Statistical Analysis of the GLOBOCARB Dataset (1900–2000)

Michael Schneider - TU Bergakademie Freiberg - Biogeochemistry WS 2025/26

Abstract. We tested whether organic carbon accumulation rates (OCAR) in the GLOBOCARB dataset (143 biome-decade means from 516 ^{210}Pb-dated cores) increased over the 20th century (H1) and more steeply in tropical than boreal regions (H2). Lake C burial rose 2.5-fold (49.0–121.1 Tg C yr^{-1}); post-1950 OCAR was 68.7% higher than pre-1950 (p = 0.004), supporting H1. Steeper tropical slopes (8.6× boreal; 7.9× excluding Mangroves, p = 0.002) confirmed H2. Including reservoirs, total burial reached 133.3 Tg C yr^{-1} by 2000, sequestering ~9.6 Pg C over the 20th century.

1 Introduction

Inland waters cover <4% of non-glaciated land but bury ~0.2 Pg C yr^{-1} in lake sediments- three times the per-area rate of ocean sediments (Cole et al., 2007; Tranvik et al., 2009). During the 20th century, reactive nitrogen deposition increased tenfold (Galloway et al., 2008) and phosphorus fertilizer use surged post-WWII. Anderson et al. (2020) synthesized 516 lake records and attributed burial increases primarily to nutrient enrichment rather than temperature. We test: **H1**: OCAR increased over the 20th century, with post-1950 rates exceeding pre-1950 rates. **H2**: The increase was steeper in tropical than boreal biomes, consistent with nutrient enrichment as the primary driver.

1.1 Data Provenance

The GLOBOCARB dataset was produced by a consortium led by N.J. Anderson (Loughborough University) with A.J. Heathcote and D.R. Engstrom (Science Museum of Minnesota), published in *Science Advances* (Anderson et al., 2020). The supplementary data is hosted on Mendeley Data (DOI: 10.17632/34hsd2jygc.1) under CC BY-NC 4.0. Lake areas derive from the Global Lakes and Wetlands Database (GLWD; Lehner & Döll, 2004); reservoir areas from GRanD (Lehner et al., 2011).

1.2 Connections to Other Datasets

GLOBOCARB complements the Global Carbon Budget (Friedlingstein et al., 2023), which tracks terrestrial/oceanic sinks but excludes inland-water burial. HydroLAKES (Messager et al., 2016) could disaggregate biome-level means to individual lakes. Nitrogen deposition datasets (e.g., Ackerman et al., 2019) would enable direct testing of the nutrient-enrichment mechanism.

2 Material and Methods

The dataset contains decadal OCAR means (g C m^{-2} yr^{-1}) for 13 biomes spanning 1900–2000 (143 observations). Two biomes- Large Lakes (OCAR = 10.43, SD = 0) and Flooded Grasslands (OCAR = 31.00, SD = 0) -have zero temporal variance, indicating placeholder data; these were included in total burial but excluded from trends (reliable n = 121). Analyses used R v4.5.2. Total C burial = OCAR × Lake Area × 10^6 / 10^{12}; reservoir burial computed analogously. Temporal trends were assessed via linear regression, Welch's t-test (pre-/post-1950), and mixed-effects models with random intercepts and slopes per biome (lme4). ANOVA assumptions failed (Shapiro-Wilk and Levene's p < 0.001); we report Welch's ANOVA with Games-Howell post-hoc tests. The tropical–boreal slope difference was tested via fixed-effects and mixed-effects interaction models. Sensitivity of total burial to suspect-biome exclusion was assessed. Tropical biomes were defined as Mangroves, Tropical Moist/Dry Forest, and Tropical Grasslands; boreal as Boreal Forest and Taiga and Tundra. The 1950 threshold follows Steffen et al. (2015), who identify this decade as the onset of the Great Acceleration. A GLS model with AR(1) errors per biome was fitted as a robustness check for temporal autocorrelation.

3 Results

3.1 Biome Differences and Temporal Patterns

OCAR is right-skewed (mean = 28.84, median = 17.85 g C m^{-2} yr^{-1}; range 1.86–145.67). Mangroves show the highest mean (92.9 ± 33.2), Tundra the lowest (3.6 ± 1.2). Welch's ANOVA confirms biome differences (F = 42.6, df = 10/42.5, $p < 2.2\times10^{-16}$, $\eta^2 = 0.75$); Games-Howell tests show Mangroves differ from all other biomes ($p < 10^{-13}$). Fig. 1 indicates temporal shifts from blue (1900) to red (2000), with suspect biomes flagged.

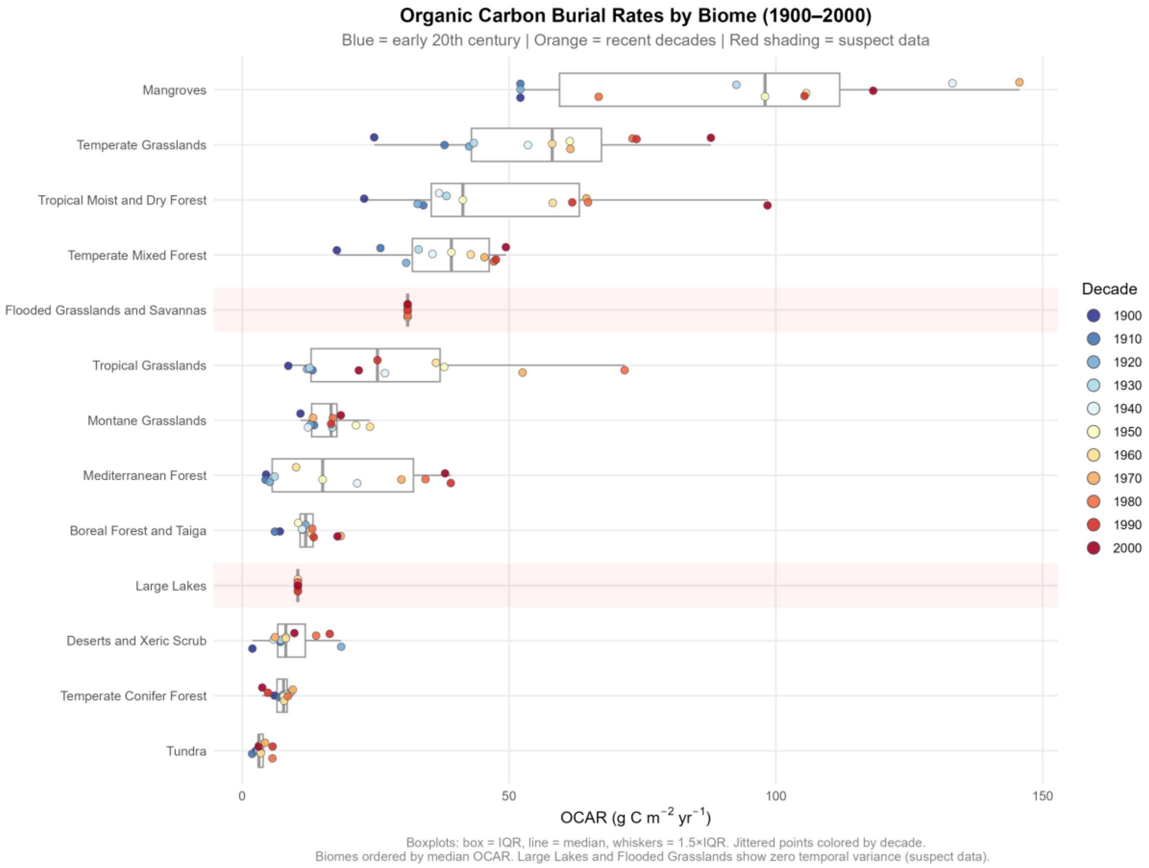

Fig. 1. OCAR by biome (1900–2000). Data: Anderson et al. (2020).

3.2 Temporal Trends and the Anthropocene Signal

Global OCAR increased (slope = 0.273 g C m^{-2} yr^{-1} per decade, R^2 = 0.084, p = 0.001). The low R^2 reflects inter-biome variation; a GLS model with AR(1) errors yielded an identical slope (0.273, SE = 0.083, p = 0.001; estimated AR(1) Phi = 0), confirming no detectable autocorrelation and that OLS standard errors are unbiased. A random-intercept/random-slope mixed-effects model (OCAR ~ Decade + (Decade | Biome)) further confirms a significant global upward trend after absorbing biome-level heterogeneity. The steepest increases occurred in Tropical Moist/Dry Forest (0.599/decade, R^2 = 0.85) and Temperate Grasslands (0.538, R^2 = 0.95). Post-1950 mean OCAR was 68.7% higher than pre-1950 (37.21 vs. 22.06; Welch's t = 2.94, p = 0.004, Cohen's d = 0.52), supporting H1. After Bonferroni correction (m = 11), only Temperate Grasslands (p_{corr} = 0.019) and Temperate Mixed Forest (p_{corr} = 0.038) remain individually significant.

3.3 Tropical vs. Boreal Trajectories

Tropical biomes show a linear slope of 0.518 g C m^{-2} yr^{-1} per decade vs. 0.060 for boreal (8.6× difference). A fixed-effects interaction model yields p = 0.048; a mixed-effects model with biome as random intercept confirms the divergence (t = 3.52 for the interaction term), supporting H2 (Fig. 2). Excluding Mangroves-coastal/tidal systems not strictly representative of freshwater lakes - the tropical slope reduces to 0.473/decade (ratio: 7.9×) but the interaction strengthens markedly (p = 0.002), confirming that H2 is robust and not an artefact of Mangrove inclusion. This divergence supports H2: despite Arctic Amplification driving faster warming in high latitudes, the steeper tropical rise confirms that land-use change and nutrient loading- not temperature- are the primary drivers. The 8.6× slope difference reflects intensified soil erosion and allochthonous C delivery in the tropics, amplified by deforestation and precipitation (Amora-Nogueira et al., 2022).

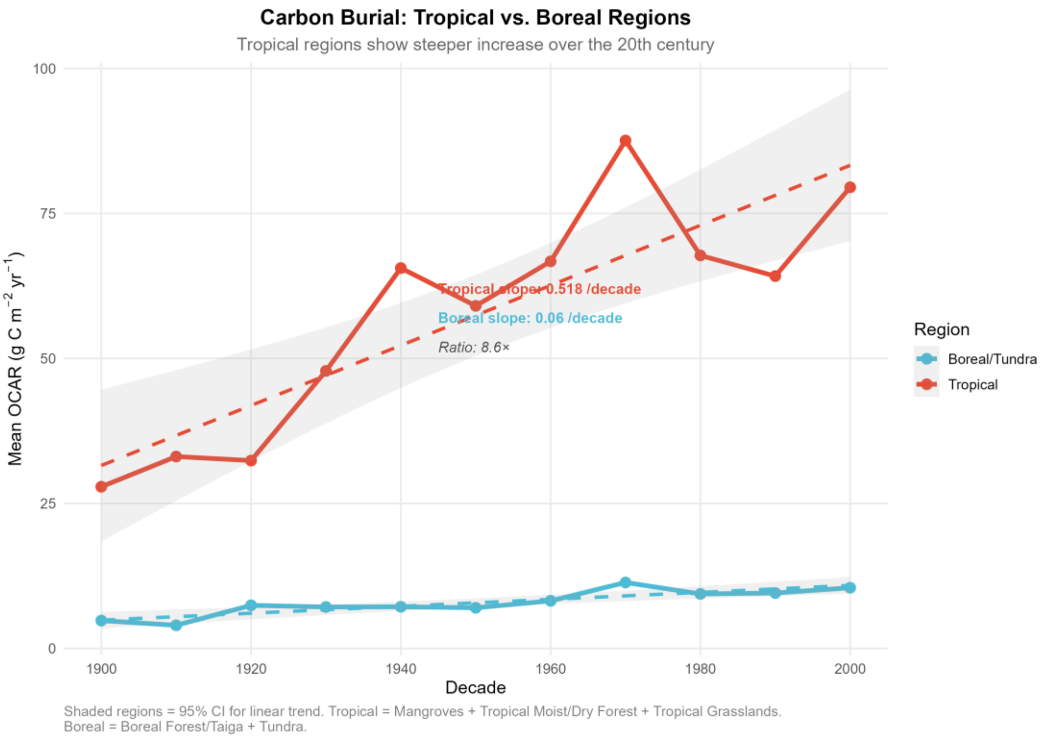

Fig. 2. Tropical vs. boreal OCAR trajectories (1900–2000). Data: Anderson et al. (2020).

3.4 Total Carbon Burial and Reservoir Contribution

Lake C burial rose from 49.0 to 121.1 Tg C yr^{-1} (2.5-fold; Fig. 3). In 2000, Boreal Forest/Taiga contributed 24.2% despite low OCAR due to vast spatial extent (1.64×10^{6} km^{2}), followed by Tropical Moist/Dry Forest (21.9%); Mangroves contributed only 3.1%. Reservoir burial grew from <0.1 to 12.2 Tg C yr^{-1} (9.1% of the combined 133.3 Tg C yr^{-1} sink in 2000). However, applying natural-lake OCAR to reservoirs is likely conservative; given their higher watershed-to-lake area ratios and trapping efficiencies (Vörösmarty et al., 2003; Mendonça et al., 2017), the true anthropogenic sink is likely considerably larger. The Spearman correlation between reservoir area and OCAR ($\rho = 0.167$, $p = 0.067$) remained significant unexpectedly after linear detrending ($\rho = 0.228$, $p = 0.012$), possibly an artifact of non-linear reservoir expansion rates rather than a causal link. Integrating decadal burial rates across the century yields a cumulative lake sink of ~9.6 Pg C (10.0 Pg C including reservoirs). Propagating within-biome OCAR variability in quadrature gives a lake burial uncertainty of ±10.7 Tg C yr^{-1} in 2000 (reported as 121.1 ± 10.7 Tg C yr^{-1}). Sensitivity analysis confirms the two suspect biomes contribute a fixed absolute amount (11.56 Tg C yr^{-1}) across all decades; their relative share declines from ~24% (1900) to ~10% (2000) as total burial grows, while temporal trend analyses are unaffected by their exclusion.

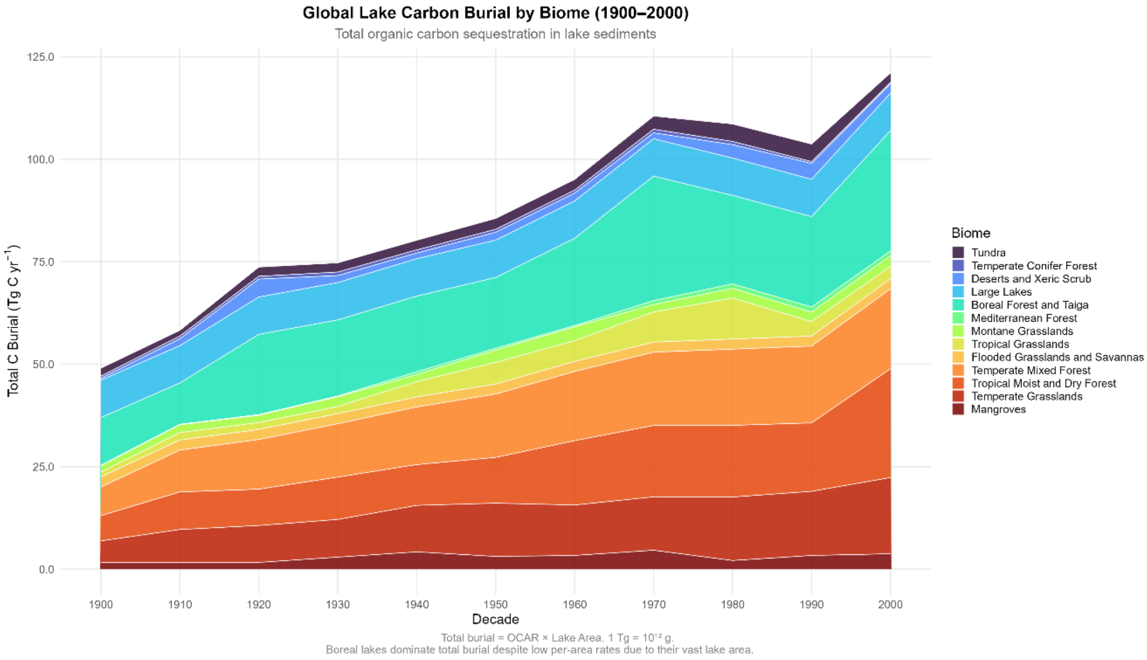

Fig. 3. Global lake carbon burial by biome (1900–2000). Data: Anderson et al. (2020).

4 Discussion

The 2.5-fold burial increase is consistent with independent estimates: Mendonça et al. (2017) estimated global inland-water C burial at 0.15 Pg C yr^{-1} via mass-balance, and Kastowski et al. (2011) reported 0.05–0.07 Pg C yr^{-1} for lakes- our 2000 estimate of 0.12 Pg C yr^{-1} falls within this range. Heathcote et al. (2015) found 3–5× higher contemporary burial in northern lakes versus Holocene baselines, implicating nitrogen deposition. The tropical-boreal divergence is consistent with Amora-Nogueira et al. (2022), who showed tropical lakes bury carbon at ~3× boreal rates due to greater allochthonous inputs.

Two caveats deserve emphasis. First, each observation is a biome-decade mean; while a GLS model with AR(1) errors detected no residual autocorrelation (Phi = 0, slope unchanged), standard errors remain underestimated at the lake level without individual core data. The mixed-effects model partially addresses biome-level heterogeneity, but lake-level replication would be needed for fully conservative inference. Second, the tropical time series (Fig. 2) suggests a possible leveling in the 1980s–1990s; GAMs or changepoint analysis could identify acceleration phases. The additional ~72 Tg C yr^{-1} offsets 20–30% of freshwater CO_2 emissions (Raymond et al., 2013) and, equivalent to ~2.6% of the ocean sink (~2.8 Pg C yr^{-1}; Friedlingstein et al., 2023), represents storage on 10^2–10^4 year timescales.

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Supplementary Material. All source code, statistical output, and additional figures are available on GitHub (github.com/michi-sxc/biogeochem).

Declaration of Authorship

I hereby confirm that I have written this report independently and have not used any sources and aids other than those specified. The manuscript's language and style were partly refined using DeepL Write (DeepL SE, 2026). This AI-assisted writing tool was employed for grammar correction and language enhancement while maintaining the original scientific content and meaning.

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