Analysis of *Suaeda heteroptera* cover change and its hydrology driving factors in the Liao River Estuary wetlands, China

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**Abstract.** *Suaeda heteroptera* (*S. heteroptera*) is the most common indicator plant of solonchak in coastal wetlands of the Liao River Estuary, the influence of meteorology, hydrology environment on vegetation distribution is of growing interest. With the help of satellite remote sensing (RS) technology and geographic information system (GIS), we investigated the spatial-temporal distribution and area change of *S. heteroptera* in the wetlands of the Liao River Estuary from 1997 to 2016, and the identification of the main driving mechanisms in the *S. heteroptera* evolution was analyzed in this coastal wetland. The SPSS Statistics 22 software was used to calculate the correlation coefficients between total area of *S. heteroptera* and each driving factor based on available long-term (1997-2016) and medium-term (2007-2016) data. Correlation analysis results indicated that the change in *S. heteroptera* coverage had insignificant correlations (correlation coefficients \( r = -0.241 \), \( r = -0.188 \) and \( r = -0.269 \)) with annual mean temperature, precipitation, and sunshine duration, respectively. The results also showed that the growth of *S. heteroptera* was extremely relevant to runoff from the Liao River from April to June \( (r = 0.889) \) over the last 10 years. This study revealed that some potential factors, such as river discharge may be related to the large-scale degeneration of *S. heteroptera* in Liao River Estuary wetlands.

1. **Introduction**

As an important ecosystem connecting land and water, wetlands provide rich food, nutrient sediments, and habitats for animals and plants. They play a unique role in maintaining the ecological equilibrium and protecting biodiversity [1], and also have a significant influence on the local hydrological cycle [2]. However, with expanded urbanization, population growth, and environmental degradation, wetlands worldwide are confronted with greater challenges and wetland loss and degradation have become a global issue. It has been reported that more than half of global wetlands have degenerated or been modified by human activities in the past 150 years [3]. For example, in Orlando, Florida, 26% of isolated wetlands were destroyed or degraded from 1984 to 2004 [4]. Researchers have reported that 33% of wetlands have been lost in eastern South Africa over the last 20 years [5]. Finally, in China, wetland area has been greatly reduced and wetland function has degraded over the past few decades, which were mainly caused by economic development and human activities [6].

As one wetland type, coastal wetlands are of great value for our living environment, food supply, recreation, and civilization. Coastal wetlands are dynamic systems that are influenced by a complex...
range of environmental variables and undergo wet and dry cycles with temporal and spatial variability in water level. Coleman et al (2008) studied coastal wetlands loss in 42 deltas over the past 14 years and concluded that the average rate of loss was 95 km² per year [7]. In recent years, researchers have put an enormous amount of effort into investigating the driving factors leading to coastal wetland degradation and loss of salt marsh vegetation area. These study results showed that coastal wetlands have been under considerable stress as a result of land reclamation, city and port development, and certain natural factors including coastal erosion, environmental factors change, and surface elevation change [8]. Overexploitation of coastal biological resources has also caused significant degradation of coastal wetlands [9]. Other studies on the driving forces for wetland degradation have indicated that water shortages caused by the rapid deterioration of the hydrological regime threatens wetland health [10]. As an annual halophyte and typical tidal marsh plant, *S. heteroptera* grows in the upper coastal intertidal zone, which is regularly flooded by the tides with the rise and fall of sea level and forms a rare natural landscape known as “Pink beach” in the Liao River Estuary. In recent years, however, *S. heteroptera* in the Liao River Estuary wetland has been seriously reduced.

In order to explain the driving factors of *S. heteroptera* degradation in the Liao River Estuary wetland, the spatial-temporal dynamic processes of vegetation coverage were monitored and mapped from 1997 to 2016 using RS data and GIS technology. The purpose of this study was to conduct correlation analysis between vegetation coverage change and related variables using statistical methods, and then study the potential factors causing the degradation of *S. heteroptera* in wetlands.

2. Materials and methods

2.1. Description of the study area

The study area lies within the Liao River Estuary (40° 50′ N, 121° 50′ E), which covers an area of 316 km², including several shoals and plain tidal flats, one island, and one body of water, as shown in Figure 1. We chose this region north of Liaodong Bay because it is one of the largest coastal wetlands in China and also an important economic zone in Northern China, it has been listed as the largest reed wetland and the second largest marsh in the world. Moreover, this wetland supports a high diversity of bird species, such as the Black-headed gull and the Red-crowned crane. Tides along this coastal wetland region are semi-diurnal with two high and low tides each day. The Liao River Delta wetland is a salt marsh wetland covered with reed and *S. heteroptera* growing in the inter-tidal zone. It is frequently submerged and exposed as sea level changes due to flood and ebb tides.

2.2. Data acquisition

Because of the complex environmental conditions in coastal wetland zones, it is difficult to conduct traditional field surveys. With the development of RS technology, it had been widely utilized for mapping wetland vegetation types and detecting historical changes in ecosystem cover, as well as investigating wetland degradation status. In the present study, RS technology was used to evaluate the vegetation cover of *S. heteroptera* from 1997 to 2016 in the Liao River wetland, but data from 2003 and 2010 were unavailable because of high cloud coverage. The remote sensing images used in this paper were downloaded from the USGS website (https://glovis.usgs.gov/next). For the convenience of interpreting RS images, the spectral signatures of crops and wetland plants in the Liao River Delta were investigated and results showed that the spectra for crops and natural wetland vegetation were similar in spring and summer, but clearly different in autumn. Therefore, the highest quality images from September to October of each year were selected; wetland vegetation was exposed when the RS images were taken that corresponded to low tidal conditions.
2.3. Construction of the decision tree method

A decision tree is made up of a series of binary tree classifiers based on a set of decision rules. It first divides each image into relative homogeneous subsets and then determines their proper coverage types. Decision tree algorithms have been successfully used to obtain preliminary classifications of multiple image features, including urban land use, land coverage, coastal environment monitoring and flooding, as well as wetlands classification. Based on the USGS Landsat data, which included 18 images from the TM, ETM and OLI sensors over the Liao River Estuary, wetland objects were divided into two types: vegetation and non-vegetation. The main vegetation classes included reed, paddy, and *S. heteroptera*, while non-vegetated objects included water, bare soil, and structures. A decision tree algorithm was established to extract the object classification and outline the identification of wetland vegetation types through selecting the appropriate threshold value.

These techniques such as MNDWI, NDVI, and NDBI have distinct advantages for classifying water, vegetation, tidal flats, and structure, and have been widely applied in object classification. They can be calculated as follows:

\[
\text{MNDWI} = \frac{(\rho_G - \rho_{MIR})}{(\rho_G + \rho_{MIR})} \tag{1}
\]

\[
\text{NDVI} = \frac{(\rho_{NIR} - \rho_R)}{(\rho_{NIR} + \rho_R)} \tag{2}
\]

\[
\text{NDBI} = \frac{(\rho_{MIR} - \rho_{NIR})}{(\rho_{MIR} - \rho_{NIR})} \tag{3}
\]

where \( \rho_B \) is the blue band reflectance, \( \rho_G \) is the green band reflectance, \( \rho_R \) is the red band reflectance, \( \rho_{NIR} \) is the near infra-red band reflectance, and \( \rho_{MIR} \) is the middle-infrared band reflectance.

According to wetland coverage features, a new SI index (the *S. heteroptera* Index) was proposed to distinguish the vegetation distribution and identify *S. heteroptera* vegetation from satellite images combined with spectral characteristics analysis in this study. The equation is as follows:

\[
\text{SI} = \frac{(\rho_G - \rho_B)}{(\rho_R - \rho_G)} \tag{4}
\]

In ENVI 5.1 software, we used the decision tree algorithm described above to classify reed, paddy, soil, and structures from RS images over the Liao River Estuary wetland. *S. heteroptera* area was extracted using ArcGIS 10.1 software. Figure 2 shows the calculated area within the Liao River Estuary wetland from 1997 to 2016. The vegetation area data in 2003 and 2010 could not be obtained due to poor weather conditions. From 1997 to 2016, the change in *S. heteroptera* area in the study area can be summarized as follows: a small-scale volatility phase (1997–2000), an extensive death phase (2000–2004), a steady increase phase (2005–2014), and a sharp decrease phase (2015–2016). From Figure 2, it can be seen that the *S. heteroptera* area generally increased from 2004–2014 and reached its maximum in 2014, but then decreased dramatically in 2015 and 2016. The *S. heteroptera* area was the smallest at 2.29 km\(^2\) in 2002 and the largest at 24.15 km\(^2\) in 2014, while it decreased to 8.41 km\(^2\) by 2016.
3. Results and discussion

3.1. Relationships between S. heteroptera coverage and meteorological variables

The wetland coverage in Liao River Estuary showed significant annual change in both spatial and temporal distribution. Meteorological factors are usually important for wetland ecosystems and exert a strong influence on vegetation growth in rivers and lakes. However, coastal wetlands adjust to rising and falling tide levels, which could dynamically alter their natural conditions (such as wetland hydrology, biogeochemical cycling, meteorological variables and other processes), so coastal wetland habitats became more complex compared to those of inland wetlands. In order to explore the effects of meteorological factors on S. heteroptera growth, we collected a series of long-term meteorological data including temperature, sunshine duration, and the timing, frequency, and magnitude of precipitation in the Panjin region. The meteorological data used in this paper were obtained from the Editorial Committee of Panjin Statistical Yearbook. Linear trend analysis was used to detect the long term change in meteorological parameters for 1997-2016 across the whole wetland. Figure 3 shows S. heteroptera area change and the annual mean temperature from 1997 to 2016 in the Liao River wetland, where the maximum annual average temperature was 10.73°C in 2014, the minimum annual mean temperature was 8.72°C in 2010, and annual average temperature was 9.67°C. Linear regression on average annual temperature data revealed an increasing trend from 1997 to 2016 in the Panjin region and a rate of 0.141°C per 10 years. Figure 4 shows a comparison between S. heteroptera area and average annual precipitation from 1997 to 2016 in the study area, where precipitation in the last 20 years has increased at a linear rate of 22.7 mm per 10 years and the average annual precipitation was 609.9 mm. The maximum annual precipitation was 1081.7 mm in 2010 and the minimum annual amount of precipitation was 399.5 mm in 2014. Figure 5 compares S. heteroptera area and average annual sunshine duration from 1997 to 2016, where the maximum annual sunshine duration was 3038.3 h in 2000, the minimum annual average sunshine duration was 2282.3 h in 2006, and the average annual sunshine duration was 2625.7 h. This variable had a decreasing trend between 1997 and 2016 at a rate of -190.5 h per 10 years. According to the correlation analysis on data from 1997 to 2016, the coefficients (r) for annual precipitation, mean temperature, and mean sunshine duration were -0.241, -0.188 and -0.269, respectively. These results implied that S. heteroptera vegetation cover in the Liao River Estuary wetlands had a lower sensitivity to climate change. On the other hand, these results did not reveal a significant impact of temperature and sunshine duration on S. heteroptera growth. Compared to the precipitation with S. heteroptera area change, precipitation had no significant correlation with vegetation growth in this complex coastal wetland. The results demonstrated that S. heteroptera can adapt to long-term changes in air temperature and sunshine duration, so those
meteorological factors may not be the main driving factors causing the loss of *S. heteroptera* area in the Liao River Estuary wetlands.

![Figure 3. Comparison of air temperature and *S. heteroptera* area from 1997 to 2016.](image)

![Figure 4. Comparison of precipitation and *S. heteroptera* area.](image)

![Figure 5. A graph of long-term variability of sunshine duration and *S. heteroptera* area.](image)

**3.2. Relationships between average annual runoff and *S. heteroptera* cover**

The Liao River Estuary is influenced by both tidal currents and river discharge. The dominant vegetation type, *S. heteroptera*, is a typical saline-alkaline plant, that needs a suitable salinity concentration for plant growth. The impact of upstream discharge on salinity distribution in the Liao River Estuary is fairly remarkable: in the wet season, due to the higher water discharge, salinity concentrations are relatively lower. The opposite is true in the dry season, so offshore water salinity and upper stream freshwater are dominant factors affecting *S. heteroptera* growth. In order to define the relationship between river discharge and *S. heteroptera* growth, it is essential to analyze the runoff processes in the Liao River. River discharge data from 2006 to 2016 used in this study were available from the Panshan hydrological station. In the present study, four sets of runoff data were analyzed using yearly average runoff, average runoff for Jan-Jun, average runoff for Jul-Dec and average runoff for Apr-Jun in Figure 6. Correlations analysis between *S. heteroptera* area and runoff data were conducted using SPSS software. An extremely positive relationship was found between the total runoff for Jan-Jun and *S. heteroptera* area ($r=0.83$, $P=0.003$). A positive relationship was also found...
between yearly average runoff and *S. heteroptera* area (r=0.573 P=0.083). However, there was no observed correlation between annual runoff and *S. heteroptera* area for Jul-Dec (r=0.389; P=0.267). A high correlation between total runoff during the flood season (from April to June) and *S. heteroptera* area (r=0.889, P=0.001) was found in this study, and results indicate that the growth of *S. heteroptera* each year was strongly correlated with runoff from April to June. These results showed that upstream runoff was important for the growth of *S. heteroptera* vegetation in the Liao River Estuary wetland.

**Figure 6.** Long-term (2006-2016) river runoff data in the Panjin region. 
(a). Annual runoff and *S. heteroptera* area (b). First half year runoff and *S. heteroptera* area (c). Second half year runoff and *S. heteroptera* area (d). Runoff from April to June and *S. heteroptera* area.

4. Conclusions
Using long-term Landsat5, Landsat7 and Landsat8 satellite remote sensing imagery, the Liao River Estuary wetland was classified into reed, *S. heteroptera*, paddy, structures, bare soil, and water bodies. The spatial-temporal distribution maps of *S. heteroptera* vegetation from 1997 to 2016 were derived from GIS database and the inter-annual variability in *S. heteroptera* was calculated. From 1997 to 2016, the overall characteristics of *S. heteroptera* area were as follows: a small-scale volatility phase (1997~2000), an extensive death phase (2000~2004), a steady increase phase (2005~2014), and a sharp decrease phase (2015~2016). The correlations between several factors and *S. heteroptera* area were analyzed using statistical correlation analysis, which found that temperature, sunshine duration, and precipitation were not the important driving forces affecting the growth of *S. heteroptera*. There was overlap between the death cycle of *S. heteroptera* and the dry years in the Liao River. *S. heteroptera* area in wet years was greater than in dry years. The correlation coefficients between runoff from April to June and *S. heteroptera* area were the highest, demonstrating that runoff from the Liao River may be one of the driving factors affecting the growth of *S. heteroptera*. 


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References
[1] McClain M E, Boyer E W, Dent C L, Gergel S E, Grimm N B, Groffman P M, Hart S C, Harvey J W, Johnston C A, Mayprga E, McDowell W H, Pinay G 2003 Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems Ecosystems 6 301-312
[2] Bullock A, Acreman M 2003 The role of wetlands in the hydrological cycle Hydrology And Earth System Sciences 7 358-389
[3] Sica Y V, Quintana R D, Radeloff V, Gavier-Pizarro G I 2016 Wetland loss due to land use change in the lower paraná river delta Argentina Science of the Total Environment 568 967-978
[4] Mccauley L A, Jenkins D G, Quintana-Ascencio P F 2013 Isolated wetland loss and degradation over two decades in an increasingly urbanized landscape Wetlands 33 117-127
[5] Rivers-Moore N A, Cowden, C 2012 Regional prediction of wetland degradation in South Africa Wetlands Ecology and Management 20 (6) 491-502
[6] Wang M J, Qi S Z, Zhang X X 2012 Wetland loss and degradation in the yellow river delta, Shandong Province of China Environmental Earth Sciences 67 185-188
[7] Coleman J M, Huh O K, Jr D W B 2008 Wetland Loss in World Deltas Journal of Coastal Research 24 1-14
[8] Kim D, Bartholdy J, Jung S, Cairns D M 2011 Salt marshes as potential indicators of global climate change Geography Compass 5 219-236
[9] Jiang T T, Pan J F, Pu X M, Wang B, Pan J J 2015 Current status of coastal wetlands in China: Degradation, restoration, and future management Estuarine Coastal and Shelf Science 164 265-275
[10] Jia M M, Wang Z M, Liu D W, Ren C Y, Tang X G, Dong Z Y 2015 Monitoring Loss and Recovery of Salt Marshes in the Liao River Delta, China Journal of Coastal Research 31 371-377