



Integrated Approach Based on a Regional Habitat Succession Model to Assess Wetland Landscape Ecological Degradation

Linlin Cui · Guosheng Li · Huajun Liao ·
Ninglei Ouyang · Yue Zhang

Received: 25 October 2014 / Accepted: 19 December 2014 / Published online: 23 January 2015
© Society of Wetland Scientists 2015

Abstract Wetland degradation is a predicament in wetland research. Constructing a robust, universal method to assess wetland landscape ecological degradation is a critical issue. This study proposes an integrated approach based on a regional habitat succession model to assess wetland landscape ecological degradation. The approach consists of a landscape change monitoring module, a regional habitat succession model, and a quantitative analysis module. The proposed approach is theoretically universal, although the regional habitat succession model is not universal. The approach is implemented and evaluated with Yancheng National Natural Reserve (YNNR) in East China as the study area. Results show that (1) wetland landscape ecological degradation in YNNR exhibits an accelerated degradation rate and an area percentage of 39.39 % for approximately 30 years; (2) the results are similar to those of previous studies and correspond to actual practice; (3) the proposed integrated approach can quantitatively assess the area, rate, and trend of degradation, and determine the dominant degradation processes and their drivers; and (4) the dominant processes and factors established in this study can provide directions for studies on the mechanism of wetland degradation and support the conservation and management of wetlands. Therefore, the proposed method is a

promising approach to evaluate the ecological degradation of wetland landscapes.

Keywords Wetland degradation · Habitat succession · Remote sensing · Yancheng National Natural Reserve (YNNR)

Introduction

A wetland is a transition area between terrestrial and aquatic ecosystems; it is an important landscape and a unique ecosystem for the maintenance of ecological balance and protection of biodiversity (Bullock and Acreman 1999; McClain et al. 2003). It also is a vulnerable ecosystem (Kirwan and Megonigal 2013). Its structure and function have been altered, and many ecological and environmental issues have been caused by natural environmental changes, anthropogenic activities, and synergistic combinations of the two (Davis and Froend 1999; Nicholls and Cazenave 2010). The ecological deterioration of wetlands is referred to as “wetland degradation”, which has become a serious problem worldwide (Millennium Ecosystem Assessment 2005). It is mainly manifested in the structural and functional degradation of population ecology (Mitchell et al. 2002; Ogden 2005; Klimkowska et al. 2010), community ecology (Owino and Ryan 2007; Dinka et al. 2008), ecosystem (Bridgham et al. 2006; Kansiiime et al. 2007; García et al. 2008), and landscape ecology (Cushman 2006; Knutson et al. 1999). These four research fields require different approaches and data. Data on these fields can be generally divided into two categories, namely, traditional field ecological data and remote sensing data. Traditional field ecological data cannot be readily used in regional and global extents (Kerr and Ostrovsky 2003), whereas remote sensing data can be well utilized in regional and global extents. Hence,

L. Cui · G. Li (✉) · H. Liao · N. Ouyang · Y. Zhang
Key Laboratory of Land Surface Pattern and Simulation, Institute of
Geographic Sciences and Natural Resources Research, Chinese
Academy of Sciences, 11A Datun Road, 100101 Beijing, China
e-mail: ligscas@gmail.com

G. Li
Key Laboratory of Coastal Wetland Biogeosciences, China Geologic
Survey, 62 Fuzhou Road, 266071 Qingdao, China

L. Cui · H. Liao · N. Ouyang · Y. Zhang
University of Chinese Academy of Sciences, 19A Yuquan Road,
100049 Beijing, China

remote sensing data are promising data for the monitoring of wetland changes.

Remote sensing data have been widely utilized in landscape ecology (Wu 2000). The ecological degradation of wetlands is often characterized by fragmentation, area loss, and diversity loss. These characteristics have been studied with various landscape indices (Jaeger 2000; Schulz et al. 2010), which can substantially summarize the information of landscape patterns and serve as quantitative indices that describe the structures or patterns of landscapes (Wu 2000). Nevertheless, scaling, ecological significance, and the relationship between landscape indices and ecological processes require further study prior to application (Wu and Hobbs 2002; Wu 2013). Additionally, a hypothetical condition may also exist, wherein the landscape type is significantly converted and the value of the landscape index remains constant. The landscape index would not be suitable in this case. Therefore, a universal approach to analyze the ecological degradation of wetlands, including human and natural landscapes, is urgently needed.

Ecological succession shows the succession of processes and directions but does not consider human landscapes which are significant components of wetland landscapes and comprise a vital part of holistic landscape ecology (Wu 2004). Landscape conversion involves human landscapes but does not consider direction. A mixture of ecological succession and landscape conversion might be the correct approach. Landscape is composed of various habitats in a specific region and time window. Habitat is a comprehensive body that comprises human activity, landform, hydrology, soil, and vegetation in a specific space and stage. Habitat succession occurs with the change in the ecological sensitivity factor (e.g., human activity, landform, hydrology, and soil) during a specific time period; habitat succession ultimately presents landscape changes. The direction of landscape conversion or habitat succession can be defined based on the direction of the change in the ecological sensitivity factor. Based on the above analysis, a regional habitat succession model can be constructed to evaluate wetland landscape ecological degradation, which takes different forms in different regions. Therefore, an approach-based habitat might be suitable to assess the ecological degradation of wetlands. An integrated approach was developed in this study to assess the ecological degradation of wetlands. The approach is based on the regional habitat succession model, which combines landscape conversion with the corresponding habitat information (includes landscape change monitoring, habitat succession model, and conversion contribution rate). The landscape change monitoring module is the basic component, the regional habitat succession model is the core, and the conversion contribution rate module is the quantitative analysis method.

The integrated approach proposed in this study to assess the ecological degradation of wetlands is theoretically universal. Many methods for landscape change monitoring have

been developed (e.g., Berberoglu et al. 2000; Sluiter 2005; Filippi and Jensen 2006; Adam et al. 2010; Dronova et al. 2011); the conversion contribution rate has also been presented (Zeng et al. 2003). The most significant challenge in applying the proposed approach is the construction of a suitable habitat succession model for the specific study area. To test the approach's suitability for the evaluation of wetland degradation, it was implemented and evaluated with Yancheng National Natural Reserve (YNNR) in East China as the study area.

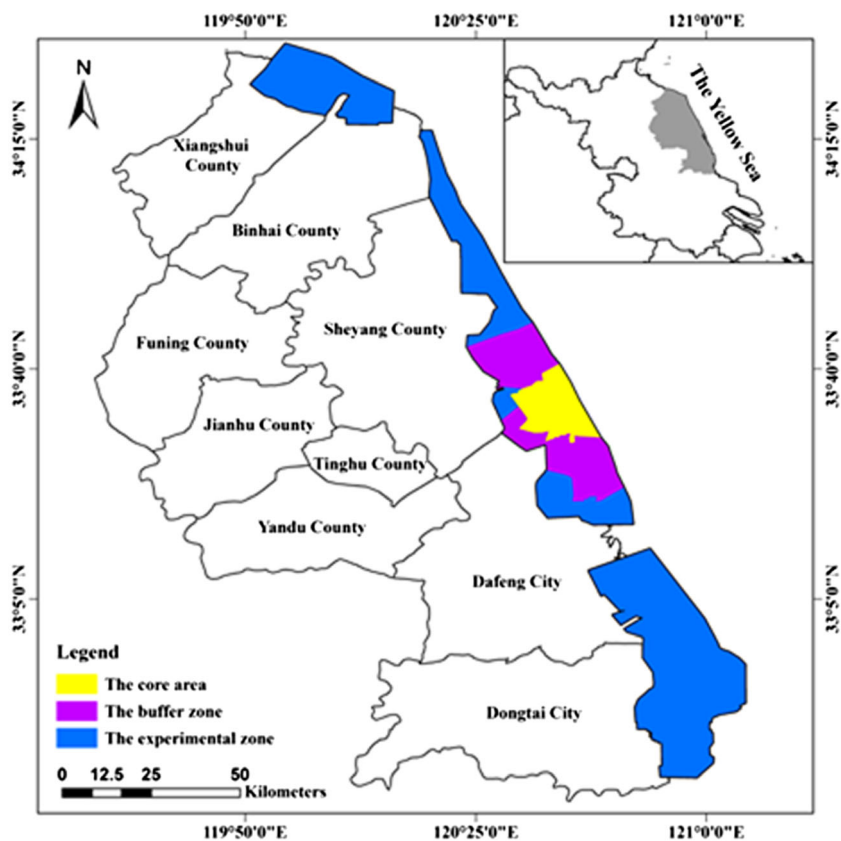
Study Area and its Habitat Succession Model

YNNR is a typical silty coastal reserve located at 119°53'2" E to 121°14'21" E and 32°48'47" N to 34°29'27" N in the east coast of Jiangsu Province, China (Fig. 1). Common natural communities include the following: *Spartina alterniflora* (SA), *Suaeda glauca* (SG), *Imperata cylindrica* and *Aeluropus sinensis*, *Tripolium panonicum*, *Phragmites australis* (PA), *Salicornia europaea*, *Tamarix chinensis* and *Apocynum venetum*, *Carex cinerascens* and *I. cylindrica*, and *Scirpus planiculmis*.

A classification system of wetland landscapes was constructed based on field investigations, historical data, and the object recognition capacity of the remote sensing data utilized in this study (Figs. 2 and 3). The study area was divided into wetlands and non-wetlands (NoWs). The wetlands were classified into natural wetlands (NWs) and constructed wetlands (CWs). The NWs were further categorized into mudflats (MFs), SA, SG, PA, grassland species (GS), and rivers (RS); the CWs were classified into paddy fields (PFs), aquaculture ponds (APs), salt fields (SFs), and pools (PS).

The wetlands were accordingly converted to NoWs, and the NWs (except for invasive species) were converted to CWs, which belong to wetland landscape ecological degradation. The coastal wetland vegetation in NWs contains various halophytes, as indicated by the evident soil water-salt gradient from the sea to the inland in the coastal wetland area (from the shallow sea region below the mean low tide line to the intertidal zone between the mean low tide line and the mean high tide line and to the land area above the mean high tide line) (Li et al. 1998). Ecological succession in wetland systems has been extensively investigated (Liu et al. 1992; Yang et al. 2002; Yao et al. 2009). SG is the pioneer community in YNNR, followed by PA and GS with soil desalination. GS is the climax community, and its dominant species is *I. cylindrica*. The drivers of ecological succession in wetland systems include soil water, salinity, and species invasion (Millennium Ecosystem Assessment 2005; Mendez Linares et al. 2007; Zhang et al. 2014). Therefore, the ecological retrogressive succession of natural landscapes in coastal wetlands involves three directions: soil dehydration (Zedler et al. 1986;

Fig. 1 Location of the study area



Chow-Fraser et al. 1998; Muller et al. 2006), soil salt accumulation (Huang et al. 2010), and species invasion (MacDougall and Turkington 2005; Schulz et al. 2010; Qiu 2013). Therefore, the conversions of GS to PA and SG, which belong to the direction of soil salt accumulation, represent retrogressive succession; the conversions of PA, SG, and MF to SA, which belongs to the direction of species invasion, also demonstrate retrogressive succession (Fig. 2).

Defining the direction of degradation in CWs is difficult. Ecological service value, a major manifestation of wetland states, was selected as the criteria of wetland evolution and degradation in this study. Therefore, the degradation direction of CWs is the direction of the ecological service value reduction. Research has shown that PFs exhibit the highest ecological service value, followed by APs, SFs, and PS in YNNR (Chen 2006; Zhang et al. 2007). Figure 2 presents the regional habitat succession model of YNNR.

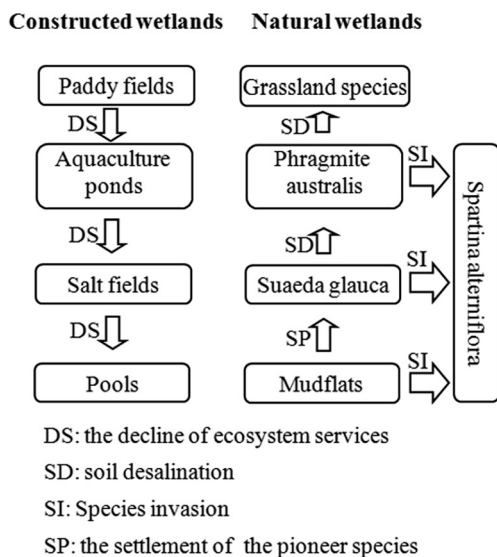


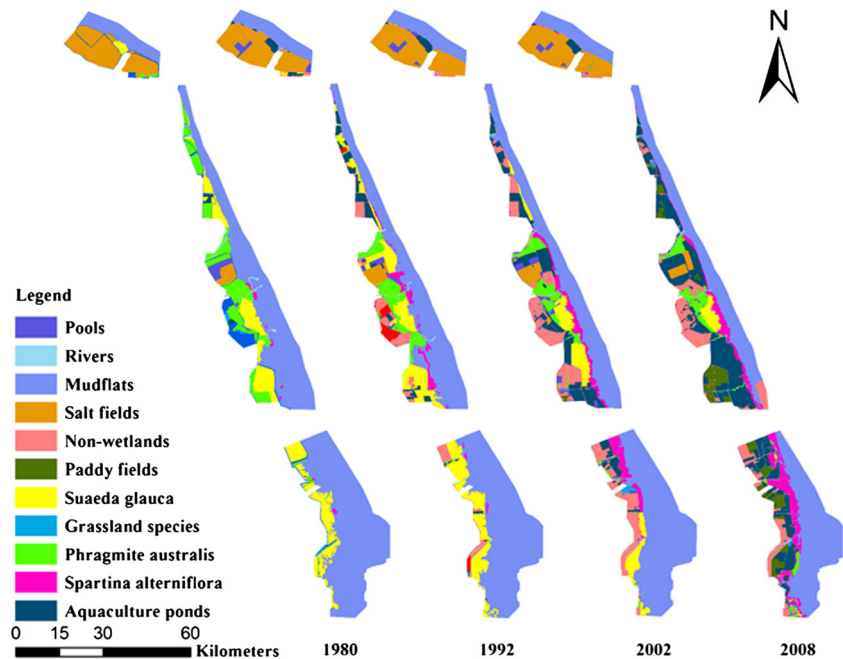
Fig. 2 Regional habitat succession model of YNNR

Materials and Methods

Monitoring Landscape Changes

Remote sensing data and the atlas of the National Multipurpose Investigation of the Coastal Zone and Tidal Wetland Resources (1980s) were utilized to monitor landscape changes. Two scenes of the images acquired from the closest dates to the four target years (1980, 1992, 2002, and 2008) were selected because the source images should be cloud-free for landscape mapping (Table 1); pre-processing was performed before they were utilized. A hybrid classification technique that includes the iterative self-organizing data analysis technique (ISODATA), support vector machine classifier (SVM),

Fig. 3 Classification results of the remote sensing images



and visual interpretation (using pseudo-color images) was applied to extract different wetland clusters. The Kappa coefficients of the four classification results on different dates were computed to determine the process accuracy of the assessment. The obtained coefficients were higher than 0.70 (Fig. 3). All data processes were implemented with the software package ENVI 5.0 (Environment for Visualizing Images) and ArcGIS 10.0 (Geographic Information System software).

Table of Wetland Landscape Succession

The degradation process of wetland landscapes was further elucidated by constructing a table of wetland landscape succession based on the regional habitat succession model. The form of wetland landscape ecological degradation was categorized into absolute loss (conversion of wetlands to NoWs), gradual loss (retrogressive succession within NWs or CWs), habitat loss (conversion of NWs to CWs), and species invasion. Table 2

shows the degradation process and the type of wetland landscapes.

Conversion Contribution Rate Method

In this study, A_{ij} is the conversion area from landscape element i to landscape element j , A_t is the total landscape conversion area, and n is the number of landscape elements.

Conversion-in Rate

Conversion-in contribution rate is the ratio of the conversion area from other landscape elements to a specific landscape element to the total landscape conversion area (Zeng et al. 2003). The conversion-in rate is provided by

$$T_{in_i} = \sum_{j=1}^n \frac{A_{ji}}{A_t}, \quad (1)$$

where T_{in_i} denotes the conversion-in rate of the i th landscape element.

Table 1 Acquisition dates, spatial resolutions and sources of the images

Dates	Path/row				Resolution	Sources
	128/037	129/036	119/037	120/036		
Around 1980	10 September 1979	6 August 1979	–	–	80 m	[1]
Around 1992	–	–	7 June 1992	29 May 1992	30 m	[1]
Around 2002	–	–	23 September 2002	30 September 2002	30 m	[1]
Around 2008	–	–	5 July 2008	15 July 2009	30 m	[2], [1]

“–” denotes no data; [1] <http://earthexplorer.usgs.gov/> [2] <http://ids.ceode.ac.cn/>

Table 2 Conversion table of wetland landscapes based on the regional habitat succession model

Habitat	Later period									
	MFs	SG	PA	GS	PFs	APs	SFs	PS	SA	
Earlier period	MFs	☆	★	★	★	●	●	●	●	▼
	SG	▲	☆	★	★	●	●	●	●	▼
	PA	▲	▲	☆	★	●	●	●	●	▼
	GS	▲	▲	▲	☆	●	●	●	●	
	PFs	★	★	★	★	☆	◆	◆	◆	
	APs	★	★	★	★	★	☆	◆	◆	
	SFs	★	★	★	★	★	★	☆	◆	
	PS	★	★	★	★	★	★	★	☆	
	SA	★	★	★	★	★	★	★	★	☆

Mudflats (MFs), *Spartina alterniflora* (SA), *Suaeda glauca* (SG), *Phragmites australis* (PA), glassland species (GS), paddy fields (PFs), Aquaculture ponds (APs), salt fields (SFs), pools (PS). : not existing; ★: progressive succession; ☆: no change; ▲: retrogressive succession within NWs; ◆: retrogressive succession within CWs; ●: the conversion of NWs to CWs; ▼: species invasion

Conversion-out Rate

Conversion-out contribution rate is the ratio of the conversion area from a specific landscape element to other landscape elements to the total landscape conversion area (Zeng et al. 2003). The conversion-out rate is provided by

$$T_{out_i} = \sum_{j=1}^n \frac{A_{ij}}{A_t} \tag{2}$$

where T_{out_i} denotes the conversion-out rate of the i th landscape element.

Specific Conversion Process Contribution Rate

The contribution rate of a specific conversion process is the ratio of the area of the specific conversion process to the total landscape conversion area (Zeng et al. 2003). The contribution rate of the specific conversion process is defined by

$$T_{ij} = \frac{A_{ij}}{A_t} \tag{3}$$

where T_{ij} denotes the contribution rate from the i th landscape element to the j th landscape element.

Results and Discussion

Main Degradation Characteristics

Stages 0, 1, 2, and 3 represent the period from 1980 to 2008, 1980 to 1992, 1992 to 2002, and 2002 to 2008, respectively. Table 3 shows the conversion-in and conversion-out rates of each landscape type in YNNR as well as the core area, buffer zone, and experimental zone for stage 0. The area percentage of landscape ecological degradation in different stages is summarized in Table 4. The wetland landscape ecological degradation in YNNR was mainly characterized as follows: the conversion-out rate of NWs is higher than the conversion-in

Table 3 Contribution rates of conversion-in and conversion-out for different landscape types (1980–2008)

Category	Landscape type	YNNR		Core area		Buffer zone		Experimental zone	
		Conversion-in (%)	Conversion-out (%)	Conversion-in (%)	Conversion-out (%)	Conversion-in (%)	Conversion-out (%)	Conversion-in (%)	Conversion-out (%)
Natural wetlands	MFs	1.56	49.17	0.99	48.02	0.48	54.87	2.00	47.38
	SA	14.20	0.79	30.82	2.12	7.09	1.53	14.55	0.36
	SG	5.39	25.14	18.96	32.19	0.00	3.51	5.53	31.64
	PA	3.29	15.32	24.82	11.60	1.10	21.33	1.35	13.73
	GS	0.96	0.62	0.00	0.00	0.08	0.77	1.39	0.64
	RS	0.87	1.08	0.13	3.64	0.68	1.32	1.03	0.68
	Total	26.27	92.12	75.72	97.57	9.43	83.33	25.86	94.43
Constructed wetlands	APs	42.99	0.23	19.09	0.00	70.84	0.64	36.47	0.12
	PFs	11.99	0.00	0.00	0.00	1.10	0.00	17.19	0.00
	SFs	2.50	2.38	0.00	0.00	5.70	5.43	1.71	1.64
	PS	1.93	2.24	3.64	2.43	0.54	8.61	2.19	0.04
	Total	59.41	4.85	22.72	2.43	78.17	14.69	57.57	1.80
Non-wetlands		14.32	3.03	1.55	0.00	12.40	1.98	16.57	3.77

Mudflats (MFs), *Spartina alterniflora* (SA), *Suaeda glauca* (SG), *Phragmites australis* (PA), glassland species (GS), Rivers (RS) paddy fields (PFs), Aquaculture ponds (APs), salt fields (SFs), pools (PS)

Table 4 Area percentage of the retrogressive transformation process in different stages (%)

Region	YNNR				Core area				Buffer zone				Experimental zone			
	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
DAR	39.39	12.74	21.22	16.70	25.80	3.92	23.08	5.01	49.49	15.90	29.48	25.98	38.46	12.98	18.97	15.76
Type1	17.20	23.55	37.86	18.47	2.87	0.00	3.21	0.00	15.25	16.63	26.72	17.06	18.92	26.43	46.95	19.71
Type2	2.82	28.49	6.25	4.70	1.55	17.55	1.09	6.45	0.79	24.69	4.41	10.71	3.57	30.01	7.67	2.20
Type3	62.96	33.62	35.22	46.30	38.59	2.73	48.86	28.51	75.25	17.28	51.65	57.04	60.94	39.62	27.03	42.59
Type4	17.01	14.36	20.68	30.53	56.98	79.71	46.84	65.04	8.72	41.39	17.21	15.20	16.57	3.95	18.35	35.50
ASR	81.14	62.27	76.28	68.21	41.46	2.73	52.07	28.51	90.49	35.45	80.92	83.82	81.22	72.32	77.87	63.33

DAR represents the area proportion of wetland degradation; Type 1, Type 2, Type 3, and Type 4 represent absolute loss, gradual loss, habitat loss, and species invasion, respectively; ASR is the area ratio of wetland degradation caused by human activities over the total area of wetland degradation; Stages 0, 1, 2, and 3 represent the period from 1980 to 2008, 1980 to 1992, 1992 to 2002, and 2002 to 2008, respectively

rate (92.12 % > 26.27 %); the conversion-out rate of CWs is lower than the conversion-in rate (7.88 % < 73.73 %); the proportion of the degradation area to the total area is 39.39 %; and habitat loss is the main form of wetland landscape ecological degradation (62.96 % of the total degradation area).

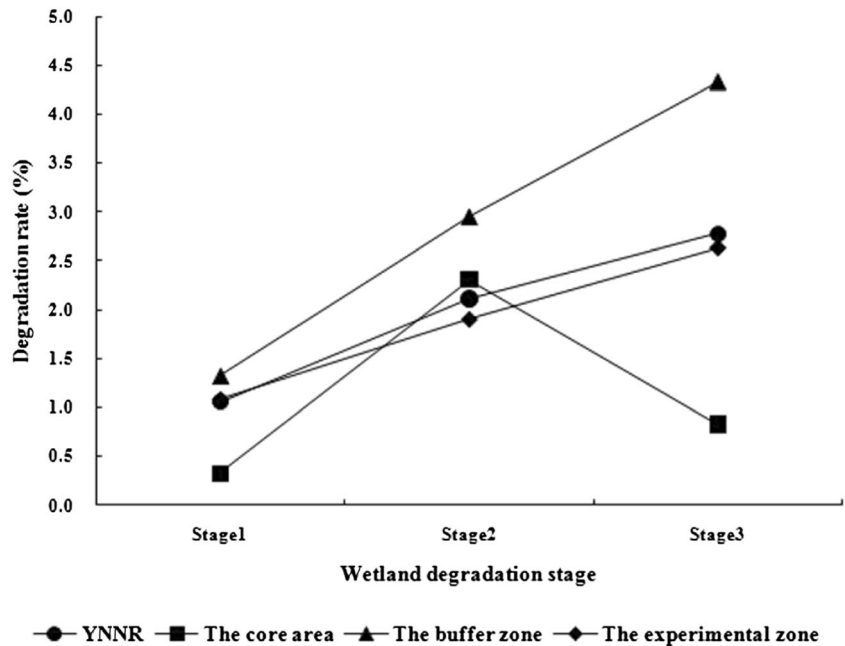
The main characteristics of the wetland landscape ecological degradation of the buffer and experimental zones are in accordance with those of YNNR. These characteristics were presented as follows: the conversion-out rate of NWs is higher than the conversion-in rate; the conversion-out rate of CWs is lower than the conversion-in rate; the degradation area proportions of the total area are 49.49 and 38.46 % in the buffer and experimental zones, respectively; and habitat loss is the main form of wetland landscape ecological degradation. By contrast, the conversion-in and conversion-out rates of the core area are 75.72 and 97.57 %, respectively. The degradation area proportion is 25.80 % and species invasion is the

main degradation form. The qualitative conclusions obtained from the proposed approach for evaluating wetland landscape ecological degradation are consistent with the conclusion reported by Sun et al. (2010).

Trend of Wetland Landscape Ecological Degradation

The change in wetland degradation area proportions in stages 1, 2, and 3 does not reflect the trend of wetland degradation because of the different time intervals of the three stages. Degradation rate is defined as the percentage of the average degradation area of wetland landscape each year over the total area of a specific area; this rate can reflect the trend of wetland degradation. Therefore, degradation rate was utilized to clarify the trend of wetland landscape ecological degradation. Figure 4 shows the degradation rates of different study areas in different stages and the ecological degradation trends of wetland landscapes.

Fig. 4 Rates of wetland landscape degradation of different regions in different stages



The degradation rates in stages 1, 2, and 3 and the slope of the fitting curve are 1.06, 2.12, 2.78 %/y, and 0.86 for YNNR, respectively; 1.32, 2.95, 4.33 %/y, and 1.51 for the buffer zone, respectively; and 1.08, 1.90, 2.63 %/y, and 0.78 for the experimental zone, respectively. The wetlands in YNNR, buffer zone and experimental zone demonstrated accelerated degradation. The degradation rates of the core area in stages 1, 2, and 3 are 0.33, 2.31, and 0.83 %/y, respectively, indicating that the rates are initially high and then subsequently decrease.

Stage 2 is a critical stage in which absolute and habitat losses are the main forms of wetland landscape ecological degradation. This condition was induced by the strategy of “constructing marine eastern Jiangsu” implemented in the early 1990s to prompt economic development. The gross domestic product of Yancheng City significantly increased from 16.71 billion yuan in 1990 to 67.33 billion yuan in 2002 and 160.33 billion yuan in 2008, with a total increase of 143.62 billion yuan (Yancheng Bureau of Statistics 1993, 2003, 2009). Hence, the area of NWs gradually decreases, and the areas of CWs and NoWs gradually increase, which is consistent with the conclusions reported in previous studies (Zhang et al. 2013; Zuo et al. 2012).

Dominant Factors and Processes

The proportion of the area of ecologically degraded wetland landscapes caused by human activities with respect to the total area is 81.14 % for YNNR, 41.46 %, for the core area, 90.49 % for the buffer zone, and 81.22 % for the experimental zone in a period of approximately 30 years (Table 4). The evident dominant factor of wetland landscape ecological degradation is human activity, which is consistent with the conclusions obtained by Hao et al. (2010), Kirwan and Megonigal

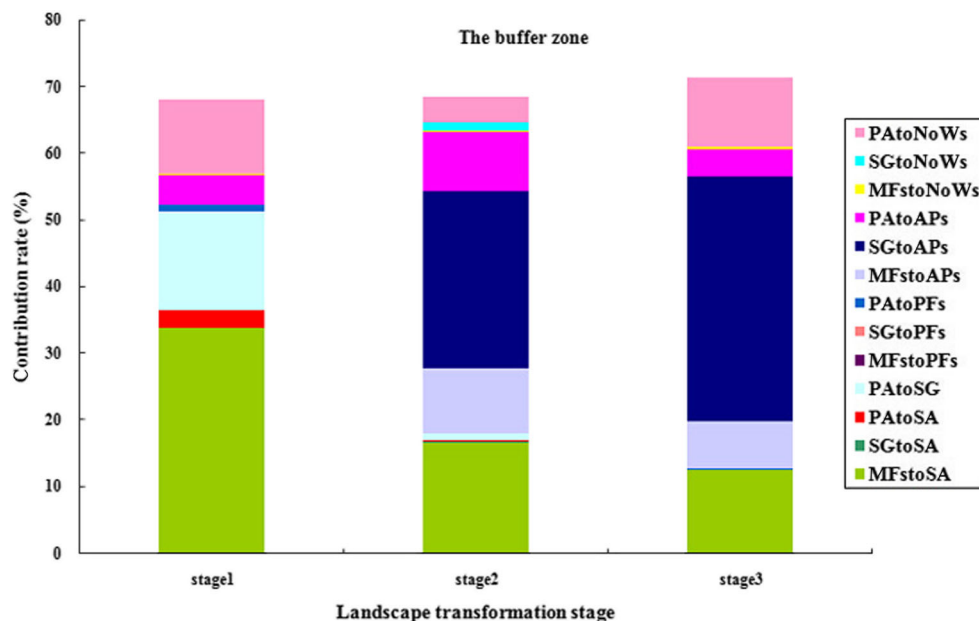
(2013), and Millennium Ecosystem Assessment (2005). The main body of wetland landscapes has shifted from natural to human landscapes. Nevertheless, natural factor dominated wetland landscape ecological degradation in the core area in stages 1 and 3. The proportions of the area of wetland landscape ecological degradation caused by species invasion with respect to the total area are 79.71 and 65.04 % in stages 1 and 3, respectively.

The dominant process of wetland landscape ecological degradation is as important as the dominant factor of degradation for conserving and managing wetlands. The integrated approach developed in this study can also be utilized to determine the dominant process of wetland landscape ecological degradation. The contribution rate of the specific degradation process compared with all the degradation processes in different stages is presented in Fig. 5 with the buffer zone as an example. The dominant degradation process differed in stages 1 and 3, although the main form of wetland landscape ecological degradation remained the same (habitat loss). The dominant degradation processes in stage 2 are the conversions of MFs, SG, and PA to APs and MFs to SA as well as the conversion of MFs to SA. The dominant degradation processes in stage 3 are the conversions of MFs and SG to APs, PA to NoWs, and MFs to SA. This finding provides additional information for the management of wetland landscape ecological degradation.

Conclusion

An integrated approach to assess the ecological degradation of wetland landscapes based on a regional habitat succession

Fig. 5 Contribution rates of specific retrogressive transformation processes over the total retrogressive transformation processes in different stages



model was proposed. The approach consists of landscape change monitoring, habitat succession model, and conversion contribution rate. The landscape change monitoring module is the basic component, the regional habitat succession model is the core, and the conversion contribution rate module is the quantitative analysis method. To test the approach's suitability for evaluating wetland degradation, it was implemented by conducting a case study in YNNR, China. A hybrid classification technique includes ISODATA, SVM, and visual interpretation, was applied in the landscape change monitoring module, and a regional habitat succession model of YNNR was constructed. The conclusions of this study are as follows.

- (1) The integrated approach based on the regional habitat succession model for the assessment of the ecological degradation of wetland landscapes is theoretically universal; its greatest challenge is the construction of a suitable habitat succession model for a specific study area.
- (2) This approach can be utilized to describe the main characteristics, rate, and trend of wetland landscape ecological degradation as well as determine the dominant degradation processes and factors.
- (3) The area percentage of wetland landscape ecological degradation in YNNR is 39.39 % for approximately 30 years. The degradation rates in stages 1, 2, and 3 and the slope of the fitting are 1.06, 2.12, 2.78 %/y, and 0.86, respectively, indicating accelerated degradation. The degraded area ratio is 49.49 % for the buffer zone, 38.46 % for the experimental zone, and 25.80 % for the core area from 1980 to 2008.
- (4) Human activity and species invasion are the main factors of wetland ecological degradation in YNNR.

Acknowledgments This work was supported by the National Key Technology Research and Development Program of the Ministry of Science and Technology of China under grant number 2012BAC21B01 and the Ministry of land and resources of public welfare scientific research under grant number 201511057. Many thanks go to the anonymous reviewers for the comments on the manuscript. We would also like to thank “Data Sharing Network of Earth System Science (<http://www.geodata.cn>)” and “China Meteorological Data Sharing Service System (<http://cdc.cma.gov.cn>)”.

References

- Adam E, Mutanga O, Rugege D (2010) Multispectral and hyperspectral remote sensing for identification and mapping of wetland vegetation: a review. *Wetlands Ecology and Management* 18(3):281–296. doi:10.1016/j.rse.2011.07.006
- Berberoglu S, Lloyd CD, Atkinson PM, Curran PJ (2000) The integration of spectral and textural information using neural networks for land cover mapping in the Mediterranean. *Computers & Geosciences* 26(4):385–396. doi:10.1016/S0098-3004(99)00119-3
- Bridgman SD, Megonigal JP, Keller JK, Bliss NB, Trettin C (2006) The carbon balance of North American wetlands. *Wetlands* 26(4):889–916. doi:10.1672/0277-5212(2006)26[889:TCBONA]2.0.CO;2
- Bullock A, Acreman M (1999) The role of wetlands in the hydrological cycle. *Hydrology and Earth System Sciences* 7(3):358–389. doi:10.5194/hess-7-358-2003
- Chen H (2006) Tidal flat ecosystem service functions assessment and reclaimed area ecosystem optimization—a case study of Ganyu and Sheyang coastal reclaimed area. Dissertation, Nanjing Normal University
- Chow-Fraser P, Loughheed V, Thiec VL, Crosbie B, Simser L, Lord J (1998) Long-term response of the biotic community to fluctuating water levels and changes in water quality in Cootes Paradise Marsh, a degraded coastal wetland of Lake Ontario. *Wetlands Ecology and Management* 6(1):19–42. doi:10.1023/A:1008491520668
- Cushman SA (2006) Effects of habitat loss and fragmentation on amphibians: a review and prospectus. *Biological Conservation* 128(2):231–240. doi:10.1016/j.biocon.2005.09.031
- Davis JA, Froend R (1999) Loss and degradation of wetlands in southwestern Australia: underlying causes, consequences and solutions. *Wetlands Ecology and Management* 7(1–2):13–23. doi:10.1023/A:1008400404021
- Dinka M, Ágoston-Szabó E, Urbanc-Berčič O, Germ M, Šraj-Kržič N, Gaberščik A (2008) Reed stand conditions at selected wetlands in Slovenia and Hungary. Springer, Netherlands
- Dronova I, Gong P, Wang L (2011) Object-based analysis and change detection of major wetland cover types and their classification uncertainty during the low water period at Poyang Lake, China. *Remote Sensing of Environment* 115(12):3220–3236. doi:10.1016/j.rse.2011.07.006
- Filippi AM, Jensen JR (2006) Fuzzy learning vector quantization for hyperspectral coastal vegetation classification. *Remote Sensing of Environment* 100(4):512–530. doi:10.1016/j.rse.2005.11.007
- García M, Oyonarte C, Villagarcía L, Contreras S, Domingo F, Puigdefábregas J (2008) Monitoring land degradation risk using ASTER data: the non-evaporative fraction as an indicator of ecosystem function. *Remote Sensing of Environment* 112(9):3720–3736. doi:10.1016/j.rse.2008.05.011
- Hao J, Liu H, Li Y, Hu H, An J (2010) Spatio-temporal variation and driving forces of the coastal wetland resources based on the transition matrix in Jiangsu province. *Journal of Natural Resources* 25(11):1918–1929. doi:10.11849/zrzyxb.2010.11.011
- Huang C, Liu G, Wang X, Ge L, Fan X, Wang R, Shan K (2010) Scenario simulation of wetlands restoration in the Yellow River Delta. *Geographical Research* 29(11):2026–2034
- Jaeger JA (2000) Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. *Landscape Ecology* 15(2):115–130. doi:10.1023/A:1008129329289
- Kansiime F, Saunders MJ, Loiselle SA (2007) Functioning and dynamics of wetland vegetation of Lake Victoria: an overview. *Wetlands Ecology and Management* 15(6):443–451. doi:10.1007/s11273-007-9043-9
- Kerr JT, Ostrovsky M (2003) From space to species: ecological applications for remote sensing. *Trends in Ecology & Evolution* 18(6):299–305. doi:10.1016/S0169-5347(03)00071-5
- Kirwan ML, Megonigal JP (2013) Tidal wetland stability in the face of human impacts and sea-level rise. *Nature* 504(7478):53–60. doi:10.1038/nature12856
- Klimkowska A, Bekker REEM, Van Diggelen R, Kotowski W (2010) Species trait shifts in vegetation and soil seed bank during fen degradation. *Plant Ecology* 206(1):59–82. doi:10.1007/s11258-009-9624-1
- Knutson MG, Sauer JR, Olsen DA, Mossman MJ, Hemesath LM, Lannoo MJ (1999) Effects of landscape composition and wetland fragmentation on frog and toad abundance and species richness in

- Iowa and Wisconsin, USA. *Conservation Biology* 13(6):1437–1446. doi:10.1046/j.1523-1739.1999.98445.x
- Li X, Tang G, Wang D, Xu H (1998) Studies on the community characteristics, the distribution and succession patterns of wetland vegetation in Jiangsu Province. *Journal of Nanjing Forestry University* 22(1):47–52. doi:10.3969/j.jssn.1000-2006.1998.01.011
- Liu F, Zong S, Huang Z (1992) A study on the succession of beach vegetation in Jiangsu Province. *Journal of Plant Resources and Environment* 1(1):13–17
- MacDougall AS, Turkington R (2005) Are invasive species the drivers or passengers of change in degraded ecosystems? *Ecology* 86(1):42–55. doi:10.1890/04-0669
- McClain ME, Boyer EW, Dent CL, Gergel SE, Grimm NB, Groffman PM, Hart SC, Harvey JW, Johnston CA, Mayprga E, McDowell WH, Pinay G (2003) Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. *Ecosystems* 6(4):301–312. doi:10.1007/s10021-003-0161-9
- Mendez Linares AP, Lopez-Portillo J, Hernandez-Santana JR, Ortiz Perez MA, Oropeza Orozco O (2007) The mangrove communities in the Arroyo Seco deltaic fan, Jalisco, Mexico, and their relation with the geomorphic and physical–geographic zonation. *Catena* 70(2):127–142. doi:10.1016/j.catena.2006.05.010
- Millennium Ecosystem Assessment (2005) *Ecosystems and human well-being*. Island Press, Washington DC
- Mitchell EA, Buttler A, Grosvernier P, Rydin H, Siegenthaler A, Gobat J (2002) Contrasted effects of increased N and CO₂ supply on two keystone species in peatland restoration and implications for global change. *Journal of Ecology* 90(3):529–533. doi:10.1046/j.1365-2745.2002.00679.x
- Muller F, Schrautzer J, Reiche E, Rinker A (2006) Ecosystem based indicators in retrogressive successions of an agricultural landscape. *Ecological Indicators* 6(1):63–82. doi:10.1016/j.ecolind.2005.08.017
- Nicholls RJ, Cazenave A (2010) Sea-level rise and its impact on coastal zones. *Science* 328(5985):1517–1520. doi:10.1126/science.1185782
- Ogden JC (2005) Everglades ridge and slough conceptual ecological model. *Wetlands* 25(4):810–820. doi:10.1672/0277-5212(2005)025[0810:ERASCE]2.0.CO;2
- Owino AO, Ryan PG (2007) Recent papyrus swamp habitat loss and conservation implications in western Kenya. *Wetlands Ecology and Management* 15(1):1–12. doi:10.1007/s11273-006-9001-y
- Qiu J (2013) China's cordgrass plan is 'overkill'. *Nature* 499(7459):392–393. doi:10.1038/499392a
- Schulz JJ, Cayuela L, Echeverria C, Salas J, Rey Benayas JEMI (2010) Monitoring land cover change of the dryland forest landscape of Central Chile (1975–2008). *Applied Geography* 30(3):436–447. doi:10.1016/j.apgeog.2009.12.003
- Sluiter R (2005) *Mediterranean land cover change: modelling and monitoring natural vegetation using GIS and remote sensing*. Dissertation, Utrecht University
- Sun X, Liu H, Fu X (2010) Effects of Land use change on wetland landscapes in the Yancheng Nature Reserve. *Resources Science* 32(9):1741–1745
- Wu J (2000) *Landscape ecology—pattern, process, scale and hierarchy*. Higher Education Press, Beijing
- Wu J (2004) The key research topics in landscape ecology. *Acta Ecologica Sinica* 24(9):2074–2076
- Wu J (2013) Key concepts and research topics in landscape ecology revisited: 30 years after the Allerton Park workshop. *Landscape Ecology* 28(1):1–11. doi:10.1007/s10980-012-9836-y
- Wu J, Hobbs R (2002) Key issues and research priorities in landscape ecology: an idiosyncratic synthesis. *Landscape Ecology* 17(4):355–365. doi:10.1023/A:1020561630963
- Yancheng Bureau of Statistics (1993) *Yancheng statistics yearbook*. China Statistics Press, Beijing
- Yancheng Bureau of Statistics (2003) *Yancheng statistics yearbook*. China Statistics Press, Beijing
- Yancheng Bureau of Statistics (2009) *Yancheng statistics yearbook*. China Statistics Press, Beijing
- Yang G, Shi Y, Zhang C (2002) The ecological response of typical mud flat to sea level change in Jiangsu coastal plain. *Acta Geographica Sinica* 57(3):325–332
- Yao C, Wan S, Sun D, Qin P (2009) Ecological mechanism of vegetation succession of coastal wetland in Yancheng Nature Reserve. *Acta Ecologica Sinica* 29(5):2203–2210
- Zedler JB, Covin J, Nordby C, Williams P, Boland J (1986) Catastrophic events reveal the dynamic nature of salt-marsh vegetation in Southern California. *Estuaries* 9(1):75–80. doi:10.2307/1352195
- Zeng H, Gao L, Xia J (2003) Dynamic analysis of urban landscape using a modified conversion matrix method: a case study in Nanchang City. *Acta Ecologica Sinica* 23(11):2201–2209
- Zhang H, Liu H, Hou M, Li Y (2014) Building model based on processes and simulating landscape change in the coastal wetlands—a case study of the core area in Yancheng Natural Reserve. *Journal of Natural Resources* 29(7):1105–1115. doi:10.11849/zrzyxb.2014.07.002
- Zhang M, Wang L, Liu M, Xu C (2013) Landscape dynamics of aggradational coastal wetland in Jiangsu Province in the past three decades. *Chinese Journal of Ecology* 32(3):696–703
- Zhang W, Ding Y, Wang L, Rui W, Guo J (2007) The significance of Paddy ecosystems in environmental health and sustainable development of economy in the regions around Tai lake. *Science & Technology Review* 25(17):24–29
- Zuo P, Li Y, Zhao S, Zhou X, Teng H, Chen H (2012) Landscape changes of Jiangsu Yancheng coastal wetlands and their driving forces since 1976. *Acta Oceanologica Sinica* 34(1):101–108