Supplemental Information

Title. Prompt active restoration of peatlands substantially reduces climate impact

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S1 Study sites information

The four tables provided below detail the main characteristics of the study sites, the measurements that were taken, how the data was managed and the annual flux results.

| Site Name          | Coordinates     | Climate           | Ecosystem State/Type                      | Age at study start (yr) | Vegetation Composition | T (°C)   | P (mm) | WTD (m) | References                          |
|--------------------|-----------------|-------------------|------------------------------------------|------------------------|------------------------|----------|--------|---------|-------------------------------------|
| Bois-des-Bel       | 47.97 N, 69.43 W | Temperate         | Unrestored peat extraction site          | 19                     | BP, O                  | 3.5 ± 2.9 | 964     | 0.55     | Waddington et al., 2010             |
| Bois-des-Bel       |                 |                   | Restored peat extraction site            | 1                      | BP, S, E, O            |          |        | 0.32     | Waddington et al., 2010             |
| Bois-des-Bel       |                 |                   | Restored peat extraction site            | 14                     | S, ES, E, O            | 0.29 ± 0.12 |        | 0.29 ± 0.12 | Nugent et al., 2018               |
| Mer Bleue          | 45.41 N, 75.52 W | Temperate continental | Intact ombrogenic bog                   | 8500                   | S, ES, E, O            | 6.4 ± 0.8 | 943     | 0.41 ± 0.06 | Nugent et al., 2018               |
| Saint-Alexandre    | 47.73 N, 69.61 W | Temperate         | Unrestored peat extraction site          | 14                     | BP, E, O               | 3.5 ± 2.9 | 964     | 0.46 ± 0.14 | Rankin et al., 2018; this study    |
| Seba Beach Restored| 53.46 N, 114.88 W | Boreal continental | Unrestored peat extraction site          | 1                      | S, C, E, O             | 3.5 ± 1.1 | 550     | 0.45 ± 0.12 | This study                         |
| Seba Beach Unrestored| 53.46 N, 114.88 W | Boreal continental | Unrestored peat extraction site          | 1                      | BP                     | 3.5 ± 1.1 | 550     | 0.66 ± 0.07 | This study                         |
| Seba Beach Wet     | 53.46 N, 114.88 W | Boreal continental | Restored peat extraction site            | 4                      | O, S, BP, E            | 3.5 ± 1.1 | 550     | 0.34 ± 0.07 | This study                         |

Temperature (T) and precipitation (P) are 30-year climate normals (1981-2010; Environment Canada), water table depth (WTD) refers to seasonal averages, with positive values indicating a water table below the surface.

S, Sphagnum spp.; ES, ericaceous shrub spp.; E, Eriophorum spp.; C, Carex spp.; O, others; BP, bare peat.
| Site name          | Timeline          | Measurement technique, CO₂ fluxes | Measurement technique, CH₄ fluxes | DOC fluxes | References                  |
|-------------------|-------------------|-----------------------------------|----------------------------------|------------|-----------------------------|
| Bois-des-Bel      | 1999-2001         | -                                 | -                                | Yes        | Waddington et al., 2008     |
|                   | 1999-2002         | -                                 | Closed chambers                  | -          | Waddington and Day, 2007    |
|                   | 2000-2001         | Eddy covariance LI-7500           | -                                | -          | Petrone et al., 2003        |
|                   | 2014-2016         | Eddy covariance LI-7500A          | Eddy covariance LI-7700          | Yes        | Nugent et al., 2018         |
| Mer Bleue         | 1999-2015         | Eddy covariance LI-7000           | Autochambers LI-6262             | Yes        | Nugent et al., 2018         |
| Saint-Alexandre   | 2014-2015         | Eddy covariance LI-7500A          | Eddy covariance LI-7700          | -          | Rankin et al., 2018; this study |
| Seba Beach Restored | 2013-2015        | -                                 | Closed chambers                  | -          | This study                  |
|                   | 2014-2015         | Eddy covariance LI-7500A          | -                                | -          | This study                  |
|                   | 2016              | Eddy covariance LI-7500A          | Eddy covariance LI-7700          | -          | This study                  |
| Seba Beach Unrestored | 2013-2015   | -                                 | Closed chambers                  | -          | This study                  |
|                   | 2014              | Eddy covariance LI-7500A          | -                                | -          | This study                  |
| Seba Beach Wet    | 2016              | Eddy covariance LI-7500A          | Eddy covariance LI-7700          | -          | This study                  |
Table S1.3  
| Site name              | Timeline          | Gap-filling CO₂                                                                 | Gap-filling CH₄                                      | References                          |
|------------------------|-------------------|--------------------------------------------------------------------------------|-----------------------------------------------------|-------------------------------------|
| Bois-des-Bel           | 1999-2002         | -                                                                               | Weighted average seasonal flux                       | Waddington and Day, 2007            |
|                        | 2000-2001         | Time dependent light and temperature response (e.g. Barr et al., 2004)          | -                                                   | Petrone et al., 2003                |
|                        | 2014-2016         | Marginal distribution sampling method (MDS; e.g. Reichstein et al., 2005)       | MDS, exponential temperature model                   | Nugent et al., 2018                |
| Mer Bleue              | 1999-2015         | Time dependent light and temperature response                                 | Linear regression with log 10 flux                   | Roulet et al., 2007; Lai et al., 2012 |
| Saint-Alexandre        | 2014-2015         | MDS                                                                             | MDS, exponential temperature model                   | Refer to Nugent et al., 2018       |
| Seba Beach Restored    | 2013-2015         | -                                                                               | Weighted average seasonal flux                       | refer to Strack et al., 2016       |
|                        | 2014-2015         | MDS                                                                             | -                                                   | refer to Nugent et al., 2018       |
|                        | 2016              | MDS                                                                             | MDS, exponential temperature model                   | refer to Nugent et al., 2018       |
| Seba Beach Unrestored  | 2013-2015         | -                                                                               | Weighted average seasonal flux                       | refer to Strack et al., 2016       |
|                        | 2014              | MDS                                                                             | -                                                   | refer to Nugent et al., 2018       |
| Seba Beach Wet         | 2016              | MDS                                                                             | MDS, exponential temperature model                   | refer to Nugent et al., 2018       |
Table S1.4  
Annual CO\(_2\), CH\(_4\) and DOC fluxes at the study sites

| Site name                        | Period      | Chronosequence | CO\(_2\) (95% CI) (g C m\(^{-2}\) yr\(^{-1}\)) | CH\(_4\) (95% CI) (g C m\(^{-2}\) yr\(^{-1}\)) | DOC (g C m\(^{-2}\) yr\(^{-1}\)) |
|----------------------------------|-------------|----------------|-----------------------------------------------|---------------------------------------------|-----------------------------------|
| Bois-des-Bel (unrestored section) | 1999        | UNR            | -                                             | 0.1                                         | 31.7                              |
|                                  | 2000        | UNR            | -                                             | 0.9                                         | 33.7                              |
|                                  | 2001        | UNR            | -                                             | 0.4                                         | 48.6                              |
|                                  | 2002        | UNR            | -                                             | 1.0                                         | -                                 |
| Bois-des-Bel (section restored in Fall 1999) | 1999        | UNR            | -                                             | 0.0                                         | 26.2                              |
|                                  | 2000        | RES-1yr        | 695 (587-804)\(^2\)                           | 0.1                                         | 7.9                               |
|                                  | 2001        | RES-1yr        | 685 (577-794)\(^2\)                           | 1.4                                         | 10.6                              |
|                                  | 2002        | RES-4yr        | -                                             | 4.1                                         | -                                 |
|                                  | 2014        | RES-15yr       | -94 (-102--82)                                | 4.4 (4.3-4.5)                               | 9.2                               |
|                                  | 2015        | RES-15yr       | -105 (-111--97)                               | 4.5 (4.3-4.6)                               | 6.6                               |
|                                  | 2016        | RES-15yr       | -70 (-76--63)                                 | 4.2 (4.1-4.4)                               | 4.8                               |
| Mer Bleue                        | 1999-2015   | REF (RES-30yr) | -73 ± 40\(^1\)                               | 6 ± 4\(^1\)                                 | 17 ± 3\(^1\)                     |
| Saint-Alexandre                  | 2014        | UNR-15yr       | 173 (169-177)                                 | 0.5 (0.5-0.6)                               | -                                 |
|                                  | 2015        | UNR-15yr       | 259 (253-274)                                 | 0.8 (0.7-0.8)                               | -                                 |
| Seba Beach Restored              | 2013        | RES-1yr        | -                                             | 1.8                                         | -                                 |
|                                  | 2014        | RES-1yr        | 275 (271-279)                                 | 0.9                                         | -                                 |
|                                  | 2015        | RES-1yr        | 362 (358-366)                                 | 1.5                                         | -                                 |
|                                  | 2016        | RES-4yr        | 225 (220-231)                                 | 1.2 (1.1-1.3)                               | -                                 |
| Seba Beach Unrestored            | 2013        | UNR-1yr        | -                                             | 0.7                                         | -                                 |
|                                  | 2014        | UNR-1yr        | 445 (426-460)                                 | 0.4                                         | -                                 |
|                                  | 2015        | UNR-1yr        | -                                             | 0.5                                         | -                                 |
| Seba Beach Wet                   | 2016        | RES-4yr        | 65 (54-72)                                    | 7.6 (7.0-8.0)                               | -                                 |

\(^1\) Mean ± SD for the 17-year period

\(^2\) Annual flux was estimated from the published seasonal flux by adding 1 (± 0.5) g C m\(^{-2}\) day\(^{-1}\) for the missing period.
**S2 Additional model methodology**

We simulated the peatland atmospheric flux perturbations as annual net fluxes of CO₂ and CH₄ from peatland initiation to 500 years after peat extraction termination that occurred in 1980 CE. The spin up period, of peatland initiation through to extraction termination, was used to establish an atmospheric concentration perturbation baseline. Peat accumulation at Bois-des-Bel was 3 m over 6985 years (Lavoie et al., 2001) and was represented as a constant CO₂ sequestration rate of 22 g CO₂-C m⁻² yr⁻¹. Peat extraction lasted 10 years, during which 334 g CO₂-C m⁻² yr⁻¹ and 0.5 g CH₄-C m⁻² yr⁻¹ was emitted. The CO₂ flux is based on a 19-yr peat oxidation/erosion rate of 5.7 ± 1.1 mm y⁻¹ measured at Bois-des-Bel prior to restoration (Waddington and McNeil, 2002). This gas loss during extraction implicitly includes wind erosion and particulate organic carbon (POC) export, the latter of which can represent upward of 65% of total carbon loss at peat extraction sites (excluding extracted peat) (Evans et al., 2016). For this analysis, we assume that any POC exported was oxidized during the year it was lost. The CH₄ flux for the extraction period is a multiplication of ditch cover fraction (0.05) and mean growing season ditch emissions (10.9 g CH₄-C m⁻²) measured in a section of Bois-des-Bel that remains unrestored (Waddington and Day, 2007). While we lack direct measurements from peatlands under extraction, we expect the fluxes to be broadly similar, as no management actions occurred at the site after extraction termination.

**S3 Additional model analysis including nitrous oxide**

We neglected N₂O emissions in our main analysis because we had insufficient data from our undrained, unrestored and restored post-extraction peatlands to make a defensible estimate of mean annual fluxes. IPCC Tier 1 assumes a N₂O flux of 0.03 g N m⁻² yr⁻¹ when drained and a
negligible flux after rewetting (IPCC, 2014). The N₂O lifetime in the atmosphere is 121 years (Myhre et al., 2013), whereby a constant addition to the atmosphere will reach equilibrium after about 500 years. Thus, the climate impact of even a small amount of N₂O is likely non-negligible over the 500-year time frame of our study. To test this, we conducted an additional IPCC Tier 1 simulation with N₂O included. Figure S3.1, which compares the no rewetting scenario with and without N₂O, clearly demonstrates the N₂O emission rates being discussed for post-extraction peatlands have a minimal climate impact relative to CO₂ and CH₄.

![Figure S3.1](image)

**Figure S3.1** Instantaneous net radiative forcing of a post-extraction unrestored peatland using IPCC Tier 1 emission factors with (light blue line) and without (dark blue line) N₂O emission included.
S4 Comparison of atmospheric perturbation model results to applying the global warming potential metric

In Table S4.1, modelled RF and GWP show both a net warming effect for the Drained/Unrestored scenario. However, RF is increasing with longer timeframes while GWP is decreasing (Table S4.1). The difference is caused by considering a one-time pulse emission for GWP vs. continuous emissions for the modelled RF. Constant net CO₂ emissions for the Drained/Unrestored scenario lead to a steadily increasing positive RF. In contrast, the shorter atmospheric lifetime of CH₄ (compared to CO₂) causes GWP to decrease from the 20- to 100-year timeframe (Table S4.1). If continuous CH₄ emissions would be considered, instantaneous RF would increase and then remain constant after a few decades (Neubauer & Megonigal, 2015). Since a drained/unrestored peatland is a constant source of CO₂ and CH₄, modelled instantaneous RF is the appropriate tool to assess climate impacts.

For the Prompt Rewetted/Restored scenario, GWP is positive for Tier 1 for both timeframes, positive for Tier 2 for the 20-year timeframe and negative for Tier 2 for the 100-year timeframe (Table S4.1). The larger reductions in GWP between the 20- and 100-year timeframe compared to the Drained/Unrestored scenario are due to larger contributions from CH₄ emissions. For the Tier 2, the Prompt Rewetted/Restored scenario has a cooling effect (i.e. negative RF) for the 100- and 500-year timeframe (Table S4.1). The switch is caused by the development of a continuous net CO₂ sink, which leads to a cooling effect due to the longer atmospheric lifetime of CO₂ compared to CH₄. In this case, using a GWP approach does also identify the cooling effect of prompt rewetting/restoring activities within a century.
|                        | RF (nW m\(^{-2}\)) | GWP (g CO\(_2\)e m\(^{-2}\) yr\(^{-1}\)) |
|------------------------|---------------------|--------------------------------------|
|                        | at 20 yr | at 100 yr | at 500 yr | over 20 yr | over 100 yr |
| Drained/Unrestored     | Tier 1    | 0.36 (0.13 - 0.59) | 1.15 (0.45 - 1.79) | 3.80 (1.53 - 5.81) | 1405 (457 - 2207) | 1220 (420 - 1874) |
|                        | Tier 2    | 0.18 (0.11 - 0.25) | 0.76 (0.43 - 1.08) | 2.90 (1.76 - 4.07) | 963 (592 - 1341) | 926 (570 - 1289) |
| 20-yr Delay Rewetted/Restored | Tier 1 | 0.36 (0.13 - 0.59) | 0.46 (-0.07 - 2.29) | 0.28 (-0.56 - 2.70) | - | - |
|                        | Tier 2    | 0.18 (0.11 - 0.25) | 0.14 (-0.25 - 0.58) | -0.41 (-1.38 - 0.62) | - | - |
| Prompt Rewetted/Restored | Tier 1 | 0.27 (-0.04 - 1.58) | 0.32 (-0.17 - 2.06) | 0.31 (-0.63 - 2.53) | 1027 (-160 - 5190) | 339 (-182 - 1862) |
|                        | Tier 2    | 0.03 (-0.09 - 0.10) | -0.09 (-0.46 - 0.21) | -0.57 (-1.52 - 0.33) | 190 (85 - 299) | -140 (-229 - 45) |
### S5 Relative climate benefit of peatland restoration actions

The relative climate benefit of peatland restoration actions at 20 years, calculated by defining a reference and calculating the difference in net radiative forcing between the baseline and alternative management action.

| Table S5.1 | Prompt active restoration | Active restoration | No restoration | Prompt average rewetting | Average rewetting | No rewetting |
|-------------|---------------------------|--------------------|---------------|--------------------------|------------------|-------------|
| Prompt active restoration | -                         | -83%               | -83%          | -89%                     | -92%             | -92%        |
| Active restoration           |                           |                    | 0%            | -32%                     | -50%             | -50%        |
| No restoration               |                           |                    | -32%          | -50%                     | -50%             | -50%        |
| Prompt average rewetting     |                           |                    | -26%          | -26%                     | -26%             | -26%        |
| Average rewetting            |                           |                    | -             | 0%                       | -                | -            |
| No rewetting                 |                           |                    |               |                          |                  |             |

Negative values in Table S5.1 indicate a reduction in radiative forcing. Example: After 20 years, Prompt Active Restoration results in an 83% reduction in the radiative forcing when compared with No Restoration.
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