Original Research Article

Investigation and Evaluation of Tidal Flat Plant Recovery after Spartina Alterniflora Eradication

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Abstract: The introduction of Spartina alterniflora to China has resulted in severe ecological consequences, elevating the need for its control to a national strategic priority. Focusing on Meishan Bay, this study examines the beach area following Spartina alterniflora management efforts, providing a comprehensive assessment of vegetation recovery and the factors influencing it. Our findings indicate that the primary restored vegetation consists of Spartina alterniflora, Suaeda salsa, and reed communities. Notably, Spartina alterniflora demonstrates the fastest recovery rate, Suaeda salsa recovers at an average speed, while reed shows the slowest recovery. This pattern can be attributed to Spartina alterniflora's inherent growth traits and its adaptability to specific beach environmental conditions, including lower elevation, extended seawater submergence duration, and deeper seawater submergence.

***Keywords*：** Spartina alterniflora; Tidal flat; Plant investigation

1. Introduction

Spartina alterniflora, introduced to China from North America during the 1970s and 1980s, was initially valued for its beneficial contributions in wave dissipation, dike reinforcement, disaster prevention and mitigation, as well as siltation enhancement. Nevertheless, because of its exceptional adaptability and reproductive capacity, this species has rapidly proliferated along China's coasts. Currently, it has emerged as the salt marsh plant with the most extensive distribution along coastal beaches, particularly posing significant ecological challenges in Jiangsu, Zhejiang, and other provinces. Consequently, it has been designated as one of the first alien invasive species.

In the 21st century, Spartina alterniflora has undergone rapid expansion in China's coastal regions, leading to increasingly prominent negative impacts. Consequently, scholars have begun exploring effective management strategies for Spartina alterniflora, including physical interventions like cutting and tillage, chemical treatments such as glyphosate application, and community replacement with mangroves. Focusing on Meishan Island, Ningbo has planned and executed a marine ecological conservation and restoration initiative, specifically targeting the elimination of Spartina alterniflora in the island and its adjacent areas. This study focuses on the tidal flats located offshore of Meishan Bay. Through a comprehensive examination of natural vegetation restoration across various locations within the tidal flat zone, we conduct a thorough assessment of the effectiveness of this natural regeneration. Our findings aim to offer scientific insights and empirical data to support tidal flat preservation and coastal wetland rejuvenation efforts following the removal of Spartina alterniflora in other regions.

2. Overview of the Study Site

Meishan Bay is situated in Zhejiang Province, China, specifically in the middle of the eastern coast, south of Hangzhou Bay, within the Meishan port zone of Ningbo Zhoushan port. Its geographical coordinates range from 29°44' to 29°49'N and 121°54' to 122°01'E. The bay is narrow and elongated, positioned between Meishan Island and the Chuanshan Peninsula. Currently, the heart of Meishan Bay comprises a semi-closed bay enclosed by artificially built northern and southern embankments, while the remaining sections are exposed to the open sea.

To restore the ecological environment of the beach and address ecological issues stemming from Spartina alterniflora, an invasive alien species, the open sea region of Meishan Bay underwent comprehensive clearance via physical methods including cutting and digging. This study focuses on this specific area, conducting plant surveys to analyze plant restoration efforts.

3. Research Methods

3.1. Survey Locations

In the tidal flat area formerly inhabited by Spartina alterniflora, five survey stations (labeled as communities a to e) have been established. Each station corresponds to an independent community set up based on the vegetation distribution boundary (or tidal flat extension length) of the respective area, along the vertical coastline direction, to conduct surveys independently.

3.2. Survey Content

The survey contents encompass several aspects: vegetation community type, elevation value relative to the Yellow Sea, duration of sea water submergence (observed over 7 days from spring tide to neap tide, with an average value calculated), depth of sea water submergence (monitored and documented using permanent benchmarks), sea water salinity, sea water pH, pH level of beach sediment, and salt content.

The plant survey was conducted using a sampling method. To determine the elevation of the survey area, we employed field measurements, utilizing RTK measuring equipment to assess five positions in each survey area and calculating their average. Field observations were conducted to determine the duration and height of seawater submergence, including observations during spring tide, flat tide, and neap tide days. Over a total of 7 observation days, averages were recorded. Seawater inundation time was tracked from the moment seawater entered the observation area until it completely exited. The submerged height of the seawater was documented with reference to pre-buried stakes in the community, again averaging the data from the 7-day observation period. Seawater salinity and pH were measured on-site using a portable water quality instrument, while sediment pH and salt content were analyzed in the laboratory, adhering to relevant specifications.

Table 1. Survey location and basic information table.

Num	Place	Length（m）	Elevation（m）	Average flood duration(h)	Average flood height（m）
A-1	Ningbo City fishery emergency rescue base northeast tidal flat	12	1.03	2.8	0.5
A-2		38	0.32	5.6	1.0
B-1	Meishan pilot base west beach	6	1.53	1.6	0.2
B-2		13	1.19	3.2	0.4
B-3		53	0.52	5.0	0.7

C	Beilun Kangda shipyard east beach	36	-0.01	6.1	1.4
D	South beach of the seawall on the east side of Panzhi Mountain	44	0.07	6.2	1.3
E	Motou water gate northeast tidal flat	49	0.89	4.1	0.7

4. Results and Analysis

4.1. Vegetation Restoration

The survey results indicated varying degrees of vegetation restoration across the five sites. Spartina alterniflora community emerged as the dominant type, followed by Suaeda glauca community, while Phragmites australis community was the least prevalent.

The restoration of the Spartina alterniflora community is primarily attributed to the asexual reproduction of residual roots after the removal of the treatment, as well as the sexual reproduction of seeds from the previous year. Since all the investigated areas were previously occupied by the Spartina alterniflora community prior to the removal measures, it indicates that these areas are highly conducive to the survival of Spartina alterniflora. Consequently, the community has been swiftly restored through methods such as root cutting sprouting and seed germination.

Please refer to relevant websites for more information, and feel free to ask me any other questions.

The primary reason for the restoration of the reed community lies in the presence of a few reed plants that remained in their original position prior to the removal of the treatment. Since these plants are situated near the seawall, the reed distribution area wasn't excavated deeply to prevent damage to the embankment. Instead, only the aboveground portions of the plants were trimmed, preserving most of the reed roots. Consequently, these residual roots gave rise to new communities in the developing city after the treatment was lifted.

Spartina alterniflora demonstrates the strongest natural recovery among the species studied. Despite a notable difference between its current average density and historical survey data (600-800 plants/m2), and its average height not yet matching historical records (1.8-2.0m), it can fully colonize a beach in just 3-5 years due to its diverse reproduction methods. This swift community regeneration poses greater demands on the subsequent project maintenance, necessitating a fresh set of management measures. Suaeda salsa also recovers quickly, but its distribution is more confined and significantly influenced by micro-topography. Reed, on the other hand, recovers the slowest. Historical surveys indicate that its recovery is confined to its original habitat, and its growth status is relatively average.

Table 2. Vegetation survey.

Num	Type of plant community	Density (plant /m2)	Average height (m)	Average coverage (%)
A-1	Suaeda	12	0.25	20
A-2	Spartina alterniflora	42	1.05	45
B-1	Seed	4	0.55	30
B-2	Suaeda	18	0.25	20
B-3	Spartina alterniflora	43	1.10	70
C	Spartina alterniflora	38	0.95	65
D	Spartina alterniflora	31	1.05	70
E	Spartina alterniflora	54	1.15	70

Table 3 Questionnaire of environmental factors.

Plate	Seawater salinity (‰)	Seawater pH	Sediment salinity (g/kg)	Sediment pH value
A-1	24.44	7.54	10.9854	7.11
A-2			14.9832	7.35
B-1	25.52	7.52	11.1387	7.05
B-2			13.2467	7.25
B-3			15.6849	7.56
C	25.63	7.41	17.3641	7.64
D	24.38	7.39	15.6548	7.59
E	24.45	7.36	13.2779	7.95

4.2. Influence of Location Condition on Vegetation Restoration

In general, the average elevation of survey locations ranges from -0.01m to 1.45M, indicating that they belong to low-elevation tidal flats. The elevation conditions are intricately linked to the duration and depth of flooding, both of which have a combined impact on vegetation restoration.

Based on elevation data, vegetation restoration efforts can be implemented within the range of -0.01 to 1.45M. However, it's crucial to note that the restored vegetation primarily consists of the Spartina alterniflora community. Specifically, in areas with an elevation below 1m, the communities restored are predominantly Spartina alterniflora, accompanied by a small number of Suaeda salsa communities around 1.0m and reed communities around 1.5m.

Regarding flooding duration, the Spartina alterniflora community demonstrates remarkable tolerance, enduring floods for up to 6 hours. Comparatively, the Suaeda salsa community can recover from floods lasting no longer than 4 hours, while the reed community tolerates floods for no more than 2 hours.

In terms of inundation depth, Spartina alterniflora can withstand submergence of up to nearly 1.5m, Suaeda salsa tolerates depths of approximately 0.5m, and Phragmites australis can handle depths of around 0.2m.

These findings indicate that Spartina alterniflora exhibits the highest flexibility in adapting to varying elevations, flooding durations, and submergence heights within the restoration area, surpassing the tolerance levels of the other two species. Suaeda salsa's tolerance falls between that of Spartina alterniflora and Phragmites australis, while the reed community demonstrates the lowest tolerance among the three.

4.3. Impact of Environmental Factors on Vegetation Restoration

The salinity, pH of the seawater, as well as the salt content and pH value of sediments in the survey area, were carefully measured. The results indicated that these indicators exhibited relatively similar values. However, it's worth noting that the survey locations were not uniformly spaced (approximately 1km apart from each other), which contributed to these findings. The comparable characteristics of both seawater and sediment suggest that the restoration of plant communities remained unaffected by these properties. This further validates that location factors, such as elevation, played a pivotal role in determining the success of vegetation restoration.

5. Conclusion and Discussion

5.1. Conclusion

Combined with survey results, it is evident that the ecological space vacuum zone created after removing Spartina alterniflora has transformed into a focal point for plant community competition. Survey data reveals that naturally restored vegetation communities consist of treated Spartina alterniflora, an invasive plant, along with Suaeda salsa and Phragmites australis, which are native plants suitable for mudflat environments.

Upon analyzing the recovery capabilities of these vegetation communities, Spartina alterniflora demonstrates the strongest resilience and fastest recuperation rate. Remarkably, it only took approximately one year after removal treatment for this species to reclaim its original distribution area. While there remains a significant disparity in community density and plant height compared to the pre-treatment state, past management experience suggests that it takes merely 3-5 years for Spartina alterniflora to fully restore its distribution, density, and height.

On the other hand, Suaeda salsa recovers at a slower pace, relying on external factors for seed dispersal, and its growth rate is notably slower than Spartina alterniflora. Phragmites australis, commonly known as reed, exhibits the weakest recovery capacity, heavily reliant on its existing root system. Consequently, its growth and expansion rates are the least favorable among the three species.

The key factors influencing vegetation restoration are the elevation of the tidal flat, the duration of seawater inundation, and the depth of inundation, all of which dictate the restoration intervals of various plant communities. Typically, lower tidal flat elevations, longer submergence times, and deeper submergence depths favor the restoration of the Spartina alterniflora community. Conversely, higher elevations, shorter submergence times, and shallower depths are more conducive to the restoration of Suaeda salsa and Phragmites australis communities.

5.2. Discussion

For the control and long-term management of Spartina alterniflora, numerous studies have been conducted nationwide. Some scholars have suggested using artificial vegetation communities to prevent Spartina alterniflora's recurrence and secondary invasion. However, several factors limit the practicality of this approach. Firstly, the beach's elevation poses a challenge. Our survey revealed that Spartina alterniflora communities are found at elevations of 1.0m or below. Historically, Spartina alterniflora has been documented to reach elevations of approximately 2.0m, indicating its adaptability to various beach environments. Secondly, the availability of suitable plant species is limited. In Fujian, Guangdong, Hainan, and even southern Zhejiang, mangrove plants like Kandelia can be effectively used to create artificial vegetation communities, providing dense canopy cover that suppresses Spartina alterniflora recurrence. Nevertheless, in Ningbo and regions further north, mangrove plants cannot survive harsh winters. Additionally, suitable local plants like Suaeda salsa and Phragmites australis are confined to elevated, narrow beach areas, and their slow growth rate and low plant height hinder effective competition with Spartina alterniflora.

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