sustainability

MDPI

Article

Trade-Offs Analysis of Ecosystem Services for the Grain for Green Program: Informing Reforestation Decisions in a Mountainous Headwater Region, Northeast China

Xiufen Li [1,2,†], Yichen Tian [1,2,3,†], Tian Gao [2,4,5,*], Lei Jin [1,6], Shuangtian Li [2,5], Dan Zhao [7], Xiao Zheng [2,4,5], Lizhong Yu [2,4] and Jiaojun Zhu [2,4,5]

1 Agronomy College, Shenyang Agricultural University, Shenyang 110866, China; lixiufen2019@syau.edu.cn (X.L.); tianyichen95@stu.syau.edu.cn (Y.T.); jinlei@stu.syau.edu.cn (L.J.)
2 CAS Key Laboratory of Forest Ecology and Management, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China; lishuangtian18@mails.ucas.ac.cn (S.L.); xiaozheng@iae.ac.cn (X.Z.); yuliz@iae.ac.cn (L.Y.); jiaojunzhu@iae.ac.cn (J.Z.)
3 Liaoning Provincial Meteorological Training Center, Liaoning Branch of China Meteorological Administration Training Center, Shenyang 110166, China
4 Qingyuan Forest CERN, Chinese Academy of Sciences, Shenyang 110016, China
5 University of Chinese Academy of Sciences, Beijing 100049, China
6 Dalian Meteorological Bureau, Dalian 116001, China
7 State Key Laboratory of Remote Sensing Science, Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing 100094, China; zhaodan@radi.ac.cn
* Correspondence: tiangao@iae.ac.cn; Tel.: +86-24-8397-0342
† These authors contributed equally to this work.

Received: 12 May 2020; Accepted: 5 June 2020; Published: 11 June 2020

check for updates

Abstract: The effects of forest restoration on ecosystem services and their trade-offs are increasingly discussed by environmental managers and ecologists, but few demonstrations have analyzed ecosystem service trade-offs with a view to informing afforestation choices. Here, we examined how the Grain for Green Program (GGP), an ambitious reforestation program in China, affected ecosystem services. We quantified regulating services and provisioning service in the potential scenarios, which were developed to improve ecosystem services better. The results indicated the GGP drove 14.5% of land-use/land-cover from 2000 to 2015, and all the regulating services increased. Prioritizing reforestations in steep-sloped and riparian farmlands can promote flood mitigation, water purification, and soil retention services by 62.7%, 25.5%, and 216.1% as compared with 2015 levels, respectively, suggesting that the improvements strongly depend on afforestation locations. Driven by the new GGP policy, a high proportion of economic forest increased provisioning service (272.2%), but at the expense of decreases in soil retention (−25.1%), flood mitigation (−11.4%), water purification (−36.6%), and carbon storage (−48.5%). We identified a suitable scenario that would reduce the trade-offs, which associated with afforestation types and their spatial allocation. Identifying priority areas of afforestation types can inform the GGP policy to assure sustainable and broader benefits.

Keywords: forest restoration; regulating services; provisioning service; ecosystem services trade-offs; scenario analysis

1. Introduction

The expansion of agricultural land use and urbanization processes are the primary drivers of deforestation [1–3]. Facing great pressure in food security, as well as the challenge of land scarcity caused by accelerated urbanization in China, more available lands were converted to farmlands, and agricultural intensification was developed to satisfy the increases in demand for food provision [4]. Nevertheless, the pursuit of maximizing agricultural production was realized at the indirect expense of the regulating ecosystem services (e.g., soil conservation, flood mitigation, wind, and fixing sands) [5–7], leading to ecological degradation and catastrophe, such as severe flooding along the Yangtze River in 1998. In around 2000, China's government implemented several national-scale ecological programs through vegetation restoration, aiming to maintain environmental sustainability and improve livelihoods.

The Grain for Green Program (GGP) was known as the largest ecological restoration project in China due to its ambitious goals, great spatial range, huge government investment, and broad participation degree [8,9]. The GGP aims to alleviate soil erosion through converting slope or sand farmlands into forests or grasslands [10]. According to the report from the National Forestry and Grassland Administration, 9.27 million ha of farmlands had been converted to forests in the first round of the GGP (1999 to 2014). Approximate 32 million households participated in the GGP, and 405.7 billion Yuan (US$66.4 billion) was cumulatively invested as subsidies for their loss of benefit from agricultural activity, as well as their efforts in the GGP [11]. As expected, the implementation of GGP has improved the regulating services, such as a reduction in soil erosion [10,12,13], and improvements in carbon storages and carbon sequestration potentials [14,15]. Although great achievements have been accomplished by the GGP in the first round, some problems have been reported. Given the GGP primarily aims to improve regulating services, the afforestation types under the GGP was restricted by a fixed area proportion of afforestation types at a county level: more than 80% of ecological forests (primarily aims to improve environmental conditions) area, while less than 20% of economic forests (primarily aims to provide non-timber forest products, e.g., fruit and nuts). Despite the fact that ecological forests (e.g., *Larix* spp.) can produce timber as well, the long rotation period (>40 years) suppresses economic benefit from selling timber, depressing farmers' enthusiasm of participation in the GGP, in particular when the GGP's subsidies end. This problem has been recognized by policymakers. To achieve the dual goals of improvements in the environment and in farms' livelihoods, China's government announced not to limit the proportion of afforestation area of economic forest in the second round of the GGP since 2015. Driven by the sustainable benefit from an economic forest, farmers are supposed to plant economic trees preferentially. It should be noted that an economic forest is usually managed with a lower tree density, a lower vegetation coverage, a lower tree height, and a sparse undergrowth, which are entirely different from those characteristics of an ecological forest. The stand structure of an economic forest aiming to enhance non-timber forest products, as well as to facilitate management, may lead to a decline in their regulating services. An assessment of the change in ecosystem services under the second round of the GGP can reveal the benefits and deficiencies of the new policy, and can inform optimum strategies and policies of the GGP.

The GGP is implemented through remarkable land cover change, which is a typical and practical topic for ecosystem service management across landscapes, thus its influences on multiple ecosystem services have interested ecological scholars. Being limited by biophysical, economic, and social factors, however, it is difficult for multiple needs to be met simultaneously [16]. Researchers have repeatedly reported that forest restoration can improve soil retention, water conservation, and carbon sequestration [10,12,17–20]. Furthermore, some studies focused on the ecosystem service tradeoffs under a reforestation program [8,18,19,21], but few cases delivered provisioning services (here refers to forest or agricultural productions) benefiting private interests in the concerned ecosystem service bundles. It should be noted that ecosystem service trade-offs are more likely to occur when a private interest is involved [16], showing a stark conflict between public interest in regulating services and private interest in provisioning service. For a reforestation program characterized by broadly public participation, the participant behavior can strongly influence its success [11], and thus must be considered as a key factor for its sustainability. The alternative afforestation types (e.g., ecological forest and economic forest) are expected to mitigate this problem, delivering more provisioning services to stakeholders with a private interest. Previous studies have reported that the tradeoffs could be primarily driven by land-use management [22] and, in particularly, can be mitigated by the optimization of prioritizing areas that provide highly targeted ecosystem services [16,23]. However, there is little understanding of the effect of afforestation choices on ecosystem services under a large reforestation program.

The primary objective of our study was to understand how afforestation choices (location and forest types) under the GGP influence ecosystem services and their trade-offs. Here, a mountainous area implementing the GGP in Northeast China, including three counties of eastern Liaoning Province, was selected as the study area, covering wellhead protection zones. We examined the changes in the GGP-driven land-use change between 2000 and 2015, and assessed its impact on ecosystem services. We then developed alternative trajectories of afforestation patterns (where and which forest types to be reforested) to analyze their potential impacts on ecosystem services by a comparison to the actual level of ecosystem services.

2. Materials and Methods

2.1. Study Area

The study area (41°10′ N–42°65′ N, 123°66′ E–125°73′ E) is located in the east of the Liaoning Province, Northeast China, including Qingyuan Manchu Autonomous County, Xinbin Manchu Autonomous County, and Fushun County (Figure 1). It has a continental monsoon climate, with an annual mean temperature of 6.1 °C and an annual mean precipitation of 810 mm. The total area of the three counties is 10,046 km^2, of which mountainous rural areas approximately account for 80%. The topography is characterized by a descent from east to west, showing a transition from mountain to plain. The Dahuofang Reservoir is located in the confluence zone of the rivers from the mountainous area of the three counties (west part of study area, Figure 1), with a maximum water storage area of 114 km^2 and a storage capacity of 2.268×10^9 m^3 [24], providing the farmlands and cities (e.g., Shenyang and Fushun) in the downstream plain with water. One national nature reserve zone and four provincial nature reserve zones are located in the study area, aiming to protect natural forests and water sources. The total population in the three counties is approximately 772,000 of which approximately 570,000 (74%) are engaged in agriculture. Due to farmland scarcity in this area, patches of forests were reclaimed for crop planting. There was a conflict between ecological protection and improvement in farmer's livelihoods in the study area, which is regarded as a typical mountainous area for the GGP.

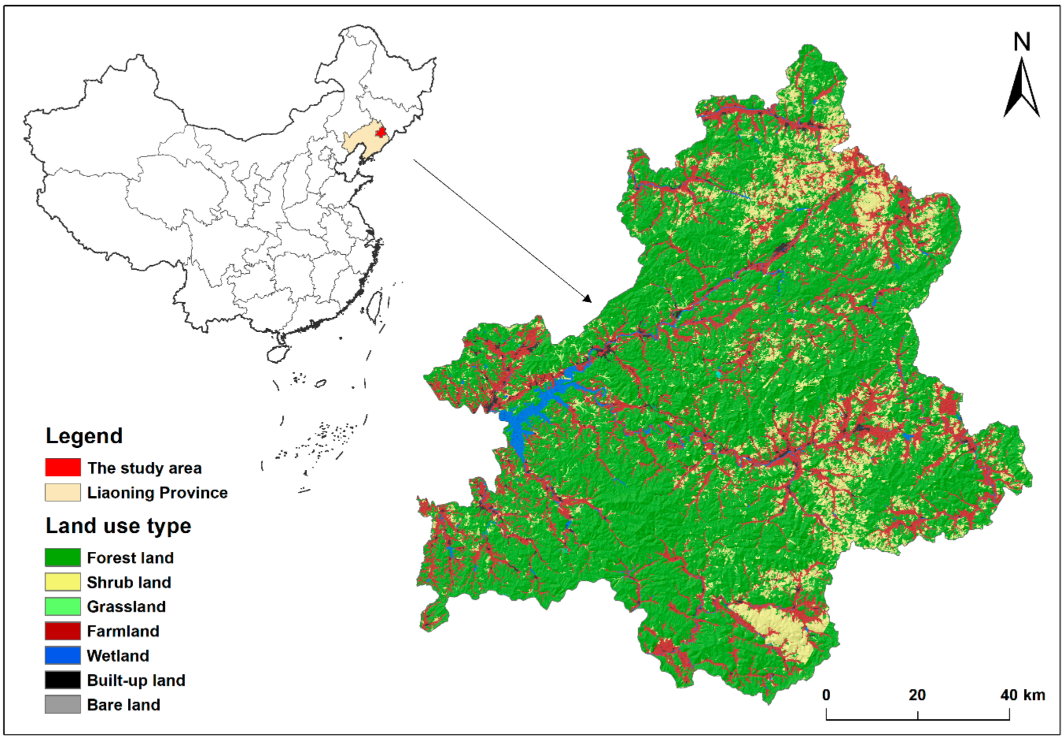

Figure 1. Location and land-use types of the study area in 2000.

2.2. Research Framework and Selection of Ecosystem Services

A research framework for ecosystem service assessment and scenario design was developed. First, we examined the changes in GGP-driven land-use change between 2000 and 2015, and assessed their effect on the concerned regulating services in this study area. Second, according to the realistic effect of the first round of the GGP, we found the current questions and developed alternative trajectories in an effort to improve the regulating services more efficiently through converting farmlands in prioritizing area. Finally, we identified a feasible afforestation resolution through analyzing alternative scenarios with the proportional combinations of economic forest and ecological forest, in order to minimize trade-offs between regulating services and provisioning service. The ecological regionalization for the study area and the goals of the GPP informed our selection of ecosystem services. Four regulating services, including flood mitigation, soil retention (actual soil export to streams or rivers), water purification, and carbon storage, were selected. Food mitigation and soil retention represent the major regulating services that alleviate ecological problems in a mountainous headwater region (flood and soil erosion), and constitute the primary goal of the GGP. Water purification service is a good indicator for water source protection. Carbon storage service is a useful indicator for ecological engineering, especially for forest restoration. Further, from a socioeconomic perspective of the GGP, non-timber product provisioning service was included the ecosystem service bundles.

2.3. Data Sources

The Chinacover Dataset was used to identify the GGP-driven land use and land change (LULC) (www.geodata.cn) between 2000 and 2015. The Chinacover dataset contains 6 land cover categories (forestland, grassland, farmland, wetland, built-up land and other land) and 40 sub-land cover categories, with 30 m spatial resolution, and the overall accuracy was greater than 86% [25].

These basic data were used to quantify ecosystem services and test the results: (1) a digital elevation model (DEM) was downloaded from the Resource and Environment Data Cloud Platform (http://www.resdc.cn/Default.aspx) with a spatial resolution of 30 m. (2) Soil data were provided by Cold and Arid Regions Sciences Data Center (http://www.crensed.ac.cn/portal/). (3) Daily climate data were obtained from the China meteorological data sharing service system (https://data.cma.cn/), where daily records of maximum and minimum temperatures, sunshine hours, and precipitation were available. To avoid the effect of inter-annual climate change on ES assessment, the dataset of anual average climate factors was produced over the time periods of 1986 to 2015. The Anusplin 4.3 software package was employed to interpolate and produce the spatial distributions of the climate factors. (4) Annual runoff data from the hydrological station between 2000 to 2015 were collected from the Hydrological Yearbook.

2.4. Household Questionnaire and Field Survey

To understand farmers' attitudes towards afforestation choice and the income, we conducted a household questionnaire survey in 2019, and collected a total of 150 questionnaires from different households of 10 villages by face-to-face interview. In the questionnaire survey, we investigated the questions about demographic factors (e.g., respondent's age, income source, and involved area of converting farmland to forest), attitudes of farmers towards the GGP (e.g., choice of afforestation types, tree species), and economic income from forest management of the GGP (e.g., seed yield, price per kilogram, cost and benefit from economic forest). We also collected the statistical data about afforestation area and types of the GGP in 2017 and 2018 from the local forestry administration. All the above information supported the reasonable scenario development of the GGP afforestation.

To obtain carbon storages, we conducted a field survey, and sampled soil and litter of 138 plots for the GGP-related land use types. Three soil cores were taken from three soil depth ranges (0–10 cm, 10–20 cm, 20–30 cm) at each site in study area, and the samples were naturally air dried before soil organic carbon density was measured. Furthermore, we collected litter within each plot, and oven-dried at 85 °C to measure its carbon density.

2.5. Scenario

A baseline LULC map from 2000 to 2015 was generated by the Chinacover Dataset, and the GGP-driven LULC were identified. According to the aims of the GGP that alleviating soil erosion, steep-sloped farmlands (greater than 15 degrees) are the primary target in this study area, thus slope degree is considered as a critical factor for the scenario development. Furthermore, the choice of different afforestation types may influence regulating services and provisioning service and their trade-offs. To illustrate the changes in ecosystem services and their potential trade-offs associated with afforestation choices for the GGP, we developed scenarios according to the potential afforestation location and alternative types.

2.5.1. Scenario Development for Prioritizing Afforestation Locations

The ecological problems of the study area informed the scenario development for prioritizing afforestation locations. Soil erosion occurs more easily in steep-sloped farmlands, also with a low crop yield. In addition, farmlands near riparian buffer zones are more likely to increase nitrogen concentration and export to rivers [26], which should be focused on for a waterhead region. Taking these two ecological problems into consideration, the corresponding two scenarios of potential LULC, aiming respectively to prioritize steep-sloped conservation (PSC) and riparian conservation (PRC), were developed with the unchanged amount of converting farmland area during the first round of the GGP:

(1) PSC scenario: primarily convert the more steep-sloped farmlands (>15°).

(2) PRC scenario: primarily convert riparian farmlands; the riparian buffer was defined by a 30 m distance from a river [27]. If all the riparian farmlands are converted, steep-sloped farmlands will be converted.

2.5.2. Scenario Development for Choice of Ecological Forest and Economic Forest

In addition to the goal of improving environmental conditions, the GGP simultaneously aims to alleviate poverty and to improve local economic development [9]. For this mountainous headwater region with a high agricultural population, planting economic trees is considered as a feasible way promote farmers' income. According to the GGP's plan, all the steep-sloped farmlands will be converted to forests until 2050. As such, by extraction of the targeted farmlands in the study area, we developed future scenarios for potential combinations of economic forest and ecological forest under the GGP. According to farmers' attitudes towards the choice between ecological forest and economic forest, the scenario that converting 77% of targeted farmlands to economic forest was developed, which is supposed to be a realistic situation under the policy of the second round of the GGP. The corresponding scenario converting 20% of targeted farmlands to economic forest, was also developed, which is regarded as a realistic situation under the first round of the GGP. The differences in ecosystem services were compared under the two scenarios to quantify the effect of the new policy of the second round of the GGP. Furthermore, the other alternative scenarios with the proportional combinations (a step of 10%) of economic forest and ecological forest were developed. The changes in ecosystem services and their trade-offs associated with different proportions of afforestation types were analyzed to find an optical resolution for afforestation choice.

2.6. Ecosystem Service Assessment

Four types of concerned regulating services, including flood mitigation, water purification, soil retention, and carbon storage, were quantified by an integrated valuation of environmental service and trade-offs (InVEST). The main input parameters of ecological forest and economic forest to InVEST are listed in Supplementary Table S1. The provisioning service (marketed goods) of economic forest was estimated by site condition and collected household survey data. The levels of ecosystem services between the current status in 2015 and alternative afforestation scenarios were compared to those of the status in 2000 to quantify their difference in the improvement of the GGP in the ecosystem services. In order to compare the relative benefit of the different ecosystem services, as well as to analyze their trade-offs, we calculated the standardized ecosystem service value (ranges from 0 to 1) of each concerned ecosystem service as follows [28]:

$$ES_i = \frac{ES_{i\_obs} - ES_{i\_min}}{ES_{i\_max} - ES_{i\_min}} \quad (1)$$

where ES_{i_obs} is observed value of a special ecosystem service type i, while ES_{i_max} and ES_{i_min} represent its maximum and minimum values, respectively.

2.6.1. Food Mitigation

Due to mountainous terrain and intense rainfall in summer, the study area was frequently threatened by flood. The flood mitigation service can represent an ecosystem's capacity to reduce the amount of quick runoff from heavy rainfall [29], which is of interest to water managers. The InVEST seasonal water yield model computes spatial indices that distinguish the contribution of land parcels (or pixels) to the generation of quick flow (runoff shortly after rain events) [30]. Monthly climate data (evapotranspiration, precipitation, and rain event), DEM, LULC, and soil type were required for running the SWY model [31]. The evapotranspiration was calculated using modified Hargreaves equation [32], and all the monthly climate data were generated by daily climate data (see Section 2.3). Here the flood mitigation service was simulated by a realistic intense rain event (284 mm day^{-1}, 16 August 2013), and the reduction in the amount of quick flow after the rain event represented the flood mitigation service [5,33].

2.6.2. Water Purification

Combining the advantages of nutrient transport models [34], the InVEST nutrient delivery ratio (NDR) model can quantify nutrient export and retention across watersheds, and can simulate changes in nutrient export or retention under different LULC scenarios [35]. Here, we used the model to describe movement of nutrient (N) from watersheds to stream, and further to evaluate water purification service provided by vegetation. Sources of N are determined by LULC types and their associated loading rates, and the N export is computed as the sum of the pixel-level contributions [30]. We used the reduction in concentration (mg/L) of total N before and after conversion of farmland to forest to represent the improvement in water purification service. The major input coefficient required by the NDR model is listed in Supplementary Table S1.

2.6.3. Soil Retention

The InVEST sediment delivery ratio (SDR) module is a spatially explicit model running at the spatial resolution of the input DEM raster [30]. Considering data availability and model uncertainty, we employed the SDR model to quantify generation of overland sediment and delivery to stream or river [30], which it has received increasing attention in recent years [36–38]. At the pixel level, the SDR model first estimates the amount of annual soil loss for a given pixel by the revised universal soil loss equation (RUSLE). Then, annual soil loss was multiplied by the SDR factor, which defined as a proportion of soil loss actually reaching streams [30]. The alleviated soil export (SE) to streams or rivers by the conversion farmland to forest was introduced to represent the improvement in soil retention (SR, units: ton·ha^{-1} year^{-1}) by the GGP. The *SE* is calculated by the model as follows [36,39]:

$$SE = R_i \times K_i \times LS_i \times C_i \times P_i \times SDR_i \tag{2}$$

R is rainfall erosivity (MJ mm (ha^{-1} h^{-1})) calculated by monthly rainfall, *K* is soil erodibility (ton ha h (MJ ha mm)$^{-1}$), *LS* is a slope length-gradient factor (dimensionless), *C* is a crop-management factor (dimensionless), and *P* is a support practice factor (dimensionless). The calculation was processed at pixel level, and the soil retention service is calculated by the amount of the value of each pixel.

2.6.4. Carbon Storage

The carbon storage capacity was estimated by the InVEST Carbon Storage and Sequestration model. The carbon storage includes four carbon pools, which carbon densities were localized as follow: (i) the aboveground biomass carbon storage (C_{above}) was estimated from the local field-based survey [40] and forest management practices manual, (ii) the belowground biomass carbon storage (C_{below}) was estimated by aboveground biomass and the ratio of root-shoot biomass [41], and (iii) soil and litter carbon storage (C_{soil} and C_{dead}) were calculated by the field sample data (Section 2.4). Carbon storage can be calculated by multiplying the average carbon density of above carbon pools of each land use/cover type by their corresponding areas.

$$C_{total} = C_{above} + C_{below} + C_{soil} + C_{dead} \tag{3}$$

The total carbon storage (C_{total}, t/ha) was estimated by the sum of the four pools. The detail in carbon storage density for the main GGP-related land use types (farmland, ecological forest and economic forest) can be found in Supplementary Table S1.

2.6.5. Non-Timber Product Provisioning Service from Economic Forest

The main tree species of economic forest is Korean pine (*Pinus koraiensis*), which accounts for 90.7% of the total economic forest area in this study area. Korean pine produces edible seeds, with a high content of the pinolenic acid, which are the most important pine nut in domestic and international trade [42]. To simplify provisioning services of economic forest, we introduced Korean pine plantation as a representation of economic forests of the study area. The household surveys indicated that seed yield of Korean pine economic forest is variable (ranges from 150 to 330 kg/ha), depending on forest management practice and site condition (represented by mean dominant tree heights), showing strong interannual fluctuations. We assumed that the Korean pine economic forest are managed on the same level, and the seed yield primarily associates with site condition. A simplified equation (originally used for *Pinus sylvestris* var. *mongolica* in this study area), together with input variables concerning soil, topography, and forest age, were used to map site condition across the study area [43].

$$H = \mathrm{a} \times T + \mathrm{b} \times P + \mathrm{c} \times S + \mathrm{d} \times A + \mathrm{e} \times \lg G \tag{4}$$

where T, P, S, A, and G are soil thickness (cm), slope position, slope degree (°), aspect (°), and forest age (year), respectively, while a, b, c, d, and e are the coefficients for the variables [43]. Economic forests with different gradations of site condition were correspondingly associated with the different levels of seed yield, which was estimated from household surveys. The comparable levels of annual averaged seed yield (kg/ha) of Korean pine economic forest across the landscape were obtained to represent to its provisioning service.

3. Results

3.1. Land Use Change and Its Impact on Ecosystem Services

A significant change of LULC patterns has taken place in the study area during the period of the first round of the GGP. The GGP involves four types in this study area, namely, conversion of farmland to forest (TFF), conversion of farmland to shrub (TFS), conversion of unused land to forest (TUF) and conversion of unused land to shrub (TUS). Between 2000 and 2015, the GGP-driven conversion area is 4209.7 ha, accounting for 14.5% of the overall LULC. The area of TFF was the major type of LULC change, with an area of 3459 ha, accounting for 82.16% of the GGP area.

The GGP areas are mainly distributed around riverbanks and western parts of the study area (Figure 2). In this mountainous study area, unexpectedly, most of converted farmlands distributed relatively flat area, where the degree of slope was less than 15°. The GGP area that degree of slope ranges 0° to 8° and 8° to 15° accounted for 44.99% and 42.41%, respectively, while the area where the degree of slope ranges >15° only accounted for 12.60%. Steep-sloped farmlands with a total area of 6156.5 ha were still cultivated.

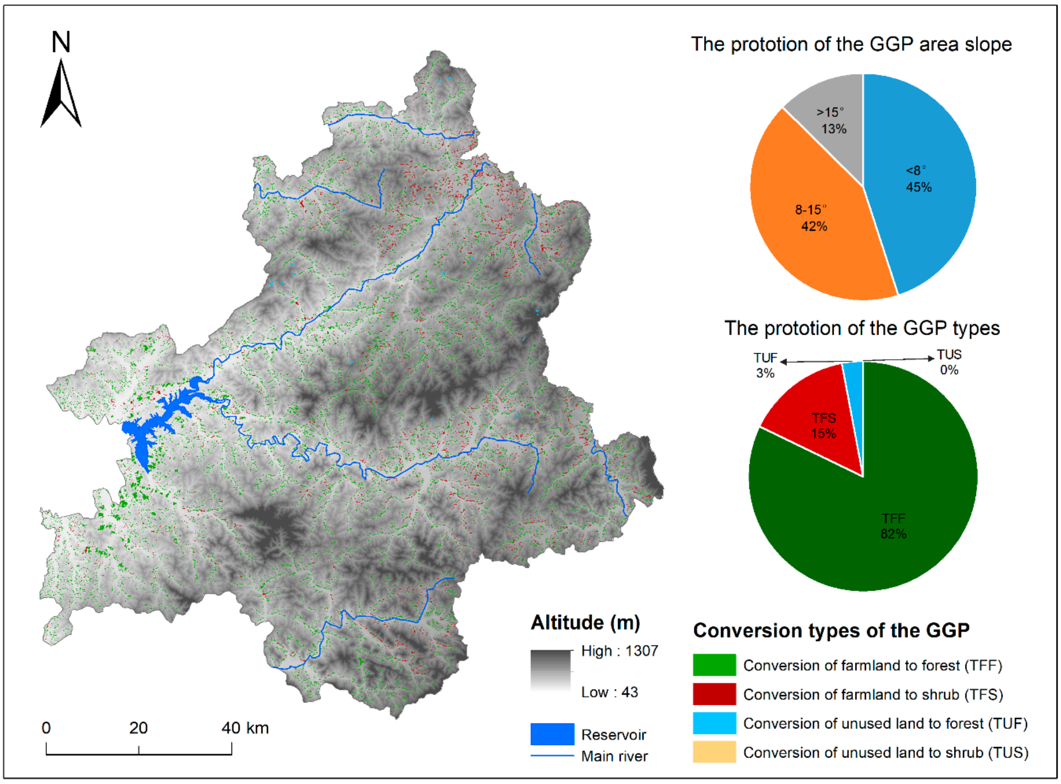

Figure 2. Land-use conversion type of the Gain for Green Program between 2000 and 2015 and their slope distribution.

The concerned regulating services in the GGP area was greatly improved in the first round (Figure 3). The flood mitigation, water purification, soil retention, and carbon storage increased by 58.72%, 82.31%, 55.95%, and 504.77% over the 15-year period, respectively. These results revealed that implementation of the GGP in mountain areas can significantly contribute to an improvement in the regulating services.

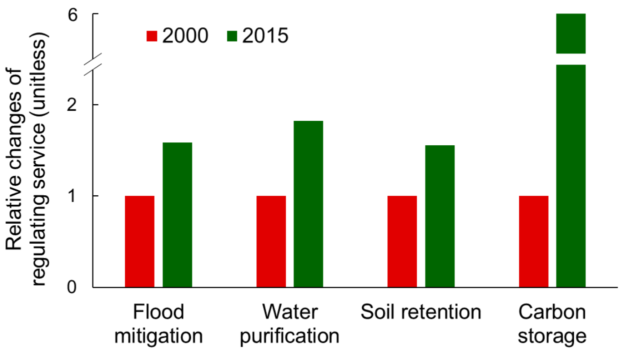

Figure 3. Relative changes of the regulating services between 2000 and 2015.

3.2. *Changes in the Ecosystem Services and Trade-Offs under Prioritizing Area Scenarios*

We estimated the concerned regulation services, including flood mitigation, water purification, soil retention, and carbon storage, under the two alternative scenarios developed in an effort to prioritize the conversion of steep-sloped and riparian farmlands. The result indicated that, except for carbon storage, the other regulating services under the two alternative scenarios greatly improved as compared with those under the current status in 2015 (Figure 4a). Under the PSC scenario, preferentially converting slope-steep farmlands resulted in significant increases of soil retention, flood mitigation, and water purification services by 216.1%, 62.7%, and 25.5%, respectively. Under the PRC scenario, preferentially converting riparian farmlands can increase soil retention, flood mitigation, and water purification services by 143.9%, 5.5%, and 57.3%. The alternative scenarios did not change carbon storage.

Despite the alternative scenarios both promoted the regulating services, they showed the different preferences on the four types of concerned regulating services, presenting difficult trade-offs (Figure 4b). The PSC scenario can promote better in soil retention and flood mitigation services, whereas the PRC scenario can more efficiently promote water purification service.

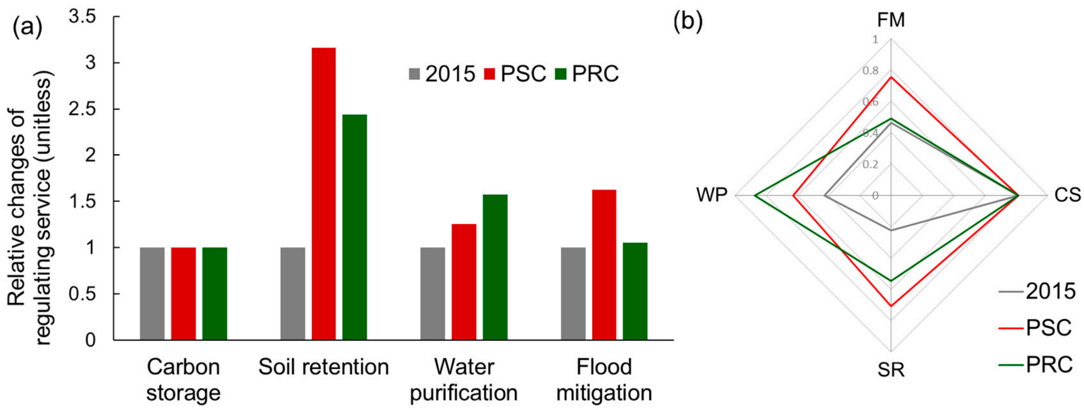

Figure 4. Relative changes of the regulating services (**a**) and their trade-offs (**b**) in current status of 2015 and the alternative afforestation scenarios (PSC scenario: convert steep-sloped farmlands with an area of 4209.7 ha; PRC scenario: convert riparian farmlands with an area of 3393.29 ha and steed-slope farmlands with an area of 816.41 ha to forest). FM: flood mitigation; WP: water purification; SR: soil retention; CS: carbon storage.

3.3. Effect of Afforestation Types and Their Spatial Allocation on Ecosystem Services and Trade-Offs

We modelled the scenarios for proportional combinations of economic forest and ecological forest under the GGP, with a total simulating afforestation area of 8704.4 ha (the steep-sloped farmlands: 6156.5 ha; the riparian farmlands: 2597.0 ha; the intercepted area of the two types: 49.1 ha). According the rank of site condition, farmlands with a higher site condition were preferentially converted to economic forests (Section 2.5.2), and the remaining farmlands were converted to ecological forests. Table 1 illustrates that the changes in regulating services and product provisioning service along a gradience of increase in afforestation area of economic forest. Not surprisingly, the total amount of the seed product increased with the proportion (from 10% to 100%) of economic forest, whereas all the regulating services showed a decreasing trend. The soil export and N export to stream or river increased from 2.77 t/ha year to 4.59 t/ha year and from 0.37 mg/L to 0.65 mg/L, respectively; flood mitigation and carbon storage decreased from 89.93 mm to 73.14 mm and from 207.32 t/ha to 60.84 t/ha, respectively. We further examined the changes in ecosystem services between the two scenarios, which represents realistic situations under the first round (20% of retired farmlands were converted to economic forests and the rest farmlands were converted to ecological forests) and the second round (77% of farmlands were converted to economic forests and the rest farmlands were converted to ecological forests) of the GGP, respectively. The seed production provision increased (272.2%) under the policy of the second round of the GGP, but at the expense of significant decreases in soil retention (−25.1%), flood mitigation (−11.4%), carbon storage (−48.5%), and water purification (−36.6%), showing stark trade-offs between the regulating services and provisioning service.

Table 1. Changes in product provisioning service and regulating services under the different proportions of economic forest.

Proportions of Economic Forest (%)	Seed Yield (10^4 kg)	Seed Yield Per Hectare (kg/ha)	Soil Export (t/ha·year)	N Export (mg/L)	Flood Mitigation (mm)	Carbon Storage (t/ha)
10	283.46	325.65	2.77	0.37	89.93	207.32
20	566.63	325.48	2.95	0.41	88.16	190.92
30	849.49	325.31	3.13	0.44	86.36	169.71
40	1131.96	325.11	3.19	0.46	85.01	158.50
50	1413.80	324.85	3.24	0.48	83.77	144.13
60	1673.07	320.35	3.37	0.51	81.73	125.94
70	1930.33	316.81	3.56	0.54	79.58	109.67
77	2109.28	314.70	3.69	0.56	78.07	98.27
90	2435.99	310.95	4.13	0.61	75.28	76.63
100	2613.03	300.19	4.58	0.65	73.14	60.84

Although the total amount of seed product increased with afforestation area of economic forest increasing, the seed product per unit hectare showed a decreasing trend (R^2 = 0.81, P < 0.01) along a gradient of site condition, with a reduction from 325.7 kg ha^{-1} to 300.2 kg ha^{-1}. Meanwhile, we compared the difference in regulating services between economic forest and ecological forest for the specific area that identified by the proportional interval according the rank of site condition (Figure 5). The result indicated that the differences in soil retention between economic forest and ecological forest enhanced with a decrease in site condition (Figure 5a; R^2 = 0.73, P < 0.01). The similar trends were also observed in water purification (Figure 5b; R^2 = 0.68, P < 0.01), whereas the differences in flood mitigation (Figure 5c; R^2 = 0.26, P = 0.14) did not show a significant trend. Furthermore, we found a well-marked turning point (50%). The differences in soil retention and flood mitigation services between economic forest and ecological forest fluctuated with no significant trend before this turning point, whereas dramatic increases were observed after this turning point. On the other hand, the seed product per unit hectare also showed a decline after this turning point. This result indicated that the converting farmland to economic forest beyond an area proportion of 50% was less cost-effective at the expense of the concerned regulating service. A similar proportion was found to be 60% for water purification service.

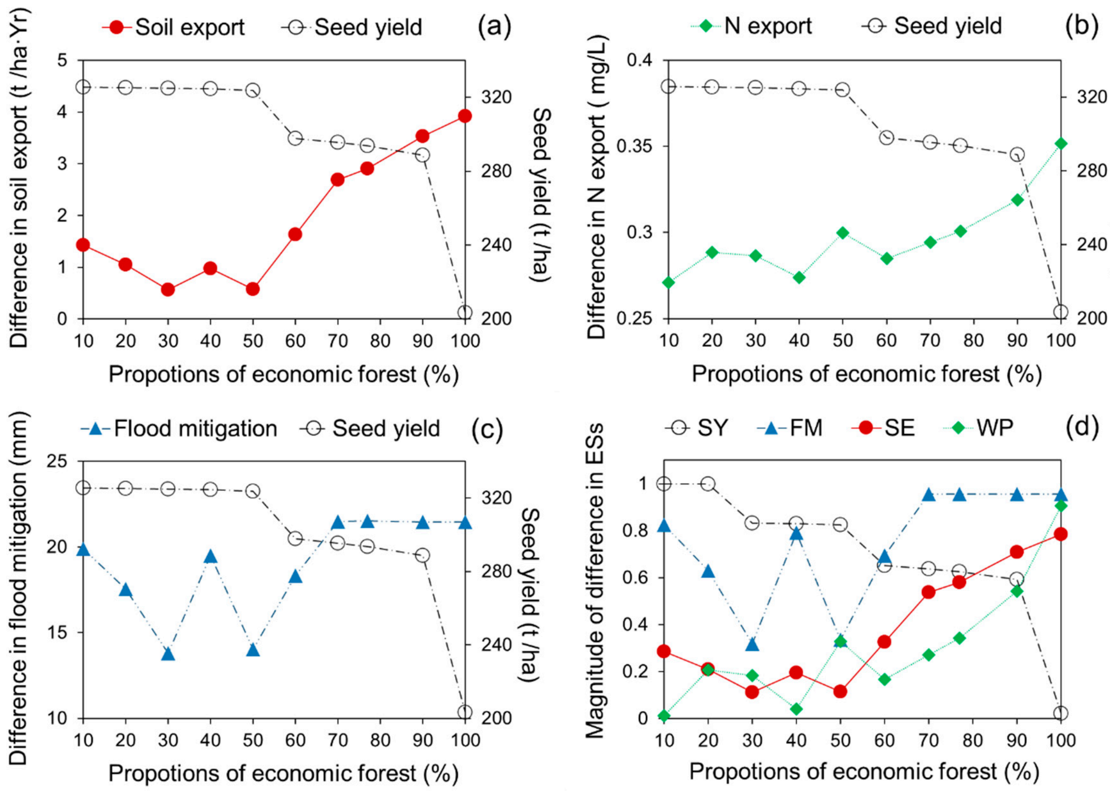

Figure 5. The difference in regulating services and provisioning service between economic forest and ecological forest along a gradient of site condition. Soil retention service and provisioning service (**a**); water purification service and provisioning service (**b**); flood mitigation service and provisioning service (**c**); the trends of difference in the regulating services and provisioning service (**d**).

4. Discussion

4.1. Prioritizing Areas for the GGP

Reforestation is an approach of ecosystem management, aiming to increase regulating services and to improve well-being in multiple dimensions [44]. A key question confronts managers looking to maximize the return on investment in forest restoration, and what is required for this achievement is understanding the tradeoffs between the concerned ecosystem services [16,45,46].

In this study, we observed a significant change of LULC patterns driven by the first round of the GGP, and quantified the improvement in the capacity to supply regulating services. This finding accords with the most of reported findings in the studies [13,47,48]. However, most of converted farmlands (87.4%) were distributed across a relatively flat area, which is not the primarily target of the GGP. The scenario analysis suggested that this improvement would be more efficient by prioritizing conversions of steep-sloped or riparian farmlands to forests, where the conversions of farmlands to forests can enhance regulating services better. Given the importance of water conservation in our focal region [49], we considered water purification, flood mitigation, and soil retention as the preferential regulating services. Through scenario simulation, we found that water purification service was promoted greatly by the PRC scenario, indicating riparian vegetation restoration as a feasible approach to water conservation for a headwater area. This result was reported to be similar in other contexts [23], and was supported by the field-based evidences [26,50]. As expected, the PSC scenario, original concern of the GGP for converting slope-steep farmlands to forests, could efficiently promote soil retention and flood mitigation services. Notably, the trade-offs among the regulating ecosystem services occurred when comparing the PSC and PRC scenarios, suggesting the two potential scenarios can both promote the regulating services for the mountainous water source region, but with the different priorities. We recommend that riverain farmlands should be considered for conversion to forests as slope-steeped farmlands in the new round of the GGP. In 2015, there were still steep-sloped and riparian farmlands in the study area, with an area of 6156.5 ha and an area of 2597.0 ha, respectively, which are supposed to be converted preferentially in the new round of the GGP.

4.2. Policy Implications for Economic Forest of the GGP

Forest assets are often geographically associated with household poverty [5,51], especially in the mountainous areas of China. To enhance households' economic benefit, the new policy of the GGP that did not restrict the proportion of economic forest has been implemented since 2015. Driven by the new policy, a large number of economic trees would be planted. As results of the different management goals, economic forests are different from ecological forests in terms of tree density, vegetation coverage, and undergrowth (Figure 6). Our household surveys showed a rather high proportion (77%) of the farmers' preference towards the afforestation of economic tree species, and this result was supported by the statistical data (83%) from the local forestry administration. However, we found that the unrestricted afforestation proportion did not lead to the most desirable level of ecosystem services. The result suggested that the high proportion of economic forest significantly decreased the concerned regulation services, although a high provisioning service was obtained. It should be noted that the tradeoffs were spatially variable. The findings indicated a decline in soil retention and water purification occurred in response to the gradually enhanced proportion of economic forest. The starker tradeoffs between regulating services and provisioning service was observed when planting economic trees in ecological prioritizing areas that can provide high regulating service levels but a low provisioning service. These gainful activities were carried out by the farmers who consider that the economic benefit from an economic forest compared to ecological forest, but neglect to account for the limitations, such as site conditions, management techniques, and market, which probably suppress the expected economic benefit from planting economic trees.

Figure 6. Adjacent conversions farmlands to economic forest (**a**) and ecological forest (**b**) under the Grain-for-Green Program in this study area (location: 41°52′59′′ N, 124°55′47′′ E). The tree species of economic forest: *Pinus koraiensis*; the tree species of ecological forest: *Larix kaempferi*.

Previous studies have suggested that an excessive chase of the supply of several ecosystem services may lead to declines in many other ecosystem services [18,52–54]. A key challenge of the GGP is how to convert farmlands to forests to achieve dual goals of improving livelihood and environment. Through the scenario analysis, we found a suitable scenario with proportions (50–60%) of economic forest (Figure 5d) whereby economic forest is mainly allocated in relatively flat terrain with good site conditions. Economic forests in these areas can produce a relatively high seed yield, at the expense of relatively moderate decreases in the regulating services. On the contrary, the conversion of farmlands to economic forests in poor site conditions (e.g., steep-sloped area) may produce a relative low seed yield, and may severely reduce regulating services. The findings showed that the trade-offs of ecosystem services between economic forest and ecological forest closely associated with afforestation types and their spatial pattern. A reasonable planning for the spatial allocation of afforestation types can lessen the tradeoffs between regulating services and provisioning service. Therefore, we suggested that the afforestation pattern of the GGP should be proposed though deliberate efforts, accounting for afforestation types and their spatial allocations.

Our findings have important implications for reforestation programs beyond this case study in mountainous areas. The different forest types provide significantly variant ecosystem services. Analyzing the ecosystem service characteristics for different afforestation types (e.g., economic forest with a special tree species) can help to optimize reforestation strategies. For example, understanding yield-limiting factors of a given economic tree species and evaluating its expected yields across a landscape are necessary. This knowledge can allow us to understand why the trade-offs between provisioning service and regulating services arises [16], so it is more likely to achieve the win-win goals of improving the environment and livelihood through a reforestation program.

4.3. Limitations

For a reforestation program, the ecosystem service assessment will illustrate their multiple effects, as well as inform management decisions. While we quantified the change in ecosystem services during the first round of the GPP, and analyzed the effects of afforestation choices on ecosystem services and their trade-offs using the popular InVEST model and scenario simulation, our study has limitations primarily due to the availability of data. One shortcoming was the evaluation accuracy of the four regulating services. The InVEST model used for the qualification of ecosystem services and simplified in terms of mechanisms, with results closely depending on LULC types. The input parameters of the GGP-related land covers for InVEST model are very relevant for the evaluation accuracy. Several parameters were localized by field-sampled data and management practices (e.g., aboveground biomass carbon storage of economic forest was estimated by tree density and diameter a breast height) (Supplementary Table S1). For flood mitigation, as it is difficult to validate against observed data [30], we used observed yearly water yield from local hydrological stations to indirectly test the accuracies (relative root mean squared error is 26.59%; Supplementary Table S2). In addition, the simulated values of water purification and soil retention were compared to the previous research results [55,56], showing generally consistent ranges of the estimated values. Since the relevant literatures concerning economic forests is very limited, their parameters for ecosystem service evaluation need to be modified based on field-based studies and observations in specific regions [57].

Another limitation involves the provisioning service (seed yield). The seed yield of Korean pine shows much annual and spatial variations [42], and is influenced by forest management practices. Due to the complex controls of seed yield of Korean pine, its accurate evaluation is a difficult task. Here, we simplify that (1) the seed yield of multi-year average was employed, (2) the management practices are on the same level, and (3) the seed yield is primarily determined by the site condition. Because the seed yield was estimated from a household survey, subjective records would be introduced, leading to uncertainty in the evaluation of the seed yield. In addition, the equation of Mongolian pine was employed to map site conditions for Korean pine, which can also introduce uncertainty into seed yield evaluation. Although some simplifications were introduced, comparable magnitudes of the seed yield across the landscape could be obtained. Overall, available field-based data and specific yield models are required for accurately evaluating the provisioning service of economic forests.

5. Conclusions

This study examined the GGP-driven land use and land change in the first round of the GGP, and assessed its effects on ecosystem services. We then demonstrated alternative trajectories of afforestation patterns to analyze their potential impacts on ecosystem services by a comparison to the actual changes. Our study indicates that the GGP promoted the concerned ecosystem services, but this improvement would be more efficient by optimized afforestation locations. The choice for afforestation types also impacted the ecosystem services and their trade-offs. The arising lessons and recommendations for the GGP are as follows:

1. The GGP drove a significant change of land-use/land-cover from 2000 to 2015, and all the concerned regulating services increased. Most farmlands were converted to forests in a relatively flat area, whereas steep-sloped farmlands, the primary target of the GGP, were not received enough attentions in the first around of the GGP.
2. The GGP-driven improvements in regulating services strongly depend on the afforestation locations. Prioritizing the conversion of steep-sloped and riparian farmlands can cost-effectively promote flood mitigation, water purification, and soil retention services as compared with current level in 2015. Conversing steep-sloped farmlands to forests can promote better in soil retention and flood mitigation services, whereas conversing of riverain farmlands to forests can more efficiently promote water purification service. We recommend that riverain farmlands should be considered for conversion to forests for a headwater region in the new round of the GGP.
3. The trade-offs between provisioning service and regulating services closely associates with afforestation types. A high proportion of economic forest increased non-timber product provisioning service, but at the expense of significant decreases in the concerned regulating services. The tradeoffs were enhanced when planting economic trees in ecological prioritizing areas that can provide high regulating service levels but a low provisioning service. We identified a suitable scenario (the proportion ranges 50~60%) that would reduce these trade-offs. Therefore, we do not recommend the unrestricted proportion of economic forest of the new policy of the second round of the GGP. The GGP management strategies should be proposed though deliberate efforts, accounting for afforestation types and their spatial allocation.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/11/4762/s1, Table S1: Detailed information on the main input parameters of the main GGP-related land use types and their sources in the InVEST model. Table S2: Comparison of annual average water yield between observed values and simulated values

Author Contributions: Conceptualization, X.L. and T.G.; methodology, Y.T., J.Z. and T.G.; formal analysis, S.L., Y.T., X.Z., D.Z., L.Y., L.J. and T.G.; investigation, L.Y., X.L., Y.T. and L.J.; writing, X.L., Y.T. and T.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA19030204, XDA19050502), the National Key Research and Development Program of China (2016YFD0600206) and the Key Research Program of Frontier Sciences, Chinese Academy of Sciences (QYZDJ-SSW-DQC027).

Acknowledgments: We thank members of sampling team of Agronomy College, Shenyang Agricultural University (Jiaxin Lv, Zhe Nie and Qingda Chen). We would be grateful to Shengli Liu of the Department of Natural Resources of Qingyuan Manchu Autonomous County for providing the local statistical data of the Grain-for-Green Program.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tilman, D.; Fargione, J.; Wolff, B.; D'Antonio, C.; Dobson, A.; Howarth, R.; Schindler, D.; Griscom, B.; Simberloff, D.; Swackhamer, D. Forecasting agriculturally driven global environmental change. *Science* **2001**, *292*, 281–284. [CrossRef]
2. Laurance, S.G.W.; Sayer, J.; Cassman, K.G. Agricultural expansion and its impacts on tropical nature. *Trends Ecol. Evol.* **2014**, *29*, 107–116. [CrossRef]
3. Janeczko, E.; Dąbrowski, R.; Budnicka-Kosior, J.; Woźnicka, M. Influence of urbanization processes on the dynamics and scale of spatial transformations in the Mazowiecki Landscape Park. *Sustainability* **2019**, *11*, 3007. [CrossRef]
4. Yu, Q.; Van Vliet, J.; Verburg, P.H.; You, L.; Yang, P.; Wu, W. Harvested area gaps in China between 1981 and 2010: Effects of climatic and land management factors. *Environ. Res. Lett.* **2018**, *13*, 044006. [CrossRef]
5. Zheng, H.; Wang, L.; Peng, W.; Zhang, C.; Li, C.; Robinson, B.E.; Wu, X.; Kong, L.; Li, R.; Xiao, Y.; et al. Realizing the values of natural capital for inclusive, sustainable development: Informing China's new ecological development strategy. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 8623–8628. [CrossRef]
6. Rodríguez, J.P.; Beard, J.T.D.; Bennett, E.M.; Cumming, G.; Cork, S.J.; Agard, J.; Dobson, A.P.; Peterson, G.D. Trade-offs across space, time, and ecosystem services. *Ecol. Soc.* **2006**, *11*, 11. [CrossRef]
7. Assessment, M.E. *Ecosystems and Human Well-Being: The Assessment Series*; Island Press: Washington, DC, USA, 2005.
8. Peng, J.; Hu, X.; Wang, X.; Meersmans, J.; Liu, Y.; Qiu, S. Simulating the impact of Grain-for-Green Programme on ecosystem services trade-offs in Northwestern Yunnan, China. *Ecosyst. Serv.* **2019**, *39*, 100998. [CrossRef]
9. Liu, J.; Li, S.; Ouyang, Z.; Tam, C.; Chen, X. Ecological and socioeconomic effects of China's policies for ecosystem services. *Proc. Natl. Acad. Sci. USA* **2008**, *105*, 9477. [CrossRef]
10. Fu, B.; Liu, Y.; Lü, Y.; He, C.; Zeng, Y.; Wu, B. Assessing the soil erosion control service of ecosystems change in the Loess Plateau of China. *Ecol. Complex.* **2011**, *8*, 284–293. [CrossRef]
11. Cao, S.; Xu, C.; Chen, L.; Wang, X. Attitudes of farmers in China's northern Shaanxi Province towards the land-use changes required under the Grain for Green Project, and implications for the project's success. *Land Use Policy* **2009**, *26*, 1182–1194. [CrossRef]
12. Deng, L.; Kim, D.-G.; Li, M.; Huang, C.; Liu, Q.; Cheng, M.; Shangguan, Z.; Peng, C. Land-use changes driven by 'Grain for Green' program reduced carbon loss induced by soil erosion on the Loess Plateau of China. *Glob. Planet. Chang.* **2019**, *177*, 101–115. [CrossRef]
13. Deng, L.; Shangguan, Z.; Li, R. Effects of the grain-for-green program on soil erosion in China. *Int. J. Sediment Res.* **2012**, *27*, 120–127. [CrossRef]
14. Wang, K.; Hu, D.; Deng, J.; Shangguan, Z.; Deng, L. Biomass carbon storages and carbon sequestration potentials of the Grain for Green Program-Covered Forests in China. *Ecol. Evol.* **2018**, *8*, 7451–7461. [CrossRef]
15. Shi, S.; Han, P. Estimating the soil carbon sequestration potential of China's Grain for Green Project. *Glob. Biogeochem. Cycles* **2014**, *28*, 1279–1294. [CrossRef]
16. Howe, C.; Suich, H.; Vira, B.; Mace, G.M. Creating win-wins from trade-offs? Ecosystem services for human well-being: A meta-analysis of ecosystem service trade-offs and synergies in the real world. *Glob. Environ. Chang.* **2014**, *28*, 263–275. [CrossRef]
17. Wang, Y.; Zhao, J.; Fu, J.; Wei, W. Effects of the Grain for Green Program on the water ecosystem services in an arid area of China—Using the Shiyang River Basin as an example. *Ecol. Indic.* **2019**, *104*, 659–668. [CrossRef]
18. Wang, J.; Peng, J.; Zhao, M.; Liu, Y.; Chen, Y. Significant trade-off for the impact of Grain-for-Green Programme on ecosystem services in North-western Yunnan, China. *Sci. Total Environ.* **2017**, *574*, 57–64. [CrossRef]
19. Jia, X.; Fu, B.; Feng, X.; Hou, G.; Liu, Y.; Wang, X. The tradeoff and synergy between ecosystem services in the Grain-for-Green areas in Northern Shaanxi, China. *Ecol. Indic.* **2014**, *43*, 103–113. [CrossRef]
20. Rosário, V.A.C.; Guimarães, J.C.; Viani, R.A.G. How changes in legally demanded forest restoration impact ecosystem services: A case study in the atlantic forest, Brazil. *Trop. Conserv. Sci.* **2019**, *12*, 12. [CrossRef]
21. Zeng, Y.; Gou, M.; Ouyang, S.; Chen, L.; Fang, X.; Zhao, L.; Li, J.; Peng, C.; Xiang, W. The impact of secondary forest restoration on multiple ecosystem services and their trade-offs. *Ecol. Indic.* **2019**, *104*, 248–258. [CrossRef]
22. Zheng, H.; Wang, L.; Wu, T. Coordinating ecosystem service trade-offs to achieve win-win outcomes: A review of the approaches. *J. Environ. Sci.* **2019**, *82*, 103–112. [CrossRef] [PubMed]

23. Zheng, H.; Li, Y.; Robinson, B.E.; Liu, G.; Ma, D.; Wang, F.; Lu, F.; Ouyang, Z.; Ouyang, Z. Using ecosystem service trade-offs to inform water conservation policies and management practices. *Front. Ecol. Environ.* **2016**, *14*, 527–532. [CrossRef]
24. Yan, B. Water quality evaluation and trend analysis of Hunhe River Basin in the upstream of Dahuofang Reservoir. *Appl. Ecol. Environ. Res.* **2019**, *17*, 11717–11729. [CrossRef]
25. Mao, D.; Wang, Z.; Wu, J.; Wu, B.; Zeng, Y.; Song, K.; Yi, K.; Luo, L. China's wetlands loss to urban expansion. *Land Degrad. Dev.* **2018**, *29*, 2644–2657. [CrossRef]
26. Sunohara, M.; Topp, E.; Wilkes, G.; Gottschall, N.; Neumann, N.; Ruecker, N.; Jones, T.H.; Edge, T.; Martí, R.; Lapen, D. Impact of riparian zone protection from cattle on nutrient, bacteria, F-coliphage, cryptosporidium, and giardia loading of an intermittent stream. *J. Environ. Qual.* **2012**, *41*, 1301–1314. [CrossRef]
27. Chen, J. Riparian vegetation characteristics and their functions in ecosystems and landscapes. *Chin. J. Appl. Ecol.* **1996**, *7*, 439–448.
28. Bradford, J.B.; D'Amato, A.W. Recognizing trade-offs in multi-objective land management. *Front. Ecol. Environ.* **2012**, *10*, 210–216. [CrossRef]
29. Stürck, J.; Poortinga, A.; Verburg, P.H. Mapping ecosystem services: The supply and demand of flood regulation services in Europe. *Ecol. Indic.* **2014**, *38*, 198–211. [CrossRef]
30. Sharp, R.; Chaplin-Kramer, R.; Wood, S.; Guerry, A.; Tallis, H.; Ricketts, T. *InVEST 3.7.0 User's Guide*; Natural Capital Project: Stanford, CA, USA, 2018.
31. Yang, S.; Zhao, W.; Liu, Y.; Wang, S.; Wang, J.; Zhai, R. Influence of land use change on the ecosystem service trade-offs in the ecological restoration area: Dynamics and scenarios in the Yanhe watershed, China. *Sci. Total Environ.* **2018**, *644*, 556–566. [CrossRef]
32. Droogers, P.; Allen, R.G. Estimating reference evapotranspiration under inaccurate data conditions. *Irrig. Drain. Syst.* **2002**, *16*, 33–45. [CrossRef]
33. Wang, L.; Zheng, H.; Wen, Z.; Liu, L.; Robinson, B.E.; Li, R.; Li, C.; Kong, L. Ecosystem service synergies/trade-offs informing the supply-demand match of ecosystem services: Framework and application. *Ecosyst. Serv.* **2019**, *37*, 100939. [CrossRef]
34. Arnold, J.G.; Srinivasan, R.; Muttiah, R.S.; Williams, J.R. Large area hydrologic modeling and assessment part i: Model development. *JAWRA J. Am. Water Resour. Assoc.* **1998**, *34*, 73–89. [CrossRef]
35. Redhead, J.W.; May, L.; Oliver, T.H.; Hamel, P.; Sharp, R.; Bullock, J.M. National scale evaluation of the InVEST nutrient retention model in the United Kingdom. *Sci. Total Environ.* **2018**, *610*, 666–677. [CrossRef] [PubMed]
36. Borselli, L.; Cassi, P.; Torri, D. Prolegomena to sediment and flow connectivity in the landscape: A GIS and field numerical assessment. *Catena* **2008**, *75*, 268–277. [CrossRef]
37. Jiao, Y.; Zhao, D.; Xu, Q.; Liu, Z.; Ding, Z.; Ding, Y.; Liu, C.; Zha, Z. Mapping lateral and longitudinal hydrological connectivity to identify conservation priority areas in the water-holding forest in Honghe Hani Rice Terraces World Heritage Site. *Landsc. Ecol.* **2020**, *35*, 709–725. [CrossRef]
38. Cavalli, M.; Trevisani, S.; Comiti, F.; Marchi, L. Geomorphometric assessment of spatial sediment connectivity in small Alpine catchments. *Geomorphology* **2013**, *188*, 31–41. [CrossRef]
39. Renard, K.G.; Foster, G.R.; Weesies, G.A.; Porter, J.P. RUSLE: Revised universal soil loss equation. *J. Soil Water Conserv.* **1991**, *46*, 30–33.
40. Gao, T.; Zhu, J.J.; Yan, Q.L.; Deng, S.Q.; Zheng, X.; Zhang, J.X.; Shang, G.D. Mapping growing stock volume and biomass carbon storage of larch plantations in Northeast China with L-band ALOS PALSAR backscatter mosaics. *Int. J. Remote Sens.* **2018**, *39*, 7978–7997. [CrossRef]
41. Wang, X.; Fang, J.; Zhu, B. Forest biomass and root–shoot allocation in northeast China. *For. Ecol. Manag.* **2008**, *255*, 4007–4020. [CrossRef]
42. Jin, X.; Li, F.; Pukkala, T.; Dong, L. Modelling the cone yields of Korean pine. *For. Ecol. Manag.* **2020**, *464*, 118086. [CrossRef]
43. Wu, X. The growth and site condition of Pinus sylvestris var. mongolica plantation in mountainous areas of eastern Liaoning Province. *Liaoning For. Sci. Technol.* **1992**, *4*, 16–18.
44. Lamb, D.; Erskine, P.D.; Parrotta, J. Restoration of degraded tropical forest landscapes. *Science* **2005**, *310*, 1628–1632. [CrossRef] [PubMed]

45. Turkelboom, F.; Leone, M.; Jacobs, S.; Kelemen, E.; Garcia, M.; Baró, F.; Termansen, M.; Barton, D.N.; Berry, P.; Stange, E.; et al. When we cannot have it all: Ecosystem services trade-offs in the context of spatial planning. *Ecosyst. Serv.* **2018**, *29*, 566–578. [CrossRef]
46. Dai, E.; Wang, X.; Zhu, J.; Xi, W. Quantifying ecosystem service trade-offs for plantation forest management to benefit provisioning and regulating services. *Ecol. Evol.* **2017**, *7*, 7807–7821. [CrossRef]
47. Wang, B.; Gao, P.; Niu, X.; Sun, J. Policy-driven China's Grain to Green Program: Implications for ecosystem services. *Ecosyst. Serv.* **2017**, *27*, 38–47. [CrossRef]
48. Geng, Q.; Ren, Q.; Yan, H.; Li, L.; Zhao, X.; Mu, X.; Wu, P.; Yu, Q. Target areas for harmonizing the Grain for Green Programme in China's Loess Plateau. *Land Degrad. Dev.* **2019**, *31*, 325–333. [CrossRef]
49. Ministry of Environmental Protection of China, Chinese Academy of Sciences. *National Ecosystem Service Zoning in China*. Beijing. 2015. Available online: http://www.mee.gov.cn/gkml/hbb/bgg/201511/W020151126550511267548.pdf (accessed on 8 June 2020).
50. Boughton, E.H.; Quintana-Ascencio, P.F.; Jenkins, D.G.; Bohlen, P.J.; Fauth, J.E.; Engel, A.; Shukla, S.; Kiker, G.; Hendricks, G.; Swain, H.M. Trade-offs and synergies in a payment-for-ecosystem services program on ranchlands in the Everglades headwaters. *Ecosphere* **2019**, *10*, e02728. [CrossRef]
51. Dokken, T.; Angelsen, A. Forest reliance across poverty groups in Tanzania. *Ecol. Econ.* **2015**, *117*, 203–211. [CrossRef]
52. Raudsepp-Hearne, C.; Peterson, G.D.; Bennett, E.M. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 5242–5247. [CrossRef]
53. Bennett, E.M.; Balvanera, P. The future of production systems in a globalized world. *Front. Ecol. Environ.* **2007**, *5*, 191–198. [CrossRef]
54. Dosskey, M.; Wells, G.; Bentrup, G.; Wallace, D. Enhancing ecosystem services: Designing for multifunctionality. *J. Soil Water Conserv.* **2012**, *67*, 37–41. [CrossRef]
55. Nong, X.; Shao, D.; Zhong, H.; Liang, J. Evaluation of water quality in the South-to-North Water Diversion Project of China using the water quality index (WQI) method. *Water Res.* **2020**, *178*, 115781. [CrossRef] [PubMed]
56. Sun, Y.; Hao, R.; Qiao, J.; Xue, H. Function zoning and spatial management of small watersheds based on ecosystem disservice bundles. *J. Clean. Prod.* **2020**, *255*, 120285. [CrossRef]
57. Turner, K.G.; Odgaard, M.V.; Bøcher, P.K.; Dalgaard, T.; Svenning, J.-C. Bundling ecosystem services in Denmark: Trade-offs and synergies in a cultural landscape. *Landsc. Urban Plan.* **2014**, *125*, 89–104. [CrossRef]