Control and Management of the Invasive Plant Spartina alterniflora: Concepts, Techniques, and Practice Postprint

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Abstract

The invasive species Spartina alterniflora encroaches upon the living space of native flora and fauna, leading to reduced intertidal biodiversity and diminished wetland ecosystem service functions; therefore, it is imperative to curb the rapid expansion of Spartina alterniflora in China' s coastal regions. This article introduces the general status of Spartina alterniflora invasion in China and its major ecological damages, proposes a control concept of "ecological damage assessment—zoned effective control—monitoring and early warning" for Spartina alterniflora, and provides a comprehensive analysis of Spartina alterniflora management technologies both domestically and internationally, as well as the current state of Spartina alterniflora management in China. Different management technologies each possess distinct advantages and disadvantages, and integrated management approaches that combine multiple technologies typically yield superior control outcomes. As of early June 2023, China has implemented nearly 200 Spartina alterniflora control projects, with the majority of management costs falling below 60,000 yuan per hectare. Future research should prioritize: (1) integrating prevention and control to establish a long-term mechanism for Spartina alterniflora management; (2) optimizing integrated management technologies and strengthening the development of specialized mechanical equipment; and (3) enhancing the evaluation of control effectiveness and the assessment of environmental and biological impacts of control projects.

Full Text

Control of Invasive Plant Spartina alterniflora: Concept, Technology and Practice

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Abstract

The invasive alien species *Spartina alterniflora* (smooth cordgrass) has severely impacted China's coastal ecosystems by displacing native flora and fauna, reducing intertidal biodiversity, and diminishing wetland ecological service functions. Urgent action is required to curb its rapid expansion along China' s coastlines. This paper reviews the invasion history and primary ecological damages caused by *S. alterniflora* in China, and proposes a comprehensive control framework based on "ecological hazard assessment—zoned effective control—monitoring and early warning." We systematically analyze control technologies employed both domestically and internationally, noting that while each method has distinct advantages and limitations, integrated approaches combining multiple techniques generally yield superior results. As of early June 2023, China has implemented nearly 200 *S. alterniflora* control projects, with most control costs remaining below 60,000 yuan per hectare. Future research should prioritize: (1) integrating prevention and control to establish long-term management mechanisms; (2) optimizing integrated control technologies and developing specialized mechanical equipment; and (3) strengthening evaluations of control efficacy and environmental impacts on ecosystems and biodiversity.

Keywords: invasive species, prevention and control, ecological hazards, biodiversity, mowing, ploughing, waterlogging

2. Concept of Spartina alterniflora Control

Effective management of *S. alterniflora* requires a strategic approach due to its high reproductive capacity and substantial control costs. Although several coastal provinces have initiated large-scale control efforts, the total infested area continues to grow rapidly, posing a significant challenge for coastal wetland conservation. The ecological impacts of *S. alterniflora* invasion vary considerably across different regions, necessitating zoned and prioritized control strategies tailored to specific habitat conditions. We propose a three-tiered control concept: ecological hazard assessment, zoned effective control, and monitoring with early warning [Figure 1: see original paper].

2.1 Ecological Hazard Assessment

Hazard assessment should evaluate differences in vegetation, macrobenthic fauna, and bird communities between invaded and native ecosystems. The magnitude of these differences determines the hazard level—smaller differences indicate greater ecological harm. Assessment protocols can follow established standards such as T/CAOE 20 "Technical Guidelines for Investigation and

Assessment of Coastal Ecosystem Status." Key indicators include plant community characteristics (coverage, density, height, biomass, species diversity), macrobenthic fauna metrics (species richness, density, biomass, diversity), and avian populations (species count, individual numbers, diversity) .

2.2 Zoned Effective Control

Based on hazard assessment results and infestation area, *S. alterniflora* should be classified into three management zones: key control areas, general control areas, and effective containment zones . Key control areas require complete eradication using site-appropriate techniques, regardless of infestation size. General control areas focus on reducing existing populations through phased removal based on available funding. Effective containment zones prioritize preventing seed-based dispersal through annual mowing before seed maturation. Control methods should be selected according to habitat characteristics: close mowing for low tidal flats, mowing plus waterlogging for middle tidal flats, and mowing plus ploughing for high tidal flats and drainage channels.

2.3 Monitoring and Early Warning

Post-treatment monitoring should cover both treated areas and adjacent wetlands. A patrol-based prevention system must be established to detect and eradicate re-invasion. Using drones and hovercraft, annual inspections should focus on the seedling stage (April–June), with any detected plants removed before August when control is most cost-effective. Early detection and rapid response are critical for preventing re-establishment.

3. Control Technologies for Spartina alterniflora

Control methods include physical, chemical, biological, and integrated approaches [Figure 2: see original paper]. Each technology has distinct advantages, disadvantages, and site-specific applicability, with effectiveness varying significantly across studies.

3.1 Physical Control Technology

Physical methods such as manual removal and mowing generally avoid environmental pollution and cause only temporary biological disturbance. Manual removal, while labor-intensive and unsuitable for large areas, effectively manages newly invaded or resprouting patches. Mowing reduces plant vigor and seed production, with timing being more critical than frequency. Optimal control is achieved by mowing during the booting to flowering stage; improper timing may stimulate regrowth. Multiple mowing cycles enhance effectiveness, particularly in areas with prolonged inundation. Waterlogging is another effective physical method—while established clones tolerate flooding, seedlings are highly vulnerable. Continuous waterlogging at 10–20 cm depth for 2–3 months achieves 100% mortality of 5–10 cm tall seedlings.

3.2 Chemical Control Technology

Chemical control primarily involves herbicide application. Herbicides are classified as contact or systemic based on translocation capacity, and as selective or broad-spectrum based on specificity. Commonly used herbicides include haloxyfop-R-methyl, glyphosate, glufosinate ammonium, and imazapyr . Haloxyfop-R-methyl demonstrates the highest efficacy, though it temporarily affects benthic fauna. Optimal application occurs during June–August. While chemical methods are simple to implement, their environmental impacts require thorough, long-term assessment before large-scale application. Studies have documented crab population declines following herbicide treatment, with recovery taking nearly a year.

3.3 Biological Control Technology

Biological control includes natural enemy introduction and biological substitution. Natural enemy research remains limited, with tested species such as the periwinkle *Littoraria irrorata*, ergot fungus *Claviceps purpurea*, and planthopper *Prokelisia marginata* showing poor control efficacy. Biological substitution uses competitive native plants to replace invaders. While effective in mangrove habitats, substitution has proven unsuccessful in salt marshes. In mangrove systems, substitution involves initial *S. alterniflora* removal followed by native mangrove planting. *Kandelia obovata* has shown promising results in Zhejiang and Fujian, though its effectiveness depends on proper maintenance during establishment. Caution is advised when using exotic mangroves like *Sonneratia apetala* due to their own invasive potential.

3.4 Integrated Control Technology

Integrated approaches combine multiple methods for enhanced effectiveness. The most effective combinations include "mowing + waterlogging," "mowing + ploughing," and "mowing + shading" . "Mowing + waterlogging" controls both vegetative growth and sexual reproduction, causing rhizome suffocation. "Mowing + ploughing" targets both reproductive modes, with multiple passes improving efficacy. "Mowing + shading" inhibits photosynthesis, achieving complete mortality within 2–3 months under <0.3% light transmission. These integrated techniques outperform single-method approaches in both salt marsh and mangrove habitats.

4. Current Status of Spartina alterniflora Control in China

4.1 Control Projects in Coastal Provinces

From January 2012 to early June 2023, China implemented 188 large-scale *S. alterniflora* control projects with a total investment of 2.381 billion yuan . Shanghai, Fujian, and Guangdong initiated large-scale control efforts during 2012–2014, while most other provinces began in 2017. Project numbers remained low until 2020, after which they increased dramatically. Shanghai, Shandong, Fujian, and Jiangsu have invested substantially more than other coastal provinces [Figure 4: see original paper][Figure 5: see original paper].

Literature on control costs is scarce. Reported costs vary widely: chemical control in Washington State cost approximately $17,500/km coastline; chemical and "mowing + waterlogging" methods in China' s Yellow River Delta cost 7,920 and 29,325 yuan/ha, respectively; and chemical control in South Africa cost 55,536 yuan/ha. Analysis of 54 publicly tendered projects reveals an average cost of 44,370 yuan/ha (median: 29,700 yuan/ha) [Figure 6: see original paper]. Chemical methods are generally cheaper than physical approaches, though costs vary significantly based on infestation characteristics, environmental conditions, and selected technologies.

5. Strategies and Recommendations for Spartina alterniflora Control

5.1 Integrate Prevention and Control to Establish Long-Term Mechanisms

Long-term management requires both proactive monitoring and 成果巩固. First, establish a multi-scale monitoring system integrating high-resolution satellite imagery, drone surveys, and field inspections to detect re-invasion promptly. Second, restore native vegetation and utilize reclaimed mudflats to prevent re-establishment. Planting fast-growing mangroves or conducting benthic seeding can effectively consolidate control achievements.

5.2 Integrate Research and Practice to Optimize Integrated Technologies

While researchers have developed numerous effective integrated technologies, most derive from small-scale experiments. Large-scale implementation faces new challenges. Encouraging collaboration between research institutions and enterprises during large-scale projects will optimize existing technologies, develop new methods, and ensure practical applicability, thereby improving efficiency and reducing costs.

5.3 Strengthen Equipment Development to Ensure Technology Implementation

Complex and variable geographic environments pose significant challenges for control operations. Different habitats require specialized technologies and 配套 equipment. The lack of professional machinery substantially limits technology effectiveness. Developing specialized equipment tailored to specific control methods, geographic conditions, and geological features will enhance operational efficiency, reduce costs, and ensure successful technology deployment.

5.4 Strengthen Evaluation of Control Efficacy and Environmental Impacts

All control methods disturb coastal wetland ecosystems to varying degrees. Regular monitoring and assessment of control effectiveness and environmental impacts are essential for lifecycle project management. Additionally, post-control assessments should evaluate changes in coastal erosion and storm surge risks to inform coastal protection strategies.

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Note: Figure translations are in progress. See original paper for figures.