### The Boreal Region

<table>
<thead>
<tr>
<th>Biome</th>
<th>Area (10^6 ha)</th>
<th>Soil Carbon (Pg)</th>
<th>Plant Biomass Carbon (Pg)</th>
<th>Total Carbon (Pg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreal Forest</td>
<td>1509</td>
<td>624</td>
<td>51</td>
<td>675</td>
</tr>
<tr>
<td>Tropical Forest</td>
<td>1756</td>
<td>216</td>
<td>159</td>
<td>375</td>
</tr>
<tr>
<td>Temperate Forest</td>
<td>1040</td>
<td>100</td>
<td>21</td>
<td>121</td>
</tr>
</tbody>
</table>
How Might a Climate Warming Change the Vegetation of the NEESPI Region?

The most straight-forward approach would be to use the current relations between climate and vegetation to interpret the future pattern.

But at what level does one resolve the vegetation?

• Biome Level
• Species or Functional Type Level

Recent work of Nedezda Tchebakova explored these.
Siberian Bioclimatic Model:

Three principal climatic constrains representing plant requirements for:

1. Water stress tolerance (an annual moisture index, a ratio $GDD_5$/annual precipitation), and
2. Cold resistance (negative degree-days)
3. Warmth (growing degree-days, base $5^\circ C$).

These “envelopes” have limits for each vegetation class, tree species and even climatypes of species in climatic space.
Climatic surfaces for Siberia

- Data from about 1000 Siberian weather stations were used to map climatic variables.

- Hutchinson’s (2000) thin plate splines were used to produce climate surfaces on DEM grids (1 km) for monthly temperature and precipitation.

- $GDD_5$ and $DD_0$ surfaces were produced from regressions ($R^2 > 0.9$) driven by monthly temperatures ($T_1$ and $T_7$).

- AMI was calculated as the ratio of the $GDD_5$ surface to the precipitation surface.
Current Vegetation Patterns in Russia
Climate change by 2090 for Siberia (Hadley Center, HadCM$_3$GGa1)

January temperature (+4/+9°C)

Precipitation (-4/+25%)

July temperature (+4/+6°C)
Vegetation change in Siberia by 2090

Current

2090

Legend:
- Water (0)
- Tundra (1)
- Forest-tundra (2)
- Northern dark taiga (3)
- Light taiga (4)
- Middle dark taiga (5)
- Light taiga (6)
- Southern dark taiga (7)
- Light taiga (8)
- Forest-steppe (9)
- Steppe (10)
- Semi-desert (11)
- Broadleaved (12)
- Temperate forest-steppe (13)
- Temperate steppe (14)
- Ice (15)
So from a static approach, there are significant shifts at the vegetation level.

Are these seen if we evaluate species as well?

- **Larix spp.** 51.5%
- **Pinus sylvestris** 17.5%
- **P. sibirica** 5.5%
- **P. obovata** 5.0%
- **Abies sibirica** 3.0%
Major conifer distributions in Siberia

Pinus sylvestris

Larix sibirica

Larix sukaczewii

Larix gmelini & cajanderii

Pinus & Abies sibirica
Distribution of *P. sylvestris* in Siberia

Current

2090
Distribution of *L. sibirica* in Siberia

**Current**

**2090**
Distribution of *L. dahurica* in Siberia

**Current**

**2090**
Distribution of *L. sukaczewii* in Siberia

Current

2090
Distribution of *Pinus sibirica* in Siberia

Current

2090
Potential and actual (in brackets) distributions (%) of main tree species in current and 2090 climates

<table>
<thead>
<tr>
<th>Tree species</th>
<th>Current climate</th>
<th>Future climate</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pinus sylvestris</em></td>
<td>68 (38)</td>
<td>87 (62)</td>
</tr>
<tr>
<td><em>Larix sibirica</em></td>
<td>58 (26)</td>
<td>71 (28)</td>
</tr>
<tr>
<td><em>Larix dahurica</em></td>
<td>60 (33)</td>
<td>38 (24)</td>
</tr>
<tr>
<td><em>Larix sukaczewii</em></td>
<td>12 (12)</td>
<td>26 (23)</td>
</tr>
</tbody>
</table>
If we see large changes from a static evaluation of climate altering the vegetation potentials, what are the results from dynamic studies?
Dynamics of the Principal Areas of Forest Harvest for Russia

Area of main harvesting, hectares 10^3

Years


Clear cutting

Other

USSR ends
Contemporary Biosphere and Carbon Cycle Changes in Northern Eurasia

H.H. Shugart
Department of Environmental Sciences
University of Virginia

With Much Appreciated Help from Many Colleagues
Central to the Understanding of Dynamics is an Appreciation of Scale

Fish whose scales are fish at another scale (M.C. Escher)
Leaf Level:
- Photosynthesis
- Water Balance
- Temperature
- Nutrient Status

Plant Level:
- Flowering
- Fertilization
- Germination
- Growth
- Mortality

Stand Level:
- Regeneration
- Establishment
- Growth
- Competition
- Thinning
- Death
- Gap Creation

Landscape Level:
- Dispersal
- Migration
- Disturbance
Testing of Forest-DNDC against observed NEE fluxes

Comparison between observed and Forest-DNDC modeled NEE fluxes.
Testing of Forest-DNDC against observed NEE fluxes

Observed and modeled NEE fluxes from a wetland spruce forest in Central Forest Reserve at Fyeodorovskoe, Russia in 1999-2004

Comparison between observed and Forest-DNDC modeled NEE fluxes.
Modeled C fluxes composing NEE: Soil is a key factor determining sink or source.

Observed and Modeled CO2 Fluxes from a Wet Spruce Forest at Central Forest Reserve in Fyeodorovskoe, Tver, Russia in 2004

Photosynthesis - Respiration - Soil Respiration = Modeled NEE

Observed NEE
Modeled C fluxes composing NEE: Soil is a key factor determining sink or source

<table>
<thead>
<tr>
<th>Stand</th>
<th>Photosynthesis kgC ha(^{-1}) yr(^{-1})</th>
<th>Plant respiration kgC ha(^{-1}) yr(^{-1})</th>
<th>Soil respiration kgC ha(^{-1}) yr(^{-1})</th>
<th>GPP kgC ha(^{-1}) yr(^{-1})</th>
<th>NEE kgC ha(^{-1}) yr(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSF</td>
<td>13132</td>
<td>10361</td>
<td>3481</td>
<td>2771</td>
<td>711</td>
</tr>
<tr>
<td>DSF</td>
<td>14162</td>
<td>9616</td>
<td>2683</td>
<td>4546</td>
<td>-1863</td>
</tr>
</tbody>
</table>
NEE was sensitive to forest age, SOC content and temperature. Along with increase in
Norilsk Industrial Region
Prediction of Temperature Profiles at Different Elevations on Different Days.
Aspen Forest
1994

Clearness Index

Relative Change in NEE of CO$_2$ (%)

$\beta = 40 - 45^\circ$

$\beta = 45 - 50^\circ$

$\beta = 50 - 55^\circ$

$\beta = 55 - 60^\circ$

From Gu et al. (1999)
Leaf Level:
- Photosynthesis
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FAREAST: A Boreal Forest Simulator

**Growth:**
- Available Light
- Soil Moisture
- Site Quality
- Growing-Degree Days
- Depth of Thaw
- Diameter
- Age
- Height

**Mortality:**
- Stress
- Fire
- Insects
- Age

**Regeneration:**
- Available Light
- Soil Moisture
- Site Quality
- Depth of Thaw
- Seed Bed
- Seed Availability
- Sprouting
- Layering
Data Needs:

Process information on the silvicultural features of the boreal tree species, allometric equations, light extinction coefficients, and other biological, biophysical and physical aspects of stand dynamics.

Much of this has been derived from earlier synthesis activities but there remains a need for a characterization of the fundamental processes, particularly thermal fluxes and ice-related processes.
Testing Individual-based Models of the Boreal Forest
Chang Bai Shan Vegetation Gradient
Tests of the FAREAST Model on Mountain Gradients

Actual Versus Observed Basal Area by Species at Four Elevations

$y = 0.8546x$

$R^2 = 0.8539$
Test sites in China and Russia

85% Correct (Validation Mode)
95% Correct (Verification Mode)
Gap Models Simulate Cover Dynamics and Carbon Dynamics.

Simulated Net Primary Production (kgCm$^{-2}$yr$^{-1}$) for 593 Chinese Forest Survey Stations versus Observed Data

Validation Mode (Unfitted Data)

Simulated Forest Species Composition for Biomass (tC/Ha) for Vladivostok, Russia
By running the FAREAST model (200 simulated plots for 700 years starting with an open plot) for 234 weather stations in the NEESPI region, one obtains both the expected successional dynamics and mature forest condition.

Size of circles indicates the biomass of mature (700-year-old) forests across the NEESPI region.
By running the FAREAST model (200 simulated plots for 700 years starting with an open plot) for 234 weather stations in the NEESPI region, one obtains both the expected successional dynamics and mature forest condition.

Size of pie slices indicates the biomass composition of mature forests across the NEESPI region.
How does one know the reliability of these predictions? How does one determine the highest priorities for additional model development?
There are data for testing these predictions but the comparisons involve knowing the history of disturbance and harvest regimes for vast land areas.

Carbon Store in Forest Lands of Russia (tC ha\(^{-1}\))

Annual Carbon Accumulation in Forest Lands of Russia (tC ha\(^{-1}\) yr\(^{-1}\))
WHAT IS NEEDED?

We need to develop a system for monitoring and validating the distribution and change in land cover across Northern Eurasia.
Location of NELDA test sites (Map was created at EC JRC as part of GLC 2000 project, Bartalev et al. 2003)
Age cohorts of forest stands as a footprint of past disturbance.
Leaf Level:
- Photosynthesis
- Water Balance
- Temperature
- Nutrient Status

Stand Level:
- Regeneration
- Establishment
- Growth
- Competition
- Thinning
- Death
- Gap Creation

Landscape Level:
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Landscape Level:
- Dispersal
- Migration
- Disturbance
The net effect of changes will enhance or mitigate warming. Responses of water, energy, and trace gas exchange may result in either positive or negative feedbacks to both regional and global warming.

**Negative Feedbacks to Warming**

- ↑ NPP in response to N min
- Fire: Veg change: ↑ Albedo, ↓ Sensible heat
- Treeline advance: ↑ NPP
- Thermohaline shutdown

**Positive Feedbacks to Warming**

- Early snowmelt: ↓ Albedo
- Decomposition: ↑ CO₂ release
- Shrub growth: ↑ Sensible heat
- Thermokarst: ↑ CH₄ release
- Fire: ↑ CO₂ release
- Treeline advance: ↓ Albedo
Implications of Change:

- CO₂ Release
- Methane Release
- Drainage and Decomposition
- Cover Change
- Physical Surface Change
Eurasian Land Cover Change in response to climate change may be more complex than merely “painting-by-numbers” of vegetation onto climate.
“... in large parts of the temperate and boreal forest areas, the decrease in surface albedo by forestation is as important as carbon sequestration in its forcing of climate. As a result, forest carbon sinks in these regions could exert a much smaller cooling influence than expected, or even exert an overall warming influence.”

Replacing Larch with Evergreen Conifers has an effect on pine regeneration under a Larch canopy growing trees.
Multi-model-ensemble annual-mean change of the temperature (Gray shading), its range (Unit: °C) mean change divided by the multi-model standard deviation for the IPCC-DDC scenario IS92a (GS: greenhouse gases and Sulphate aerosols) for the year 2021 to 2050 relative the period 1961 to 1990.
What happens to Larch (Larix sp.) under a climate change?

Current Climate

Temperature

Precipitation

Larch (Larix sp.)

Biomass (tC/ha)

Larix nochang
Larix IS92a
Larix CMIP
Relating Model Results to Actual NELDA Project Data

Proportion of Larch in Age Cohorts of forest stands

Less presence of Larch in younger stands
Where do we stand?
Models and observations across multiple scales.
Fusion among different sensors with different resolutions and capabilities.
Development of an increased capability to represent land dynamics as an essential part of the
The net effect of changes will enhance or mitigate warming. Responses of water, energy, and trace gas exchange may result in either positive or negative feedbacks to both regional and global warming.

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An Example
Spatial distribution of changes in snow cover (days year$^{-1}$) for:

- Changes in snowmelt (b) plus
- Changes in snow return (d) equals
- Changes in total length of snow cover duration (f).

![Maps showing spatial distribution of changes in snow cover](image)

Legend:
- Anomaly: Days per year earlier (or shorter for the 'total change')
- Days per year later (or longer for the 'total change')

No Change