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Interrelations of Ecosystem Services and Rural Population Wellbeing in an Ecologically-Fragile Area in North China

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Abstract: Ecosystem services (ES) are indispensable contributors to rural population wellbeing (RPWB). Understanding the relationship between ES and RPWB is important to human welfare and conserving ecosystem services. Ecologically-vulnerable areas are widely distributed in China and are concentrated with impoverished people. This study explored the relations of ES and RPWB in an ecologically-fragile area, and provided some recommendations for regional improvement. We developed an evaluation framework, analyzed the spatio-temporal characteristics of services and RPWB, and examined their relations. Results showed that: (1) the level of RPWB in an ecologically-vulnerable area was lower than that in the downstream region; however, the wellbeing gap between regions has narrowed over time; (2) Regions with a higher ecosystem service capacity had higher levels of rural population wellbeing, and vice versa; (3) In addition to the food supply, other ES indicators were closely associated with RPWB in the region. Specifically, the net income and living space were closely related to food supply, while rural-urban income ratio and water environment were more relevant to the other services. Lastly, it is important to address environment and poverty issues simultaneously.

Keywords: ecological fragile areas; ecosystem service; rural population wellbeing

1. Introduction

Exploring the relations between human wellbeing and ecosystem services (ES) is one of the research hotspots in ecology and relevant disciplines. The consumption of ES enables the fulfillment and improvement of human welfare [1]. Although activities promoting human welfare have influenced ecosystem processes and the regeneration capacity of ES sometimes, a relevant feedback processing occurs between them [2,3]. ES contributes to human wellbeing under the influence of anthropogenic activities, and there are complex interrelationships among them. In order to achieve sustainable and harmonious development of the environment and human wellbeing, it is necessary to determine the linkages between ES and human wellbeing.

An ecologically-fragile area (EFA) has the following characteristics: lack of ecosystem stability, inferior ability to survive and maintain homeostasis from interference, prone to ecosystem degradation, and difficult spontaneous recovery. Compared with a single ecosystem, EFAs are more complicated systems, typically located within various ecotones, marginal zones, and connective band regions. Furthermore, EFAs are natural resource-rich, sensitive, and unstable areas with weak anti-disturbance abilities [4]. Thus, EFAs are usually not suitable for living and production, and people who live in EFAs

are always economically disadvantaged [5,6]. Many EFAs, which are in the vicious circle of ecological degradation and poverty, are in the intersectional region of environmental protection and poverty alleviation. Most areas in Western China are EFAs [7]. In recent years, this region has experienced rapid desertification and ecological environment deterioration, which brought harm and loss to local production and living. Understanding the linkages between ES and human wellbeing is essential for policy-makers to balance human demands and the environment.

We selected the northern farming-pastoral region and its downstream region in Northern China as our research area. The Khorchin sandy land, which is a tropical grassland degeneration zone with a fragile ecological environment, is an EFA, where living conditions need to be improved. This northern farming-pastoral area is a crucial barrier that resists the eastward and southward land desertification, and plays an irreplaceable role in safeguarding ecological security and social, as well as economic, stability of the district. Thus, it is important to take measures for ecological protection and livelihood promotion in this region.

In this study, we evaluated the RPWB and key ecosystem services in 2002–2012, and described their spatial distribution and changes over time. Then we conducted spearman correlation analysis between wellbeing and ES in 16 administrative regions in our study area, to discuss the relationship between ES factors and RPWB, especially in the ecologically fragile areas, thus to provide some theoretical support for the regional wellbeing and environmental improvement.

2. Interactions of Ecosystem Services and Human Wellbeing

2.1. Human Wellbeing

Human wellbeing is a broad concept which involves anthropology, psychology, economics, sociology, and other disciplines [8,9]. Many scholars and research institutions conducted human wellbeing studies through the establishment of indicators and hierarchical division of human wellbeing. For example, the Human Development Report [10] selected lifetime, knowledge, and capacity of access to basic resources into its human welfare measurement index. Cummins et al. [11] considered that human wellbeing comprised seven key domains, including the satisfaction of living standard, health, achievement, interpersonal relationship, sense of security, community links, and safety in the future. Clark [12] established an integrated wellbeing concept by overlapping the utility and living quality based on resource demand.

The broadest and most systematic theories of human wellbeing are Sen's Capability Approach and Millennium Ecosystem Assessment (MA). The Capability Approach focuses directly on the quality of life which is measured by the 'functioning' and 'capability', where in the capability represents the effective freedom of an individual to choose between different functioning combinations, that is, between different kinds of life [13]. According to MA, human wellbeing is defined in five dimensions, that is, the ability to maintain a high quality of life, health, good social relationships, security, freedom, and choice; the connotation of the five dimensions is a progressive cascade [14] (Figure 1).

The concept of human wellbeing is divided into subjective and objective wellbeing [15]. The objective wellbeing refers to the satisfaction degree of various kinds of demands [16,17], whereas the subjective wellbeing emphasizes individual assessment of self-condition, ideas, and feelings [2,18,19].

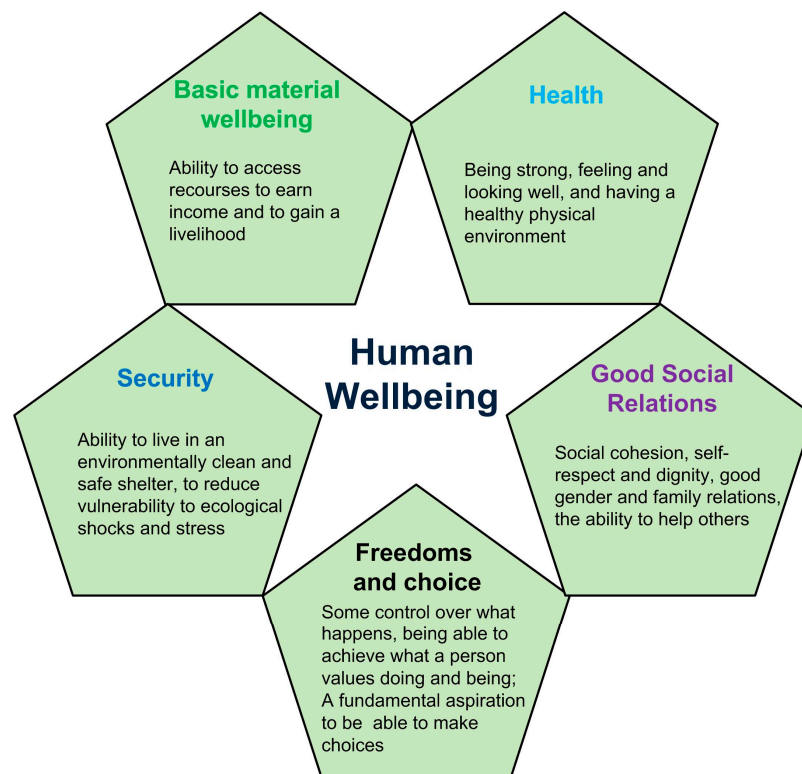


Figure 1. Connotation of human wellbeing [14].

Except for the aggregative indicator methods, such as the gross national product (GNP), United Nations Human Development Index (HDI) [20], quality-of-life index [21], human welfare index [22,23], and the survey-based subjective index [24], most of the current wellbeing evaluation studies use the hierarchical classification of MA. In practice, the five dimensions of wellbeing are simplified, some researches even choose the objective part of wellbeing for evaluation. For example, the index system of Yang et al. includes the income, material conditions for good life, health, security, and good social relations [25].

2.2. Ecosystem Services and Human Wellbeing

Ecosystem service (ES) refers to the quantity and quality of services that are provided by the ecosystem processes in a particular time range [14,26–28]. It includes provisioning services, regulating services, cultural services, and supporting services, which are indispensable for human wellbeing; and changes of ecosystem directly or indirectly impact human wellbeing.

Human wellbeing affected by the ecosystem accounts for only a subset of wellbeing; however, it is definitely a significant contribution to human wellbeing [29].

The change of ES could directly or indirectly influence each elements of human wellbeing. Owing to the feedback effect from various human activities, the negative and positive feedbacks directly or indirectly influence ES [30].

3. Materials and Methods

3.1. Study Region

Our research area comprised the grassland and desert-dominated regions in the northwest district, which is an EFA of the ecotone of agriculture-animal husbandry, and the cropland and woodland-dominated regions in the southeast. The region is in the Liao River Basin, and covers the major river systems in this basin. The northwest and southeast districts belong to the upstream and

downstream regions, respectively. The whole area is $25.68 \times 10^4 \text{ km}^2$ (Figure 2). The indices were calculated in 16 regions, and these sub-regions are the basic administrative units in the region.

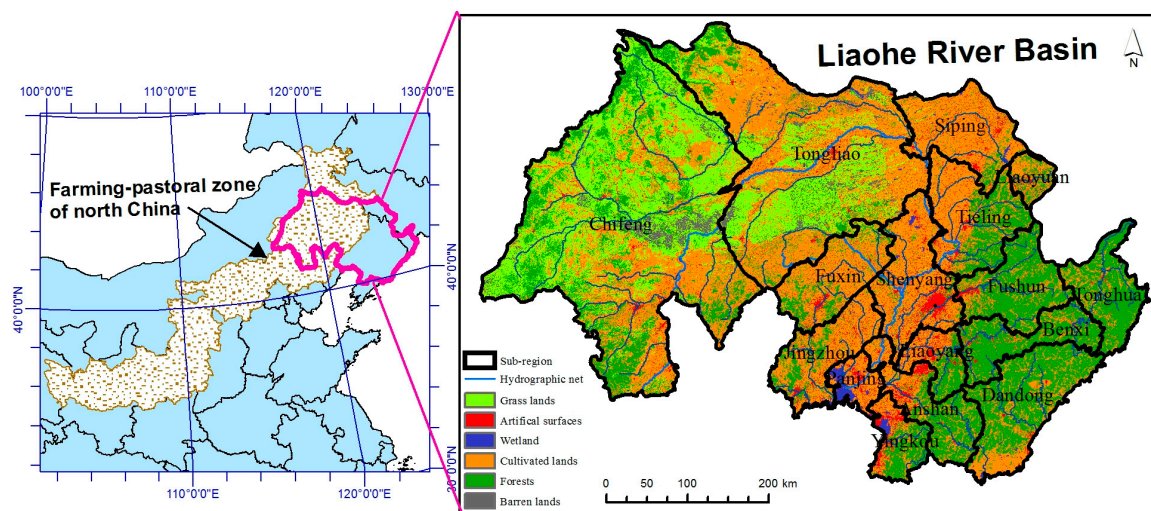


Figure 2. Geographical location of the research area.

Ecosystem composition (Figure 2) of the region showed that the major types of ecosystem in the upstream are grasslands and deserts; the central region comprised the cereal and industrial base, and distributed with cultivated land; and the southeast region comprised the forests. From the northwest to southeast, it emerged as an overt transformation from the grasslands and deserts to cultivated lands and forests. Diverse ecological communities enable great difference in the type and amount of ES.

The upstream region comprises of the Laoha and Xiliao sub-rivers of the Liao River Basin, with grass and desert plants as the main vegetation of this region. The fragile environment and ecological degradations might be caused by the prominent conflicts between land and population. Land degradation has been observed in Khorchin sandy land, which is a source region of sand storms in Northern China. Ecosystem degradation in this region is not only affected by its climatic variations, but also by its overdevelopment, land reclamation, and grazing.

Key industries in the southeast region are food production and old industries. As the water source of this region, the upstream guarantees the regional water supply to a great extent. At the same time, the EFA also plays an important role as the ecological barrier which controls the eastward and southward expansion of desertification. In other words, the upstream EFA region provides the direct ecological barrier for this region, ensuring ecological security of the downstream.

The upstream and the downstream are closely related and interdependent. Understanding the relationship between the EFA and its surrounding areas is significant for the local environment and the residents' wellbeing.

3.2. Rural Population Wellbeing

We selected rural population wellbeing as our evaluation object which has a relatively greater reliance on the primary industry and is closely linked with ES, and we majorly evaluated its objective wellbeing. The criteria for our study are "objective wellbeing + rural population + ecosystem related". Based on the existing research, we assessed human wellbeing in three different layers, including economic [31], environmental, and social wellbeing [32]. Specific indicators could be found in Table 1, which was calculated for year 2002, 2004, 2006, 2008, 2010, and 2012.

Table 1. Rural population wellbeing assessment index.

	Layer	Indicator	Unit
Rural population wellbeing (RPWB)	Economic wellbeing (ECWB)	Per capita net income	Yuan
	Environmental wellbeing (ENWB)	Water environmental quality	-
	Social wellbeing (SWB)	Per capita living space Rural and urban income ratio	km ² -

Note: SWB was averaged the two indices of per capita living space and rural and urban income ratio after normalization.

Farming and grazing activities are the primary income sources of rural populations, and we selected the per capita net income as an indicator of ECWB, as more net income guarantees a better material life. The surface water environmental quality can be ascribed to the regional environmental conditions and water environmental quality is selected as one important indicator. The water environment is indispensable to the survival and reproduction of population and the socio-economic development, and clean water also elevates the comfort level of life. SWB has two indicators. The ratio of rural and urban income is calculated using per capita income of farmers divided by per capita income of urban residents. It illustrates the degree of poverty of the rural inhabitants; a higher ratio represents a smaller gap between the rural and urban areas. The per capita living space assesses the means of living, calculated using residential building areas divided by residential population. In China, housing is one of the most important assets in a rural family. When people have some savings, they are accustomed to maintaining or building larger houses, sometimes even for the next generation of their families.

We normalized the indices by:

$$x' = x / \max(x) \quad (1)$$

where, x refers to the wellbeing indicators including ECWB, ENWB and SWB, is the original value of the index, and x' is the normalized value within the scope of (0, 1].

Then we calculate RPWB using the normalized indicators including ECWB, ENWB, and SWB. The three aspects of RPWB are equally weighed in our study with reference to similar studies [33,34]:

$$RPWB = \sqrt[3]{ECWB \times ENWB \times SWB} \quad (2)$$

3.3. Ecosystem Service

In accordance with the regional ecological and environmental problems, we selected five indicators to assess ES indices [35]: (1) Carbon fixation plays a vital role in climate regulation and climate change mitigation; this effect is mainly revealed in large scale and has its externality; meanwhile, when it yields 1 g of dry substance, the ecosystem absorbs 1.63 g CO₂ [36] during the carbon fixation process. This process can serve as an indicator of the regional vegetation, better ecosystem quality, higher biomass, and carbon fixation service. (2) The EFA experienced low river flow in recent years; thus, we chose the hydrological adjustment service. (3) Seated in the arid and semi-arid area, the region faces serious wind erosion and is threatened by desertification; therefore, we chose the sand-fixation service. (4) River has a high sediment concentration, accompanied with soil impoverishment and water loss and soil erosion issues; thus, we selected the soil conservation service. (5) The last index is food supply, which represented agriculture, forestry, animal husbandry, and fishery product availability in the region.

The data of ES was provided by the “Survey and Assessment of National Ecosystem Changes”, which includes 90 m classifying land data, 250 m hydrological adjustment, sand fixation, carbon fixation, and soil conservation (Table 2). Food supply was calculated using the Statistical Yearbook data. Detailed materials and methodologies can be found in Supplementary Materials of Ouyang [37]. We used the ES data in 2002 and 2012 in our research.

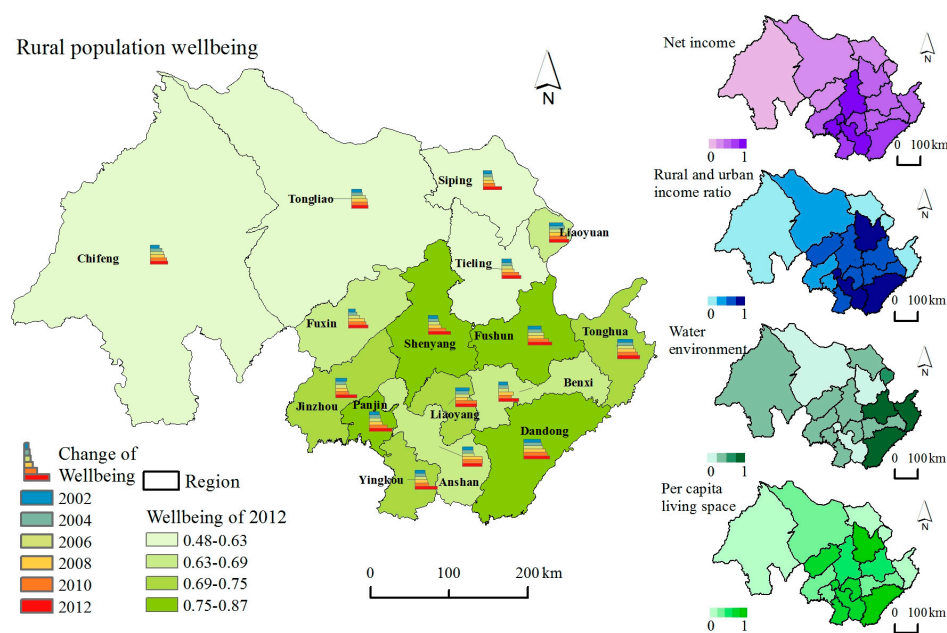
Table 2. Ecosystem service index.

	Indicator	Unit	Issue	Modeling Method
ES	Carbon fixation	Mg/hm ²	climate regulation and vegetation protection	Soil organic carbon sequestration of vegetation and soil
	Food supply	kcal/hm ²	Production capacity	Statistical yearbook
	Soil conservation	t/hm ²	Water erosion	Universal soil loss equation (USLE)
	Sand fixation	t/hm ²	Wind erosion	Revision wind erosion equation (RWEQ)
	Hydrological adjustment	m ³	Regulate water resource	Reserves of precipitation resources

4. Results

4.1. Spatial Distribution and Change of Rural Population Wellbeing

From 2002 to 2012 the economic wellbeing of rural population in different regions showed different magnitudes of improvement. RPWB was found at the lowest level in the EFA, at a higher level in the eastern part, and the southeast forest region showed the highest levels of RPWB (Figure 3).

**Figure 3.** Spatial distribution of rural population wellbeing and each indicator.

The spatial distribution was also a key factor affecting the relative change of RPWB. The normalization calculation was carried out annually and we got the relative horizontal of each region, which emphasized the importance of assessing the relative gaps between regions. Results showed that the differences in welfare levels among different areas narrowed in 2002–2012 (Figure 4).

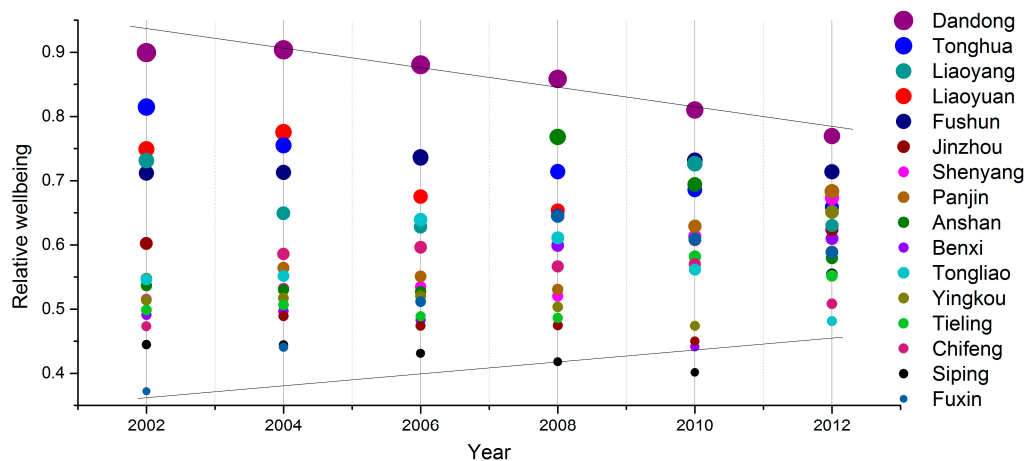


Figure 4. Changes of RPWB.

4.2. Spatial Distribution of Ecosystem Service

The spatial distribution of ES is obvious and ecosystem composition is a fundamental and crucial factor of ES: (1) It is accompanied by the high level of sand fixation (Figure 5a) and low level of carbon fixation (Figure 5b) in the grasslands. The high binding sand quantity regions always experience severe wind erosion and desertification, and the degree of sand fixation service characterized the degree of sandy desertification, while the severe desertification has a high demand of sand fixation service; the carbon fixation service shows maximum values in the forest regions, followed by the arable lands, and the grasslands; and (2) the arable land is accompanied with inferior soil conservation and the hydrological adjustment service (Figure 5c,d), and superior food supply capacity (Figure 5e). It is observed that, along with the accommodation of high food supply, the arable lands incurs the most serious water loss and soil erosion with low ES values. The regional scale ES data is shown in Appendix A (Table A1).

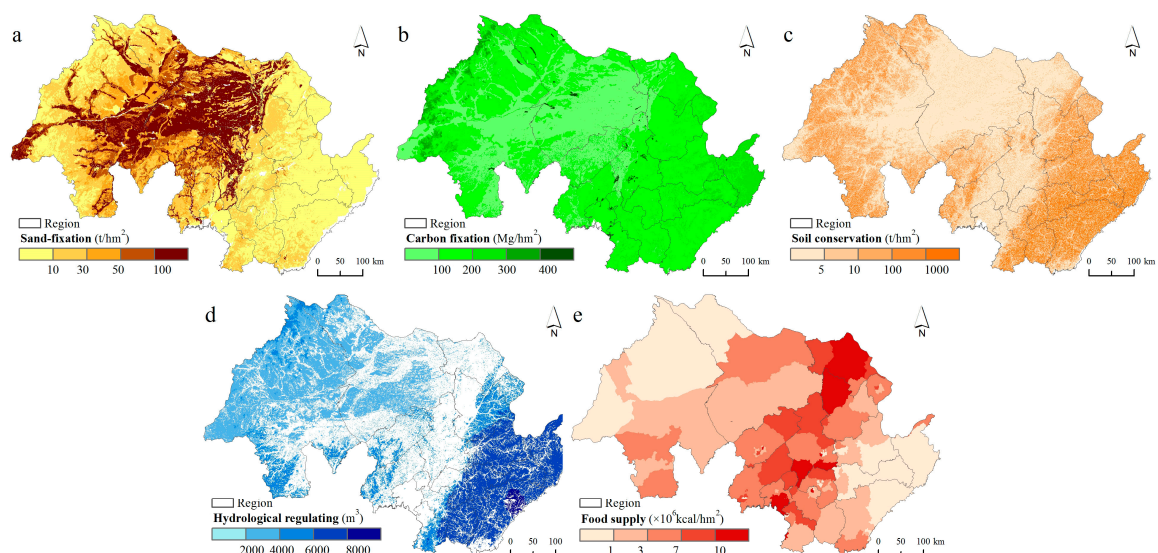


Figure 5. Spatial distribution of major ecosystem services in 2012; (a) sand-fixation; (b) carbon fixation; (c) soil conservation; (d) hydrological adjustment; (e) food supply.

4.3. Interrelations of Ecosystem Service and Rural Population Wellbeing

Overall, the distribution of RPWB was spatially heterogeneous, the EFA of upstream region was inferior to the downstream region and each ecosystem service has different spatial distribution. We conducted a Spearman correlation analysis between ES and RPWB (Table 3).

Table 3. Interrelations of ecosystem services and rural population wellbeing.

Spearman Correlation	RPWB	Net Income	Water Environment	Rural-Urban Income Ratio	Living Space
Carbon fixation	0.529 **	0.096	0.409 *	0.402 *	−0.221
Food supply	0.009	0.479 **	0.076	−0.155	0.647 **
Soil conservation	0.422 *	0.122	0.545 **	0.338	−0.169
Sand fixation	−0.616 **	−0.117	−0.306	−0.503 **	0.179
Hydrological adjustment	0.560 **	0.195	0.642 **	0.353 *	−0.124

** Correlation is significant at the 0.01 level (two-tailed). * Correlation is significant at the 0.05 level (two-tailed).

In addition to food supply, the ES indicators were closely associated with RPWB in the region. Positive correlation was presented between carbon fixation, soil conservation, hydrological adjustment services, and RPWB, indicating the increase of these services was beneficial to higher RPWB. In contrast, a negative relationship was shown between the sand fixation service and RPWB, indicating the decrease of the sand fixation value is conducive to the improvement of RPWB.

Specifically, the food supply index was closely related to the economic wellbeing, and it accorded with the common sense that a high grain production leads to high incomes.

A high correlation was found between the environmental wellbeing and carbon fixation, soil conservation, and hydrological adjustment. Carbon fixation had a positive role in promoting water quality; biomass absorbed contaminants and reduced their concentration in water. Higher soil conservation capacity controlled water and soil loss and alleviated water pollution. By regulating soil runoff, the hydrological adjustment influenced the water environment; high inflow provided better water quality.

In respect of social wellbeing, the carbon fixation, sand fixation, and hydrological adjustment were greatly correlated with the rural-urban income ratio, and food supply was more correlated with the living space. The rural-urban income ratio was positively related to the service of carbon fixation and hydrological adjustment. This is possibly because the region had a higher supply of the above-mentioned conciliation services, usually possessed a good environment, and could share some functions of urban areas, such as outings, catering, and other services. These conciliation services benefited farmers by increasing their income and narrowing the gap between the rural and urban areas. The sand fixation service was negatively related to rural-urban income ratio. The region with strong sand fixation capacity was located in the upstream region of grasslands, experiencing severe blowing sand. The rural residents of this region belonged to low-income population, and the poverty increased the income gap of the rural and urban. Conversely, the income gap was relatively narrowed in the region with slight blown sand and low sand fixation capacity.

5. Discussion

The western area of our study region is an ecotone of agriculture-animal husbandry, which is eco-environmentally fragile. Meanwhile, it is also the upstream region of the Liao River Basin, and a water conservation district of this region. In contrast, the downstream region enjoys a fairly good ecological environment with high ES capacity.

Manufacturing and living activities of farmers and herdsmen in the upstream region were constrained by natural conditions; while there is less limitation in the downstream, which has better wellbeing than the upstream region. The average rural population wellbeing in the downstream region was 1.24 times greater than that in the upstream EFA region; the highest value in Dandong was even

1.56 times more than the lowest in Tongliao; it showed significant differences in the upstream and downstream regions. The wellbeing distribution is presented in Figure 6.

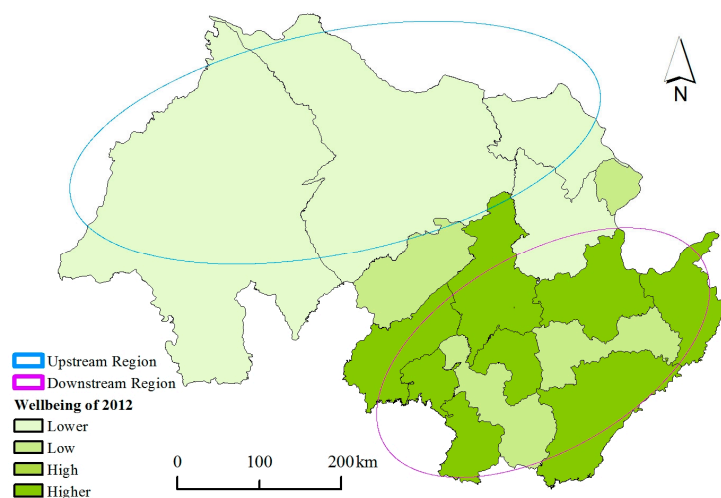


Figure 6. Regionalization map of interrelation of ecosystem service and rural population wellbeing.

As a whole, the region has a fine environment and high ES always reflects significant wellbeing, and vice versa. Previous studies showed that a distinct relationship exist between poverty and EFA, with correlation coefficients ranging from 0.78 to 0.86 [38]. The major reason behind this phenomenon is that excavating and overdrawing regional natural resources will break the thresholds of key environmental processes and aggravate ecological degradation.

The phenomenon that a harsh environment accompanies low rural population wellbeing is ultimately a development issue—the conflict between land and population. Our study results of the linkages between the upstream and the downstream regions can also be applied to all EFAs and surrounding areas. How to coordinate the upstream and the downstream is one of the key issues of EFAs and surrounding regions.

The EFA in the upstream region affects rural population wellbeing greatly. Higher-intensity production would exceed the ecological capacity and cause more severe ecological degradation and environmental destruction. Previous studies believed that the ecological degradation in this region is mainly caused by anthropogenic activities [39]. This will lead to mid-long term destruction of landscape ecology and regenerative abilities of ES, if no control measures are implemented. Moreover, it effectively eased the current conflicts between people and land in this region.

We have emphasized above that EFAs are not independent systems: they exchange and consume the substance and energy within their surroundings. The EFA in our research undertakes the function of an ecological safety barrier, effectively preventing the development of desertification. The downstream region is the beneficiary of the upstream region EFA ecosystem service.

The problem of the regional ecosystem and inhabitant wellbeing cannot be solved simply by poverty relief or increasing investment of environmental protection alone. To break the vicious circle of ecological degradation and long-time poverty of rural populations, we need to work with both poverty relief and environmental protection together, thus, to effectively ease the conflicts between local resident and land. In the EFA region, it is necessary to adopt ecological compensation measures and improve grass quality. In downstream regions, we need to control the expansion of cultivated land and improve ecosystem services.

6. Conclusions

The regional difference of RPWB has declined during the past decade. By analyzing the interrelation of ecosystem service and rural population wellbeing in EFA and the downstream

region, we concluded that high-ES regions and high-wellbeing regions overlap. The improvement of wellbeing profits from socioeconomic development and its regional differences diminished in the past decade. However, the level of wellbeing in the downstream region was higher than that in the upstream EFA region. This conforms with our observation that high-ES regions have high levels of wellbeing. The priority task for the EFA in our research is to ease the conflicts between people and land, introducing poverty alleviation and environmental protection projects at the same time and, thus, to overcome poverty and environmental deterioration.

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

Appendix A

Table A1. Region indicators of ES in 2002 and 2012.

Region	Carbon Fixation		Food Supply		Soil Conservation		Sand Fixation		Hydrological Adjustment	
	(Mg/hm ²)		(×10 ⁶ kcal/hm ²)		(t/hm ²)		(t/hm ²)		(m ³)	
Year	2002	2012	2002	2012	2002	2012	2002	2012	2002	2012
Chifeng	112.66	112.60	0.44	1.12	75.74	75.78	44.37	49.21	3174.07	3173.04
Tongliao	78.90	78.91	1.01	2.54	12.22	12.33	71.36	82.22	2903.80	2901.50
Siping	129.08	129.07	4.47	11.54	19.75	19.87	24.86	26.90	4532.35	4555.86
Liaoyuan	170.50	170.46	3.45	4.60	102.27	102.62	3.17	3.20	5465.34	5447.40
Fuxin	94.40	94.37	1.35	6.89	49.03	50.47	73.58	79.81	4110.86	4106.79
Shenyang	120.72	120.46	4.47	8.01	17.90	18.23	40.45	41.69	5026.69	4997.70
Tieling	143.62	143.52	3.67	7.80	161.43	161.60	12.91	13.11	5699.61	5687.85
Jinzhou	134.10	134.07	3.70	6.60	88.13	89.02	31.37	32.92	4493.54	4487.04
Fushun	174.84	174.77	0.93	1.21	542.93	542.16	5.64	5.48	6512.64	6498.23
Tonghua	223.41	223.42	0.75	0.80	861.83	860.97	0.95	0.95	6969.17	6968.49
Benxi	181.37	181.27	0.69	0.88	1085.79	1085.03	3.28	3.21	6933.47	6918.76
Dandong	169.07	168.93	1.12	1.49	1049.96	1047.82	6.99	6.99	7480.01	7474.94
Yingkou	157.19	156.94	2.34	4.10	425.18	426.01	10.96	10.86	5869.72	5857.25
Anshan	158.54	158.43	3.31	4.75	485.63	485.31	14.76	14.74	6453.68	6451.75
Liaoyang	149.24	149.13	3.72	4.24	365.81	365.94	7.886	7.79	6326.57	6307.43
Panjin	122.78	122.75	4.73	7.52	2.64	2.64	9.92	9.71	4226.01	4231.48

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