Effects of the Development of the Baikal-Amur Mainline Railroad on Patterns of Boreal Forest Cover and Carbon Fluxes in Southern Siberia

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- Part 3: Modeling Forest - Carbon Dynamics in the Western BAM - Importance of Disturbance (H. Shugart)
Part I.
Perspectives on Land Cover Change in the Boreal Forest Region
Issues in Conducting Global Change Research in the Boreal Forest Region - Dealing with Scientific Perspectives

The Scientific Process has 3 important steps:

1. Examine the Data
2. Ponder the Facts
3. Form Conclusions
Issues in Conducting Global Change Research in the Boreal Forest Region - Dealing with Scientific Perspectives

• Problems

• In the terrestrial science community, global change science is often not conducted by researchers who are trained using a global perspective, but by researchers with unique biome or geographic perspectives

• Conclusions are often drawn about specific processes in a biome/region based upon perspectives developed in other biomes/regions

• Examples

• Fire in the boreal forest is not an important process on a global scale

• Just as in the temperate forest, tropical forest and savanna regions, human activities are a primary driver behind land cover change
Relative Importance of Fires in the Boreal Forest (as viewed by the “global” fire community)

<table>
<thead>
<tr>
<th>Biome</th>
<th>Carbon Released (Tg/yr)</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savanna</td>
<td>1660</td>
<td>70</td>
</tr>
<tr>
<td>Tropical Forests</td>
<td>570</td>
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<td>107</td>
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<td>Boreal Forests</td>
<td>23</td>
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Seiler and Crutzen 1980; Hao, Liu and Crutzen 1990
<table>
<thead>
<tr>
<th>Source of Disturbance</th>
<th>Area (average)</th>
<th>Percent (average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>6 to 24 (15)</td>
<td></td>
</tr>
<tr>
<td>Human land clearing</td>
<td>2 (2)</td>
<td>33 to 8 (13)</td>
</tr>
<tr>
<td>Insects/pathogens</td>
<td>2 to 4 (3)</td>
<td>33 to 17 (20)</td>
</tr>
<tr>
<td>Fire</td>
<td>2 to 18 (10)</td>
<td>33 to 75 (67)</td>
</tr>
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</table>
Data Availability for Studies of Land Cover Change in the Boreal Forest Region

Over the past decade, the satellite remote sensing community has created a number of important initiatives to collect the data sets necessary to document patterns of disturbance and land-cover change in many regions of the earth.

<table>
<thead>
<tr>
<th>Biome/Region</th>
<th>Disturbance/Land Cover Change Pattern</th>
<th>Data Set Initiative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperate Forests/U.S.</td>
<td>Patterns of forest clearing and regrowth</td>
<td>NALC, MLRC</td>
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<tr>
<td>Tropical Forests/S. America, SE Asia</td>
<td>Deforestation</td>
<td>AVHRR/Landsat Pathfinders</td>
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<tr>
<td>Savannas, Tropical Forests/SE Asia, Africa, S. America</td>
<td>Seasonal fires</td>
<td>Global AVHRR/ATSR Fire Maps</td>
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<tr>
<td>Boreal Forest/Russia, N. America</td>
<td>Summer fires, insects, deforestation</td>
<td>?????????</td>
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</table>
Key Unresolved Questions with Respect to Land Cover Changes in the Boreal Forest Region

- What is the annual area burned and area disturbed by insects and diseases?
- Are fires in the Russian boreal forest predominately surface fires (as maintained by Russian forestry community) or crown fires (as suggested by satellite observations)?
- What are the levels of greenhouse gases released directly from fires and during the years immediately after fire (due to post-fire soil respiration enhancement)?
- In the southern and far-eastern portion of the Russian boreal forests, what are the rates of forest clearing due to human activities?
Key Unresolved Questions with Respect to Land Cover Changes in the Boreal Forest Region

- In response to recent distinct trends in warming in the boreal region:
- Are levels of fire increasing in the boreal region (in terms of area burned as well as fire severity)?
- Are levels of insect and disease infestation increasing?
- At what rate are the northern boundaries of the boreal forest expanding?
- Are patterns of forest recovery after disturbance changing (indicated by a shift from coniferous forests to deciduous forests)?
- Is the ratio between forest area and non-forest area (peatlands) in the boreal region increasing or decreasing?
- Will the boreal forest region remain an atmospheric carbon sink or will it become an atmospheric carbon source?
### Episodic Fire Years in the Boreal Forest

<table>
<thead>
<tr>
<th>Region</th>
<th>Year</th>
<th>% of Total Area Burned</th>
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<tbody>
<tr>
<td>Khabarovsk/Sakhalin Island</td>
<td>98</td>
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<tr>
<td>Boreal Plains</td>
<td>80-81</td>
<td>4.2</td>
</tr>
<tr>
<td>Alaska Boreal</td>
<td>90-91</td>
<td>4.2</td>
</tr>
<tr>
<td>West Taiga Shield</td>
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<td>4.8</td>
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<tr>
<td>West Boreal Shield</td>
<td>80-81</td>
<td>4.4</td>
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<tr>
<td>East Taiga Shield</td>
<td>90</td>
<td>3.0</td>
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</tbody>
</table>
The Role of Land Cover Change in the Boreal Forest Region

- On a relative scale, direct human activities are responsible for a small portion of land cover change in the boreal region.

- Natural disturbances (fire, insects, disease) play a far greater role in land cover change than do human disturbances.
The Role of Land Cover Change in the Boreal Forest Region

- The increase in large-scale, natural disturbances associated with climate change will have significant socio-economic impacts on human society
- Increased fire activity represents a significant and direct threat to human life and property
- Any human-related activity that occurs in the boreal region has to consider fire, especially those associated with exploitation of natural resources
- Increased fire and insect/diseases will reduce the amount of wood and fiber available for harvesting
- Increased fire will change the habitat for a wide range of fish, bird and wildlife species, many of which are commercially exploited or used by indigenous peoples
- Increased fire will alter the availability of other products harvested from forested landscapes (mushrooms, berries, etc.)
The Role of Land Cover Change in the Boreal Forest Region

- Alteration of the fire regime will have significant impacts on global climate change treaties
- Issue of carbon credits in the Kyoto Protocol
- Increased fire will influence the debate on allocation of funding for natural resource management
- Command and Control Viewpoint
  - Given sufficient resources (manpower and equipment), all fire can be controlled
- Ecological viewpoint
  - Even with unlimited resources, natural fire cannot be controlled or even reduced. Efforts should be focused on protecting high-priority life and property
Values at Risk in the Boreal Forest

- While the boreal forest region has a low population density, it is home to a large population of Native Peoples who maintain traditional, subsistence-based lifestyles
- The southern boreal forest contains significant timber resources that may be exploited in the future
- The boreal forest region contains the largest terrestrial carbon reservoir
- Significant non-renewable resources exist in this region, and the routes for NRR in the Arctic go through the boreal forest
- The boreal forest region provides habitat for a large number of fish, bird and mammal species
Part 2:
Monitoring Land Cover Changes
in the BAM Regions - Examples and Challenges
Summary of Project Goals, Objectives, and Deliverables

- **Goal:** Develop a better understanding of the role of human disturbance on patterns of carbon storage and assessment along the Baikal-Amur Mainline (BAM) Railroad

- **Objectives:**
  - Create a baseline map of forest fire locations for the BAM for the period of 1980 through 1990 and later periods where possible
  - Use the fire maps to estimate the amounts of carbon lost from fire along the BAM
  - Using available Landsat imagery, create maps of human-caused deforestation and patterns of reforestation along the entire length of the BAM
  - Develop models of forest regrowth for the different forest ecoregions along the BAM
  - Combine the forest regrowth models with information on patterns of forest disturbance and regrowth derived from satellite imagery to estimate carbon forest fluxes along the BAM
Mid-Course Corrections

• An analysis of the Landsat archive revealed there is not enough imagery available to achieve Objective 3 of the study
• Over the past year, we have developed approaches to merge use higher resolution (5 to 80 m) satellite imagery from multiple sources to monitor and map forest clearing and regrowth at our test sites
• Based on these analyses, we have decided to limit our studies to four specific test sites that have varying degrees of human and natural disturbance:
  • Chuna Test Site - high rates of human land clearing over a very long time period (1960 to present)
  • Usolsk Test Site - more recent (after 1980) human land clearing combined with heavy disturbance from insects and moderate fire disturbance
  • Tynda Test Site - Human land clearing since the 1980's combined with moderate natural fire
  • Gursky Test Site - Heavy disturbance from fire, especially in 1998
Common Interest with other LCLUC Projects

• We have established links with several other LCLUC projects
  
  • We will work with the McGuire Project to estimate carbon emissions from fire for the entire boreal forest
  
  • Will will work with the DeFries Project to evaluate the ability of the continuous forest cover product to detect deforestation in boreal forests
Key Components of BAM Study

- Patterns of Fire Disturbance Using AVHRR Imagery

- Sub-regional scale patterns of deforestation/reforestation using multiple-resolution satellite imagery

- Modeling patterns of forest regrowth/carbon sequestration
Patterns of Fire Disturbance Using AVHRR Imagery
Patterns of Fire Disturbance Using AVHRR Imagery

- Use AVHRR to document location and extent of fires in the Russian boreal forest during the 1980's and early 1990's
- Study spatial/temporal patterns of fire
  - Relative to the BAM
  - Relative to other boreal regions (North America)
- Estimate greenhouse gas emissions from Russian fires
  - Compare to North American estimates
Significant Event in the Study Area:
1998 Severe Fires in Eastern Siberia
Mapped from AVHRR
Sub-regional scale patterns of deforestation/reforestation using multiple-resolution satellite imagery
Sub-regional Scale Patterns of Deforestation/Reforestation Using Multiple-Resolution Satellite Imagery

- Focus on three regions of Russia where anthropogenic deforestation is occurring
  - Biryusa River Basin (two sites)
  - Tynda Region
  - Gursky Forest Region
- Address issues related to using satellite imagery to monitor changes in forest cover in these regions
- Detection of disturbance as a function of system resolution
- Analysis of deforestation using multiple-satellite systems
- Analysis of reforestation using time-series MSS data
- Comparison to theoretical forest growth models - model validation
### Sensor Characteristics

<table>
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<th>Sensor</th>
<th>Resolution</th>
<th>Extent</th>
<th>Spectral Range</th>
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<td>AVHRR</td>
<td>1.1 km</td>
<td>2580 km</td>
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<td>MSU-SK</td>
<td>170 m</td>
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<tr>
<td>MSS</td>
<td>80 m</td>
<td>185 km</td>
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<tr>
<td>MSU-E</td>
<td>45m x 33 m</td>
<td>45 x 220 km</td>
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<tr>
<td>TM</td>
<td>30 m</td>
<td>185 km</td>
<td></td>
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<tr>
<td>SPOT-XS</td>
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<td>60 km</td>
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<td>SPOT-PAN</td>
<td>10 m</td>
<td>60 km</td>
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<td>MK-4</td>
<td>~6 m</td>
<td>120 km</td>
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<tr>
<td>KFA-1000</td>
<td>5 m</td>
<td>60 km</td>
<td></td>
</tr>
<tr>
<td>DISP</td>
<td>~6 m</td>
<td>~15 x 209 km</td>
<td></td>
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</table>
Multi-Scale Imagery Example - Usolsk Study Site


DISP: 26 May 1970

AVHRR LAC: 20 Day Composite 21 June - 1 July 1992, Bands 2,1,1 (R,G,B)
Usolsk Study Area - Image Resolution Comparison

1 km Cell Size
AVHRR 20 Day Composite -

35 M Cell Size
Chuna River Forest Change Study

ISSUES UNDER INVESTIGATION

• Extraction of useful information
  - Forest cutting
  - Forest regeneration

• Extraction of comparable information from different types of remote sensing data (for example, DISP, Landsat, KFA-1000)

• Assessment of data adequacy
  - Geographic coverage
  - Temporal frequency
  - Phenological equivalence
  - Phenomenological suitability
Time Series/Sensors for Chuna Site
Four decades by combining U.S. and Russian Sources

DISP 1965
DISP 1970
LANDSAT MSS 1974

KFA-1000 1983
LANDSAT TM 1990
LANDSAT TM 1999

Congratulations on a Successful LANDSAT 7 Launch!
Additional Site Example: Krasnoyarsk--Usolsk

1980 U.S. Landsat MSS 1997 Russian MSU-E

deforestation

0 10 km

fire scar
deforestation
deforestation
Overview of Forest Harvesting Procedure

• Forest harvesting is characterized by removal of tree cover.
• Removal of tree cover produces a distinct change in the spectral properties of an area.
• For each acquisition of remote sensing data, the study area is categorized into forest and non-forest.
• Areas that change from forest to non-forest are considered to have been cut during the time interval between acquisitions.
• Annualized cutting is calculated by dividing the area cut within a time interval by the number of years in the interval.
• Trend information is derived from the change in the amount of area cut per time interval.
• Sustainability of forest cutting is estimated by comparing the average annual cut with the nominal rotation cycle of the forest type being cut.
Forest Harvesting

**Data (images)**

- DISP 1965
- DISP 1970
- MSS 1974
- KFA1000 1983
- TM 1990
- TM 1999

**Status Information (maps)**

- FOREST, NON-FOREST MAP
- FOREST, NON-FOREST MAP
- FOREST, NON-FOREST MAP
- FOREST, NON-FOREST MAP
- FOREST, NON-FOREST MAP
- FOREST, NON-FOREST MAP

**Temporal Analysis (maps)**

- I.D. OF RECENT CUTS
- I.D. OF RECENT CUTS
- I.D. OF RECENT CUTS
- I.D. OF RECENT CUTS
- I.D. OF RECENT CUTS

**Trend Information (statistics)**

- CHANGE IN AMOUNT OF RECENT CUTS
- CHANGE IN AMOUNT OF RECENT CUTS
- CHANGE IN AMOUNT OF RECENT CUTS
- CHANGE IN AMOUNT OF RECENT CUTS
OVERVIEW OF FOREST REGENERATION ASSESSMENT PROCEDURE

- Forest regeneration assessments will be made on areas where removal of forest cover is detected, based on acquisitions after the removal of forest.

- Removal of forest cover is detected by comparing land cover categories between pairs of images.

- Regeneration assessment is based in part on the condition, and changes in condition of the vegetation cover that is present in the time intervals following forest clearing.

- The length of the regeneration period available for analysis depends on in which time interval forest cutting was detected.

- For areas where regeneration has had many years to develop, it may be possible to assess the relative amount of hardwoods versus conifers present.
FOREST REGENERATION ASSESSMENT FOR FIRST TIME INTERVAL

Date 1  Date 2  Date 3  Date 4  Date 5  Date 6

Forest

Non-forest

Vegetation condition

Change in vegetation condition t2-t3

Change in vegetation condition t4-t5

Change in vegetation condition t5-t6

Change in vegetation condition t6-t7

Plot of veg condition change by time

Data

Status Information

Temporal Analysis

Trajectory Generation
VEGETATION CONDITION TRAJECTORY ANALYSIS FOR AREAS CUT IN FIRST TIME INTERVAL

Time (Acquisition Dates)

Vegetation Condition

1    2          3                        4            5         6

Forest Regeneration

Pasture

Conifer forest

deforestation

Forest Regeneration
FOREST REGENERATION COMPOSITION ASSESSMENT FOR AREAS CUT IN FIRST TIME INTERVAL

Current Leaf-On TM Data

Spectral Feature

CVA

Change Angle Computation

Change Angle Analysis

Relative amount of conifers and hardwoods in regenerating areas

Current Leaf-Off TM Data

Spectral Feature

Areas identified as regenerating forest that were cut in the first time interval
Chuna River: Preliminary Results

- Equivalent information about forest harvesting can be extracted from a variety of combinations of historical remote sensing data. This capability makes it possible to assemble a set of acquisitions with sufficient temporal frequency to effectively monitor forest cutting.
- Phenological timing of some of the acquisitions may make regeneration assessment more difficult.
- Large area coverage sensors (like Landsat) may help assess the representativeness of information derived from higher spatial resolution sensors (like DISP).
- Data adequacy is likely to vary on a case-by-case basis. DISP data may limit geographic coverage. Differences in phenology between acquisitions may make interpretation difficult.
- Ortho-rectification of the DISP and KFA data is difficult, but should greatly facilitate comparisons between acquisitions.
Deforested Areas near the Chuna River 1965-1990
Generated Through Analysis of DISP and Landsat
Map of Defoliation in the Biryusa River Basin from Siberian Silkworm Outbreaks 1994-1996 using SPOT Imagery

Legend:
- Defoliation Level:
  - 10% 50-60%
  - 10-20% 60-70%
  - 20-30% 70-80%
  - 30-40% 80-90%
  - 40-50% 90%

- Light Coniferous
- Broad Leaf
- Bare Soil
- Water
- Shadows
- Clouds

Map of Forest Defoliation Created by SPOT Imagery
Part III.
Modeling Patterns of Forest Regrowth/Carbon Sequestration
Modeling Boreal Forest Succession and Disturbance in the Krasnojarsk Kray Forest of Siberia

A. J. Hill, D.F. Clark and H.H. Shugart
Russia: Administrative Divisions

- Republic, oblast, or kray boundary
- National capital
- Autonomous okrug (AO) or autonomous oblast (AO) boundary

Legend:
- Republic
- Oblast
- Kray

An oblast is named only when its name differs from that of its administrative center. Moscow and St. Petersburg are federal cities having oblast-level status.

Names of administrative divisions are not authoritative. Boundary representation is not necessarily authoritative.

1. Krasnodar
2. Stavropol
3. Adygea
4. Karachay-Cherkessia
5. Kabardino-Balkaria
6. North Ossetia
7. Ingushetia
8. Chechnya
9. Moldova
10. Chukotka
11. Mari El
12. Udmurtia

* Boundary between Chechenia and Ingushetia has not been established.
* Chukotka may be independent of Magadan Oblast.
Objectives:

• To create a landscape scale succession model of Krasnojarsk, Siberia that incorporates fire and insect infestation.

• To investigate forest composition under shifting disturbance regimes at times scales that are difficult to empirically investigate.
• An initial model uses differential equations to simulate large areas of forest being transferred from one cover state to another.

• Rates of change and transfers among cover states are determined from species attributes or direct empirical measurements.
The fundamental idea is that the successional development of a forest is a progression of changes. The model keeps track of the area in each forest cover type and describes this dynamic change as a differential equation.
We used an already compiled synthesis of boreal sylvicultural data to estimate the rates of expected landscape change.
Using silvicultural descriptors to estimate change

Table 2.15. Silvical parameters of boreal tree species in Eurasia

Values for ETSmax, ETSmin and Tcold are estimated by overlapping of species distribution maps and climatic maps prepared by Dr. W. Cramer (personal communication). Values for Hmax in brackets are obtained in estimating IS from height and diameter data (see parameter explanation). Values for B2 and B3 are estimated so that the parabolic function for the diameter–height relation matches the asymptotic one (see explanation for parameter IS). Values for Tl, Td and Tn are based on unpublished data by N. P. Polikarpov.

<table>
<thead>
<tr>
<th>Species</th>
<th>ETSmax</th>
<th>ETSmin</th>
<th>Tcold</th>
<th>SPrf</th>
<th>Diap</th>
<th>SPrf</th>
<th>Smal</th>
<th>Sm</th>
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<th>SPrf</th>
<th>Min</th>
<th>Rlr</th>
<th>SprTnd</th>
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<th>SprMin</th>
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<td>510</td>
<td>35</td>
<td>30</td>
<td>T</td>
<td>F</td>
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Longevity

Growth Rate

Tolerance to environmental factors
Results

Mature Species: Succession Only

Years

Dominant Forest Species Area (ha)

P. sylvestris
Larix
P. siberica
Betula
Picea
Populus
Abies siberica
Mature Species: Succession and Infestation

- *P. sylvestris*
- Larix
- *P. siberica*
- Betula
- Picea
- Populus
- Abies siberica

**Infestation**
Mature Species: Succession, Infestation, and Fire

**Fire**

![Forest Fire Image]

**Graph:**
- *P. sylvestris*
- *Larix*
- *P. siberica*
- *Betula*
- *Picea*
- *Populus*
- *Abies siberica*

**Graph Details:**
- Y-axis: Dominant Forest Species Area (ha)
- X-axis: Years
- Legend:
  - *P. sylvestris*
  - *Larix*
  - *P. siberica*
  - *Betula*
  - *Picea*
  - *Populus*
  - *Abies siberica*
Fire
Current work involves the development of an individual-based model of forest dynamics that integrates directly with the landscape simulator.
The 6-week visit of Slava Kharuk allowed us to reparameterize the land-cover change model. We have also developed an spatial individual based model for the central Siberian site.