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ORIGINAL PAPER

Impact of land use and land cover dynamics on Zhalong wetland reserve ecosystem, Heilongjiang Province, China

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Abstract In view of the significant hydrological and ecological role of wetlands, an analysis was made on the impact of land use and land cover dynamics on the spatial status of Zhalong wetland, a Ramsar site located downstream of Wuyuer River Basin in Northeast China. The impact assessment analyzed multi-temporal changes in the upstream land use/land cover characteristics of the wetland watershed using remote sensing data of Landsat MSS/TM. The multi-temporal land use/land cover statistics revealed that significant changes have taken place in the Wuyuer River Basin. In response to these upstream land use/cover changes, the marsh landscape in Zhalong wetland has showed changes in spatial extension, landscape pattern, and water quality characteristics. The major impacts have resulted from construction of a reservoir and water diversion engineering that has altered the wetland hydrological conditions and reduced the spatial distribution of the marsh landscape. In addition, inputs of agricultural nutrients, and industrial and human wastes from the upper catchments have resulted in increased signs of eutrophication. This study suggests that effective wetland hydrological restoration measures are needed to avoid further deterioration of this internationally important ecosystem.

Keywords Land use/Land cover · Dynamics · Wetland ecosystem · Zhalong wetland

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Introduction

Wetlands are integral parts of the global ecosystem as they can prevent or reduce the severity of floods, as feeding ground water, and provide unique habitats for flora and fauna (Mitsch and Gosselink 1993). The Chinese government has also realized the significance of wetlands and has been taking measures to protect them (Zhang et al. 2009). Numerous wetland nature reserves were established over the past 20 years, and China now has 473 wetland nature reserves, with up to 45 % (17.2 million ha) of natural wetlands being protected (Jiang et al. 2006). Most wetland conservation policies therefore aim to prevent direct loss of wetland habitat. However, there is mounting evidence that wetland functions can be impaired not only by rehabilitation of the wetland itself, but also by adjacent land use (Burbridge 1994; Detenbeck et al. 1996). As reported in various studies, urban areas may threaten wetland ecosystems through direct habitat conversion (Clergeau et al. 1998; Blair 1999; McKinney 2002) and through various indirect effects of urbanization putting pressure on resource use, habitat fragmentation, waste generation, and freshwater consumption (Mikusinski and Angelstam 1998; Serra et al. 2008; Arjoon et al. 2013). Agriculture is another, perhaps even greater, global threat to wetland ecosystem health. Similar to urbanization, agriculture presents both direct problems of habitat conversion and indirect effects of shortage of water, vegetation degradation, and increased nutrients and alkalinity (Pimentel et al. 1992; Rizvi et al. 2012; Parmar and Bhardwaj 2013).

In the current study, the impacts of land use/cover changes on Zhalong national nature reserve (Zhalong NNR), which was listed in 1992 as wetlands of international importance by the Ramsar Convention, were investigated. We assessed whether the large-scale agricultural development and urbanization that has occurred over the past 30 years in Wuyuer River watershed resulted in the degradation of the Zhalong Wetland ecosystems. The degradation extent was reflected by detailed analyses of the marsh vegetation loss, landscape fragmentation, and the spatial characteristics of eutrophication. The objectives of the current study were to (1) contrast marsh area and landscape pattern between 1980 and 2010 in the Zhalong wetland under the influence of upstream land use and cover dynamics and (2) analyze eutrophication spatial characteristics of overlaying water quality related to direct and in direct human impacts using geostatistical methods.

Materials and methods

Study area

Zhalong wetland is located at 46°52′N − 47°32′N, 123°47 E′ − 124°37′E and forms an inland delta at the lower reaches of Wuyuer River. Wuyuer River watershed is located at 46°23′ − 48°25′N, 123°47′ − 127°27′E, lies in the northeast Songnen Plain, Heilongjiang Province, China (Fig. 1), and is approximately 19,004 km^2 in size. Zhalong wetland was listed as a wetland of international importance in 1992 and forms Zhalong National Natural Reserve (ZNNR). The wetland is a transition zone from the continental sub-humid area to the continental sub-arid region and measures approximately 2,100 km^2. The natural water sources are mainly from Wuyuer and Shuangyang Rivers, and the greatest depths are approximately 75 cm in the wetland and 5 m in wetland lakes. Within the wetland, the main land cover types are reed, sedge, wet meadow, grassland, and farmland, and 69 families and 525 species of plant have been reported in this area.

Data sources

We developed a spatial–temporal database including layers of land cover and environmental variables. Twelve cloud-free Landsat MSS/TM remote sensing images, for 1980, 1990, 2000, and 2010, were used to detect land cover change in the Wuyuer River Basin study area. All the images were acquired from June to September, which is during the growing season and best for land cover research. Other ancillary GIS data used in this research were as follows: (1) a digital district map and topographic maps at the scale of 1:50,000 in 1986 for Wuyuer River Basin and 1:10,000 in 1995 for Zhalong NNR from the Heilongjiang Mapping and Surveying Bureau, (2) a vegetation thematic map at the scale of 1:200,000 from the Geography Institution of Changchun, Chinese Academy of Sciences in 1985, (3) meteorological data from 1980 to 2010 from the Heilongjiang Meteorological Bureau, (4) runoff data from 1980 to 2010 at two hydrological stations, and (5) social and economic statistics from the statistical yearbook for Qiqihar provided by the Heilongjiang Land Use Bureau.

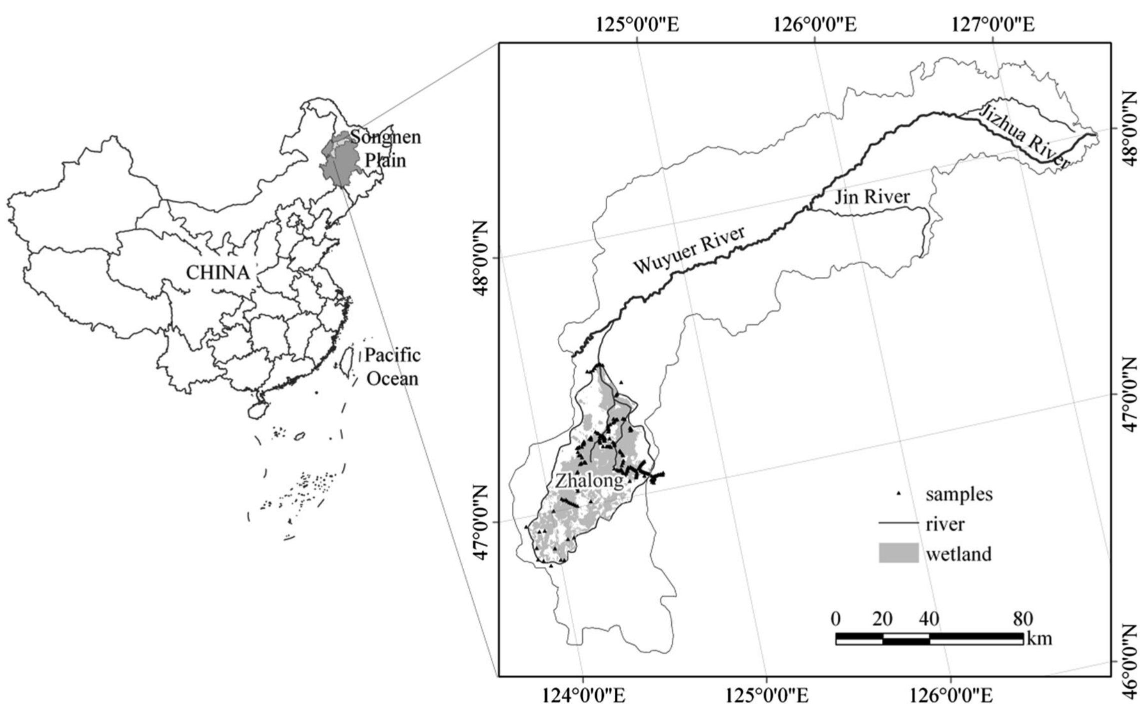

Fig. 1 Map of Wuyuer River Basin in northwestern Songnen Plain, China, and water sampling locations, 2010

Table 1 Accuracy assessment of the maximum likelihood classification of the 1980, 1990, 2000, and 2010 Landsat images of the Wuyuer River Basin

Year	User's accuracy (%)						Producer's accuracy (%)						Overall accuracy (%)	Kappa
	Mar	Mea	Cul	Ope	Res	Sal	Mar	Mea	Cul	Ope	Res	Sal		
1980	86.7	73.3	78.6	100.0	74.7	72.7	96.3	73.3	75.9	63.6	80.1	53.3	79.3	0.7181
1990	92.5	70.0	87.5	100.0	77.7	74.7	89.1	84.0	82.4	89.5	75.3	82.6	85.7	0.8109
2000	89.8	63.3	100.0	100.0	52.9	100.0	88.0	79.2	80.0	87.5	90.0	66.7	82.9	0.7816
2010	97.7	72.7	65.4	100.0	31.3	100.0	91.5	75.0	80.6	73.3	71.4	55.6	78.6	0.7286

Mar marsh, *Mea* meadow, *Cul* cultivated land, *Ope* open water, *Res* residential area, *Sal* saline and alkaline land

Land cover classification

Digital values recorded at the top of the atmosphere were converted to total radiance values at the satellite level and corrected for atmospheric effects by the dark pixel subtraction technique (Chavez 1988; Tang et al. 2005). All images were registered to the Albers projection (identical to that of the digital district map) using 66 ground control points (GCPs). The registration procedure achieved an accuracy of less than 0.5 pixel root mean square error (RMSE) for all images. The images in 1980 were re-sampled to pixel size 30 × 30 m, so as to match the TM image's resolution for other years. Three scenes of TM imagery covered our study area each year, so a mosaic had to be made in the preprocessing step. We performed histogram matching between the adjacent scenes for the same year using the ERDAS Imagine 9.2 so that the distributions of brightness values within the two images were as close as possible in the resultant mosaic image (Tang et al. 2005).

Land use/land cover mapping of Wuyuer River watershed was carried out using satellite data from the years 1980, 1990, 2000, and 2010. Supervised classification helped in identifying, delineating, and mapping land use/land cover into several classes (Rogan et al. 2008). The classes identified include cultivated land, forestland, meadow, marsh, residential area, open water, and saline and alkaline land. Considering the requirement of MLC and size of the study area, a separate set of training and test samples of approximately 750 pixels were chosen for the images (Na et al. 2010). The changes in land use/land cover classes were mapped and quantified, and accuracy assessment was done for all 4 years (1980, 1990, 2000, and 2010). An error matrix was generated, and the producer's accuracy, user's accuracy, overall accuracy, and Kappa coefficients were derived for accuracy assessment (Congalton and Green 1999; see Table 1).

Landscape characteristics

How the marsh landscape pattern changed in Zhalong NNR under the impact of land use/cover changes of Wuyuer River Basin was a central concern. Five landscape indices commonly used in landscape ecology studies were used to analyze landscape patterns over time at the class level for Zhalong NNR including mean of fractal dimension index (FRAC_MN), mean of the contiguity index (CONTIG_MN), number of patches (NP), patch cohesion index (COHESION), and largest patch index (LPI) (McGarigal et al. 2002, Table 2). The FRAC_MN and CONTIG_MN defined the patch shape complexity and patch boundaries connectedness, respectively. The NP was an indicator of the degree of fragmentation, and COHESION and LPI reflected the connectivity and dominance of marsh landscape, respectively (McGarigal et al. 2002).

On-the-ground sampling

Three hundred and forty-four representative sampling points were selected for surveying water quality during August and September 2010. Each sampling site was located using global position system, and a Hydrolab was used to measure water quality. The parameter measured by the Hydrolab was chlorophyll-a concentration (CHLA). Water was sampled by holding a water bottle vertically 10–40 cm below the surface of the water column. All water samples were immediately acidified with sulfuric acid in the field to a pH <2.0 (1 ml H_2SO_4: 50 ml water) and then refrigerated for further analysis in the laboratory. All samples were analyzed for total phosphorus (TP) and total nitrogen (TN) using standard colorimetric methods (APHA 1995), and chemical oxygen demand (COD) using K_2MnO_4 oxidation method (HJ/T 132, 2003). There are 12 observed concentration values for each index (CHLA, TP,TN, and COD). At each sampling point. The average of 12 observed values for each index was calculated at the sampling points.

Assessment of water eutrophication

In the current study, the modified trophic state index (TSIM) was chosen to assess the tropic state of the Zhalong wetland. The TSIM is a general method for evaluating

Table 2 Landscape metrics selected for use in this study

Acronym	Name	Algorithm	Parameter Description	Value range	Range Description
NP	Number of patches	$NP = N_i$	N_i: total number of patches in the landscape.	$NP \geq 1$, without limit	NP = 1 when the landscape contains only 1 patch of the corresponding patch type, that is, when the class consists of a single patch.
FRAC_ MN	Mean of Fractal dimension index	$\mathrm{FRAC} = \frac{2\ln(0.25P_{\mathrm{ij}})}{\ln a_{\mathrm{ij}}}$	P_{ij}: perimeter (m) of patch ij. a_{ij}: area (m^2) of patch ij.	$2 \geq FRAC \geq 1$	A fractal dimension greater than 1 for a 2-dimensional patch indicates a departure from Euclidean geometry. FRAC approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 for shapes with highly convoluted perimeters.
CONTIG_MN	Mean of contiguity index	$\mathrm{CONTIG} = \frac{\sum_{r=1}^{z} C_{\mathrm{ijr}} \big/ a_{\mathrm{ij}} - 1}{v-1}$	C_{ijr}: contiguity value for pixel r in patch ij. v: sum of the values in a 3-by-3 cell template (13 in this case). a_{ij}: area of patch ij	$1 \geq \mathrm{CONTIG} \geq 0$	CONTIG equals 0 for a one-pixel patch and increases to a limit of 1 as patch contiguity, or connectedness, increases.
COHESION	Patch cohesion index	$\mathrm{COHESION} = \left[1 - \frac{\sum_{j=1}^{m} p_{\mathrm{ij}}}{\sum_{j=1}^{m} p_{ij}\sqrt{a_{\mathrm{ij}}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1} \cdot (100)$	P_{ij}: perimeter of patch ij in terms of number of cell surfaces. a_{ij}: area of patch ij A: total number of cells in the landscape.	$100 > COHESION \geq 0$	COHESION approaches 0 as the proportion of the landscape comprised of the focal class decreases and is less connected physically. It increases monotonically as the proportion of the landscape comprised of the focal class increases.
LPI	Largest patch index	$\mathrm{LPI} = \frac{\max(a_{\mathrm{ij}})}{A} \cdot (100)$	a_{ij}: area of patch ij A: total landscape area	$100 \geq \mathrm{LPI} > 0$	LPI approaches 0 when the largest patch of the corresponding patch type is increasingly small. LPI = 100 when the entire landscape consists of a single patch of the corresponding patch type

Table 3 Area (ha) and percentage of different land cover classes of classified images between 1980 and 2010 in the Wuyuer River Basin

Class name	1980		1990		2000		2010	
	Area	Percentage of total area (%)	Area	Percentage of total area (%)	Area	Percentage of total area (%)	Area	Percentage of total area (%)
Marsh	330,097	17.4	298,232	15.7	285,386	15.0	203,222	10.7
Meadow	196,218	10.3	175,206	9.2	167,646	8.8	164,295	8.6
Cultivated land	1,035,628	54.5	1,106,059	58.2	1,136,232	59.8	1,214,515	63.9
Forestland	131,805	6.9	120,962	6.4	111,979	5.9	111,951	5.9
Open water	97,193	5.1	89,163	4.7	87,451	4.6	86,547	4.6
Residential Area	63,994	3.4	65,933	3.5	66,779	3.5	72,399	3.8
Saline and alkaline land	45,516	2.4	44,896	2.3	44,978	2.4	47,522	2.5

Table 4 Area (ha) and percentage of different land cover classes of classified images between 1980 and 2010 in Zhalong National Natural Reserve

Class name	1980		1990		2000		2010	
	Area	Percentage of total area (%)	Area	Percentage of total area (%)	Area	Percentage of total area (%)	Area	Percentage of total area (%)
Marsh	116,516	51.8	114,173	50.8	107,359	47.7	89,926	40.0
Meadow	50,762	22.6	50,443	22.4	52,338	23.3	63,323	28.2
Forestland	28,772	12.8	27,030	12.0	27,399	12.2	27,464	12.2
Open water	10,208	4.5	11,915	5.3	10,714	4.8	10,669	4.7
Residential Area	10,896	4.8	13,514	6.0	19,673	8.7	23,628	10.5
Saline and alkaline land	7,746	3.5	7,825	3.5	7,417	3.3	9,890	4.4

wetland's tropic state (Carlson 1977, Aizaki 1981; Chuai et al. 2012). Each TSIM for CHLA, TP, TN, and COD was calculated based on formula (1)–(4):

$$\mathrm{TSI_M(CHLA)} = 10 \times (2.46 + \ln(\mathrm{CHLA})/\ln 2.5) \quad (1)$$

$$\mathrm{TSI_M(TP)} = 10 \times (2.46 + (6.7 + 1.15 \times \ln(\mathrm{TP}))/\ln 2.5) \quad (2)$$

$$\mathrm{TSI_M(TN)} = 10 \times (2.46 + (3.93 + 1.35 \times \ln(\mathrm{TN}))/\ln 2.5) \quad (3)$$

$$\mathrm{TSI_M(COD)} = 10 \times (2.46 + (1.50 + 1.36 \times \ln(\mathrm{COD}))/\ln 2.5) \quad (4)$$

CHLA = surface algal chlorophyll-a (mg/m3);TP = total phosphorus (mg/l);

TN = total nitrogen (mg/l);

COD = chemical oxygen demand (mg/l).

In order to determine the spatial distribution of the trophic state in the Zhalong NNR, the TSIM for CHLA, TP, TD, and COD was interpolated to produce distribution maps used as an expression of the trophic states of corresponding water bodies. In the current study, the ordinary kriging method was used to form these theme maps. The kriging interpolation method takes into account the mathematical characteristics of the general structure of the spatial phenomenon studied (Lancaster and Salkauskas 1986); it is an optimized, linear, unbiased interpolation method (Gunnink and Burrough 1996).

The 0-100 scale in each trophic state index for CHLA, TP, TD, and COD was divided into eight ranges: extremely oligotrophic(0–10), oligotrophic(10–30), lower-mesotrophic (30–40), mesotrophic(40–50), upper-mesotrophic(50–60), eutrophic(60–70), hypereutrophic(70–80), extremely hypereutrophic(80–100) according to a criterion in Table 5, (Xing et al. 2005).

Results and discussion

Land use/cover dynamics of Wuyuer River Basin

Our study used remote sensing and GIS to identify ecological problems in the Zhalong NNR associated with

Table 5 The evaluation standards of the trophic state index (TSI_M) for Zhalong national natural reserve

Eutrophication level	TSI_M	CHLA (mg/m^3)	TP (mg/l)	TN (mg/l)	COD (mg/l)
Extremely oligotrohpic(0–10)	0	0.10	0.12	0.0004	0.06
	10	0.26	0.22	0.02	0.12
Oligotrophic(10–30)	20	0.60	0.40	0.03	0.24
	30	1.60	0.73	0.05	0.48
Lower-mesotrophic(30–40)	40	4.10	1.30	0.16	0.96
Mesotrophic(40–50)	50	10.00	2.40	0.31	1.80
Upper-mesotrophic(50–60)	60	26.00	4.40	0.65	3.60
Eutrophic(60–70)	70	64.00	8.00	1.20	7.10
Hypereutrophic(70–80)	80	160.00	15.00	2.30	14.00
Extremely Hypereutrophic	90	400.00	27.00	4.60	27.00
(80–100)	100	1000.00	48.00	9.10	54.00

human influences. Landsat classifications were used to produce land use and land cover maps and statistics. The classification accuracy assessment showed that the % accuracy and Kappa coefficient ranged from 78.6 to 0.7286, respectively, in 2010, to 85.7 % and 0.8109 in 1990 (Table 1). The accuracy for the six land use/cover categories was similar at each time period. The classification accuracy is highest for open water, and this is related to its distinct spectral characteristics. In contrast, the accuracy for residential area and saline and alkaline land is relatively low. This is due to their similar spectral characteristics leading to some lack of discrimination.

The statistical analysis of the multi-temporal land use/land cover maps revealed that significant changes have taken place from 1980 to 2010 (Table 3, Fig. 2). In brief, the area of cultivated land, residential area, and saline and alkaline land has increased, and the area of marsh, meadow, and forest has greatly decreased. Specifically, the area of cultivated land within the study area increased continuously over the 30 years, from 1,035,628 ha in 1,980 (54.5 % of the total area) to 1,214,515 ha in 2005 (63.9 % of the total area). The marsh area continued to decrease over the entire 30 years of the study period. The rate of decrease was extremely high between 2000 and 2010, declining from 15 % of the total area to only 10.7 %. The reason for the rapid decrease in marsh area was the construction of cultivated and residential area along both sides of the Wuyuer River during this period.

Meadow decreased rapidly between 1980 and 1990, decreasing from 10.3 to 9.2 % of the total area, and mainly distributed in the Zhalong NNR (Fig. 2). Since 2000, there has been virtually no meadow left to develop in the upper Wuyuer River Basin. Forestland area, mainly distributed in the upper Wuyuer River Basin, decreased from 6.4 to 5.8 % between 1990 and 2010. The areas of saline and alkaline land increased and the area of open water decreased between 1980 and 2010 (Table 3).

Our results indicate that the Wuyuer River Basin, northeast of the Zhalong wetland, has undergone major land use changes. Massive pristine marshlands on both sides of the Wuyuer River have decreased considerably during the last 30 years. The marshlands have been largely transformed into cultivated land and residential areas, indicating that the marsh landscape changes in the study area have primarily resulted from direct human impacts.

Spatiotemporal assessment of the Zhalong wetland

Landscape pattern dynamics of Zhalong NNR

The area of meadow and marsh combined was over 150,000 ha at each time interval, and the amounts of each decreased gradually in Zhalong NNR. Individually, the area of marshland decreased greatly during the past thirty years, while the area of meadow increased at the same time (Table 4). Cross-tabulation indicated that many marshes in Zhalong NNR have been converted to the meadow during the past 30 years. The reason for the variation of the two land covers may be partly because of the change of hydrological conditions under both heavy natural and human influences. For example, water resources of Wuyuer River were utilized for agricultural development and wetlands reclamation which reduced water supply to Zhalong NNR. Wetlands are very fragile ecosystems (Wang and He 2003), and human activities in the Wuyuer River Basin may have indirect impacts on the Zhalong wetland ecosystem. Another reason may in part be due to the construction of ditches that prevent recharge of surface water from outside the Zhalong NNR. Alterations of hydrological conditions have led to decrease in the marsh landscape area, changing plant species composition from aquatic vegetation to graminoids.

The number of patches (NP) declined continuously after 1990 accompanied by a decline in marsh area in the Zhalong NNR (Fig. 3a). Between 1980 and 1990, the marsh patches connectedness (FRAC_MN) decrease significantly while the shape complexity of marsh patches (CONTIG_MN) increase (Fig. 3b). In contrast, the FRAC_MN tended to increase slightly and CONTIG_MN decrease between 1990 and 2010. The dominance of marsh landscape (LPI) in Zhalong NNR decreased continuously, except for the early period between 1980 and 1990. The COHESION in Zhalong NNR changed irregularly from time to time without a distinct trend during the past 30 years. In summary, the marsh landscape pattern changed more intensively during the first 10 years than between 1990 and 2010. The decreasing of marsh area and

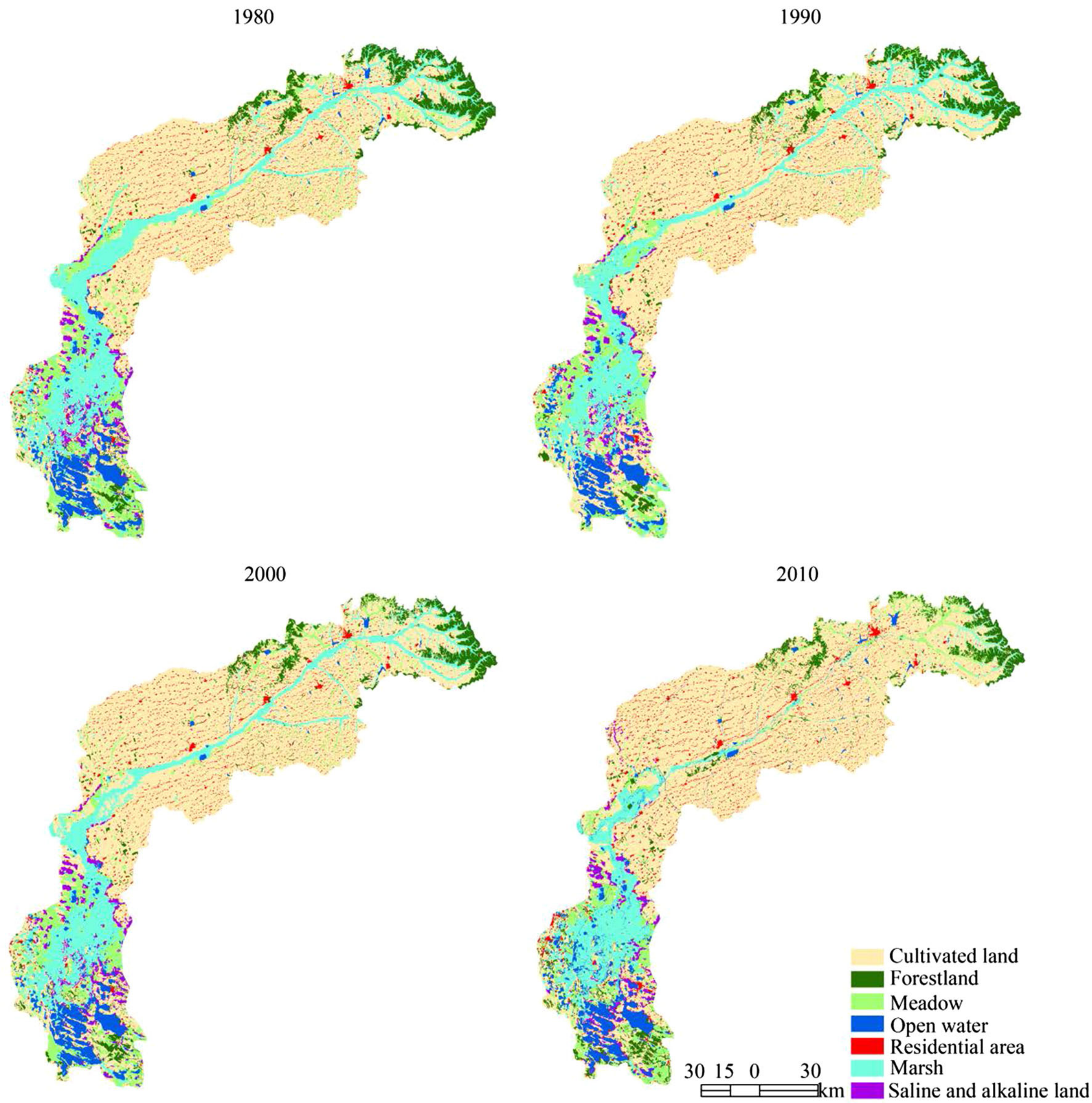

Fig. 2 Land use classification maps of the Wuyuer River Basin in 1980, 1990, 2000, and 2010

connectivity of marsh patches along with increasing shape complexity of marsh patches demonstrates the severe fragmentation process of marsh landscape during the first 10 years. However, the landscape indices fluctuated within a small range in recent 20 years signified a relative low human influence in this period (Fig. 3).

Our results indicated that the marsh landscape at Zhalong NNR first became more fragmented and heterogeneous from 1980 to 1990, and then became more aggregated and homogeneous. During the late 1970s to the early 1980s, increasing settlements and the introduction of the family contracted responsibility system, which accomplished the cultivated land circulation and transfer and established the family mode farm, led to wetland reclamation and landscape fragmentation (Zhang and Zhang 2008). When the Zhalong NNR was listed as a Ramsar wetland in 1992, the wetlands reclamation in the interior of reserve was forbidden. Since then, the marsh landscape has been undergoing a slow aggregation and homogenization process. Whether this trend will continue through time is problematic and will require further investigation based on the latest remote sensing images to document future trends (Table 5).

Spatial entrophic characteristic assessment of Zhalong NNR

The spatial distribution of TSIM (CHLA) and TSIM (TN) in 2010 is illustrated in Fig. 4a, b. Only the north and southeast of the Zhalong NNR were in eutrophic or hypereutrophic states. The other parts of Zhalong NNR were in oligotrophic

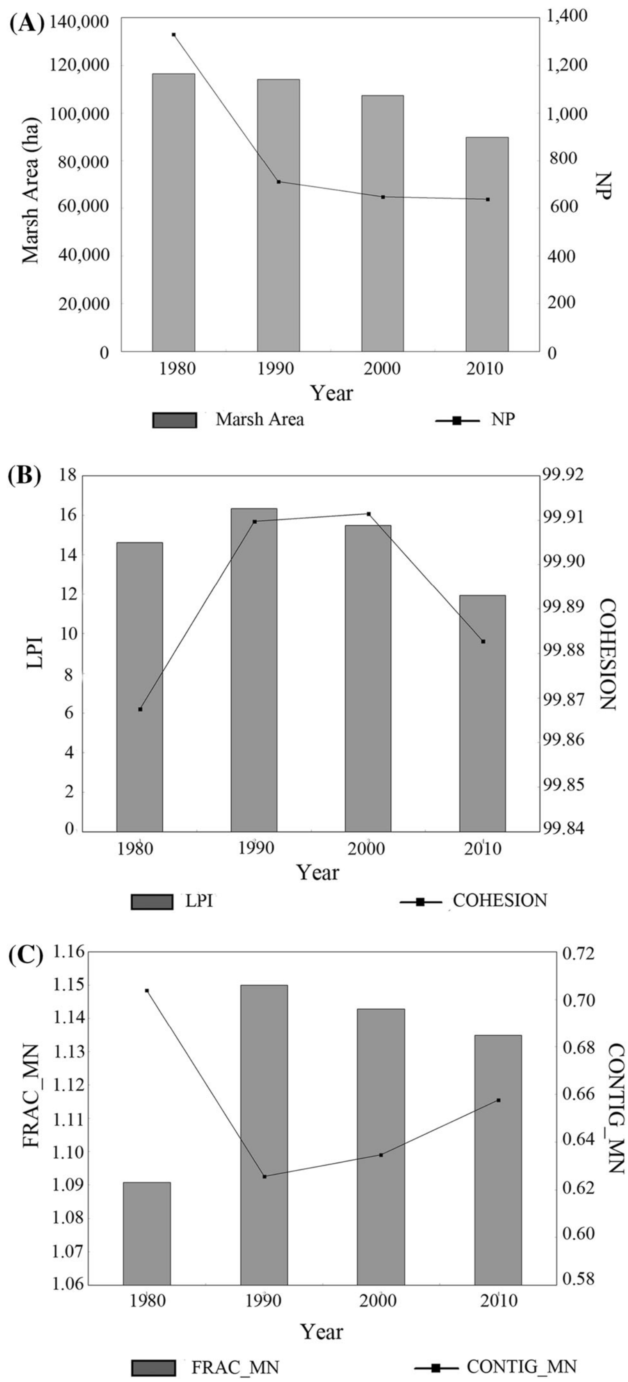

Fig. 3 Marsh area and landscape dynamics from 1980 to 2010 in Zhalong NNR; **a** marsh area and number of patches (NP); **b** mean of fractal dimension index (FRAC_MN) and mean of the contiguity index (CONTIG_MN); and **c** patch cohesion index (COHESION) and largest patch index (LPI)

or mesotrophic states. The spatial distribution of TSIM (TP) indicates eutrophication or hypereutrophication conditions throughout the Zhalong NNR wetland except for the core area of the reserve which is in mesotrophic state (Fig. 4c). Based on the spatial distribution of TSIm (COD), all of the study area can be characterized as being in a eutrophic and hypereutrophic state except the southeast and the northwest of the Zhalong NNR (Fig. 4d).

The overlaying water of Zhalong NNR has undergone eutrophication and in some areas is in a hypereutrophic state. The calculated TSIM (TP) and TSIM (COD) had the greatest values indicating these parameters play an important role in the eutrophication of Zhalong NNR. According to the trophic state spatial characteristics analysis in Zhalong NNR, the trophic state in the north and southeast regions of the Zhalong NNR is more serious than that of other locations. Industrial wastewater, fertilizers, silt, solid waste, and pesticides flow into the Wuyuer River through natural ditches upstream of the Zhalong wetland. Because the Wuyuer River flows into the northern regions of the Zhalong NNR, this region has a higher eutrophication state. Similarly, industrial wastewater and sewage from Lindian County, which is located in the southeast region of the reserve, drain directly into the Zhalong wetland resulting in increased eutrophication. With the increased input of nitrogen, phosphorus, and organic matter, the Zhalong wetland has become increasingly more polluted, and the diversity of the biological communities has been threatened.

Management implications

Driven largely by farmers' tendency for maximization of income, agricultural expansion has also been reported in other ecologically fragile and economically underdeveloped area (Semwal et al. 2004; Tanik et al. 2013). Rapid expansion of cropland and built-up land, and evident shrinkage of native freshwater marsh ecosystem resulting from improvement of socioeconomic conditions and population growth, also has occurred in other areas in China (Li and Wang 2003, Wang et al. 2008). However, agricultural expansion usually causes excessive water use and salinization, especially in arid and semiarid regions wherever irrigation is practiced. Based on our field investigation, problems of water shortage, eutrophication, and salinization were common in the study area. In Honghe NNR of the Sanjiang Plain, Heilongjiang province, the marsh landscape was degraded by changing plant species composition from aquatic vegetation to graminoids and shrubs due to increased cultivation (mainly paddy fields) around the reserve. In the case of the Honghe NNR, the crops are irrigated with pumped underground water that results in lowering of the groundwater level, a indirect impact on the wetland ecosystem by human activity (Zhang et al. 2009). The current study indicates that the present management of the Zhalong NNR is not sufficient to meet the protection objectives. A more comprehensive water use policy and additional regulations to reduce industrial and human

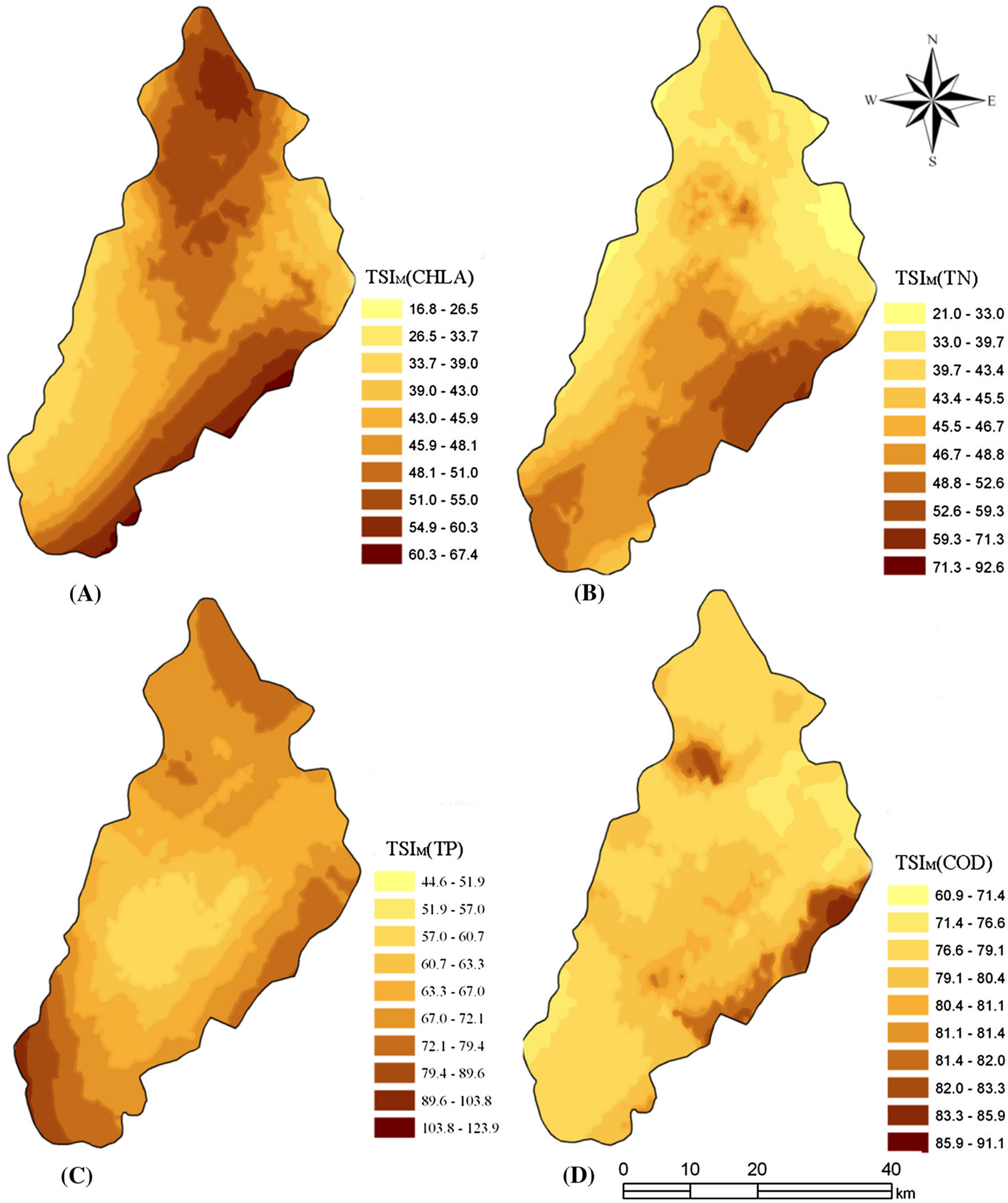

Fig. 4 Spatial distribution of the Zhalong National Natural Reserve Trophic State Index (TSI) based on indicators in August 2010; **a** TSI_M (CHLA); **b** TSI_M (TN); **c** TSI_M (TP) and **d** TSI_M (COD)

sewage inputs are needed to mitigate human impacts on this internationally important wetland ecosystem.

Conclusion

Wuyuer River Basin, northeast of the Zhalong wetland, has undergone major land use changes during the last 30 years. Massive marshlands have been transformed into cultivated land and residential areas. The consequences of land use changes surrounding Zhalong wetland have been characterized by a reduction in wetland area, decrease in water depth, degradation of water quality, and deterioration of the natural ecosystem. The wetlands of Zhalong NNR play a significant role in overall water cycle of Wuyuer River Basin and management ofWuyuer River Basin, specifically the Zhalong NNR, must address complex direct and indirect impacts of human activity on wetland ecology. A comprehensive adaptive management approach, informed by continued monitoring efforts, may best achieve the long-term conservation goals of this internationally important wetland ecosystem.

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