

Full Length Research Paper

Study on the seasonal dynamics of zonal vegetation of NDVI/EVI of costal zonal vegetation based on MODIS data: A case study of *Spartina alterniflora* salt marsh on Jiangsu Coast, China

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The temporal and spatial variation of vegetation index is a hot issue in global change research currently. *Spartina alterniflora* salt marsh in Jiangsu coastal areas is taken as an example in this study, MODIS data is used to research NDVI/EVI seasonal variation laws of coastal zonal vegetation. The results show that the major phenological periods of *S. alterniflora*, such as turning green (seedling emergence), heading and seed maturity, could be well reflected with VI curves. This study provides basic data for monitoring expansion trend of *S. alterniflora* salt marsh, strengthening management, drawing on advantages and avoiding disadvantages, as well as supplying references for monitoring of other zonal vegetation in coastal areas.

Key words: *Spartina alterniflora*, seasonal dynamics, zonal vegetation.

INTRODUCTION

A variety of types of zonal wetland vegetation are distributed in China's coastal areas with widths ranging from a few hundred meters to several kilometers, such as coastal grass flat, *Spartina alterniflora* salt marsh and mangrove. These vegetation types play a significant role in maintaining the sustainable development of coastal socio-economic systems and natural ecosystems. Normalized difference vegetation index (NDVI) is not only an important indicator to characterize land features, but also a basis for large and meso-scale land-cover classification (Ada et al., 1990; Shi et al., 2000). The dynamic variation of NDVI reflects the response degree of land vegetation to global change (Nathalie et al., 2005). Therefore, the temporal and spatial variation of NDVI is becoming a hot issue in global change research. Extensive researches have been carried out by domestic and foreign scholars, mainly in the fields of vegetation regionalization on various scales (Sheng et al., 1995), land cover classification and its variation (Pan et al. 2000),

crop growth and phenological monitoring (Manasah et al., 2005; Mark et al., 2002; Zhang et al., 2004), correlation analysis between NDVI and climate factors (Li and Tao, 2000), natural disaster monitoring (Zhou, 1998) and other fields, which basically adopt NOAA/AVHRR NDVI as data sources. However, MODIS is the main detector of earth observing system terra and aqua launched by United States on December 18, 1999 and May 4, 2002, respectively. MODIS VI products include two types of global terrestrial vegetation index employed as new data sources, that is, NDVI and enhanced vegetation index (EVI). The purpose of developed MODIS NDVI is to succeed the AVHRR-NDVI, while the purpose of developed MODIS EVI is to improve defects of NDVI, especially in decreasing atmospheric noise. Now MODIS NDVI and EVI are applied to the studies on seasonal variation of vegetation index gradually (Zhao et al., 2004; William and Maik, 2005; Wang et al., 2003; Liu et al., 2004).

As a perennial herb belonging to *gramineous spartina*, *S. alterniflora* was introduced to China from the United States in December 1979. Its current distribution area has exceeded 18,000 hm² currently, and its maximum

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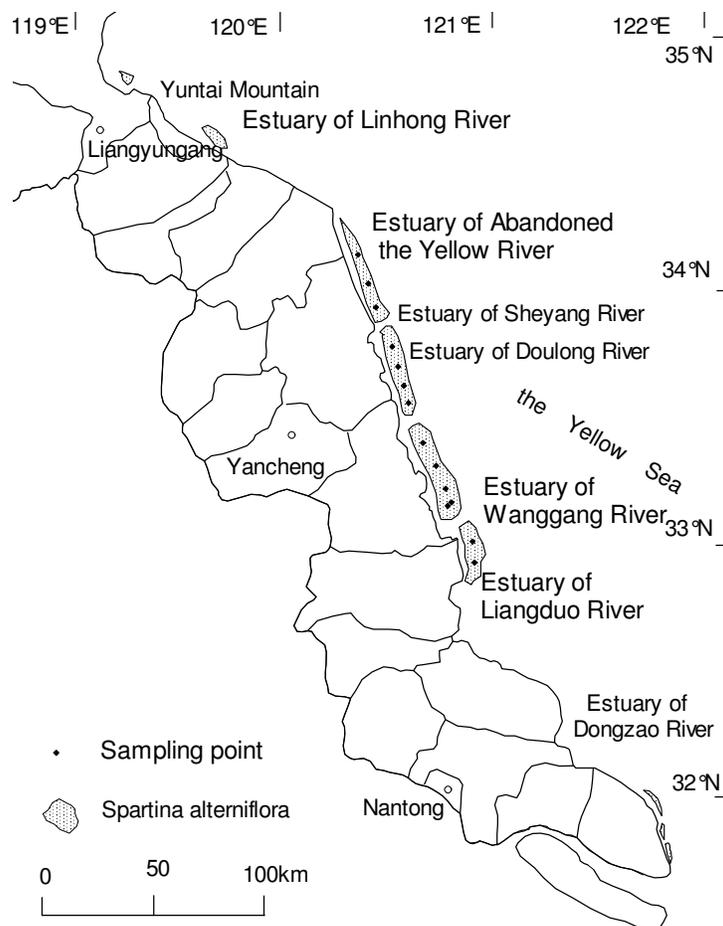


Figure 1. The distribution of study area.

distribution is found in Jiangsu coastal areas. The invasion of *S. alterniflora* has major impacts on the biodiversity, biomass, hydrodynamics, sedimentation, nutrient cycling and vegetation succession of tidal flat ecosystem (Li et al., 2005). The case study of *S. alterniflora* salt marsh in Jiangsu coastal areas is carried out in this study, and MODIS data are used to study the seasonal variations in NDVI/EVI of coastal zonal vegetation, providing basic data for monitoring expansion trend of *S. alterniflora* salt marsh, strengthening management, drawing on advantages and avoiding disadvantages, as well as supplying references for monitoring of other zonal vegetation in coastal areas.

STUDY AREA

Jiangsu coast is located at Central China, the west bank of South Yellow Sea, and its continental coastline extends from Xiuzhen Estuary from the north to the north branch of Yangtze River in the south, with a total length of 954 km, of which the muddy coastline is 884 km in length (Figure 1). At present, the area of mudflat is 6, 524

km² in Jiangsu Province alone, accounting for about 1 / 4 of the national total, and the areas of supralittoral zone, mesolittoral zone and offshore radial bars (above zero line) are 2,598, 2,657 and 1269 km², respectively. *S. alterniflora* has been planted experimentally in Jiangsu coastal areas since 1982, and successful pilot planting was achieved extensively in Qidong, Sheyang, Binhai, Guanyun, Lianyungang, Ganyu and other cities (counties) in 1983 (Zhuo and Xu, 1985). After 20-year expansion, spartina alterniflora has become major salt marsh vegetation in Jiangsu coastal areas with a zonal distribution area of 137 km², and it played an important role in beach and bank protection, siltation promotion, land reclamation, soil improvement, beach greening and ecosystem improvement (Li and Zhang, 2003).

MATERIALS AND METHODS

MODIS-NDVI/EVI data were mainly derived from the MODIS sensor of United States earth observation system (EOS) Terra and Aqua satellite (Liu and Ge, 2000). 16d synthetic data with MODIS-NDVI and MODIS-EVI in 2002 were applied with a spatial resolution of 0.25 km × 0.25 km in this study, and NDVI and EVI data at a total of

23 time intervals in 2002 were involved.

Field investigations were carried out for several times on *S. alterniflora* salt marsh in Jiangsu coastal areas in February, May, August, October and December of 2002, respectively, and relevant ground data were thus obtained. With Lianyungang image (Orbit No: 120-036, May 25, 2002, TM), Yancheng image (Orbit No: 119-37, May 26, 2002, ETM) and Yangtze River Estuary remote sensing image (Orbit No: 118-38, July 30, 2002, TM) adopted as base maps, image registration and tessellation were carried out in ENVI 4.0 with the registration error less than 0.4 pixel. Based on the acquisition of distribution data of *S. alterniflora* through field investigation combined with satellite image interpretation, the main distribution area of *S. alterniflora* salt marsh in Jiangsu coastal areas was then drawn (Figure 1). It can be seen from Figure 1 that the distribution belts of *S. alterniflora* in northern and southern Jiangsu coastal areas were mostly narrow with the width less than 1 km. Therefore, a total of 13 monitoring points were selected only along the wider distribution belt of *S. alterniflora* salt marsh in central Jiangsu coastal areas in this study, where GARMIN 12-frequency handheld GPS was used for location. MODIS-NDVI/EVI data were opened in ENVI 4.0. Since the data had geographical coordinates of their own, NDVI and EVI values at 23 time intervals could be read by entering the coordinates of the monitoring points. NDVI and EVI values at each time interval were the 16 d synthetic products, which could be converted into monthly average values of NDVI and EVI according to the following equation:

$$\overline{VI}_j = a \cdot VI(i) + b \cdot VI(i+16) + c \cdot VI(i+32) \quad (1)$$

Where \overline{VI}_j is the monthly average value of NDVI or EVI, and $j = \text{Jan, Feb, ..., Nov, Dec}$; VI is MODIS-NDVI/EVI 16d product containing part of the days of j -th month; i is the serial number of MODIS-NDVI/EVI 16d product, and $i = 001, 017, \dots, 305, 321$; a , b and c are the ratio of the number of days of i -th, $i+16$ -th and $i+32$ -th product in j -th month to the total number of days of j -th month, respectively.

RESULT ANALYSIS

Monthly average values of NDVI and EVI at each monitoring point could be calculated according to Equation (1). In order to verify the effectiveness of NDVI and EVI values obtained from MODIS-based NDVI and EVI products at each monitoring point and their feasibility for analyzing seasonal variations in vegetation index of *S. alterniflora*, monthly variation curves of NDVI and EVI at each measuring point were developed (Figure 2). In addition, statistical analysis was carried out on their averages, standard deviations and variation coefficients (Table 1). The results showed that monthly variation curves of NDVI and EVI values at 13 measuring points exhibited similar variation laws, with the variation coefficients of monthly averages of NDVI and EVI values mostly being less than 20.0%. Moreover, significant correlations existed among various NDVI values as well as among various EVI values, with most correlation coefficients greater than 0.80 on the significance level of 0.01 or 0.05.

Intra-annual variation characteristics of NDVI and EVI at monitoring points of *spartina alterniflora*

According to the analysis of original MODIS-based NDVI and EVI data at 23 time intervals at 13 monitoring points, it can be seen that NDVI values from January to April were smaller, ranging between 0.10 and 0.20. NDVI values began to increase gradually from May on, and those varied between 0.20 and 0.29 in June. NDVI values increased rapidly in July, when all the values were greater than 0.30 with the maximum reaching 0.52. NDVI values reached the maximum in August, when all the values were greater than 0.40 with the maximum of 0.62. NDVI values began to fall from September on, ranging between 0.35 and 0.50. The values further reduced in October, ranging between 0.23 and 0.37. NDVI values decreased to the lowest level of growth period in November, ranging between 0.15 and 0.22, and those in December were slightly smaller than those in November.

Similar to the variations of NDVI values, intra-annual variation of EVI values at 13 monitoring points mainly occurred from May to November, but EVI values were significantly smaller than NDVI. EVI values in May and June ranged between 0.09 and 0.15. They rapidly increased in July, and all were greater than 0.16 with the maximum of 0.28. Peak value of EVI appeared in August, and all of the EVI were all greater than 0.22 with the maximum of 0.31. EVI values hovered at a high level in September, ranging between 0.20 and 0.27. EVI values experienced a sharp decline in October with the minimum dropping to 0.12 and the maximum reaching only 0.20. In November, EVI values fell to 0.05-0.10, and the variation of those in December was basically identical with those in November.

Correspondence analysis between phenological periods of *spartina alterniflora* growth and NDVI/EVI curves

Phenological data in the growth period are integral data for growth monitoring, grass yield prediction and biomass utilization of *S. alterniflora*. Since vegetation index can precisely reflect vegetation greenness, photosynthetic intensity, vegetation metabolism intensity and seasonal variation information in different growth periods (Wang et al., 2003), the vegetation index variation curves in the growth period could be used to indicate major phenological periods. The objective of phenological monitoring of *S. alterniflora* is mainly to understand the date corresponding to its significant morphological variation and the growth time from turning green to seed shattering.

According to original MODIS-based NDVI and EVI data at 23 time intervals at various monitoring points, *S. alterniflora* growth curve could be obtained through sliding and averaging (Figure 2a). Meanwhile, in order to further analyze the variation characteristics of NDVI and

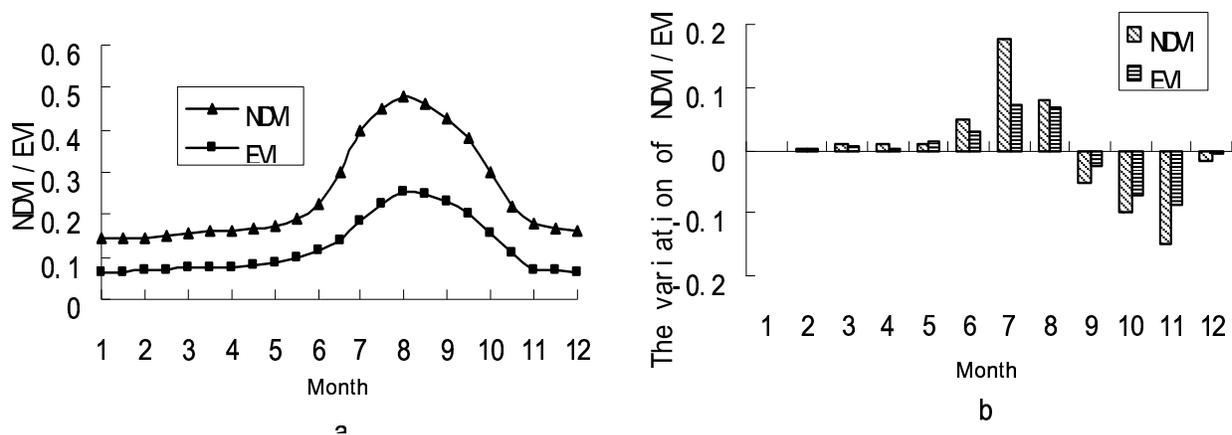


Figure 2. The change of NDVI and EVI in *Spartina alterniflora*'s phenological stages.

Table 1. Statistical characteristics of monthly average NDVI for *Spartina alterniflora*

		Month(月份)											
		1	2	3	4	5	6	7	8	9	10	11	12
NDVI	Average	0.144	0.143	0.155	0.164	0.173	0.223	0.398	0.479	0.424	0.3	0.178	0.162
	Standard	0.024	0.029	0.03	0.04	0.037	0.029	0.075	0.07	0.059	0.054	0.032	0.028
	cv. (%)	16.96	20.05	19.42	24.33	21.19	13.2	18.77	14.52	13.99	18.04	17.86	17.08
EVI	Average	0.066	0.068	0.072	0.075	0.088	0.116	0.213	0.255	0.229	0.157	0.07	0.066
	Standard	0.012	0.014	0.016	0.017	0.017	0.017	0.038	0.027	0.026	0.034	0.021	0.015
	cv. (%)	18.15	20.46	22.01	22.23	19.39	14.75	18.06	10.53	11.29	21.43	30.54	23.05

EVI values, the NDVI and EVI values in January were taken as reference point to calculate the monthly variation of NDVI values, by means of which Figure 2b was obtained. By comparing field monitoring data and the data in Figure 2, it could be found that remote sensing information of MODIS-based NDVI and EVI could well reflect the growth process and major phenological periods of *S. alterniflora*.

As a perennial herb belonging to gramineous spartina, *S. alterniflora* experiences turning green, heading, flowering, fruiting and other growth phenological periods during intra-annual growth process. It can be seen from Figure 2a that NDVI/EVI of *S. alterniflora* growth process shows obvious uni-modal curves, and the growth process can be divided into three stages depending on its curve morphology, that is, two slow variation stages of vegetation index from January to April and in December as well as a rapid variation stage of vegetation index from May to November. From the period from January to April and in December when slow variations in vegetation index occurred, the average values of NDVI and EVI were 0.16 and 0.07, respectively, corresponding to the phenological period of non-growth season of *S. alterniflora*. NDVI and EVI values could be taken as the

background values of vegetation index of *S. alterniflora* salt marsh with little variations and the minimum of vegetation index reached in January. The period from May to November was the growth season for *S. alterniflora*, and NDVI and EVI values rose first and then fell on the basis of background values. The temperature began to pick up in May, when *S. alterniflora* started to turn green (emerge) and grow rapidly. With the growth of *S. alterniflora* and the enlargement of leaves, the stomas in leaves increased, resulting in enhanced chlorophyll absorption capacity. The reflectance entering MODIS near-infrared and red light channel also varied correspondingly, which was mainly reflected in the gradual increase of the value of near-infrared band, while that of red light band decreased gradually and therefore the values of NDVI and EVI increased correspondingly (Figure 2a). In July and August, *S. alterniflora* moved into heading and flowering stage. At this stage, the leaf area index of *S. alterniflora* reached the maximum, and NDVI and EVI values also reached their maximum values in the growth period. It can be seen from Figure 2a that from germination in May to heading and flowering in August, NDVI and EVI values of *S. alterniflora* constantly increased, and monthly variations of NDVI and EVI

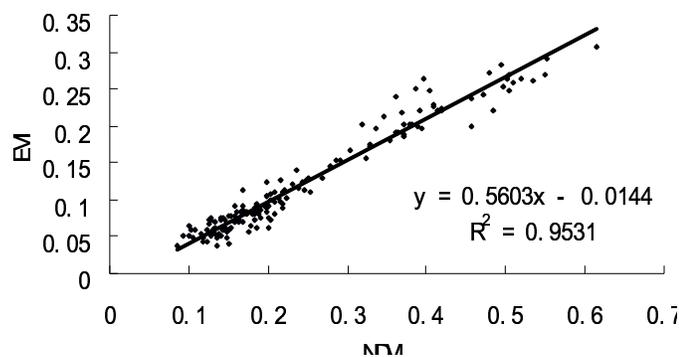


Figure 3. The relation between MODIS NDVI and EVI.

values were all positive. The increment was the most significant in July, when the average values reached 0.18 and 0.08, respectively, accounting for 56 and 33% of total vegetation index increment in the growth season (Figure 2b). In September, *S. alterniflora* moved into maturity stage, when seeds were gradually formed, and the vegetation index of NDVI and EVI intra-annual variation curves began to reduce (Figure 2a), with the monthly variation of corresponding NDVI and EVI values being negative (Figure 2b). Seeds matured in October, when leaves started to yellow, stomas closed, chlorophyll absorption capacity weakened correspondingly, and reflectance of red band channel of the sensor increased, while that of near-infrared band decreased gradually, and NDVI and EVI values were further reduced. It can be seen from Figure 2b that the NDVI and EVI values of *S. alterniflora* decreased constantly from September to November at an accelerated reduction rate. The reductions were the maximum in November, being 0.15 and 0.09, respectively. At the end of November, NDVI and EVI values fell to the minimum in the growth stage, when *S. alterniflora* gradually withered, moving into the non-growth season.

DISCUSSION

As the vegetation index is closely related to plant growth conditions and developmental stages, MODIS-based NDVI and EVI were applied to the studies on the intra-annual variation in vegetation index of *S. alterniflora* salt marsh in Jiangsu coastal areas. The research results showed that by applying the intra-annual variation curves of two MODIS vegetation indices, vegetation characteristics of *S. alterniflora* in growth season and non-growth season can be determined and seasonal variation information, together with major phenological periods including turning green, heading, flowering and fruiting, etc. As a new type of remote sensing data with high temporal and spatial resolution, NDVI and EVI seasonal change based on MODIS can be used for

monitoring the growth of by combining with ground measurements, which provides basic data for strengthening expansion management of *S. alterniflora*, makes full use of its biomass and draws on advantages and avoids disadvantages in coastal areas.

The relationship between MODIS NDVI and EVI

By comparing monthly values of NDVI and EVI, it can be seen that NDVI values were significantly higher than EVI with the difference greater than 0.1, as a result of the definitions of MODIS-based NDVI and EVI themselves (Wang et al., 2003). Obvious defects exist in the MODIS-based NDVI algorithm to eliminate atmospheric noises, that is, without considering the noises of background soil and no guaranteeing the selection of optimal pixel with minimum visual angle, resulting in the difference between NDVI and EVI.

In order to further clarify the relationship between NDVI and EVI values based on MODIS, the correlation analysis was carried out on 156 pairs of NDVI and EVI values at 13 monitoring points in 12 months (Figure 3). The results revealed that NDVI and EVI values based on MODIS showed typical linear correlations. In the case of NDVI less than 0.35, most of the points were located adjacent to the regression line, while in the case of NDVI greater than 0.35, the correlation was relatively dissatisfactory, which was related to the easy saturation of NDVI values in highly covered vegetation areas (because its red light channel and NDVI formula were easy to saturate). Defects existing in NDVI values also could be proven by Figure 2a where NDVI and EVI values increased in the high-value area to some extent. The comparison analysis of NDVI and EVI shows that MODIS EVI could describe the seasonal dynamics of vegetation better than MODIS NDVI. However, as a continuation of AVHRR-based NDVI, MODIS-based NDVI will still play an important role in long-term dynamic monitoring of land cover.

Application prospects of MODIS-based NDVI and EVI to zonal vegetation monitoring in coastal areas

As coastal areas are susceptible to land-ocean interaction, vegetation shows significant zonal distribution features along the coastline with widths no more than a few kilometers generally, such as coastal grass flats, shelterbelts, mangroves and other zonal vegetations. However, monitoring and protection of such ecosystems is of a very important practical significance to the protection of coastal environment and sustainable development of social economy. MODIS-based NDVI and EVI with a spatial resolution of 0.25 km × 0.25 km were adopted in this study, and the study area of *S. alterniflora* salt marsh was only 1-2 km in width. The research results showed that MODIS-based NDVI and EVI data could be

used to identify zonal terrains with narrow widths (greater than 1 km). Therefore, MODIS-based NDVI and EVI remote sensing data also display application prospects in dynamic monitoring of coastal grass flats, mangroves, shelterbelts and other zonal vegetation, for instance, the monitoring of grass production of coastal grass flats, mangrove ecosystems, coastal shelterbelt diseases and pests. However, mixed pixels exist in narrower zonal vegetation inevitably. Therefore, the vegetation indices calculated according to MODIS-based NDVI and EVI data may be lower in the actual monitoring to some extent, which needs further discussion in future studies.

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