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REVIEW

Tidal Forested Wetlands Can Be Incorporated into Blue Carbon Conservation and Restoration Strategies

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Abstract

Purpose of Review Blue carbon is an important concept for environmental policy. Blue carbon strategies (conservation and restoration for carbon gain) have been primarily implemented with mangroves, though are likely to be suitable for other tidal forested wetlands. Here, we discuss the expanding definition of blue carbon encompassing all tidal forested wetlands, synthesize ecological and carbon sink knowledge of tidal forested wetlands, and reflect on key actions in mangrove blue carbon research and implementation that could be applied to other tidal forested wetlands.

Recent Findings Conceptually, the blue carbon concept has now expanded beyond traditional coastal vegetated ecosystems to include all tidal wetlands, including tidal forested wetlands. Emerging data on carbon sequestration, emissions, and budgets from around the world now show that many tidal forested wetland ecosystems are carbon sinks at a magnitude similar to mangroves. At the global scale, mangroves have become incorporated into blue carbon strategies rapidly compared to other tidal forested wetlands, facilitated by agenda-setting papers, adequate data addressing concerns on emissions and permanence, the availability of global maps, a clear ecosystem definition, clear accounting and policy frameworks, and international stakeholders who acted as high profile ecosystem advocates, alongside long-term capacity building efforts. This provides a roadmap for implementation in other tidal forested wetlands.

Summary Tidal forested wetlands other than mangroves have high potential for blue carbon management. Many tidal forested wetlands share biophysical similarities with mangroves, carbon stocks can be similar, and methane emissions are often no higher. An increasing evidence base, challenging assumptions around greenhouse gas fluxes, and robust engagement with policy actors and frameworks, could increase the use of blue carbon for tidal forested wetland conservation and restoration.

Keywords Climate change mitigation · Tidal freshwater forested wetlands · Mangroves · Supratidal forests · Tropical peatlands

Introduction

Natural climate solutions are an important pathway for climate change mitigation [1] and for countries and companies to meet their net-zero emission ambitions. Vegetated coastal ecosystems such as mangroves, seagrasses and tidal marshes, known as blue carbon ecosystems [2], have received particular attention for their capacity to deliver measurable carbon benefits, storing carbon at densities often surpassing other ecosystem types [3] and showing large potential for carbon additionality through habitat conservation [4] and restoration [5]. As such, blue carbon is being incorporated into a range of national and international policy mechanisms [6], alongside commercial carbon credit pathways [7].

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Mangrove forests are the most actioned blue carbon ecosystem, both in terms of incorporation into national climate change mitigation policies, and commercial carbon credit projects; 69 out of 70 registered carbon credit projects involve mangrove forests [7]. However, the definition of blue carbon has recently expanded to incorporate a broader range of tidally influenced forested wetland ecosystems other than mangroves [8], which are also expected to provide substantive blue carbon benefits. Examples of tidal forested wetland ecosystems other than mangroves include supratidal forests, *Barringtonia*-dominated forests, tidal freshwater forests, brackish tidal forested wetlands, and tidally influenced tropical peatlands (refer to Kelleway et al. [9] for in-depth descriptions of major tidal forested wetland types). These other tidal forested wetlands have high potential for carbon sequestration and long-term storage [10, 11], but are underutilized in national and voluntary carbon accounting frameworks. Conservation opportunities may be missed for tidal forested wetlands other than mangroves because they fall outside of existing blue carbon policy frameworks. Furthermore, tidal forested wetlands are generally located landward of traditional blue carbon ecosystems at the interface with human encroachment. As such, they have experienced substantial historical human impact and land use change [12, 13], and may show high potential for restoration in many locations [14].

Here, we discuss the potential role of an expanded definition of blue carbon that incorporates tidal forested wetlands other than mangroves as a natural climate solution, by highlighting their biophysical similarities, how aspects of their carbon budgets compare with mangroves, and identifying what conceptual, management and policy lessons can be learned from the mangrove management experience that can be applied to other tidal forested wetlands. We aim for this Perspective to start more conversations about how tidal forested wetlands other than mangroves could be considered under formalized blue carbon strategies (such as National Greenhouse Gas Inventories and commercial carbon credit frameworks). Better representation of all tidal forested wetlands in blue carbon management can increase the feasibility of their management for carbon purposes in the future.

Broadening Definitions of Blue Carbon to Include Other Tidal Forested Wetlands

The definition of a species is critical to defining conservation outcomes, for example, to measuring the decline in biodiversity loss. Similarly, the definition of an ecosystem determines whether it falls within or outside the boundaries of a national or international policy. The definition of blue carbon originally encompassed the carbon sequestered by the oceans, in contrast to "green carbon" sequestered by terrestrial ecosystems [15]. The concept was further clarified, recognising that blue carbon is now more of a policy term to preserve or restore coastal ecosystems for climate change mitigation, rather than a biophysical or geochemical definition [16]. Generally, blue carbon has been narrowly considered to refer to mangroves, tidal marshes and seagrasses [17]. However, new definitions of blue carbon are emerging [8], clarifying the boundaries of blue carbon as being primarily related to tidal influence. Accordingly, blue carbon ecosystems are *"ecosystems influenced by marine waters that fix carbon dioxide and that store and accumulate it as organic carbon. They are bounded by the highest levels of tidal inundation at the terrestrial edge and by the limits of the photic zone in the marine edge."* [8].

Within this definition, all forests with tidal influence have physicochemical and biological characteristics that may contribute to climate change mitigation. This classification can be embedded into international wetland classifications such as the Ramsar Wetlands Convention [18]. Within the Ramsar definition, blue carbon ecosystems fall within the Marine/Coastal wetland group, within the following subgroups: B: Marine subtidal (aquatic beds, including kelp beds, seagrass beds, and tropical marine meadows); G: Intertidal marshes (salt marshes, salt meadows, saltings, raised salt marshes, includes tidal brackish and freshwater marshes); and H: Intertidal forested wetlands (mangrove swamps, *Nypa* swamps, and tidal freshwater swamp forests) [18]. Many tidal forested wetlands, including mangroves, fit within subgroup H. However, some tidal forests (particularly brackish tidal forested wetlands such as those in the US Pacific Northwest and peatlands in Indonesia) are considered "transitional forests" [19], "forests associated with mangroves" [20] or "supratidal forests" [21]. Thus, existing classifications could unintentionally exclude some tidal forested wetlands from being considered in national key initiatives, such as Wetland Inventories or the Nationally Determined Contributions within the Paris Agreement. Thus, inclusive definitions with clear boundaries can aid the scientific community, as well as with decision makers.

Key differences between mangroves and other tidal forested wetlands

Mangroves and other tidal forested wetlands are not often compared and are often studied by different research groups. While all tidal forested wetlands share similarities, perceived differences have prevailed, particularly related to the production of methane [8]. Mangrove forests are now considered a well studied ecosystem [22], though many other tidal forested wetlands, and especially supratidal forests, escaped attention until the mid-1980s, with research

remaining sparse through the next two decades [23]. Lugo et al. [24] provided the first attempt to compare freshwater forested wetlands (albeit non-tidal) with mangrove forests, contributing significantly to our contemporary understanding of how these communities compare. Although comprehensive biophysical data are not yet available for many types of tidal forested wetlands, decades of research on freshwater tidal forested wetlands of the southeast United States allow broad comparison between this ecosystem and mangroves. Mangroves in general have higher salinity tolerance than tidal forested wetlands, greater nutrient use efficiency, faster litter decomposition, reduced toxicity to the build-up of porewater hydrogen sulphide, thicker leaves that promote nutrient retention (sclerophylly), and better regeneration capacity on inundated soils (Table 1) [24].

Biophysically, a key difference between mangroves and other tidal forested wetlands, particularly those in freshwater environments, is their location in the tidal frame. Mangroves generally exist between mean sea level and the upper part of the tidal range, with different niches for different species [25] depending on species-specific tolerances to inundation, with some species showing adaptive plasticity within this range [26]. In contrast, many other tidal forested wetlands are found further landward at higher elevations, and supratidal forests extend upslope farther than mangroves [27]. Permanent flooding is a characteristic of many freshwater tidal forested wetlands (such as those in the southeast United States) and leads to only slight stress in these systems, but can kill mangroves [28].

Biologically and ecologically, other tidal forested wetlands often show marked physiological and structural differences from mangroves. Most of these factors are related to energy and water use. Many tidal forested wetlands show moderate to high shade tolerance compared to mangroves [29], leading to a relative lack of understory in mangroves compared to other forest types. Water usage by many tidal forested wetlands is salinity dependent [30], though mangroves use low amounts of water at the stand level as a tree-scale stress response mechanism. Many tidal forested wetlands are found across climatic zones, while mangroves are intolerant to cold weather, which limits their latitudinal range.

Table 1 Relative differences between some freshwater tidal forested wetlands and mangroves. Sources: [24]; authors' knowledge

Characteristic	Tidal Forested Wetlands (e.g., southeast United States)	Mangroves
Biophysical Characteristics		
Intertidal location	Upper to supratidal	Mean Sea Level to upper
Species presence related to tides	No	Yes
Sensitivity to permanent flooding	Low (species-specific)	High (mortality common)
Salinity	< 2 to 3 ppt (non-halophytes)	0 to > 70 ppt (facultative halophytes)
Sensitivity to hydrogen suphide^{-} toxicity	More sensitive	Less sensitive
Carbon Cycle Characteristics		
Basal area along elevation gradient	Decrease	Increase, stable
Aboveground carbon stock	Moderate-to-high	Low-to-high
Soil carbon storage	High	High
Litter decomposition	Slightly lower	Higher
Primary respiratory pathway	$CO_2 + 8\ H^+ \rightarrow CH_4 + 2H_2O$	$4H_2 + SO_4^{2-} \rightarrow H_2S + 2H_2O + 2OH^-$
Methanotrophy	High (tidal), low (ephemerally tidal)	Low
Biological and Ecological Characteristics		
Nutrient use efficiency	Lower	Higher
Nutrient conservation mechanism	Low retranslocation, recycling	High retranslocation, recycling
Leaf structure, specific leaf weight	Lower	High, sclerophylly
Tree spp. diversity along elevation gradient	Decrease	Increase, stable
Vivipary	No	Yes (many species)
Regeneration requirement	Exposed soils	Exposed soils to < 0.5 m deep
Shade tolerance	Moderate-to-high	Low (intolerant); except Pelliciera
Cold tolerance	High	Low (limited to > −6.6° C)
Stand transpiration	Moderate-to-high	Low
Human Characteristics		
Ecosystem service knowledge	Piecemeal, local	Well conceptualized
Key habitat loss drivers	Development, agriculture	Development, agriculture, aquaculture
Policy integration	Low	Increasing

Differences in Methanogenesis between Mangroves and Other Tidal Forested Wetlands

A key assumed difference between mangroves, and more brackish or freshwater tidal forested wetlands, is the degree of methanogenesis, with implications for whether these ecosystems can be considered net sources or net sinks of carbon. It is generally assumed that salinity acts as a control on methanogenesis [31], so saline tidal forested wetlands such as mangroves will generate lower methane emissions, and therefore have a more negative radiative forcing and Sustained Global Warming Potential than brackish or freshwater tidal forested wetlands [32]. However, recent data compilations (Fig. 1) show that a salinity threshold is not clearly observed within tidal forested wetlands.

Other processes may therefore be influencing methane dynamics in tidal forested wetlands, compared to non-tidal freshwater systems. Frequent transition between oxic and anaerobic surface soils with tidal action facilitate the proliferation of a prominent methanotrophic bacterial community. Methane is produced in the anaerobic soil layers but oxidized back to CO_2 before release; 51–82% of CH_4 undergoes oxidation as it transits soils toward the atmosphere [33]. Thus, in tidal forested wetlands, the production of methane from soils can often be low, even in oligohaline to freshwater conditions [34, 35], and does not differ from emissions of mangroves (Fig. 1).

Soil methane dynamics may be more complex in tidal tropical forested peatlands, as these communities are sometimes influenced by tides only during equinoctial events, emulating a supratidal condition, or through tidally influenced groundwater flux during times of drought [36]. Major flood pulses along rivers can also infrequently extend surface tidal floods to wetland forests occurring far inland of mangroves, occasionally exposing surface and sub-surface soils to salinity and sulphates from marine water [37]. Methane emissions are likely to be high in some settings [38], with drainage reducing methane emissions through microbially mediated oxidation both in-situ and within drainage canals [39]. In cases where tidally influenced tropical forested peatlands are periodically exposed to salinity, soil CH_4 emissions may decline as peat soils experience a rapid increase in sulfate reduction, as observed in temperate freshwater marsh soils [40].

While soil methane emissions are now well understood, we have greater uncertainty in vegetation emissions. Herbaceous plants are strong conduits of methane emissions [46], and are common in some tidal forested wetlands such as tropical forested peatlands [47]. Such emissions are considered rare in mangroves, though, mangrove tree stems are likely to be an underrecognised pathway for methane emissions [48].

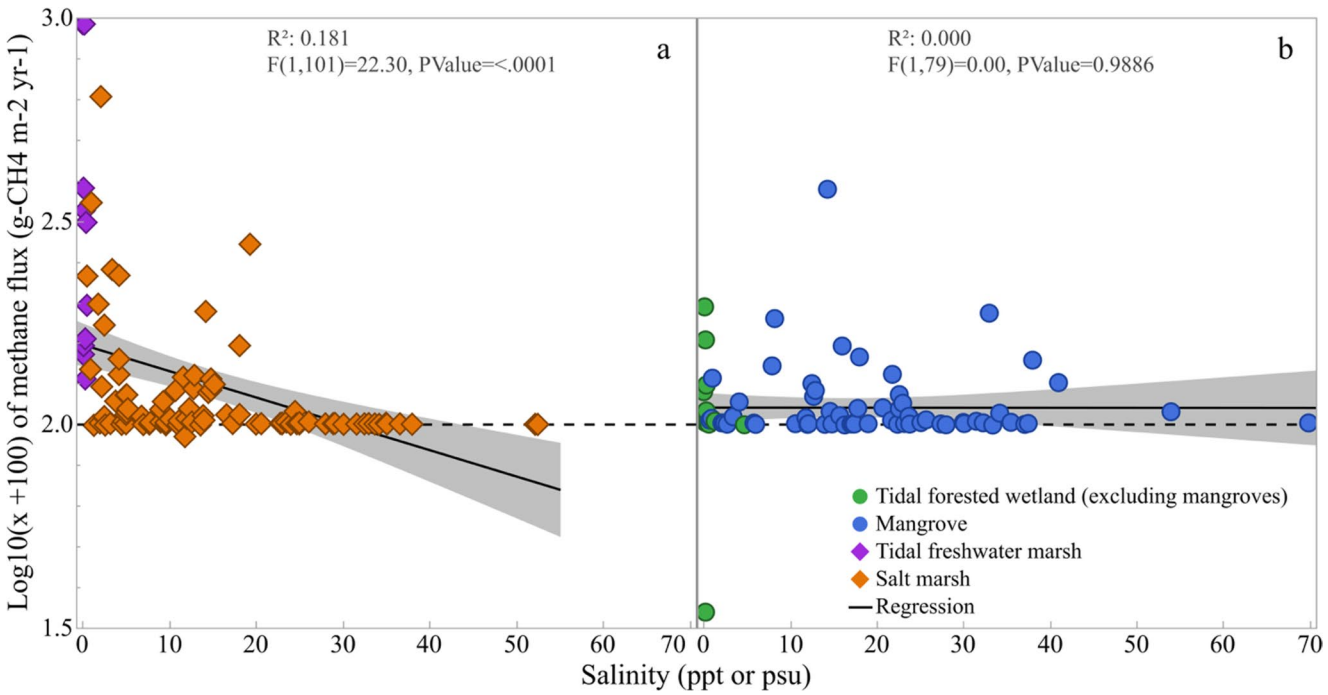

Fig. 1 In this data compilation, soil to air methane fluxes in tidal freshwater marshes (purple) tend to be greater than in saline salt marshes (orange) (**a**), though soil methane fluxes from tidal forested wetlands (green) are generally similar to the fluxes of mangroves (blue), showing no clear change with salinity in both tidal forest types (**b**). Data are Log10-transformed site means of soil-to-air fluxes and salinity of natural tidal wetlands from published studies identified from a literature search and from reviews by Poffenbarger et al. [41], Rosentreter et al. [42], and Arias-Ortiz et al. [43], summarized by Noe et al. [44] and new data from authors [45]. Solid line and gray band are the regression with 95% confidence limit. Dotted line represents un-transformed flux of zero

Example Carbon Budgets of Tidal Forested Wetlands

Tidal forested wetlands accumulate, preserve, and convey large quantities of carbon in biomass and soils. Regional carbon stock assessments have been developed in recent years for tidal freshwater forested wetlands of southeast United States, tidal swamps of northwest United States, and tropical and temperate Australian supratidal forests (Table 2; Fig. 2) [10, 11, 21, 49, 50]. These assessments demonstrate the carbon-rich nature of tidal forested wetlands, yet al.so point to continental-scale variations attributable to differences in landscape position (intertidal vs. supratidal elevations), vegetation composition and structure, and other

Table 2 Carbon pools and accumulation rates (mean ± 1SD unless otherwise stated) across mangrove and selected other tidal forested wetland ecosystems

Pool/Flux	Units	Mangroves (global)	Tidally influenced tropical forested peatlands (global)	Tidal freshwater forested wetlands - southeast United States	Tidal forest - northwest United States	Supratidal forest - Australia
Aboveground carbon	Mg C ha^{-1}	114.9 ± 7.2 (SE) [54]	98 ± 13 (SE) [53]	140 ± 33 [10]	220 ± 45(SE) [11]	130 ± 119 [21, 49]
Belowground carbon	Mg C ha^{-1}	334 ± 11(SE), 1 m depth [54]	1889 ± 277, variable depth 1–9.3 m (SE) [53]	346 ± 257, 1 m depth [10]	355 ± 230, 1 m depth [50]	193 ± 98, 1 m depth [21]
Ecosystem carbon stocks	Mg C ha^{-1}	856 ± 32(SE) [54]	1983 ± 224 (SE) [53]	604 ± 286 [10]	1064 ± 38(SE) [11]	364 ± 170 [21]
Soil carbon accumulation rate	Mg C ha^{-1} yr^{-1}	2.3 ± 2.8 [55]	-	2.16 ± 0.84 [10]	-	0.62 ± 0.05 [56]

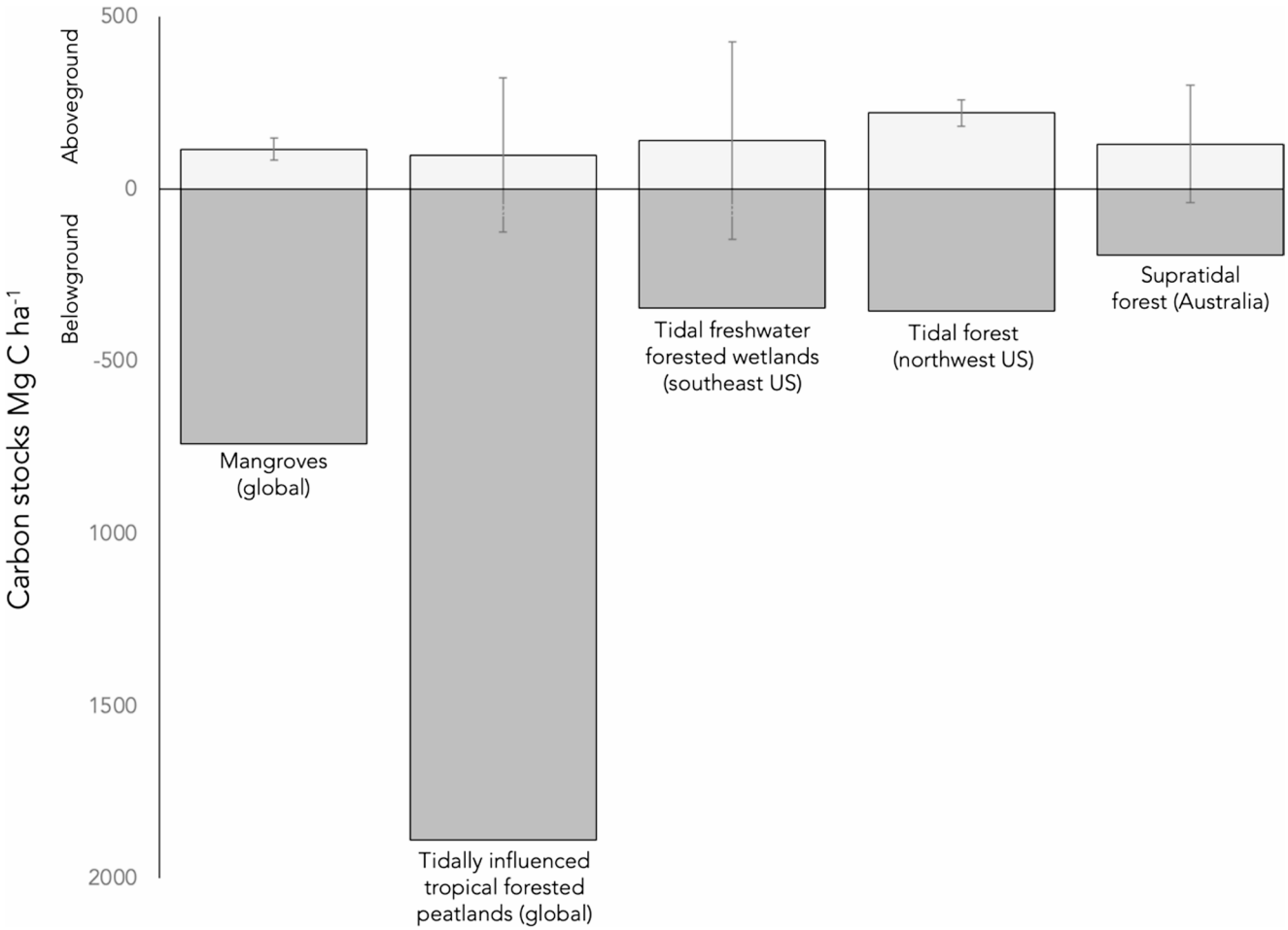

Fig. 2 Comparison of average aboveground and belowground ecosystem carbon stocks per hectare for selected tidal forested wetland types. Refer to Table 2 for data sources

drivers. While global-scale compilations and analyses of carbon drivers are well established for mangroves, similar efforts for tidal forested wetlands are constrained by data paucity and associated uncertainty both within and beyond the settings summarised here.

Nevertheless, comparisons at regional and local scales demonstrate similar storage capacities among tidal forested wetlands and mangrove forests. For example, Janousek et al. [50] report similar soil carbon storage among mangroves (357 ± 230 Mg C ha^{-1}) and tidal swamps (355 ± 230 Mg C ha^{-1}) along the Pacific coast, comparable to the most carbon-rich terrestrial ecosystems in North America. A global synthesis of tidal forested wetland soil carbon storage showed that these systems can store a median of 341.6 ± 98.4 Mg C ha^{-1} [51], which also compares well to mangroves. Similarly, comparisons between Australian supratidal forests and adjacent mangrove forests suggest similar aboveground and belowground carbon stocks at the site scale [21, 52]. Tidally influenced tropical forested peatlands likely store the largest amounts of carbon, averaging 1979 Mg C ha^{-1}, and as high as 5591 Mg C ha^{-1}) [53]. Overall, the potential for tidally influenced tropical forested peatlands to serve as valuable sources of carbon storage rivals that of any previously defined blue carbon ecosystem.

Full ecosystem carbon budgets are now well established at local through to global scales for mangroves. In contrast, full budgets are non-existent for most non-mangrove tidal forested wetlands, with the exception of tidal freshwater forested wetlands of the Waccamaw and Savannah Rivers of the southeast United States [10]. This represents a significant knowledge and data gap that could be met with the broader measurement of carbon and greenhouse gas fluxes across the diversity of tidal forested wetland types. These new insights and data compilations can consolidate the blue carbon status of these tidal forested wetlands and support carbon accounting and trading mechanisms.

Blue Carbon Additionality and Implementation

Scope for Carbon Abatement

Natural climate solutions must show a net carbon benefit that is additional compared to the business-as-usual baseline [1]. Blue carbon can be used for climate change mitigation through (a) conservation that reduces or eliminates habitat loss (avoided deforestation or other drivers of loss); (b) restoration of previously lost or degraded ecosystems; or (c) other management actions resulting in net carbon benefit. With available mapping tools, it is possible to estimate the potential for carbon abatement in mangroves. Mangroves have long experienced anthropogenic stressors, with concomitant impacts on carbon stocks [57]. At least 1.1 million ha of mangrove forest could be conserved instead of deforested, abating 29.8 $MtCO_2e\ yr^{-1}$ [4]. Similar estimates have been made for mangrove restoration, with aquaculture pond restoration in Southeast Asia alone potentially able to remove 84 $MtCO_2e$ over 40 years [58].

A general lack of national, regional and global mapping products for many tidal forested wetlands around the world often hinders similar large-scale estimations of carbon abatement potential. However, management actions for tidal forested wetlands have demonstrable carbon benefits. Many tidal forested wetlands around the world have experienced substantial losses [59, 60]. Restoration is feasible for many tidal forested wetlands [13, 61], and restoration guidelines exist [62], though the carbon benefits of such actions are rarely measured in systems such as tidally influenced tropical forested peatlands [63].

Current Blue Carbon Implementation in Tidal Forested Wetlands

While conservation, restoration, and management are common in tidal forested wetlands, outside of mangroves they are rarely undertaken with a verifiable blue carbon objective in mind. This is surprising considering that carbon verification methodologies exist for tidal forested wetlands, albeit with limited information available to provide default values for carbon accounting [64]. A methodology specific to tidal forested wetlands in the Mississippi Delta was approved under the American Carbon Registry in 2012, and a project was initially registered. However, the project was ultimately withdrawn due to uncertainties in greenhouse gas emissions, permanence risks, as well as monitoring and verification costs [65]. At least two other projects within the Lower Mississippi watershed are registered under the American Carbon Registry (projects ACR848 and ACR855), though it is assumed they do not relate to tidal systems.

In Australia, supratidal forests have been incorporated into the country's first blue carbon crediting scheme [56]. The Blue Heart Sunshine Coast carbon project includes 19 ha of paperbark supratidal forest, along with 20 ha of mangroves, and will soon deliver carbon credits to the Australian Market [66]. This project removed tidal gates previously used to drain the land for sugarcane plantations, allowing tidal water back into the site for the reestablishment of tidal forested wetlands.

Tropical forested peatlands have experienced much attention for carbon credit projects. While it is unclear how many projects have been applied to tidally influenced

systems, at least some seem to be. For example, project documents for the recently proposed Kubu Peatland Project in Indonesia describe the system being tidally influenced, with other coastal ecosystems in close proximity. This project is expected to result in emissions reduction of 597,165 tCO_2e yr^{-1} across 20,155 ha through the reduction of anthropogenic threats such as forest fires [67].

Key Steps Required to Establish Other Tidal Forested Wetlands as Actionable Blue Carbon Ecosystems

The implementation of blue carbon strategies has so far focused on mangroves, without strong incorporation of other tidal forested wetlands. Tidal forested wetlands other than mangroves are rarely discussed in national-scale accounting, e.g., for Nationally Determined Contributions to the Paris Agreement, nor are they the focus of commercial blue carbon credit projects. The conservation and restoration of mangrove forests accounts for almost all registered blue carbon credit projects [7], with only a small number of registered projects in other tidal forested wetlands in the last ~ 10 years. The successful implementation of carbon projects and policies in mangroves provides a blueprint to increase implementation in other tidal forested wetlands (Fig. 3).

1. Papers that raise the profile of tidal forested wetlands as blue carbon ecosystems

Mangroves received early academic and policy attention in part because of key papers that synthesised available data, highlighting their climate change mitigation potential to international, non-academic audiences. A seminal paper in *Nature Geoscience* [3] took mangrove carbon stock data from limited sites in South Asia and the Pacific and compared them to average carbon stocks from three other terrestrial ecosystems. It showed that these mangrove sites contained, on average, three to five times more carbon per unit area than other terrestrial ecosystems. Other foundational papers estimated emissions from mangrove deforestation, providing stakeholders with early numbers on potential carbon additionality [68]. Similar documents synthesising carbon data for other tidal forested wetlands are now emerging [8] and may spur further academic research on carbon dynamics in these ecosystems, attracting the interest of decision-makers.

2. Mapping ecosystem distribution and additionality

Global maps of mangrove distribution have existed for 15 years [69], and several groups have produced freely accessible data products since. These mapping products provide the foundation for numerous mangrove blue carbon models, including above-ground biomass [70], soil carbon [71], and carbon sources [72], amongst others. In contrast, the global extent of tidal forested wetlands is poorly constrained. While global wetland databases exist [73], they focus on fully inland or fully marine/coastal wetland types, and tidal

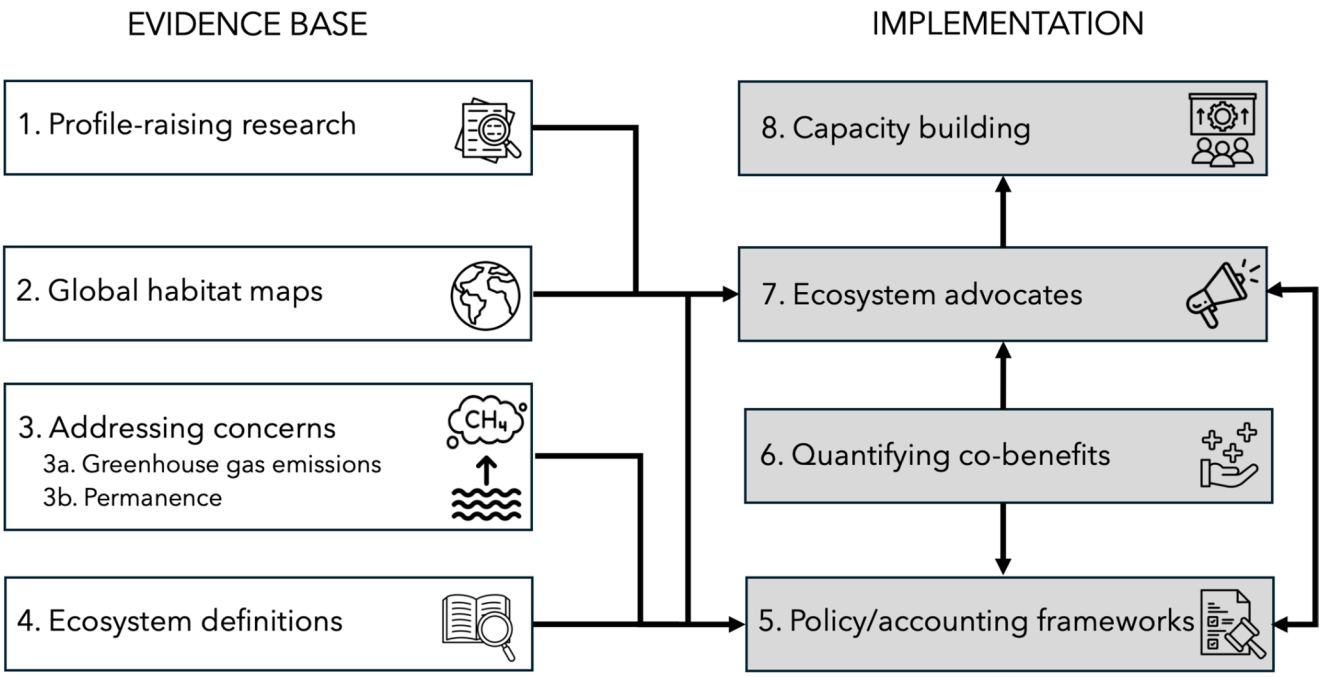

Fig. 3 Key steps that improved the evidence base and implementation of blue carbon management strategies in mangroves, which could be applied to other tidal forested wetlands

forested wetlands that exist between inland and marine realms are poorly defined. As such, many countries may not have a clear consensus on their extent of tidal forested wetlands and associated carbon resources.

Once a global mangrove map was available, researchers created time series to show changes in area over time, and platforms now provide near-real time deforestation alerts [74]. Data on temporal mangrove habitat dynamics led to the estimation of carbon accumulation over time [75], and carbon stocks and emissions from land use change and climate change in the future [76, 77]. We can now estimate the regional and global potential for mangrove carbon additionality through avoided deforestation [4] and restoration [58]. While global maps of many tidal forested wetland ecosystems do not yet exist, data on habitat dynamics are increasing for some tidal forested wetlands in specific locations, such as supratidal forest extent in Australia [78], individual tree loss across tidal coastal forests along the US Atlantic coast [79], and habitat conversion to agriculture along the US Pacific coast [13, 59, 80]. Remote sensing can go beyond mapping habitat loss to modelling stressors such as tidal restrictions [81], which may help identify areas where tidal forested wetlands could be restored [59].

3a. Addressing greenhouse gas emissions concerns

Carbon accounting guidance [31] assumes that saline tidal forested wetlands (> 18 ppt) such as mangroves do not produce appreciable greenhouse gas emissions, due to microbial competition and inhibition of methanogenesis in the presence of sulphates, while tidal forested wetlands with salinities < 18 ppt would produce emissions. This threshold is based primarily on studies from tidal marshes, and does not represent all tidal forested wetlands, where the salinity-methane relationship is unclear (Fig. 1).

Some tidal forested wetlands will produce high methane emissions, reducing their carbon abatement potential and impacting the financial viability of carbon credit projects in the past [65]. However, the salinity threshold will vary between ecosystems and settings. For example, *Melaleuca*-dominated tidal forested wetlands in Australia generally have salinities below the 18 ppt threshold, and yet have low or negative methane emissions, so could support carbon abatement [82]. Studies [35] have shown that on an annual basis, methane fluxes from northwestern United States tidal forested wetlands remained low down to 2 ppt – far lower than the 18 ppt threshold. Thus, there will be settings where methane will not be a major issue for tidal forested wetland carbon projects, and a blanket assumption that all lower salinity systems emit methane could lead to missed opportunities for blue carbon management. More studies assessing the influence of salinity on methane emissions can help to establish which tidal forested wetlands can be effective carbon sinks and identify management strategies that can maintain their net carbon benefit.

3b. Addressing permanence concerns

Blue carbon mechanisms have faced criticism due to the vulnerability and non-permanence of coastal vegetated ecosystems and their carbon to anthropogenic and environmental stressors. The impacts of climate change on mangroves, related to sea-level rise, increased storminess, changes in precipitation, and changing climatic oscillations such as ENSO are geographically variable, and have myriad impacts on mangrove blue carbon [83]. Such knowledge is well advanced in mangroves, to the extent that we have regional spatially explicit models of permanence risks to mangrove blue carbon projects due to anthropogenic land use and climate change threats [84], and carbon credit verification methodologies have mechanisms to calculate risk of non-permanence that are specific to blue carbon [85].

Some tidal forested wetlands may face similar land use and climate change stressors as mangroves, though one stressor unique to them is salinization. Wetland salinization occurs for reasons related to human water management, storms or sea-level rise, all changing local physiochemical conditions beyond species-specific tolerances [86]. Salinization can kill non-salt tolerant tidal forested wetland vegetation and impact carbon stocks [87] and biodiversity, although carbon accumulation rates can increase under some circumstances [10]. A better understanding of the full range of human, natural, and climate change-induced permanence threats for tidal forested wetlands, and mapped locations where carbon stocks are most vulnerable, can inform decision making.

4. Clear ecosystem definitions

The role of mangroves in blue carbon is straightforward to communicate to stakeholders because the ecosystem has a clear definition. However, the concept and spatial boundaries of some other tidal forested wetlands are less distinctly defined. For example, tidal forested wetland flora in the eastern United States. overlaps with upstream nontidal floodplain forests along the same river corridor, resulting in a nuanced boundary. Species such as *Barringtonia racemosa* can be classified as tidal forest, mangrove, or mangrove associates. Similarly, *Melaleuca* spp. and *Casuarina* spp., which dominate supratidal forests in Australia and Southeast Asia, can grow either in coastal forested wetlands (supratidal forests) or terrestrial forests. In the northwest United States, typical woody dominants of tidal forested wetlands such as Sitka spruce (*Picea sitchensis*) are also

commonly dominant in nontidal wetlands and upland forests. Thus, existing classifications and mapping approaches based on plant communities alone may overestimate the extent of tidally-influenced forests, necessitating the inclusion of biophysical data into mapping. Unambiguous and clearly bounded ecosystem definitions can help inform national or international policy mechanisms.

One example of a clear biophysical definition of a tidal forested wetland does exist for the Pacific northwest United States [59], combining a hydrogeomorphic definition of a tidal wetland [88] with the definition of a forested wetland from the U.S. Coastal and Marine Ecosystem Classification Standard [89]. This definition was used in a "first principles" mapping approach to produce a comprehensive map of estuary habitats, including tidal forested wetlands, for the U.S. West Coast [59].

5. Frameworks for inclusion in policy and accounting

Several international guidance, frameworks and methodologies exist to aid decision makers in incorporating mangroves into climate change mitigation plans. National level examples include guidance for the incorporation of mangroves into Nationally Determined Contributions, including template language that governments can use [90]. At the project level, several blue carbon credit verification methodologies are available for mangrove projects [91], including international methodologies (VM00033 under the Verified Carbon Standard, Gold Standard, PlanVivo, BCarbon) and national methodologies specific to or inclusive of mangroves in Australia [56], Thailand, and China. We also note that there are numerous conservation and restoration projects with carbon benefits occurring in tidal forested wetlands around the world that occur outside of formalized blue carbon frameworks. Thus, projects within formalized frameworks represent a small percentage of carbon benefits from tidal forested wetlands.

Many international blue carbon credit methodologies are not specific to mangroves, but to coastal wetlands more broadly, so may already be able to incorporate other tidal forested wetlands or could be modified to incorporate them. Some methodologies, such as the American Carbon Registry, have been specifically designed for other tidal forested wetlands. Though their deployment has faced challenges relating to cost-effectiveness versus carbon returns [65], they provide a template for future methodologies specific to other tidal forested wetlands. In many instances, improved quantification of carbon fluxes under baseline and restoration scenarios is a precursor to ensure accounting mechanisms are robust for tidal forested wetlands.

While we focus here on predominantly international frameworks and approaches, there is large potential for the incorporation of tidal forested wetlands into subnational climate change mitigation approaches, a scale that has been identified as important for blue carbon actions generally [92, 93]. Blue carbon policy in the Pacific northwest United States provides a framework for the incorporation of other tidal forested wetlands. The incorporation of Sitka spruce and other tidal forested wetlands has been proposed for the State of Oregon's blue carbon inventory [94] and Natural and Working Lands policies [95], and suitable areas for blue carbon conservation and restoration have been identified [13, 96].

6. Framing carbon with co-benefits for local communities

Mangroves benefit from a long history of ecosystem services research, highlighting their myriad benefits in provisioning services, fisheries, and coastal protection, amongst others [97], and associated local livelihood benefits. Indeed, coastal ecosystem research in general has seen a shift in framing towards ecosystem services in recent years [98]. Highlighting ecosystem services from other tidal forested wetlands is relevant on two levels. Broadly, it can increase awareness, highlighting the importance of these ecosystems. Awareness can help challenge misconceptions of an ecosystem; for hundreds of years, mangroves were perceived to be the source of a range of ecosystem disservices such as areas of danger or disease [99], and received substantially less public attention compared to other ecosystems such as coral reefs [100]. However, the recent ecosystem service framing in mangroves has shown their importance for both communities [101] and the broader public, and could benefit positive perceptions of other tidal forested wetland types.

At the implementation level, blue carbon is considered a 'boutique' carbon credit, with buyers paying substantially above the average carbon credit price [102] because of perceived value (such as ecosystem services and livelihood benefits) beyond carbon. The quantification of co-benefits can also help increase the credit value of a blue carbon project, as co-benefits can be stacked, stapled, and bundled into a carbon credit project, such as with biodiversity credits, nutrient regulation credits, or coastal protection insurance. This can increase the overall cost-effectiveness of carbon projects, which has been a major constraint to tidal forested wetland projects in the past [65].

7. The role of international ecosystem advocates

In part because of their perceived co-benefit value, mangrove forests benefited from international organizations who promoted their inclusion in various implementation pathways, both for carbon and through other mechanisms. The International Blue Carbon Initiative focuses primarily

on mangroves, seagrasses, and tidal marshes [103], though is expanding to other emerging blue carbon ecosystems. The Global Mangrove Alliance focuses on mangrove forests and their benefits, including carbon [104]. The Mangrove Breakthrough is a coalition of governments, financial institutions, the private sector, nonprofits, and community groups, aiming to mobilize US$4 billion to protect 15 million ha of mangroves by 2030 [105]. The Mangrove Alliance for Climate is a recent partnership between the United Arab Emirates and Indonesia, focusing on mangroves as a nature-based solution to climate change [106]. These are just some examples of the complex network of blue carbon actors, many of which focus on mangroves [107], although similar groups are now emerging for seagrasses [108] and tidal marshes [109]. Existing or new international organizations and networks could help inform decision makers regarding the potential and implementation of blue carbon for other tidal forested wetlands.

8. Capacity building

Mangrove blue carbon participants have benefited from ~ 15 years of capacity building in carbon measurements. Organizations such as the Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF) have held trainings across the tropics, in collaboration with the U.S. Forest Service and U.S. Agency for International Development. Several manuals have been published on how to measure mangrove carbon [110], alongside management best practice guidelines [111]. Institutions such as the International Blue Carbon Institute have been established to build implementation capacity, and several organizations have created training programs and academies. Similar networks and activities could be initiated for other tidal forested wetland ecosystems.

Conclusions

Blue carbon has been shown to be an influential policy concept for some coastal ecosystems, but there is now strong evidence that tidal forested wetlands broadly may be suitable for inclusion. Carbon dynamics in many tidal forested wetlands compare favourably to mangroves, and contrary to previous assumptions, greenhouse gas emissions may not be any greater than in mangroves. But despite their contribution to carbon cycling, only a handful of pilot projects have tried to utilise the carbon capacity of tidal forested wetlands, with mixed success. Mangroves underwent a similar learning curve for blue carbon implementation, and experiences from this ecosystem can be used to improve implementation outcomes for other tidal forested wetlands. Many of these experiences relate to filling knowledge gaps in tidal forested wetlands, particularly synthesising the evidence base for their role in climate change mitigation, improved mapping in order to estimate carbon additionality, and challenging outdated scientific assumptions. Many steps also relate to policy contexts and implementation pathways, particularly capacity building, and the creation of policy and implementation pathways, so that these ecosystems become 'actionable'. Lessons learned from the experience of mangrove implementation show how tidal forested wetlands can be effectively implemented into blue carbon strategies.

Key References

- Adame MF, Kelleway J, Krauss KW, Lovelock CE, Adams JB, Trevathan-Tackett SM, Noe G, Jeffrey L, Ronan M, Zann M, Carnell PE, Iram N, Maher DT, Murdiyarso D, Sasmito S, Tran DB, Dargusch P, Kauffman JB, Brophy L. All tidal wetlands are blue carbon ecosystems. BioScience 2024a;74:253−68.
- Kauffman JB, Adame MF, Adinugroho WC, Anshari G, Basuki I, Donato D, et al. Total ecosystem carbon stocks of tropical peat forests and greenhouse gas emissions from their disturbance. For Ecol Manage. 2025;593: 122840.
- Krauss KW, Noe GB, Duberstein JA, Conner, WH, Stagg CL, Cormier N, et al. 2018. The role of the upper tidal estuary in wetland blue carbon storage and flux. Glob Biogeochem Cycles. 2018; 32: 817–839.
- Lovelock CE, Duarte CM. Out of the blue carbon box: toward investable blue natural capital. Biol. Lett. 2025;21:20240648.
- Lugo AE, Brown S, Brinson MM. Forested wetlands in freshwater and salt-water environments. Limnol. Oceanogr. 1988;33:894–909.
- Mack SK, Lane RR, Holland K, Bauer J, Cole J,. Cowan R. A blue carbon pilot project: lessons learned. Carbon Manage. 2022;13:420−34.
- Sapkota Y, Berkowitz JF, Stagg CL, Busby RR. A synthesis of freshwater forested wetland soil organic carbon storage. Front. For. Glob. Chang. 2025;8:1528440.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Ellis PW, Page AM, Wood S, Fargione J, Masuda YJ, Denney VC, et al. The principles of natural climate solutions. Nat Commun. 2024;15:547.
2. Lovelock CE, Duarte CM. Dimensions of blue carbon and emerging perspectives. Biol Lett. 2019;15:20180781.
3. Donato DC, Kauffman JB, Murdiyarso D, Kurnianto S, Stidham M, Kanninen M. Mangroves among the most carbon-rich forests in the tropics. Nat Geosci. 2011;4:293–7.
4. Zeng Y, Friess DA, Sarira TV, Siman K, Koh LP. Global potential and limits of Mangrove blue carbon for climate change mitigation. Curr Biol. 2021;31:1737–43.
5. Sasmito SD, Basyuni M, Kridalaksana A, Saragi-Sasmito MF, Lovelock CE, Murdiyarso D. Challenges and opportunities for achieving sustainable development goals through restoration of Indonesia's mangroves. Nat Ecol Evol. 2023;7:62–70.
6. Li P, Liu D. How blue carbon financing can sustain blue carbon ecosystems protection and restoration: a proposed conceptual framework for the blue carbon financing mechanism. Ocean & Coastal Management. 2025;265:107644.
7. Perera NS, Costa MD, Macreadie PI, Wartman M. Trends in market-based blue carbon projects. Sustain Dev. 2025;33:3377–402.
8. Adame MF, Kelleway J, Krauss KW, Lovelock CE, Adams JB, Trevathan-Tackett SM, Noe G, Jeffrey L, Ronan M, Zann M, Carnell PE, Iram N, Maher DT, Murdiyarso D, Sasmito S, Tran DB, Dargusch P, Kauffman JB, Brophy L. All tidal wetlands are blue carbon ecosystems. Bioscience. 2024a;74:253–68.
9. Kelleway JJ, Noe GB, Krauss KW, Brophy LS, Conner WH, Duberstein JA, Friess DA, Gedan K, White E, Adame MF, Adams JB, Carvalho RC, Freddie A, Ikenna IN, Ocasio ER, Owers CJ, Sasmito S, Swales A, Stewart, Sinclair P, Ward RD, Zabarte-Maeztu I. Beyond the mangroves: a global synthesis of tidal forested wetland types, drivers and future information needs. EarthArXiv. 2026.
10. Krauss KW, Noe GB, Duberstein JA, Conner WH, Stagg CL, Cormier N, et al. The role of the upper tidal estuary in wetland blue carbon storage and flux. Glob Biogeochem Cycles. 2018;32:817–39.
11. Kauffman JB, Giovanonni L, Kelly J, Dunstan N, Borde A, Diefenderfer H, et al. Total ecosystem carbon stocks at the marine-terrestrial interface: blue carbon of the Pacific Northwest coast, United States. Glob Chang Biol. 2020a;26:5679–92.
12. Gómez N, Licursi M, Bauer DE, Ambosio ES, Capítulo AR. Assessment of biotic integrity of the coastal fresnwater tidal zone of a temperate estuary of South America through multiple indicators. Estuaries Coasts. 2012;35:1328–39.
13. Brophy L. Where have all the tidal forests gone? Mapping losses of forested and emergent tidal wetlands on the Oregon coast, USA. Estuar Coast Shelf Sci. 2026;328:109542.
14. Drexler JZ, Krauss KW, Sasser MC, Fuller CC, Swarzenski CM, Powell A, et al. A long-term comparison of carbon sequestration rates in impounded and naturally tidal freshwater marshes along the lower Waccamaw River, South Carolina. Wetlands. 2013;33:965–74.
15. Nellemann C, Corcoran E, Duarte CM, Valdes L, DeYoung C, Fonseca L, et al. Blue Carbon. The role of healthy oceans in binding carbon. A rapid response assessment. Arendal, Norway: United Nations Environment Programme, GRID-Arendal; 2009.
16. Lovelock CE, Duarte CM. Out of the blue carbon box: toward investable blue natural capital. Biol Lett. 2025;21:20240648.
17. Macreadie PI, Costa MDP, Atwood TB, Friess DA, Kelleway KK, Kennedy H, Lovelock CE, Serrano O, Duarte CM. Blue carbon as a natural climate solution. Nat Rev Earth Environ. 2021;2:826–39.
18. Finlayson CM. In: Finlayson MC, Everard M, Irvine K, McInnes RJ, Middleton BA, van Dam AA, Davidson NC, editors. Ramsar convention typology of wetlands. The wetland book I. The Netherlands: Springer; 2018. pp. 1529–32.
19. Aslan A, Rahman AF, Warren MW, Robeson SM. Mapping spatial distribution and biomass of coastal wetland vegetation in Indonesian Papua by combining active and passive remotely sensed data. Remote Sens Environ. 2016;183:65–81.
20. Ochoa-Gomez JG, Acosta-Velazquez J, Anguamea-Valenzuela CA, Marinetto P. Distribution and structure of *Conocarpus erectus* L. (Combretaceae) in the Northern limit of the Pacific ocean (Gulf of California). Ocean Coast Manage. 2021;209:105645.
21. Kelleway JJ, Gorham C, Trevathan-Tackett SM, Palacios M, Serrano O, Lavery P, Nagel-Tynan Z, Conroy B, Bendall-Pease G, Rigney S, Deutscher N, Hughes M, Carvalho R, Owers C, Jones AR, Russell SK, Planque C, Saintilan N, Rogers K. Inundation and salinity regimes support blue carbon conditions in temperate supratidal forests. Ecol Appl. 2025.
22. Qin Y, Zhu G, Liang M, Feng B. Exploring global research trends in Mangrove ecosystems: a bibliometric analysis of key issues and future directions (1996–2022). Land Degrad Dev. 2025;36:3163–77.
23. Rheinhardt RD, Hershner C. The relationship of below-ground hydrology to canopy composition in five tidal freshwater swamps. Wetlands. 1992;12:208–16.
24. Lugo AE, Brown S, Brinson MM. Forested wetlands in freshwater and salt-water environments. Limnol Oceanogr. 1988;33:894–909.
25. Creecy D, Chapman SK, Vervaeke WC, Santoro JA, Adgie T, Canas G, Feller IC, Langley AJ. The fundamental and realized

vertical niches of avicennia germinans in a Florida marsh-mangrove ecotone. Bull Mar Sci. 2025;101:1391–411.
26. Buckmire ZE, Daniel J, Koper N. Plasticity as a contributor to community zonation: a case study using white mangroves (*Laguncularia racemosa*) in Grenada, West Indies. Bull Mar Sci. 2025;101:1125–42.
27. Kirwan ML, Michael HA, Gedan KB, Tully KL, Fagherazzi S, McDowell NG, et al. Feedbacks regulating the salinization of coastal landscapes. Ann Rev Mar Sci. 2025;17:461–84.
28. Lewis RR, Milbrandt EC, Brown B, Krauss KW, Rovai AS, Beever JW III, et al. Stress in mangrove forests: early detection and preemptive rehabilitation are essential for future successful worldwide mangrove forest management. Mar Pollut Bull. 2016;109:764–71.
29. Snedaker SC, Lahmann EJ. Mangrove understory absence: a consequence of evolution? J Trop Ecol. 1988;4:311–4.
30. Duberstein JA, Krauss KW, Baldwin MJ, Allen ST, Conner WH, Salter JS Jr., et al. Small gradients in salinity have large effects on stand water use in freshwater wetland forests. For Ecol Manage. 2020;473:118308.
31. IPCC. Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. Switzerland: Intergovernmental Panel on Climate Change; 2014.
32. Taillardat P, Thompson BS, Garneau M, Trottier K, Friess DA. Climate change mitigation potential of wetlands and the cost-effectiveness of their restoration. Interface Focus. 2020;10:20190129.
33. Megonigal JP, Schlesinger WH. Methane-limited methanotrophy in tidal freshwater swamps. Glob Biogeochem Cycles. 2002;16:35–1. -35 – 10.
34. Krauss KW, Whitbeck JL. Soil greenhouse gas fluxes during wetland forest retreat along the lower Savannah River, Georgia (USA). Wetlands. 2012;32:73–81.
35. Williams T, Janousek CN, McKeon MA, Diefenderfer HL, Cornu CE, Borde AB, et al. Methane and nitrous oxide fluxes from reference, restored, and disturbed estuarine wetlands in Pacific Northwest, USA. Ecol Appl. 2025;35:e70011.
36. Drexler JZ, Ewel KC. Effect of the 1997–1998 ENSO-related drought on hydrology and salinity in a Micronesian wetland complex. Estuar Coasts. 2001;24:347–56.
37. Bernardino AF, Mazzuco AC, Souza FM, Santos TM, Sanders CJ, Massone CG, Costa RF, Silva AE, et al. The novel Mangrove environment and composition of the Amazon delta. Curr Biol. 2022;32:3636–40.
38. Melling L, Hatano R, Goh KJ. Methane fluxes from three ecosystems in tropical peatland of Sarawak. Malaysia Soil Biol Biochem. 2005;37:1445–53.
39. Perryman CR, Bowen JC, Shahan J, Silviani DPAB, Dayanti E, Andriyani Y, et al. Fate of methane in canals draining tropical peatlands. Nat Commun. 2024;15:9766.
40. Weston NB, Dixon RE, Joye SB. Ramifications of increased salinity in tidal freshwater sediments: geochemistry and microbial pathways of organic matter mineralization. J Geophys Res Biogeosci. 2006;111:G01009.
41. Poffenbarger HJ, Needelman BA, Megonigal JP. Salinity influence on methane emissions from tidal marshes. Wetlands. 2011;31:831–42.
42. Rosentreter JA, Laruelle GG, Bange HW, Bianchi TS, Busecke JJ, Cai W-J, et al. Coastal vegetation and estuaries are collectively a greenhouse gas sink. Nat Clim Chang. 2023;13:579–87.
43. Arias-Ortiz A, Wolfe J, Bridgham SD, KNox S, McNicol G, Needelman BA, Shahan J, et al. Methane fluxes in tidal marshes of the conterminous united States. Glob Chang Biol. 2024;30:e17462.
44. Noe GB. Literature rates of measured methane fluxes from tidal wetland soils to the atmosphere. U.S. Geological survey data release 2026a;https://doi.org/10.5066/P1FXRJBM
45. Noe GB, Napora KM, Krauss KW, Doody TR. Greenhouse gas fluxes along a tidal gradient of low salinity freshwater forested wetlands. U.S. Geological Survey data release 2026b;https://doi.org/10.5066/P1IY7V9Q
46. Sutton-Grier AE, Megonigal JP. Plant species traits regulate methane production in freshwater wetland soils. Soil Biol Biochem. 2011;43:413–20.
47. Pangala SR, Moore S, Hornibrook ERC, Gauci V. Trees are major conduits for methane egress from tropical forested wetlands. New Phytol. 2013;197:524–31.
48. Jeffrey LC, Reithmaier G, Sippo JZ, Johnston SG, Tait DR, Harada Y, Maher DT. Are methane emissions from Mangrove stems a cryptic carbon loss pathway? Insights from a catastrophic forest mortality. New Phytol. 2019;224:146–54.
49. Adame MF, Ree R, Wong VN, Balcombe SR, Turschwell MP, Kavehei E, Rodríguez DC, Kelleway JJ, Masque P, Ronan M. Carbon and Nitrogen Sequestration of Melaleuca Floodplain Wetlands in Tropical Australia. Ecosystems. 2019;23:454 – 66.
50. Janousek CN, Krause JR, Drexler JZ, Buffington KJ, Poppe KL, Peck E, Adame MF, Watson EB, et al. Blue carbon stocks along the Pacific Coast of North America are mainly driven by local rather than regional factors. Glob Biogeochem Cycle. 2025;39:e2024GB008239.
51. Sapkota Y, Berkowitz JF, Stagg CL, Busby RR. A synthesis of freshwater forested wetland soil organic carbon storage. Frontiers in Forests and Global Change. 2025;8:1528440.
52. Kelleway JJ, Adame MF, Gorham C, Bratchell J, Serrano O, Lavery PS, Owers CJ, Rogers K, Nagel-Tynan Z. Saintilan, N. Carbon storage in the coastal swamp oak forest wetlands of Australia. In: Krauss KW, Zhu Z, Stagg CL, editors. Wetland carbon and environmental management. Washington DC: American Geophysical Union; 2021. pp. 339–53.
53. Kauffman JB, Adame MF, Adinugroho WC, Anshari G, Basuki I, Donato D, et al. Total ecosystem carbon stocks of tropical peat forests and greenhouse gas emissions from their disturbance. For Ecol Manage. 2025;593:122840.
54. Kauffman JB, Adame MF, Arifanti VB, Schile-Beers LM, Bernardino AF, Bhomia RK, et al. Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. Ecol Monogr. 2020b;90:e01405.
55. Jennerjahn TC. Relevance and magnitude of "Blue Carbon" storage in mangrove sediments: carbon accumulation rates vs. stocks, sources vs. sinks. Estuar Coast Shelf Sci. 2020;247:107027.
56. Lovelock CE, Adame MF, Bradley J, Dittmann S, Hagger V, Hickey SM, et al. An Australian blue carbon method to estimate climate change mitigation benefits of coastal wetland restoration. Restor Ecol. 2022;31:e13739.
57. Kauffman JB, Arifanti VB, Trejo HH, Garcia M, Norfolk J, Cifuentes M, et al. The jumbo carbon footprint of a shrimp: carbon losses from Mangrove deforestation. Front Ecol Environ. 2017;15:183–8.
58. Jiang Y, Zheng Z, Friess DA, Li Y, Zhang Z, Xin R, et al. Restoring mangroves lost by aquaculture offers large blue carbon benefits. One Earth. 2025;8:101149.
59. Brophy LS, Greene CM, Hare VC, Holycross B, Lanier A, Heady WN, O-Connor K, Imaki H, et al. Insights into estuary habitat loss in the Western united States using a new method for mapping maximum extent of tidal wetlands. PLoS ONE. 2019;14:e0218558.
60. Girkin NT, Cooper HV, Ledger MJ, O'Reilly P, Thornton SA, Åkesson CM, Cole LE, Hapsari KA, et al. Tropical peatlands in the anthropocene: the present and the future. Anthropocene. 2022;40:100354.
61. Janousek CN, Bailey SJ, Brophy LS. Early ecosystem development varies with elevation and pre-restoration land use/land cover

in a Pacific Northwest tidal wetland restoration project. Estuaries Coasts. 2021;44:13–29.
62. Recht F, Brophy LS, Drinkwin J. Restoring tidal swamps in the U.S. Pacific northwest: information for restoration practitioners. Pacific States marine fisheries commission. Pacific Marine & Estuarine Fish Habitat Partnership, and the Institute for Applied Ecology; 2024.
63. Sinclair AL, Graham LL, Grover SP. More field-based carbon monitoring of tropical peatland restoration is urgently needed: findings from a systematic literature review. Mires Peat. 2024;30:07.
64. Needelman BA, Emmer IM, Emmett-Mattox S, Crooks S, Megonigal JP, Myers D, Oreska MP, McGlathery K. The science and policy of the verified carbon standard methodology for tidal wetland and seagrass restoration. Estuaries Coast. 2018;41:2159–71.
65. Mack SK, Lane RR, Holland K, Bauer J, Cole J, Cowan R. A blue carbon pilot project: lessons learned. Carbon Manage. 2022;13:420–34.
66. Clean Energy Regulator. Blue Heart Project. 2025. https://cer.gov.au/schemes/australian-carbon-credit-unit-scheme/accu-project-and-contract-register/project/ERF188599. Accessed 10 Sep 2025.
67. Verra. Kubu Peatland Project. https://registry.verra.org/app/projectDetail/VCS/5371. 2024. Accessed 1 Oct 2025.
68. Pendelton L, Donato DC, Murray BC, Crooks S, Jenkins WA, Sifleet S, et al. Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. PLoS One. 2012;7:e43542.
69. Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, et al. Status and distribution of mangrove forests of the world using earth observation satellite data. Glob Ecol Biogeogr. 2010;20:154–9.
70. Rovai AS, Twilley RR, Castañeda-Moya E, Midway SR, Friess DA, Trettin CC, Bukoski JJ, Stovall AEL, Pagliosa PR, Fonseca AL, Mackenzie RA, Aslan A, Sasmito SD, Sillanpää M, Cole TG, Purbopuspito J, Warren MW, Murdiyarso D, et al. Macroecological patterns of forest structure and allometric scaling in Mangrove forests. Glob Ecol Biogeograph. 2021;30:1000–13.
71. Atwood TB, Connolly RM, Almahasheer H, Carnell PE, Duarte CM, Ewers-Lewis C, Irigoien X, Kelleway JJ, et al. Global patterns in Mangrove soil carbo stocks and losses. Nat Clim Chang. 2017;7:523–8.
72. Zhang J, Gan S, Yang P, Xhou J, Huang X, Chen H, et al. A global assessment of mangrove soil organic carbon sources and implications for blue carbon credit. Nat Commun. 2024;15:8994.
73. Lehner B, Anand M, Flute-Chouinard E, Tan F, Aries F, Allen GH, Bousquet P, Canadell JG, et al. Mapping the world's inland surface waters: an upgrade to the global lakes and wetlands database (GLWD v2). Earth Sys Sci Data. 2025;17:2277–329.
74. Bunting P, Hilarides L, Rosenqvist A, Lucas RM, Juto E, Gueye Y, et al. Global mangrove watch: monthly alerts of mangrove loss for Africa. Remote Sens. 2023;15:2050.
75. Wang M, Zhang T, Xie Y, Zhang Z, Wu X. Mapping accumulated carbon storage of global mangroves from 2000 to 2020 at a 1 km resolution. Sci Data. 2025;12:552.
76. Chatting M, Al-Maslamani I, Walton M, Skov MW, Kennedy H, Husrevoglu YS, et al. Future mangrove carbon storage under climate change and deforestation. Front Mar Sci. 2022;9:781876.
77. Adame MF, Connolly RM, Turschwell MP, Lovelock CE, Fatoyinbo T, Lagomasino D, et al. Future carbon emissions from global mangrove forest loss. Glob Chang Biol. 2021;27:2856–66.
78. Carvalho RC, Owers CJ, Kelleway JJ. Towards continental-scale mapping of supratidal forests in australia: filling the knowledge gap using the open data cube. IGARSS 2024;4784–87.
79. Yeung H, Pavelsky T, Wang C, McDowell N, Emanuel R, Bernhardt E, Yang X. Overlooked and extensive ghost forest formation across the US Atlantic Coast. Nat Sustain. 2025;8:1445–54.
80. Marcoe K, Pilson S. Habitat change in the lower Columbia river estuary, 1870–2009. J Coast Conserv. 2017;21:505–25.
81. Nuyts S, Wartman M, Macreadie PI, Costa MDP. Mapping tidal restrictions to support blue carbon restoration. Sci Total Environ. 2024;949:175085.
82. Iram N, Maher DT, Lovelock CE, Baker T, Cadier C, Adame MF. Climate change mitigation and improvement of water quality from the restoration of a subtropical coastal wetland. Ecol Appl. 2022;32:e2620.
83. Lovelock CE, Reef R. Variable impacts of climate change on blue carbon. One Earth. 2020;3:195–211.
84. Kwan V, Friess DA, Sarira TV, Zeng Y. Permanence risks limit blue carbon financing strategies to safeguard Southeast Asian mangroves. Communications Earth & Environment. 2025;6:57.
85. Verra. Verra Releases Updated AFOLU Non-Permanence Risk Tool https://verra.org/verra-releases-updated-afolu-non-permanence-risk-tool/. 2023. Accessed 1 Oct 2025.
86. Herbert ER, Boon P, Burgin AJ, Neubauer SC, Franklin RB, Ardón M, Hopfensperger NN, Lamers LP, Gell P. A global perspective on wetland salinization: ecological consequences of a growing threat to freshwater wetlands. Ecosphere. 2015;6:1–43.
87. Smart LS, Taillie PJ, Poulter B, Vukomanovic J, Singh KK, Swenson JJ, et al. Aboveground carbon loss associated with the spread of ghost forests as sea levels rise. Environ Res Lett. 2020;15:104028.
88. Adamus PR. Hydrogeomorphic (HGM) assessment guidebook for tidal wetlands of the Oregon Coast, part 1: rapid assessment method. Prod. Coos Watershed Assoc. Oregon Dep. State Lands U.S.E.P.A.-Region 10. Charleston, Oregon: Coos Watershed Assoc. 2006;https://doi.org/10.13140/RG.2.2.34954.77764
89. Federal Geographic Data Committee. Coastal and Marine Ecological Classification Standard (CMECS). 2012; FGDC-STD-018-2012. https://repository.library.noaa.gov/view/noaa/27552
90. Mangrove Breakthrough NDC. Taskforce. Template Language for including mangroves in nationally determined contributions (NDCs). Mangrove Breakthrough; 2025.
91. Sapkota Y, White JR. Carbon offset market methodologies applicable for coastal wetland restoration and conservation in the United States: a review. Sci Total Environ. 2020;701:134497.
92. Wedding LM, Moritsch M, Verutes G, Arkema K, Harge E, Reiblich J, et al. Incorporating blue carbon sequestration benefits into subnational climate policies. Glob Environ Chang. 2021;69:102206.
93. Zhao P, Ge S, He D, Zhong C, Wang B, Wang X, et al. Incorporating coastal blue carbon into subnational greenhouse gas inventories. Front Mar Sci. 2022;9:932984.
94. Oregon Global Warming Commission. Incorporating coastal blue carbon data and approaches in oregon's first generation natural and working lands proposal. Or Global Warming Comm. 2021.
95. Oregon Global Warming Commission. Natural & Working Lands Proposal. Oregon Global Warming Commission. 2021.
96. Lyle JT, Graves RA, Carter K, Tabor L. Oregon's blue carbon ecosystems: state of the science, a summary of the current understanding of the climate mitigation potential of Oregon's coastal and marine habitats. Nat Conservancy. 2022.
97. Mitra A. Ecosystem services of mangroves: an overview. In: Mitra A, editor. Mangrove forests in India. Switzerland, Springer.; 2020. pp. 1–32.
98. Balke T, Vovides AG, Ladd CJ, Huxham M. The coastal conservation narrative is shifting from crisis to ecosystem services. Mar Biodivers. 2023;53:3.
99. Friess DA. Ecosystem services and disservices of Mangrove forests: insights from historical colonial observations. Forests. 2016;7:183.
100. Duarte CM, Dennison WC, Orth RJ, Carruthers TJ. The charisma of coastal ecosystems: addressing the imbalance. Estuaries Coasts. 2008;31:233–8.
101. de Souza Queiroz L, Rossi S, Calvet-Mir L, Ruiz-Mallén I, García-Ruiz S, Salvà-Prat J, et al. Neglected ecosystem services:

highlighting the socio-cultural perception of mangroves in decision-making processes. Ecosystem Serv. 2917;26:137–45.
102. Ecosystem Marketplace. State of the blue carbon market. Ecosystem Marketplace; 2024.
103. Blue Carbon Initiative. Mitigating climate change through coastal conservation. https://www.thebluecarboninitiative.org/. 2019. Accessed 1 Oct 2025.
104. Global Mangrove Alliance. The Global Mangrove Alliance. http://www.mangrovealliance.org.2025. Accessed 1 Oct 2025.
105. Mangrove Breakthrough. The Mangrove Breakthrough Financial Road Map. Mangrove Breakthrough. 2023.
106. Mangrove Alliance for Climate. About Us. https://mangrovealliance4climate.org/about/. 2023. Accessed 1 Oct 2025.
107. International Partnership for Blue Carbon. Inventory of global blue carbon actors. International Partnership for Blue Carbon; 2022.
108. Seagrass Breakthrough. The 2030 Seagrass Breakthrough, Seagrass Breakthrough. 2024.
109. Brook T, Millington-Drake M, Garbutt A, McGarrigle A, Rodriguez K. Du plessis N. The state of the world's saltmarshes. WWF, Blue Marine Foundation.; 2025.
110. Kauffman JB, Donato D. Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. Working Paper 86, Bogor, Center for International Forestry Research. 2012.
111. Howard J, Lovelock C, Beeston M, Cameron C, Sippo J, Hagger V, et al. Best Practice Guidelines for Mangrove Restoration. The Blue Carbon Initiative/Global Mangrove Alliance; 2023.