sustainability

MDPI

Article

Analysis Framework of China's Grain Production System: A Spatial Resilience Perspective

Dazhuan Ge [1,2,3], Hualou Long [1,2,4,*], Li Ma [1,2,3], Yingnan Zhang [1,2,3] and Shuangshuang Tu [1,5,*]

1 Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; gedz.15b@igsnrr.ac.cn (D.G.); mal.17b@igsnrr.ac.cn (L.M.); zhangyn.16b@igsnrr.ac.cn (Y.Z.)
2 Center for Assessment and Research on Targeted Poverty Alleviation, Chinese Academy of Sciences, Beijing 100101, China
3 University of Chinese Academy of Sciences, Beijing 100049, China
4 College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China
5 Key Laboratory of Environment Change and Resources Use in Beibu Gulf, Guangxi Teachers Education University, The Ministry of Education, Nanning 530001, China
* Correspondence: longhl@igsnrr.ac.cn (H.L.); tuss@gxtc.edu.cn (S.T.); Tel.: +86-10-6488-8169 (H.L.)

Received: 22 September 2017; Accepted: 11 December 2017; Published: 15 December 2017

Abstract: China's grain production has transformed from absolute shortage to a current structural oversupply. High-intensity production introduced further challenges for the eco-environment, smallholder livelihood, and the man-land interrelationship. Driven by urban-rural transformation, research on food security patterns and grain production has expanded into a new field. To analyze the challenges and required countermeasures for China's grain production system (GPS), this study constructed a theoretical GPS framework based on space resilience. Firstly, a new GPS concept was proposed and a functional system was established for protecting the regional food security, thus guaranteeing smallholder livelihood, stabilizing urban-rural transformation, and sustaining the eco-environment in terms of economic, social, and ecological attributes of the GPS. Secondly, based on a cross-scale interaction analysis that varied from a smallholder scale to a global scale, the systematic crisis of the GPS was analyzed. Thirdly, a cross-scale analytic framework of the GPS was formed from the perspective of spatial resilience, integrating both inner and external disturbance factors of the GPS. Both spatial heterogeneity and connectivity of internal and external disturbance factors are important contents of system space resilience. Finally, the hierarchy of spatial resilience of GPS became clear. The transformation of labor force and the land use transition form key thresholds of the GPS. In summary: based on protecting the basic functions of the GPS, the cross-scale effect of systematic disturbance factors and relevant countermeasures for spatial resilience are effectively influenced by the coordination of the interests of multiple stakeholders; spatial resilience is an effective analytical tool for GPS regulation, providing a reference for revealing the inherent mechanism and functional evolution of the GPS in the process of urban-rural transformation.

Keywords: agricultural labor transition; land use transition; food security; smallholder livelihood; cross-scale analysis; stakeholders

1. Introduction

The strong contrast between the large population and limited available land resources creates a significant challenge for China's food security [1,2]. In 2014, total grain production amounted to 557 million tons and the per capita grain possession was 408.58 kg (Figure 1). In a global comparison for the same interval, the total grain production and per capita grain possession were 2818 million tons and 387.74 kg, respectively (https://data.worldbank.org.cn) [3]. The proportion of China's grain production, compared to the total grain produced globally, stabilized at a level of approximately 20%. This indicates that China has achieved significant achievements in guaranteeing grain self-sufficiency and in ensuring the absolute safety of rations [4]. Even if a small amount of imported grain has not been taken into consideration, China can still meet its enormous grain demand. In some ways, the current grain production, in fact, appears to be a structural oversupply [5]. Changes in the dietary and consumption structures of urban-rural residents in the process of urbanization resulted in a decline of the grain demand and an increased requirement for quality [6,7]. Therefore, protecting food security should focus not only on production, but also on retail and consumption [8,9]. In conclusion, research on food security in China has stepped into a completely new field and category [10,11].

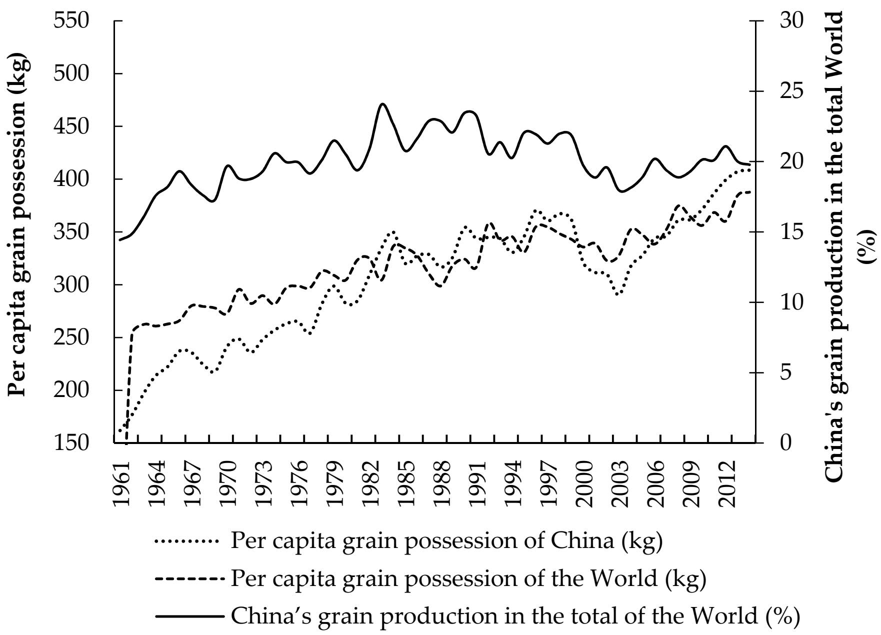

Figure 1. Basic pattern of the Chinese grain production. Data Source: [3].

Furthermore, statistics about per capita water and land resources and other limiting factors should be investigated, as should issues regarding resources and the environment caused by high-intensity grain production. During 2014, China's per capita farmland area was 0.08 ha, which was only 40% of the world average level [12]. In addition, farmland owned by smallholders mostly consisted of small-scale and dispersed paddy fields, of which 60% were below 0.1 ha in size [13]. In 2012, the per capita water resources were only 2000 m^3, which is equivalent to 32% of the world level. Nevertheless, agricultural water consumption depleted nearly 70% of the total available water resources [14]. Resulting from a considerable limitation of natural resources, the high grain production of China mainly depends on an increase of per unit area grain yield. China's farmland productivity has increased from 2802 kg/ha to 5520 kg/ha in the years from 1990 to 2010, which ranked 16th around the world (the global average is 3564 kg/ha) in 2010 [15]. As for the basic prerequisites, high intensity and density input jointly contributed to an increase of farmland productivity. Using chemical fertilizer input as an example, the per hectare farmland input has increased by 50% from 2002 to 2014, amounting to 565.26 kg/ha, which was much higher than the average of 138.04 kg/ha for other countries (ranking 11th in comparison to the world). Chemical fertilizer input per hectare of farmland in China was about four times that of the global average level, 4.1 times that of America, and 2.3 times that of Japan (Figure 2). Moreover, recent decades have witnessed a tremendous growth of pesticide input [16], agricultural machinery utilization, and irrigation proportion [17].

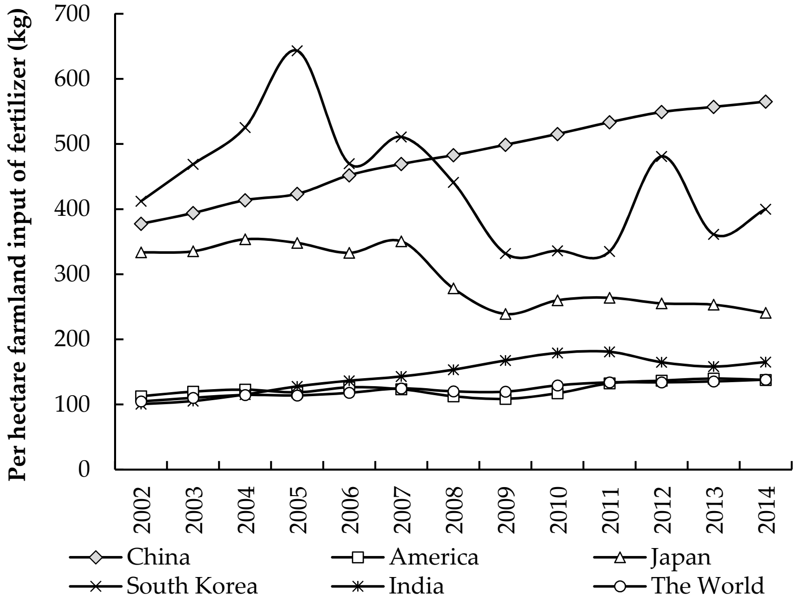

Figure 2. Per hectare farmland input of fertilizer. Data Source: [3].

Severe eco-environmental issues have been caused by high-intensity grain production and these require an urgent structural transformation of the grain production status [18,19]. Relevant research revealed that China's carbon footprint is higher than that of America and Japan. In 2013, the carbon footprints of corn, wheat, and paddy were 4052 kg·ce/ha, 5455 kg·ce/ha, and 11881 kg·ce/ha, respectively, which mostly originated from the overuse of nitrogenous fertilizers, straw burning, and fuel consumption by agricultural machinery [20]. The carbon footprint as a result of the process of grain production and consumption occupied 70% of the total carbon footprint in China and is closely related to excessive chemical fertilizer input [21]. Research indicated that the super scale of nitrogenous fertilizer input amounts to 50 kg/ha [22]. At the same time, soil acidification [23] and soil pollution [24] triggered by the overuse of chemical fertilizers threatens sustainable soil use. Moreover, large-scale irrigation, which strongly depends on underground water in northern China, has resulted in the continuous decline of the groundwater level and has caused land subsidence [25].

High-intensity intensification not only results in high production, but also in high cost and low income. This intensive mode of grain production leads to agricultural involution rather than increasing the benefit for smallholders [26,27]. In other words, the already marginal benefit brought by agricultural activities gradually declines with the further increase of additional input (i.e., agricultural involution) [28]. Consequently, the income decline of grain-producing smallholders, decreased the attractiveness of grain production, part-time farming, and inefficient utilization of farmland continuously aggravated the situation [29]. Under this situation, some scholars have argued that large-scale production, reducing agricultural labor, promoting farmland circulation, and de-peasantization may be appropriate choices for China's grain production [30]. However, others have suggested that preventing threats to the food security [31] and social stability caused by land grabbing are essential [32], and have consequently proposed a policy vision that guarantees food sovereignty and peasant rights [33,34].

The concept of "resilience" refers to the system capacity of resisting disturbance and has mainly been applied to engineering and ecology [35]. With its application to different disciplines to the research of social-ecological systems, in particular, it has greatly influenced global momentous scientific issues [36,37]. Currently, 15 global Non-Governmental Organizations (NGOs) regard "resilience" as their main project objective [38]. Research on resilience related to grain production has vastly increased, such as agricultural system resilience [39], food system resilience [40], and smallholder livelihood resilience [41]. All of these achievements will contribute to research on grain production resilience.

From the aforementioned analysis, we can draw the conclusion that China's grain production conditions offer profound potential for both transformation and crisis whether analyzed from the perspective of a comparison between the domestic and international environments, the transition and evolution patterns of inner key elements [11,42], or the opinion divergence regarding the future mode of development of China's grain production modes between different scholars. Both opportunities and challenges of the required grain production transformation create appropriate conditions for the optimization of China's grain production pattern. The challenges of environmental protection surrounding the intensification mode of grain production have aroused widespread concern within the whole of society. The transformation of internal and external conditions for grain production has deeply changed. If we can make good use of these opportunities, it will improve the plight of smallholder agricultural production in China. However, the current research on grain production in China still mainly focuses on influential factors, which cannot effectively explain the complex system structures of grain production activities. Under the background of urban-rural transformation and development, a socio-economic development transformation process due to rapid urbanization and industrialization affected by the traditional dual urban-rural structure of China, profound changes have taken place in the status and pattern of Chinese grain production. However, little effective research has been conducted on how to effectively deal with various systemic crises and challenges for China's grain production strategy during this vital transitional period. An effective analysis of the challenges and opportunities of China's grain production activities will create conditions that are supportive for safeguarding food security and for coordinating the urban and rural development during the new period.

Based on the above analysis, this study focused on systematic thinking to investigate the challenges of China's grain production, and to provide a useful reference for optimizing grain production activities. This study addressed the following aspects: (1) Based on the concept and connotation of the grain production system (GPS), the main influencing factors, core functions, and cross-scale internal structure of the GPS were analyzed. (2) Using the cross-scale interaction effect, spatial heterogeneity, and connectivity of internal and external disturbance factors, a spatial resilience analysis framework of the GPS has been constructed. (3) By analyzing the hierarchical structure, key thresholds, and system functions of spatial resilience of the GPS, a conceptual framework for optimizing the spatial resilience of China's GPS has been established. Therefore, this study will help to analyze the systemic crisis faced by the GPS during the rapid transition period and provide practical guidance for the optimization of the spatial resilience of the GPS. In addition, the introduction of spatially resilient thinking into the research field of agricultural production provides a useful reference for the further deepening of the research methods of human geography, especially for the research of modern agricultural geography.

2. The Concept and Connotation of the GPS

The transformation of China's GPS is inseparable from the history of agricultural development and the man-land interrelations under the background of urban-rural transformation. To better guide the grain production while coordinating the dilemma in the process of grain production transformation, this paper introduces the concept of the GPS. Here, the GPS is defined as a dynamic and sustainable complex system [42], supported by the eco-environment and the prevailing socio-economic conditions. This complex system ensures regional food security [43], provides smallholder livelihood security [41], and coordinates the urban-rural transformation as well as other basic functions [44]. The GPS is formed under the macroscopic background of both the socio-economic and socio-ecologic environments, which contain economic-social-ecological multiple attributes with a series of human activities.

2.1. Multiple Attributes of the GPS

The concept of the GPS is a complex system with economic, social, and ecological attributes (Figure 3). Economic attributes represent value attributes that can be exchanged for the grain production process and its products, and thus form the inherent attributes of the grain production process [45].

At the same time, the smallholder grain production pattern of China fundamentally differs from that of developed countries in its large-scale mechanized grain production pattern, due to the tense patterns of the man-land interrelations of China [11]. Therefore, the social attributes of the GPS represent a social security function for smallholders [46], which forms a strong commitment to the majority livelihood sources of the rural population [46].

In addition, grain production activities cannot be separated from the local eco-environment, and the impact of the grain production process on the value of local ecosystem services is also noticeable [42,47]. Apparently, the economic, social, and ecological attributes of the GPS are closely related. Economic attributes form the basis for maintaining social attributes (Figure 3); social attributes in turn provide protection for the realization of economic attributes; and ecological attributes form prerequisites of economic and social attributes [48], which are located in the outer attribute circle (Figure 3).

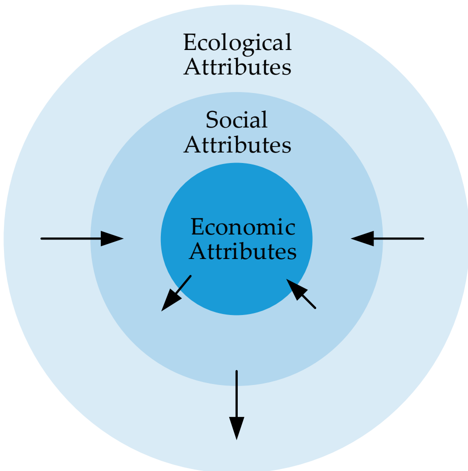

Figure 3. Concept model of the multiple attributes of the GPS. Source: Authors' design.

2.2. *Multi-Dimensional Functions of the GPS*

Its complex structure and multiple attribute characteristics determine the multi-dimensional functional system of the GPS. Furthermore, adequate food supplies and better food security level create the conditions for the multi-functionality of the GPS. Firstly, the GPS includes the functions of ensuring food security and providing high-quality food products. In addition to the basic nutritional requirements of food [43], the demand for high-quality food products is further increasing. Consequently, food security and quality food supply constitute basic functions of the GPS [6]. Corresponding to multiple attributes of the GPS, this function is a combination of economic, social, and ecological attributes (Figure 4).

Moreover, the function of the GPS to maintain smallholder livelihood, while protecting their fair status corresponds to the social attribute of the GPS. The smallholder livelihood framework under the concept of the GPS refers to the diversification of agricultural production and income sources to maintain the regional ecological balance [49,50]. At the same time, both a stable and a reasonable nutritional structure, assimilation into the rural markets and agricultural industry systems, and the enjoyment of equal and reasonable national status are also important for smallholder livelihoods [41,51].

Under the background of the urban-rural transformation development of China, the function of the GPS to guarantee an effective economic development and stable social transformation forms the specific embodiment of the economic and social attributes of the system [11,52]. Therefore, accompanied by the simultaneous transformation of the GPS and the urban-rural transformation, the process that coordinates the urban-rural development is closely related to the GPS [7]. The stable transformation of the GPS provides a guarantee for the urban-rural transformation, and furthermore creates an optimal space and regulation opportunity for the government.

The sustainability of the eco-environment corresponds to the ecological attributes of the GPS, reflecting the ecological trends of GPS transformation. The sustainable development of the eco-environment is the embodiment of system function and forms the foundation of the GPS [18]. Leaving ecosystem stability intact, the GPS is hard to preserve, the ecological crisis continues to develop, and the value of ecosystem services gradually declines [53]. At present, new forms of grain production, such as organic agriculture [54] and sustainable intensification agriculture [55] are emerging as a returning signal of the ecological attributes, thus reflecting the important function of sustainable of eco-environment for the GPS.

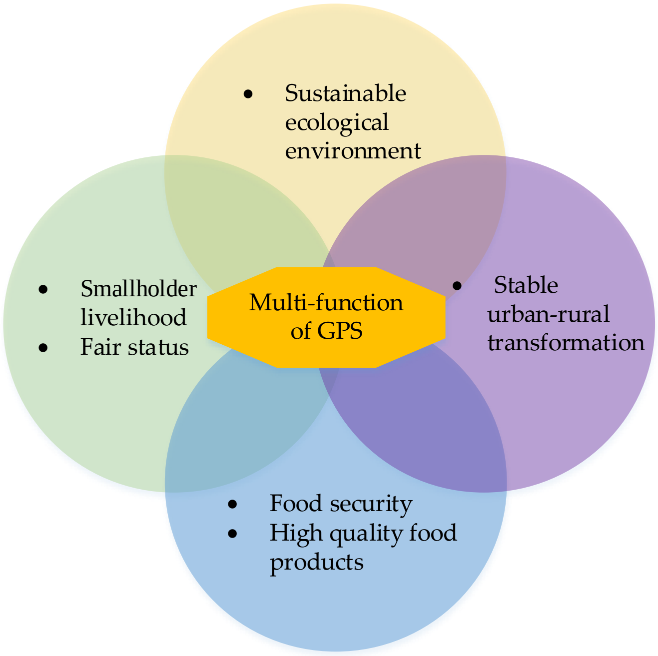

Figure 4. Multi-dimensional function of the GPS. Source: Authors' design.

2.3. *Cross-Scale Hierarchical Structure of the GPS*

The complex system of grain production has distinct cross-scale hierarchical features. This complex system is characterized by a hierarchical structure, and the potential interaction between different scales and processes may be mutually enhanced or undermined. The matching pattern between functionality and the constituent elements (i.e., the number and nature of system elements) is profoundly dependent on scale changes within the system [56]. In combination with the cross-scale connection of system elements [57], we developed the cross-scale operation mechanism and mode of the GPS. This is based on the interaction of the system structure among its economic, social, and ecological attributes [58].

Both smallholder and local scale are the underlying structures of grain production and both are influenced by upper-hierarchical system structures such as national grain production policies [59], fluctuations on international grain markets [60], and global climate change [61,62]. Similarly, upper-hierarchical structural changes are also affected by changes within the grass-roots scale. For example, the improvement of the employment structure of smallholders and their urban-rural migration characteristics [63] impacted the urban-rural structure [7]; the ability of smallholders to cope with natural disasters may affect international agricultural trade negotiations [64,65]. In addition, internal differentiation of farmers also changes the structure of local scales. The total number of farmers in China is about 180 million, who utilize 87 million ha of farmland, which amounts to a per household farmland area of only 0.1 ha. At the end of 2015, 31 million ha of this farmland had been transferred, accounting for 35.1% of the total farmland under contract [13]. Although new agricultural management entities (such as family farms) continue to emerge, the decentralized mode of smallholder agriculture still occupies the core position of grain production and its organization mode. The mode of agricultural production at the local scale is closely related to the agricultural policy at both regional and national scale. Therefore, the cross-scale hierarchical structure of the GPS is a complex and changeable system. Within the hierarchical model, the degree of connectivity determines the resilience of the grain production response to the crisis, which will be discussed in the spatial resilience of the GPS (Figure 5).

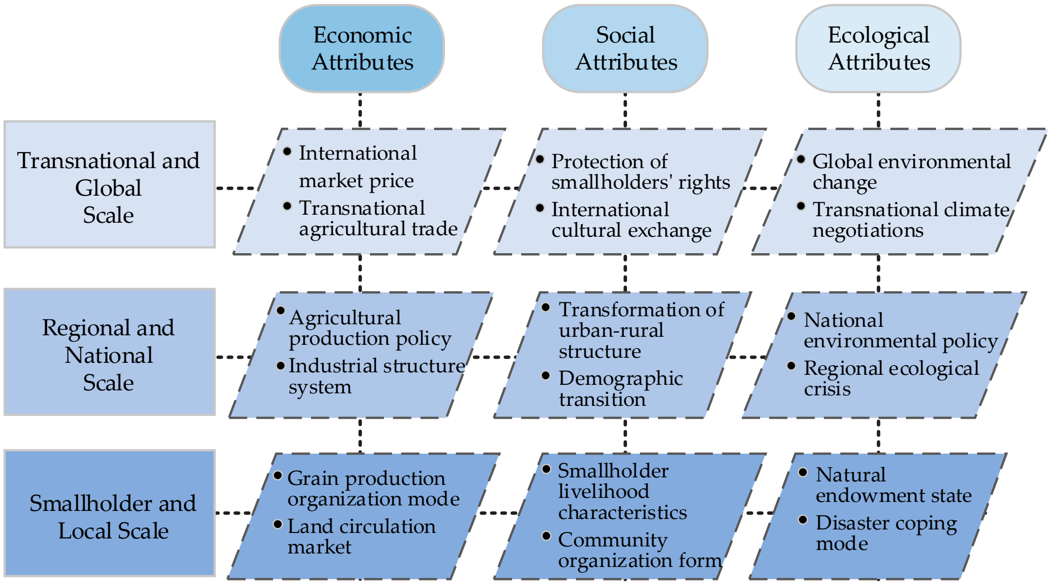

Figure 5. Hierarchical structure of the GPS under the multi-scale model. Source: Authors' design.

3. Spatial Resilience of the GPS

3.1. The Framework for the Spatial Resilience of the GPS

The theory of resilience has had continuous breakthroughs in different disciplines. At present, both the connection and decentralization of system elements, the system dynamics theory [66], the social network theory [67], the environmental gradient theory [68], and the spatial heterogeneity of system elements have all achieved important developments for resilience research. However, scholars become increasingly aware of the importance of spatio-temporal scales within resilience dynamics [69]. Facing such a complex system of multi-source perturbation and cross-scale network connection systems, resilience analyses from local data and case studies have found it difficult to reveal the real structure of the system. Therefore, the dynamic spatial resilience became an effective analytic tool for this complex system, which can explain spatial linkages at multiple scales of the system disturbance. Spatial resilience is a dynamic concept not only applying to our understanding of ecosystem resilience, but also furthering our understanding of the transformation of socio-economic systems [35].

In this study, the dynamic spatial resilience of the GPS has been defined as the ability and way of spatial variation (both internal and external disturbance factors of the system, including spatial position, spatial distribution, and spatial environment), influencing (and is influenced by) the resilience of the system across multiple spatial and temporal scales [70]. The main internal disturbance factors that affect this dynamic spatial resilience include the spatial variations of the system element and their interactions. Furthermore, the spatial attributes of the system can affect the trajectories for change within the system. Therefore, the spatially related system attributes of the GPS (e.g., the system size, shape, and number) are also important components of internal disturbance factors. The main external disturbance factors of dynamic spatial resilience are the cross-scale spatial environment (e.g., the urban-rural transformation), spatial connectivity, and spatially driven feedback under a dynamic spatial perspective.

The spatial resilience of the GPS, as a subset of system resilience, focuses on the process of the system on multiple spatial and temporal scales [71]. The spatial resilience integrates the spatial arrangement of system elements (e.g., smallholder farmers and rural communities) and the interaction between these. Under the interaction of different elements via horizontal and vertical connections, spatial resilience can be used to analyze a simple interaction between two elements as well as complex analyses including network structure analysis, hierarchical analysis, and other spatial dynamic global systems between different elements [69]. Using the spatial resilience method to construct a theoretical framework for GPS transformation is an effective tool to detect different hierarchies of disturbance factors via cross-scale system analysis. Consequently, via effective analysis of system spatial resilience, an optimization strategy for GPS transformation can be provided.

3.2. Internal Disturbance Factors of Spatial Resilience

The internal disturbance factors of the GPS mainly include spatio-temporal processes of the key elements (including subsystems of the GPS) and their interactions. The spatial resilience of the GPS depends on the cross spatio-temporal scale influence of the internal disturbance factors; i.e., the spatial resilience of the system is derived from the resilience change effect of its key elements. System elements that are directly related to the GPS include the agricultural labor force [72], the farmland, agricultural technology, capital, and agricultural policy. The spatial distributions of these elements and their interactions have noticeable effects on the GPS. The spatial distribution of both farmland and labor force directly affects the spatial pattern of the GPS [73]. Technology forms the core element of the modern GPS and its spatial distribution features directly affect the production technology system and level of modernization [74]. In addition, the role of capital in grain production is constantly strengthened [75], because the spatial difference between spread and flow of capital determines the degree of marketing of grain production in different regions [76].

In different hierarchies, the interaction between disturbance factors is apparent, while the cross-scale effect of internal disturbance factors on system resilience is also strengthened. The key condition of space resilience is the disturbance influence of internal elements. The cross-scale effect of the internal disturbance factors cannot only change the spatial distribution of the original components of the system, but also change the connection degree of the system, which has a profound impact on the change of the spatial resilience of the GPS. During the process of urban-rural transformation, the employment structure and the spatial distribution of the agricultural labor force have changed dramatically. The agricultural labor force has become an important link, connecting the rural and the urban China on different scales, thus profoundly changing the state of grain production in rural China by realizing a switch between urban and rural China (e.g., information, capital, and technology) [63,77]. At the same time, changes in the employment structure of the labor force have also converted relevant policies and measures of the national grain production [30]. For example, the proportion of agricultural labor to rural employees has decreased from 84.12% to 60.23% from 1990 to 2010. This transformation of agricultural labor has profoundly changed the cultivation mode of grain in China [72]. During the rural-urban migration of the agricultural labor force, the way and intensity of farmland use have also undergone profound changes due to increasing capital investment per unit area and decreasing labor input [78,79]. The cross-scale influence of the agricultural labor force in different hierarchies profoundly changed the spatial resilience of the GPS at different spatio-temporal scales.

Rural communities, as the grass-roots organizations of grain production, are an important subsystem of the GPS. The spatio-temporal evolution of rural communities profoundly impacted the GPS transformation and other cross-scale subsystems [80]. During the stage of traditional smallholder farming, the rural community is an important supporter of grain production organization and management. During the urban-rural transformation [11], the weakening organization functions of the rural community profoundly affected the mode of operation of the GPS (e.g., the organization of agricultural extension technology systems and the weakening function of organization smallholder farmers), thus changing the spatial resilience of the system [81]. In addition, the spatio-temporal evolution of the rural social organization system has affected the functions of other subsystems (e.g., the rural market system and the agricultural policy extension system) [82,83]. At present, the ability of smallholder farmers to cope with the current crisis is weakening, and the spatial resilience of the GPS is decreasing.

3.3. External Disturbance Factors of Spatial Resilience

The external disturbance factors of the system spatial resilience refer to the spatial environment around the system that influences the GPS, while also inducing a spatio-temporal evolution of the spatial environment as well as a spatial effect [70]. The transformation of the GPS and the change of the system spatial resilience are the epitome of social transformation. Therefore, all disturbances of the transformation of the social environment will also profoundly impact grain production.

The urbanization process is the most important external spatial environment of the GPS and profoundly affects its spatial resilience [7,84]. Firstly, urbanization poses an important problem for the spatio-temporal patterns of the component elements within the GPS, such as rural-urban population migration, changes of farmland use patterns, the urban-rural circulation of capital, and the extension of modern knowledge and technology [85]. Between 1990 and 2015, the urbanization rate of China has increased from 26.41% to 56.10% [11]. The urban-rural population living patterns have undergone fundamental changes that led to the urban population surpassing the rural population. Furthermore, 280 million migrants still remain in 2015, most of which migrate to the cities from the rural grain production departments finding hope for employment opportunities. As an important external disturbance factor to the GPS, urbanization has profoundly changed the pattern of grain production in China. In addition, the emergence of new forms of grain production (e.g., urban agriculture, leisure agriculture, and ecological agriculture) [86] and the changes of the food consumption structure (reduced cereal demand and increased meat consumption) affect the spatial resilience of the GPS during the process of urbanization [6,48].

The spatio-temporal evolution of the other spatial environments associated with the GPS and associated spatial effects also led to changes in system spatial resilience. Other departments of the agricultural system, such as the grain processing industry, the logistics system, and the retail industry affect the spatial resilience of the GPS. By developing both food processing and retail industry, smallholder farmers can easily access the food sources and reduce the proportion of self-sufficient grain production [14]. In addition, globalization and global environmental changes have also had an important impact on the spatial resilience of the GPS at different scales. Higher dependency on foreign grain products leads to the lower resilience of the domestic GPS [60]. Moreover, grain production is affected by climate change, and one-third of all fluctuations of global grain production can be attributed to climatic factors [61].

3.4. Cross-Scale Analysis of the Internal and External Disturbance Factors of Spatial Resilience

3.4.1. Cross-Scale Action of Internal and External Disturbance of Spatial Resilience

To reorganize the effects of internal and external disturbance factors on the GPS at cross spatio-temporal scales, we constructed a spatial resilience cross-scale disturbance model for the GPS based on three spatial scales and three temporal scales. Table 1 shows the effects of the utilized internal and external disturbance factors from a short time scale (weekly-monthly), a medium time scale (monthly-yearly), and a long time scale (yearly-decade), combined with three spatial scales (from local to global). These factors may not coexist within the same regions, and disturbances from different spatial and temporal scales do not remain fragmented, but communicate and interact with each other instead [48,87]. All factors that affect the spatial resilience of the GPS across the spatio-temporal scale include both the spatial response of the smallholders and the comprehensive response at the national or global scale, as well as ranging from a short time scale to a long time scale. The cross-scale linkage between internal and external disturbance factors provides the foundation for the further analysis of the spatial resilience of the GPS.

Table 1. Disturbance of internal and external systems of the GPS under cross spatio-temporal scale.

Temporal Scale / Spatial Scale	Short-Time (Weekly-Monthly)	Medium-Time (Monthly-Yearly)	Long-Time (Yearly-Decade)
Transnational and Global	▪ Food crisis and international emergency incident ▪ The short-term fluctuations of international futures market	▪ Global bulk commodity prices fluctuation ▪ Regional turmoil (e.g., the Middle East crisis) ▪ Structure changes of energy consumption (e.g., biomass energy requirements) [88] ▪ Global ecosystem crisis (e.g., tropical rain forest deforestation)	▪ Global food system changes ▪ Major breakthrough in biotechnology [89] ▪ Global cooperative organization operation ▪ Global climate changes ▪ Population and environmental crisis
Regional and National	▪ Disaster crisis of drought and flood ▪ The grain market policy ▪ Grain price changes	▪ National grain production policy (e.g., grain purchasing and storage policy) ▪ National ecological protection policy (e.g., Grain to Green, ecological fallow policy) ▪ Infrastructure improvement ▪ Agricultural subsidy policy changes	▪ Urban-rural structure transformation ▪ Demographic transition ▪ Food consumption structure changes [6] ▪ Industrial structure changes ▪ Agricultural industry policy changes
Smallholder and Local	▪ Crop variety selection ▪ The effect of short time weather changes ▪ Smallholder part-time farming [29] ▪ Rural community management ▪ Implementation effect of agricultural policy	▪ Changes of farmland use mode (e.g., dry land change to paddy) ▪ Land use right changes (e.g., land transfer) ▪ Family accident (e.g., fertility, death) ▪ Rural community management mode changes	▪ The quality of cultivated land ▪ Changes of smallholder family structure ▪ Agricultural science and technology application ▪ Changes of agricultural production model (e.g., organic agriculture, sustainable agriculture) [11] ▪ Changes of rural community agglomeration mode

3.4.2. Spatial Heterogeneity of Disturbance Factors

Spatial heterogeneity is the inherent attribute of a system and the spatial heterogeneity of the human society and the interaction between humans and the ecosystem are widely recognized [90]. Since the system scale effect is an important part of spatial resilience, it affects the internal structure and function of the system [91]. Therefore, the spatial heterogeneity of the GPS provides a central description and quantification of the disturbance of this system at cross spatio-temporal scales [69], and thus determines the change of spatial resilience. The spatial heterogeneity of the GPS mainly includes the heterogeneity of the behavior of the smallholder, the spatio-temporal evolution of the production mode and livelihood system of the smallholder [80], and the spatial differences of the operating mechanism of rural communities [2]. In addition, spatio-temporal differences of farmland quality and distribution, spatial heterogeneity pattern of the regional man-land interrelationship and grain production policy [92], and a different spatial feedback of system disturbance also profoundly impact spatial resilience [7]. The heterogeneity of regional natural location conditions and stages of socio-economic development are important factors that shape the regional spatial resilience of the GPS. A recent study has reported the existence of three significant coupling types between agricultural labor force change and grain production [72]. Regional and spatial heterogeneity are essential attributes of the system, while also profoundly impacting the spatial resilience of the GPS. Therefore, spatial heterogeneity significantly impacts both internal and external disturbance factors, and thus changes the spatial resilience of the system.

3.4.3. Connectivity of Disturbance Factors

The influences of internal and external disturbance factors as well as their cross-scale spatio-temporal processes on the spatial resilience of the system depend on their connectivity structure and intensity [93,94]. A high level of connectivity can promote recovery functions after disturbance and stimulate social transformation. The spatial adjacency effect, which forms the first law of geography [95], shows that both the interconnection and interaction of geospatial elements pose an important influence on the operation of a system. Under the cross-scale model, new research perspectives (e.g., space of flow) provide new methods for analysis of information and material connectivity [96].

The connectivity of the GPS should not only consider the connection between the internal elements of the system, but also the connectivity between internal and external system environments. The cross-scale migration of agricultural labor during urbanization is an important factor for connectivity change [11]. In addition, the improvement of the transport infrastructure further improves cross-scale connectivity. In the information age, network and the "space of flow" became powerful tools for increasing connectivity across spatio-temporal scales. Due to globalization, the connectivity and international trade between different countries are increasing [60]. In addition, the connectivity model between internal and external system environments have also undergone important changes: from regional to network [71], from single hierarchy to cross spatio-temporal, from substance to information, and from simple to complex.

During the process of urbanization, not all changes of connectivity are conducive to the improvement of the spatial resilience of the GPS. Under the improved connectivity of market and information, smallholder farmers will reduce the diversity of agricultural production to obtain more benefits by using more pesticides and chemical fertilizers. It is apparent that these actions will decrease the spatial resilience of the GPS [23]. At the same time, the weakening relationship between smallholder farmers and the social organization in the social governance system [97] (which reduce the social network connectivity) pose greater challenges to social stability and social governance. For example, both weakening and feminization of the grain-producing workforce is widespread. The cross-scale rural-urban migration of smallholders has led to a reduction of the internal connectivity of households and the connectivity among households. This transformation connectivity changed the livelihood system of smallholder and thus altered the spatial resilience of the GPS.

4. Optimization Strategy of Spatial Resilience for the GPS

4.1. The Hierarchical Structure of Spatial Resilience

The spatial heterogeneity and connectivity of the interaction between internal and external disturbances of the system create the multi-hierarchical spatial resilience structure of the GPS. The hierarchical structure of spatial resilience indicates that the spatial regulation policy should prioritize matching the system crisis. However, a mismatch between the spatial regulation policy and spatial resilience will weaken the resilience of the system [98]. The hierarchical structure of the spatial resilience corresponds with the division of the spatial scale, which forms the spatial-temporal evolution pattern of the three hierarchies of spatial resilience.

The spatial resilience of the smallholder scale is influenced by both the national scale and the global scale, and can thus reflect the change of the spatial resilience of the smallholder livelihood [99]. The spatial resilience at the national scale is influenced by the national system, which cannot separate between the local scale and the global scale. On this scale, the spatial resilience of both food security and economic development of the GPS can be concentrated. The resilience of the global scale relies on resilience changes in various countries, and therefore has a macro impact on the resilience of each country [100]. Consequently, it is necessary to find a reasonable hierarchy that corresponds to a change of the spatial resilience of the four dimensions functions in different regions, to better understand the change of the spatial resilience of the system as well as its underlying significance (Figure 6).

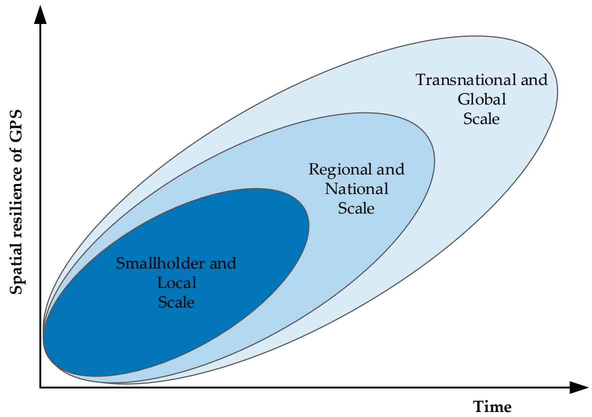

Figure 6. Hierarchical structure of spatial resilience. Source: Authors' design.

4.2. Key Thresholds of Spatial Resilience

By judging the system identity in the process of GPS transformation and by comprehensively judging the macroscopic background of the man-land interrelationship, agricultural labor force and land use become key elements of China's GPS, since they embody the cross-scale effect of the system disturbance factors and play a key role in the spatial resilience of the GPS [101]. Therefore, the transformation of the agricultural labor force and the land use transition, accompanied by spatio-temporal changes of their internal structure, become the key threshold of the space resilience of the GPS. The key threshold for the transformation of the agricultural labor force is the number and structural change of the agricultural labor force [63,102]. The "Lewis Turning Point", which explains the relationship between agricultural labor transformation and supply of agricultural products under the urban-rural dual structure [103], has also become a key threshold. Moreover, the transformation of the livelihood structure of smallholders, which is closely related to the functions of smallholder's livelihoods as well as food security dimension functions, naturally became a key threshold for system transformation [72].

Many people, little land, and lack in reserve resources, as well as other congenital conditions, determined the important position of land use transition in the spatial resilience of the GPS [12]. The land use transition, which is closely related to the transformation of the GPS, mainly involves the transition of both dominant and recessive morphologies of farmland [92], and the relationship between different types of land use. The amount of per capita farmland has become an important referencing index, directly reflecting the overall pattern of the "man-land relationship" at local and smallholder scale, and is also an important influencing factor of the spatial resilience of the GPS [1,2]. Under the background of rural-urban migration, the transition of the recessive morphology of farmland use (including the circulation proportion, the non-agricultural proportion, the non-grain proportion) has gradually been highlighted [104]. In addition, the relationships between farmland transition and other land use patterns (such as the relationship between forest transition and farmland transition) are key factors for the transformation of the system (Figure 7).

The transformation of the agricultural labor force and the transition of land use morphology provide an important reference threshold for GPS transformation. Since spatial heterogeneity and connectivity cause significant differences among internal and external disturbance factors, these key thresholds supply an important system of threshold indicators for both judgment and predictive research of system spatial resilience.

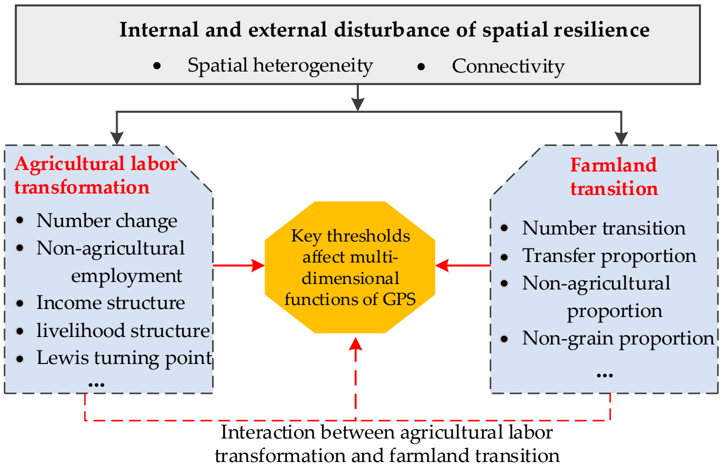

Figure 7. Key threshold of GPS transformation. Source: Authors' design.

4.3. Optimization Strategy of Spatial Resilience

Regulation of the spatial resilience of GPS is based on the system operating mechanism and optimizes the resilience capacity when the system is facing disturbances. The spatial resilience of the GPS has been derived from the cross-scale effect of internal and external disturbance factors, and spatial heterogeneity and connectivity influence the system spatial resilience at different temporal and spatial scales [69]. Direct results of spatial resilience have been embodied in the changes of the four dimensions function of the system; i.e., the livelihood and fairness of smallholders, food security and high-quality food products, stable urban-rural transformation, and a sustainable eco-environment. In light of the systemic crisis caused by disturbance, relevant stakeholders can influence both internal and external disturbance factors by optimizing their spatial feedback ability [92,105] and spatial adaptable ability of the system, to optimize the spatial resilience of the entire system.

Under the cross-scale effect of the disturbance factors, different stakeholders are also corresponding to different hierarchies; consequently, optimizing the system spatial resilience from matching hierarchical measures, may cause a multiplier effect. The optimization strategy of spatial resilience at both transnational and global scales, includes highlighting the cooperation of cross-border international organizations [106], building and promoting awareness of the global environmental crisis, and coping with the existing global framework for grain security cooperation [107]. The national scale is the main regulatory scope of spatial resilience. In light of the possible loss of function of the GPS, a grain production policy that guarantees both national food security and livelihood of the smallholder has been introduced [72]. To protect the resilience of the smallholder, as the most vulnerable part of the GPS, the commonly used peasant livelihood security measures system has been introduced, thus increasing the diversity of smallholder's livelihoods, strengthening the spatial and temporal connectivity [37], and avoiding the vicious circle of poverty [37].

Since different stakeholder hierarchies have different abilities to deal with system crisis, we should meet the requirements of different stakeholders via cross-scale community management. Community-based resource management has the effective ability to further collaboration among remote and local stakeholders at different scales [108]. The regulation of system spatial resilience at the smallholder scale critically depends on substantial coordination, supported by local and higher hierarchies, as well as continuously improving financial and administrative assistance [109]. Therefore, it is more important to establish a cross-scale common connectivity mechanism, which is effectively validating the resilience assessment in different regions [40,110].

It is possible to establish a cross-scale spatial connection mechanism according to the four dimensions functional system, and effectively realize the envisioned optimization goal of the spatial resilience via cross-scale structure. Figure 8 establishes a conceptual model for the regulation of the spatial resilience of the GPS with the goal of optimizing the functioning of the system. The model consists of three main parts, the upper part of cross-scale interaction of disturbances, the middle part of system functional change, and the lower part of the difference hierarchies interaction of different stakeholders. The upper part reflects the comprehensive impact of the internal and external disturbance for the spatial resilience of GPS, combining both spatial heterogeneity and connectivity of disturbance factors, which pose a comprehensive impact on spatial resilience and the function of different dimensions of the GPS. Regulating the food security dimensions spatial resilience, the internal connection needs to be established from the smallholder to the different hierarchies management, and different scales of stakeholders' connectivity need to be achieved via technical development, market control measures, and system control measures [4]. The regulations of the spatial resilience about smallholder livelihoods are difficult to rely on at smallholder scale. Therefore, to achieve self-improvement, we need to use the existing mature smallholder livelihood security system to integrate cross-scale protection [99]. The spatial resilience of the urban-rural transformation mainly relies on the improvement of the self-learning ability of stakeholders on different scales of the system, while constantly improving the regulation of market factors in the GPS. The control of spatial resilience of the eco-environment sustainability mainly depends on the awakening of the environmental consciousness when the system faces a significant crisis [53].

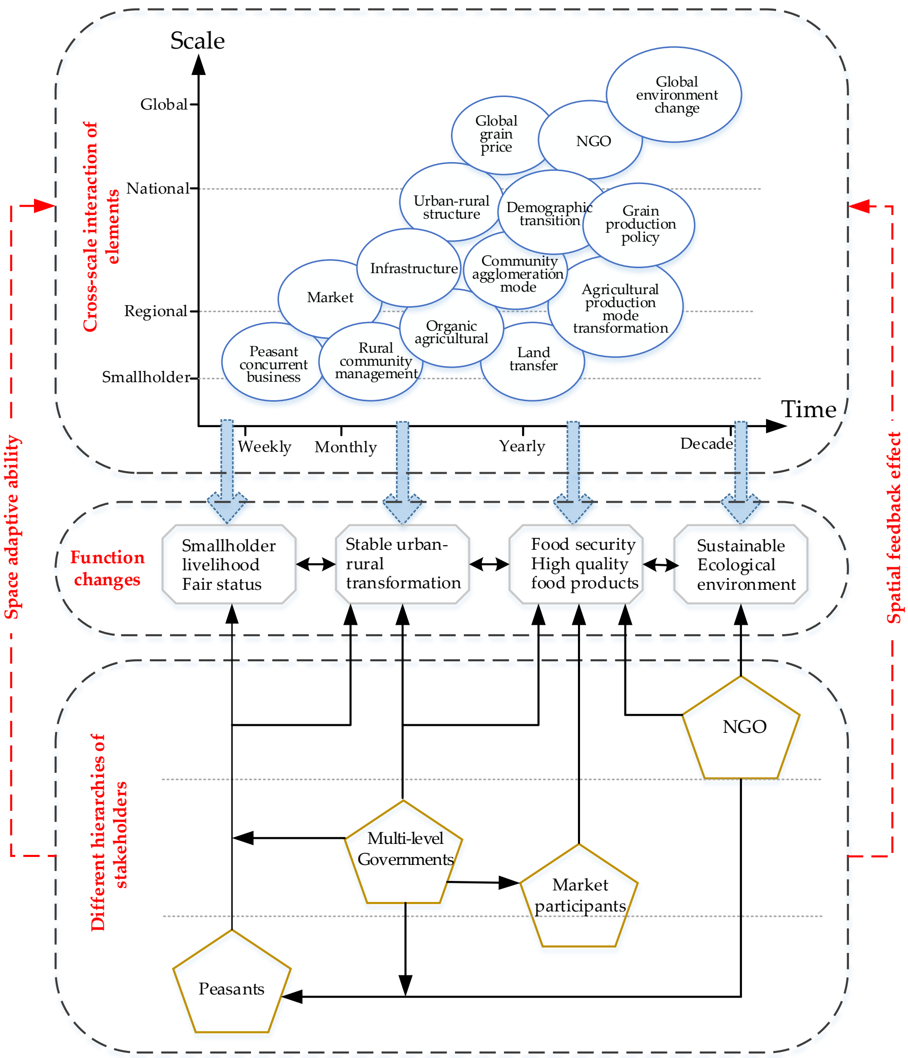

Figure 8. Schematic diagram of the spatial resilience optimization of the GPS. Source: Authors' design.

The lower part of the conceptual model mainly includes the optimization of the spatial resilience by different levels of cross-scale participation of stakeholders in the GPS. Different levels of stakeholders correspond to different system functions, such as the coordination of farmers' benefits on smallholder scale directly with the systematic functions of smallholder livelihood and fairness. Furthermore, different stakeholders have interacted with each other to jointly promote changes within system functions. Therefore, the spatial resilience optimization strategy of the four dimensions function systems is not isolated, and stakeholders at different hierarchies should coordinate in different functional dimensions. In addition, different hierarchical stakeholders influence the action mode and intensity of system disturbance factors through space application and feedback effects. In this way, the spatial resilience of the GPS optimization strategy formed an organic whole (Figure 8).

5. Discussion and Conclusions

5.1. Discussion

Under the dual influence of the socio-economic environment and the eco-environment, this paper constructs an analytical framework with the structure and function system of the GPS using the spatial resilience theory. Utilizing both internal and external disturbance factors with their spatial heterogeneity, we built a system of multi-hierarchy connectivity based on crossing the spatio-temporal scale. Aiming to achieve optimal regulation of spatial resilience of the GPS, the optimization strategy based on scale-matching effect and cross-scale connectivity effect has been discussed.

The spatial heterogeneity and connectivity of both internal and external disturbance factors of the GPS determine changes of spatial resilience; therefore, it is possible to effectively control the spatial resilience of the GPS by grasping the changing law of system disturbance factors. At the smallholder scale, effective organization enables smallholders to increase grain production [111]. Strengthening crop nutrition and water management will significantly increase crop yields [112]. Moreover, due to the scientific management of nitrogen fertilizer, grain production can reduce the nitrogen footprint [113]. The integration of organic agriculture and conservation agriculture into the modern GPS [114] can change the traditional mode of grain production [54] and promote a sustainable development of the eco-environment based on the premise of ensuring food security [42]. In response to global climate change, grain production activities urgently have to develop a "Second Green Revolution" represented by breeding technology [115]. The above specific measures show that the structure and functional framework of spatial resilience is useful for providing a top-hierarchy design, thus optimizing the GPS, and enhancing the spatial resilience of the GPS.

The economic, social, and ecological attributes of the GPS determine the optimization of spatial resilience to be closely related to the transformation of the entire society. At the same time, the influence of socio-economic factors (technological development, eco-environmental protection activities, living habits, and fairness awareness of peasants) in grain production continues to thrive. The direction of interaction between grain production and the eco-environment gradually focuses on the well-being of all mankind (especially smallholder farmers) and ecosystem services [47]. A continued "Green Revolution" is a technical prerequisite for ensuring a resilient grain production [89]. To prevent disastrous consequences of land grabbing on the livelihood of smallholder [116], the key thresholds in the process of agricultural labor force transformation, as well as land use transition, should be thoroughly studied, to effectively improve the early warning capacity of the GPS. In the process of urbanization, human diet and consumption habits have increased the burden to the GPS and the eco-environment. The high-calorie food demand system should be changed [117] and the introduction of a fine management of the food supply system, and an accompanied reduction of food waste has become an important part of the optimization of GPS resilience [8].

This study investigated the changes of grain production in China via systematic thinking, introduces the spatial resilience analysis tool to comprehensively research the resilience changes of complex systems, and constructs the spatial resilience analysis framework of GPS. The analytical framework effectively identified the internal and external disturbances that affect the GPS as well as their mechanism of action across the spatio-temporal scale. To cope with the crisis and to effectively optimize the space resilience of the GPS, this paper explores the importance of the coordination mechanism among multi-stakeholders. The optimization analytical framework of spatial resilience takes the function of GPS as the core objective and takes the multi-stakeholder spatial feedback effect and space adaptive capacity as important reference indexes. In summary, the cross-scale optimal regulation of the spatial resilience of the GPS provides an effective analytical tool to maintain structural order transition and ensure the overall function of the system. Although a framework for spatial resilience analysis of GPS has been proposed in this paper, few specific case studies on GPS transformation exist. In particular, putting forward specific proposals and optimization measures based on specific case studies will be the focus of the next step. Given the significant differences between China's regions, the operational mechanisms of spatial resilience of GPS are also different. Therefore, targeting different regions of China to optimize the spatial resilience of differentiated GPS will be an important trend for future research.

5.2. Conclusions

Under the background of both urban and rural transformation and the man-land interrelationship of China, this study analyzed multiple economic, social, and ecological attributes of the GPS, and constructed the functional and structural system via cross-scale analysis. To optimize the resilience from four functional dimensions of the GPS, to guarantee the regional food security system, to protect the livelihood of smallholders, to stabilize the urban-rural transformation, and to maintain a sustainable eco-environment, we built a cross spatial-temporal scales frame structure from a smallholder and local scale, as well as national and regional, and transnational and global scales. Based on an analysis of spatial heterogeneity and connectivity of internal and external disturbance factors (which influence the spatial resilience of the GPS), the spatial resilience of the GPS was constructed under the cross-scale interaction of disturbance factors. To guarantee the basic function of the GPS as the criterion, the spatial resilience optimization strategy has been discussed with cross-scale effect and under the coordination mechanism of multi-agent stakeholders.

This study provides a preliminary effort to optimize the spatial resilience of the GPS from different hierarchies, especially from the cross-scale influence of disturbance factors of the GPS. However, in light of the complex operating mechanism, we can only provide preliminary conclusions. The social organization and management system of the GPS for spatial resilience include an improving degree of socialization, effective participation of social capital, increasing the social learning ability, and improving community resilience, and will be our research focus in the future. With the global and Anthropocene vision [107], this will become an important opportunity for the transformation of the GPS by strengthening the study of climate change adaptation and resilience change toward a social-ecological system [118].

Acknowledgments: This work was supported by the Key Program of National Natural Science Foundation of China (Grant No. 41731286) and the BaGui Scholars Program of Guangxi Zhuang Autonomous Region.

Author Contributions: Dazhuan Ge, Hualou Long and Shuangshuang Tu designed the research and wrote the paper. Dazhuan Ge and Li Ma conducted the literature review on spatial resilience. Dazhuan Ge and Yingnan Zhang analyzed the World Bank dataset. All authors have read and approved the final manuscript.

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

References

1. Long, H.; Zou, J. Grain production driven by variations in farmland use in China: An analysis of security patterns. *J. Resour. Ecol.* **2010**, *1*, 60–67.
2. Li, T.; Long, H.; Zhang, Y.; Tu, S.; Ge, D.; Li, Y.; Hu, B. Analysis of the spatial mismatch of grain production and farmland resources in China based on the potential crop rotation system. *Land Use Policy* **2017**, *60*, 26–36. [CrossRef]

3. World Bank. World Bank Open Data. Available online: https://data.worldbank.org.cn (accessed on 10 September 2017).
4. Huang, J.; Yang, G. Understanding recent challenges and new food policy in China. *Glob. Food Secur.* **2017**, *12*, 119–126. [CrossRef]
5. Wang, D.; Jiang, H. The implications on food security of china based on the reform of agricultural supply side structure. *Economist* **2017**. (In Chinese) [CrossRef]
6. Seto, K.C.; Ramankutty, N. Hidden linkages between urbanization and food systems. *Science* **2016**, *352*, 943–945. [CrossRef] [PubMed]
7. Liu, Y.; Li, Y. Revitalize the world's countryside. *Nature* **2017**, *548*, 275–277. [CrossRef] [PubMed]
8. Xue, L.; Liu, G.; Parfitt, J.; Liu, X.; Van Herpen, E.; Stenmarck, A.; O'Connor, C.; Östergren, K.; Cheng, S. Missing food, missing data? A critical review of global food losses and food waste data. *Environ. Sci. Technol.* **2017**, *51*, 6618–6633. [CrossRef] [PubMed]
9. Buzby, J.C.; Hyman, J. Total and per capita value of food loss in the United States. *Food Policy* **2012**, *37*, 561–570. [CrossRef]
10. Lu, W.; Chen, N.; Qian, W. Modeling the effects of urbanization on grain production and consumption in China. *J. Integr. Agric.* **2017**, *16*, 1393–1405. [CrossRef]
11. Long, H.; Tu, S.; Ge, D.; Li, T.; Liu, Y. The allocation and management of critical resources in rural China under restructuring: Problems and prospects. *J. Rural Stud.* **2016**, *47*, 392–412. [CrossRef]
12. Ge, D.; Long, H.; Zhang, Y.; Ma, L.; Li, T. Farmland transition and its influences on grain production in China. *Land Use Policy* **2018**, *70*, 94–105. [CrossRef]
13. Xiao, Y.; Wu, X.; Wang, L.; Liang, J. Optimal farmland conversion in China under double restraints of economic growth and resource protection. *J. Clean Prod.* **2017**, *142*, 524–537. [CrossRef]
14. Holdaway, J. *Urbanisation, Rural Transformations and Food Security: The View from China*; International Institute for Environment and Development: London, UK, 2015.
15. Gao, F. International experience to improve agricultural productivity and china's choice. *FuDan J.* **2015**, *57*, 116–124. (In Chinese)
16. Stehle, S.; Schulz, R. Agricultural insecticides threaten surface waters at the global scale. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 5750–5755. [CrossRef] [PubMed]
17. Zhang, J. China's success in increasing per capita food production. *J. Exp. Bot.* **2011**, *62*, 3707–3711. [CrossRef] [PubMed]
18. West, P.C.; Gerber, J.S.; Engstrom, P.M.; Mueller, N.D.; Brauman, K.A.; Carlson, K.M.; Cassidy, E.S.; Johnston, M.; MacDonald, G.K.; Ray, D.K. Leverage points for improving global food security and the environment. *Science* **2014**, *345*, 325–328. [CrossRef] [PubMed]
19. Chen, X.; Cui, Z.; Fan, M.; Vitousek, P.; Zhao, M.; Ma, W.; Wang, Z.; Zhang, W.; Yan, X.; Yang, J.; et al. Producing more grain with lower environmental costs. *Nature* **2014**, *514*, 486–489. [CrossRef] [PubMed]
20. Zhang, D.; Shen, J.; Zhang, F.; Li, Y.; Zhang, W. Carbon footprint of grain production in China. *Sci. Rep.* **2017**, *7*, 4126. [CrossRef] [PubMed]
21. Gu, B.; Leach, A.M.; Ma, L.; Galloway, J.N.; Chang, S.X.; Ge, Y.; Chang, J. Nitrogen footprint in China: Food, energy, and nonfood goods. *Environ. Sci. Technol.* **2013**, *47*, 9217–9224. [CrossRef] [PubMed]
22. Grassini, P.; Cassman, K.G. High-yield maize with large net energy yield and small global warming intensity. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 1074–1079. [CrossRef] [PubMed]
23. Guo, J.H.; Liu, X.J.; Zhang, Y.; Shen, J.L.; Han, W.X.; Zhang, W.F.; Christie, P.; Goulding, K.W.; Vitousek, P.M.; Zhang, F.S. Significant acidification in major Chinese croplands. *Science* **2010**, *327*, 1008–1010. [CrossRef] [PubMed]
24. Liu, Y.; Wen, C.; Liu, X. China's food security soiled by contamination. *Science* **2013**, *339*, 1382–1383. [CrossRef] [PubMed]
25. Kong, X.; Zhang, X.; Lal, R.; Zhang, F.; Chen, X.; Niu, Z.; Han, L.; Song, W. Groundwater depletion by agricultural intensification in China's HHH Plains, since the 1980s. *Adv. Agron.* **2016**, *135*, 59–106.
26. Xie, Y.; Zhou, X. Income inequality in today's China. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 6928–6933. [CrossRef] [PubMed]
27. Tu, S.; Long, H. Rural restructuring in China: Theory, approaches and research prospect. *J. Geogr. Sci.* **2017**, *27*, 1169–1184. [CrossRef]

28. Geertz, C. *Agricultural Involution: The Process of Ecological Change in Indonesia*; University of California Press: Berkeley, CA, USA, 1963.
29. Zhang, Y.; Li, X.; Song, W.; Zhai, L. Land abandonment under rural restructuring in China explained from a cost-benefit perspective. *J. Rural Stud.* **2016**, *47*, 524–532. [CrossRef]
30. Wang, X.; Huang, J.; Rozelle, S. Off-farm employment and agricultural specialization in China. *China Econ. Rev.* **2016**, *42*, 155–165. [CrossRef]
31. Siciliano, G. Rural-urban migration and domestic land grabbing in china. *Popul. Space Place* **2014**, *20*, 333–351. [CrossRef]
32. Zhan, S. Hukou reform and land politics in China: Rise of a tripartite alliance. *China J.* **2017**, *78*. [CrossRef]
33. van der Ploeg, J.D. Peasant-driven agricultural growth and food sovereignty. *J. Peasant Stud.* **2014**, *41*, 999–1030. [CrossRef]
34. Ye, J. Land transfer and the pursuit of agricultural modernization in China. *J. Agrar. Chang.* **2015**, *15*, 314–337. [CrossRef]
35. Folke, C. Resilience (Republished). *Ecol. Soc.* **2016**, *21*, 44. [CrossRef]
36. Hughes, T.P.; Barnes, M.L.; Bellwood, D.R.; Cinner, J.E.; Cumming, G.S.; Jackson, J.B.C.; Kleypas, J.; van de Leemput, I.A.; Lough, J.M.; Morrison, T.H.; et al. Coral reefs in the Anthropocene. *Nature* **2017**, *546*, 82–90. [CrossRef] [PubMed]
37. Barrett, C.B.; Constas, M.A. Toward a theory of resilience for international development applications. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 14625–14630. [CrossRef] [PubMed]
38. Béné, C.; Chowdhury, F.S.; Rashid, M.; Dhali, S.A.; Jahan, F. Squaring the circle: Reconciling the need for rigor with the reality on the ground in resilience impact assessment. *World Dev.* **2017**, *97*, 212–231. [CrossRef]
39. Bullock, J.M.; Dhanjal-Adams, K.L.; Milne, A.; Oliver, T.H.; Todman, L.C.; Whitmore, A.P.; Pywell, R.F.; Bardgett, R. Resilience and food security: Rethinking an ecological concept. *J. Ecol.* **2017**, *105*, 880–884. [CrossRef]
40. Tendall, D.M.; Joerin, J.; Kopainsky, B.; Edwards, P.; Shreck, A.; Le, Q.B.; Kruetli, P.; Grant, M.; Six, J. Food system resilience: Defining the concept. *Glob. Food Secur.* **2015**, *6*, 17–23. [CrossRef]
41. Pelletier, B.; Hickey, G.M.; Bothi, K.L.; Mude, A. Linking rural livelihood resilience and food security: An international challenge. *Food Secur.* **2016**, *8*, 469–476. [CrossRef]
42. Lu, Y.; Jenkins, A.; Ferrier, R.C.; Bailey, M.; Gordon, I.J.; Song, S.; Huang, J.; Jia, S.; Zhang, F.; Liu, X. Addressing China's grand challenge of achieving food security while ensuring environmental sustainability. *Sci. Adv.* **2015**, *1*, e1400039. [CrossRef] [PubMed]
43. Pinstrup-Andersen, P. Food security: Definition and measurement. *Food Secur.* **2009**, *1*, 5–7. [CrossRef]
44. Tian, Q.; Holland, J.H.; Brown, D.G. Social and economic impacts of subsidy policies on rural development in the Poyang Lake Region, China: Insights from an agent-based model. *Agric. Syst.* **2016**, *148*, 12–27. [CrossRef]
45. Schneider, U.A.; Havlík, P.; Schmid, E.; Valin, H.; Mosnier, A.; Obersteiner, M.; Böttcher, H.; Skalský, R.; Balkovič, J.; Sauer, T.; et al. Impacts of population growth, economic development, and technical change on global food production and consumption. *Agric. Syst.* **2011**, *104*, 204–215. [CrossRef]
46. Wang, C.; Zhang, Y.; Yang, Y.; Yang, Q.; Kush, J.; Xu, Y.; Xu, L. Assessment of sustainable livelihoods of different farmers in hilly red soil erosion areas of southern China. *Ecol. Indic.* **2016**, *64*, 123–131. [CrossRef]
47. Bennett, E.M. Changing the agriculture and environment conversation. *Nat. Ecol. Evol.* **2017**, *1*, 0018. [CrossRef] [PubMed]
48. Cumming, G.S.; Buerkert, A.; Hoffmann, E.M.; Schlecht, E.; von Cramon-Taubadel, S.; Tscharntke, T. Implications of agricultural transitions and urbanization for ecosystem services. *Nature* **2014**, *515*, 50–57. [CrossRef] [PubMed]
49. Zheng, L.; Liu, H. Increased farmer income evidenced by a new multifunctional actor network in China. *Agron. Sustain. Dev.* **2013**, *34*, 515–523. [CrossRef]
50. Li, T.; Long, H.; Tu, S.; Wang, Y. Analysis of income inequality based on income mobility for poverty alleviation in rural China. *Sustainability* **2015**, *7*, 16362–16378. [CrossRef]
51. Barrett, C.B.; Reardon, T.; Webb, P. Nonfarm income diversification and household livelihood strategies in rural Africa: Concepts, dynamics, and policy implications. *Food Policy* **2001**, *26*, 315–331. [CrossRef]
52. Lewis, W.A. Economic development with unlimited supplies of labour. *Manchester Sch.* **1954**, *22*, 139–191. [CrossRef]

53. Foley, J. Living by the lessons of the planet. *Science* **2017**, *356*, 251–252. [CrossRef] [PubMed]
54. Seufert, V.; Ramankutty, N.; Foley, J.A. Comparing the yields of organic and conventional agriculture. *Nature* **2012**, *485*, 229–232. [CrossRef] [PubMed]
55. Smith, A.; Snapp, S.; Chikowo, R.; Thorne, P.; Bekunda, M.; Glover, J. Measuring sustainable intensification in smallholder agroecosystems: A review. *Glob. Food Secur.* **2017**, *12*, 127–138. [CrossRef]
56. Ebbesson, J. The rule of law in governance of complex socio-ecological changes. *Glob. Environ. Chang.* **2010**, *20*, 414–422. [CrossRef]
57. Duru, M.; Therond, O. Livestock system sustainability and resilience in intensive production zones: which form of ecological modernization? *Reg. Envir. Chang.* **2014**, *15*, 1651–1665. [CrossRef]
58. Darnhofer, I.; Bellon, S.; Dedieu, B.; Milestad, R. Adaptiveness to enhance the sustainability of farming systems. A review. *Agron. Sustain. Dev.* **2010**, *30*, 545–555. [CrossRef]
59. Huang, J.; Wang, X.; Rozelle, S. The subsidization of farming households in China's agriculture. *Food Policy* **2013**, *41*, 124–132. [CrossRef]
60. Suweis, S.; Carr, J.A.; Maritan, A.; Rinaldo, A.; D'Odorico, P. Resilience and reactivity of global food security. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 6902–6907. [CrossRef] [PubMed]
61. Ray, D.K.; Gerber, J.S.; MacDonald, G.K.; West, P.C. Climate variation explains a third of global crop yield variability. *Nat. Commun.* **2015**, *6*, 5989. [CrossRef] [PubMed]
62. Morton, J.F. The impact of climate change on smallholder and subsistence agriculture. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 19680–19685. [CrossRef] [PubMed]
63. Li, L.; Wang, C.; Segarra, E.; Nan, Z. Migration, remittances, and agricultural productivity in small farming systems in Northwest China. *China Agric. Econ. Rev.* **2013**, *5*, 5–23. [CrossRef]
64. Lu, B.R. Challenges of transgenic crop commercialization in China. *Nat. Plants* **2016**, *2*, 16077. [CrossRef] [PubMed]
65. Yang, J.; Huang, J.; Rozelle, S.; Martin, W. Where is the balance? Implications of adopting special products and sensitive products in Doha negotiations for world and China's agriculture. *China Econ. Rev.* **2012**, *23*, 651–664. [CrossRef]
66. Frantzeskaki, N.; Haase, D.; Fragkias, M.; Elmqvist, T. Editorial overview: System dynamics and sustainability: Urban transitions to sustainability and resilience. *Curr. Opin. Environ. Sustain.* **2016**, *22*. [CrossRef]
67. Bodin, Ö.; Crona, B.I. The role of social networks in natural resource governance: What relational patterns make a difference? *Glob. Environ. Chang.* **2009**, *19*, 366–374. [CrossRef]
68. Gurney, G.G.; Blythe, J.; Adams, H.; Adger, W.N.; Curnock, M.; Faulkner, L.; James, T.; Marshall, N.A. Redefining community based on place attachment in a connected world. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 10077–10082. [CrossRef] [PubMed]
69. Cumming, G.S.; Morrison, T.H.; Hughes, T.P. New directions for understanding the spatial resilience of social-ecological systems. *Ecosystems* **2016**, *20*, 649–664. [CrossRef]
70. Cumming, G.S. *Spatial Resilience in Social-Ecological Systems*; Springer: Cape Town, South Africa, 2011.
71. Cumming, G.S. Heterarchies: Reconciling Networks and Hierarchies. *Trends Ecol. Evol.* **2016**, *31*, 622–632. [CrossRef] [PubMed]
72. Ge, D.; Long, H.; Zhang, Y.; Tu, S. Analysis of the coupled relationship between grain yields and agricultural labor changes in China. *J. Geogr. Sci.* **2018**, *28*, 93–108.
73. Liu, J.; Zhang, Z.; Xu, X.; Kuang, W.; Zhou, W.; Zhang, S.; Li, R.; Yan, C.; Yu, D.; Wu, S.; et al. Spatial patterns and driving forces of land use change in China during the early 21st century. *J. Geogr. Sci.* **2010**, *20*, 483–494. [CrossRef]
74. Song, W.; Han, Z.; Deng, X. Changes in productivity, efficiency and technology of China's crop production under rural restructuring. *J. Rural Stud.* **2016**, *47*, 563–576. [CrossRef]
75. Zhan, S. Riding on self-sufficiency: Grain policy and the rise of agrarian capital in China. *J. Rural Stud.* **2017**, *54*, 151–161. [CrossRef]
76. Zhang, Q.; Sun, Z.; Wu, F.; Deng, X. Understanding rural restructuring in China: The impact of changes in labor and capital productivity on domestic agricultural production and trade. *J. Rural Stud.* **2016**, *47*, 552–562. [CrossRef]
77. Lipton, M. Migration from rural areas of poor countries: the impact on rural productivity and income distribution. *World Devel.* **1980**, *8*, 1–24. [CrossRef]

78. Huang, J.; Pontius, R.G.; Li, Q.; Zhang, Y. Use of intensity analysis to link patterns with processes of land change from 1986 to 2007 in a coastal watershed of southeast China. *Appl. Geogr.* **2012**, *34*, 371–384. [CrossRef]
79. Kwan, F.; Wu, Y.; Zhuo, S. Surplus agricultural labour and China's Lewis turning point. *China Econ. Rev.* **2017**. [CrossRef]
80. van der Ploeg, J.D.; Ye, J.; Pan, L. Peasants, time and the land: The social organization of farming in China. *J. Rural Stud.* **2014**, *36*, 172–181. [CrossRef]
81. Ye, J.; He, C.; Liu, J.; Wang, W.; Chen, S. Left-behind elderly: Shouldering a disproportionate share of production and reproduction in supporting China's industrial development. *J. Peasant Stud.* **2016**. [CrossRef]
82. Chen, X. Review of China's agricultural and rural development: policy changes and current issues. *China Agric. Econ. Rev.* **2009**, *1*, 121–135. [CrossRef]
83. Ge, S.; Yang, D.T. Labor market developments in China: A neoclassical view. *China Econ. Rev.* **2011**, *22*, 611–625. [CrossRef]
84. Bai, X.; Shi, P.; Liu, Y. Realizing China's urban dream. *Nature* **2014**, *509*, 158–160. [CrossRef] [PubMed]
85. Proctor, F.J.; Berdegué, J.A. *Food Systems at the Rural-Urban Interface*; Rimisp: Santiago, Chile, 2016.
86. Su, S.; Xiao, R.; Zhang, Y. Multi-scale analysis of spatially varying relationships between agricultural landscape patterns and urbanization using geographically weighted regression. *Appl. Geogr.* **2012**, *32*, 360–375. [CrossRef]
87. Nyström, M.; Folke, C. Spatial Resilience of Coral Reefs. *Ecosystems* **2001**, *4*, 406–417. [CrossRef]
88. Huang, J.; Yang, J.; Msangi, S.; Rozelle, S.; Weersink, A. Biofuels and the poor: Global impact pathways of biofuels on agricultural markets. *Food Policy* **2012**, *37*, 439–451. [CrossRef]
89. Flavell, R.B. Greener revolutions for all. *Nat. Biotechnol.* **2016**, *34*, 1106–1110. [CrossRef] [PubMed]
90. Turner, B.L., II. Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? *Glob. Environ. Chang.* **2010**, *20*, 570–576. [CrossRef]
91. Redo, D.J.; Grau, H.R.; Aide, T.M.; Clark, M.L. Asymmetric forest transition driven by the interaction of socioeconomic development and environmental heterogeneity in Central America. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 8839–8844. [CrossRef] [PubMed]
92. Long, H.; Qu, Y. Land use transitions and land management: A mutual feedback perspective. *Land Use Policy* **2017**, doi:10.1016/j.landusepol.2017.03.021.
93. Cinner, J.E.; McClanahan, T.R.; MacNeil, M.A.; Graham, N.A.; Daw, T.M.; Mukminin, A.; Feary, D.A.; Rabearisoa, A.L.; Wamukota, A.; Jiddawi, N.; et al. Comanagement of coral reef social-ecological systems. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 5219–5222. [CrossRef] [PubMed]
94. Barnes, A.; Nel, V. Putting spatial resilience into practice. *Urban Forum* **2017**, *28*, 219–232. [CrossRef]
95. Miller, H.J. Tobler's first law and spatial analysis. *Ann. Assoc. Am. Geogr.* **2004**, *94*, 284–289. [CrossRef]
96. Castells, M. Space of flows, space of places: Materials for a theory of urbanism in the information age. In *The Cybercities Reader*; Graham, S., Ed.; Routledge: London, UK, 2004; pp. 572–582.
97. Hu, Z.; Zhang, Q.F.; Donaldson, J.A. Farmers' cooperatives in China: A typology of fraud and failure. *China J.* **2017**, *78*, 1–24. [CrossRef]
98. Cumming, G.S.; Olsson, P.; Chapin, F.S.; Holling, C.S. Resilience, experimentation, and scale mismatches in social-ecological landscapes. *Land. Ecol.* **2012**, *28*, 1139–1150. [CrossRef]
99. Oberlack, C.; Tejada, L.; Messerli, P.; Rist, S.; Giger, M. Sustainable livelihoods in the global land rush? Archetypes of livelihood vulnerability and sustainability potentials. *Glob. Environ. Chang.* **2016**, *41*, 153–171. [CrossRef]
100. Clark, W.C.; Tomich, T.P.; van Noordwijk, M.; Guston, D.; Catacutan, D.; Dickson, N.M.; McNie, E. Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR). *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 4615–4622. [CrossRef] [PubMed]
101. Foley, J.A.; Ramankutty, N.; Brauman, K.A.; Cassidy, E.S.; Gerber, J.S.; Johnston, M.; Mueller, N.D.; O'Connell, C.; Ray, D.K.; West, P.C.; et al. Solutions for a cultivated planet. *Nature* **2011**, *478*, 337–342. [CrossRef] [PubMed]
102. Rozelle, S.; Taylor, J.E.; deBrauw, A. Migration, remittances, and agricultural productivity in China. *Am. Econ. Rev.* **1999**, *89*, 287–291. [CrossRef]
103. Cai, F. Demographic transition, demographic dividend, and Lewis turning point in China. *China Econ. J.* **2010**, *3*, 107–119. [CrossRef]

104. Shi, T.; Li, X.; Xin, L.; Xu, X. Analysis of Farmland Abandonment at Parcel Level: A Case Study in the Mountainous Area of China. *Sustainability* **2016**, *8*, 988. [CrossRef]
105. Lambin, E.F.; Meyfroidt, P. Land use transitions: Socio-ecological feedback versus socio-economic change. *Land Use Policy* **2010**, *27*, 108–118. [CrossRef]
106. Hughes, T.P.; Kerry, J.T.; Alvarez-Noriega, M.; Alvarez-Romero, J.G.; Anderson, K.D.; Baird, A.H.; Babcock, R.C.; Beger, M.; Bellwood, D.R.; Berkelmans, R.; et al. Global warming and recurrent mass bleaching of corals. *Nature* **2017**, *543*, 373–377. [CrossRef] [PubMed]
107. Brondizio, E.S.; O'Brien, K.; Bai, X.; Biermann, F.; Steffen, W.; Berkhout, F.; Cudennec, C.; Lemos, M.C.; Wolfe, A.; Palma-Oliveira, J.; et al. Re-conceptualizing the Anthropocene: A call for collaboration. *Glob. Environ. Chang.* **2016**, *39*, 318–327. [CrossRef]
108. Damastuti, E.; de Groot, R. Effectiveness of community-based mangrove management for sustainable resource use and livelihood support: A case study of four villages in Central Java, Indonesia. *J. Environ. Manag.* **2017**, *203*, 510–521. [CrossRef] [PubMed]
109. Bell, J.; Morrison, T. A comparative analysis of the transformation of governance systems: Land-use planning for flood risk. *J. Environ. Policy Plan.* **2014**, *17*, 516–534. [CrossRef]
110. Lindborg, R.; Gordon, L.J.; Malinga, R.; Bengtsson, J.; Peterson, G.; Bommarco, R.; Deutsch, L.; Gren, Å.; Rundlöf, M.; Smith, H.G. How spatial scale shapes the generation and management of multiple ecosystem services. *Ecosphere* **2017**, *8*, e01741. [CrossRef]
111. Zhang, W.; Cao, G.; Li, X.; Zhang, H.; Wang, C.; Liu, Q.; Chen, X.; Cui, Z.; Shen, J.; Jiang, R. Closing yield gaps in China by empowering smallholder farmers. *Nature* **2016**, *537*, 671–674. [CrossRef] [PubMed]
112. Mueller, N.D.; Gerber, J.S.; Johnston, M.; Ray, D.K.; Ramankutty, N.; Foley, J.A. Closing yield gaps through nutrient and water management. *Nature* **2012**, *490*, 254–257. [CrossRef] [PubMed]
113. Zhang, X.; Davidson, E.A.; Mauzerall, D.L.; Searchinger, T.D.; Dumas, P.; Shen, Y. Managing nitrogen for sustainable development. *Nature* **2015**, *528*, 51–59. [CrossRef] [PubMed]
114. Pittelkow, C.M.; Liang, X.; Linquist, B.A.; Van Groenigen, K.J.; Lee, J.; Lundy, M.E.; van Gestel, N.; Six, J.; Venterea, R.T.; van Kessel, C. Productivity limits and potentials of the principles of conservation agriculture. *Nature* **2015**, *517*, 365–368. [CrossRef] [PubMed]
115. Challinor, A.J.; Koehler, A.K.; Ramirez-Villegas, J.; Whitfield, S.; Das, B. Current warming will reduce yields unless maize breeding and seed systems adapt immediately. *Nat. Clim. Chang.* **2016**, *6*, 954–958. [CrossRef]
116. Edelman, M.; Oya, C.; Borras, S.M. Global Land Grabs: Historical processes, theoretical and methodological implications and current trajectories. *Third World Q.* **2013**, *34*, 1517–1531. [CrossRef]
117. Ingram, J. Perspective: Look beyond production. *Nature* **2017**, *544*. [CrossRef] [PubMed]
118. Davidson, D. Gaps in agricultural climate adaptation research. *Nat. Clim. Chang.* **2016**, *6*, 433–435. [CrossRef]