Section 4

Subchapter 5I

Salt marshes

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Key points

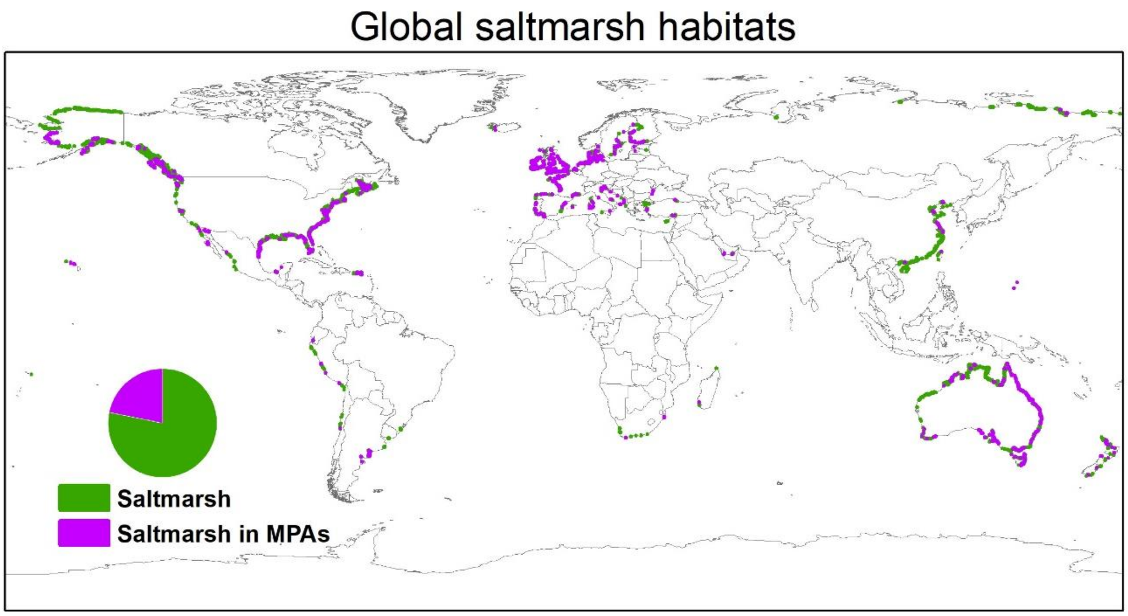
- Salt marshes are extremely valuable ecosystems that continue to be lost worldwide, due primarily to sea level rise and development.
- Techniques are being developed to restore and rehabilitate marshes; some have shown encouraging results.
- Salt marshes are also damaged by pollution and invasive species.

1. Introduction

Salt marshes are among the most valuable ecosystems on Earth (Costanza and others, 1997), providing ecosystem services, including habitat for many species, protection from storms and flooding, "blue carbon" and nitrogen storage. They face many stressors, including sea level rise and development, and are in global decline. Currently, only 21.8% of global salt marshes are inside marine protected areas (MPAs) (see figure I) (Mcowen and others, 2017), where human activities are restricted, with about 7.5% included in the marine World Heritage sites of the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Fu and others, 2024a). Worthington and others (2024) estimated their global extent in 2020 to be 52,880 km^2, distributed across 120 countries and territories, with 45% in the temperate Northern Atlantic region. There have been recent reviews of their status (Armitage, 2021; Petillon and others, 2023; He and others, 2025).

Figure I

Global distribution of salt marsh ecosystems, including those in marine protected areas



Source: Data from https://doi.org/10.34892/07vk-ws51https://habitats.oceanplus.org/, compiled by Yuan Li.

Climate change

Climate change poses the most severe threat to salt marshes worldwide. Either marsh elevation must increase at a greater rate than sea level rise or marshes must move inland, which is possible only when there is open land behind them. In developed areas with roads and buildings, marshes cannot move inland and are subject to “coastal squeeze”, eventually being submerged. Nicholls and others (1999) estimated that 1 m of sea level rise would eliminate 46% of the world’s coastal wetlands.

Rates of sea level rise are exacerbated in regions with considerable subsidence (Ohenhen and others, 2024), increasing relative sea level rise and reducing marshes’ ability to elevate fast enough. Some marshes have inadequate sediment supply (Ensign and others, 2023) or limited potential for landward migration because of steep slopes (Thorne and others, 2018). Landward migration is further hindered by infrastructure, such as sea walls and groins.

It has been recently realized that historical farming practices cause problems, especially when associated with sea level rise. Straight lines of flood-tolerant *Spartina alterniflora* have appeared in the high marsh. These lines may criss-cross each other, forming a network, inside which are “waffle pools” in which water does not drain. Adamowicz and others (2020) realized that past agricultural practices of ditching and berms, combined with sea level rise, were responsible; tidal water now floods the high marsh plants, which die and are replaced with shallow pools that expand into “megapools”.

Development

Tidal wetlands have been filled for agriculture and urban development without regard for their ecological value. "Reclamation" involves dyke installation, blocking the entry of tidal water and allowing land to dry out and be developed. Stricter reclamation policies adopted in China in 2018 resulted in an increase in coastal salt marsh area of 18.7% between 2010 and 2019, and have begun to reverse a long-term net loss of 23.7% from 1985 to 2019 (Chen and others, 2022). These reductions were attributed to sea level rise, pollution, conversion to agriculture, aquaculture, salt pans and urban development (Gu and others, 2018; Chen and others, 2022; Fu and others, 2024a). Similar losses to development are seen in Europe and America.

Bioturbation

The purple marsh crab (*Sesarma reticulatum*) causes extensive marsh damage by herbivory and bioturbation, resulting in the loss of carbon stocks in marshes along the east coast of the United States of America (Wittyngham and others, 2024). *Sesarma* "fronts" reduce elevation, causing a transition from high to low marsh (Vu and others, 2017). Martinez-Soto and Johnson (2023) found that, in the northern part of the range into which fiddler crabs expanded, *Spartina* biomass was reduced when they were present. Studies in the native range also find negative effects: Smith and Green (2015) found that fiddler crab bioturbation caused sediment loss, as excavated sediments on the surface wash away with outgoing tides. Raposa and others (2018) found negative effects of burrows near creekbanks, where erosion increased.

Protecting and rehabilitating marshes

Efforts to protect and restore salt marshes are effective in reducing decline or even increasing areal extent. Billah and others (2022) reviewed publications issued between 1990 and 2021 on restoration techniques and success indicators in North America, Europe, China and Oceania. They found that the most common techniques are recovery of tidal exchange, managed realignment, creation of marshland with dredged material and control of invasive grasses. Indicators of success included structural diversity, ecosystem functions, physical condition and species composition. They stressed that soil and plant succession functions may recover in weeks to years, while carbon storage capacity may take up to a century to recover. Raposa and others (2024) investigated whether removing upland vegetation behind marshes facilitates marsh migration. One-time removal provided little benefit; they suggested that repeated removals might be required.

Applications of thin layers of sediment over marsh (Thorne and others, 2019) can improve plant health and recruitment. As canopy density grows, sediment trapping increases and might become self-maintaining. Adequate sediment supply is essential for sustaining habitats and may promote accumulation of mineral-associated carbon (Fu and others, 2024b; Li and others, 2023). In Poplar Island, Chesapeake Bay, United States, where sediments had been added, Staver and others (2024) used over 10 years of data and found that elevation change in the low marsh was double the high marsh rate and exceeded the natural reference marsh and relative sea level rise. The increase was due mostly to belowground biomass, which contributed more than surface sediment. By stimulating organic matter production and elevation change, the substrate apparently offset the low supply of sediment. Adding sediments to increase elevation is essential to long-term sustainability.

It is possible to create marshes where they previously did not exist. Stewart and others (2024) observed recession in about half of the marsh creation projects in British Columbia, Canada, representing 9.3% of the created marsh surveyed. They attributed losses to boat wake erosion and goose herbivory. Greater recession was found upriver, as was reduced dominance of native species. These remedies are much less effective than creating policies to prevent marshes being filled in for development.

Invasive species (see sect. 4, subchap. 6A)

The common reed, *Phragmites australis* (Saltonstall, 2002), arrived on the east coast of North America over a century ago and invaded many brackish and freshwater marshes. It has become a dominant species in North America, reducing plant diversity, altering patterns of water flow and causing sediment accumulation (Windham and Lathrop, 1999). It is also beneficial in sequestering contaminants (Zhang and others, 2023) and enabling marshes to increase their elevation. It is more likely to become established at low salinity and sites where rhizomes are buried in well-drained marsh areas (Bart and others, 2006). Millions of dollars are spent annually to remove it, but it inevitably returns.

Since its introduction to coastal China in the 1960s, *Spartina alterniflora* has thrived remarkably, covering a latitudinal span of about 21 degrees from 40°47′N to 19°46′N along the coastline. By 2020, it had expanded across 519.70 km^2 (Li and others, 2022), reducing biodiversity and posing threats to artisanal fisheries and tourism (Qi and Chmura, 2023). By 2023, China had initiated nearly 200 projects to manage *S. alterniflora*, utilizing such technologies as “mowing and flooding”, “mowing and ploughing” and “mowing and shading.”

Salt marshes may also be damaged by non-native animals. Hogs in the marshes of the south-eastern United States reduce soil carbon storage and alter community structure (Persico and others, 2017; Hensel and others, 2021; Fischman and others, 2024). In addition to disturbing cordgrass by severing roots, creating wallows and overturning grass and soil clumps, hogs consume mussels (Hensel and others, 2021). In Ireland, the cessation of cattle grazing was associated with an increase in salt marsh invertebrate biodiversity (Lynch, 2022).

Pollution (see sect. 4, subchap. 6E)

Marsh plants take up high concentrations of toxic metals from contaminated sediments. Metals of concern include mercury, cadmium, lead and copper, which can bioaccumulate and cause toxicity. Metals in marsh sediments are affected by the presence of different plant species. Their concentrations in bare sediments were lower than vegetated “rhizosediment” in the Swartkops Estuary, South Africa (Nel and others, 2022).

Oil can have long-term effects on salt marshes once it sinks down below the surface and cannot “weather”. Effects can persist decades after a spill (Culbertson and others, 2007).

Large amounts of debris accumulate in tidal wetlands and along other shorelines from both the water (such as fishing gear and abandoned boats) and the land (in the form of litter). In Brazilian marshes, Pinheiro and others (2021) found more litter in the high marsh, where the water rarely reaches, than in the middle and low marsh. Most items were plastic, from food packaging, fishery and shipping activities, and personal use. Plastics in coastal wetland sediments reach 156.7 items per kg, 200 times higher than in the water column (Ouyang and others, 2022). Variation depends on climatic and geographical zones, season, population density and waste management. Tidal wetlands contain very high concentrations of microplastics, with greater amounts in urbanized areas (Lloret and others, 2021).

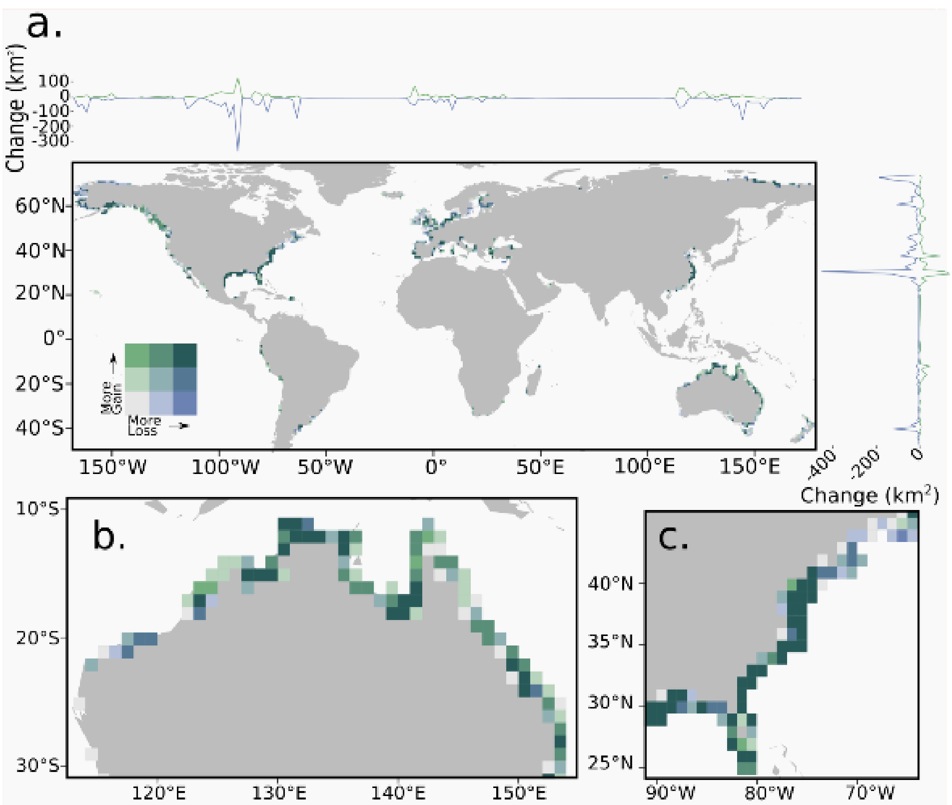
2. Environmental changes since the second *World Ocean Assessment*

Changes in overall status

Since the second *World Ocean Assessment*, marshes have continued to lose ground, though reported rates vary. In a study using satellite data conducted by the National Aeronautics and Space Administration, Campbell and others (2022) found overall global loss equivalent to two soccer (football) fields (14,280 m^2) per hour or 0.28% per year (see figure II). By contrast, a study of tidal wetlands (salt marshes, tidal flats and mangroves) found a net loss of only 4,000 km^2 over two decades (Murray and others, 2022). Coastal erosion and hurricanes accelerate marsh loss. Observed substantial reductions were primarily attributed to sea level rise, pollution, conversion to agriculture, aquaculture, salt pans and urban development (Gu and others, 2018; Chen and others, 2022).

Figure II

Map of global salt marsh loss and gain, 2000–2019



Source: Campbell and others (2022).

Note: (a) Global salt marsh loss and gain map between 2000 and 2019, visualized with a three-quantile bivariate colour ramp. Line plots of gain and loss (km^2) by longitude and latitude; (b) Salt marsh gain and loss in northern Australia; (c) Salt marsh gain and loss across the Atlantic coast and the Gulf of Mexico.

3. Region-specific changes

Arctic Ocean

Arctic salt marshes occur west of the Alaska Peninsula along the Bering Sea coastline and extend across the Alaskan coastal plain and the Arctic coastline of Canada. They are under pressure from climate change, coastal erosion, severe storms, changes in sea ice and increased industrial activities offshore, including oil drilling. From 2015 to 2019, there was 279.4 ± 35.9 km^2 and 5.6 ± 1.0 km^2 of salt marsh loss and gain in the Russian Federation, respectively (Campbell and others, 2022). Lack of knowledge and mapping prevents accurate quantification and leads to the underestimation of global soil organic carbon stocks, estimated at 1.44 Pg C in the top metre of tidal marsh soils globally. Ward (2020) found low carbon stocks in salt marshes in Norway, likely due to historical isostatic uplift and sediment accretion outpacing sea level rise.

Baltic Sea, North-East Atlantic Ocean, Mediterranean and Black Sea

Salt marsh loss is attributed mostly to reclamation. The area lost, primarily in the European region, between 2015 and 2019 was 103.2 ± 13.3 km^2, which was offset by 64.2 ± 11.3 km^2 of gain (Campbell and others, 2022).

South Atlantic Ocean and wider Caribbean

Salt marshes in South America are mostly located on the Atlantic coast, with over 95% of them in Argentina (Martinetto and others, 2023). These authors also found that these marshes store about 42.43 mg of organic carbon per·ha (40.74 below ground) and bury about 47.62 g of organic carbon per m^2 per year. In South Africa, approximately 43% of salt marsh was lost to development and agriculture between 1930 and 2018 (Adams, 2020). At their equatorial end, salt marshes are losing ground to mangroves (see sect. 4, subchap. 5H), which are moving north due to climate change (Santilan and others, 2013). Mangroves may provide increased storm protection and carbon storage (Doughty and others, 2016; Dontis and others, 2020) but may also cause a decline in habitat for some animals.

Indian Ocean, Arabian Sea, Bay of Bengal, Red Sea, Gulf of Aden and Persian Gulf, Strait of Malacca and South China Sea

Salt marsh extent in India is estimated at 290 km^2 (Viswanathan and others, 2020); salt marshes are classed as ecologically sensitive areas within the Coastal Regulation Zone, with some designated as Ramsar Sites. Although salt marshes are present in the Arabian Sea (Almahasheer, 2021), there are currently no area estimates for the region.

North Pacific Ocean

Chen and others (2022) found that salt marshes in China declined from 151,324 ha in 1985 to 115,397 ha in 2019, representing a drop of 23.7%. Over the past decade, Chinese socioeconomic reforms and stricter environmental regulations have significantly decreased the contributions of anthropogenic metals in salt marshes (Fu and others, 2023). Black carbon can contribute up to 20% of the total organic carbon in salt marsh soils and, on average, 80% of this black carbon is derived from fossil fuel combustion (Li and others, 2021).

South Pacific Ocean

Salt marshes in Oceania showed a net loss of 32.1 km^2 from 2015 to 2019, primarily due to reclamation for agriculture and urban development in Australia.

Southern Ocean

Salt marshes are not found in Antarctica.

4. Key remaining knowledge and capacity gaps and new gaps

Salt marshes are being lost worldwide due to sea level rise and continued development. There are ways to adapt to rising sea levels and preserve marshes through engineering practices (such as living shorelines and thin-layer deposition) and ways to restore or create new marshes, but legal and policy changes are needed to curtail development (Weis and others, 2021).

Roads or houses immediately upland of a marsh prevent migration and cause "coastal squeeze". Such houses are likely to be frequently flooded; some homeowners will therefore be willing to move. In such situations, marsh migration pathways could be created, opening space for the marsh. This can be facilitated by offering incentives for residents to move away, through easements, land acquisition, buyouts and other means, whereby people would receive compensation. Such agreements could be concluded with whole neighbourhoods; success will require efforts by planners and social workers, since people may be on low incomes, feel attached to their neighbourhoods, and want to stay despite the risks (Van Dolah and others, 2020).

As marsh edges erode, losses can be reduced by placing hard structures, such as oyster reefs or rocks, near the eroding edge, making a "living shoreline." Challenges include site-specific factors (marshes are not all the same), weather (Currin and others, 2017), performance standards (Sutton-Grier and others, 2015) and regional norms (Zhu and others, 2020; Morris and others, 2019). Living shorelines generally succeed if they can persist past their initial stages. Thin channels ("runnels") can be dug to connect pools to tidal creeks in order to drain them, provided that the creek has a lower elevation than the pool (Watson and others, 2022).

More work is needed to understand the effects of increased temperature on marsh structure and function (Duarte and others, 2021). While oil and chemical contaminants are decreasing due to environmental policies, plastic pollution continues unabated. If marshes are to continue to exist throughout this century, nations should take proactive steps to preserve and protect them. To reduce plastic waste, nations should ban single-use plastics, restrict plastic uses and ensure that the burden of disposal and recycling is borne by the plastic industry, not by Governments or individuals (Brander and others, 2024).

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