

Analysis of land cover and landscape change patterns in Ebinur Lake Wetland National Nature Reserve, China from 1972 to 2013

Haiyang Yu · Fei Zhang · Hsiang-te Kung · Verner Carl Johnson · Colton Spencer Bane · Juan Wang · Yan Ren · Yue Zhang

Received: 12 April 2016 / Accepted: 9 March 2017 / Published online: 16 March 2017
© Springer Science+Business Media Dordrecht 2017

Abstract For effective monitoring and protection, researchers need to analyze the trends and causes of landscape pattern change in wetlands. The present study used Geographic Information System and remote sensing technology to analyze temporal and spatial dynamics of landscape pattern and related driving forces in the Ebinur Lake Wetland National Nature Reserve (ELWNNR) in China. We used Landsat images from 1972, 1998, 2007 and 2013, and classified the landscape into six types of land cover: water body, wetland, vegetation, salinized land,

desert, and other objects (i.e., Gobi and Mountain). Landscape transition matrices and change pattern analysis were used understand wetland dynamics. Our results showed that land cover had changed dramatically during 1972–2013. The spatial extent of much of the wetland areas in the ELWNNR had reduced gradually from 1972 to 2007, and wetland loss occurred more rapidly after 2007. From 1972 to 2013, 415.8 km² of wetland area had been lost and only 250.1 km² wetland area had expanded, which represents a 22% decrease in wetland area in the ELWNNR. At the same time, the landscape pattern experienced diverse changes in the Nature Reserve. The high-density human population of the region has an intensive effect on the region. Wetlands in the nature reserve have also changed with recent rapid development in the region. This study may provide scientific information for developing effective and sustainable conservation plans for the ELWNNR.

H. Yu · F. Zhang (✉) · J. Wang · Y. Ren · Y. Zhang
Resources and Environment Department, Xinjiang University, Urumqi 830046, People's Republic of China
e-mail: zhangfei3s@163.com

H. Yu · F. Zhang · J. Wang · Y. Ren · Y. Zhang
Key Laboratory of Oasis Ecology, Ministry of Education, Xinjiang University, Urumqi 830046, People's Republic of China

F. Zhang
Key Laboratory of Xinjiang Wisdom City and Environment Modeling, Urumqi 830046, People's Republic of China

H. Kung · C. S. Bane
Department of Earth Sciences, The University of Memphis, Memphis, TN 38152, USA

V. C. Johnson
Department of Physical and Environmental Sciences, Colorado Mesa University Grand Junction, Grand Junction, CO 81501, USA

Keywords Land cover change · Landscape pattern · Landscape index · Wetland · Ebinur Lake Wetland National Nature Reserve

Introduction

Wetlands, formed in the transitional zone between land and water, are widely distributed worldwide (Li et al. 2009). These important parts of the global

ecosystem serve important functions. Wetlands support many wild animals and plant resources and preserve biodiversity, provide water conservation, control soil erosion, and regulate regional climate (Mander and Mitsch 2009; Copeland et al. 2010; Sulman et al. 2013; Jia et al. 2015). The complex diversity of plant communities of wetlands provides living space and habitat for breeding and migration for many amphibians and birds (Ji et al. 2012). As a bridge between aquatic and terrestrial environments, the boundary effect provided by wetlands promotes rich biodiversity and unique wetland ecosystem structure, processes and functions (Mitsch and Gosselink 2007; Kostara et al. 2013; Zhi and Ji 2014; Zhi et al. 2015).

The Organization of Economic Cooperation and Development estimated that wetlands are becoming more fragmented on a global scale and about 50% of wetlands have disappeared since 1900 (Lienert et al. 2002; Erwin 2009; Khaznadar et al. 2009; Zhang et al. 2000; Wang et al. 2011). Incomplete statistics shows that France lost two-thirds of its wetlands between 1900 and 1993 (Westerberg et al. 2010). In some arid regions, climate change has displaced wetlands and is often associated with increased disturbance caused by human activity (Zhao et al. 2009). Today, representative wetlands exist as nodes of critical areas in the overall landscape pattern and are crucial to the functioning of arid environments (Zhou 2005; Mwakaje 2009). Wetland fragmentation often leads to losses in biodiversity as a result of a lack of consideration of the role of wetlands in sustainable resource use (Soomers et al. 2013; Walz and Syrbe 2013; He et al. 2015). Land use/land cover maps serve as a basic component in the assessment, planning and management of wetlands (Qin et al. 2011).

Planners often use landscape indices that are calculated from many sources including direct empirical data and land use/cover maps to analyze temporal and spatial wetland change (Li et al. 2009; Fletcher et al. 2009; Soffianian et al. 2015), especially wetland fragmentation (Gibbes et al. 2009; Ke et al. 2011). Analyzing the changes in landscape patterns has been proven helpful in determining some of the most important implications of the complex interactions between human activities and the natural environment (Frondoni et al. 2011; Gül, et al. 2013). Geographic information systems (GIS) and remote sensing often play a vital and effective role in land use/cover mapping and monitoring over a large area (Ikiel et al.

2013; Vorovencii et al. 2015). Using GIS and remote sensing is particularly important when working with spatially separate but fundamentally linked land use environments.

Nature reserves are often interconnected with important non-reserve natural areas and are almost always characterized by a variety of landscapes and high biodiversity. In addition to supporting many diverse species, the unique, natural and cultural landscape of nature reserves also serve as important corridors for the movement of wildlife and as overwintering grounds for migratory birds (Zheng 1995). As the human population of the surrounding region grows, the increasing land use demands of local economic development threaten the integrity and ecological health of wetlands (Cheng et al. 2012). Therefore, this paper presents a case study of Ebinur Lake Wetland National Nature Reserve (ELWNNR) located in an arid region. The main purpose of this research was to (1) combine GIS and remote sensing technology to determine the land cover (especially for wetlands) and landscape-level spatial-temporal changes from 1972 to 2013; and (2) provide a quantitative analysis of human-induced and natural factors affecting wetlands in and around the ELWNNR in Xinjiang Province, China from 1972 to 2013.

Materials and methods

Study area

ELWNNR, located in the central part of Asia in northwestern Xinjiang Uygur Autonomous Region within 44°54′–45°08′N and 82°35′–83°10′E, includes Ebinur Lake, the largest salt water lake in Xinjiang, China (Fig. 1). Mountains, plains and water bodies of ELWNNR cover 2670.8 km². Alpine glacier melt and mountain precipitation serve as the main water recharge source for the nature reserve. In the past, three major river systems, the Bortala, Jinghe and Kuitun Rivers used to flow into Ebinur Lake. However, natural environmental changes and human activities have caused the Kuitun River to gradually lose its hydraulic connections with Ebinur Lake. Only the Bortala and Jinghe Rivers now supply water to this lake. The typical continental arid climate of Jinghe County has hot summers and chilly winters, rare

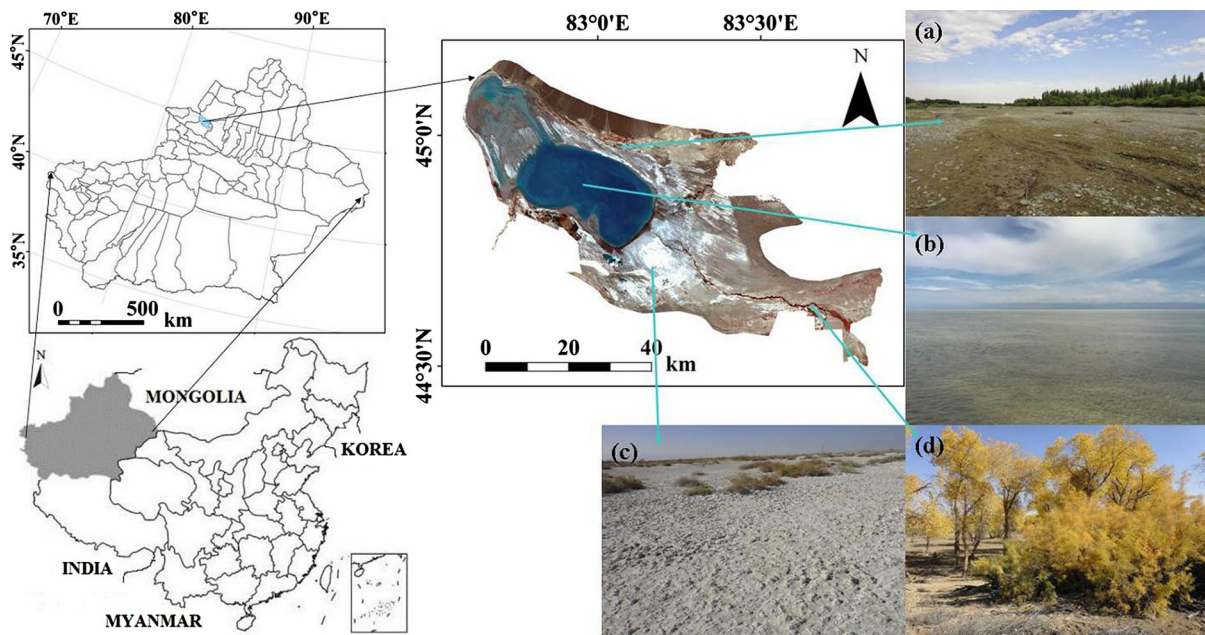


Fig. 1 Location of the study area. Clockwise from the *lower left*: map of China showing the location of Xinjiang Uygur Autonomous Region (Xinjiang); map of the study region within

Xinjiang; aerial photo of Ebinur Lake and the surrounding region; photos of **a** wetlands, **b** water body, **c** salinized land, **d** vegetation

precipitation, and strong evaporation. From 1972 to 2012, the mean annual temperature and precipitation varied from 6.7 to 9.7 °C and from 150 to 75 mm at the plains, respectively.

Image data processing

Land cover data were generated from Landsat images collected in 1972, 1998, 2007, and 2013 that were downloaded from the USGS GLOVIS website (<http://glovis.usgs.gov/>). These images had little cloud cover, had path/row designations of 146/29 and were used to examine changes in wetlands (Table 1). Table 1 provides the sensor name, path/row, date of data collection, and resolution of remote sensing data for all four time periods. The 1972 data was collected from Landsat MultiSpectral Scanner (MSS) images (September 21th, 1972, and resampling to 30 m) with a spatial resolution

80 m. These images were selected for this study because of their long term temporal coverage (He et al. 2011; Lee and Yeh 2009). Images from early autumn were selected because substantial plant growth occurred during that time in the study area.

The remote sensing images were pre-processed using ENVI 5.1 software. Universal Transverse Mercator projection was used to rectify the satellite images. Landsat images were also geometrically corrected with a previously corrected Landsat TM image with a geometric accuracy of <0.5 pixel (Luo et al. 2016). Radiometric correction was performed using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes. Atmospheric correction and normalizing of radiation was critically needed for all images to eliminate the effects of smoke, dust, and haze, as well as changes in the sun's angle (Chavez 1996). The atmospheric correction model was applied

Table 1 Data sources of landscape information in ELWNNR

Number	Sensor	Path/row	Date	Resolution (m)
1	MSS	146/29	September 21th, 1972	80
2	TM	146/29	September 2nd, 1998	30
3	TM	146/29	September 11th, 2007	30
4	OLI	146/29	September 2nd, 2013	30

using ENVI 5.1 software for atmospheric correction. After applying these corrections, the subset image was extracted for the study area.

Auxiliary data included administrative, 1:50,000 digital topographical (Zhang et al. 2015), and land use maps. Socio-economic statistics were collected from Xinjiang Statistical Yearbooks (1972–2014). We used the administrative maps to delineate wetland boundaries. We combined Google Earth photos, GPS data, field photos, and land use maps using remote sensing images to accomplish the land cover mapping.

Methodology

Land cover transition matrix

A land cover transition matrix was used in response to the structure and states of transition change of land cover types in two stages (Wan et al. 2015). Calculations were performed using Eq. (1):

$$p = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1j} \\ p_{21} & p_{22} & \cdots & p_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ p_{i1} & p_{i2} & \cdots & p_{ij} \end{bmatrix}, \quad (1)$$

where p_{ij} indicates the area in transition from landscape i to j ; each element in the transition matrix was characterized assuming (1) p_{ij} is non-negative, and (2) $\sum_{j=1}^n p_{ij} = 1$.

To facilitate a discussion of this set of maps used to depict land cover dynamics, certain terms were defined. For a comparison of two categorical land cover maps that use the same set of N categories, $N \times (N - 1)$ potential forms of map differences, with each form consisting of pixels that were classified as category i in one map and category j in the other map where i is not equal to j . In addition to map differences, there are N instances of map similarity or groups of pixels that are classified as the same category in both maps. Map differences are typically regarded as land cover change, while instances of map similarity are typically regarded as land cover persistence. The classification results from four maps show the persistence and change in land cover observed in three time intervals: 1972–1998, 1998–2007, and 2007–2013. Transition matrices that compare the two maps, which bounded each time interval, are also presented.

Landscape indices

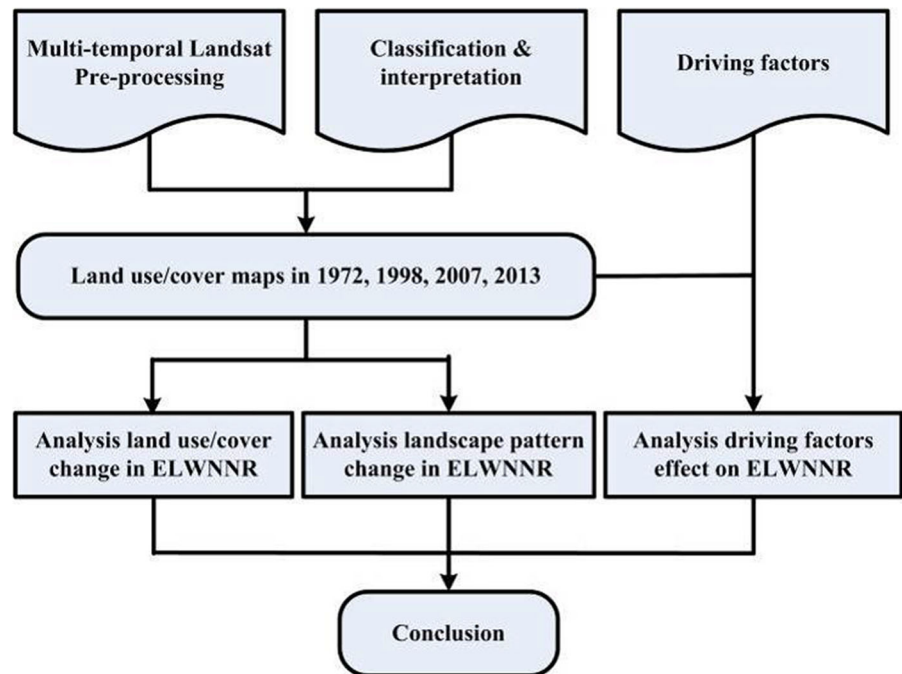
The landscape indices were selected and calculated by Fragstats 3.3 and Excel software (Zhang et al. 2000). A landscape pattern index can summarize spatial landscape patterns efficiently and reflect the landscape structure and spatial characteristic. The main objective of landscape ecology is to quantify landscape pattern change with a landscape index (Paukert et al. 2011). Based on the scale and analysis of the target areas, we selected appropriate landscape metrics (Turner et al. 2001). According to the responses comparison of landscape pattern metrics to different pattern scenarios at the landscape and class levels, McGarigal et al. (2002) found that most of the metrics only respond to some specific pattern scenarios. These metrics are sensitive to variations of particular factors but not to others. Combined with coefficients of index sensitivity (He and Zhang 2009), we chose ten ecologically representative indices that can be efficiently used in solving the problem of metric redundancy during landscape classification and evaluation (McGarigal et al. 2002; He and Zhang 2009). These ten indices were commonly accepted as effective indicators of landscape change, which have been widely used in related studies (Lausch and Herzog 2002; Zhang and Li 2013; Frazier 2014). Class level metrics are helpful for the understanding of landscape development. Landscape level metrics yield relatively general information averaged over the entire landscape.

Six class-level landscapes metrics were selected: total class area (CA), number of patches (NP), landscape shape index (LSI), mean patch area (MPS), fragmentation index (FN), and interspersion and juxtaposition index (IJI). In addition, seven landscape-pattern-level landscape metrics were selected: total landscape area (TA), number of patches (NP), mean patch area (MPS), Shannon's diversity index (SHDI), Shannon's evenness index (SHEI), and contagion index (CONTAG), and aggregation index (AI). Table 2 lists the formulas and definitions of these indices. Based on the output data from GIS, these metrics were calculated using the most commonly used landscape pattern analysis software, FRAG-STATS 3.3 (McGarigal et al. 2002). The following section explains the methodology and Fig. 2 provides a conceptual flow chart describing the methodology.

Table 2 Formulas and definitions of landscape metrics

Index	Definition	Formula
CA	It gives the sum of the areas (m ²) of all patches of the corresponding patch type. It is a measure of landscape composition representing how much a particular patch type occupies a landscape	$CA = A_i$
TA	The areas (m ²) of all landscape types	$TA = \sum_{i=1}^m (A_i)$
NP	Number of patches divided by area	$NP = N_i$
LSI	A perimeter-to-area ratio that measures the overall geometric complexity of the landscape	$LSI = \frac{25 \sum_{k=1}^m e_{ik}}{\sqrt{A}}$
AI	A measure of proximity for the same patches	$AI = 2 \ln(m) + \sum_{i=1}^m \sum_{j=1}^n P_{ij} \ln(P_{ij})$
MPS	It is the average area of a patch of a particular class. It depends on data resolution; sensitive class to addition/deletion of small patches. Mean patch size can serve as a habitat	$MPS = \frac{CA_i}{N_i}$
FN	A measure of the degree of fragmentation that the whole landscape or a landscape type in a given time	$FN = \frac{N_i}{CA_i}$
IJI	A measure of relative interspersion of each class	$IJI = \frac{-\sum_{k=1}^{m'} \left[\left(\frac{e_{ik}}{\sum_{k=1}^{m'} e_{ik}} \right) \ln \left(\frac{e_{ik}}{\sum_{k=1}^{m'} e_{ik}} \right) \right]}{\ln(m'-1)} \quad (100)$
SHDI	A relative measure of patch diversity, which is equal to zero when there is only one patch in the landscape and increases as the number of patch types or proportional distribution of patch types increases	$SHDI = -\sum_{i=1}^m (P_i \cdot \ln P_i)$
SHEI	A measure of patch distribution and abundance, which is equal to zero when the observed patch distribution is low and approaches one when the distribution patch types becomes more even	$SHEI = \frac{\sum_{i=1}^m (P_i \cdot \ln P_i)}{\ln m}$
CONTAG	Measures the extent to which patch types are aggregated or clumped	$CONTAG = \left[1 + \sum_{i=1}^m \sum_{j=1}^n \frac{P_{ij} \ln(P_{ij})}{2 \ln(m)} \right] \quad (100)$

Fig. 2 Conceptual model for the methodology employed in this study; ELWNNR Ebinur Lake Wetland National Nature Reserve



Results

J–M distance and confusion matrix

Accurate extraction is the most critical factor in wetland landscape analysis. Based on the land-use classification system of the China Agricultural Planning Committee (1984) and the actual situation of ELWNNR, six land use/cover categories were delineated: water body (including lakes, rivers, ponds, and reservoirs), vegetation (trees, grass, bushes, sparse trees, shrubs, and other vegetation), salinized land, desert, wetland (including salt marshes, beaches, flood plains, swamps, and bogs) and others objects (including medium-, and low-cover grasslands, and bare land). For this paper we selected more than 600 pixels of each land cover type as areas of interest. The Jeffries–Matusita distance of each land cover type was greater than 1.8 (Table 3), which indicated that there an obvious spectrum difference exists for each land cover type making them conducive to accurate classification by computer (Zhang et al. 2013; Daboor et al. 2014). Maximum likelihood supervised classification was used to process images while considering the calculation of landscape pattern indices was based on the classification maps. In this study, historical data, high-resolution Google Earth images, and field survey data, selected to verify that more than 100 pixels of each land cover type were used for the training data, and the confusion matrix (Shao et al. 2016) to verify the classification results (Table 4). Wetlands can be distinguished more easily than other land cover types in arid regions based on MSS, TM, and OLI images, but some confusion occurred between salinized land and wetland. This mainly occurred because salt had accumulated in the lake bed, and this confusion created increased uncertainty in this paper. Furthermore, the confusion matrix of classification maps was all greater than 80%, which indicated that the classification maps have enough accuracy to allow the analysis of land use and land cover changes in the ELWNNR.

Land covers change in ELWNNR

Six landscape pattern types were classified based on the actual situation of ELWNNR: water body, wetland, vegetation, salinized land, desert, and other objects (i.e., Gobi and Mountain) (Fig. 3; Table 5).

Water body, wetland, and salinized land were the dominant land cover types, covering more than 60% of the ELWNNR and largely determining the functions and structures of the wetland ecosystem. Over the 41 years, the spatial extent of water body and wetland land types has decreased. The lake has been shrinking since 1972, which caused the degradation of the ELWNNR ecosystem (Zhang et al. 2015). The spatial extents of both vegetation and salinized land have increased. Vegetation areas have increased in their distribution in the southeastern region of ELWNNR. Salinized land areas have increased around Ebinur Lake. The change of desert and other object areas was not obvious; desert was concentrated east of ELWNNR and is always threatening to expand into other land cover types. Especially after 2007, desert area tended to expanded creating a fragmented landscape to the south. The “Other object” land type also experienced land degradation with small changes.

Analysis of land cover transition matrix in the ELWNNR

From 1972 to 2013, a strong interaction was observed between salinized land and wetland (Table 6). Between 1972 and 1998, 251.50 km² of wetland became salinized land while 336.33 km² of salinized land became wetland. Between 1998 and 2007, 285.94 km² of wetland became salinized land while 195.37 km² of salinized land became wetland. Between 2007 and 2013, 180.13 km² of wetland became salinized land, 122.78 km² of salinized land became wetland. The main trend observed in the ELWNNR was wetland area being transformed into salinized land. From 1972 to 2013, only few areas of other land cover types were converted to water body. As a result, water body areas have experienced a declining trend. The increased areas of vegetation were transformed from salinized land, wetland, and desert. The increased areas of desert were from wetland, vegetation, and other land uses.

Spatial–temporal changes of wetland in the ELWNNR

From 1972 to 2013, the total spatial extent of wetlands decreased by 415.8 km² while at other sites in the study area the spatial extent of wetlands increased by 250.1 km², which represents an overall loss of 22% of

Table 3 The Jeffries–Matusita distance between classes in ELWNNR

	Water body	Wetland	Vegetation	Salinized land	Desert	Other objects
1972						
Water body	–					
Wetland	1.99	–				
Vegetation	2.00	1.99	–			
Salinized land	2.00	1.84	1.99	–		
Desert	2.00	1.99	1.99	1.96	–	
Other objects	2.00	1.99	1.99	1.99	1.83	–
1998						
Water body	–					
Wetland	1.99	–				
Vegetation	2.00	1.99	–			
Salinized land	2.00	1.99	1.99	–		
Desert	2.00	1.99	1.99	1.99	–	
Other objects	2.00	1.99	1.99	1.99	1.91	–
2007						
Water body	–					
Wetland	2.00	–				
Vegetation	2.00	1.98	–			
Salinized land	2.00	1.99	1.99	–		
Desert	2.00	1.99	1.99	1.99	–	
Other objects	2.00	1.99	1.99	1.99	1.90	–
2013						
Water body	–					
Wetland	1.99	–				
Vegetation	2.00	1.98	–			
Salinized land	2.00	1.97	1.99	–		
Desert	2.00	1.99	1.99	1.99	–	
Other objects	2.00	1.99	1.99	1.99	1.81	–

wetlands area in the ELWNNR. Figure 4 presents the spatio-temporal variation of wetlands for the ELWNNR which has generally declined since 1972. From 1972 to 1998, the spatial distribution of wetlands in ELWNNR obviously varied (Fig. 4a). The increased wetland area was concentrated in the eastern region of the ELWNNR; while some wetland area was converted to other land types in the northern region. From 1998 to 2007, wetland area degradation caused overall wetland area to decrease sharply in the eastern region of ELWNNR (Fig. 4b). From 2007 to 2013, wetland area experienced mainly minor changes in ELWNNR (Fig. 4c). From 1972 to 2013, overall wetland area tended to shrink sharply (Fig. 4d). Especially after 2007, the survival of wetland plants

and animals was seriously affected when wetland areas had decreased sharply.

Dynamics of landscape pattern in the ELWNNR

Quantitative characteristics changes

The total numbers of patches of landscape were 1927 (1972), 1437 (1998), 1040 (2007) and 1349 (2013) in the ELWNNR (Fig. 5a). From 1972 to 2013, the mean area of patches has increased indicating that fragmentation of the landscape of the ELWNNR has slowed. The mean patch size was 164.48 hm² in 1972, 220.78 hm² in 1998, 304.90 hm² in 2007, and 235.04 hm² in 2013 (Fig. 5a).

Table 4 The calculation of confusion matrix by Maximum likelihood supervised classification in ELWNNR

	Water body	Salinized land	Wetland	Vegetation	Desert	Other objects	Total	User's accuracy (%)
1972								
Water body	114	0	0	0	0	0	114	100.00
Salinized land	0	57	0	0	19	26	102	55.88
Wetland	0	46	101	0	0	0	147	68.71
Vegetation	4	0	0	114	0	0	118	96.61
Desert	0	0	0	0	99	17	116	85.34
Other objects	0	0	0	0	0	77	77	100.00
Total	118	103	101	114	118	120	Overall = 83.38%	
Producer's accuracy (%)	96.61	55.34	100.00	100.00	91.67	64.17	kappa = 0.80	
1998								
Water body	99	0	0	0	0	0	99	100.00
Salinized land	0	121	0	0	7	0	128	94.53
Wetland	17	0	71	0	0	0	88	80.68
Vegetation	0	0	0	131	0	0	131	100.00
Desert	0	0	0	0	105	0	105	100.00
Other objects	0	0	49	0	0	128	177	72.32
Total	116	121	120	131	112	128	Overall = 89.97%	
Producer's accuracy (%)	85.34	100.00	59.17	100.00	93.75	100	kappa = 0.88	
2007								
Water body	99	0	0	0	0	0	99	100.00
Salinized land	0	114	31	0	7	0	152	75.00
Wetland	0	7	89	11	1	0	108	82.41
Vegetation	17	0	0	120	0	0	137	87.59
Desert	0	0	0	0	104	1	105	99.05
Other objects	0	0	0	0	0	127	127	100.00
Total	116	121	120	131	112	128	Overall = 89.70%	
Producer's accuracy (%)	85.34	94.21	74.17	91.60	92.86	99.22	kappa = 0.88	
2013								
Water body	111	0	0	0	0	0	111	100.00
Salinized land	0	76	0	0	15	21	112	67.86
Wetland	7	27	101	0	0	0	135	74.81
Vegetation	0	0	0	114	0	0	114	100.00
Desert	0	0	0	0	99	17	116	85.34
Other objects	0	0	0	0	4	82	86	95.35
Total	118	103	101	114	118	120	Overall = 86.50%	
Producer's accuracy (%)	94.07	73.79	100.00	100.00	83.90	68.33	kappa = 0.84	

The bold numbers indicate the number of correctly classified pixels

The patch numbers of water body and vegetation have tended to increase during the 41-year study period, which indicated landscape fragmentation has

become a serious issue. Simultaneously, the patch numbers of salinized land, desert, and wetland decreased and their mean areas had increased; this

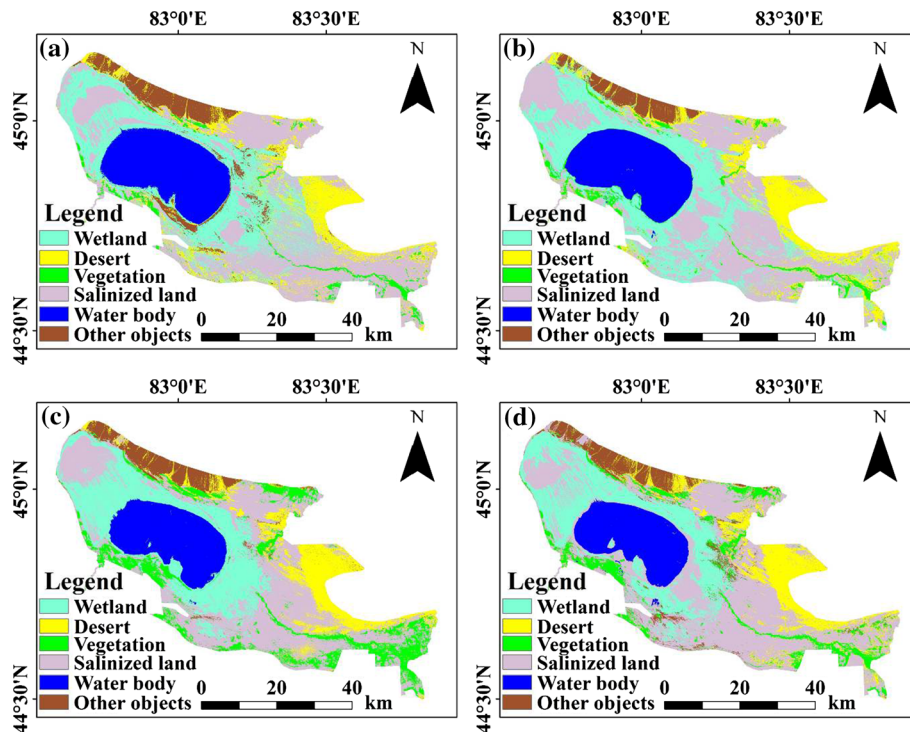


Fig. 3 Land cover classification maps in ELWNNR for **a** 1972, **b** 1998, **c** 2007, **d** 2013. (Color figure online)

Table 5 Changes of land cover in ELWNNR from 1972 to 2013

Land cover types	Area in 1972 (km ²)	Area ratio in 1972 (%)	Area in 1998 (km ²)	Area ratio in 1998 (%)	Area in 2007 (km ²)	Area ratio in 2007 (%)	Area in 2013 (km ²)	Area ratio in 2013 (%)
Water body	538.44	16.98	506.66	15.98	437.56	13.80	406.77	12.83
Wetland	754.58	23.80	798.13	25.17	657.22	20.73	588.73	18.57
Vegetation	90.67	2.86	114.16	3.60	373.45	11.78	249.46	7.87
Salinized land	1203.62	37.96	1243.42	39.21	1180.31	37.22	1371.44	43.25
Desert	354.47	11.18	380.53	12.00	351.22	11.08	354.06	11.17
Other objects	229.76	7.25	128.52	4.05	171.73	5.42	200.74	6.33

indicated desertification has intensified in ELWNNR (Fig. 5b, c). This phenomenon mainly resulted in a progression that degraded areas (i.e., desertification and salinization) increased in the ELWNNR, forming a large number of small patches. Between 1972 and 2013 the number of water body patches has increased, but those of wetland decreased. The number of wetland patches decreased from 1972 to 2007 and increased from 2007 to 2013 while the mean area was larger in 2007 than in 2013 suggesting that the

strengthening of wetland protection activities after establishment of the ELWNNR has effectively reduced wetland fragmentation. At the beginning of China Economic Reform and Open Door Policy starting in 1980s, natural forest and urbanization were the main causes of a decrease in the total areas of water bodies and wetlands in the ELWNNR. The number of vegetation patches increased continuously mainly because of Jinghe County land management policies that also resulted in wetland degradation.

Table 6 Land cover type transition matrices for 1972–1998, 1998–2007, 2007–2013, and 1972–2013 (units; km²)

Periods	Water body	Salinized land	Wetland	Vegetation	Desert	Other objects
1972–1998						
Water body	504.72	0.15	1.59	0.08	0.03	0.09
Salinized land	0.80	805.88	336.33	8.63	80.42	10.42
Wetland	24.28	251.50	386.01	5.84	57.51	72.45
Vegetation	8.62	29.56	10.57	57.25	6.47	1.50
Desert	0.01	115.51	19.82	18.32	204.33	22.08
Other objects	0.00	0.13	0.20	0.42	4.95	122.81
1998–2007						
Water body	436.85	0.13	0.42	0.16	0.00	0.00
Salinized land	4.12	857.17	285.94	4.89	27.88	0.09
Wetland	61.62	195.37	390.43	9.72	0.07	0.01
Vegetation	4.05	114.64	59.42	98.83	96.34	0.04
Desert	0.00	73.18	35.78	0.04	235.50	6.71
Other objects	0.01	2.84	26.13	0.50	20.58	121.64
2007–2013						
Water body	403.25	0.38	2.86	0.28	0.00	0.00
Salinized land	29.34	969.07	180.13	111.00	77.49	4.24
Wetland	4.96	122.78	456.75	3.99	0.00	0.24
Vegetation	0.02	24.24	10.88	206.29	4.34	3.63
Desert	0.00	33.26	0.00	39.22	259.12	22.45
Other objects	0.00	30.37	6.60	12.64	9.97	141.15
1972–2013						
Water body	403.77	0.28	1.79	0.05	0.20	0.70
Salinized land	68.00	839.19	329.37	11.11	98.29	23.94
Wetland	64.45	145.10	338.64	0.63	7.20	32.68
Vegetation	2.05	107.51	28.39	73.65	29.09	8.05
Desert	0.09	96.64	30.91	3.62	192.75	29.81
Other objects	0.08	13.75	25.36	1.48	25.80	134.14

Spatial structure changes

In the ELWNNR, the values of both the Shannon's landscape diversity and evenness indices declined overall from 1972 to 2013. The Shannon's diversity index stood at 1.33 (1972), 1.31 (1998), 1.35 (2007) and 1.32 (2013) while the Shannon's evenness index was 0.69 (1972), 0.67 (1998), 0.70 (2007) and 0.68 (2013) (Fig. 6a). These results show that the evenness and richness of the landscape types decreased and the makeup of the wetland ecosystem gradually became simplified. This was related to the shrinking of wetlands and the expansion of salinized land and desert. The decrease of landscape type diversity causing wetland ecosystem changes had an effect on the functions of the ELWNNR.

The LSI is an effective index used to represent discrete levels or clustering of landscapes. Vegetation LSI followed a rising trend over 41 years, indicating more complicated patch shape structure than other landscape types (Fig. 6b). Salinized land, wetland, and desert exhibited high LSI, an indication of irregular shapes of landscapes. The LSI of water body was comparatively low suggesting less change of water bodies since 1972. The LSI of the wetland showed a continuous downtrend, which indicates that the wetland boundary decreased and the area shrank. The IJI of wetland also shows a downtrend, which indicates that the wetland boundary with other landscape decreased (Fig. 6c). The IJI of salinized land symbolizes a rising trend, which indicates that the salinized land boundary with other landscape increased. The

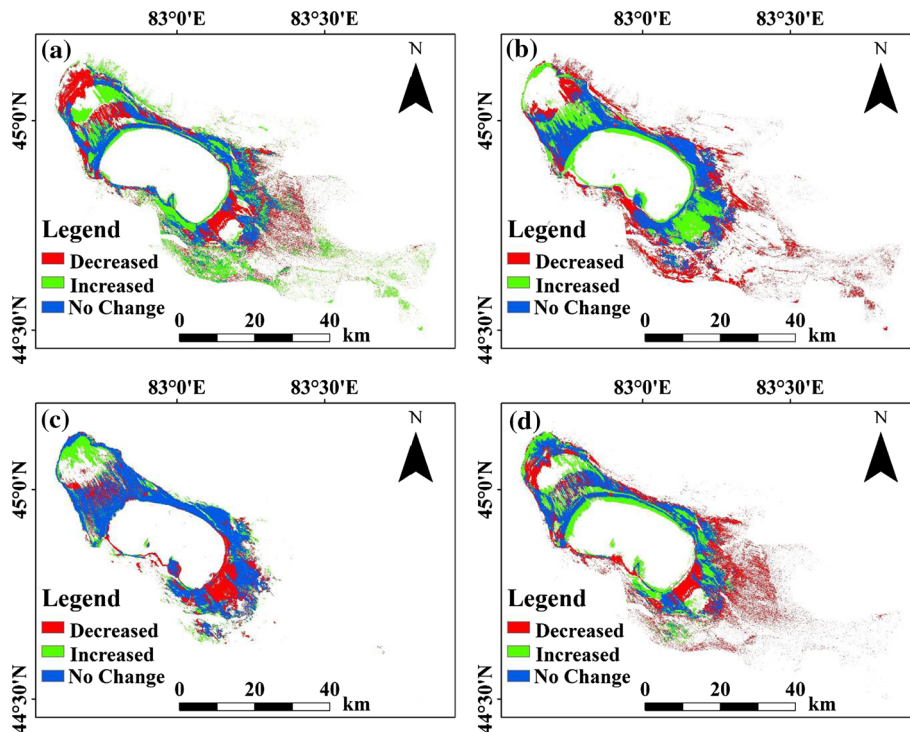


Fig. 4 Spatial-temporal change maps of wetland in ELWNNR. *Red* wetland area decreased, *Green* wetland area increased, *Blue* wetland no change, for a space. **a** 1972–1998, **b** 1998–2007, **c** 2007–2013, **d** 1972–2013. (Color figure online)

salinized land was gradually encroached on by the other landscape.

Fragmentation of landscape units

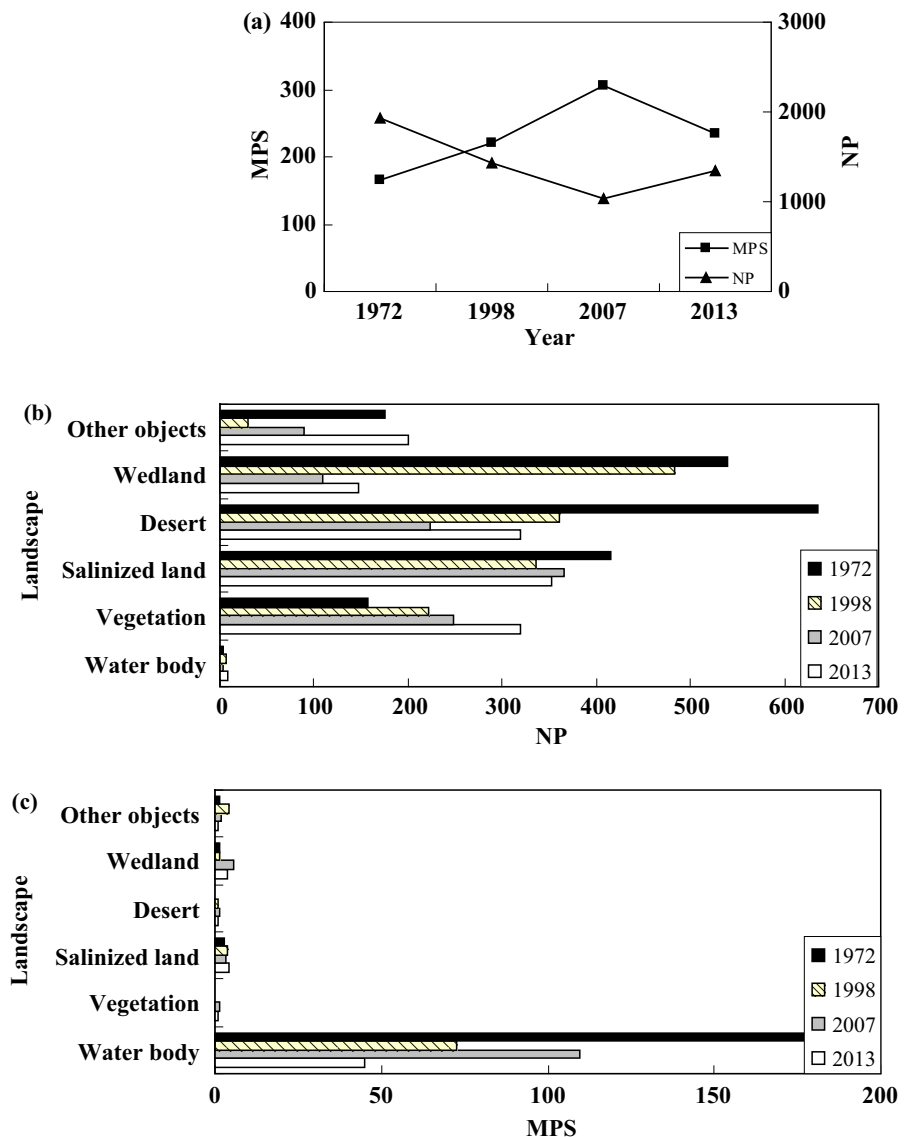
Both AI and CONTAG indices have increased, indicating that the connectivity among the same landscape type has improved from 1972 to 2013. Because of reduction of the salinized land, desert, and wetland, the landscape became more simplified and homogenized. The CONTAG indices were 55.79 in 1972, 57.54 in 1998, 56.86 in 2007 and 56.88 in 2013, and the AI indices 88.30 in 1972, 90.32 in 1998, 91.33 in 2007 and 90.27 in 2013 (Fig. 7a). The rising trend of CONTAG showed enhanced landscape connectivity and low landscape fragmentation over the ELWNNR. The enhanced connectivity of vegetation has strengthened the exchanges of species, materials and energy among the landscapes that could accelerate the alteration between wetland and terrestrial ecosystems, causing easily the control of continuous expanding desert in the wetland reserve.

Ebinur Lake is mainly a water body in the ELWNNR. It has approximately an oval shape and

the shorelines are relatively continuous and smooth (Fig. 3). The Fragmentation Index (FN) of water body, therefore, is the least in the total landscape pattern (Fig. 7b) and it has changed very little since 1972. The FN of desert has decreased since 1972, an indication that the desertification has been reduced. The FN of wetland also has declined. Combined with spatial-temporal change (Fig. 4), the wetland continued to degrade in the ELWNNR. The FN of salinized land was stable since 1972, because of the low topography, high temperature, and large evapotranspiration in the Ebinur Lake region, which increased surface salt content in soil. FN of vegetation is high, and this may be due to the presence of many sporadic shrub areas in the region.

In general, the metrics used here suggest decreased fragmentation of the ELWNNR over time. Although the fact that fragmentation metrics decreased would seem to benefit the ELWNNR, there were three landscape types that were classified in the ELWNNR maps, such as desert, salinized land, and other objects, which represent fragile land ecosystem types. Figure 7 shows those fragile land ecosystem types were highly fragmented, which indicates the paths of the

Fig. 5 Changes of landscape pattern quantitatively in ELWNNR. *MPS* mean patch area, *NP* number of patches



distribution of fragile land ecosystems in the ELWNNR. In brief, outlook for the environment and ecology of the ELWNNR is not optimistic.

Discussion

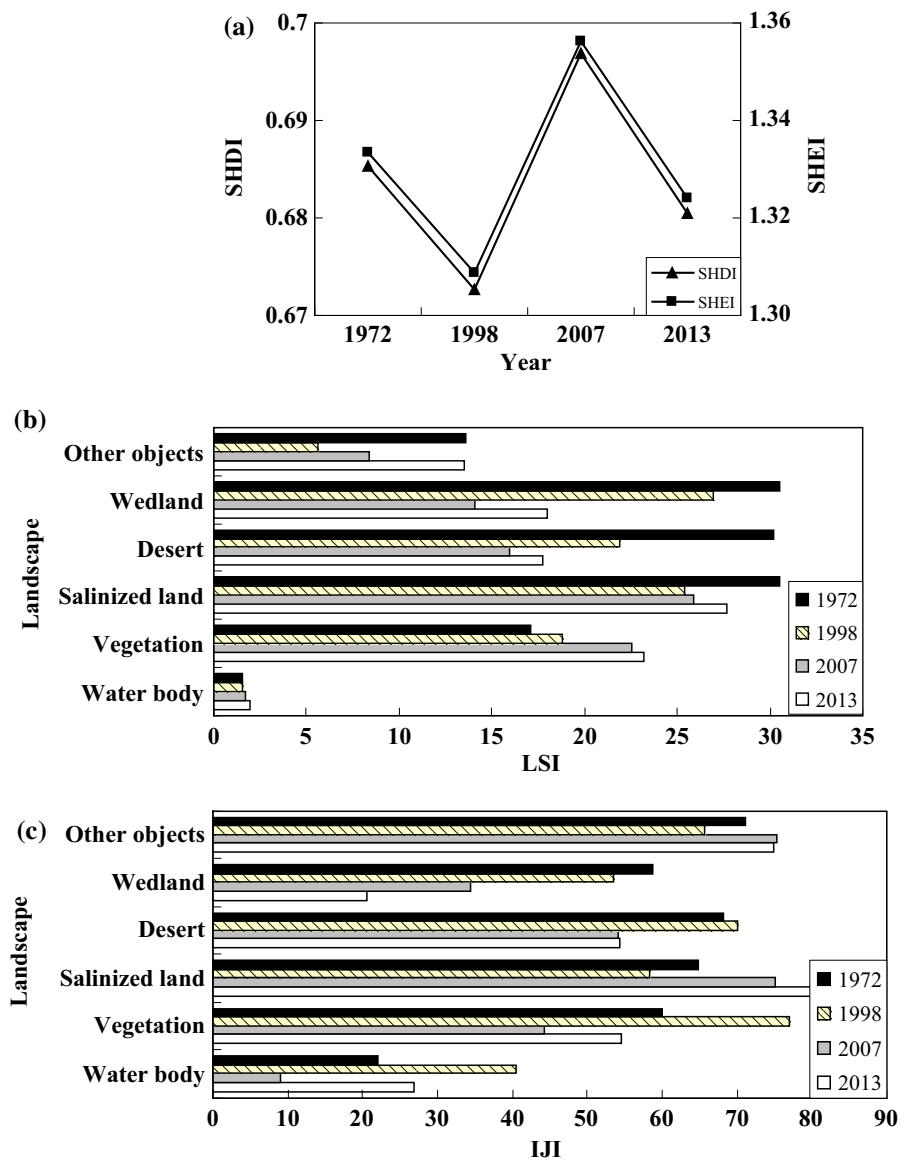
Error and accuracy assessment

After several experiments, it was determined that there were difficulties separating the wetland and salinized land, because most of these areas shared similar spectral signatures. The effectiveness of the maximum

likelihood supervised classification approach to species delineation was limited. In the supervised classification result, the classified wetlands were spread throughout the salinized land and vegetation giving a ‘pepper effect’ to the image.

The producer’s and user’s accuracy provided the assessment with an overview of how the error was distributed across the different classes. From the producer’s accuracy, we can see that the vegetation and desert had the lowest omission error between all the classes followed closely by the water body. The omission error for the salinized land, wetland, and other objects of 60% clearly reflected the delineation

Fig. 6 Changes of spatial structure of landscape pattern in ELWNNR. *IJI* interspersion and juxtaposition index, *LSI* landscape shape index, *SHDI* Shannon’s diversity index, *SHEI* Shannon’s evenness index



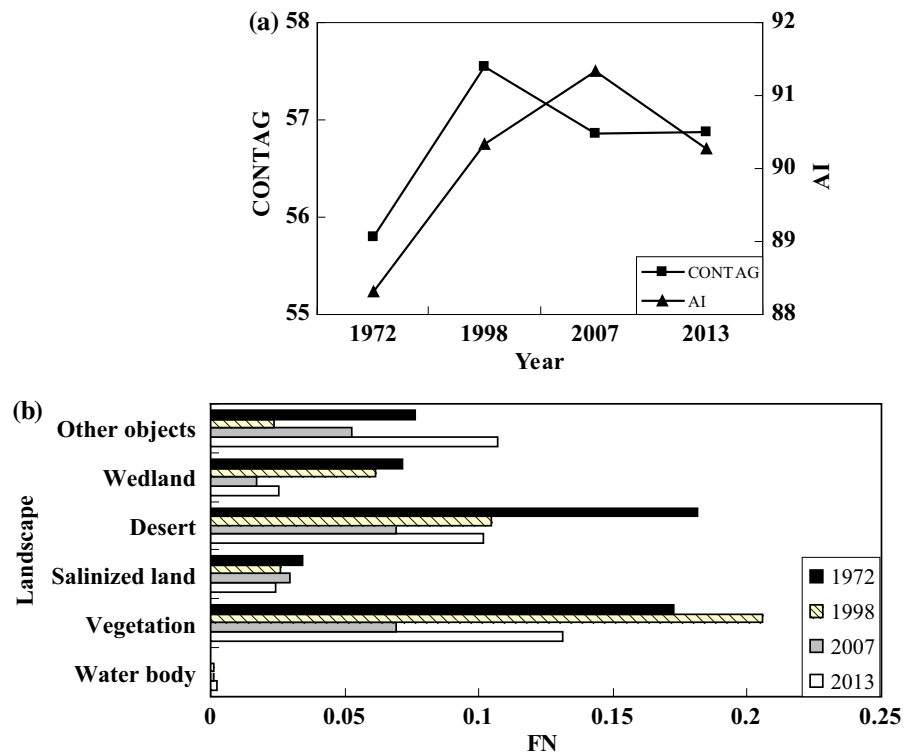
problem. The user’s accuracy on the other hand, showed that the water body the lowest commission error, indicating that 95% of the time that an area visited by the user would actually be a body of water. But the landscape of salinized land had the highest commission error of 55.88% in 1972. The details of the breakdown indicated that the salinized land and wetland were highly miss-classified in the ELWNNR. The main reason was that salt accumulated in the lake bed, which decreased the accuracy of classification in this paper. Furthermore, the confusion matrix of classification maps is all greater than 80%, which

indicates that the classification accuracy was sufficient to be used in analyzing land use and land cover changes in the ELWNNR.

Driving factors of landscape changes

ELWNNR is a fragile ecosystem determined by its special natural environment, which is located in an ecotone of oasis and desert. In arid regions, water is a critical factor controlling the development and formation of wetland vegetation and soil. Therefore, in most cases, landscape pattern change is due to human

Fig. 7 Changes fragmentation of landscape pattern in ELWNNR. *AI* aggregation index, *CONTAG* contagion index, *FN* fragmentation index



activities and climate change (Strayer et al. 2003). In order to analyze the driving forcing of landscape pattern changes in ELWNNR from 1972 to 2013, three aspects have been selected.

Effects of climate changes on ELWNNR

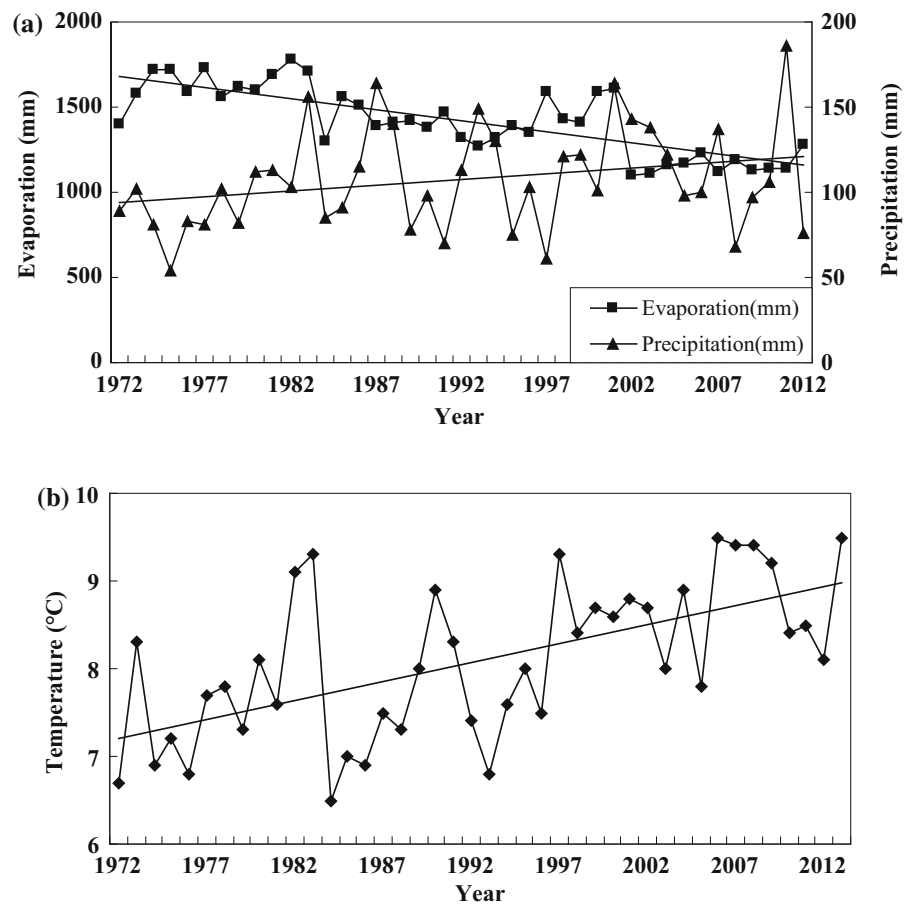
Global climate change is a major factor causing the wetland landscape changes in the structure of the ELWNNR (Xiao et al. 2013). With the change of the global climate, the precipitation and trend of temperatures have increased in the ELWNNR (Fig. 8). The annual temperature shows a gradual upward trend, resulting in a decrease of wetland, rivers and lakes, while the forest land experiences expansion (Statistical Yearbooks of Jinghe County, 1972–2013). Water area in 2007 was less than in 1998; wetland area was gradually reduced which may be caused by serious evaporation. Since 1972, the rising trend of both temperature and precipitation in the wetland reserve have not changed resulting in the degradation of wetland vegetation, the death of wetland grass roots, and plants. This finding has clear implications for consideration of land covers in nature reserve.

Effects of human activities on ELWNNR

Human activities have accelerated the transformation of landscape patterns in the ELWNNR. In recent years, animal husbandry in the Ebinur Lake area has made great progress in meeting the needs of economic development and population growth, resulting in a conflict between rational use of resources and wetland protection. The wetland has an excessive grazing rate in the range of 30–50% and salinization caused by the disappearance of main plant species, erosion and hardening of the soil, water retention capacity, and increase surface runoff loss. This led to an increase in soil erosion, plant species composition and spatial pattern of changes, and changed the entire landscape pattern of the ELWNNR. Meanwhile, salinization caused a large number of small area patches, which increased the fragmentation of the landscape.

Agriculture is the foundation of economic development, as it plays a key role in Jinghe (Fig. 9; Statistical Yearbooks of Jinghe County, 1972–2013). Agricultural patterns in Jinghe adapt to the constantly changing market demand and the pursuit of greater economic efficiency. Some crops have greater

Fig. 8 Climatic variability for 1972–2013 at the Jinghe Meteorological Station in the study area **a** annual average precipitation and evaporation, **b** annual average temperature



economic benefits, such as large areas of cultivated cotton and large-scale aquaculture. Water is the most important factor in the wetland ecosystem. The increase of agricultural water use in the area around the wetland reserve resulted in a significant decrease in the water content of the ELWNNR. The increase of irrigation agriculture is the main reason for the decline of groundwater level in the area (Foster et al. 2015). This study shows that the local water resource is inadequate to support the expansion of arable land area in the Ebinur Lake region, and that drought and habitat degradation are also resulting in lower water levels in ELWNNR.

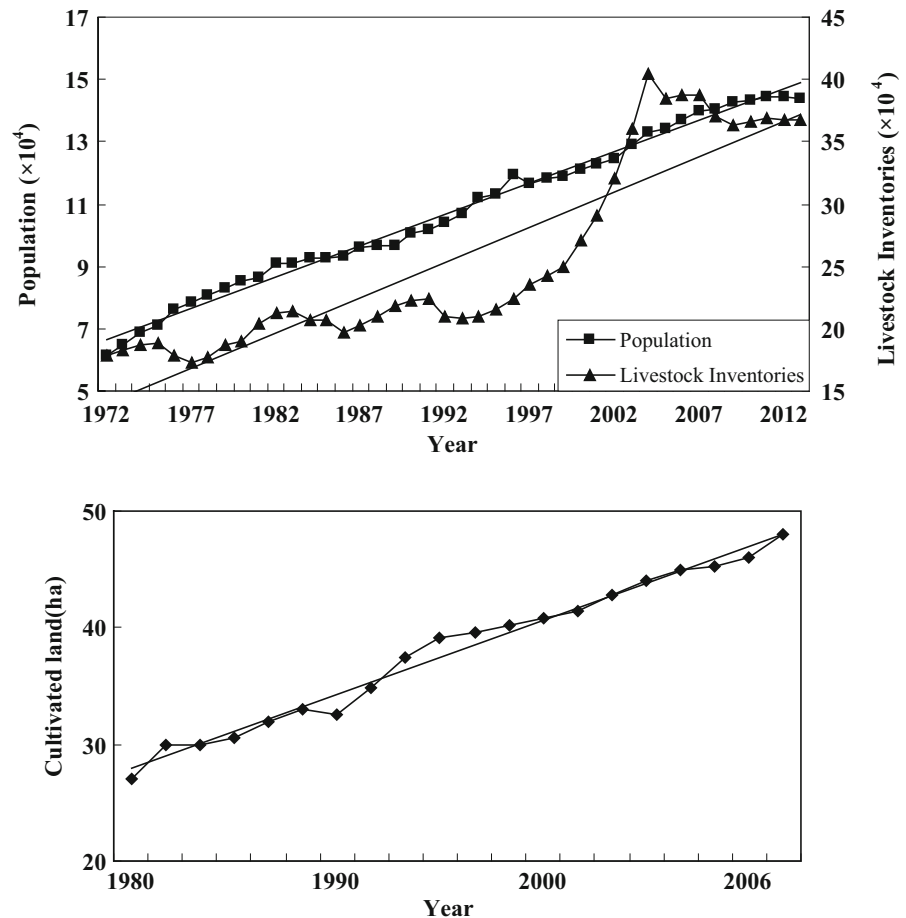
Effect of policy on ELWNNR

In the beginning of the 1980s the Chinese Economic Reform and Open Door Policy was instituted and in the 1990s the Development of the Western Region was initiated; these policies promoted the economic

development of Jinghe County rapidly, causing significant changes in landscape of the ELWNNR. In particular, the mandatory nature of government land use policy at both regional and national levels was very effective in its ability to motivate behavior and land use. The Chinese government promotes the policy advocating “cotton as the key to agriculture,” actively encouraging the development of the Great Northern Wilderness, and promoting policies designed to develop intensive farming of cotton in the ELWNNR. The Jinghe County produced hundreds of tons of cotton once the provincial government approved the creation of a green industrial economic and technological development zone in 2001. This incident resulted in changes in the hydrological conditions of the ELWNNR through adjacent farm land reclamation. Although the province has clear protection status, the wetland area still decreased sharply.

In recent years, the ELWNNR experienced serious negative effects such as: a sharply shrinking lake,

Fig. 9 Statistical information of human population, livestock and cultivated land area of Jinghe County from 1972 to 2013



increasing intensity and frequency of severe dry weather, the expansion of desertification, the succession of vegetation to land types of difficult to use, and increased levels of human activities that have negative effect on the ELWNNR. These factors accelerate the evolution of landscape patterns in the nature reserve (Wan et al. 2015). After the government of China established the ELWNNR the region's environment has improved. However, we still need scientifically sound guidelines and protective measures that are designed to restrain the loss of natural vegetation, shrinkage of the lake area, and the expansion of salinized land (Zhang et al. 2015).

Management technology and measures on ELWNNR

Large areas of wetland and water body were converted to arable land consisting predominantly of salinized land and vegetation between 1972 and 2013.

Population growth has occurred simultaneously with a degeneration of the regional environment in the ELWNNR and the Jinghe County region. Dynamic land cover analysis showed a dramatic increase in salinized land. Wetland and water body areas have changed less significantly. Landscape pattern analysis showed a similar overall pattern. NP and FN values of wetland revealed that polygons of habitat were small, scattered and fragmented. Rising CONTAG and AI along with falling SHDI and SHEI values indicated that wetland landscape diversity decreased significantly over time because of the growing anthropogenic effects in the surrounding region. This study showed that regional climatic factors also have a strong influence; wetland areas have declined with increasing temperature and decreasing precipitation in the past 40 years.

Dixon et al. (2016) presented a Wetland Extent Trends index that can be used for estimating the extent of the global wetland ecosystem. In their research, on a

global scale they found that an average of about 30% of all wetlands was lost between 1970 and 2008. Europe and Oceania had lost about 50 and 17% of their wetland areas, respectively, over the same period. At the same time, the area of wetland decreased by 22% in the ELWNNR from 1972 to 2013. Therefore, we need some measures to ensure the sustainable development of the regional wetland ecosystem in the ELWNNR. First, restoration measures need to be carried out to restore these fragmented wetlands. In the ELWNNR any cultivation must be prohibited and the reclaimed wetlands should be returned to a more natural condition. An ecological water transfer project is needed during dry periods. Secondly, a comprehensive investigation should be carried out on the resources of ELWNNR using GIS and satellite remote sensing technology, field investigations, and other techniques. Supported by multi-technologies, the process of landscape pattern change could be more easily monitored and analyzed scientifically for the ELWNNR. We can then minimize the deterioration of wetland resources in the ELWNNR.

Conclusions

With the support of remote sensing and GIS, this paper analyzed landscape pattern changes and its reasons in ELWNNR of Xinjiang Province, China, from 1972 to 2013. The following conclusions were drawn:

- (i) Human impact included high-density agriculture and other activities; the ELWNNR was also changed as a result of the rapid economic development of the region. Therefore, this study on the changes of landscape pattern in ELWNNR can provide some help for the coordination of development with wetland's protection and urbanization.
- (ii) The entire area ELWNNR wetland was reduced from 1972 to 2013 resulting from increases in regional temperatures and evaporation rates. This wetland loss was caused by drought in the Kuitun River region, an increase in the size of the human population, changes in policies related to agricultural management, urbanization, etc.

The accuracy of results might have been affected by the choice of temporal sampling of the remote sensing

data, the intensity of urbanization and human activity, and processing errors. Due to the limitations on paper length, this paper did not discuss the issues that change the wetland landscape pattern, which would certainly affect the regional environment. The results of this study are expected to provide supporting guidelines for functional classification and mainly for protection of the ELWNNR.

Acknowledgements Thanks the National Meteorological Information Center data provided meteorological data. The research was carried out with the financial support provided by the Natural Science Foundation of Xinjiang Uygur Autonomous Region, China (2016D01C029); National Natural Science Foundation of China (41361045), Xinjiang Local Outstanding Young Talent Cultivation Project of National Natural Science Foundation of China (U1503302), the National International Scientific and Technological Cooperation Projects (2010DFA92720-12), the State Key Program of National Natural Science of China (41130531), the Young Technology-Innovation Training Program Foundation for Talents from the Xinjiang Uygur Autonomous Region (2013731002), the Key Laboratory of Oasis Ecology in Xinjiang University (XJDX0201-2012-01) and the PhD Graduates in the Scientific Research Foundation (BS110125). We would like to extend our thanks to Dr. Abduwasit Ghulam at Saint Louis University, USA for his help on improving the paper for grammar and writing style. The authors wish to thank the referees for providing helpful suggestions to improve this manuscript.

References

- Chavez PS (1996) Image-based atmospheric correction revised and improved. *Photogramm Eng Remote Sens* 62:1025–1036
- Cheng Q, Wang W, Wang H, Wang W, Zhao Z (2012) Investigation of the heavy metal contamination of the sediments from the Yellow River wetland nature reserve of Zhengzhou, China. *Iran J Public Health* 41(3):26–35
- Copeland HE, Tessman SA, Girvetz EH, Roberts L, Enquist C, Orabona A, Path S, Kiesecker J (2010) A geospatial assessment on the distribution, condition, and vulnerability of Wyoming's wetlands. *Ecol Ind* 10(4):869–879
- Dabboor M, Howell S, Shokr M, Yackel J (2014) The Jeffries-Matusita distance for the case of complex Wishart distribution as a separability criterion for fully polarimetric SAR data. *Int J Remote Sens* 35(19):6859–6873
- Dixon MJR, Loh J, Davidson NC, Beltrame C, Freeman R, Walpole M (2016) Tracking global change in ecosystem area: the wetland extent trends index. *Biol Conserv* 193:27–35
- Erwin KL (2009) Wetlands and global climate change: the role of wetland restoration in a changing world. *Wetlands Ecol Manag* 17(1):71–84
- Fletcher RS, Pulich W Jr, Hardegree B (2009) A semiautomated approach for monitoring landscape changes in Texas

- seagrass beds from aerial photography. *J Coast Res* 25(2):500–506
- Foster T, Brozović N, Butler AP (2015) Analysis of the impacts of well yield and groundwater depth on irrigated agriculture. *J Hydrol* 523:86–96
- Frazier AE (2014) A new data aggregation technique to improve landscape metric downscaling. *Landsc Ecol* 29(7):1261–1276
- Frondoni R, Mollo B, Capotorti G (2011) A landscape analysis of land cover change in the Municipality of Rome (Italy): spatio-temporal characteristics and ecological implications of land cover transitions from 1954 to 2001. *Landsc Urban Plan* 100(1):117–128
- Gibbes C, Southworth J, Keys E (2009) Wetland conservation: change and fragmentation in Trinidad's protected areas. *Geoforum* 40(1):91–104
- Gül O, Onmuş O, Siki M (2013) Significant impacts of water level and human intervention on natural habitats and breeding waterbirds in Marmara Lake. *Ekoloji* 22(89): 29–39
- He P, Zhang HR (2009) Study on factor analysis and selection of common landscape metrics. *Forest Research* 4:470–474 (In Chinese with English abstract)
- He XH, Gao YJ, Niu JX, Zhao YF (2011) Landscape pattern changes under the impacts of urbanization in the Yellow River Wetland-king Zhengzhou as an example. *Procedia Environ Sci* 10:2165–2169
- He X, Hörmann G, Strehmel A, Guo H, Fohrer N (2015) Natural and anthropogenic causes of vegetation changes in riparian wetlands along the lower reaches of the Yellow River, China. *Wetlands* 35(2):391–399
- Ikiel C, Ustaoglu B, Dutucu AA, Kilic DE (2013) Remote sensing and GIS-based integrated analysis of land cover change in Duzce plain and its surroundings (north western Turkey). *Environ Monit Assess* 185(2):1699–1709
- Ji GD, Wang RJ, Zhi W, Liu XX, Kong YP, Tan YF (2012) Distribution patterns of denitrification functional genes and microbial floras in multimedia constructed wetlands. *Ecol Eng* 44:179–188
- Jia H, Pan D, Zhang W (2015) Health assessment of wetland ecosystems in the Heilongjiang River Basin, China. *Wetlands* 35(6):1185–1200
- Ke CQ, Zhang D, Wang FQ, Chen SX, Schmuttius C, Boerner WM, Wang H (2011) Analyzing coastal wetland change in the Yancheng national nature reserve, China. *Reg Environ Change* 11(1):161–173
- Khaznadar M, Vogiatzakis IN, Griffiths GH (2009) Land degradation and vegetation distribution in Chott El Beida wetland, Algeria. *J Arid Environ* 73(3):369–377
- Kostara A, Retalis A, Papastergiadou E (2013) A satellite-based approach for land cover/use changes in Acheron River catchment (Greece). *Proc SPIE* 8795(2):19
- Lausch A, Herzog F (2002) Applicability of landscape metrics for the monitoring of landscape change: issues of scale, resolution and interpretability. *Ecol Ind* 2(1):3–15
- Lee TM, Yeh HC (2009) Applying remote sensing techniques to monitor shifting wetland vegetation: a case study of Danshui River estuary mangrove communities, Taiwan. *Ecol Eng* 35(4):487–496
- Li SN, Wang GX, Deng W, Hu YM, Hu WW (2009) Influence of hydrology process on wetland landscape pattern: a case study in the Yellow River Delta. *Ecol Eng* 35(12):1719–1726
- Lienert J, Diemer M, Schmid B (2002) Effects of habitat fragmentation on population structure and fitness components of the wetland specialist *Swertia perennis* L. (Gentianaceae). *Basic Appl Ecol* 3(2):101–114
- Luo J, Li X, Ma R, Li F, Duan H, Hu W, Huang W (2016) Applying remote sensing techniques to monitoring seasonal and interannual changes of aquatic vegetation in Taihu Lake, China. *Ecol Ind* 60:503–513
- Mander Ü, Mitsch WJ (2009) Pollution control by wetlands. *Ecol Eng* 35(2):153–158
- McGarigal K, Cushman SA, Neel MC, Ene E (2002) FRAG-STATS v3: spatial Pattern analysis program for categorical maps. Computer software program produced by the authors at the University of Massachusetts Amherst. <http://www.amass.edu/landeco/research/fragstats/fragstats.html>
- Mitsch WJ, Gosselink JG (2007) *Wetlands*. Wiley, Hoboken
- Mwakaje AG (2009) Wetlands, livelihoods and sustainability in Tanzania. *Afr J Ecol* 47(s1):179–184
- Paukert CP, Pitts KL, Whittier JB, Olden JD (2011) Development and assessment of a landscape-scale ecological threat index for the Lower Colorado River Basin. *Ecol Ind* 11(2):304–310
- Qin MZ, Cheng JH, Zhang PY, Yan JH, Liu X, Wang X (2011) Research on ecological safety and utilization pattern on the lower reaches wetland of the yellow river in Kaifeng City. *Procedia Environ Sci* 10:2654–2658
- Shao Y, Lunetta RS, Wheeler B, Iames JS, Campbell JB (2016) An evaluation of time-series smoothing algorithms for land-cover classifications using MODIS-NDVI multi-temporal data. *Remote Sens Environ* 174:258–265
- Soffianian A, Rahdari V, Amiri F, Pradhan B, Tabatabaei T (2015) Geospatial modeling to identify the effects of anthropogenic processes on landscape pattern change and biodiversity. *Arab J Geosci* 8(3):1557–1569
- Soomers H, Karszenberg D, Soons MB, Verweij PA, Verhoeven JT, Wassen MJ (2013) Wind and water dispersal of wetland plants across fragmented landscapes. *Ecosystems* 16(3):434–451
- Strayer DL, Beighley RE, Thompson LC, Brooks S, Nilsson C, Pinay G, Naiman RJ (2003) Effects of land cover on stream ecosystems: roles of empirical models and scaling issues. *Ecosystems* 6(5):407–423
- Sulman B, Desai A, Mladenoff D (2013) Modeling soil and biomass carbon responses to declining water table in a wetland-rich landscape. *Ecosystems* 16(3):491–507
- Turner MG, Gardner RH, O'neill RV (2001) *Landscape ecology in theory and practice: pattern and process*. Springer Press, New York, pp 479–494
- Vorovencii I (2015) Quantifying landscape pattern and assessing the land cover changes in Piatra Craiului National Park and Bucegi Natural Park, Romania, using satellite imagery and landscape metrics. *Environ Monit Assess* 187(11):1–22
- Walz U, Syrbe RU (2013) Linking landscape structure and biodiversity. *Ecol Ind* 31:1–5
- Wan LH, Zhang YW, Zhang XY, Qi SQ, Na XD (2015) Comparison of land use/land cover change and landscape patterns in Honghe National Nature Reserve and the surrounding Jianshanjiang Region, China. *Ecol Ind* 51:205–214

- Wang ZM, Huang N, Luo L, Li XY, Ren CY, Song KS, Chen JM (2011) Shrinkage and fragmentation of marshes in the West Songnen Plain, China, from 1954 to 2008 and its possible causes. *Int J Appl Earth Obs Geoinf* 13(3):477–486
- Westerberg VH, Lifran R, Olsen SB (2010) To restore or not? A valuation of social and ecological functions of the Marais des Baux wetland in Southern France. *Ecol Econ* 69(12):2383–2393
- Xiao SC, Xiao HL, Lu Q, Li S, Wei H (2013) Evaluation on China desert and sandy land ecosystem services based on its related water process and regulating functions. *J Desert Res* 23(5):1568–1576 **(In Chinese with English abstract)**
- Zhang N, Li H (2013) Sensitivity and effectiveness and of landscape metric scalograms in determining the characteristic scale of a hierarchically structured landscape. *Landsc Ecol* 28(2):343–363
- Zhang JT, Qiu Y, Zheng FY (2000) Quantitative methods in landscape pattern analysis. *J Mt Sci* 18(4):346–352
- Zhang M, Lai ZZ, Li D, Shen Y (2013) Multi-class support vector machine classifier based on Jeffries–Matusita distance and directed acyclic graph. *J Harbin Inst Technol* 5(20):113–118
- Zhang F, Tiyip T, Johnson VC, Ding JL, Sun Q, Zhou M, Chan NW (2015) The influence of natural and human factors in the shrinking of the Ebinur Lake, Xinjiang, China, during the 1972–2013 period. *Environ Monit Assess* 187(1):1–14
- Zhao RF, Chen YN, Zhou HR, Yq Li, Zhang LH (2009) Assessment of wetland fragmentation in the Tarim River basin, western China. *Environ Earth Sci* 57(2):455–464
- Zheng GM (1995) Ornithology. Beijing Normal University Publishing Group, Beijing **(in Chinese)**
- Zhi W, Ji G (2014) Quantitative response relationships between nitrogen transformation rates and nitrogen functional genes in a tidal flow constructed wetland under C/N ratio constraints. *Water Res* 64:32–41
- Zhi W, Yuan L, Ji G, He C (2015) Enhanced long-term nitrogen removal and its quantitative molecular mechanism in tidal flow constructed wetlands. *Environ Sci Technol* 49(7):4575–4583 **(In Chinese with English abstract)**
- Zhou HR (2005) Prospect on multifunctional landscapes of marshes in arid areas. *Arid Land Geography* 28(1):16–20 **(In Chinese with English abstract)**

Reproduced with permission of copyright owner. Further reproduction prohibited without permission.