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Evaluation of ecosystem service functions and identification of ecological sources based on the SOM model: A case study of Dengkou County, Inner Mongolia

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Abstract

Ecological source identification is the basis for building an ecological security pattern. It is of great significance for the health and stability of the ecosystem, the comprehensive improvement of regional ecology and sustainable development. Taking Dengkou County, Inner Mongolia as an example, this study selected five ecosystem service function importance evaluation factors, namely water conservation, soil conservation, habitat quality, windbreak and sand fixation, and food supply, as indicators, and introduced the SOM model to identify ecological sources. Research results: Single factor evaluation results based on the importance of ecosystem services. The four indicators of windbreak and sand fixation, habitat quality, water conservation and food yield showed a spatial pattern of "high in the east and low in the west" as a whole, and the soil conservation indicator showed a pattern of "high in the west and low in the east". The ecosystem service importance factor was the input vector, and SOM clustered and integrated, and named from I to V as ecological conservation cluster, ecological reservation cluster, agricultural ecological cluster, ecological core cluster and ecological protection cluster. Cluster IV, which had comprehensive eigenvalues and high density, was preliminarily determined as an ecological source. The fine patches initially determined as ecological sources were filtered with a threshold of 0.45 km2 to become new ecological sources. A total of 39 ecological sources were identified, with a total area of 520.98 km2. From the perspective of Dengkou County, the ecological sources are mainly distributed in the central part, accounting for 15% of the total area.

Keywords

Ecosystem services; Ecological source; SOM model.

1. Introduction

In recent years, with the rapid development of urbanization and industrialization in my country, the contradiction between man and nature has become increasingly intensified, directly endangering regional ecological security [1]. The 18th National Congress of the Communist Party of my country placed ecological civilization construction in a prominent position in the overall work and comprehensively strengthened ecological civilization construction. During the "14th Five-Year Plan" period, China's ecological civilization construction has entered a critical period for achieving a qualitative change in the improvement of ecological environment quality from quantitative change. The construction of ecological security pattern has become a research boom with widespread attention. The construction of ecological security pattern mainly takes provinces, cities and counties as basic research units at the macro scale, and grids as basic research units at the micro scale [2]. The county plays an indispensable role in the construction of ecological security pattern. Through scientific planning and effective implementation, it can play an important role in promoting ecological civilization construction, ensuring the stability of the ecosystem and supporting sustainable development [3]. However, the core link in the construction of ecological security pattern is the determination of ecological source areas.

In recent decades, with the deepening of the concept of ecological civilization, scholars have mostly used traditional overlay analysis to identify ecological sources. The traditional overlay analysis method conceals the original information covered by the influencing factors, resulting in the homogenization of ecological sources. Therefore, this study introduced the self-organizing map neural network algorithm (SOM model), input the ecosystem service function importance evaluation factor into the SOM model, and identified the ecological source. The SOM model can avoid subjective evaluation, empowerment and classification processes. It is unsupervised and the clustering results have the advantages of topological structure preservation, consistent probability distribution and visualization [4]. This model can quantitatively analyze the differences and similarities of ecosystem service functions in different regions. And it can retain the original information during the analysis process, thereby completing the entire process of ecological zoning [5-7].

Ecological source areas are core ecological patches with high ecosystem service functions, and they play an important role in maintaining ecosystem integrity and promoting ecological processes [8]. Therefore, this study selected five ecosystem service function importance evaluation factors, namely soil conservation, habitat quality, windbreak and sand fixation, water conservation, and food supply, as indicators, and then used the SOM model to identify ecological source areas, in order to provide a basis for the construction of the ecological security pattern of Dengkou County.

2. Overview of the study area

Dengkou County is located in the southwest of Bayannur City, Inner Mongolia Autonomous Region. It is the junction of the Hetao Plain and the Ulan Buh Desert. It is backed by Yinshan Mountain in the north and faces the Yellow River in the south. Its geographical location is 106º9′～107º10′ east longitude and 40º9′～40º57′ north latitude.

It borders Hangjinhou Banner and Linhe District in the northeast, Jilantai-Tukumu Highway in Alxa Left Banner in the west, Langshan in the northwest, the Yellow River in the east, and Alxa Left Banner in the south. The total administrative area is 367,626.93 hectares. The permanent population is 116,400. The county has 4 towns, 1 sumu, 5 state-owned farms, 47 gacha villages and 46 sub-farms. Dengkou County has a temperate continental climate with large temperature changes and an average annual temperature of 9.4°C. The temperature difference between day and night is large, with a daily difference of 14 to 20°C from April to September. Precipitation is scarce, with 41 days of rainfall throughout the year, an average annual precipitation of 150.6mm, the highest rainfall month is September, and the total evaporation is 2862.8mm. Southwest winds prevail all year round, with an average annual wind speed of 3.2m/s.

3. Research methods

3.1. Evaluation of the importance of ecosystem service functions

Ecological source areas are core ecological patches with high ecosystem service functions, which play an important role in maintaining ecosystem integrity and promoting ecological processes[8]. Therefore, this study selected five ecosystem service function importance evaluation factors, namely soil conservation, habitat quality, windbreak and sand fixation, water conservation, and food supply, as indicators. For details, see Table 1:

Table.1 Evaluation indicators of the importance of ecosystem service functions

index	Implementation	formula	References
Habitat quality	InVEST-Habitat quality	$Q_{xj} = H_j\left[1 - \left(\frac{D_{xj}^z}{D_{xj}^z + k^z}\right)\right]$ In the formula,Qxjis the habitat quality of grid x in land use and land cover j; is the habitat suitability of habitat type j; Dxj is the habitat degradation degree of grid x in land use j; z and k are constants	[9]
Water conservation	Water balance equation	$WR_{ij} = Y_{ij} - Runoff_{ij}$ In the formula,WRij is the annual water holding capacity of grid cell i on land use type j; Yij is the annual water yield of grid cell i on land use type j; Runoffij is the surface runoff of grid cell i on land use type j.	[10]
Food supply	Spatial interpolation	$P_{ij} = NDVI_{ij} \times \frac{P_j}{NDVI_j}$ In the formula,Pij is the grain output of grid i in county j, NDVIij is the NDVI value of cultivated land grid i in county j, Pj is the total grain output of county j for the whole year, and NDVIj is the sum of the NDVI values of all cultivated land grids in county j.	[11] [12]
Wind and sand fixation	RWEQ	SR=SLq- SL In the formula,SR is the amount of sand fixation SLq is the potential amount of wind erosion SL is the actual amount of wind erosion	[13] [14]
Soil Conservation	RUSLE	$Q_{sr} = Q_{se\_p} - Q_{se\_a}$ In the formula, Qsr Soil conservation amount Qse_p Potential soil erosion amount Qse_a Actual soil erosion	[13] [15]

3.2. Ecological origin identification usingself-organizing map neural network (SOM)

The SOM model is a network structure consisting of an input layer and an output layer (Figure 1), where each grid unit is called a neuron. The neurons in the input layer and the output layer are connected to each other by weight vectors. These vectors constitute the weight matrix of the SOM. During the training process, the neurons of the SOM adjust their weights through competitive learning to better fit the input data. Given an input vector, all neurons calculate the similarity with the vector, usually using Euclidean distance or cosine similarity. The neuron that is most similar to the input vector is called the best matching unit, or winning neuron (BMU) [16-17]. The weights of the BMU and its surrounding neurons (neighborhood) are adjusted to make them closer to the input vector. The topological structure of the input space is mapped to the topological structure of the SOM, that is, similar input vectors may also be close to adjacent positions in the SOM. The specific calculation process of the SOM is as follows:

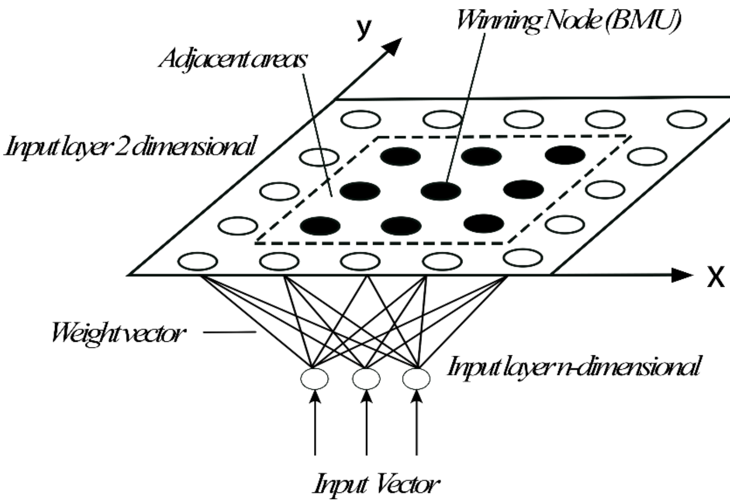

Fig. 1 Network structure of the self-organizing map neural network SOM model

Initialization: Initialize the weight matrix of SOM, which can be initialized randomly or using a specific method such as PCA (principal component analysis); Training: For each input vector, calculate the similarity of all neurons with the vector and then determine, determine the BMU. Update the weights of BMU and its neighborhood neurons to adjust them to the input vector. The domain range gradually decreases as training progresses, which is called the decay of the learning rate and neighborhood radius. Repeat the training until SOM reaches a stable state or reaches a predetermined number of training times; Mapping: After training, each input vector is mapped to a specific position (x, y) on the output layer of SOM, which can be determined by its BMU or its nearby neurons.

This study uses the SOM model to perform cluster analysis on the study area based on the evaluation index of the importance of ecosystem service functions, and specifically uses the kohonen package in R language 4.0 software to perform SOM cluster analysis.

4. Results and analysis

4.1. Results of ecosystem service importance evaluation

Results of single factor evaluation based on ecosystem service importance (Figure 2). The four indicators of windbreak and sand fixation, habitat quality, water conservation and grain output generally present a spatial pattern of "high in the east and low in the west", while the soil conservation indicator presents a pattern of "high in the west and low in the east". Among them, the high-value areas for windbreak and sand fixation are mainly distributed in Longshenghe Town, Hatengtaohai Farm, Shajintaohai Sumu and the southeastern part of Bayantaohai Farm, the western part of Ulanbuh Farm and the eastern and southern areas of the Desert Forestry Experimental Center, which are mainly composed of cultivated land and grassland; the habitat quality and water conservation are both high in the east and low in the west. This is because the western part of the study area is dominated by desert with very low vegetation coverage, resulting in low habitat quality and water conservation functions; the high-value areas for grain production are scattered in the eastern part of the entire study area, which is a concentrated area of human production activities and the main distribution area of grain production bases in Dengkou County; the soil conservation function in the study area is generally low, and the high-value areas are scattered in the mountainous areas with low vegetation coverage in the northwest.

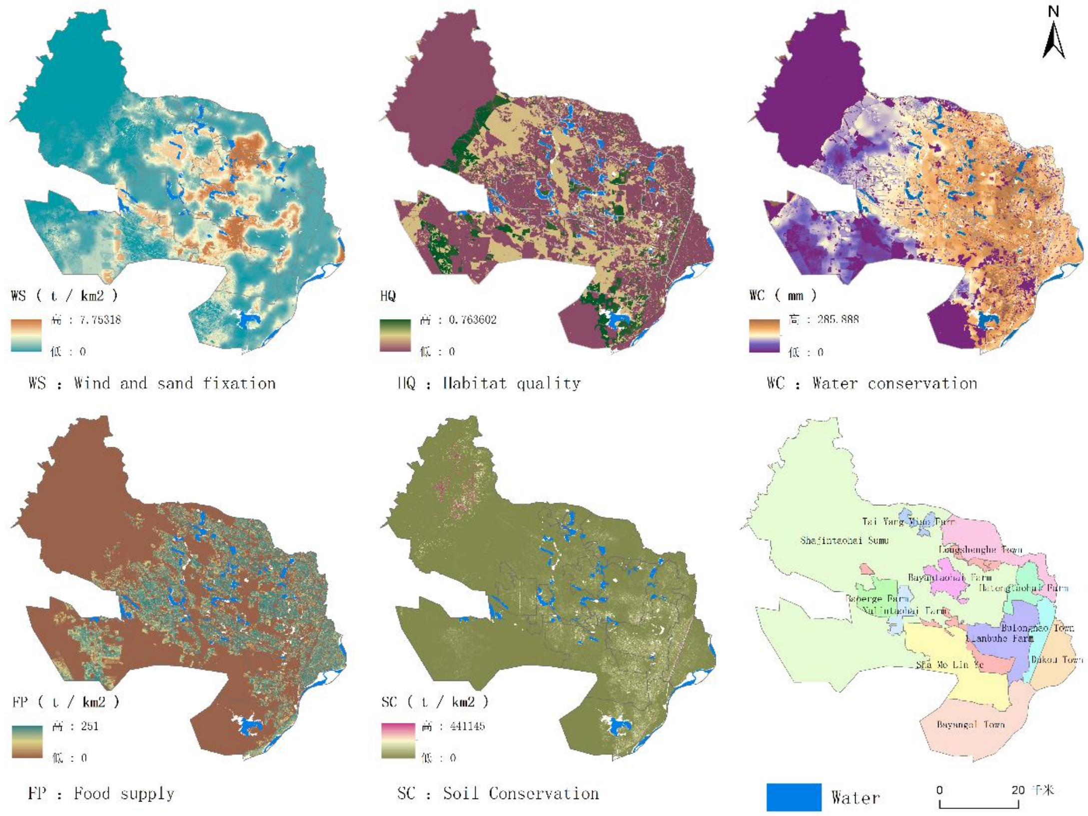

Fig.2 Spatial distribution of importance of ecosystem service functions

4.2. Preliminary identification of ecological sources based on SOM

This paper extracts the evaluation indicators of the importance of ecosystem service functions in the study area into a grid of 250 × 250 m, and performs SOM clustering using the kohonen package in R language 4.0 software. Davies-Bouldin Index and Total Within-Cluster Sum of Squares (Total WSS for short) are functions used to determine the optimal number of classification groups. Davies-Bouldin Index measures the clustering effect by calculating the compactness of each cluster and the separation between different clusters. The smaller the value, the better; Total WSS reflects the sum of the squares of the distances from all data points within the cluster to the centroid of the cluster to which it belongs. It uses the elbow rule to determine the optimal number of clusters. When Total WSS gradually decreases with the increase in the number of clusters, there is usually an "elbow point", indicating that after this point, the improvement brought by increasing the number of clusters becomes insignificant, which means that this is a better number of clusters (Figure 3a). Therefore, combining Davies-Bouldin Index and Total WSS, the study area is divided into five types of ecosystem service clusters (Figure 3c).

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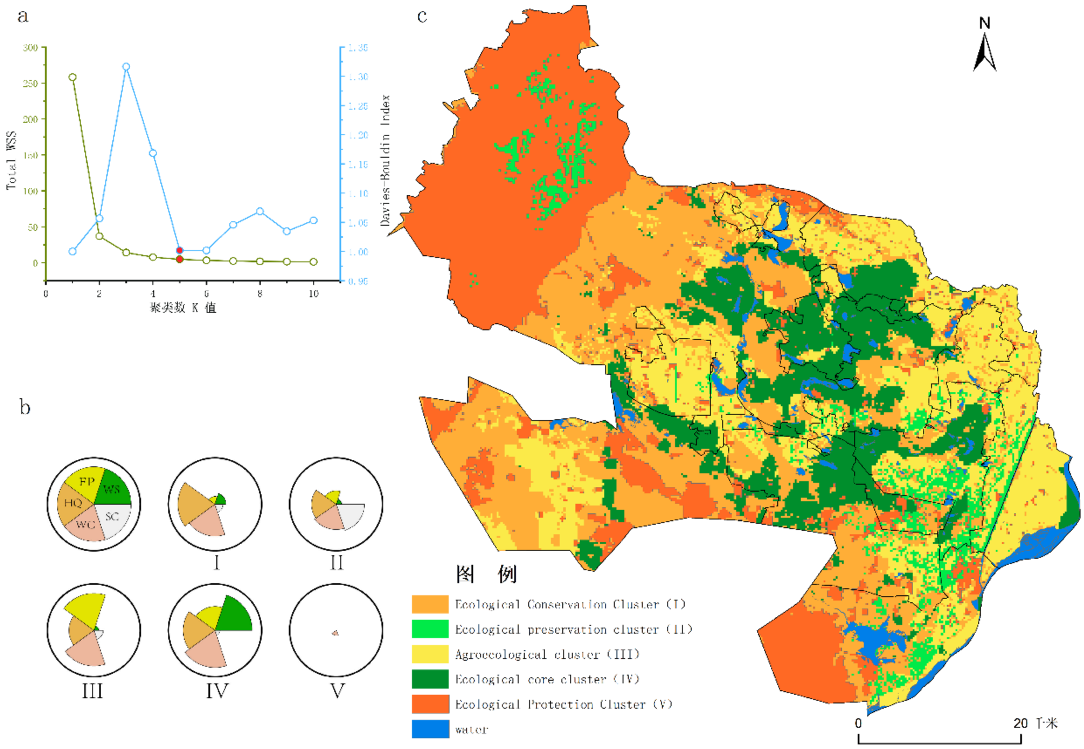

Fig.3 Spatial distribution of ecological sources

After SOM clustering of ecosystem service importance evaluation factors, Dengkou County was integrated into five ecosystem service clusters, named from I to V as ecological conservation cluster, ecological preservation cluster, agricultural ecological cluster, ecological core cluster and ecological protection cluster. The ecological conservation cluster is dominated by water conservation and habitat quality, and the windbreak and sand fixation, grain output and soil conservation capacity are relatively low. It is mainly distributed in the northwest, where shelter forests and grasslands are the main habitats, and the habitat quality is relatively outstanding; the soil conservation, water conservation and habitat quality in the ecological conservation cluster are relatively high, among which soil conservation is more prominent and higher than other clusters; the grain supply in the agricultural ecological cluster is higher than that in other clusters; the ecosystem services of the ecological core cluster are maintained at a high level, dominated by water conservation, windbreak and sand fixation, habitat quality and grain output; the ecological protection cluster has only a small amount of water conservation. Codes is a function in the plot package of the R language system, which can generate count maps, show the number of samples mapped in each SOM node and show the clustering density and distribution on different nodes in the SOM network. The longer the petals, the higher the characteristic value (Figure 3b). Therefore, this paper preliminarily determines cluster IV, which has comprehensive characteristic values and high density, as the ecological source. The fine patches initially determined as the ecological source are filtered with a threshold of 0.45km2 to become new ecological sources. Therefore, the core ecological cluster (IV) will become the source of this study after filtering the fine patches. A total of 38 ecological sources were identified, totaling 534.83 km2. From the perspective of each township, the ecological source is in the eastern and southern areas of Shajintaohai Sumu, the southern part of Longshenghe Town, the middle part of the Desert Forestry Experimental Center Farm, the northwest of Ulanbuhe Farm, the southwest of Nalintaohai Farm, the eastern part of Dukou Town, and the ecological source of Bayantaohai Farm is the largest in the town. Taiyangmiao Farm, Hatengtaohai Farm, Bulongnao Town, Baoergai Farm, etc. are distributed in small quantities. From the perspective of Dengkou County, the ecological source is mainly distributed in the central part, accounting for 15% of the total area of the district.

5. Conclusion and discussion

5.1. Conclusion

This paper takes Dengkou County, Inner Mongolia as the research object, and evaluates the importance of ecosystem services through five evaluation factors: windbreak and sand fixation, habitat quality, soil conservation, water conservation and grain production; using the SOM model, the ecological source is identified based on the evaluation of the importance of ecosystem service functions:

(1) Single factor evaluation results of ecosystem service importance. Spatially, the four indicators of windbreak and sand fixation, habitat quality, water conservation and grain production show a spatial pattern of "high in the east and low in the west" as a whole, and the soil conservation indicator shows a pattern of "high in the west and low in the east".

(2) Ecosystem service importance factors are input vectors, and SOM clustering and integration are performed. They are named from I to V as ecological conservation cluster, ecological preservation cluster, agricultural ecological cluster, ecological core cluster and ecological protection cluster. Cluster IV with comprehensive eigenvalues and high density is preliminarily determined as an ecological source. The fragmented patches initially determined as ecological sources are filtered with a threshold of 0.45 km2 to become new ecological sources. A total of 38 ecological sources were identified, totaling 534.83 km2. From the perspective of Dengkou County, ecological sources are mainly distributed in the central part, accounting for 15% of the total area.

5.2. Discussion

Currently, ecological security pattern is one of the three major strategies for the development and protection of China's land space [18]. However, the identification of ecological sources is of utmost importance. This paper introduces the SOM model into the traditional ecological source identification, selects five factors in the evaluation of the importance of ecosystem services, namely windbreak and sand fixation, habitat quality, soil conservation, water conservation and grain production, and selects cluster IV with comprehensive eigenvalues and high density after input into the SOM model for clustering. The initially identified ecological sources are filtered with a threshold of 0.45 km2 to become new ecological sources. How to define ecological sources and thresholds needs further research and confirmation. The ecological sources in the study area are mainly dominated by water conservation, windbreak and sand fixation, habitat quality and grain production, and their proportions are higher than other classification clusters. It can be seen that the results of ecological source identification are relatively reliable.

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