Water Supply

Water Supply Vol 23 No 9, 3819 doi: 10.2166/ws.2023.215

Agricultural wetland utilization based on land cover restoration and water–ecosystem nexus

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ABSTRACT

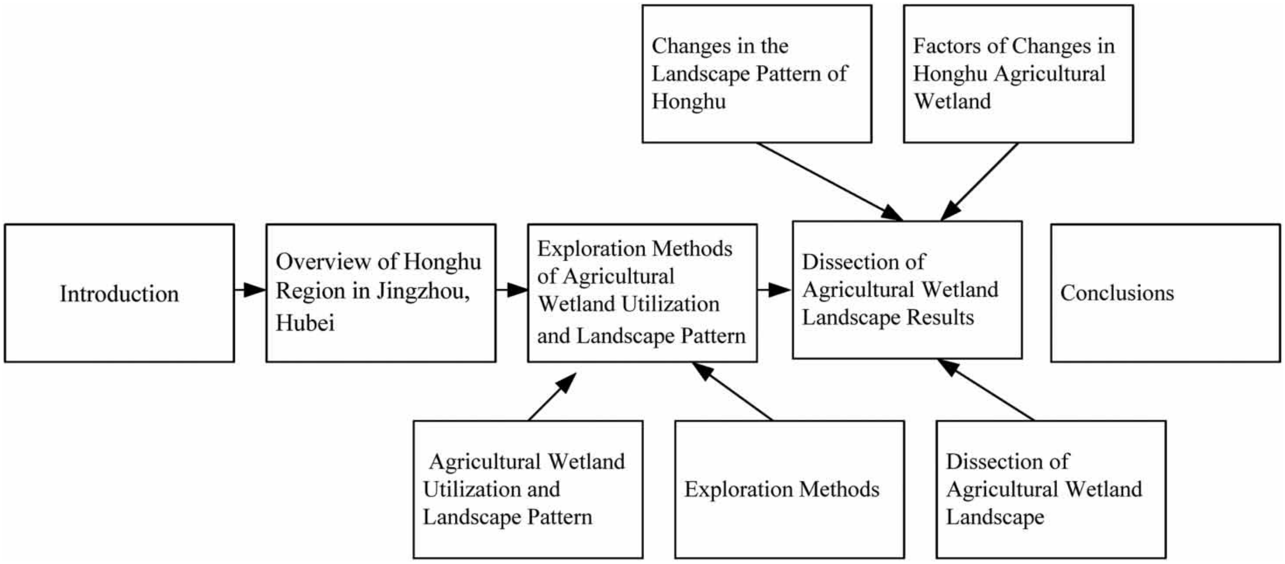
Wetlands, as a special ecological environment, are not only important biodiversity conservation areas but also one of the important agricultural resources. Agriculture plays an irreplaceable role in human society. It is directly related to human survival and development, and is also a part of people's environmental awareness and cultural inheritance. Based on the principles of sustainable development and strengthening environmental protection, people should pay more attention to the development and improvement of agriculture. However, with the advancement of urbanization, the area of wetlands continues to decrease, causing damage to ecosystems and posing a threat to some agricultural production. This article combined the transfer matrix of agricultural wetland utilization, landscape change rate, and landscape pattern index, used RS (Remote Sensing) and GIS (Geographic Information System) technologies to analyze the dynamic changes in agricultural wetland utilization and landscape of Honghu Lake in the Four Lakes region, and explored its changing factors. The results indicated that the construction land area showed an increasing trend in 2016, 2019, and 2022, while the wetland area of rice fields showed a first decreasing and then increasing trend.

Key words: agricultural wetland utilization, Honghu region, landscape pattern, variable factor

HIGHLIGHTS

- The correlation between agricultural wetland and its change factors was analyzed.
- To forecast the future development trend of the Honghu agricultural wetland.
- Help the planning department to adopt corresponding measures and strategies according to the law of change.
- Effective protection of the Honghu agricultural wetland.
- To achieve its sustainable use.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Agricultural wetlands are wetlands that are used for agricultural production and are characterized by abundant water, clean water, rich soil organic matter, and suitability for various crops. Water plays a very important role in agricultural wetlands. On the one hand, water keeps the soil moist, helps plants grow, and provides necessary nutrients for crops; on the other hand, water can also stabilize temperature and promote the growth and development of plant species. It can also reduce soil erosion and prevent the loss of nutrients and organic matter in the soil. Agricultural wetlands also play a positive role in water. Wetlands purify water quality and maintain the stability of water resources by absorbing and filtering pollutants. Water interacts and promotes with other natural elements in agricultural wetlands, forming a complex ecosystem where water plays a crucial role. It is one of the important elements in agricultural wetlands and has significant environmental and economic value. Agricultural wetlands are an ecosystem in which water and agriculture interact and play an irreplaceable role.

Wetlands, as some special landscape, have enormous resource potential and can provide various ecosystem service functions, providing high welfare for human society (Cao *et al.* 2018). The agricultural wetlands in the Honghu region of the Sihu region in Jingzhou are an important component and the most active coupling zone among marine processes, atmospheric processes, geological processes, biological processes, and human activities. They not only provide various resources for human production and life, but also have various functions such as regulating climate, controlling soil erosion, degrading pollutants, beautifying the environment and improving living conditions. It is of great significance for maintaining regional and global ecosystem balance. Water, food, energy, and wetlands complement each other. Without water, wetlands cannot exist. With water, wetlands exist accordingly. Food can be produced in wetlands, and wetlands can utilize water and food to generate energy.

In recent years, due to natural factors such as global warming and development activities, a large number of agricultural wetlands in the Sihu region have been damaged (Liu *et al.* 2019). Many scholars have conducted ecological risk assessments and explored vegetation coverage and landscape patterns in the Sihu region (Niu *et al.* 2019; Zhenxing *et al.* 2020). The changes in landscape pattern are jointly influenced by multiple factors such as nature, biology and society. The research results help to reveal its evolution mechanism and laws, thereby predicting its evolution trend and achieving its sustainable utilization. At present, the main methods for studying landscape patterns are to use Markov models (Glennie *et al.* 2023), dynamic simulations, and other technologies. By using Markov models, it is possible to quantitatively describe landscape patches in a region and predict their development trends. This landscape pattern indicator (Yu *et al.* 2020) can quantitatively reflect the static and dynamic landscape patterns of the same location, different times and different locations. On this basis, quantitative analysis of landscape patterns in different regions and scales is conducted using GIS technology.

After 1950, due to the combined effects of natural and human factors, the area of Honghu decreased, leading to frequent dry deposition and significant changes in surface cover (Xu *et al.* 2022). The ecological function of the Honghu wetland is gradually deteriorating, leading to serious environmental problems such as water scarcity, wetland shrinkage, sediment deposition, dry deposition, and decreased biodiversity. On this basis, an in-depth analysis of the changes in the utilization mode and landscape pattern of the Honghu wetland, revealing its changing patterns, driving factors and characteristics, is of great significance for the future planning, establishment of ecological protection areas and restoration of the ecological environment of Honghu. Although some scholars have conducted some research on the changes in the landscape pattern of Honghu, there is a lack of specific analysis for different regions and targeted ecological planning (Zhang *et al.* 2022). This paper selected the Honghu region in Jingzhou, Hubei Province as the research region, used the principles and methods of landscape ecology, RS, GIS, and other related technical means to support (Wei *et al.* 2020), studied the use and change of agricultural wetlands in the Honghu region and analyzed the transfer matrix, dynamic degree, and landscape pattern index of agricultural wetlands in the Honghu region. The landscape dynamics change patterns in the past 3 years, 2016, 2019, and 2022, were revealed, providing long-term sustainable development of agricultural wetlands in the region by combining water and food.

The research focus of this article is to explore how to balance the relationship between land cover restoration and water ecosystems in the process of utilizing agricultural wetlands, in order to achieve sustainable development of agricultural wetlands. Based on previous studies, it can be concluded that the utilization of agricultural wetlands should not only take into account the benefits of agricultural production but also pay more attention to the maintenance and restoration of land ecosystem and water ecosystem. Therefore, the relationship between the use of agricultural wetland and the ecosystem was deeply explored and analyzed in this paper. The theoretical contribution of this paper is to emphasize the importance of ecosystem in the current research on the utilization of agricultural wetland, and put forward the management idea of 'sustainable development and ecological security', which provides a new idea and theoretical support for the sustainable utilization of agricultural wetland. The study can also provide references for policymakers, agricultural producers, and researchers to promote the conservation and sustainable use of wetland resources.

The innovation of this article lies in the organic integration of agriculture and wetland ecosystems, promoting comprehensive ecosystem management, and achieving a win–win situation between ecosystem services and agricultural production. In fact, it has achieved a positive interaction between agricultural production and wetland ecosystems, maximizing the ecological benefits of agriculture while ensuring the sustainability of agriculture and the health of ecosystems.

2. OVERVIEW OF THE HONGHU REGION IN JINGZHOU, HUBEI

Taking the Honghu region, one of the Sihu in the Jianghan Plain as an example, Honghu is the central area of the Jianghan Plain in Hubei Province. Its geographical location is between E112°00′–E114°05′ and N29°21′–N30°00′. Honghu is the seventh largest freshwater lake in China and the largest lake in Hubei Province, which is known as the 'Thousand Lakes Province'. It is the only large-scale freshwater lake that maintains a good ecological environment and meets overall water quality standards. It has 34,820 m^2 of water surface, integrating domestic water, water conservancy, fisheries, shipping, tourism, and irrigation. In addition, there are many kinds of aquatic animals in Honghu. Therefore, maintaining the ecological environment of Honghu can have a huge social, economic, and ecological impact. Honghu is a warm and humid northern subtropical region with an average annual temperature of 16.6 °C and a frost-free period of 264 days throughout the year. The average temperature in July is 28.9 °C, with a minimum temperature of −13.2 °C and a total of 1,987.7 h of sunlight throughout the year. Winds are predominantly from the northwest in winter and from the south in summer. The temperature of lakes can reach a maximum of 36 °C and a minimum of 2 °C.

From a macro perspective, the geomorphic type of Honghu is relatively single. Honghu is basically composed of a series of river depressions, so it has the characteristics of 'large flat and small uneven' and obvious differentiation of micro geomorphic morphology. There are significant differences in material composition and morphology between the low-humidity plains and the high-humidity plains in the lower reaches of the Yangtze River. In addition, the lakes and dams in the lower reaches of the river also exhibit a basin-like and plate-like micro-topography with four-side high and middle low, resulting in differences in groundwater level, material composition, soil properties, etc. This has had a huge impact on the regional agricultural production mode and ultimately formed the existing agricultural structure and agricultural wetland landscape pattern in the Honghu region. The Honghu basin in Jingzhou is the farmland area with the best soil condition in Hubei Province. Its soil distribution is restricted by micro-topography, human factors, and other factors. The lake cofferdam and the 'concentric circle' type are the main types. From the edge of the cofferdam to the bottom of the cofferdam, there are 'grey tide soil', 'gleyed paddy soil', 'swamp type', and 'waterloggogenic paddy soil', respectively. The soil structure is good, among which, the penetration rate of medium and light soils exceeds 80%. The organic matter content of 80% of paddy soil exceeds 2%. The location overview of the Honghu agricultural wetland is shown in Figure 1.

3. EXPLORATION METHODS OF AGRICULTURAL WETLAND UTILIZATION AND LANDSCAPE PATTERN

3.1. Agricultural wetland utilization and landscape pattern

3.1.1. Overview of agricultural wetland utilization

(1) Definition of agricultural wetlands

Agricultural wetlands refer to the combination of agriculture and wetlands in the region after human large-scale development of natural wetlands after the rise of agriculture.

There are three reasons for the formation of agricultural wetlands: Firstly, the area is mainly dominated by monsoons with more natural precipitation. Secondly, the terrain is flat and low-lying, making it easy to form natural swamps. Thirdly, after a long period of cultivation, large-scale agriculture has been formed.

Specifically, according to the results of Chinese comprehensive agricultural zoning, the annual precipitation of less than 500 mm is classified as arid areas; the annual precipitation between 500 and 800 mm is classified as semi-arid areas; the annual precipitation more than 800 mm is classified as wet areas. The agriculture within the arid and semi-arid regions is collectively referred to as arid and semi-arid agriculture. China is divided into two regions, which are the southeast and northwest with the 800 mm precipitation as the boundary. A large number of agricultural low-humidity areas evolved from natural wetlands are distributed in the large humid area in the east south of the 800 mm precipitation boundary. These low-humidity

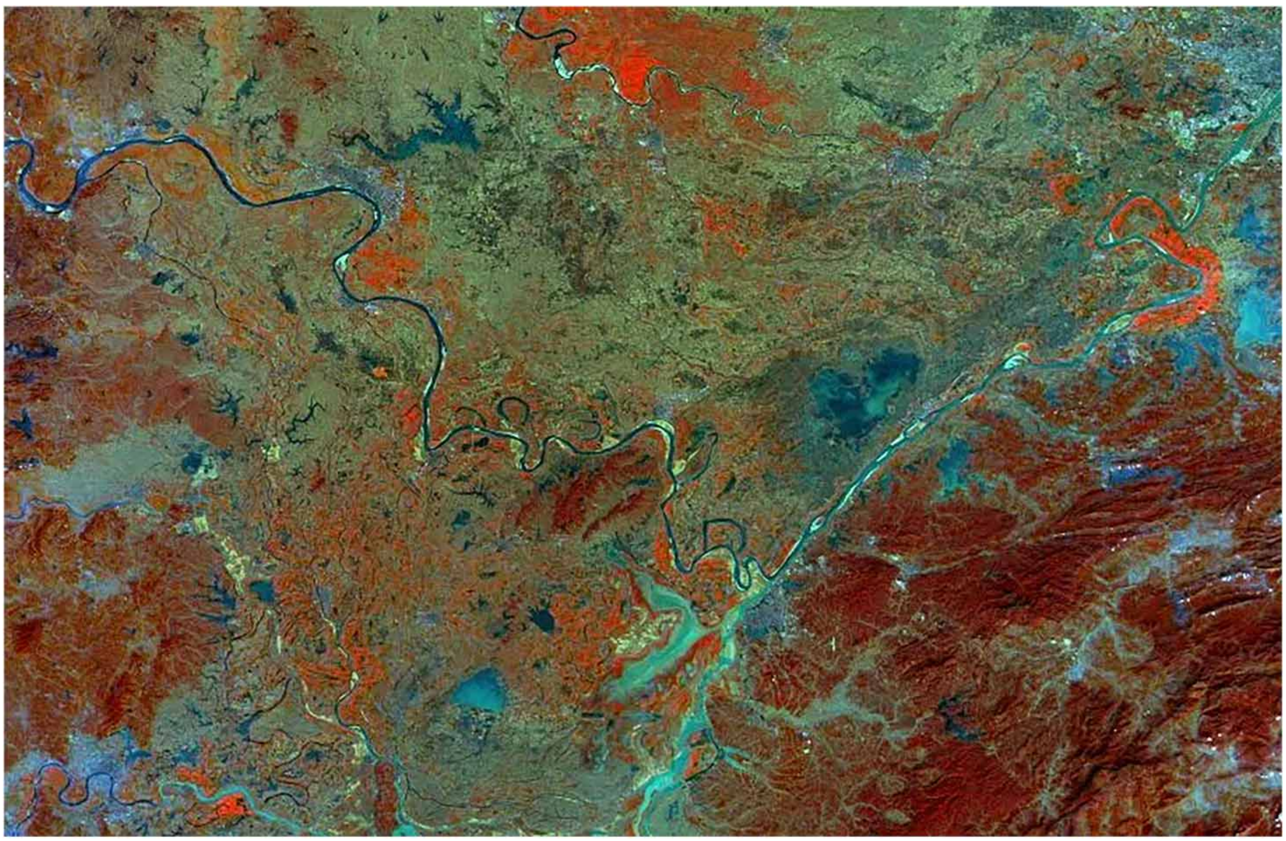


Figure 1 | Location profile of the Honghu agricultural wetland in the Sihu region.

areas mainly include: the middle and lower reaches of the Yangtze River Plain, the plains in the middle and lower reaches of the Huai River, the Songnen-Sanjiang Plain, the reed marshes in the east of the Taihu, the Sanjiang Plain, and the Pearl River Delta. Agricultural wetlands refer to the combination of wetlands formed by human development from natural wetlands in humid and rainy areas with agriculture.

(2) Basic characteristics of agricultural wetlands

The main problem faced by agricultural wetland development is flood disasters. The research on agricultural wetlands is closely related to waterlogging disasters. Taking Honghu as an example, a series of studies were conducted on it. Agricultural wetlands have the following basic characteristics:

Good agricultural location advantages: Chinese agricultural wetlands are mainly distributed in the middle and lower reaches of the Yangtze River Plain, the Taihu Plain in the lower reaches of the Yangtze River and the Pearl River Delta. Most of them are agricultural and sideline production areas in China, and the agriculture is relatively developed. The region is sunny, rainy, hot and rainy, with flat terrain, deep soil and good natural conditions for agriculture. It is currently a region with a high level of grain production in China.

Fragile agricultural ecosystem: When developing agricultural wetlands, there may be some constraints. On the one hand, it causes great damage to the natural ecosystem of wetlands, and on the other hand, it is also constrained by the natural ecosystem of wetlands. Flooding disasters have become the main constraint factor for agricultural production (Shaoli *et al.* 2007; Wu *et al.* 2022). The agricultural 'flood and drought' problem in the Jianghan Plain of Hubei Province has become an important bottleneck for the sustainable development of agriculture, presenting the characteristics of 'flood and drought disasters' between years and regions.

Agricultural wetlands have rich ecological diversity, with crop cultivation and aquaculture being the most developed. From agricultural cultivation to the cultivation of vegetables, fruits, trees, and flowers, and from animal husbandry to aquaculture, the original product manufacturing industry is transformed to the processing service industry. The development of agricultural wetlands cannot be separated from the science of soil and water resources, nor can it be separated from the support of wetland ecosystems. Agricultural wetlands are closely related to specific regions. Therefore, agricultural wetland science should pay more attention to the comprehensive development of regional agriculture.

(3) Principles of agricultural wetland utilization (Yang *et al.* 2022)

Ecological protection principle: As one of the most precious natural resources in cities, agricultural wetlands are a non-renewable natural heritage. Therefore, their existence value is fundamental. Agricultural wetlands and their surrounding environment should be ecologically protected to maintain their original natural attributes and integrity.

Principle of reasonable utilization: In the process of constructing a wetland park, it is necessary to achieve its reasonable development and utilization. Before design, it is necessary to investigate and study the local climate conditions, regional culture, humanities and other factors and adjust measures to local conditions to maximize the various benefits of the wetland, such as economic and social benefits. To fully utilize various animal and plant resources in wetlands, which have both economic value and ornamental value, agricultural wetlands should also be fully utilized. Activities such as leisure vacation and science education should be carried out.

Sustainable development principle: In the long run, the development and construction of agricultural wetlands should maintain a certain degree of elasticity, which means that in agricultural production, it is necessary to balance the integrity of the ecosystem with the needs of economic development, adhere to the principle of sustainable development, and provide certain flexibility and adaptability in specific implementation.

3.1.2. Concept of landscape pattern

Landscape pattern, usually referring to its spatial pattern, is the arrangement and combination of landscape elements of different sizes and shapes in space, including the type, number, spatial distribution and configuration of landscape composition. Different types of patches can be spatially distributed in a random, uniform, or clustered pattern (Risser 2021; Walsh *et al.* 2022). It not only reflects the heterogeneity of the landscape, but also reflects the mutual influence of various ecological processes at different scales.

3.1.3. Landscape pattern indicators

(1) Indicator selection

The landscape pattern index can better reflect the evolution characteristics of the landscape pattern in this area, and has an important guiding role in the landscape ecology planning and land space planning of this area. There are three main types of landscape pattern distribution indicators, namely patch, type and landscape. This article selected four indicators for analysis: the total number of patches (NP), patch density (PD), largest patch index (LPI), and landscape shape index (LSI) of the Sihu in 2016, 2019, and 2022.

(2) Indicator definition

NP: It refers to the sum of various types of patches in the landscape.

PD: It represents the density of a patch in a landscape, which can reflect the overall heterogeneity and fragmentation of the landscape, as well as the degree of fragmentation of a certain type. It can also reflect the heterogeneity of the landscape per unit area (Li *et al.* 2019).

LPI: It refers to the proportion of the largest patch area in a certain type to the entire type area (at the type level), or the proportion of the largest patch area in a landscape to the entire landscape area.

LSI: It refers to the shape index of patches in a landscape pattern, which is used to calculate the degree of deviation between the shape of a patch in an area and a circle or square of the same area, in order to measure the complexity of its shape (Holgersson *et al.* 2022).

3.2. Exploration methods

3.2.1. Exploration method conceptual model

The conceptual model diagram is shown in Figure 2:

3.2.2. Exploration method formula

(1) Area change matrix

The area transfer matrix is an important quantitative method for studying the quantity and direction of mutual transformation between different landscape types. It can transform the structural characteristics of landscape changes and the transformation direction among different types. The mathematical form of the transfer matrix is:

$$H_{ab} = \begin{bmatrix} H_{11} & H_{12} & \dots & H_{1m} \\ \dots & \dots & \dots & \dots \\ H_{m1} & H_{m2} & \dots & H_{mm} \end{bmatrix} \quad (1)$$

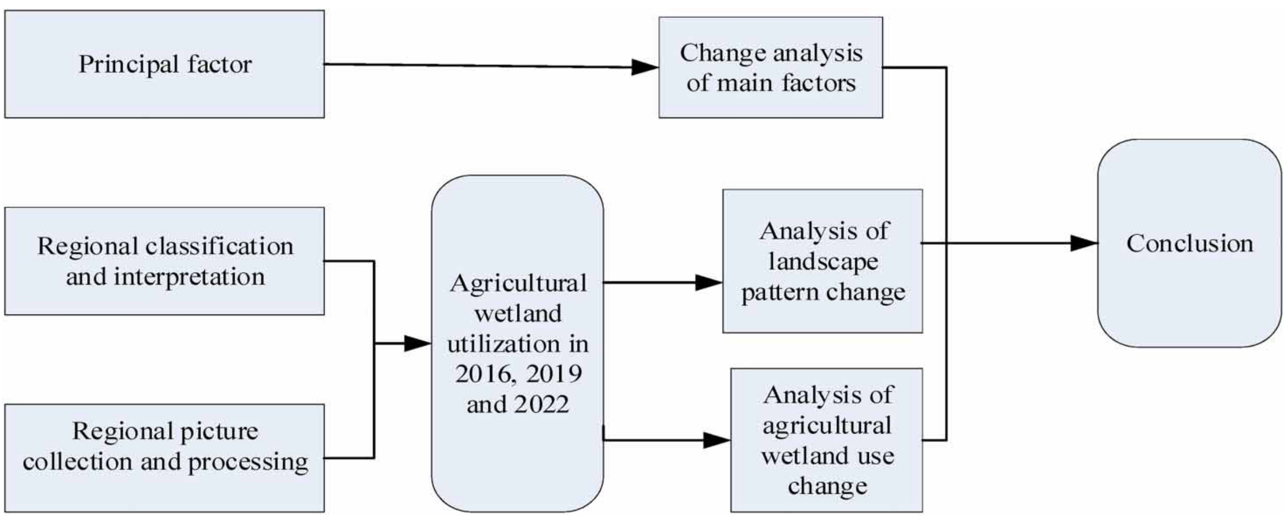


Figure 2 | Conceptual model of research methods.

In Formula (1), m is the number of agricultural wetland utilization types before and after migration; a is the agricultural wetland utilization type before migration; b is the agricultural wetland utilization type after migration; H is the area converted from wetland type a to wetland type b.

(2) Change rate indicator

1. Dynamic degree of single agricultural wetland utilization: The dynamic degree of single agricultural wetland utilization expresses the quantity change of certain agricultural wetland utilization within a certain time range in a certain research area, and its expression is:

$$B = \frac{T_i - T_j}{T_i} \times \frac{1}{D} \times 100\% \tag{2}$$

In Formula (2): B represents the usage of a specific agricultural wetland during the research period; T_i and T_j represent the quantity of agricultural wetland utilization during the initial and final stages of the study, respectively; D is the length of the research period. When the time period of D is set to year, B is the annual change rate of a specific agricultural wetland during that time period.

2. The dynamic degree of comprehensive agricultural wetland utilization: The dynamic degree of comprehensive agricultural wetland utilization reflects the overall landscape changes of a certain research area over a period of time, and its expression is:

$$CN = \left[\frac{\sum_{e=1}^{z} \Delta \mathrm{CH}_{e-f}}{2\sum_{e=1}^{z} \mathrm{CH}_e} \right] \times \frac{1}{Z} \times 100\% \tag{3}$$

In Formula (3): CH_e is the utilization area of agricultural wetlands in category e at the monitoring start time; $\Delta\mathrm{CH}_{e-f}$ is the absolute value of the area converted from category e agricultural wetland utilization to non category e agricultural wetland utilization during the monitoring period; Z is the investigation time range. When the time period of Z is set to years, the value of CN is the comprehensive rate of land use change in the study area for each year.

There is a close relationship between exploration methods and agricultural wetland utilization based on land cover restoration and water ecosystem relationships. Exploration methods refer to scientific investigations, sampling, and data collection activities carried out to obtain relevant information, understand phenomena, or solve problems. In the study of agricultural wetland utilization based on the relationship between land cover restoration and water ecosystem, exploration methods play an important role, mainly reflected in data collection, remote sensing technology application, hydrological measurement and monitoring, and biological investigation and sample collection. Through the application of exploration methods, a large amount of empirical data can be obtained to gain a deeper understanding of the impact mechanism of land cover restoration and water ecosystem relationship on agricultural wetland utilization. These data and information provide scientific support for formulating scientific strategies and management measures for agricultural wetland utilization, as well as scientific basis for decision-makers and farmers to promote the coordinated development of agriculture and water ecosystems.

4. DISSECTION OF AGRICULTURAL WETLAND LANDSCAPE RESULTS

4.1. Dissection of agricultural wetland landscape

4.1.1. Classification of agricultural wetland landscape

The classification of wetland types is a prerequisite for conducting research on the evolution of landscape patterns, and it is also the basis for correctly understanding the evolution of landscape patterns. Due to the different regional characteristics of wetlands, at present, countries have not formed a unified understanding of the principles, indicators and methods of their classification. Therefore, in practice, it is usually combined with the remote sensing characteristics of the sites in the study area, with reference to relevant classification standards and interpretation marks, to build a set of wetland classification system suitable for the study region (Mahdianpari *et al.* 2020; Asare *et al.* 2022). Based on the *National Wetland Classification Standard*, the *Convention on Wetlands*, and remote sensing images, the Honghu farmland wetland in the Sihu region was classified (Bridgewater & Kim 2021). According to the current situation and characteristics of agricultural wetlands in the Honghu region, a wetland classification system suitable for agricultural wetlands in the Sihu region was established. The agricultural wetlands in the Sihu region were divided into agricultural wetlands and non-agricultural wetlands. Agricultural wetlands include paddy wetlands and dry field wetlands. Non-agricultural wetlands include wetland types such as forest and grass land, bare ground and building land, forming the landscape classification system of the region. The classification system is shown in Table 1.

4.1.2. Change of agricultural wetland landscape

From Table 2, it can be seen that in the agricultural wetlands of the Honghu region in 2016, 2019, and 2022, the paddy wetlands decreased from 12,135 hm^2 in 2016 to 12,010 hm^2 in 2019 with a decrease of 0.3%. Then the paddy wetlands increased to 12,450 hm^2 in 2022 with an increase of 1.1%. Dry field wetlands, forest and grass land and bare ground have been decreasing all the time, with the largest reduction in bare ground. They decreased from 16.7% in 2016 to 14.4% in 2019 and then to 7.0% in 2022 with a significant decrease of 7.4% from 2019 to 2022. The building land have been increasing for all the time, and the reason for the changes was due to the increase in population and ecological issues, which have led to environmental changes. The 5.1% of building land in 2016 increased to 10.4% in 2019 and then to 21.8% in 2022. As the number of people increased, dry field wetlands decreased. Paddy wetlands first decreased and then increased.

From Table 2, it can be seen that the area of dryland wetlands, forests, grasslands, and bare ground shows a decreasing trend, while the area of rice field wetlands and construction land shows an upward trend, with a significant decrease and increase in bare ground and construction land.

4.2. Changes in the landscape pattern of Honghu

4.2.1. Changes in the landscape pattern of the Honghu agricultural wetland

(1) NP: The total NP refers to the number of consecutive areas of all different types within the study area. By calculating the number of different types of patches, one can understand the complexity and degree of fragmentation of the landscape.

Table 1 | Landscape classification system of the Honghu agricultural wetland in the Sihu region

Wetland classification	Wetland types	Wetland meaning
Agricultural wetland	Paddy wetland	Most of the paddy fields are rice fields, which are distributed on the plain. Some of them are large rice fields and some are distributed around lakes, which are low-lying lake fields.
	Dry field wetland	A land mainly is used for wheat and cotton cultivation, and it is located on the high river bed and channel alluvial plain in the Sihu region, with an elevation of 27–28 m.
Non-agricultural wetland	Forest and grass land	The distribution of forest and grass land in this area is influenced by the agricultural wetland in the Sihu region, and cultivated land is used as a barrier in the Honghu region.
	Bare ground	The ground is bare, devoid of vegetation and unused land.
	Building land	It is mainly some land for building

Table 2 | Data table of the Honghu wetland region in 2016, 2019, and 2022

	2016		2019		2022	
Wetland type	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)
Paddy wetland	12,135	29.3	12,010	29.0	12,450	30.1
Dry field wetland	10,112	24.5	10,096	24.3	8,983	21.7
Forest and grass land	10,126	24.4	9,061	21.9	8,009	19.4
Bare ground	6,896	16.7	5,945	14.4	2,916	7.0
Building land	2,143	5.1	4,300	10.4	9,054	21.8

(2) PD: PD refers to the NP within a given unit of area or length. It reflects the distribution density of patches and is typically used to evaluate the connectivity and fragmentation of landscapes. High PD means that more patches are relatively small or close, while low PD means that fewer patches are relatively large or scattered.
(3) LPI: The LPI is an indicator used to evaluate the size and importance of the largest patch in the study area. The maximum patch index can be used to understand the most significant and concentrated continuous areas in a landscape, which typically have a significant impact on ecosystem function and species protection.
(4) LSI: The LSI is an indicator used to measure the shape characteristics of landscape patches. It involves the shape, boundary length, and compactness of patches. For example, the shape index can be used to evaluate the regularity of patches, the boundary length index can measure the complexity of patches, and the compactness index can describe the compactness of patches. These indices can help one understand the structure and function of landscapes and evaluate their potential impact on ecosystem services.

The landscape pattern changes at the landscape level of Honghu are shown in Table 3. NP of wetland has been increasing in 2016, 2019, and 2022, from 59 in 2016 to 70 in 2019 and then to 88 in 2022. The PD and LSI have also been increasing. Increasing NP and PD indicates that the fragmentation of the Honghu agricultural wetland landscape continued to increase and human activities have had an important impact on the national wetland park. The LPI first decreased and then increased, which was 25.4% in 2016, 14.5% in 2019 and 16.1% in 2022. This showed that the dominance of the agricultural wetland landscape in Honghu had a slight growth advantage after the continuous reduction. The exponential growth of the landscape shape proved that the irregularity of the landscape in the study area have increased year by year.

4.2.2. Landscape pattern changes in patch types

From Figure 3, it can be seen that the NP in paddy wetlands decreased first in 2019 and then increased in 2022. Dry field wetlands, forest and grass land and bare ground have been decreasing, while building land has been increasing. The change in NP directly led to a change in PD.

Table 3 | Landscape pattern changes at the landscape level of the Honghu agricultural wetland

Date	NP (number)	PD (PCS/hm^2)	LPI (%)	LSI (%)
2016	59	17.4	25.4	10.5
2019	70	21.6	14.5	12.8
2022	88	27.5	16.1	13.7

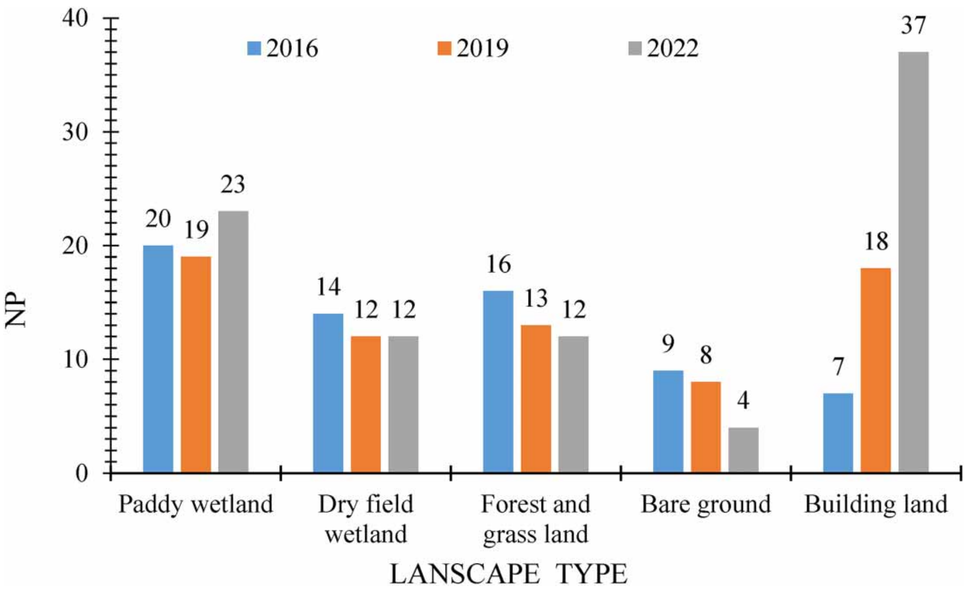


Figure 3 | NP analysis of the Honghu agricultural wetland.

It can be seen from Figure 4 that through the analysis of the change law of NP and PD values in 2016, 2019, and 2022, the landscape fragmentation degrees of dryland wetland, forest and grass land and bare ground in each landscape type were relatively high. Therefore, in the future agricultural wetland landscape ecology planning, ecological restoration of these landscape types should be considered again.

From Figure 5, it can be seen that in 2016, 2019, and 2022, the landscape of paddy field wetlands first decreased and then increased, while dry field wetlands, forest and grass lands and bare ground have been decreasing. The LPI of building land has been increasing.

From Figure 6, it can be seen that the value of LSI could reflect the shape changes of the landscape. The larger the value the more complex the shape of the landscape. The landscape shape value of building land changed greatly, from 1.3% in 2016 to 4.2% in 2019 and then to 6.1% in 2022. The changes in paddy wetlands, forest and grass land and bare ground were not significant. Dry field wetlands changed from 2.3% in 2016 to 2.2% in 2019 and then to 1.1% in 2022, with significant changes. Due to the policy of returning farmland to wetlands, many dry field wetlands have become paddy field wetlands.

4.3. Factors of changes in the Honghu agricultural wetland

By analyzing and studying changes in landscape patterns, the role of landscape pattern factors can be more clearly revealed, thus avoiding the fragmented impact of certain factors on landscape patterns to a certain extent (Shilong *et al.* 2022). Overall, there are two factors that cause changes in the landscape pattern. One is natural factor and the other is social factor. The impact of natural factors on landscape is long-term, while social factors can change the overall landscape structure of a region in the short term.

4.3.1. Natural factors

Natural factors have varying degrees of impact on the landscape pattern of farmland humidity in Honghu. Based on natural factors such as climate, terrain and soil, different types of landscape patterns have been formed. Climate factors are key factors affecting landscape patterns. Without human interference, current climate change may cause significant changes in plants, animals and even biological communities. From 1970 to 2022, the average annual temperature in the Honghu region continued to rise, with the highest historical temperature change in the Honghu region between 0.2 and 3.2 °C in 2016. The environment of the Honghu agricultural wetland is very mild. The precipitation in Honghu area has been relatively

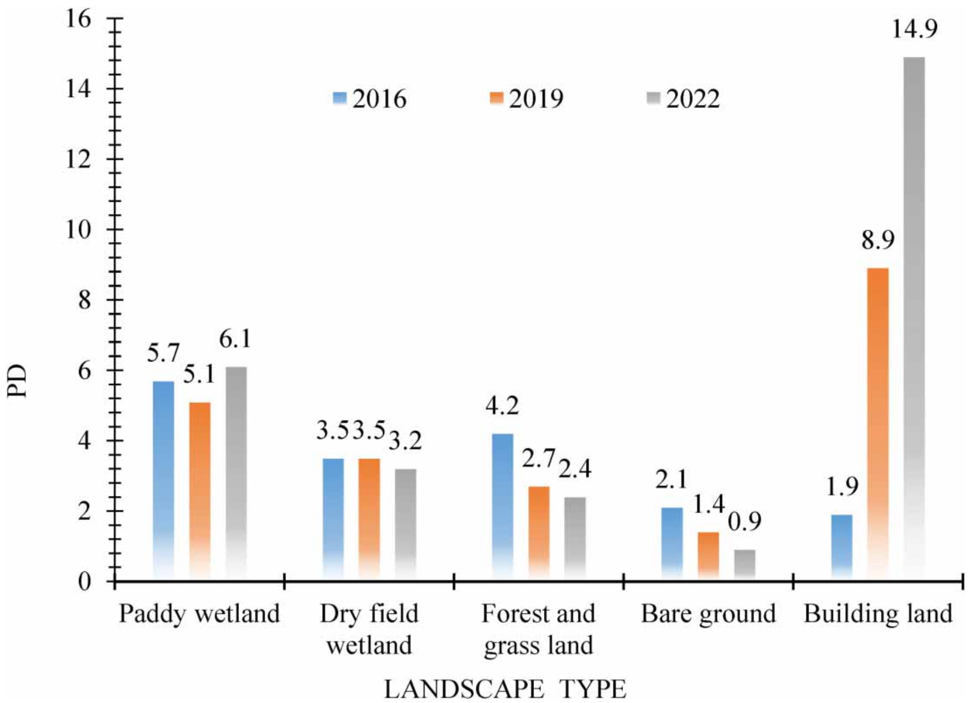


Figure 4 | PD analysis of the Honghu agricultural wetland.

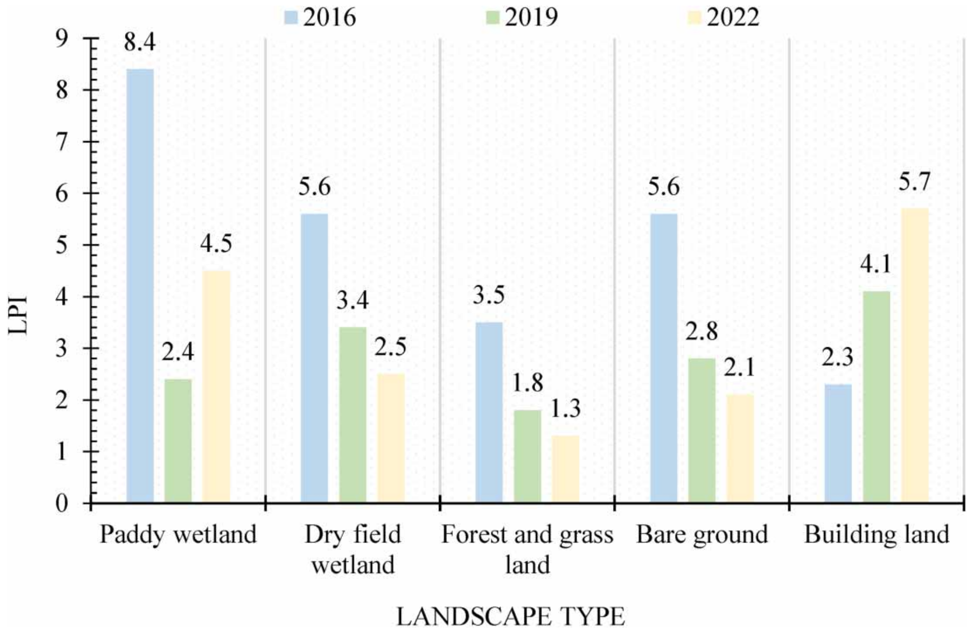


Figure 5 | LPI analysis of the Honghu agricultural wetland.

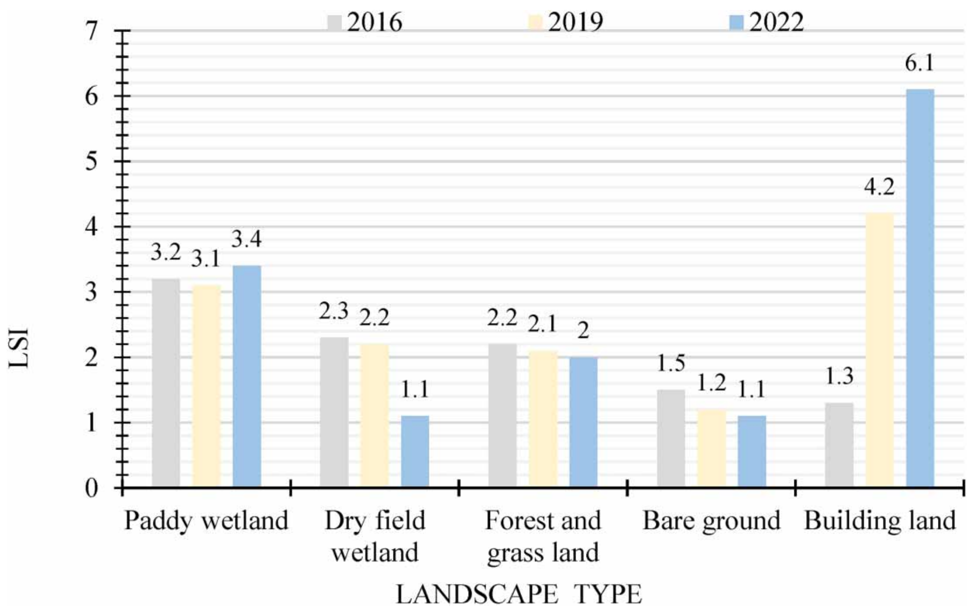


Figure 6 | LSI analysis of the Honghu agricultural wetland.

large for many years, but with the temperature rising, the large evaporation of Honghu also increases greatly. In this case, the available water volume of Honghu wetland is affected by terrain, altitude and other factors, and the area of the Honghu agricultural wetland may shrink. In addition, human activities have significantly changed the landscape pattern of Honghu farmland wetland. In the early 1950s, large-scale 'lake reclamation' led to a significant fragmentation of the overall landscape pattern of farmland and wetlands in Honghu. Since 2005, Hubei Province has carried out large-scale demolition and enclosure of Honghu. Over a period of 3 years, more than 300,000 acres of enclosure nets have been demolished, causing the water environment quality of Honghu to rapidly improve from class IV, class V and other categories to class II and class III after undergoing a baptism. This has promoted the rapid development of agricultural wetlands in Honghu and the connection between wetland patches, expanding the area of wetland patches and improving the overall landscape quality of wetland plants.

4.3.2. Economic factors

Economic factors: According to statistical data on population mobility, the GDP of Jingzhou City has been continuously increasing since 2011, which is the result of the rapid economic development of Jingzhou City and an important reason for the formation of the Honghu agricultural wetland. The construction of the Honghu agricultural wetland has gradually reduced the original types of dry field wetlands, and all bare ground within the Honghu landscape has been gradually replaced by other landscape types during the development and renovation process, resulting in certain impacts on the Honghu agricultural wetland.

5. CONCLUSIONS

The study of agricultural wetland can reveal the evolution characteristics of agricultural wetland at different time scales, and indirectly reflect the landscape pattern of agricultural wetland to a certain extent. By analyzing the correlation between agricultural wetland and its change factors, the future development trend of the Honghu agricultural wetland can be predicted, and the corresponding measures and strategies can be adopted according to the change rules to effectively protect the Honghu agricultural wetland and realize its sustainable utilization. Taking Honghu Wetland area as an example, this paper analyzed the impact of landscape pattern changes on landscape types by comparing the changes of NP, PD, LPI, and LSI in 2016, 2019, and 2022. The study found a rapid decline in bare land in 2016, 2019, and 2022. The landscape types of agricultural wetlands in Humboldt Lake are predominantly rice wetlands and built-up land, rather than bare land. The area of forest and grassland decreased year by year, but the decrease was not significant. The connectivity between patches decreased. The complexity of patch shape and landscape pattern increased. In the process of returning farmland to forest in Honghu Basin, the abandonment phenomenon caused by population flow leads to the vulnerability of farmland landscape. The results can provide reference for optimizing the landscape pattern of the Honghu agricultural wetland and promoting urban ecological construction and sustainable development. Due to the limitation of research data and samples, the conclusions of this paper may have some limitations. In addition, the research in this paper only explores the specific time period and region, and fails to cover the nationwide situation. In future studies, this paper will further optimize the research methods and sample selection, and strengthen the exploration of the characteristics and rules of different regions and different types of agricultural wetlands.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Asare, E., Chrystal, M.-P., Erik, A., Kenneth, B. & Robert, C. 2022 Evaluating ecosystem services for agricultural wetlands: a systematic review and meta-analysis. *Wetlands Ecology and Management* **30** (6), 1129–1149.

Bridgewater, P. & Kim, R. E. 2021 The Ramsar convention on wetlands at 50. *Nature Ecology & Evolution* **5** (3), 268–270.

Cao, S. X., Zhang, J. Z. & Su, W. 2018 Net value of wetland ecosystem services in China. *Earth's Future* **6** (10), 1433–1441.

Glennie, R., Adam, T. & Leos-Barajas, V. 2023 Hidden Markov models: pitfalls and opportunities in ecology. *Methods in Ecology and Evolution* **14** (1), 43–56.

Holgersson, M., Baldwin, C. Y., Chesbrough, H. & Bogers, M. L. A. M. 2022 The forces of ecosystem evolution. *California Management Review* **64** (3), 5–23.

Li, W., Wang, D. & Jiao, J. 2019 Effects of vegetation patch density on flow velocity characteristics in an open channel. *Journal of Hydrodynamics* **31** (5), 1052–1059.

Liu, Y., Tang, H. & Muhammad, A. 2019 Emission mechanism and reduction countermeasures of agricultural greenhouse gases–a review. *Greenhouse Gases: Science and Technology* **9** (2), 160–174.

Mahdianpari, M., Salehi, B. & Mohammadimanesh, F. 2020 Big data for a big country: the first generation of Canadian wetland inventory map at a spatial resolution of 10-m using sentinel-1 and sentinel-2 data on the google earth engine cloud computing platform. *Canadian Journal of Remote Sensing* **46** (1), 15–33.

Niu, Q., Xiao, X. & Zhang, Y. 2019 Ecological engineering projects increased vegetation cover, production, and biomass in semiarid and subhumid Northern China. *Land Degradation & Development* **30** (13), 1620–1631.

Risser, S. 2021 Dynamic analysis of landscape pattern in natural environment protection areas based on GIS. *Nature Environmental Protection* **2** (3), 21–30.

Shaoli, W., Xiugui, W. & Brown L, C. 2007 Current status and prospects of agricultural drainage in China. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage* **56** (S1), S47–S58.

Shilong, P., He, Y., Wang, X. & Chen, F. 2022 Estimation of China's terrestrial ecosystem carbon sink: methods, progress and prospects. *Science China Earth Sciences* **65** (4), 641–651.

Walsh, M. G., Pattanaik, A., Vyas, N., Saxena, D., Webb, C., Sawleshwarkar, S. & Mukhopadhyay, C. 2022 High-risk landscapes of Japanese encephalitis virus outbreaks in India converge on wetlands, rain-fed agriculture, wild Ardeidae, and domestic pigs and chickens. *International Journal of Epidemiology* **51** (5), 1408–1418.

Wei, S., Pan, J. & Liu, X. 2020 Landscape ecological safety assessment and landscape pattern optimization in arid inland river basin: Take Ganzhou District as an example. *Human and Ecological Risk Assessment: An International Journal* **26** (3), 782–806.

Wu, J., Tao, R., Zhao, P., Martin, N. F. & Hovakimyan, N. 2022 Optimizing Nitrogen Management with Deep Reinforcement Learning and Crop Simulations. In: *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 1712–1720.

Xu, H., Dong, B. & Wang, P. 2022 Study on land-Use change and prediction of chongming dongtan wetland in Shanghai City. *Journal of the Indian Society of Remote Sensing* **50** (12), 2429–2445.

Yang, S., Wang, Y. & Fang, Q. 2022 The transformation of 40-year coastal wetland policies in China: network analysis and text analysis. *Environmental Science & Technology* **56** (22), 15251–15260.

Yu, D., Li, X. & Cao, Q. 2020 Impacts of climate variability and landscape pattern change on evapotranspiration in a grassland landscape mosaic. *Hydrological Processes* **34** (4), 1035–1051.

Zhang, L., Liu, X. & Wei, H. 2022 Impact of land use on surface water quality: a case study of active agriculturally disturbed basin in China. *International Journal of Environmental Science and Technology* **19** (5), 4435–4446.

Zhenxing, B., Yufei, Z. & Yibo, Y. 2020 Effects of agricultural landscape pattern on qualitative food web structure of corn pest-predatory natural enemies. *Chinese Journal of Eco-Agriculture (Chinese and English)* **28** (10), 1475–1487.

First received 5 May 2023; accepted in revised form 27 July 2023. Available online 18 August 2023