# Soil organic carbon preservation and decay trends in tidal marsh, mangrove and seagrass blue carbon ecosystems

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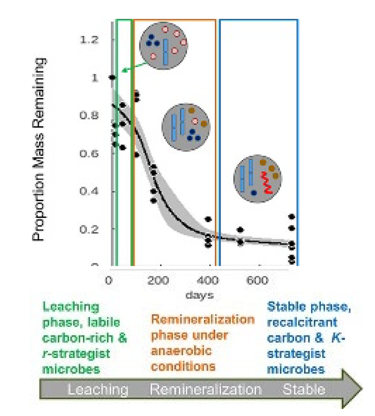
BlueCarbon R Package to estimate stocks and sequestrations rates from raw laboratory data!

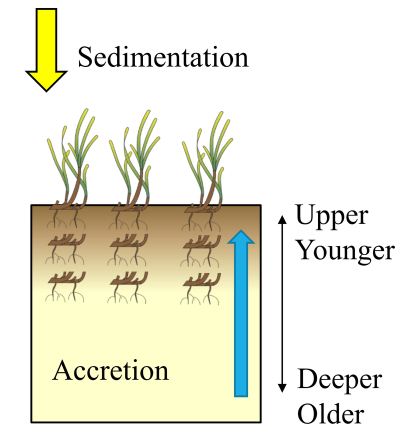
## Introduction

Organic matter decay in laboratory experiments lead to the exponential decrease in organic carbon (OC) with time

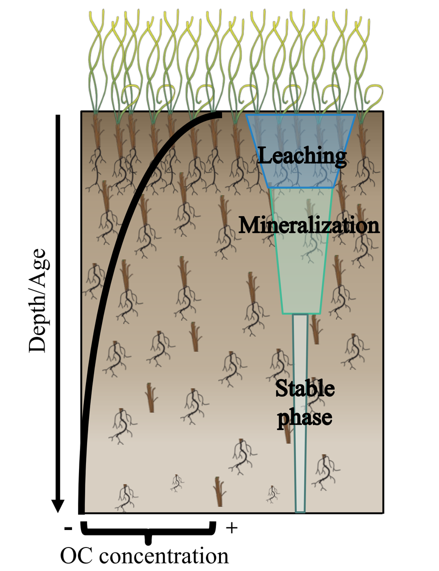



Modified from Trevathan-Tackett et al. (2020)

In depositional environments, deeper equals to older.




If deeper = older, in stable depositional environments OC concentration should exponentially decrease with depth/time




- If organic carbon decreases with depth, the accumulated OC mass with depth will show a concave curve. For this to be true, **decay must be the main process shaping OC concentrations.**
- This was consider improbable, because "it seemed unlikely that input and decay rates would have remained almost constant over millennia" (Clymo 1998).
- **However, Clymo et al. (1998) found this concave profile in the majority of the peat bogs profiles studied that had a coherent $^{14}$C chronological model.**
- Therefore, they develop a simple diagenetic model to estimate centennial and millenary OC decay rates in peat bogs, as decay was likely the main process shaping OC with depth.
- **Seagrass meadows, tidal marshes and mangrove forest are depositional environments where deeper = older. Could the model be applied to estimate centennial and millennial decay rates in their soils?**

## Main Assumptions and Research Questions

Here, we examined 3761 blue carbon cores across the world to assess OC decay patterns with soil depth. In 83 cores with reliable $^{210}$Pb age-depth models, decreasing OC trends with depth and coherent $\delta^{13}$C profiles, decay rates over centuries to millennia were modelled.

How common are decreasing OC concentrations with depth in blue carbon ecosystems?

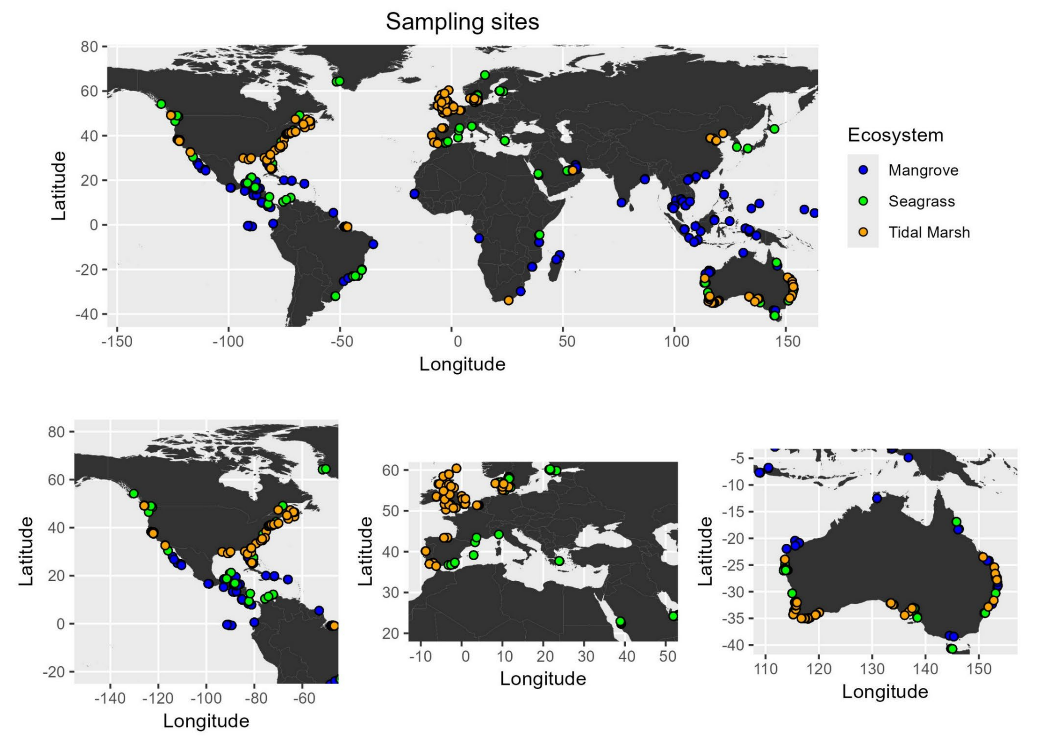
In stable (protected) areas, is decay the main factor shaping OC trends with depth?

Acknowledging that a scenario with constant OC inputs is only theoretical, we hypothesize that given a sufficiently long profile with absence of OC inputs from the rhizosphere or disturbances, the downcore trend will always be an exponential decay. Therefore, a continuous soil profile with a decay OC trend would be indicative of good preservation of the stratigraphic record, not of mixing, and of a stable environment over time.

Can we estimate centennial and millennial OC decay rates?

## Organic Carbon and Depth

### Methods




Geographic distribution of the whole core data collection (n = 3761).

3761 cores:

- 2174 from mangrove forests
- 1014 from tidal marshes
- 573 from seagrass meadows

Correlation of OC and depth (Spearman method)

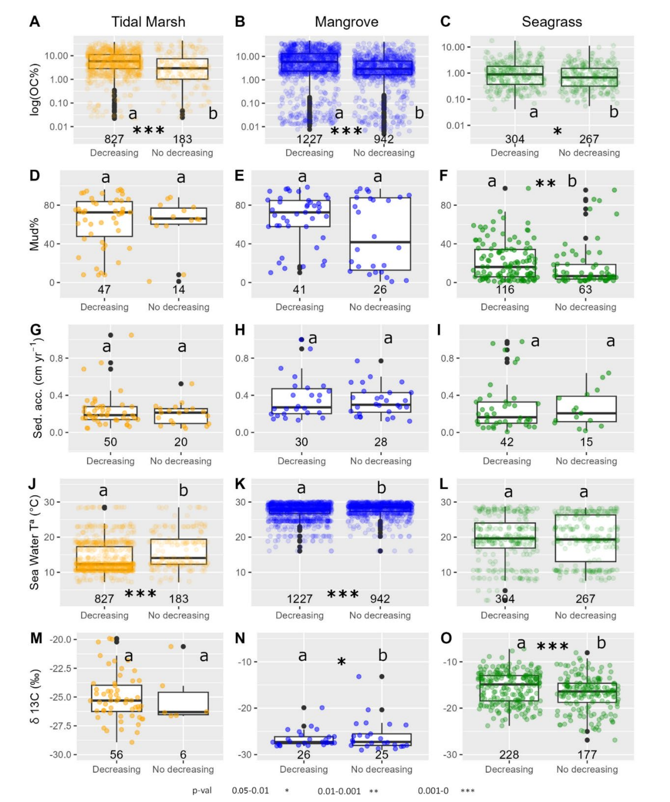
Identifying/Assessing OC trends with depth.

Classifying OC depth trend into decreasing vs no-decreasing (stable or increasing)

Wilcoxon test

Assessing soil characteristics (OC%, Mud%, sediment accretion rate, and $\delta^{13}$C) and seawater temperature on group classification: decreasing vs. no-decreasing.

### Results and Discussion




**63% of the cores across all habitats showed decreasing trends of OC with depth**
82% in tidal marshes, 57 in mangrove forest and 53 in seagrass meadows

Mangrove forests and tidal marshes

Cores with decreasing trends:

↑ OC content

↓ Sea Water Tª

Seagrass meadows

Cores with decreasing trends:

↑ OC content

↑ Mud content (<0.063 mm)

↑ $\delta^{13}$C

Cores with OC decreasing trends with depth are, likely, to be located in protected areas, with higher OC burial

In the figure to the left: Organic carbon and mud contents, sediment accretion rates, sea water temperature, and $\delta^{13}$C in the top 25 cm of soil in cores showing decreasing or no decreasing (stable or increasing) downcore OC trends. Boxplot horizontal lines indicate median values; box, 25th to 75th percentiles; whiskers: highest and lowest value excluding outliers (Q3+1.5xIQR to Q1-1.5xIQR, IQR: interquartile range); black dots, potential outliers. Different lower-case letters indicate significant differences between cores (Wilcoxon test, p-value: * 0.05-0.01, ** 0.01-0.001, *** <0.001). Numbers above x-axis labels indicate the number of cores per category.

## Organic Carbon and Time

### Methods

- Cores with a coherent $^{210}$Pb model
- Decrease OC trend with time
- Coherent $\delta^{13}$C profiles

83 cores

To estimate decay rates

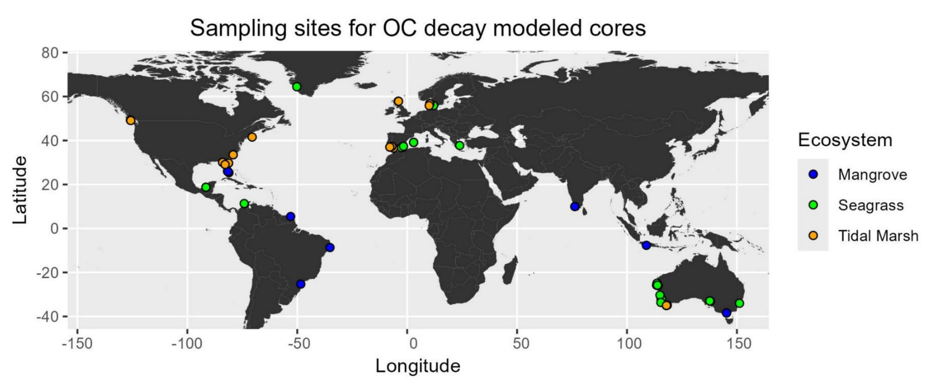
$$M = \left(\frac{p}{k}\right) * \left(1 - e^{-k*t}\right)$$

Where $M$ is the OC accumulated mass, $t$ is the age, and OC production ($p$) and decay ($k$) are the parameters to be estimated. Clymo et al. (1984, 1998).

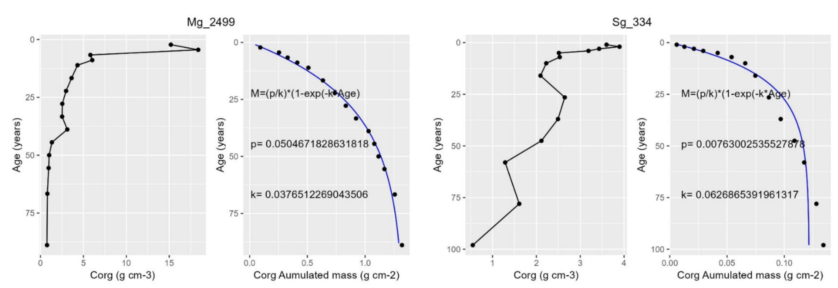
To estimate the remaining OC after a known time

$$OC(t) = OC_0 * e^{k*t}$$

Where A(t) is the fraction of OC remaining after time t, A0 is the initial mass and k is the decay rate




Geographic distribution of the cores in which soil OC decay rates were estimated (n = 83).

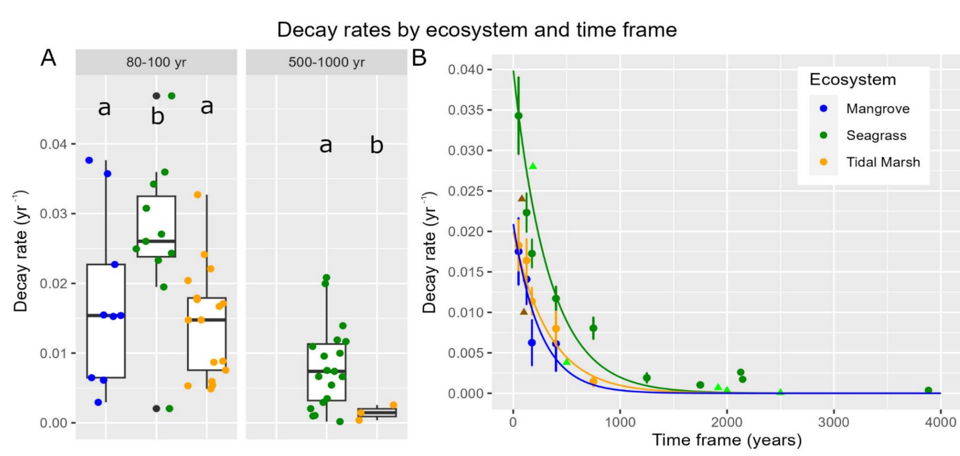



Example of modelled cores (left, mangrove core; right, seagrass core right).

### Results and Discussion

Soil organic carbon decay rates ($k$) estimated by modelling decreasing organic carbon mass with age over 80–100 and 500–1,000 yr time frames. SE = Standard Error.

| Time frame | | Decay rate ($k$; $yr^{-1}$) 80–100 yr | Decay rate ($k$; $yr^{-1}$) 500–1,000 yr |
|---|---|---|---|
| Mangrove | Mean | 0.017 | |
| | SE | 0.003 | |
| | n | 9 | |
| Seagrass | Mean | 0.034 | 0.008 |
| | SE | 0.003 | 0.001 |
| | n | 14 | 19 |
| Tidal Marsh | Mean | 0.018 | 0.0015 |
| | SE | 0.003 | 0.0002 |
| | n | 19 | 3 |
| **All** | **Mean** | **0.023** | **0.007** |
| | **SE** | **0.002** | **0.0007** |
| | **n** | **44** | **18** |




A) OC decay rates ($yr^{-1}$). B) Exponential regression of soil organic carbon decay rates with age.

- Decay rates declined as the time frame used for their estimation increased.
- Mangrove and tidal marsh cores exhibited lower decay rates in the first 100 years.
- Decay rates at 100 yr were correlated with mud content across habitats, but this relationship did not hold within individual ecosystems.
- Sea water temperature had no significant effect on decay rates.

## Study Limitations

Inferring organic carbon decay from sediment cores in ecosystems with vascular plants requires caution (Belshe et al. 2019). While various factors can affect downcore trends, selecting cores with consistent chronological models, coherent $\delta^{13}$C profiles, and decreasing OC with depth from diverse sites enabled reliable estimates of OC decay rates in blue carbon ecosystems soils. Other study limitations include:

- Estimates for mangrove forests are based on only nine data points.
- Mangrove forests present unique challenges due to deep root inputs, which can skew OC decay estimates.
- Subsurface OC additions from roots, fauna, or microbes may lead to overestimated decay rates.
- Allochthonous OC is more resistant to decay and may cause underestimation of autochthonous OC degradability.
- Fitted decay models showed residuals influenced by other processes; due to the lack of information in the specific biogeochemistry processes of each core a one-component model was used to avoid overfitting.
- The *Posidonia* genus is overrepresented in the modelled seagrass cores, which may limit the representativeness of the seagrass data.

## Useful numbers for Blue Carbon projects implementation

Soil OC decay rates:

- 100 yr, 0.023 ± 0.002 $yr^{-1}$
- 1,000 yr, 0.007 ± 0.0007 $yr^{-1}$

**9% of initial OC remains after 100 years, 0.1% remains after 1,000 years.**

Decay rates at 1 m depth (average age ~1,471 years):

- Mangroves: 0.00005 $yr^{-1}$
- Tidal marshes: 0.0002 $yr^{-1}$
- Seagrasses: 0.0005 $yr^{-1}$

Our results offer baseline data for estimating $CO_2$ emissions from blue carbon ecosystems degradation and benefits from conservation/restoration. These soil OC decay rates can inform Monitoring, Reporting, and Verification (MRV) frameworks and support default values for emissions accounting.

CIM Centro de Investigación Mariña Universidade de Vigo
CEAB exploring aquatic ecosystems
CSIC Consejo Superior de Investigaciones Científicas

**References: Belshe et al (2019).** Modeling organic carbon accumulation rates and residence times in coastal vegetated ecosystems. Journal of Geophysical Research: Biogeosciences 124, 3652–3671. **Clymo et al. (1998).** Carbon accumulation in peatland. Oikos 81. **Trevathan-Tackett et al. (2020).** Long-term decomposition captures key steps in microbial breakdown of seagrass litter. Science of The Total Environment.

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