Ecosystem Feedbacks to Climate Change

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Will ecosystem responses exacerbate or moderate climate change?
Atmospheric evidence of large carbon exchanges by the biosphere that are changing
What is a feedback?

Driver

+ -

Response
Climate Change Feedbacks from Ecosystem Responses

Fossil fuels → CO₂ → Climate change

Plant growth Decomposition +, −
Negative feedbacks
(moderate climate change)

- Land C response to CO₂
- including N-cycle
- Ocean C response to CO₂
- Land C response to climate
- including N-cycle
- Ocean C response to climate

Positive feedbacks
(exacerbate climate change)

- Permafrost CO₂
- Wetlands CH₄
- Climate CH₄ lifetime
- Climate on N₂O
- BVOC on ozone
- fire
- climate-aerosol
- climate-ozone
- climate-dust
- climate-DMS

W m² K⁻¹
Terrestrial Carbon Cycle

**CO₂** Plant respiration

**CO₂** Soil respiration

**CO₂** Photosynthesis Growth

C accumulates when inputs > outputs

Negative feedback

Erosion, Fire

Groundwater transport

Litter

Roots

Microbes

Soil Organic Carbon
Terrestrial Carbon Cycle

CO₂
Plant respiration

CO₂
Soil respiration

C released when inputs < outputs
Positive feedback

Photosynthesis
Growth

Litter

Erosion, Fire

Groundwater transport

Roots

Microbes

Soil Organic Carbon
Negative feedbacks
(moderate climate change)

Positive feedbacks
(exacerbate climate change)

Land C response to CO2
including N-cycle

Ocean C response to CO2

Land C response to climate
including N-cycle

Ocean C response to climate

Permafrost CO2

Wetlands CH4

Climate CH4 lifetime

Climate on N2O

BVOC on ozone

fire

climate-aerosol

climate-ozone

climate-dust

climate-DMS

W m² K⁻¹
Climate Change Feedbacks from Ecosystem Responses

- Fossil fuels
- CO₂
- Plant growth
  - Decomposition
  - +, -
- Climate change
- N
Cedar Creek Ecosystem Science Reserve
The NSF LTER Network

Number of Plant Species by Terrestrial Ecoregion
Kier et al. (2005)

- More than 7500
- 5001 - 7500
- 3501 - 5000
- 2501 - 3500
- 1501 - 2500
- 1001 - 1500
- 500 - 1500
- 500 - 1000
- Less than 500
- No Data
What do plants need to grow?

$CO_2$, light, water, soil nutrients

Photosynthesis:

Conversion of $CO_2$ to sugar using light energy
Leaf

Boundary layer

Bulk air

Mesophyll cells

Guard cell

Stoma

Epidermal cell

Cuticle

CO₂

H₂O
Atmospheric CO$_2$ at Mauna Loa Observatory

Scripps Institution of Oceanography
NOAA Earth System Research Laboratory

PARTS PER MILLION vs YEAR


June 2015
Leaf-level response to elevated CO$_2$

Net photosynthesis ($\mu$mol m$^{-2}$ s$^{-1}$)

Atmospheric CO$_2$
BioCON: CO$_2$, N, & diversity + temp & precip
The graph shows the biomass (g/m²) in relation to the number of treatments at limiting levels. The treatments are indicated by numbers 3, 2, 1, and 0, with corresponding biomass values.

- Number 3: Biomass value indicated by 'c'
- Number 2: Biomass value indicated by 'c'
- Number 1: Biomass value indicated by 'b'
- Number 0: Biomass value indicated by 'a'

The error bars indicate the variability in the biomass measurements.
Terrestrial Carbon Cycle

- **CO₂**
  - Plant respiration
  - Soil respiration

- **CO₂**
  - Photosynthesis
  - Growth

- **Erosion, Fire**

- **Groundwater transport**

- **Litter**

- **Soil Organic Carbon**

- **Microbes**

- **Roots**
"CO₂ fertilization" may moderate climate change, but only where nutrients and water are adequate.
Climate Change Feedbacks from Ecosystem Responses

Fossil fuels $\rightarrow$ CO$_2$ $\rightarrow$ Climate change $\rightarrow$ Plant growth decomposition $\rightarrow$ +, - $\rightarrow$ N
atmosphere: 829 Pg

soils: 1500-2400 Pg
Terrestrial Carbon Cycle

CO₂
Plant respiration

CO₂
Soil respiration

Photosynthesis
Growth

Erosion, Fire

Groundwater transport

Litter

Roots

Microbes

Soil Organic Carbon
Two sites
Three temperature treatments
Two rainfall treatments
Boreal forest warming at an ecotone in danger
Boreal Species

- white spruce
- jack pine
- aspen
- paper birch
- balsam fir
Temperate Species

- bur oak
- sugar maple
- red maple
- white pine
- red oak
- buckthorn
Species

- Red maple
- Paper birch
- Red oak
- Balsam fir
- White spruce
- White pine

Ambient
Dry

Growth (cm)

Moisture

- Ambient
- Dry

Temperature
- 1.7°C
- 3.4°C
Terrestrial Carbon Cycle

- CO₂ Growth
- Soil respiration
- Erosion, Fire
- Groundwater transport
- Litter
- Roots
- Microbes
- Soil Organic Carbon
Warming effects might exacerbate or moderate climate change, depending on species, precipitation, ...
Climate Change Feedbacks from Ecosystem Responses

- Fossil fuels → CO₂
- CO₂ → Climate change
- Climate change → Plant growth
- Plant growth → Decomposition

- Fossil fuels → + CO₂
- CO₂ → + Climate change
- Climate change → + Plant growth
- Plant growth → + Decomposition
atmosphere: 829 Pg

soils: 1500-2400 Pg

permafrost: 1700 Pg

1 Pg = 10^{15} g = billion tonnes
Melting Permafrost, Kolyma River, Siberia

By 2040: 12% loss
By 2100: 54% loss
By 2300: 73% loss

(Schuur et al. 2011)
Warming effects on permafrost thaw and decomposition will exacerbate climate change
Will ecosystem responses exacerbate or moderate climate change?
Shorter Term
Terrestrial ecosystems likely will moderate climate change

Longer Term
Moderation of climate change will decline, and terrestrial ecosystems may even exacerbate climate change

- Plant growth response to elevated CO$_2$ will saturate
- Climate warming will likely be accompanied by soil drying and drought that will limit plant growth
- Permafrost thaw will accelerate
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