# Ecological Consequences of Coastal Biological Invasions and Management Recommendations: Postprint

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## Abstract

Coastal ecosystems provide critically important economic and ecological service functions, while simultaneously representing one of the most vulnerable ecosystems susceptible to alien species invasion. To date, China has documented 196 invasive alien species in its coastal zones, accounting for over one-quarter of the nation' s total invasive species. Intentional introduction and shipping constitute the primary pathways for alien species invasion into coastal ecosystems. Coastal biological invasions cause severe ecological consequences, including restricted growth and reproduction of native species, loss of biodiversity, and decline in ecosystem service functions, while simultaneously exerting substantial impacts on coastal fisheries, agricultural production, and even public health. To scientifically manage coastal biological invasions, we recommend conducting comprehensive and systematic scientific investigations of coastal alien species in China at the earliest opportunity, implementing risk analyses for major invasive species, further investigating the invasion mechanisms and ecological impacts of key invasive species, improving relevant laws, regulations, and policy frameworks, strengthening ballast water management, and thereby safeguarding coastal ecological security and regional economic and social development.

## Full Text

## Coastal Science and Sustainable Development

### Special Feature: Ecological Consequences and Management Strategies for Biological Invasions in the Coastal Zone

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## Abstract

Coastal ecosystems provide vital economic and ecological services, yet they are also among the most vulnerable ecosystems susceptible to biological invasions. According to China's Alien Invasive Species Database, at least 196 invasive alien species have been identified in the coastal zone, accounting for more than one-quarter of all invasive species recorded nationwide. Intentional introductions and ship-mediated transport represent the primary pathways for alien species to invade coastal ecosystems. Biological invasions in coastal zones cause severe ecological consequences, including suppressed growth and reproduction of native species, loss of biodiversity, and degradation of ecosystem services, while also posing significant threats to coastal fisheries, agriculture, and human health. To address these challenges scientifically, we recommend conducting comprehensive inventories of alien species in China' s coastal zone, implementing risk analyses for major invasive species, deepening research on invasion mechanisms and ecological impacts, improving relevant laws and policies, and strengthening ballast water management to safeguard coastal ecological security and regional socioeconomic development.

**Keywords:** management, coastal zone, ecosystem services, biological invasions, alien species

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The coastal zone is defined as a belt extending landward and seaward from the coastline, encompassing both terrestrial and nearshore marine areas. The Millennium Ecosystem Assessment defines coastal boundaries as "areas between 50 m below mean sea level and 50 m above the high tide line, or up to 100 km inland from the shore, including coral reefs, intertidal zones, estuaries, coastal aquaculture areas, and seagrass communities" [1]. By this definition, coastal zones support more than half of the world' s population, with low-elevation coastal areas—occupying only 2% of global land area—nurturing 10% of humanity [2]. As hotspots of economic and cultural activity, coastal zones provide abundant ecological resources and critical ecosystem services [3], making their ecological health intimately linked to human well-being.

China' s mainland coastline stretches approximately 18,000 km, with coastal zones concentrated in the eastern and southern regions. Though these areas account for just 13% of the nation' s total land area, they harbor roughly 50% of China' s population and generate over 60% of its gross national product [4]. Coastal ecosystems provide crucial ecological functions—maintaining regional ecological balance, mitigating natural disasters, and conserving biodiversity—playing an indispensable role in national socioeconomic development. The estimated value of ecosystem services from China' s coastal zones exceeds 1 trillion RMB annually, representing approximately one-fifth of the total value of ecosystem services nationwide [5]. However, these regions face mounting ecological and

environmental challenges, including sea-level rise, coastal erosion, habitat fragmentation, pollution, eutrophication, and biological invasions, which severely threaten ecosystem health [4]. Among these threats, biological invasions have particularly pronounced impacts on biodiversity and ecosystem services, drawing considerable attention from government agencies, the public, and scientists [6]. This paper reviews the current status of coastal biological invasions globally and in China, analyzes the causes behind successful invasions, outlines their ecological consequences, and proposes management strategies to strengthen China' s capacity to address coastal biological invasions.

## 1 Status and Causes of Coastal Biological Invasions

### 1.1 Current Status of Coastal Biological Invasions

Although the concept of biological invasion was introduced by Elton in 1958 [7], early research focused primarily on terrestrial ecosystems. Global attention to coastal biological invasions emerged only after the 1970s [8,9]. Studies of terrestrial plant invasions in coastal zones began relatively early; for instance, Australia initiated systematic research in 1976 on the invasion mechanisms and control methods for *Chrysanthemoides monilifera*, an aster invading its southern coast [9]. Research on marine invasions lagged behind, with studies on ballast water in the mid-1980s highlighting the threat of transoceanic species introductions [8]. Currently, invasive alien species in coastal zones are found across nearshore terrestrial areas, supratidal, intertidal, and offshore zones, encompassing diverse taxonomic groups including algae, seed plants, cnidarians, mollusks, arthropods, urochordates, parasites, and pathogens. Commonly invaded habitats range from nearshore lands, salt marshes, and mangroves to coastal dunes and shallow marine waters [10-12].

China began addressing coastal biological invasions in the late 1990s. According to the China Alien Invasive Species Database, among 753 established alien species nationwide, 196 are associated with coastal zones—exceeding one-quarter of China' s total invasive species inventory [13]. Plants constitute the largest group, with 115 species accounting for 60% of coastal invaders, followed by small invertebrates and microorganisms [13]. While terrestrial plants dominate in numbers, aquatic plants tend to cause more severe impacts. Notably, beyond currently documented invaders, some terrestrial or pelagic alien species pose potential invasion risks to China' s coastal zones [10,12]. Furthermore, limited systematic surveys have left the invasion status of many species unclear, suggesting the actual number of coastal invaders may exceed current records.

### 1.2 Pathways and Causes of Coastal Biological Invasions

Alien species invade coastal zones primarily through intentional and unintentional human-mediated pathways. Intentional introductions represent a major route, exemplified by *Spartina alterniflora*, a North American cordgrass introduced globally to coastal salt marshes for its sediment-trapping capacity, which

has since become a widespread invader [6]. Similarly, alien crops, aquaculture species, and ornamental plants may escape cultivation and establish in coastal areas [10]. Unintentional introductions occur through canal operations, such as the Suez Canal facilitating the invasion of Red Sea fish into the Mediterranean [14], and via maritime shipping, where ballast water transports vast numbers of planktonic organisms (e.g., sea squirts) worldwide [15]. Recreational boating further disperses highly invasive sea squirts and algae [16].

In China, poorly regulated intentional introductions—such as higher plants and shellfish for aquaculture—have been major drivers of coastal invasions. Additionally, some algae have invaded through ballast water discharge, while various aquatic invertebrates arrive as hull fouling organisms on transoceanic vessels [17]. Notably, China introduced *Spartina alterniflora* to eastern coastal mudflats in the late 1970s, which subsequently spread across eastern and southern coasts from Liaoning to Guangxi and Hainan, creating an extensive invasion [6] [Figure 1: see original paper].

Beyond direct introductions, successful invasions in China' s coastal zones are facilitated by several underlying factors. China's extensive and convoluted coastline spans tropical, subtropical, and temperate climate zones, offering diverse environmental conditions conducive to alien species establishment. Coastal ecosystems, characterized by high salinity and frequent hydrological fluctuations from tides, typically support relatively simple biological communities under high-stress conditions, creating opportunities for competitively superior invaders. Moreover, intensive anthropogenic disturbances, particularly coastal reclamation [Figure 2: see original paper], aquaculture expansion, and land-use changes, have reduced native biodiversity and weakened ecosystem resistance to invasion [18], potentially exacerbating invasion trends.

## 2 Ecological Consequences of Coastal Biological Invasions

Biological invasions not only harm coastal socioeconomic sectors (e.g., aquaculture, agriculture) and human health, but also inflict severe ecological consequences on native ecosystems across individual, population, community, and ecosystem levels [19]. Here we summarize major ecological impacts of coastal invasions worldwide. First, invaders compete with native species, reducing their living space and causing population declines. For example, the invasive mudsnail *Batillaria attramentaria* in California coastal zones efficiently utilizes resources, posing a risk of displacing the native California horn snail *Cerithidea californica* [20]. Second, invaders alter community composition and food web structure. In California' s Tomales Bay, the invasive European green crab *Carcinus maenas* preferentially preys on native oysters, disrupting food webs and ultimately causing habitat loss for native oyster populations [21]. Third, invaders modify soil nutrient status, energy flow, and material cycling. The invasive aster *Chrysanthemoides monilifera* in Australian coastal dunes alters local soil carbon and nitrogen content through its litter, affecting biogeochemical cycles [22]. Fourth, introduced pathogens and parasites seriously threaten coastal fisheries, agricul-

ture, and human health. Harmful microorganisms in ballast water endanger aquaculture operations, and surveys of ballast water in ships arriving at Chesapeake Bay detected *Vibrio cholerae*—the causative agent of epidemic cholera—in all samples [23].

Similar to global patterns, biological invasions have caused severe ecological consequences in China' s coastal zones. The invasive vine *Mikania micrantha* competes with mangroves for resources in invaded habitats [Figure 3: see original paper], threatening mangrove survival [12]. The invasive false mussel *Mytilopsis sallei* reduces diversity of native fouling communities in southern coastal waters [24]. Blooms of invasive dinoflagellates such as *Noctiluca scintillans*, *Cochlodinium polykrikoides*, and *Phaeocystis globosa* have triggered harmful algal blooms exceeding 100 km², severely damaging nearshore ecosystem health [25]. Some highly threatening invaders cause comprehensive, multi-level impacts. As previously mentioned, *Spartina alterniflora* invasion in the Yangtze River estuary salt marshes has caused severe contraction and local extinction of the endemic *Scirpus mariqueter*, altered insect and bird communities, and reduced diversity of soil nematodes and rhizosphere microorganisms. By modifying benthic food webs, the invasion has transformed nutrient structures, changed carbon and nitrogen pools, and profoundly affected biogeochemical cycles, substantially diminishing the ecosystem service value of the Yangtze estuary salt marshes [6]. Consequently, the Shanghai municipal government has invested 1.3 billion RMB to control this invader and restore the damaged salt marsh habitat at Chongming Dongtan, a critical bird sanctuary.

## Management Strategies for Coastal Biological Invasions

### 3.1 Conduct Comprehensive Scientific Inventories of Coastal Invasive Species

Confronted with the serious challenges of coastal biological invasions, China urgently needs to develop more systematic and effective management strategies. While North America, Europe, and Australia have conducted long-term, comprehensive inventories of coastal invasions and extensive research on invasion mechanisms, impacts, and control methods, China has primarily focused on a few high-impact species [26]. The lack of thorough surveys has left us with an incomplete understanding of the full spectrum of invasive species across China' s vast coastal zones. Conducting comprehensive scientific inventories to document species composition and distribution is therefore the most fundamental and critical step for improving coastal invasion management in China.

### 3.2 Implement Risk Analysis for Major Alien Species

Risk analysis is essential for scientifically managing biological invasions, as effective risk assessment helps prevent coastal invasions [27-29]. While risk analysis is well-established in agricultural and forestry ecosystems, these studies often emphasize economic losses, with fewer cases examining impacts on nat-

ural ecosystem biodiversity and services. Risk analysis specifically tailored to coastal ecosystems remains particularly inadequate. Given the strategic importance of China' s coastal zones, we must promptly develop a coastal-specific risk assessment framework based on comprehensive inventories and international experience. This system should systematically evaluate both established invaders and species proposed for introduction to prevent new invasions.

### 3.3 Strengthen Ecological Research on Major Invasive Species

As understanding of ecosystem dynamics and stability becomes increasingly important, comprehensive assessment of invasion impacts has emerged as a key research frontier in invasion biology. Given that current research in China remains limited to a few individual species, we recommend expanding systematic and in-depth studies on multiple invasive taxa (plants, animals, and microorganisms) to elucidate invasion mechanisms and impacts on coastal ecosystems. Research should particularly focus on ecosystem-level processes, including how invasions alter community structure and composition, biogeochemical cycles, ecosystem services, and ecological security. Additionally, greater understanding is needed of interactions between global change and coastal invasions and their consequences. From a socioeconomic perspective, research should also address impacts and mechanisms of invasions on coastal aquaculture and shipping industries. Building upon thorough understanding of invasion mechanisms and impacts, targeted control and management strategies can be developed.

### 3.4 Improve Laws, Regulations, and Policies

Establishing comprehensive laws, regulations, and policies is crucial for effective invasion management. While China has enacted several relevant laws—including the Law on the Entry and Exit Animal and Plant Quarantine, Plant Quarantine Regulations, Animal Epidemic Prevention Law, and Marine Environmental Protection Law—the legal framework specifically addressing coastal biological invasions remains weak and requires substantial strengthening. Furthermore, given the coastal zone' s unique position, invasion management involves multiple sectors including fisheries, aquaculture, shipping, and quarantine inspection, necessitating effective inter-agency coordination and collaboration to advance integrated coastal invasion management.

### 3.5 Strengthen Ballast Water Monitoring and International Cooperation

The ocean' s global connectivity makes coastal biological invasion management an international challenge requiring active participation and cooperation. Although China is a party to the UN Convention on Biological Diversity, global collaboration on coastal invasion management needs strengthening. Ballast water monitoring is particularly critical, as ballast-mediated invasions are ubiquitous in global shipping [15]. Since the threat was first recognized in 1985 [8], the United States and Canada pioneered ballast water management regulations,

with many nations subsequently establishing their own measures. China should promptly develop corresponding management policies. The International Maritime Organization adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments in 2004; however, as of now, China has not yet acceded to this convention, and we recommend that relevant authorities seriously consider joining. Despite the difficulties in international cooperation on ballast water management, the inherently global nature of ballast-related coastal invasions demands concerted multinational efforts. As a responsible major power, China should demonstrate leadership and voice in these critical global public welfare issues.

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