consolidation (Pašakarnis and Maliene, 2010). The current extensive use of land in China has created a severe shortage of reserves of cultivated land resources (Wu et al., 2009). In order to ensure food security, China began to push land consolidation on a large scale in 1998 (Lu, 2002). Land consolidation is

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currently one of the most organized human activities in China (Wang and Zhong, 2017). Agricultural land consolidation (ALC) is the most important part of land consolidation. In some countries, including China, intensive agriculture as a result of inappropriate ALC has resulted in serious problems such as pollution of soils, water, and air, as well as a decrease in the number of wild animals and plants (Wang et al., 2018; Pašakarnis and Maliene, 2010; Lisec et al., 2005). Changes in land use structure or configuration during consolidation will result in spatial competition and will thus affect the relationships among ecosystem services (Turner et al., 2014; Zhang et al., 2011), thereby causing changes in the trade-off relationships among many such services (Bodnaruk et al., 2017). Researchers have shown that natural and semi-natural ecosystems persist longer and have greater cultural value than highly modified ecosystems; these ecosystems also provide greater economic benefits than highly utilized or purely protected ecosystems or landscapes and can provide more services for human society (Bradford and D'Amato, 2012; Groot et al., 2010). Foley et al. (2005) compared food production, timber supply, habitat and biodiversity conservation, as well as runoff and water quality regulation of three land use models—natural ecosystems, intensive farming, and agriculture—in a way that takes ecosystem services into account. They showed that all ecosystem services could achieve balance, and that efficient development could be achieved in the agriculture model that accounts for the value of ecosystem services.

Many studies have analyzed the effects of ALC on ecosystem services from various perspectives (Wang et al., 2015; Liu et al., 2017; Zhang et al., 2014; Natuhara, 2013). These studies provide valuable information on past experiences and results that serve as references for studies on the effects of ALC on ecosystem services. However, great efforts still should be made to study the effects of ALC on the synergies and trade-offs among different ecosystem services and identify the reasons why ALC causes changes in the relationships. The execution of ALC can increase food supply while simultaneously highlighting the trade-off relationships among crop production capacity, carbon storage, and soil conservation ecosystem services (Bennett et al., 2010; Fu et al., 2015) and the effects on the structural and functional stability of ecosystems. Therefore, understanding the effects of ALC on synergies and trade-offs among ecosystem services has significance for optimizing ALC measures and the development of regional ecology and production functions.

Before estimating three ecosystem services (crop production capacity, carbon storage, and soil conservation) in the Jianxi Watershed in Fujian Province, this paper put forward a logical framework for the ALC's impact on ecosystem service trade-offs and synergies. We selected 50 typical ALC projects to study. These projects experienced no changes in crop type, farming method, or crop rotation system before and after ALC. Pearson's correlation analysis was employed to distinguish the synergies and trade-offs among the three ecosystem services, and the root mean square deviation was employed to quantify the trade-off intensity among ecosystem services. We further selected 23 factors reflecting the conditions of climate, terrain, soil, and ALC measures to analyze the causes of ALC's effects on synergies and trade-offs among ecosystem services.

2. Relationship between ALC and ecosystem services

2.1. ALC

Twenty years ago, land consolidation in some Western European countries changed from being agricultural/farming-focused to being a tool to cover public demands for access to land and to resolve the resultant land use conflicts (Thomas, 2004). Land consolidation may be described as the planned readjustment of the pattern of the ownership of land parcels with the aim of forming larger and more rational land holdings (Pašakarnis and Maliene, 2010). In China, ALC refers to the comprehensive management of cultivated land, water, roads, woodland, and villages in areas dominated by cultivated land. ALC is an effective instrument in regional sustainable development, which includes improvements to agricultural production, employment, taxation policy, infrastructure, public facilities, housing, and ecological environment, and the protection of natural resources (Long, 2013; Pašakarnis and Maliene, 2010; Maliene et al., 2005). On the basis of previous studies (Feng, 1997; Wu et al., 2011), we put forward a functional system of ALC (Fig. 1), which is composed of fundamental function, core function, and additional function.

At present, ALC in China mainly includes land leveling projects, irrigation and drainage engineering, farm road engineering, soil and water conservation and ecological shelter forest projects.

2.2. Synergies and trade-offs between ecosystem services

Ecosystems services have become a key concept in understanding the way humans benefit from ecosystems. Despite the progress in ecosystems services research (Andersson et al., 2007; Daily and Matson, 2008), we still lack a satisfying and comprehensive understanding of the interactions and feedback among different ecosystem services (Locatelli et al., 2014). They may both support and impair each other, which suggests the presence of a range of synergies, trade-offs, and independences (Rodríguez et al., 2006). Here, a trade-off/synergy refers to the increase in the provisioning of one ecosystem service and the simultaneous decline/rise of another service at the same location. An independence indicates that changes in one ecosystem service have no effect on another service. Identification of synergies and trade-offs allows policy-makers to better understand the hidden consequences of preferring one ecosystem service to another. Synergistic interactions allow for simultaneous enhancement of more than one ecosystem service (Bastian et al., 2011; Holzkämper and Seppelt, 2007). Because increasing the supply of one ecosystem service can enhance the supply of others, the successful management of synergisms is a key component of any spatial development strategy that aims to increase the supply of agroecosystem services for the well-being of humans. For ALC purposes, a better understanding of the synergy and trade-off patterns of agroecosystem services is absolutely necessary.

2.3. Logical framework for the study of ALC's impact on trade-offs and synergies of ecosystem services

The implementation of ALC projects has a profound impact on the function and sustainability of agroecosystem services. ALC

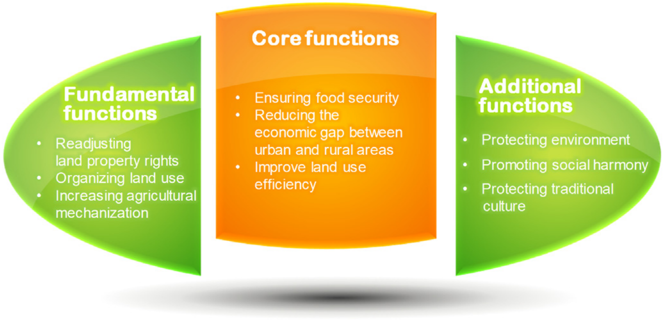

Fig. 1. Functional system of agricultural land consolidation.

indirectly affects agroecosystem services by changing landscape types and patterns and also directly affects ecosystem services. Intensively managed agricultural land is able to produce food in abundance (at least in the short run), at the cost of decreasing other ecosystem services. However, agricultural land that is explicitly managed to maintain other ecosystem services may be able to support a broader portfolio of ecosystem services (Foley et al., 2005). Paying attention to the trade-offs and synergies among various ecosystem services under the background of ALC is of great significance for ensuring crop production capacity and achieving balanced and efficient development among different ecosystem services. Based on the above analysis, we established a logical framework for the study of ALC's impacts on ecosystem trade-offs and synergistic (Fig. 2). ALC measures have a direct impact on ecosystem services. The location and layout of ALC projects also have an indirect impact on ecosystem services by changing landscape types and landscape patterns. ALC measures that consider trade-offs and synergies among ecosystem services can promote the development of agricultural systems into sustainable agriculture systems. In sustainable agricultural systems, the value of ecosystem services is relatively high, and the development of ecosystem services is balanced. If many ecosystem services are at low levels, except for food production, agricultural systems may not be sustainable.

3. Data and methods

3.1. Study area

The Jianxi Watershed covers an area of 1.65×10^6 hm^2 and lies in the upper reaches of the Minjiang River Watershed in Fujian Province, Southeast China (ca. 26°38′–28°20′N and 117°30′–119°18′E), including the counties of Wuyishan, Pucheng, Songxi, Jianyang, Zhenghe, and Jian'ou in Nanping City. The study area has a mild subtropical humid monsoon climate, with abundant rainfall. The area has a mean annual temperature of 17°C–19 °C (2010–2019), average sunshine duration of 1700–2000 h, average frost-free period of 250–300 days, and mean annual rainfall of 1684–1780 mm (Guo et al., 2016a). In 2010–2016, approximately 1000 ALC projects were initiated in the Jianxi Watershed, covering a total area of 23,330 hm^2.

3.2. Data sources and analysis

The Fujian Land Consolidation Center provided ALC project vector data, ALC project design text, 1:10,000 land use maps, topographical maps, and soil maps for 2010 and 2016. Statistical yearbooks of all administrative areas were obtained from the Nanping Bureau of Statistics for 2010 and 2016. The status of the agricultural crop cultivation conditions was obtained from the Nanping Agricultural Bureau. Landsat remote sensing data (resolution of 30 m) of the Jianxi Watershed acquired in 2010 and August 2016 as well as digital elevation models were obtained from the Geospatial Data Cloud (http://www.gscloud.cn/). Normalized difference vegetation index (NDVI) data were obtained from Landsat remote sensing images. Rainfall, temperature, humidity, sunshine duration, and evapotranspiration data were obtained from the sharing services platform of the National Meteorological Information Center of China (http://data.cma.cn/). Soil bulk density, sand, silt, clay, and gravel content, as well as soil pH, and some soil physiochemical data were obtained from the China Soil Database (http://vdb3.soil.csdb.cn/). The quantity of newly added cultivated land, spatial extent of leveled land, investment, area of the project site, volume of stripped and backfilled topsoil, length of newly built farm roads, and other data were obtained from the project design reports for classical ALC.

Field monitoring and surveys conducted in August 2017 also served as an important source of data for this study. Fifty sampling points were set up in the Jianxi Watershed after a comprehensive consideration of different land-use and soil types. A soil sampling auger was used to collect mixed samples within 20 cm of the topsoil from three separate locations. Soil samples from the same soil layer in each location were mixed to form a single soil sample. Soil samples were analyzed in the laboratory to obtain the soil organic matter content, soil pH, and other soil physiochemical data. The field sample data were calibrated with data from the China Soil Database Sharing Infrastructure using the best fit method. Because annual changes in soil physiochemical characteristics were quite small (Yao et al., 2017), these data were combined with the spatial distribution of soil types and land use to obtain soil data in 2010 and 2016.

Litter biomass accounts for a small proportion of vegetation cover (Xu et al., 2011), and it changes with land-use types based on ALC. These changes are the primary reason for changes in carbon storage in regional litter layers. Therefore, litter biomass data from different land use types obtained from field investigations in 2017 were used to calculate total carbon storage in 2010 and 2016; minor annual changes were ignored. This was done primarily to determine changes in litter biomass caused by changes in land-use type resulting from ALC. Small 20 cm × 20 cm quadrats were used for sampling from the litter layers in different land-use types. Litter samples from each quadrat were placed in an 80 °C oven and dried to a constant weight, and the amount of litter biomass was calculated. The dried samples were used for quantification of the carbon content. The carbon content (g of carbon per 100 g of dried matter) was quantified using the potassium dichromate-sulfuric acid method. The mean value of several quadrats from the same land use type was taken as the amount of carbon stored in the litter layer in each land-use type. In addition, field investigations were used to refine crop cultivation zoning data.

3.3. Ecosystem service estimation methods

3.3.1. Estimation of carbon storage

The Jianxi Watershed features nine different land uses. Of these land uses, the carbon stocks of industrial and mining storage land, township-village land, transportation corridors, water bodies, and water conservation facilities were obtained from the InVEST 3.3.0 model parameter database (Richard et al., 2015). Next, the carbon stocks of forests, cultivated lands, gardens, and grasslands were calculated. The grid sizes were all set to 30 m × 30 m.

Aboveground biomass estimation of forests was carried out using the estimation model proposed by Zhao (2016) based on Landsat TM images. According to previous studies, belowground biomass was 8% of the aboveground biomass, and the carbon stock of forest plants was obtained by multiplying the biomass by a conversion coefficient (0.5) (Guo et al., 2016b). A simplified model based on the carbon cycle constructed by Gu et al. (2012) was used to estimate the carbon stock of cultivated land and gardens. The carbon stock of grasslands was estimated using the NDVI and the estimation model for China's grassland aboveground biomass that was previously established by modeling remote sensing parameters by Piao et al. (2004). Belowground biomass is usually estimated from the proportionality coefficient of belowground and aboveground biomass. The study by Li et al. (1998) showed that the proportionality coefficient of belowground and aboveground biomass in grasslands in Fujian Province is 4.42. Litter carbon stock data were obtained from field sampling. Soil organic carbon density was calculated using the model established by Xu et al. (2005), which is one of the most widely used models for calculating organic

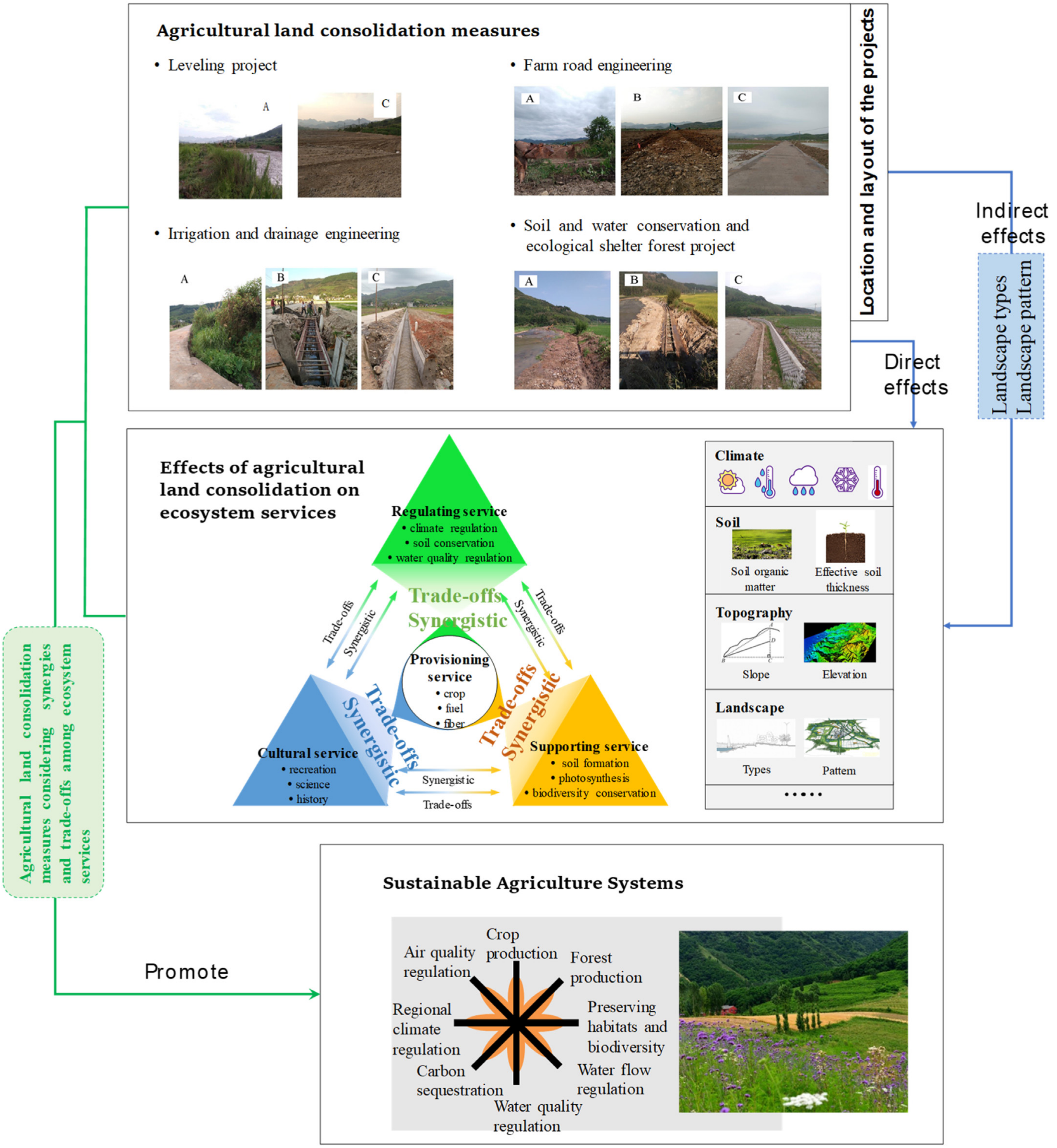

Fig. 2. Logical framework for the study of ALC's impact on ecosystem service trade-offs and synergies. (The provisioning of multiple ecosystem services can be illustrated with these simple "flower" diagrams in which the condition of each ecosystem service is indicated along each axis. In this qualitative illustration, the axes are not labeled or normalized with common units. A, B, and C indicate the situation before, during, and after consolidation, respectively.)

carbon density in China. Principles of the InVEST 3.3.0 model were used to calculate total carbon storage in 2010 (C2010) and 2016 (C2016), which is the sum of aboveground, belowground, litter, and soil carbon stocks (Richard et al., 2015).

3.3.2. *Estimation of crop production capacity*

Among the ecosystem services, the crop production capacity service represents the potential productivity of cultivated land. Rice, the staple crop of Fujian Province, accounts for 80% of total food yield in Fujian Province (Fujian Provincial Bureau of Statistics, 2016). Therefore, in order to comprehensively consider the effects of ALC on crop production capacity services, the staple crop (rice) of the Jianxi Watershed was used as a standard to quantify the productivity potential for rice in cultivated land in this watershed and to evaluate the crop production capacity in 2010 (F2010) and 2016 (F2016). The model used to estimate the potential productivity of cultivated land constructed by Gao et al. (2009) is based on the potential degression method used to estimate crop production capacity services in the Jianxi Watershed.

$$\begin{aligned} Y_L &= Q \times f(Q) \times f(T) \times f(W) \times f(S) = Y_L \times f(T) \times f(W) \times f(S) \\ &= Y_T \times f(W) \times f(S) = Y_W \times f(S) \end{aligned} \tag{1}$$

where Y_L is the potential of cultivated land production (t/hm^2), Q is the total solar radiation (MJ/hm^2), $f(Q)$ is the effective coefficient of photosynthesis, Y_Q is the productive potential of photosynthesis, $f(T)$ is the effective coefficient of temperature, $f(W)$ is the effective coefficient of moisture, Y_T is the light and temperature productive potential, Y_W is the agroclimatic potential productivity, and $f(S)$ is the effective coefficient of soil and topography.

3.3.3. Estimation of soil conservation

We used the sediment retention model from InVEST 2.5.6 to quantify soil conservation (Tallis et al., 2013). The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) provides a foundation of the InVEST sediment retention model, and soil conservation is the sum of soil loss reduction and sediment interception. However, in InVEST version 3.3.0, the calculation principle of soil conservation changed, and the sediment retention model was renamed the sediment delivery ratio model. The calculation of the sediment delivery ratio model needs parameters such as the sediment transport ratio, but there are no corresponding data for the Jianxi Watershed. Considering the availability of data, InVEST2.5.6 (Tallis et al., 2013) was used to calculate soil conservation in 2010 (S2010) and 2016 (S2016). Previous studies have shown that the InVEST2.5.6 can effectively simulate the ecosystem function of erosion control (Gao et al., 2017). And the calculation principle of soil conservation module in InVEST2.5.6 is widely used (Song et al., 2015; Xiao et al., 2017).

First, the potential for soil loss based on geomorphological and climate conditions was estimated.

$$S_{e0x} = R_x \cdot K_x \cdot LS_x \tag{2}$$

where S_{e0x} is the potential for soil loss of grid x ($\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$), R_x is the rainfall erosivity ($\mathrm{MJ \cdot mm \cdot hm^{-2} \cdot h^{-1} \cdot a^{-1}}$), K_x is the soil erodibility factor ($\mathrm{t \cdot h \cdot MJ^{-1} \cdot mm^{-1}}$), and LS_x is the slope length-gradient factor.

Then, the actual annual soil loss was calculated according to USLE.

$$USLE_x = R_x \cdot K_x \cdot LS_x \cdot C_x \cdot P_x \tag{3}$$

where $USLE_x$ is the annual soil loss of grid x ($\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$), C_x is the crop-management factor, and P_x is the support practice factor.

The reduction in soil loss (A_{dx}) was obtained by subtracting the actual soil loss ($USLE_x$) from the potential soil loss (S_{e0x}):

$$A_{dx} = S_{e0x} - USLE_x = R_x \cdot K_x \cdot LS_x \cdot (1 - C_x \cdot P_x) \tag{4}$$

The calculation of soil conservation in the InVEST model includes two parts: one is the reduction in soil loss caused by crop-management and supporting practice measures (A_{dx}); the other is sediment interception ($SEDR_x$), which is expressed as the product of the sediment interception rate and the sediment amount generated on the uphill slope.

$$SEDR_x = SE_x \sum_{y=1}^{x-1} USLE_y \prod_{z=y+1}^{x-1} (1 - SE_z) \tag{5}$$

where SE_x is the sediment interception rate of grid x, $USLE_y$ is the sediment yield from uphill grid y, SE_z is the sediment interception rate of uphill grid z.

The soil conservation (SEC_x) is equal to the sum of the reduction in soil loss (A_{dx}) and the sediment interception ($SEDR_x$).

$$SEC_x = A_{dx} + SEDR_x \tag{6}$$

3.4. Identification and quantitation of ecosystem service synergies and trade-offs

By considering the location and layout of the projects, we selected 50 typical ALC areas that experienced no changes in crop type, farming method, or crop rotation system before and after ALC as study subjects. After removing the outliers, the mean values of each ecosystem service (crop production capacity, carbon storage, and soil conservation) were calculated in each ALC area. These mean values were normalized prior to conducting Pearson's correlation analysis to identify the synergies and trade-offs among the three services.

The root mean square deviation was employed to quantify the trade-off relationship between two ecosystem services (tradeoff intensities) and to also quantify how synergistic development of the two ecosystem services is biased towards one of those services (Bradford and D'Amato, 2012; Lu et al., 2014; Feng, 2017). This method used the distance from points to straight lines to express the relationship between two ecosystem services. The greater the distance, the more severe the trade-off relationship between the two ecosystem services. In contrast, the smaller the distance, the more the relationship between two ecosystem services tends to be synergistic. When the distance is zero, an ideal synergistic relationship exists between the two services.

Because the units and magnitudes of different ecosystem service values are different, the ecosystem service data must be standardized so that ecosystem service values lie between 0 and 1 in Eq. (7):

$$ES_{stdi} = (ES_{obsi} - ES_{mini}) \,/\, (ES_{maxi} - ES_{mini}) \tag{7}$$

where $ES_{stdi}$is the ecosystem service value after standardization, ES_{obsi} is the value to be assessed, ES_{mini} is the minimum value of each ecosystem service, and ES_{maxi} is the maximum value of each ecosystem service.

Next, the trade-off intensity of the two ecosystem services was calculated. This value is the root-mean-square error of the two ecosystem services in Eq. (8):

$$RESM = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (ES_{stdi} - \overline{ES})} \tag{8}$$

where RMSE is the ecosystem service tradeoff intensity, n is the number of ecosystem services and $\overline{ES}$ is the mathematical expectation of the two ecosystem services.

3.5. Selection of factors influencing ecosystem service synergies and trade-offs

We selected 23 factors reflecting climate, terrain, soil, and ALC conditions that might influence ecosystem service synergies and trade-offs (Table 1). Then, the difference between the trade-off intensity of ecosystem services before and after land consolidation of the 50 typical ALC areas was calculated. A smaller difference value reflects strong synergistic relationship between two ecosystem services while the trade-off relationship is weakened. In contrast, a larger difference value indicates the trade-off relationship is strengthened. Pearson correlation analysis was used to analyze the relationship between the factors and difference values, and the causes of effects of ALC on ecosystem service synergies and trade-offs were analyzed.

4. Results

4.1. *Identification of synergies and trade-offs among the three ecosystem services*

After ALC, significant changes occurred in the synergies and trade-offs among the three ecosystem services analyzed here, crop production capacity, carbon storage, and soil conservation, in the consolidated area.

The relationship between F2010 and C2010 evolved from a synergistic to a trade-off relationship in 2016 while the relationship between F2010 and S2010 developed from a trade-off to a synergistic one in 2016. The relationship between C2010 and S2010 was a trade-off relationship. The Pearson's correlation coefficient of soil conservation and carbon storage services was insignificant ($p = 0.04$), so there was no significant trade-off, and no synergistic relationship was observed between S2016 and C2016 (Table 2). This shows that ALC increased crop production capacity and soil conservation services in the project site but had negative effects on carbon storage services.

4.2. *Trade-off intensity analysis of ecosystem services*

After ALC, the trade-off intensity among the three ecosystem services changed. When trade-off happened between crop production capacity and each other ecosystem service, it was always conducive to the development of crop production. The relationship between crop production capacity and carbon storage services developed from a synergistic relationship in 2010 into a trade-off relationship that benefitted crop production capacity by 2016. The trade-off intensity was 0.295, which is higher than that in 2010 (Fig. 3). After ALC, the development of the crop production capacity inhibited the development of carbon storage services.

In 2010, the trade-off intensities between crop production capacity, soil conservation, and carbon storage were crop production capacity–soil conservation (F–S) > soil conservation–carbon storage (S–C) > crop production capacity–carbon storage (F–C). In 2016, the trade-off intensities of these three ecosystem services were S–C > F–C > F–S (Fig. 4). Compared with 2010, the trade-off relationship of F–S weakened. However, the trade-off relationships of S–C and F–C strengthened.

Table 2
Pearson correlation analysis of crop production capacity, soil conservation, and carbon storage.

	F2010	S2010	C2010	F2016	S2016	C2016
F2010	1	−0.56**	0.61**			
S2010	−0.56**	1	−0.37*			
C2010	0.61**	−0.37*	1			
F2016				1	0.57**	−0.46*
S2016				0.57**	1	−0.04
C2016				−0.46*	−0.04	1

$N = 50$; ** and * show significant correlations at $P = 0.05$ and $P = 0.1$ levels (two-tailed), respectively.

4.3. *Analysis of the causes of effects of ALC on ecosystem service synergies and trade-offs*

4.3.1. *The causes of effects of ALC on trade-off intensity between crop production capacity and carbon storage*

Among all factors influencing ecosystem services, the increase in temperature (X_2), humidity (X_3), gradient (X_7), elevation (X_8), investment amount per unit area (X_{11}), volume of leveled land (X_{14}), and newly built drainage system (X_{21}) could reduce the intensity of trade-offs between crop production capacity and carbon storage to some extent. Of these, X_2, X_8, and X_{21} weakened trade-off intensity relatively more significantly. In contrast, other factors resulted in a significant increase in the trade-off intensity between crop production capacity and carbon storage, including percentage of sunshine (X_1), rainfall (X_4), project area (X_9), investment amount (X_{10}), area of new cultivated land (X_{13}), volume of stripped and backfilled topsoil (X_{15}), and newly built production roads (X_{19}) (Table 3).

4.3.2. *The causes of effects of ALC on trade-off intensity between crop production capacity and soil conservation*

An increase in factors influencing ecosystem services can reduce the intensity of the trade-off between crop production capacity and soil conservation, including X_1, X_3, soil organic matter (X_5), effective soil thickness (X_6), X_9, proportion of new cultivated land to the area of the consolidation project (X_{12}), X_{21}, number of new dams (X_{22}), and newly built revetment (X_{23}). Among these factors, the effects of X_9, X_{12}, X_{21}, and X_{23} weakened trade-off intensity more significantly. In contrast, an increase in other factors significantly increased the trade-off intensity between crop production capacity and soil conservation, such as X_1, X_8, X_{13}, X_{15}, a reconstructed farm road (X_{16}), reconstructed production road (X_{17}), and newly built farm road (X_{18}).

4.3.3. *The causes of effects of ALC on trade-off intensity between carbon storage and soil conservation*

The reduction in trade-off intensity between carbon storage and

Table 1
Factors that may affect ecosystems services used in the study.

Classification of factors	Factors influencing ecosystem services (unit, name)
Climate	Percentage of sunshine (%, X_1), Temperature (°C, X_2), Humidity (%, X_3), Rainfall (cm, X_4)
Soil	Soil organic matter (%, X_5), Effective soil thickness (cm, X_6)
Topography	Slope (°, X_7), Elevation (m, X_8)
ALC measures	Project area (hm^2, X_9), Investment (10^3 US Dollars, X_{10}), Investment per unit area (Dollars/hm^2, X_{11}), The proportion of new cultivated land to the area of consolidation project (%, X_{12}), Area of new cultivated land (hm^2, X_{13}), Earth volume of land leveling (10^4 m^3, X_{14}), Earth volume of topsoil stripping and backfilling (10^4 m^3, X_{15}), Length of reconstructed farm road (km, X_{16}), Length of reconstructed production road (km, X_{17}), Length of new farm road (km, X_{18}), Length of new production road (km, X_{19}), Length of new irrigation system (km, X_{20}), Length of new drainage system (km, X_{21}), Number of new dams (X_{22}), Length of newly built revetment (m, X_{23})

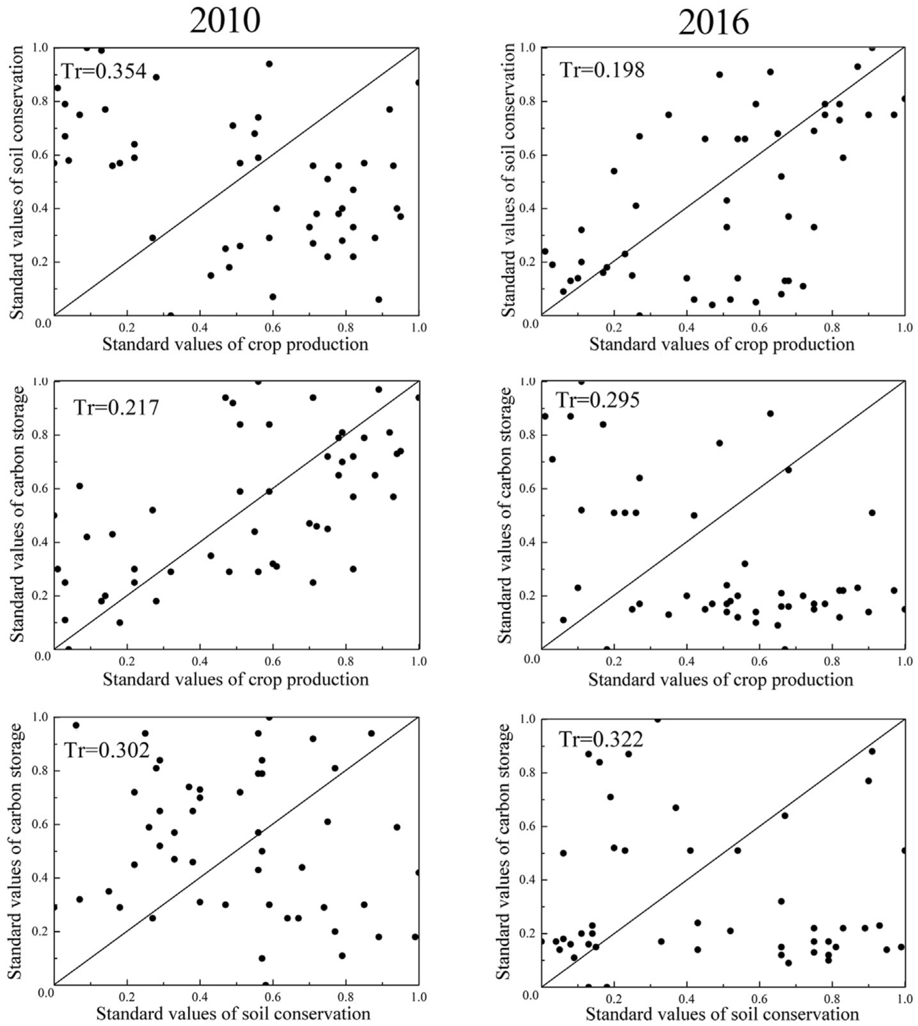

Fig. 3. Trade-off map of crop production capacity, soil conservation and, carbon storage in 2010 and 2016 (Each point represents a typical ALC area; Tr indicates trade-off intensity.).

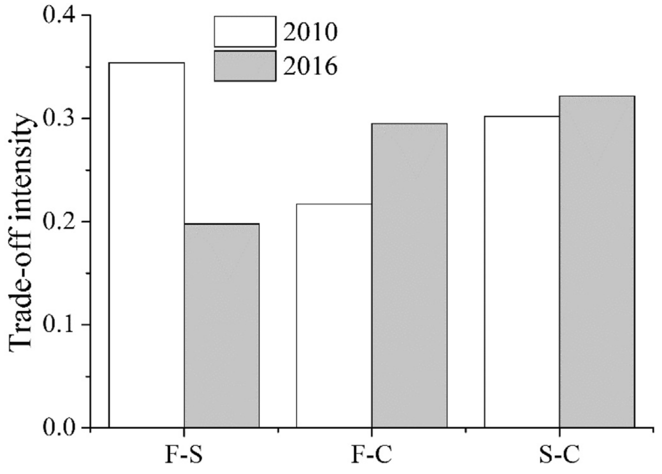

Fig. 4. Comparison map of the trade-off among crop production capacity, soil conservation, and carbon storage services in 2010 and 2016.

soil conservation was intimately associated with X_3, soil organic matter (X_5), X_8, X_{10}, X_{11}, X_{12}, X_{14}, X_{15}, X_{16}, X_{22}, and X_{23}. Among these factors, X_3, X_{12}, X_{14}, X_{15}, X_{22}, and X_{23} had the most significant effects in reducing the trade-off intensity between carbon storage and soil conservation. An increase in other factors influencing ecosystem services will increase the intensity of the trade-off between carbon storage and soil conservation; Significantly, these included X_6, X_{13}, X_{18}, X_{19}, and length of new irrigation system (X_{20}).

5. Discussion

The implementation of ALC projects has increased crop production capacity services while simultaneously increasing the value of soil conservation services in the ecosystem, but neglected the carbon storage services of the consolidated areas. This caused an increase in the trade-off intensity between crop production capacity and carbon storage services, hindering the stable development of ecosystem structure and function (Vogdrup-Schmidt et al., 2017; Ting et al., 2018). Therefore, the measures of ALC should be adjusted purposefully to reduce the loss of organic carbon pool during the implementation of ALC projects. However, when adjusting the ALC measures, we should not only focus on the improvement of carbon storage services of the consolidated area, but also improve the overall ecosystem service function of the consolidated area. While reducing the loss of organic carbon pool, we should also consider reducing the trade-off strength between crop production and carbon storage services and between soil

Table 3
Pearson correlation analysis of the change in the trade-off strength and the analyzed factors.

Factor		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
F–C	Correlation$^{\#}$	0.21*	−0.32**	−0.10	0.29 **	0.19	0.04	−0.17	−0.31**
	Sig.	0.04	0.00	0.22	0.01	0.19	0.39	0.08	0.01
F–S	Correlation$^{\#}$	−0.01	0.32**	−0.06	0.04	−0.15	−0.05	0.06	0.29**
	Sig.	0.25	0.00	0.18	0.21	0.06	0.19	0.17	0.00
C–S	Correlation$^{\#}$	0.05	0.04	−0.38**	0.13	−0.09	0.16**	0.05	−0.06
	Sig.	0.19	0.20	0.00	0.11	0.13	0.00	0.18	0.16
Factor		X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
F–C	Correlation$^{\#}$	0.19*	0.35**	−0.07	0.08	0.34**	−0.04	0.24**	−0.06
	Sig.	0.03	0.00	0.16	0.14	0.00	0.20	0.01	0.17
F–S	Correlation$^{\#}$	−0.21*	0.08	0.16*	−0.39**	0.22*	0.01	0.40**	0.48**
	Sig.	0.02	0.15	0.05	0.00	0.02	0.26	0.00	0.00
C–S	Correlation$^{\#}$	0.05	−0.13	−0.06	−0.20*	0.30**	−0.36**	−0.40**	0.01
	Sig.	0.19	0.08	0.17	0.03	0.00	0.00	0.00	0.27
Factor		X_{17}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}	
F–C	Correlation$^{\#}$	0.15	0.01	0.26**	0.07	−0.20*	0.11	0.09	
	Sig.	0.06	0.27	0.00	0.15	0.05	0.10	0.13	
F–S	Correlation$^{\#}$	0.37**	0.31**	0.03	0.09	−0.27**	−0.13	−0.25*	
	Sig.	0.00	0.00	0.21	0.12	0.01	0.22	0.05	
C–S	Correlation$^{\#}$	0.15	0.38 **	0.16*	0.36**	0.09	−0.29**	−0.21**	
	Sig.	0.06	0.00	0.05	0.00	0.13	0.00	0.00	

$N = 50$; $^{\#}$ Pearson correlation; * and ** indicate significant correlations at the 0.1 (two-tailed) and 0.05 (two-tailed) level, respectively; F–C, F–S, and C–S are the changes in trade-offs between crop production capacity and carbon storage, between crop production capacity and soil conservation, and between carbon storage and soil conservation before and after consolidation, respectively.

conservation and carbon storage services in order to achieve stability of ecosystem structure and function.

Previous studies have shown that land leveling projects produce the highest carbon emissions; therefore, such projects should be limited in scope as much as possible during ALC (Guo et al., 2015). However, according to the results of this study, an increase in land leveling can reduce the trade-off between crop production and carbon storage, as well as the trade-off between carbon storage and soil conservation to a certain extent. Therefore, reducing land leveling projects does not necessarily increase the carbon storage in the project area.

Farm road construction results in a direct loss of the carbon pools in surface vegetation, litter, and soil organic carbon and has negative effects on carbon storage in cultivated land areas (Fei et al., 2017). The implementation of water conservation projects in farmland also leads to a loss of soil organic carbon pools in the short term. According to the results of this study, the trade-off between ecosystem services should be considered when increasing carbon storage by adjusting farm road engineering and water conservation works. For example, an increase in new irrigation systems significantly increased the trade-off strength between carbon storage and soil conservation, but the impact on other trade-offs was not significant. In addition, an increase in new drainage systems weakened the trade-off strength between crop production and carbon storage, as well as between crop production and soil conservation, but had little impact on the trade-off between carbon storage and soil conservation. Therefore, when adjusting the measures of ALC to reduce carbon losses, the specific measures of the consolidation project should be comprehensively adjusted according to the main objectives of the consolidation project.

ALC is a form of intense human interference activity that is carried out on cultivated land to readjust and rearrange land management practices. It is designed to maximize human benefits through intense land use and is widely implemented in every country in the world. Currently, ALC has many goals, such as increasing the spatial extent and fertility of cultivated lands, improving the environment, and increasing the income of farmers (Li et al., 2018; Jin et al., 2016; Keesstra et al., 2017; Niroula et al., 2005). Therefore, it is necessary to balance different ecosystem services during ALC while scientifically and rationally integrating different ecosystem services in order to optimize the available ecosystem services. Only in this way can we promote the sustainable development of the world's agricultural ecosystem. From the perspective of ecosystem services synergies and trade-offs, reducing the trade-offs between carbon storage and other ecosystem services is one of the main challenges in ALC projects. Some suggestions are proposed to reduce the trade-off strength between carbon storage and other ecosystem services.

(1) Land leveling projects produce the highest carbon emissions; therefore, such projects should be limited in scope as much as possible during ALC. If this type of consolidation results in the removal of soil in the tillage layer, then topsoil stripping, backfilling, and soil dressing should be used to protect the carbon sequestration capacity of soil. Spreading green manure and straw reapplication also provide effective biological measures that can be used to increase carbon fixation in soil.
(2) Careful attention should be paid to the construction of farmland water conservation projects and farm roads created for ecological purposes, which can reduce the loss of organic carbon pools caused by hardening and excessive coagulation of road surfaces. These can be realized through the use of environmentally friendly farm gravel road additives, soft slope protection materials, heavy metal passivators, water and fertility retention mitigation measure, and other emerging environmentally friendly materials (Wang and Zhong et al, 2017).
(3) Late-stage management for ALC should be strengthened, using intercropping, crop rotation and manure. Late-stage management can increase the carbon stock in cultivated land areas.

6. Conclusions

In this study, we examined the trade-offs and synergies among three main ecosystem services (crop production capacity, carbon storage, and soil conservation) in Jianxi Watershed. Currently, ALC in the Jianxi Watershed focuses more on increasing crop production capacity and soil conservation in the consolidated region and generally ignores the carbon sequestration capacity. Significant changes occurred in synergies and trade-offs among the three ecosystem services in the consolidated areas from 2010 to 2016. After ALC, the strength of trade-offs between crop production capacity and soil conservation decreased, and the strength of trade-offs between soil conservation and carbon storage and between crop production capacity and carbon storage increased. The synergies and trade-offs among ecosystem services can be changed by changing ALC measures. For example, the trade-off strength between carbon storage and soil conservation can be reduced to some extent by increasing the earth volume of land leveling and the earth volume of topsoil stripping and backfilling.

Future studies need to combine ALC measures and construct a more comprehensive effector index system for ecosystem services. This may be achieved by integrating and optimizing ecosystem services in consolidated areas. An analysis of the environmental effects produced by ALC should also be included, relevant to different scenarios and various ALC measures.

Author contributions section

Data curation, Lina Zhong.
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Methodology, Lina Zhong.
Project administration, Jun Wang.
Software, Lina Zhong, Lingxiao Ying.
Supervision, Jun Wang.
Writing—original draft, Lina Zhong, Jun Wang.
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Declaration of competing interest

The authors declare no conflict of interest.

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