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RESEARCH ARTICLE

Ecosystem health assessment on the hill and gully area of Loess Plateau in Inner Mongolia, China

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Abstract Maintenance of ecosystem health is the primary focus of a sound ecological restoration. Yet methods involved in quantifying and assessing the health level remain a challenge to the ecological community. In this study, we selected the hill and gully area of Loess Plateau, Inner Mongolia, China, as our study area. The soil and water erosions in this area continue to be responsible for many environmental problems in northern China because of its fragility and long disturbance history. In this study, we developed an assessment method of indicator system (AMIS) based on analytical hierarchy process (AHP), fuzzy mathematics, and the theory of net-hierarchy. At ecosystem or catchment scale, three sample areas, that is (1) intact vegetation (i.e., Aguimiao Natural Reserve, 110°45′E, 39°28′N), (2) reconstructed vegetation (Wufendigou Soil and Water Conservation Experimental Area, 111°07′E, 39°45′N), and (3) severely degraded vegetation (Yangquangou Catchment, 111°06′E, 39°45′N) in the hill and gully area of Loess Plateau in Inner Mongolia, China, were selected to examine ecosystem vigor, organizational structure, service function, and soil health. We applied the AMIS for all three landscapes by categorizing each ecosystem into five health levels. We found that the health index for reconstructed vegetation were at levels of IV, II, IV, and III, while those of degraded vegetation were ranked at V, IV, V, and IV. Overall, the comprehensive ecosystem health index of reconstructed vegetation was lower than that of intact vegetation but higher than that of degraded vegetation. The health index for reconstructed vegetation was at level III, and that of degraded vegetation was still at level IV. The contributing values were: organization structure > soil health > vigor > service function. Based on our results and assessments, we proposed several management recommendations and methods for restoring the regional ecosystems.

Keywords Loess Plateau, Inner Mongolia, ecosystem, health assessment, indicator system, sustainable development

1 Introduction

The hill and gully area of Loess Plateau, China, means the low loess mountains where land-surface was fragmentally cut, density of the hill and gully was very high, vegetation cover rate was low, and water and soil erosions were very severe. The area of hill and gully is about 227 400 km^2. The hill and gully mainly spread around the middle reach of Huanghe River and the north of Loess Plateau, and is the main sources of water and soil erosions in the Loess Plateau (Fu, et al., 2002). Because of the formidable natural conditions, frequent incidences of natural disasters, and low level of agricultural, forestry and livestock production for a long time, the state of ecosystem health in this region has been falling under these threats and has become one of the weakest ecological environmental regions in China (Fu, et al., 2002; Wu and Yang, 1998).

At present, concerned studies on this region mainly focused on the rules of water and soil erosion, engineering measures of comprehensive treatments, systematic models of soil eroding and harnessing modes, structures of land use and ecological processes, analysis on basin vegetation and water physiological ecological mechanism, and so on. And these studies have acquired many important achievements (Jin et al., 1992; Yang, et al., 2001, 2002; Fu, et al., 2002; Huang and Yang, 2003), but the ecosystem health assessment on this region has never been reported.

Assessment on ecosystem health aims at ecological re-

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covering and management, and realization of the sustainability of global or regional eco-environment. For the strongly disturbed ecosystem, it is unrealistic to recover to the original state before the disturbance. Ecological recovering should be based on the largest realizable naturalness of certain regional conditions, simulate the near natural state, and take the relatively ecological integrality as its target (Bundi et al., 2000). Therefore, the healthy ecosystem is not always the original ecosystem, but it must be a relatively intact ecosystem which is characterized in complex heterogeneous ecological environment and is stable and sustainable, i.e., it is provided with considerable vigor and enable to maintain its self-organization and independency along with time history, and is easy to recover from certain externally induced stress (Costanza, 1992). These are the basis of ecosystem health assessment (Luo et al., 2003).

Presently, studies on ecosystem health assessment both in China and abroad mainly focus on the index system, such as the ocean ecosystem health index system established by the U.N. Environmental Program (UNEP) in Geneva in 1992, which can be applied to ecosystem service and management as optimized choice indices (Rapport, 1995). There are some research progresses in this field in China. For example, Xiao et al. (2003) probed into the forestry ecosystem health assessment indices and their application in China; Cui and Yang (2002) established the theory and method of wet land ecosystem health assessment by taking Naolihe basin of Three-rivers Plain for example, and graded the assessment results and arranged serial number by taking the two level branches as evaluating units, and their studies have certain theoretical and practical value. Hao et al. (2004) measured the organizational capacities of plant community of the classic steppe in Xilinhe basin of Inner Mongolia from the point of ecological recovering. However, the measuring methods and evaluating system of all studies above are not yet systematic and perfect from the view of ecosystem health.

A more general method for assessing ecosystem health is to distinguish the comprehensive index of structural and functional conformability of the ecosystem. But, presently the essential standards in forming ecosystem health have not reached an extensive agreement. It shows that a relative lesser index combination of ecosystem level is enough to distinguish the strongly disturbed ecosystems by human activities from the hardly disturbed ones from the view-point of comparative experiment study on ecosystem behavior under the disturbed state. In practice, these indicators provide discriminated standards for judging the variation of the natural region's health (Rapport, 1989). The assessment method of indicator system (AMIS) (Kong et al., 2002) was used in this study. Based on the natural index system, the hill and gully area of Loess Plateau in Inner Mongolia, China, especially the different recovering stages or different vegetation patterns in Huangfuchuan basin, were discussed from the aspects of ecosystem vigor, organizational structure, service function, and soil health. Aguimiao Natural Reserve, 7 km away from the south-west edge of Huangfuchuan basin, was regarded as the original island vegetation, and an ecosystem health assessment model suitable for this region was established.

2 Study area and assessment units' choice

The hill and gully area of Loess Plateau in Inner Mongolia refers to the loess hill region that lies around the south to Yinshan Mountains and the east edge of Ordos Plateau. The hill and gully area is the area where the Loess Plateau extended to the inside of Inner Mongolia Autonomic Region, also the border regions of Shanxi Province, Shaanxi Province, and Inner Mongolia Autonomic Region, China. It is the main contribution region of Pishayan, a kind of gritstone, with an area of 20 775 km^2. And it is also a region with very low resilience against eroding and strong water and soil erosion (Fu et al. 2002). The crude barrier of Yinshan Mountain Chain weakens the influence of Mongolia cold-high-pressure in winter at a certain extent, and makes the climate relatively warmer with the annual average temperature at 5°C–7°C, the cumulative temperature degree above 10°C at 2 700°C–3 200°C, the precipitation is 300–450 mm and the humidity is 0.30–0.45. It belongs to warm classic steppe and half drought climate. *Stipa bungeana* steppe is the representative zonal grassland vegetation type of this region. However, because of the long history of cultivation, the crude *S. bungeana* steppe hardly survives, and it only distributes at the top of hill or the fragile mound. The wind erosion often restrains the upgrowth of *S. bungeana*, and the invasion of small half shrub *Thumus serpyllum* forms a hypo-grew departure community (Inner Mongolia Plant Annals, 1998).

On the scale of system or community, by taking the catchment as evaluating unit, the health states of three sample areas that represented different recovering vegetation states (intact vegetation, reconstructed vegetation, and severely degraded vegetation) were assessed according to degenerative gradients.

Aguimiao Natural Reserve (110°45′ E, 39°28′ N) is chosen as the intact vegetation area with an average altitude of 1,150 m and the area of 1.23 km^2. It is an integrate catchment bordering Huangfuchuan basin and is located inside Yangshita town of Zhungeer county, which is about 7 km away to the south-west of Huangfuchuan basin. It belongs to the north hill and gully area of Loess Plateau on the natural geographic belt. The soil is castaneous calcium soil (Ligaitu) and characterized by loess, gritstone, and aeolian sandy soil inlaid. The belt vegetation is *S. bungeana* + *Artemisia girandii* steppe. The Natural Reserve is protected by the local government for the existence of a temple, thus the natural vegetation which belongs to original island vegetation, including crude *Pinus tabulaeformis* woods, *Juniperus rigida* woods, *Prunus davidiana* woods and *Artemisia girandii* steppe, survives better.

The whole catchment of Wufendigou Soil and Water Conservation Experiment Area (111°07′ E, 39°45′ N) is chosen as the reconstructed vegetation area. It is 5 km away from the south to Haizita Town, Zhungeer County, i.e., Wufendigou channel, with the area of approximately 4.18 km^2 and the average altitude of 1 130 m. It is one of the 11 afforestation example regions, located in the east bank of the middle reach of Changchuan River which is one of the two branches of Huangfuchuan basin. The soil is mainly composed of three types: castaneous calcium soil whose parent materials are gritstone, aeolian sandy soil, and loessal soil whose parent materials are loess. The main vegetation types are artificial *Pinus tabulaeformis* woods, artificial *Popunus simonii* woods, artificial shrub woods such as *Salix psammophyla*, *Hippophae rhamnoides*, *Caragana intermedia*, and crude vegetation such as *Stipa bungeana*, *Thumus serpyllum*, etc.

The whole catchment (i.e., Yangquangou catchment) (111°06′ E, 39°45′ N) in the north-west to Ninggeerta village is chosen as the severely degraded vegetation area. It lies on the west bank of the middle breach of Chuangchuan River and faces Wufendigou Soil and Water Conservation Experimental Area, with the average altitude of 1 160 m and has an area of 1.82 km^2. The conditions of soil evolvement, and terrain and physiognomy are analogous to those of Wufendigou. Because of the intense influence of human activities and no harnessing, the vegetation recovers very slowly. The main vegetation types are only sparse shrub woods of *Caragana intermedia*, *Thumus serpyllum* community, etc. Arbor woods are very scarce.

3 Methods

3.1 Deciphering remote sense image and surveying vegetation pattern

The 2002 IKONOS image (4, 3, 2 band compound and interfusion with 8 band, the pixel diameter is 1 m), the output from the remote sense image treating system of satellite picture information data stored in the High-Density Tapes, was visually deciphered, then checked in combination with on the spot ground investigation. With the support of GIS software, the vegetation pattern actuality charts of the three sample areas were made, and the attributed data were extracted for analysis.

3.2 Investigation on plant communities and flora

Twelve sample lines, 45 sample terra, and 187 sample squares were investigated by classical sampling methods with representative community types for the above three sample areas in the growth seasons of 2002 and 2003. Detailed methods are given below.

Arbor woods: setting sample terra of 20 m×20 m, measuring chest diameter, height, amount, and stand crown density of each tree according to the species, noting every species' coverage, height and abundance under the woods by route method, respectively. Their biomass was mainly calculated by the experience formulas (relative growth formulas) provided by Wu et al. (1994).

Shrubbery and small arbor woods: choosing the representative terra and setting sample terra of 20 m×20 m or 10 m×10 m, measuring each tree's height, amount, crown breadth, quantity of branches, coverage, and frequency, respectively, selecting the representative branches according to the average crown breadth and average height and cutting them with scissors so as to measure the biomass of their branches and leaves.

Small-half shrubbery and herbage layer: setting sample squares of 1 m×1 m according to "×"arrangement, noting the structure of species, coverage, height, and the amount of trunk or clump. Then all were mowed to get the biomass.

As for the moss (soil crust) layer, combining sample lines with sample squares, and choosing the representative slop sides, lugging a sample line from the channel bottom to the slop top, then setting sample squares of 1 m×1 m every 10 m or 5 m and setting down all the names of moss plants and the coverage. Then the moss of highest coverage and better growth was chosen to be cut to measure the biomass.

Plant samples were identified referring to Inner Mongolia Plant Annals (1998). In addition, the flora composition, life-form spectrum, and water ecological types of the vegetations in the three sample areas were divided and contrasted to analyze them by referring to China Vegetation (1980) and Inner Mongolia Vegetation (1998).

3.3 Investigation on soil erosion

With the combination of qualitative and quantitative methods, the level of soil erosion was estimated while the plant communities were investigated. The annual amount of modulus of soil erosion were calculated by using the American Universal Soil Loss Equation (USLE) by extracting slope gradient, slope length, etc. supported by GIS (Jin et al. 1992).

3.4 Investigation on soil

While investigating the plant communities, the representative terra were chosen in which to dig soil section paralleled contour line according to 1 m×0.5 m×1 m. The soil type was confirmed and sampled from three levels by loop knife every 20 cm so as to measure soil content weight, water content, and so on. The measuring methods were loop knife method and drying weigh-up method (Wang 2004). Approximately 250 g soil sample was randomly gathered from every level and taken into the hop-pocket so as to measure their content of organic matter, full N, full P, and the total amount of microorganism species. The references were consulted for the measuring methods (Li et al., 2004; Zhang and Song, 2004).

4 Establishment of ecosystem health assessment model and gradation of evaluating indicator standard

4.1 Establishment of the systems of ecosystem health evaluating indicators and their weights

Based on the concerned principles and methods of establishing ecosystem health assessment index system, and in combination with the facts of our research regions, analysis of hierarchy process (AHP) was used to divide the assessment system into four levels: the first level takes ecosystem health as object level, and the next level is rule level, which was sub-divided into four functional indicators (vigor, organization structure, service function, and soil health). Under the rule level was the index level, i.e., every functional indicator could be divided into several indicators, and then divided into sub-indicators, till each indicator could be measured directly (Wang et al., 2004). The relation between each level and its low-level's indicators was of the complete comprising and comprised relation, according to the theory of net-hierarchy (Wu, 2000). This was also convenient to integrate the low-level's indicators with that of high-level. Then the method of specialist survey was used to design the specialist consultation questionnaires of assessment index system structure. The consultation questionnaires were sent to 93 experts or specialists in the concerned field all around China by email or were handed to them, and 27 questionnaires were sent back. The health assessment indicators system and the weights system were established (Table 1) by calculation and analysis.

4.2 Establishment of ecosystem health assessment model

For the convenience of the comparison between different elements and different systems, essential no-dimension or standardization process was applied to each element or indicator, i.e., the relativization process of each element or indicator was compared to a certain ideal value or reference value to obtain the vector (***D***) of a relative indicator value. Then the relative indicators values vector were multiplied by the unitary weight value vector; the products of the two vectors were integrated to the subjected high-level indicator or element. The weighting integration was taken level by level till the aim level. Finally, the comprehensive index was obtained which could illustrate the whole health state. The formula was:

$$\boldsymbol{C} = \boldsymbol{D} \cdot \boldsymbol{W}^{\mathrm{T}} \qquad (1)$$

wherein, ***C*** was the health assessment value of the up-level assessment element or indicator; ***D*** was the indicator relative vector quantities of low level, $\boldsymbol{D} = [\boldsymbol{D}_1, \boldsymbol{D}_2, \ldots, \boldsymbol{D}_n]$; $\boldsymbol{W}^{\mathrm{T}}$ was the unitary weight vector quantities of low level, $\boldsymbol{W}^{\mathrm{T}} = [\boldsymbol{W}_1, \boldsymbol{W}_2, \ldots, \boldsymbol{W}_n]^{\mathrm{T}}$.

Based on the principles and methods of identifying ecosystem health, combining with the concrete conditions of the research region and the three sample areas, and following the method of integrating level by level from low level to high level, the health indices of the four functional index system about vigor, organizational structure, service function, and soil health in the three sample areas were calculated and then the comprehensive indicators of ecosystem health in the three sample areas were also obtained.

Table 1 The construction of ecosystem health indicator and weight statistic result in hill and gully area of Loess Plateau in Inner Mongolia, China

Layer A (objective layer)	Layer B (rule layer)			Layer C (indicator layer)			Layer D (vice indicator layer)		
	Function	Weight	Unitary weight	Indicator	Weight	Unitary weight	Weight	Weight	Unitary weight
Ecosystem health	Vigor	3.88±1.01	0.28	Primary production	1.88±0.34	1.00	Arbor woods	2.04±0.79	0.24
							Shrub woods	2.40±0.65	0.28
							Grassland	2.32±0.75	0.27
							Moss	1.92±0.80	0.22
	Organization structure	3.72±0.98	0.27	Community property	2.25±0.68	0.36	Vegetation cover	1.84±0.37	0.26
							Moss cover	1.24±0.56	0.18
							Species diversity	2.76±0.66	0.39
							Moss diversity	1.24±0.56	0.18
				Horizontal structure	2.08±0.76	0.33	Community pattern	1.80±0.82	0.49
							Water ecotype structure	1.88±1.054	0.51
				Vertical structure	1.92±0.86	0.31	Layer biomass	1.02±0.51	0.26
							Layer cover	1.31±0.61	0.34
							Life form structure	1.52±0.51	0.39
	Service function	3.12±1.130	0.22	Soil and water conservation	1.64±0.49	1.00	Soil erosion modulus	2.28±0.84	1.00
	Soil health	3.24±1.30	0.23	Physic property	2.36±0.64	0.36	Humus layer depth	3.08±0.91	0.39
							Soil water content	2.96±0.89	0.37
							Organism content	1.88±0.60	0.24
				Chemical property	1.96±0.68	0.30	Full *N* content	1.72±0.46	0.50
							Full *P* content	1.72±0.46	0.50
				Biologic property	2.28±0.85	0.35	Microbe community quantity	2.04±0.74	1.00

The identifying model or formula of ecosystem health was:

$$HI_i = V_i \cdot P_v + O_i \cdot P_o + S_i \cdot P_s + L_i \cdot P_l \quad (2)$$

wherein, HI_i indicated the ecosystem health index value of sample area i, which ranged from 0 to 1. V_i, O_i, S_i and L_i respectively indicated ecosystem vigor, organizational structure, service function and soil health of sample area i, which ranged from 0 to 1. P_v, P_o, P_s and P_l respectively indicated the unitary weight values of ecosystem vigor, organizational structure, service function and soil health, and $P_v + P_o + P_s + P_l = 1$.

4.3 Gradation of assessment index standards

Presently, there is no uniform method in grading assessment index standards in ecological assessments, especially in ecosystem health assessment (Ma and Liu 1997). Therefore, this paper tried to raise a series of index standards and pursued the aim suitable for the study areas based on referring to related standards of concerned studies both here and abroad and the special geographical and ecological conditions of the study areas. Referring to the method of identifying the wet ecosystem health assessment index levels reported by Cui and Yang (2002), the assessment index standards were divided into five levels in this paper: excellent health (I level), health (II level), sub-health (III level), morbidity (IV level), and illness (V level) (Table 2).

5 Results and analysis

The calculated results of ecosystem vigor, organizational structure, service function, and soil health of the four functional index systems were mainly analyzed focusing on the B level of the ecosystem health index system. Then, the comprehensive index of ecosystem health of each sample area was obtained by integrating the four functional index systems to set forth in detail.

5.1 Vigor

The health index of vigor in three sample areas (Table 3) were obtained by calculating the low-level index and their unitary weight values in Tables 1 and 2 by Formula (2).

Table 2 The grade of ecosystem health index standards

Indicators		Level standard I	II	III	IV	V
(Health index)		Excellent health 0.80−1.00	Health 0.60−0.80	Sub-health 0.40−0.60	Morbidity 0.20−0.40	Illness 0.00−0.20
Arbor woods biomass / ($\times 10^3$ kg·hm^{-2})		54.53−68.17	40.90−54.53	27.27−40.90	13.63−27.27	0.00−13.63
Shrub woods biomass / ($\times 10^3$ kg·hm^{-2})		0.52−0.87	0.52−0.69	0.35−0.52	0.17−0.35	0.00−0.17
Grassland biomass / ($\times 10^3$ kg·hm^{-2})		0.56−0.70	0.42−0.56	0.28−0.42	0.14−0.28	0.00−0.14
Moss biomass / ($\times 10^3$ kg·hm^{-2})		0.25−0.31	0.19−0.25	0.12−0.19	0.06−0.12	0.00−0.06
Vegetation cover / %		30.33−37.91	22.75−30.33	15.17−22.75	7.58−15.17	0.00−7.58
Moss cover / %		4.37−5.46	3.28−4.37	2.18−3.28	1.09−2.18	0.00−1.09
Species diversity (species quantity)		168−210	126−168	84−126	42−84	0−42
Moss diversity (species quantity)		58−72	43−58	29−43	14−29	0−14
Community pattern		0.80−1.00	0.60−0.80	0.40−0.60	0.20−0.40	0.00−0.20
Water ecotype structure		0.80−1.00	0.60−0.80	0.40−0.60	0.20−0.40	0.00−0.20
Layer biomass /(t·hm^{-2})	Arbor layer	58.07−72.59	43.55−58.07	29.04−43.55	14.52−29.04	0.00−14.52
	Shrub layer	1.24−1.55	0.93−1.24	0.62−0.93	0.31−0.62	0.00−0.31
	Herbage layer	0.90−1.12	0.67−0.90	0.45−0.67	0.22−0.45	0.00−0.22
	Moss layer	0.25−0.31	0.19−0.25	0.12−0.19	0.06−0.12	0.00−0.06
Layer cover /%	Arbor layer	15.86−19.83	11.90−15.86	7.93−11.90	3.97−7.93	0.00−3.97
	Shrub layer	30.82−38.52	23.11−30.82	15.41−23.11	7.70−15.41	0.00−7.70
	Herbage layer	27.86−34.82	20.89−27.86	13.93−20.89	6.96−13.93	0.00−6.96
	Moss layer	4.37−5.46	3.28−4.37	2.18−3.28	1.09−2.18	0.00−1.09
Life form spectrum construction		0.80−1.00	0.60−0.80	0.40−0.60	0.20−0.40	0.00−0.20
Soil and water conservation benefit /%		100.00−80.00	60.00−80.00	40.00−60.00	20.00−40.00	0.00−20.00
Humus layer depth /cm		2.91−3.63	2.18−2.91	1.45−2.18	0.73−1.45	0.00−0.73
Soil water content /%		6.27−7.84	4.71−6.27	3.14−4.71	1.57−3.14	0.00−1.57
Organism content /%		0.551−0.689	0.413−0.551	0.276−0.413	0.141−0.276	0.000−0.138
Full N content /%		0.029−0.036	0.022−0.029	0.014−0.022	0.007−0.014	0.000−0.007
Full *P* content /%		0.027−0.034	0.020−0.027	0.013−0.020	0.007−0.013	0.000−0.007
Microbe quantity /($\times 10^4$·g^{-1})		1039−11298	779−1039	519−779	260−519	0−260

Note: The pattern of community contribution, water ecotype construction and life form spectrum composition in the table are all expressed by their comprehensive index.

Table 3 Health index of ecosystem vigor in three sample areas

Sample area	Layer B	Layer C	Layer D			
	Health index	Primary production	Arbor woods	Shrub woods	Grassland	Moss (soil crust)
Intact vegetation	1.000 0	1.000 0	0.235 0	0.276 5	0.267 3	0.221 2
Reconstructed vegetation	0.361 2	0.361 2	0.039 6	0.106 2	0.055 4	0.160 1
Degraded vegetation	0.196 9	0.196 9	0.000 6	0.046 0	0.086 6	0.063 8

The health indices of vigor in reconstructed vegetation and degraded vegetation are 0.3612 and 0.1969 respectively and very low compared with that of intact vegetation (on the assumption that its health index was 1). Then, a conclusion can be made that they belongs to morbidity (IV level) and illness (V level) .respectively according to the grading standards in Table 2. The reason is that the present biomass of arbor woods, shrubbery, and grassland in reconstructed vegetation and degraded vegetation are all far lower than those of intact vegetation. Especially, the arbor woods are scarcely in degraded vegetation and its contributing value is almost 0, and the shrubbery also accounted for a small deal.

5.2 Organizational structure

The health indices about organizational structure of three sample areas were obtained by former methods and certain formulas (Table 4).

The health index about organizational structure in reconstructed vegetation is far higher than that of degraded vegetation and lower than that of intact vegetation which belongs to II level (health level), and that of degraded vegetation belonging to IV level (morbidity level). In reconstructed vegetation, the main contributing value is from horizontal structure, and the next are community characteristics and vertical structure. The state of degraded vegetation is similar with that of reconstructed vegetation. While it needs to point out that the contributing value of community characteristics is apparently low and only is one-half of that of reconstructed vegetation and more than one-fourth of that of intact vegetation. It shows that the space configuration of communities in reconstructed vegetation after over 20 years' recovering and reconstruction, the community characteristics need to be optimized, though the comprehensive health index of organizational structure has been improved much and achieved the edge of the lower limit of II level, which shows the effects of vegetation recovering and construction on the area.

Table 4 Health index of organizational structure in three sample areas

Sample area	Layer B	Layer C		
	Health index	Community characteristics	Horizontal structure	Vertical structure
Intact vegetation	1.000 0	0.360 4	0.332 6	0.307 0
Reconstructed vegetation	0.610 0	0.208 2	0.231 7	0.170 2
Degraded vegetation	0.393 8	0.107 8	0.173 2	0.112 7

5.3 Ecosystem service function

The ecosystem service functional health indices of three sample areas were shown in Table 5.

The health indices of ecosystem service function in reconstructed vegetation and degraded vegetation are all far lower than those of intact vegetation; they are at IV level (morbidity level) and V level (illness level), respectively. After over 20 years' of recovering and reconstruction, certain effects of soil and water conservation have been achieved in the reconstructed vegetation; however, there is still a great gap between it and the intact vegetation. While the gap between degraded vegetation and intact vegetation is still much greater. It sufficiently highlights that the methods of vegetation recovering and soil and water conservation, including biological and engineering methods, make certain promoter action on the functions of soil and water conservation and in delaying erosion. On the other hand, it is hardly ensured to provide persistent and steady service function for people by ecosystem because of the frequent human activities, such as unreasonable agriculture, forestry, and husbandry activities and changes of land use forms in addition to the proper soil substratum lithology characteristics in the basin.

Table 5 Health index of ecosystem service function in three sample areas

Sample area	Layer B	Layer C	Layer D
	Health index	Diminish erosion	Soil erosion modulus
Intact vegetation	1.000 0	1.000 0	1.000 0
Reconstructed vegetation	0.214 2	0.214 2	0.214 2
Degraded vegetation	0.062 2	0.062 2	0.062 2

5.4 Soil health

The soil health indices of the three sample areas were shown in Table 6.

The soil health index of reconstructed vegetation (III level or sub-health level) is higher than that of degraded vegetation (IV level or morbidity level) and lower than that of intact vegetation. The contributing values of the index in reconstructed vegetation are mainly from chemical and biological characteristics, and the contributing value from physical characteristics was the least. The situation of degraded vegetation is even the same. It shows that the soil health state have improved in some extent after over 20 years' vegetation recovering and re-harness in the reconstructed vegetation. Especially, the improvement of the conditions of ecological environment resulted from vegetation recovering have also improved the physical and biological characteristics in much extent compared with the degraded vegetation. However, the comprehensive soil health index of degraded vegetation, especially the health indices of physical and biological characteristics, are always at very low level because the vegetation has not been recovered and ecological environment has not been improved also.

Table 6 Health index of soil in three sample areas

Sample area	Layer B	Layer C		
	Health index	Physical	Chemical	Biological
Intact vegetation	1.000 0	0.357 6	0.297 0	0.345 4
Reconstructed vegetation	0.513 3	0.142 8	0.175 2	0.195 3
Degraded vegetation	0.388 5	0.081 5	0.170 8	0.136 2

5.5 Analysis of ecosystem health comprehensive index

The ecosystem health comprehensive index values of three sample areas were obtained by synthesizing the four functional indicators above and further integrated according to the methods above and concerned formulas (Table 7).

the ecosystem health comprehensive index of reconstructed vegetation (III level or sub-health level) is higher than that of degraded vegetation (IV level or morbidity level) and far lower than that of intact vegetation. In the reconstructed vegetation, the contributing value of the health index is mainly from organizational structure, and the next are soil health and vigor, and that from service function is the lowest. The results of degraded vegetation are substantially consistent with those of reconstructed vegetation. It shows that the ecosystem health comprehensive index of reconstructed vegetation have been improved in some extent compared with degraded vegetation because of the gradual vegetation recovering and relevant improvements of the ecological environment after over 20 years' of recovering and harness, which shows the effects of many years' reconstruction, especially at the aspects of vigor and organizational structure. On the other hand, because of strong human disturbances such as frequent agriculture, forestry, and husbandry activities and changes of land use forms, the proportion of vegetation cover acreage is still very low, and the configuration structure of plant community types is yet unreasonable. All kinds of functional indices of ecosystem health, especially vigor, service function, and soil health, still have significant differences when compared with those of intact vegetation, which is particularly apparent in degraded vegetation.

6 Conclusions and discussion

6.1 Conclusions

By analyzing a series of functional indices of intact vegetation, reconstructed vegetation, and degraded vegetation, we can draw several conclusions.

(1) In (For) the theories and methods, combining with the facts of the hill and gully area of Loess Plateau in Inner Mongolia, China, especially the three chosen sample areas, primary trial is applied on the establishment of assessing index system, weight system and foundation of the assessing model, and the gradation of index ranging standards in this paper, which provide a consultable embryo for following research of concerned fields.

(2) In the results of the four functional indices about vigor, organizational structure, service function, and soil health, the health indices of reconstructed vegetation and degraded vegetation fluctuate. Those of reconstructed vegetation are in IV level, II level, IV level and III level respectively, while those of degraded vegetation in V level, IV level, V level and IV level respectively, and are all lower than those of reconstructed vegetation.

(3) As a whole, the ecosystem health comprehensive index is still lower than that of intact vegetation and higher than that of degraded vegetation. It was in III level (sub-health level), while that of degraded vegetation is still in IV level (morbidity level). And the order of the contributing values is organizational structure > soil health > vigor > service function.

6.2 Discussion

Based on analysis and conclusions above, the following perspectives are put forward for the further discussion.

Table 7 Ecosystem health comprehensive index in three sample areas

Sample area	Layer A	Layer B							
	Health index (*HI*)	Vigor		Organization structure		Service function		Soil health	
		HI	Added weight value	*HI*	Added weight value	*HI*	Added weight value	*HI*	Added weight value
Unitary weight		0.277 9		0.266 5		0.223 5		0.232 1	
Intact vegetation	1.000 0	1.000 0	0.277 9	1.000 0	0.266 5	1.000 0	0.223 5	1.000 0	0.232 1
Reconstructed vegetation	0.429 9	0.361 2	0.100 4	0.610 0	0.162 6	0.214 2	0.047 9	0.513 3	0.119 1
Degraded vegetation	0.263 7	0.196 9	0.054 7	0.393 8	0.104 9	0.062 2	0.013 9	0.388 5	0.090 2

(1) Some effects of ecological environment conservation and construction are achieved because of vegetation's recovering and reconstruction after over 20 years' recovering and harness in reconstructed vegetation. While there is a major disadvantage in the land use/cover forms and their configuration proportion because of huge barrier in adjusting the structure of agriculture, forestry, and husbandry as well as the lag of subsequent management. Hence, it is still a very pressing task to adjust the configuration proportion of all kinds of plant community types, enhance the species' quantity and quality of arbor, shrub and herb, especially shrub trees adapted to local ecological environment, increase the area of vegetation cover, strengthen the subsequent management and elevate the ecosystem vigor or productivity.

(2) Vegetation recovery and water and soil conservation measurements, including biological and engineering measurements, can apparently promote the service function of soil and water conservation and delay erosion, but its contributing values of service function in reconstructed vegetation and degraded vegetation are the lowest. Hence, this paper considers that the configuration proportion of community types' arranging, especially that of the layer biomass and the layer cover, should be further optimized by consulting with the almost steady vegetation pattern in intact vegetation so as to achieve the biggest benefits of water and soil conservation. On the other hand, human disturbances should be reduced as far as possible and returning land from farming to forestry or pasture should be taken into effect. In addition, we should reduce and delay the power of erosion, increase the soil clinging ability, accelerate the evolving succession of plant communities and the formation of soil moss crust, reduce water and soil erosion at least extent, and increase the ecosystem service function.

(3) Soil degradation has lagging effect compared with vegetation degradation, which vacates some buffering time for vegetation recovering and reconstruction. However, the nutrient components, such as N and P in soil, still appears at higher level because of strong disturbance upon ecological environment by human activities such as the chemical fertilizers and pesticides' use in the agricultural and pasture production, etc. While the transformation of soil organic matters has been apparently fast and the humus layer is hard to form so that the soil health recovering is baffled apparently, it was especially apparent in degraded vegetation. On the other hand, because water and soil erosion resulted from vegetation destruction, it should be accompanied with the lapse of soil nutrient and organic matters, destructive tragedy happens to the local ecosystem when it was longer than the buffering time.

(4) Ecosystem health can be commonly evaluated by measuring their vigor, organizational structure, and resilience (Rapport, et al., 1998a). From the view of application on natural system, social economy, human health, and so on, the assessing indicators of ecosystem health should include vigor, organizational structure, resilience, system service's maintenance, management choice, reducing investment, harm to neighbor system and human health (Rapport, et al., 1998b). For some indicators, such as vigor and organizational structure, it is intuitionistic and easy to measure. But for other indicators, such as resilience, the time scale and related information, are hard to grasp. There are several topics needing further study in the future. How long the ecosystem resilience could be measured? To what degree does the change of water and temperature conditions could influence the succession and recovering of biological communities?

(5) Establishment of ecosystem health assessment indicators and the index system is a very complicated issue. The difference in ecosystem types should result in the different selected key indicators and standards. The index system and a series of indicators established in this paper can just guide the vegetation recovering and reconstruction as well as ecosystem management in the hill and gully area of Loess Plateau in Inner Mongolia, China, especially in Huangfuchuan basin. And they are just references for other watersheds of the classic warm steppe in which Huangfuchuan basin is located. Therefore, it is an important issue needing further study on this field.

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