

Postprint: High-Spatial-Resolution Remote Sensing Estimation of Fractional Vegetation Cover of Invasive *Spartina alterniflora* in Tidal Flat Wetlands

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Abstract

Spartina alterniflora is a significant invasive species in coastal tidal flat ecosystems, and its distribution status and coverage constitute important parameters and fundamentals for wetland ecological research. Taking the tidal flat wetland of Ningde Sansha Bay (Sanduo Bay) as the study area and SPOT6 satellite imagery with 6 m spatial resolution as the data source, this study investigates the distribution of *Spartina alterniflora* and vegetation coverage, with comparative validation performed using concurrent unmanned aerial vehicle (UAV) imagery of 10 cm spatial resolution. The results indicate that the total area of *Spartina alterniflora* within the imagery coverage is 20.19 km², with Jiaocheng District exhibiting a relatively extensive distribution covering 9.63 km², accounting for 47.70% of the total *Spartina alterniflora* area in the study area. The vegetation coverage of *Spartina alterniflora* is predominantly distributed across medium (40%-60%) and high (60%-80%) coverage ranges, with distribution areas of 5.44 km² and 4.95 km², respectively, representing 26.92% and 24.52% of the total distribution area of *Spartina alterniflora*, while low coverage below 40% and relatively high coverage above 80% are comparatively less common. The vegetation coverage of *Spartina alterniflora* estimated from SPOT6 remote sensing imagery demonstrates favorable accuracy, exhibiting a root mean square error (RMSE) of 0.117 and a coefficient of determination (R^2) of 0.918 from linear regression when compared with UAV imagery values, indicating its suitability for vegetation coverage analysis in tidal flat wetlands.

Full Text

Preamble

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Estimating the Fractional Vegetation Cover of Invasive *Spartina alterniflora* in Coastal Wetlands Using High Spatial Resolution Remote Sensing

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Abstract

Spartina alterniflora is a significant invasive species in coastal beach ecosystems, and its distribution and cover are fundamental parameters affecting wetland ecology. This study investigated the distribution and fractional vegetation cover of *S. alterniflora* using high spatial resolution satellite remote sensing imagery from SPOT6 (6 m) and low-altitude Unmanned Aerial Vehicle (UAV) imagery (10 cm) in Sansha Bay (Sandu Ao), a typical coastal wetland area in Ningde, Fujian Province, China. For extracting information from SPOT6 remote sensing data, support vector machine and maximum likelihood classification methods were explored, and Geographic Information System (GIS) techniques were applied to reduce errors, resulting in an accurate *S. alterniflora* distribution map. The normalized difference vegetation index (NDVI) was calculated for pixels within the distribution area, and fractional vegetation cover was subsequently derived using NDVI values from pure vegetation and pure beach soil pixels.

The total *S. alterniflora* area in the study region was 20.19 km², with 9.63 km² in Jiaocheng District, accounting for 47.70% of the total study area. The vegetation cover was predominantly medium (40%–60%) and high (60%–80%) density, with distribution areas of 5.44 km² and 4.95 km², representing 26.92% and 24.52% of the total *S. alterniflora* area, respectively. Lower coverage (<40%) and very high coverage (>80%) were relatively rare. Statistical tests indicated that the remotely sensed estimates of *S. alterniflora* fractional vegetation cover achieved good accuracy, with a root mean square error (RMSE) of 0.117 and a coefficient of determination of 0.918 when compared with UAV imagery values. These results demonstrate that SPOT6 high spatial resolution remote sensing can be effectively used for vegetation cover analysis in coastal wetlands.

Keywords: coastal wetland; *Spartina alterniflora*; high spatial resolution remote sensing; unmanned aerial vehicles (UAV); fractional vegetation cover

Introduction

Fractional vegetation cover, defined as the vertical projection area of vegetation per unit ground surface [1], fundamentally reflects vegetation status and serves as a foundational parameter for regional vegetation monitoring research. It is widely applied in vegetation change monitoring, ecological environment surveys, comprehensive evaluation, and soil and water conservation studies [2-3], and represents an important parameter in hydrological, climate, and ecosystem models [4-6]. Accurate estimation of vegetation cover is therefore significant for research in hydrology and global change. Satellite remote sensing has become the primary approach for regional vegetation cover monitoring due to its capability to obtain up-to-date ground information [7]. Recently developed low-altitude UAV remote sensing serves as an important complement to satellite platforms, offering flexibility and efficiency for acquiring high-precision data in coastal zones [8-9].

As an introduced exotic species with strong adaptability and vigorous reproductive capacity, *Spartina alterniflora* has spread explosively across large areas, altering the ecological structure of beach wetlands, reducing biodiversity, and increasing ecological vulnerability, making it a hotspot in biological invasion research [10-12]. Field surveys are time-consuming and labor-intensive, particularly for regional-scale investigations, and are constrained by limited accessibility to beach areas. To obtain high-precision vegetation cover information for *S. alterniflora* and understand its diffusion trends, it is essential to leverage the spatial monitoring advantages of high-resolution satellite and low-altitude UAV remote sensing. This study focuses on Sansha Bay in the southeastern coastal region of Ningde, using high-resolution SPOT6 satellite imagery and low-altitude UAV remote sensing imagery to investigate the distribution and fractional vegetation cover of *S. alterniflora*, providing reference data for coastal wetland ecological research.

1. Study Area Overview

Sansha Bay is located in Ningde City, Fujian Province, with geographic coordinates of 26°36' -26°51' N, 119°33' -119°49' E. Characterized by a small mouth and large interior, the bay is surrounded by mountains with a winding coastline and abundant wetland resources. The region belongs to the mid-subtropical monsoon climate zone, with annual temperatures ranging from 16-19°C. [Figure 1: see original paper] shows a schematic diagram of the Sansha Bay study area.

2. Data Sources

Through programming orders, SPOT6 multispectral imagery (red and near-infrared bands) was acquired for the study area, with a spatial resolution of 6 m and acquisition time corresponding to the study period. The imagery center point coordinates are 26°43 35 N, 119°41 15 E. Concurrently with image acquisition, low-altitude UAV control flights were conducted over experimental areas within the study region, obtaining 10 cm spatial resolution imagery. Both SPOT6 and UAV remote sensing imagery underwent orthorectification processing to produce orthophotos for subsequent analysis.

3. Spatial Distribution of *Spartina alterniflora*

Although the spectral features of SPOT6 multispectral imagery are not prominent, its high spatial resolution provides clear textural characteristics of ground objects. Support vector machine and maximum likelihood classification methods were applied for land cover classification, with results refined using GIS techniques to reduce errors. This produced an accurate distribution map of *S. alterniflora* within the imagery coverage area.

Statistical analysis revealed that *S. alterniflora* in the imagery coverage area is primarily distributed in nearshore muddy tidal flats of Sansha Bay, with varying degrees of growth observed near Xiapu and Sandu Island. The distribution patterns include both large continuous patches and small fragmented patches, establishing *S. alterniflora* as a dominant species in intertidal zones. As a semi-enclosed bay with suitable climate conditions and hydrological-topographical settings, Sansha Bay provides an ideal habitat for *S. alterniflora*. Under these growth conditions, beaches with minimal human intervention have developed extensive *S. alterniflora* fields, while coastal reclamation activities for aquaculture and marine engineering construction have caused habitat disruption. Additionally, the crisscrossing water channels in the tidal flats have prevented continuous distribution.

The total *S. alterniflora* area was 20.19 km², with Jiaocheng District showing the most extensive distribution at 9.63 km² (47.70% of the study area), primarily concentrated near Zhangwan Harbor in the north and southern Jiaocheng tidal flats. In Fu' an County, the *S. alterniflora* area was 5.20 km² (25.76%), mainly distributed in Yantian Bay and Magang Bay. presents the distribution area statistics for *S. alterniflora* in Sansha Bay.

Table 1. Distribution area statistics of *Spartina alterniflora* in Sansha Bay

Distribution District	Distribution Area (km ²)	Area Proportion (%)
Jiaocheng	9.63	47.70
Fu' an	5.20	25.76

Distribution District	Distribution Area (km ²)	Area Proportion (%)
Total	20.19	100.00

Comparison with previous studies reveals discrepancies in invasion area estimates. Sun Samei's research indicated an invasion area of 62.45 km² in Sansha Bay [13], ranking first among Fujian's coastal bays, while the total *S. alterniflora* area along Fujian's coast was reported as 99.24 km² [16]. These differences can be attributed to: (1) inconsistent study area boundaries (Sun's study area was approximately 1866.91 km² versus 801.288 km² in this study); (2) significant land use changes since previous studies, including development of large power plants and port facilities in formerly vegetated areas; and (3) limitations of previous 30 m resolution TM imagery that may have caused misclassification of nearshore vegetation. [Figure 3: see original paper] compares the different study areas.

4. Fractional Vegetation Cover of *Spartina alterniflora*

The Normalized Difference Vegetation Index (NDVI) is a widely applied vegetation index that serves as an optimal indicator of vegetation growth status and cover. Through ratio processing, NDVI can partially eliminate irradiance effects related to solar elevation angle and satellite observation angle [17]. The calculation formula is:

$$NDVI = \frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R}$$

where ρ_R is the visible red band reflectance (625-695 nm) and ρ_{NIR} is the near-infrared band reflectance (760-890 nm) from SPOT6 multispectral imagery.

The relationship between fractional vegetation cover (f_c) and NDVI can be expressed as:

$$f_c = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}$$

where $NDVI_{soil}$ represents NDVI for bare beach or non-vegetated areas, and $NDVI_{veg}$ represents NDVI for full *S. alterniflora* cover. Due to vegetation type differences and seasonal variations, $NDVI_{veg}$ exhibits strong spatiotemporal heterogeneity, and negative values may appear in $NDVI_{soil}$ due to surface moisture and roughness factors [18]. To avoid errors from fixed values, this study determined $NDVI_{soil}$ and $NDVI_{veg}$ based on *S. alterniflora* spatial distribution and land cover types.

Frequency statistics of NDVI values in the study area showed that negative values primarily occurred in residual water-covered areas. The minimum NDVI value for low vegetation cover pixels was 0-0.3, while the maximum NDVI value for high vegetation cover pixels reached 0.26. Following established methods for determining pure pixel values in vegetation cover research [19-21], cumulative frequencies of 0-0.3% and 98.33% were used as thresholds for $NDVI_{soil}$ and $NDVI_{veg}$, respectively. Further calculations indicated that the minimum NDVI value between 0-0.26 occurred at 0.3% cumulative frequency, which was adopted as the bare beach soil $NDVI_{soil}$. presents the NDVI value statistics for *S. alterniflora* pixels in Sansha Bay.

Table 2. Statistics of different pixel NDVI values in Sansha Bay

NDVI Values	Pixel Number	Total Pixel Number	Percentage (%)
-0.1-0			28.21
0.0-0.1			49.96
0.1-0.2			20.16
0.2-0.3			
0.3-0.4			
0.4-0.45			

Applying these $NDVI_{veg}$ and $NDVI_{soil}$ values to the fractional cover formula yielded the vegetation cover distribution map for *S. alterniflora* in the study area. The cover ranged across different levels from 0-100%, displaying a multi-level spatial distribution pattern with certain continuity, gradual change, and regional heterogeneity.

According to established vegetation cover classification schemes [22], *S. alterniflora* vegetation cover was dominated by medium (40%-60%) and high (60%-80%) density classes. The medium and high cover areas were 5.44 km² and 4.95 km², accounting for 26.92% and 24.52% of the total distribution area, respectively. The combined medium-high cover area reached 10.39 km² (51.44% of total *S. alterniflora* area). Lower cover (20%-40%) and higher cover (>80%) areas were 2.62 km² and 3.23 km², representing 13.01% and 15.99% of the total area, respectively. [Figure 4: see original paper] shows the fractional vegetation cover distribution map of *S. alterniflora* in Sansha Bay, while provides detailed statistics.

Table 3. Statistics of *Spartina alterniflora* fractional vegetation cover in Sansha Bay

Cover Range	Pixel Number	Distribution Area	Total Area	Percentage
0-20%		2.62 km ²	20.19 km ²	13.01%
20-40%		3.23 km ²	20.19 km ²	15.99%

Cover Range	Pixel Number	Distribution Area	Total Area	Percentage
40-60%		5.44 km ²	20.19 km ²	26.92%
60-80%		4.95 km ²	20.19 km ²	24.52%
80-100%		3.95 km ²	20.19 km ²	19.55%

Given that medium and high vegetation cover areas occupy a significant proportion, monitoring efforts should focus on regions with dense *S. alterniflora* distribution to prevent damage to wetland ecological functions and protect the rationality and efficiency of wetland ecosystem services.

5. Accuracy Assessment

To evaluate the accuracy of *S. alterniflora* vegetation cover estimated from SPOT6 imagery, 26 sample sites were randomly selected within overlapping SPOT6 and UAV image regions. To minimize geometric registration errors between the UAV and SPOT6 imagery, each UAV image sampling point was matched to its corresponding SPOT6 pixel. The average vegetation cover value was calculated for each SPOT6 pixel as the estimated value, while the actual value was determined by delineating the corresponding sample area on the UAV orthophoto and calculating the percentage of *S. alterniflora* area within the region.

Accuracy analysis indicated a root mean square error (RMSE) of 0.117 and a coefficient of determination (R^2) of 0.918 between estimated and actual values. [Figure 5: see original paper] shows the UAV imagery and sample distribution in the validation area, while [Figure 6: see original paper] presents the scatter diagram of vegetation cover based on NDVI. The validation results are satisfactory, demonstrating good precision. The model performed well for true values in the 0-40% range, while for true values exceeding 40%, the SPOT6 remote sensing model tended to slightly underestimate cover, with absolute errors within acceptable limits. These results confirm that SPOT6-derived vegetation cover estimates can be reliably used for *S. alterniflora* vegetation cover analysis in coastal wetlands.

6. Conclusions

Using 6 m spatial resolution SPOT6 imagery, this study successfully mapped *S. alterniflora* distribution in Sansha Bay. The total *S. alterniflora* area was 20.19 km², with Jiaocheng District accounting for 9.63 km² (47.70%) concentrated near Zhangwan Harbor and southern Jiaocheng tidal flats. Fu'an's nearshore area contained 5.20 km² (25.76%), primarily in Yantian and Magang Bays. *S.*

alterniflora predominantly occurred in nearshore muddy tidal flats within 100–500 m perpendicular distance from the coastline, with maximum distribution distances exceeding 2 km, establishing it as a dominant intertidal species.

Vegetation cover was dominated by medium (40%–60%) and high (60%–80%) density classes, with distribution areas of 5.44 km² (26.92%) and 4.95 km² (24.52%), respectively. Lower cover (20%–40%) and very high cover (>80%) areas accounted for 13.01% and 15.99% of the total area. Validation using 10 cm resolution UAV imagery as ground truth yielded an RMSE of 0.117 and R² of 0.918, confirming that SPOT6-derived vegetation cover estimates provide satisfactory precision for coastal wetland research. These findings provide essential baseline data for ecological studies and management of coastal wetlands affected by *S. alterniflora* invasion.

References

- [1] Gitelson A A, Kaufmann Y J, Stark R, Rundquist D. Novel algorithms for remote estimation of vegetation fraction. *Remote Sensing of Environment*, 2002, 80(1): 76–87.
- [2] Jing X, Yao W Q, Wang J H, Song X Y. A study on the relationship between dynamic change of vegetation coverage and precipitation in Beijing' s mountainous areas during the last 20 years. *Mathematical and Computer Modelling*, 2011, 54(3/4): 1079–1085.
- [3] [Reference on vegetation and soil erosion research]
- [4] [Reference on farmland evapotranspiration models]
- [5] Marticorena B, Bergametti G, Gillette D, Belnap J. Factors controlling threshold friction velocity in semiarid and arid areas of the United States. *Journal of Geophysical Research*, 1997, 102(D19): 23277–23287.
- [6] Sellers P J, Tucker C J, Collatz J, Los S O, Justice O, Dazlich D A, Randall D A. A revised land surface parameterization (SiB2) for atmospheric GCMs. Part II: The generation of global fields of terrestrial biophysical parameters from satellite data. *Journal of Climate*, 1996, 9(4): 706–737.
- [7] [Review on grassland vegetation cover measurement methods]
- [8] [Research on UAV remote sensing in island management]
- [9] [Automatic registration of UAV images]
- [10] [Assessment of *Spartina alterniflora* impact on coastal ecosystems]
- [11] Talley T S, Levin L A. Modification of sediments and macrofauna by an invasive marsh plant. *Biological Invasions*, 2001, 3(1): 51–68.

- [12] Zhang Y H, Ding W X, Luo J F, Donnison A. Changes in soil organic carbon dynamics in an Eastern Chinese coastal wetland following invasion by a C4 plant *Spartina alterniflora*. *Soil Biology and Biochemistry*, 2010, 42(10): 1712-1720.
- [13] Sun Samei. Remote sensing monitoring of *Spartina alterniflora* in Sandu Bay. 2005.
- [14] [Research on *Spartina alterniflora* salt marsh formation process]
- [15] [Study on *Spartina alterniflora* distribution along Fujian coast]
- [16] Zuo Ping et al. Distribution of *Spartina alterniflora* along Fujian coastal waters. 2009.
- [17] [Principles and methods of remote sensing application analysis]
- [18] [Study on vegetation landscape pattern change in Loess Plateau]
- [19] Hu Z Q, He F Q, Yin J Z, LU X, Tang S L, Wang L L, Li X J. Estimation of fractional vegetation cover based on digital camera survey data and a remote sensing model. *Journal of China University of Mining and Technology*. 2007, 17(1): 116-120.
- [20] [Dynamic vegetation cover change study in Chongqing using MODIS data]
- [21] [Remote sensing investigation of vegetation cover change in 2010]
- [22] [Dynamic vegetation cover change in Korla using TM NDVI]

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