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## LETTER TO THE EDITOR

# Climate Benefits of Saltmarsh Restoration Greatly Overstated by Mason et al. (2023)

Phillip Williamson<sup>1</sup>  | Robert W. Schlegel<sup>2</sup>  | Jean-Pierre Gattuso<sup>2,3</sup>  | Julian E. Andrews<sup>1</sup>  | Tim D. Jickells<sup>1</sup> 

<sup>1</sup>School of Environmental Sciences, University of East Anglia, Norwich, UK | <sup>2</sup>Laboratoire d'Océanographie de Villefranche, CNRS, Sorbonne Université, Villefranche-sur-Mer, France | <sup>3</sup>Institute for Sustainable Development and International Relations, Sciences Po, Paris, France

**Correspondence:** Phillip Williamson ([p.williamson@uea.ac.uk](mailto:p.williamson@uea.ac.uk))

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The meta-analysis by Mason et al. (2023) provides many important insights into carbon storage and dynamics in saltmarsh ecosystems. However, we consider that their estimate of the net global mean climate benefit of saltmarsh restoration of 64.70 t CO<sub>2</sub>e ha<sup>-1</sup> year<sup>-1</sup> is too high, by at least an order of magnitude.

Mason et al. determined the above value by adding atmospherically measured net CO<sub>2</sub> uptake (also known as net ecosystem exchange, NEE) to sediment-based organic carbon accumulation (C-acc) rates, then subtracting CO<sub>2</sub>e values for methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) emissions, using global arithmetic means for all parameters. However, the same atoms are involved in NEE and C-acc; such carbon was therefore double-counted (disregarding C imports/exports, a simplification also made by Mason et al.). Furthermore, most NEE data in Mason et al.'s database were daytime, growing-season measurements at low or mid-tide, using chambers. It is invalid to extrapolate these short-term CO<sub>2</sub> fluxes to annual rates since photosynthesis by saltmarsh vegetation either does not occur or is much reduced during nighttime, winter, and tidal immersion.

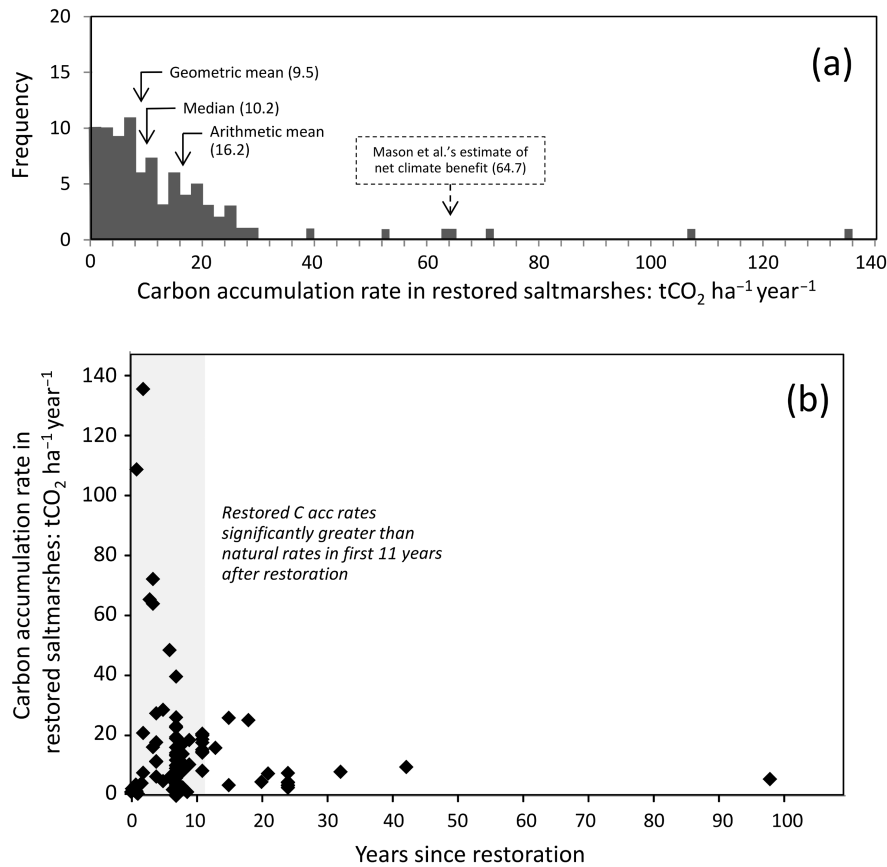
Eddy correlation NEE measurements in the database better integrate gas exchanges over large spatial areas and temporal periods. Their global mean value provides a carbon removal estimate of 7.8 t CO<sub>2</sub> ha<sup>-1</sup> year<sup>-1</sup>, combining data for restored and natural salt marshes. Correcting for CH<sub>4</sub> and N<sub>2</sub>O fluxes (using arithmetic mean values from Mason et al.'s table 1), changes this estimate to -1.3 t CO<sub>2</sub>e ha<sup>-1</sup> year<sup>-1</sup>; that is, indicating potential for net climate warming. Mason et al.'s CH<sub>4</sub> and N<sub>2</sub>O data are

also mostly from chamber measurements; however, they are less likely to be affected by diel bias.

Although of interest, atmospherically based determinations of carbon sequestration are indirect, and the relatively few eddy correlation studies ( $n=34$ ) are geographically biased. We, therefore, consider that C-acc rates provide a better (upper) estimate of climate benefit, being more directly derived from depth profiles of sediment organic carbon content and sediment accretion rates. Using data from Mason et al.'s table 1, global arithmetic mean C-acc (expressed in terms of CO<sub>2</sub> uptake) is 16.2 and 7.8 t CO<sub>2</sub> ha<sup>-1</sup> year<sup>-1</sup> for restored ( $n=82$ ) and natural ( $n=312$ ) salt marshes, respectively. With corrections for CH<sub>4</sub> and N<sub>2</sub>O fluxes made separately for restored and natural sites, global mean values become -0.8 and 2.6 t CO<sub>2</sub>e ha<sup>-1</sup> year<sup>-1</sup> respectively, for the two conditions, showing the nonnegligible (yet highly uncertain, Rosentreter et al. 2021) importance of these emissions, contrary to the conclusion drawn by Mason et al.

Several other carbon accounting issues complicate the quantification of the climate mitigation benefit of saltmarsh restoration. They include

- *Nonnormal distributions.* The frequency distributions of C-acc rates in Mason et al.'s database are highly skewed, as found for other blue carbon ecosystems (e.g., Breithaupt and Steinmüller 2022). Under such circumstances, medians or geometric means are generally considered preferable to arithmetic means in representing the central tendency: such



**FIGURE 1** | Additional analyses of the global data set of carbon accumulation rates for restored salt marshes expressed as  $t\text{ CO}_2\text{ ha}^{-1}\text{ year}^{-1}$  from the Mason et al. (2023) database. (a) Frequency distribution showing strong skewness (kurtosis), with range of values for their central tendency. Mason et al.'s estimate of net climate benefit also shown, after correcting for  $\text{CH}_4$  and  $\text{N}_2\text{O}$  fluxes. (b) Carbon accumulation rates as a function of time since restoration, showing that high initial rates are not sustained.

values for restored salt marshes are given in Figure 1a. If medians are used both for C-acc rates and their  $\text{CH}_4$  and  $\text{N}_2\text{O}$  corrections, net global climate benefits for restored and natural salt marshes become 9.6 and 3.9  $t\text{ CO}_2\text{e ha}^{-1}\text{ year}^{-1}$  respectively.

- *Effect of time since restoration.* The enhanced C-acc rate in restored salt marshes compared to natural ones is relatively short-lived (Figure 1b): 12 years after restoration, there is no statistical difference (Mann–Whitney  $U$  test).
- *Lateral carbon transport.* A high proportion (> 25%) of carbon accumulating in salt marshes can be allochthonous (externally derived), either from terrestrial or marine sources (Williamson and Gattuso 2022; Smeaton et al. 2024). Such carbon is conventionally excluded from climate benefit accounting since additionality (Gustavsson et al. 2000) cannot be verified. High C-acc in recently restored sites can arise from a pulse of allochthonous carbon on re-flooding, prior to the re-establishment of halophilic vegetation (Mossman et al. 2022).
- *Regional and subregional variability.* Mason et al.'s data set shows a 25-fold and 3-fold intercontinental variability in mean C-acc rates for restored and natural salt marshes, respectively, with 3-fold variability for the latter on a national basis within Europe (Smeaton et al. 2024). Data on African

and South American salt marshes are currently lacking. A single global value is therefore potentially misleading, being dominated (76%) by North American studies.

- *Climate change impacts.* Saltmarsh productivity is expected to significantly decline under future warming and sea-level rise (Bindoff et al. 2019; Li et al. 2020). Currently determined C-acc rates are therefore likely to overestimate future benefits.

We therefore disagree with Mason et al. that saltmarsh restoration has clear potential to offset carbon emissions: the maximum benefit would seem <0.05% of current  $\text{CO}_2$  emissions rather than the 0.51% that they claim. Nevertheless, we recognize the value of protecting salt marshes (and their restoration, wherever feasible) for the many other environmental services that these ecosystems provide (Vegh et al. 2019).

#### Author Contributions

**Phillip Williamson:** conceptualization, investigation, methodology, writing – original draft, writing – review and editing. **Robert W. Schlegel:** formal analysis, validation, writing – review and editing. **Jean-Pierre Gattuso:** conceptualization, validation, writing – review and editing. **Julian E. Andrews:** validation, writing – review and editing. **Tim D. Jickells:** validation, writing – review and editing.

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## Conflicts of Interest

The authors declare no conflicts of interest.

## Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

## Linked Article

This article is a Letter to the Editor on Mason et al., <https://doi.org/10.1111/gcb.16943>. See also response to this letter by Mason et al., <https://doi.org/10.1111/gcb.17526>.

Phillip Williamson  
Robert W. Schlegel  
Jean-Pierre Gattuso  
Julian E. Andrews  
Tim D. Jickells

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