frontiers | Frontiers in Marine Science

TYPE Perspective
PUBLISHED 03 December 2025
DOI 10.3389/fmars.2025.1714372

OPEN ACCESS

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RECEIVED 27 September 2025
REVISED 31 October 2025
ACCEPTED 12 November 2025
PUBLISHED 03 December 2025

CITATION
Chmura GL (2025) Protected areas are not enough to protect blue carbon ecosystems and their services.
Front. Mar. Sci. 12:1714372.
doi: 10.3389/fmars.2025.1714372

Protected areas are not enough to protect blue carbon ecosystems and their services

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Carbon credits generally cannot be awarded for organic carbon stored in salt marshes (called “blue carbon”) that are already protected. To be approved projects must provide activities that are in addition to this protection, more than what is occurring through “business-as-usual”. This requirement is referred to as “additionality”. “Protection” usually is considered to constitute prevention of direct disturbance to a marsh. However, threats to marshes often occur outside the borders of the protected area and amelioration of such threats should be eligible for blue carbon crediting. This paper reviews the threats of coastal squeeze, excessive nitrogen loading, deprivation of allochthonous sediments, and waterfowl grazing. Although the impacts can result in loss of marsh area and erosion of their carbon-rich soil, these threats are the result of activities in the watershed outside the bounds of the protected area. Some examples of actions within watersheds that reduce or remove these threats are provided and should be fundable through carbon credits.

KEYWORDS

tidal marsh, watershed, waterfowl; nitrogen, sediments, carbon credits, coastal squeeze

1 Introduction

Salt marshes are recognized as valuable ecosystems that provide a wide range of ecosystem services, such as filters for pollutants (Hung and Chmura, 2006, Hung and Chmura, 2007), buffers to storm erosion (Barbier et al., 2011) and valuable habitat for fish and wildlife (e.g., Boesch and Turner, 1984; Shriver et al., 2004) as well as for endangered species (Drever et al., 2021). However, in consideration of our present climate crisis the most important may be their uptake of atmospheric carbon dioxide (CO_2). Thus, prevention of the loss of threatened marshes and marsh restoration serve as natural climate solutions (Griscom et al., 2017; Drever et al., 2021). The organic carbon, termed “blue carbon” (Nellemann et al., 2009), is found in organic matter fixed by plants as they take up CO_2 from the atmosphere during photosynthesis. Much of the organic carbon is transferred into soils through root growth (e.g., Ampuero-Reyes and Chmura, 2022) and through burial of plant litter. Along with inputs of mineral sediment deposited from tidal waters the soils of these ecosystems are accretionary, accumulating volume and elevation, processes that have enabled them to keep pace with sea level rise over the last few millennia (Rogers et al., 2019). Because it plays a critical role in maintaining marsh resilience and persistence blue carbon accumulation is essential for maintenance of other ecosystem services.

Blue carbon thus is clearly related to Target 3 of the Biodiversity Plan adopted by the Convention on Biological Diversity Conference of the Parties 15 (United Nations, 2022). The purpose of Target 3 is to "Ensure and enable that by 2030 at least 30 per cent of terrestrial, inland water, and of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem functions and services, are effectively conserved and managed through ecologically representative, well-connected and equitably governed systems of protected areas and other effective area-based conservation measures, recognizing indigenous and traditional territories where applicable, and integrated into wider landscapes, seascapes and the ocean, while ensuring that any sustainable use, where appropriate in such areas, is fully consistent with conservation outcomes, recognizing and respecting the rights of indigenous peoples and local communities, including over their traditional territories.

It is generally recognized that meeting the goal of Target 3 will be through the establishment of Protected Areas, yet in many instances effective conservation and protection of the carbon accumulation in soils of salt marshes require modifications of activities outside the bounds of conventionally established Marine Protected Areas (MPAs), primarily land-sea connections. The need to consider land-sea interconnections has been brought forward by others (e.g., Stoms et al., 2005; Álvarez-Romero et al., 2011; Wang et al., 2024), but not in the context of blue carbon sinks and the value of salt marshes as natural climate solutions contributing to the mitigation of the present climate crisis. This article provides examples of the activities that can occur beyond the bounds of the conservation measures provided by MPAs, how these activities outside the MPAs impact the ability of salt marshes to store carbon, and examples of management practices that can reduce the impacts of those activities outside the MPA. Suggestions are also provided regarding how financial carbon crediting could help fund management practices that serve to protect and conserve blue carbon stocks and accumulation.

2 Nitrogen loading from watersheds and coastal lands

2.1 Impacts

Sources of nutrients to coastal waters include runoff from agricultural and urban lands within a coastal watershed, as well as municipal wastewater treatment plants (e.g., Ayoub, 1999; Gerber and Menzi, 2006). Although the vegetation of salt marshes requires nutrients for growth, these sources can provide excess nitrogen that cause reduction of root growth critical to soil stability and accretion needed to maintain marsh resilience under the threat of increasing rates of sea-level rise (Crosby et al., 2021; Deegan et al., 2012; Wigand et al., 2014).

Even if the resilience of a salt marsh is not threatened by excess nitrogen in run-off from a watershed, a marsh's value as a blue carbon sink may be compromised. Excess nitrogen in coastal waters can increase the emissions of N_2O (nitrous oxide) from marsh soils, changing salt marshes from sinks to sources of this greenhouse gas (Roughan et al., 2018; Moseman-Valtierra et al., 2011). As N_2O is 273 times more potent as a greenhouse gas than CO_2 (Intergovernmental Panel on Climate Change, 2023) its emissions reduce the value the stored blue carbon has in mitigating climate warming.

2.1 Management

Swales are low areas or shallow channels that are unpaved and, when engineered and vegetated, sometimes called bioswales. Bioswales have been shown as effective means to trap nitrogen (Fardel et al., 2019). Installation of bioswales cannot only help reduce nitrogen inputs from urban lands to coastal waters but also can help to reduce the local flooding that accompanies high intensity rainfall events that are becoming more common with climate warming (Ekka et al., 2021; Lu et al., 2024; Lapointe et al., 2022).

In agricultural portions of a watershed, reduction of fertilizer applied would obviously reduce nutrient concentrations in run-off but fertilizer application is highly dependent upon a farmer's perceived needs to maintain production. One solution is to create and retain riparian vegetated buffer strips (RVBS) along waterways that pass through pastures and crop fields. RVBSs have been shown to reduce the movement of nitrogen into streams. The effectiveness is dependent upon the size and type of vegetation (Kumwimba et al., 2024; Wang et al., 2024). In Iowa researchers have shown that interspersing strips of perennial vegetation representative of native prairie resulted in significant reductions of nitrogen runoff (Schulte et al., 2017). Schulte et al. (2017) reported that this practice served to not only restore the endangered prairie ecosystem but provided a considerable number of other ecological services such as increases in abundance of pollinators, diversity of insects and birds as well as carbon sequestration.

3 Low or no sediment supply

3.1 Impacts

Although accumulation of locally produced organic matter (primarily roots and rhizomes) is important to marsh soil vertical accretion (Ampuero-Reyes and Chmura, 2022) deposition of inorganic sediments is required to enable most marshes to be resilient in the face of rapidly rising sea levels (Weston, 2014). In Europe from Medieval Times (Brown et al., 2018) and in many other regions from colonial times there has been a simultaneous increase in the sediment transport by global rivers through soil erosion, yet reservoirs have caused a reduction of sediments reaching the world's coasts (Syvitski et al., 2005; Walter and Merritts, 2008; Larsen and

Milligan, 2023). In some regions this has resulted in a noticeable deficit in marsh soil accretion and growth, increased marsh erosion and loss of marsh area along with the blue carbon held in those soils (e.g., Mariotti et al., 2024; Peteet et al., 2018; Vörösmarty et al., 2009). This impact is greatest in locations where rates of relative sea level rise are most rapid (Vörösmarty et al., 2009).

3.2 Management

Marsh accretion has been enhanced by deliberate application of sediments made available through dredging. The procedure, referred to as thin layer application or thin-layer sediment placement has been shown to stimulate biomass production, with continued increase in marsh accretion (Raposa et al., 2022; Davis et al., 2022). Such procedures can substantially increase marsh resilience in the face of decades of rising sea level but provide ecosystem services limited to those directly related to the marsh.

Removal of dams in the watershed will allow passage of sediments and provide a wider range of ecosystem services (e.g., Adams et al. 2023; Magilligan et al., 2026). By removing hydrological connectivity, dams have not only caused sediment retention upstream but had significant impacts on diadromous fishes which are prevented from reaching their spawning grounds (Waldman and Quinn, 2022; Hall et al., 2011). Recovery of fish runs has been demonstrated after removal of both small and large dams (Duda et al., 2021; Turner et al., 2018; Watson et al., 2018; Raabe and Hightower, 2014; Hogg et al., 2013).

4 Coastal squeeze

4.1 Impacts

Coastal squeeze results when steep topography, constructed barriers or the imperviousness of the land surface inland to a tidal wetland prevents marsh inland migration as tidal flooding extends inland of the marsh border with rising sea levels (Torio and Chmura, 2021). The accelerated rates of sea level rise accompanying anthropogenic climate change are likely to increase the frequency and duration of flooding beyond the tolerance of salt marsh vegetation, which is largely responsible for soil accumulation (e.g. Cahoon et al., 2006; FitzGerald et al., 2008). As a result, the seaward edge of many wetlands is likely to retreat. If marshes can migrate and expand inland, a portion of the seaward losses may be compensated for. However, suitable expansion areas might not be available due to steep slopes and the land surface might be impervious. These limit the resilience and permanence of salt marshes putting them in a coastal squeeze.

4.2 Management

Managing for coastal squeeze requires identification of barriers. Some, such as vertical seawalls or dikes are easily identified. If the land behind the barrier is undeveloped the removal of the barrier should allow inland migration as tidal waters flood the land. The severity of the threat of coastal squeeze can be compared amongst target sites by calculating the coastal squeeze index designed by Torio and Chmura (2013) to set priorities for and choice of salt marshes to include in a new MPA. In their analysis of coastal squeeze threats on the coasts of North America Torio and Chmura [2021] found that 40 existing MPAs contained tidal wetlands facing a high threat of coastal squeeze. The coastal squeeze index also can be used to compare the severity of the squeeze threat along the upland edges of the salt marsh in an existing MPA, informing management plans and revealing where it would be useful to obtain rights to the inland land to reduce the barriers.

5 Waterfowl feeding

5.1 Impacts

Overpopulation of waterfowl can result in serious degradation of salt marshes with catastrophic results by reducing vegetation growth thus reducing the potential for carbon storage. In extreme cases such as on the shore of Hudson Bay, the marsh could be lost. Jeffries et al (2006) have documented changes in marshes of Nunavut, Manitoba and Ontario on the west coasts of James and Hudson Bay and concluded that there has been a change in state of the coastal wetlands there. There, vegetation loss due to grazing by lesser snow geese (*Chen caerulescens caerulescens*) results in hypersaline soils as salt moves to surface soils from buried marine clays (Jeffries et al., 2006 and references therein). Jeffries et al. (2006) report that the change in soil properties is irreversible and revegetation requires deposition of new soil, thus recovery takes decades. If these barren marsh soils are then eroded, previously stored organic matter could be oxidized and a century's worth of stored carbon returned to the atmosphere as CO_2.

Lesser snow geese both nest and stage (feed) on the western shores of Hudson and James Bay. They had reached exceptionally high numbers that increased because of human activities as far south as Texas. Abraham et al. (2005) and Jeffries et al. (2003) discuss the changes in the Central Flyway which likely caused the population increase of lesser snow geese. From the 1930s to the 1970s a number of hunting refuges were established which not only reduced population losses to hunting but provided food resources in the refuges and nearby agricultural areas promoting further population increases. Changes in agricultural practices would also have stimulated growth of goose populations. In Texas and Louisiana, rice fields increased in size and the duration of their field flooding increased – attracting geese to agricultural sites where hunting was restricted. In the 1970s crop production increased elsewhere along the migration route of the geese as farmers adopted high yield corn varieties and increased their use of fertilizer. Spillage of corn and other crops provided more food resources for migrating geese. The increase in food resources were accompanied by a decline in hunting in the United States and Canada.

5.2 Management

Management to reduce the impact of excessive waterfowl populations would seem to present one of the greatest challenges of the examples provided here, as waterfowl migration routes can be on continental to inter-continental scales and international cooperation would be required. Allowing hunting in the agricultural fields and along the migration routes can help to reduce species' populations that are excessive. However, in many jurisdictions, this requires explicit permission of the landowners.

Since 1999 there has been an example of such international cooperation through implementation of more liberal hunting regulations in attempt to control goose populations [Abraham et al., 2005]. A spring hunting season was opened along the goose migration route from Arkansas north within the United States through to the Canadian provinces [Leafloor et al., 2012].

6 Discussion

In many cases, managing threats to salt marshes and their value as blue carbon sinks requires land-sea planning. Avlarez-Romero et al. (2011) discuss the need to consider land-based activities that affect sediment and nutrient discharges. Although their focus is in fishing grounds and coral reefs they provide a framework for integrated land-sea planning that can be applied to salt marshes. However, because of their focus they do not consider funding sources or planning directly applicable to blue carbon.

With appropriate measurements, inclusive setting of project boundaries (e.g., a watershed) and descriptions, carbon markets could help fund many of the management activities suggested here (Emmer et al., 2025). Sapkota and White (2020) provide a review describing carbon markets. Carbon trading can be performed through the voluntary or compliance market. The latter deals with the mandatory emission reductions imposed by regional jurisdictions such as the State of California or the European Union. Voluntary markets credit actions in reducing GHG (greenhouse gas) emissions. The major voluntary organizations that provide crediting programs relevant to salt marshes are Verra (formerly the Verified Carbon Standard; VCS), American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard, and Plan Vivo. One carbon credit is awarded for each reduction of 1 ton of CO_2e, (carbon dioxide equivalent) thus covers CO_2, CH_4 (methane), and N_2O. The latter two have greater global warming potentials (i.e., are more potent as greenhouse gases) than CO_2. (The CO_2e of CH_4 and N_2O are calculated based upon their global warming potentials.) Carbon credits can also be awarded for restoration or increase in carbon storage of a salt marsh, as well as conservation of a threatened marsh.

Carbon credits cannot be awarded for activities within existing MPAs that protect the salt marshes within their boundaries because an activity must constitute an *additional* effort that would reduce emissions above the business as usual (baseline) condition. However, activities that threaten the marsh value as a blue carbon sink should meet this requirement of additionality if the activities are outside the borders of an MPA or outside any marsh protected from direct disturbance. Once deemed eligible for carbon credits, funding could be available for many of the management actions suggested previously, if evidence is provided regarding the quantity of GHG emissions that could be reduced or additional carbon that would be stored.

Indeed, effective actions to reduce nitrogen loading, restore sediment supplies and address coastal squeeze must occur outside the bounds of a protected marsh. In the case of coastal squeeze for instance, carbon credits could be applied to the cost of removal of barriers and purchase of lands inland to the marsh that are outside of the boundaries of an existing MPA. Where there is a potential to remove dams blocking sediment transport downstream, actors involved should explore the potential for obtaining carbon credits to reduce the costs. Funds available from carbon crediting programs may not be adequate to entirely cover the purchase of highly priced coastal properties or removal of large dams but could be combined with other funding programs. Although carbon credits may not compensate entirely for the cost of installation of urban bioswales they can reduce the financial burden faced by municipalities which will also benefit from flood control programs.

Implementation and maintenance of riparian buffer strips, prairie strips and urban bioswales can reduce nitrogen in receiving waters which would reduce marsh N_2O emissions and increase root growth, thus marsh resilience. As profits from agriculture can be marginal, financing through carbon credits could help alleviate reductions in income due to agricultural production lost from the area dedicated to a prairie strip. Further, carbon credits could be substantial enough to make a difference in impact of agricultural activities in upstream watersheds as agricultural runoff is likely to affect more than one marsh. For instance, on Prince Edward Island, Canada Implementation of Best Management Practices that include changes such as shifting tillage from fall to spring can make a difference in nitrogen run-off from agricultural fields (McFatridge et al., 2022), likely reducing N_2O emissions from marshes downstream (e.g., Roughan et al., 2018). Greater funding could be available if reduction of fertilizer runoff is combined with agricultural land management (ALM) programs. The VERRA provides a methodology for obtaining carbon credits for ALM under the program VM0042 Improved Agricultural Land Management, v2.1 (https://verra.org/methodologies/vm0042-improved-agricultural-land-management-v2-1/).

7 Conclusions

Carbon crediting systems could help to fund marsh conservation once land-sea interactions are considered. Research on marsh stability and root growth comparing highly impacted watersheds to those in relatively natural conditions will likely be needed to support quantification of carbon credits.

Author contributions

GC: Conceptualization, Writing – review & editing, Writing – original draft.

Funding

The author(s) declare financial support was received for the research and/or publication of this article. This research was supported, in part, through awards from the Commission on Environmental Cooperation and the Natural Sciences and Engineering Research Council of Canada Grant No. 06501-2018.

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