1 S1. Cell count to volume conversion
2 \[ \text{Length} = h_1 \]
3 \[ \text{Width} = h_2 \]
4 \[
\text{bacterial carbon} = \left( \frac{\pi}{4} \times h_2^2 \times \left( \frac{h_1 - h_2}{3} \right) \right) \times 2.2 \times 10^{-7}
\]
5 (Bratbak and Dundas, 1984)

---

6 S2. \(^3\text{H}\)-Leucine concentration calibration

(S2) Fig. S1. \(^3\text{H}\)-Leucine concentration calibration (error bars show 1 standard deviation).

---

7 S3. Model Implementation and set-up

7.1 Initial conditions

Initial conditions are informed by analysis of 0-years-of-exposure soil collected adjacent to the ice
snout, and values for all state variables are presented in Table - state variables and initial conditions.
Microbial biomass is estimated by microscopy. Initial community structure is derived by 16S analysis
of year-0 soils. An initial value for carbon substrate (\(S_1 + S_2\)) is estimated based on the average TOC
content of year-0 soil (Carlo-Erba NC2500 elemental analyzer). Bioavailability is assumed to be 30%
labile (\(S_1\)) and 70% refractory (\(S_2\)). Organic Nitrogen (ON) and organic Phosphorus (OP) are
assumed to be stoichiometrically linked by the measured C:N:P ratio from which the model was
initially developed and tested (Bradley et al., 2015). An initial value for DIN is taken from a previous
evaluation of biogeochemistry of Svalbard tundra, whereby the lowest value is taken to represent the
soil of least development, according to traditional understanding of forefield nutrient dynamics (Alves
et al., 2013; Bradley et al., 2014). An initial value for DIP is established stoichiometrically from
previous model development and testing.
S3.2. Forcing data

The following external forcings drive and regulate the system’s dynamics:

- Photosynthetically-active radiation (PAR) (wavelength of approximately 400 to 700nm) (W m$^{-2}$).
- Snow depth (m).
- Soil temperature (°C).
- Allochthonous inputs (µg g$^{-1}$ d$^{-1}$).

Soil temperature (at 1cm depth) for the entire of 2013 is provided by AWI from the permafrost observatory near Ny-Ålesund, Svalbard. Similarly, PAR for 2013 is measured at the AWI meteorological station near Ny-Ålesund, Svalbard. Averaged daily snow depth for 2009 to 2013 is provided by the Norwegian Meteorological Institute (eKlima). The presence of snow on the ground attenuates sunlight and inhibits PAR from reaching the soil surface. This is accounted for in preprocessing of forcing data. Light attenuation is estimated according to the equation:

$$n = n_0 e^{-mx}$$

(S2)

Whereby $n$ is the irradiance (W/m$^2$), $x$ is the snow depth (m) and $m$ is the extinction coefficient for snow. The extinction coefficients for various types of snow can be measured and an estimate of 6 is used in this instance to represent snow in the Midtre Lovénbreen forefield (Greenfell and Maykut, 1977). Due to its high latitude, the study site experiences continual daylight for much of the summer and continual darkness for much of the winter. Forcing data is provided as daily averages, and linear interpolation is used between any (very infrequent) missing data points.

Allochthonous inputs are estimated based on the best available budget of catchment hydrology and nutrients for Midtre Lovénbreen presented in Hodson et al. (2005). Data from two summer-winter seasons allow nutrient deposition, runoff and retention to be estimated. In SHIMMER, prescribed inputs ($I$) are only partially retained ($v$). $v_{DIN}$ is equal to the average of the residual (retained) DIN divided by the total DIN deposition flux over the two years of observations. The retention flux is assumed to be equal for all nutrient species ($v_{DIN} = v_{Sub} = v_{DIP}$) and this allows the total deposition of DIP to be back-calculated from the runoff flux.

$$v_{DIN} = \frac{retention}{inputs \ (snow \ & \ rain)}$$

(S3)
Table S1. \(v\)-values

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(v_{\text{NO}_3\ 1999})</td>
<td>0.146</td>
</tr>
<tr>
<td>(v_{\text{NH}_4\ 1999})</td>
<td>-0.056</td>
</tr>
<tr>
<td>(v_{\text{NO}_3\ 2000})</td>
<td>-0.089</td>
</tr>
<tr>
<td>(v_{\text{NH}_4\ 1999})</td>
<td>0.688</td>
</tr>
<tr>
<td>average (v_{\text{DIN}})</td>
<td>0.172</td>
</tr>
</tbody>
</table>

\(I_{\text{DIN}}\) is estimated as 69.605 kg N km\(^{-2}\) y\(^{-2}\) for the average of 1999 and 2000 inputs (\(\text{NO}_3 + \text{NH}_4\)) as.

We assume that \(v_{\text{DIN}}\) is equal to \(v_{\text{Sub}}\) and \(v_{\text{DIP}}\).

\(I_{\text{DIP}}\) is estimated as 585.15 kg P km\(^{-2}\) y\(^{-2}\) by:

\[
I_{\text{DIP}} = (1 - v_{\text{DIP}}) \times DI_{\text{P output}}
\]  
(S4)

We based our estimation of organic carbon, nitrogen and phosphorus inputs considering initial analysis of organic carbon in glacier forefield soils, chemical analyses of glacier meltwater (Hodson et al., 2005) and the ornithogenic contribution to soils (Jakubas et al., 2008; Ziolek and Melke, 2014), and used the stoichiometry from Bradley et al. (2015) and Bernasconi et al. (2011).

Final allochthonous inputs are as follows:

Table S2. Final allochthonous inputs

<table>
<thead>
<tr>
<th>Variable</th>
<th>Annual input ((\mu g\ 1.19 cm^{-2} y^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIN</td>
<td>8.283</td>
</tr>
<tr>
<td>ON(_1)</td>
<td>20.790</td>
</tr>
<tr>
<td>ON(_2)</td>
<td>48.540</td>
</tr>
<tr>
<td>S(_1)</td>
<td>147.51</td>
</tr>
<tr>
<td>S(_2)</td>
<td>344.19</td>
</tr>
<tr>
<td>OP(_1)</td>
<td>12.240</td>
</tr>
</tbody>
</table>
\[ \text{OP}_2 \quad 28.560 \]

\[ \text{DIP} \quad 69.633 \]

Inputs are evenly spread over snowmelt and summer period (days 155 to 264), and through 20 cm depth \((v = 0.17/20 = 0.0085)\).

The sensitivity of microbial and nutrient dynamics to this allochthonous flux is the focus of future work, in which we hope to address the issues of uncertainty of external inputs and leaching.

The model is run for 120 years to encapsulate the entirety of the observational dataset. Annual forcings (Fig. S2) are repeated for the entire duration of the model run.
Fig. S2. Annual forcings.
### S3.3. Table S3. Model parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Units</th>
<th>Value</th>
<th>(Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{ref}}$</td>
<td>Reference temperature for rates</td>
<td>°C</td>
<td>25</td>
<td>(Frey et al., 2010)</td>
</tr>
<tr>
<td>NC</td>
<td>C:N ratio (mass)</td>
<td>Unitless</td>
<td>0.141</td>
<td>(Bernasconi et al., 2011)</td>
</tr>
<tr>
<td>PC</td>
<td>C:P ratio (mass)</td>
<td>Unitless</td>
<td>0.083</td>
<td>(Bernasconi et al., 2011)</td>
</tr>
<tr>
<td>$\alpha_A$</td>
<td>Death rate (autotrophs)</td>
<td>d$^{-1}$</td>
<td>0.070</td>
<td>(Bradley et al., 2015)</td>
</tr>
<tr>
<td>$\alpha_H$</td>
<td>Death rate (heterotrophs)</td>
<td>d$^{-1}$</td>
<td>0.070</td>
<td>(Bradley et al., 2015)</td>
</tr>
<tr>
<td>$e_{\text{exA}}$</td>
<td>Exudates &amp; EPS production (autotrophs)</td>
<td>Unitless</td>
<td>0.014</td>
<td>(Allison, 2005)</td>
</tr>
<tr>
<td>$e_{\text{exH}}$</td>
<td>Exudates &amp; EPS production (heterotrophs)</td>
<td>Unitless</td>
<td>0.014</td>
<td>(Allison, 2005)</td>
</tr>
<tr>
<td>$\rho_{\text{Sub}}$</td>
<td>Slow-down of subglacial microbial growth rate</td>
<td>Unitless</td>
<td>0.2</td>
<td>(Bradley et al., 2015)</td>
</tr>
<tr>
<td>$K_{\text{Sub}}$</td>
<td>Lower half-saturation constants ($K_s$, $K_N$, $K_P$) for subglacial microbes</td>
<td>Unitless</td>
<td>0.8</td>
<td>(Bradley et al., 2015)</td>
</tr>
<tr>
<td>$K_L$</td>
<td>Light half-saturation constant for autotrophs ($A_2$ &amp; $A_3$)</td>
<td>W m$^{-2}$ (PAR)</td>
<td>11.88</td>
<td>(De Nobel et al., 1998; Van Liee and Walsby, 1982; Chapra et al., 2014; Thornton et al., 2010; MacIntyre et al., 2002)</td>
</tr>
<tr>
<td>$K_S$</td>
<td>Substrate half-saturation constant for heterotrophs</td>
<td>µg g$^{-1}$</td>
<td>349.00</td>
<td>(Bradley et al, 2015)</td>
</tr>
<tr>
<td>$K_N$</td>
<td>DIN half-saturation constant</td>
<td>µg g$^{-1}$</td>
<td>49.21</td>
<td>(stoichiometric)</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
<td>Unit</td>
<td>Value</td>
<td>Source</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>------</td>
<td>-------</td>
<td>--------</td>
</tr>
<tr>
<td>$K_D$</td>
<td>DIP half-saturation constant</td>
<td>$\mu g \cdot g^{-1}$</td>
<td>28.967</td>
<td>(stoichiometric)</td>
</tr>
<tr>
<td>$n_I$</td>
<td>Downscaling of $Y$ and $I_{max}$ when fixing nitrogen</td>
<td>Unitless</td>
<td>0.25</td>
<td>(Bottomley and Myrold, 2007; LaRoche and Breitbarth, 2005; Breitbarth et al., 2008; Goebel et al., 2008)</td>
</tr>
<tr>
<td>$K_{N2}$</td>
<td>Nitrogen fixation inhibition</td>
<td>$\mu g \cdot g^{-1}$</td>
<td>49.209</td>
<td>(Bradley et al., 2015; Holl and Montoya, 2005; Rabouille et al., 2006)</td>
</tr>
<tr>
<td>$DIN_I$</td>
<td>Threshold value of DIN for nitrogen fixation inhibition</td>
<td>$\mu g \cdot g^{-1}$</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>$q$</td>
<td>Proportion of necromass that becomes labile ($S_1$)</td>
<td>Unitless</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>$J_{S1}$</td>
<td>Bioavailability (preference) of $S_1$</td>
<td>Unitless</td>
<td>0.68</td>
<td>(Bradley et al., 2015)</td>
</tr>
<tr>
<td>$J_{S2}$</td>
<td>Bioavailability (preference) of $S_2$</td>
<td>Unitless</td>
<td>0.15</td>
<td>(Bradley et al., 2015)</td>
</tr>
<tr>
<td>$g_{Sub}$</td>
<td>Leaching of substrate</td>
<td>$d^{-1}$</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>$g_{DIN}$</td>
<td>Leaching of DIN</td>
<td>$d^{-1}$</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>$g_{DIP}$</td>
<td>Leaching of DIP</td>
<td>$d^{-1}$</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>$d$</td>
<td>Active fraction of microbial biomass</td>
<td>Unitless</td>
<td>0.285</td>
<td>(Wang et al., 2014)</td>
</tr>
<tr>
<td>$V_{Sub}$</td>
<td>Proportion of allochthonous substrate deposition retained</td>
<td>Unitless</td>
<td>0.0085</td>
<td></td>
</tr>
<tr>
<td>$V_{DIN}$</td>
<td>Proportion of allochthonous DIN deposition retained</td>
<td>Unitless</td>
<td>0.0085</td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Units</td>
<td>Value determined in lab (Standard Error)</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>-------</td>
<td>------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Imax_H</td>
<td>Maximum growth rate (heterotrophs)</td>
<td>d^{-1}</td>
<td>0.550 (0.027)</td>
<td></td>
</tr>
<tr>
<td>Imax_A</td>
<td>Maximum growth rate (autotrophs)</td>
<td>d^{-1}</td>
<td>0.550 (assumed)</td>
<td></td>
</tr>
<tr>
<td>Q_{10}</td>
<td>Temperature sensitivity</td>
<td>Unitless</td>
<td>2.91 (0.013)</td>
<td></td>
</tr>
<tr>
<td>Y_H</td>
<td>Growth efficiency (heterotrophs)</td>
<td>g carbon (g consumed)^{-1}</td>
<td>0.060 (0.003)</td>
<td></td>
</tr>
<tr>
<td>Y_A</td>
<td>Growth efficiency (autotrophs)</td>
<td>g carbon (g consumed)^{-1}</td>
<td>0.060 (assumed)</td>
<td></td>
</tr>
</tbody>
</table>

S4. Statistical significance test of lab measurements (ANOVA & Tukey)

Table S4. Bacterial carbon production

<table>
<thead>
<tr>
<th>Difference between treatments</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low - High</td>
<td>0.064</td>
</tr>
<tr>
<td>Medium - High</td>
<td>0.488</td>
</tr>
<tr>
<td>None – High</td>
<td>0.100</td>
</tr>
<tr>
<td>Medium – High</td>
<td>0.547</td>
</tr>
<tr>
<td>None – Low</td>
<td>0.994</td>
</tr>
<tr>
<td>None - Medium</td>
<td>0.697</td>
</tr>
</tbody>
</table>

Table S5. Growth rate
### Table S6. Respiration

<table>
<thead>
<tr>
<th>Difference between incubation temperatures</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>5°C - 25°C</td>
<td>$2.6\times10^{-6}$</td>
</tr>
<tr>
<td>Killed (autoclave) - 25°C</td>
<td>$2.0\times10^{-7}$</td>
</tr>
<tr>
<td>Killed (furnace) - 25°C</td>
<td>$5.0\times10^{-7}$</td>
</tr>
<tr>
<td>Killed (autoclave) - 5°C</td>
<td>0.464</td>
</tr>
<tr>
<td>Killed (furnace) - 5°C</td>
<td>0.764</td>
</tr>
<tr>
<td>Killed (furnace) – Killed (autoclave)</td>
<td>0.954</td>
</tr>
</tbody>
</table>

### S5. References


