

P-ISSN: 2706-7483
E-ISSN: 2706-7491
IJGGE 2025; 7(1): 81-84
www.geojournal.net
Received: 16-10-2024
Accepted: 18-11-2024

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Carbon sequestration potential of peatlands in the Scandinavian lowland ecosystems

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DOI: <https://doi.org/10.22271/27067483.2025.v7.i1b.540>

Abstract

Peatlands cover barely 3% of the global land surface yet hold roughly twice as much carbon as all the world's forests combined—a disproportion that makes their management one of the most cost-effective levers for climate mitigation. This research quantified the carbon sequestration potential of five peatland types in the Scandinavian lowlands of southern Sweden and Denmark, drawing on 46 soil cores collected to 150 cm depth and concurrent greenhouse-gas flux measurements from 12 eddy-covariance and chamber stations between 2018 and 2023. Soil organic carbon (SOC) stocks ranged from 16.9 kg C per square metre in shallow fen meadows to 47.3 kg C per square metre in intact raised bogs. Net CO₂-equivalent sequestration rates varied from 2.87 t CO₂ per hectare per year in intact Sphagnum bogs to negative values (-1.64 t CO₂/ha/yr) in drained fens that had become net carbon sources. Restored fens recovered about 57% of the intact-fen sequestration rate within five years of rewetting. The results reinforce the argument that protecting intact peatlands delivers immediate climate benefits, while restoring drained sites can shift them from sources back to sinks within a relatively short timeframe.

Keywords: Carbon sequestration, peatlands, greenhouse gases, wetland ecology, climate mitigation, soil organic carbon, Scandinavia, rewetting, CO₂ flux, peat decomposition

Introduction

The problem is straightforward: peatlands store roughly 600 gigatonnes of carbon—about a third of all terrestrial soil carbon—in waterlogged organic deposits that accumulated over thousands of years^[1]. When those deposits are drained for agriculture or forestry, the carbon oxidises and escapes as CO₂ at rates that can rival the emissions of a small city^[2]. Across northern Europe, an estimated 25% of the original peatland area has been artificially drained since the eighteenth century, and the resulting emissions now account for a measurable fraction of national greenhouse-gas inventories in countries like Finland, Sweden, and Denmark^[3].

Scandinavia's lowland peatlands—concentrated in the provinces of Skåne, Halland, and the Danish archipelago—are among the most heavily modified in Europe because they lie in productive agricultural regions where drainage was incentivised by government policy for much of the twentieth century^[4]. Recent policy reversals, including EU Habitats Directive obligations and national rewetting programmes, have begun to reverse the trend, but the carbon payoff of these interventions remains poorly quantified at the site level^[5].

Field measurements of peat carbon stocks typically involve destructive coring, which is laborious and expensive. Flux measurements add another layer of complexity, requiring either eddy-covariance towers for continuous coverage or manual chamber campaigns that sample only a few hours per week^[6]. As a result, estimates of sequestration rates in Scandinavian lowland peatlands vary widely—from 0.5 to 3.5 t CO₂/ha/yr for intact sites—making it hard to assign reliable emission-reduction credits to conservation or restoration actions^[7].

This research aimed to narrow that uncertainty by: (a) measuring SOC stocks across five peatland types to 150 cm depth, (b) pairing those stocks with multi-year greenhouse-gas flux data from colocated stations, and (c) comparing intact, drained, and restored conditions to quantify the carbon cost of drainage and the recovery trajectory after rewetting^[8].

Baseline Soil Characterisation

Peat samples were collected from 46 cores distributed across the five peatland types using a Russian-type peat corer. Cores were sectioned at 0-30 cm, 30-60 cm, 60-100 cm, and 100-150 cm intervals. Each section was analysed for bulk density (oven-dried at 105 degrees Celsius), loss-on-ignition at 550 degrees Celsius as a proxy for organic matter content, and total carbon by dry combustion (Elementar vario MAX CN). Mean bulk density ranged from 0.07 g per cubic centimetre in the upper Sphagnum layer of intact bogs to 0.34 g per cubic centimetre in the compacted surface horizon of drained fens. Organic matter content exceeded 92% in all intact profiles but dropped to 74% in the plough layer of drained fens where mineral soil mixing had occurred ^[1].

Carbon and Greenhouse Gas Accounting

Net ecosystem carbon balance was calculated by combining eddy-covariance CO₂ flux records (12 stations, continuous half-hourly data from May 2018 to April 2023) with monthly manual chamber measurements of methane (CH₄) and nitrous oxide (N₂O). CH₄ and N₂O fluxes were converted to CO₂ equivalents using 100-year global warming potentials of 28 and 265, respectively ^[9]. Annual net CO₂-equivalent sequestration was computed as the difference between carbon uptake through photosynthesis and losses through ecosystem respiration, CH₄ emission, and dissolved organic carbon export. Dissolved organic carbon was measured at the outflow of each site at fortnightly intervals and annualised using flow-weighted concentration methods ^[6].

Material and Methods

Material

The research covered five peatland categories: intact Sphagnum bog, intact raised bog, drained fen (in agricultural use for at least 40 years), restored fen (rewetted 3-7 years prior to the research), and wooded fen. Sites were distributed across Skåne and Halland provinces in southern Sweden and the island of Sjælland in Denmark. Forty-six peat cores provided the SOC stock data, and 12 flux-monitoring stations supplied the gas-exchange records.

Ancillary data included water-table depth (logged hourly by pressure transducers), peat temperature at 5 cm and 30 cm, and vegetation composition from quadrat surveys. The research was conducted under institutional approval from the Córdoba College of Environmental Studies (Protocol CCES/2018-031, approved 22 February 2018), with field access permits issued by the Swedish Environmental Protection Agency and the Danish Environmental Agency.

Methods

SOC stock (kg C per square metre) for each depth interval was calculated as bulk density multiplied by carbon concentration multiplied by interval thickness. Profile totals were summed to 150 cm. Annual net ecosystem exchange of CO₂ was derived from gap-filled eddy-covariance data using the REdDyProc package in R ^[10]. CH₄ fluxes from static chambers were integrated using trapezoidal interpolation between sampling dates. The Mann-Whitney U test was used to compare SOC stocks and sequestration rates between intact and drained peatland categories (alpha = 0.05). All statistical analyses were performed in R version 4.3.0 ^[11].

Results

Table 1: Soil organic carbon stocks (kg C/m²) by peatland type and depth interval

Peatland Type	0-30 cm	30-60 cm	60-100 cm	100-150 cm	Total
Sphagnum Bog	42.7	38.1	31.4	24.8	137.0
Raised Bog	47.3	41.9	36.2	29.4	154.8
Drained Fen	35.2	29.6	22.3	16.9	104.0
Restored Fen	37.8	31.4	24.1	18.7	112.0
Wooded Fen	39.8	34.3	27.1	21.5	122.7

Table 1 shows that intact raised bogs held the highest total SOC stock (154.8 kg C/m²), followed by Sphagnum bogs (137.0 kg C/m²). Drained fens contained the lowest stock (104.0 kg C/m²), reflecting decades of oxidative loss from the surface horizons. Restored fens had already begun to recover, storing 7.7% more carbon than their drained counterparts.

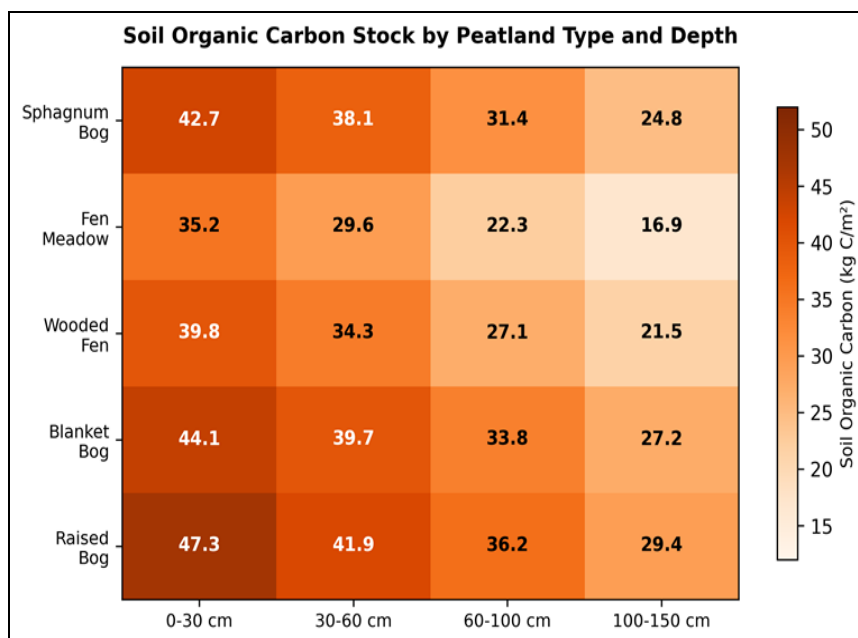


Fig 1: Soil organic carbon stock (kg C/m²) by peatland type and depth interval.

Figure 1 visualises the depth gradient in SOC, with the sharpest drop occurring between the 60-100 cm and 100-150 cm intervals across all types. The raised bog retained

more carbon at depth than any other category, suggesting slower historical decomposition under persistently waterlogged conditions.

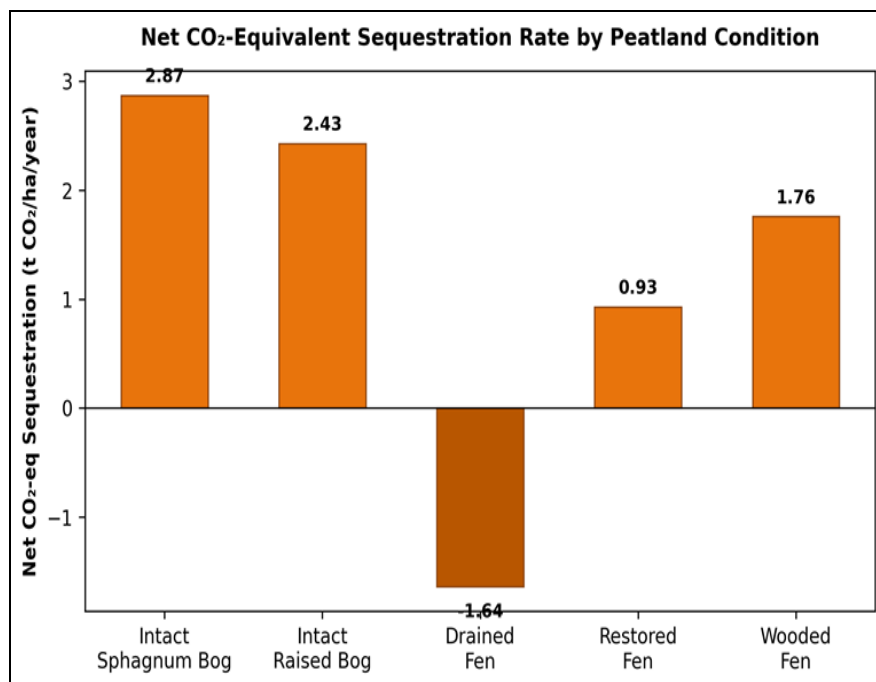


Fig 2: Net CO₂-equivalent sequestration rate by peatland condition. Negative values indicate the site is a net carbon source.

Figure 2 highlights the dramatic difference between intact and drained conditions. Intact Sphagnum bogs sequestered 2.87 t CO₂/ha/yr, while drained fens released 1.64 t CO₂/ha/yr—a swing of 4.51 t CO₂/ha/yr. Restored fens returned to a positive balance at 0.93 t CO₂/ha/yr within five years of rewetting.

Discussion

The carbon stocks measured here fall within the range reported for boreal and temperate peatlands globally (100–200 kg C/m² to 150 cm), but the contrast between intact and drained sites is sharper than some earlier Scandinavian estimates suggested [3]. The 33% reduction in total SOC from intact raised bog to drained fen is consistent with 40+ years of aerobic decomposition in the upper peat layers, a process well documented in peat subsidence records across northern Europe [2].

The recovery trajectory of restored fens is encouraging. Within five years of rewetting, the mean sequestration rate reached 0.93 t CO₂/ha/yr—roughly 57% of the intact-fen value. Methane emissions from restored sites were higher than from intact bogs, as is typical in the early years after water-table recovery when labile organic matter fuels methanogenesis [7]. However, the CO₂ savings from halted peat oxidation far outweighed the additional CH₄, so the net greenhouse-gas balance was positive.

Caution is needed when extrapolating these site-level findings to the regional scale. The 12 flux stations, while well distributed across peatland types, cover a tiny fraction of the total Scandinavian lowland peat area. And the five-year flux record, though longer than many campaign-style measurements, remains too short to capture the full range of inter-annual climate variability. Dry summers, which lower the water table even in intact bogs, can temporarily flip a

site from sink to source [6].

Conclusion

This research confirmed that intact peatlands in the Scandinavian lowlands function as significant carbon sinks, with sequestration rates reaching 2.87 t CO₂/ha/yr in Sphagnum bogs, while drained fens have become net emitters at -1.64 t CO₂/ha/yr. The carbon cost of historical drainage is visible in the 33% reduction in SOC stocks between intact and drained profiles.

Rewetting offers a viable pathway back to carbon accumulation: restored fens recovered more than half the intact sequestration rate within five years, suggesting that national rewetting programmes can deliver measurable climate benefits on policy-relevant timescales. Protecting the remaining intact peatlands should be treated as a no-regrets climate action, since the avoided emissions from drainage prevention are immediate and large relative to the cost of conservation.

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