Modeling Siberian Boreal Forest Land-Cover Change and Carbon under Changing Economic Paradigms

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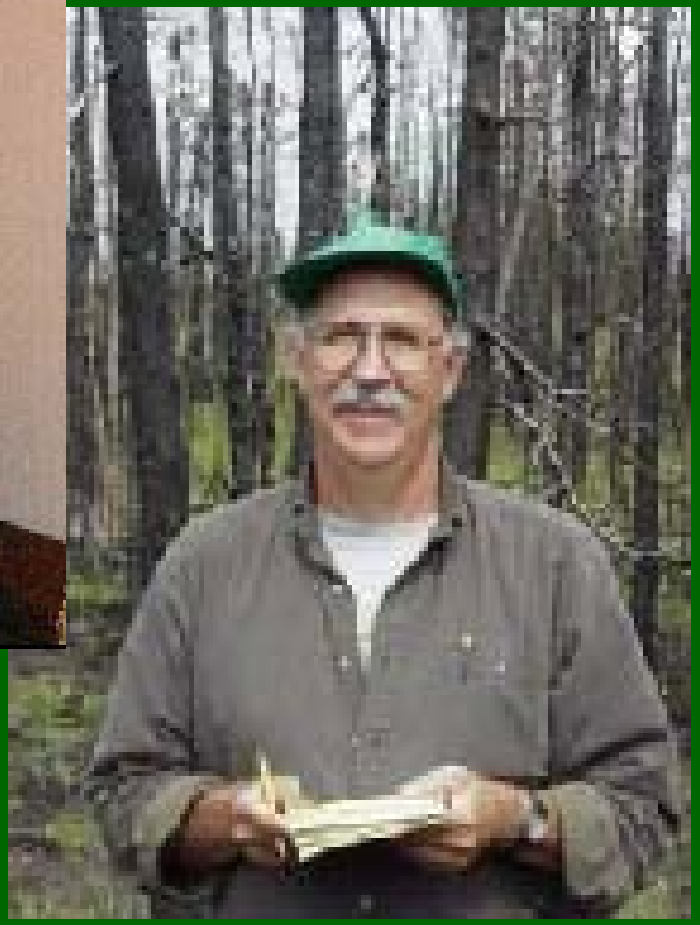
Long Before Most of Us in NASA LCLUC Ever Thought of Going to Siberian Russia to Do Research There Was . . .

Hank Shugart . . .and. . . Eric Kasischke

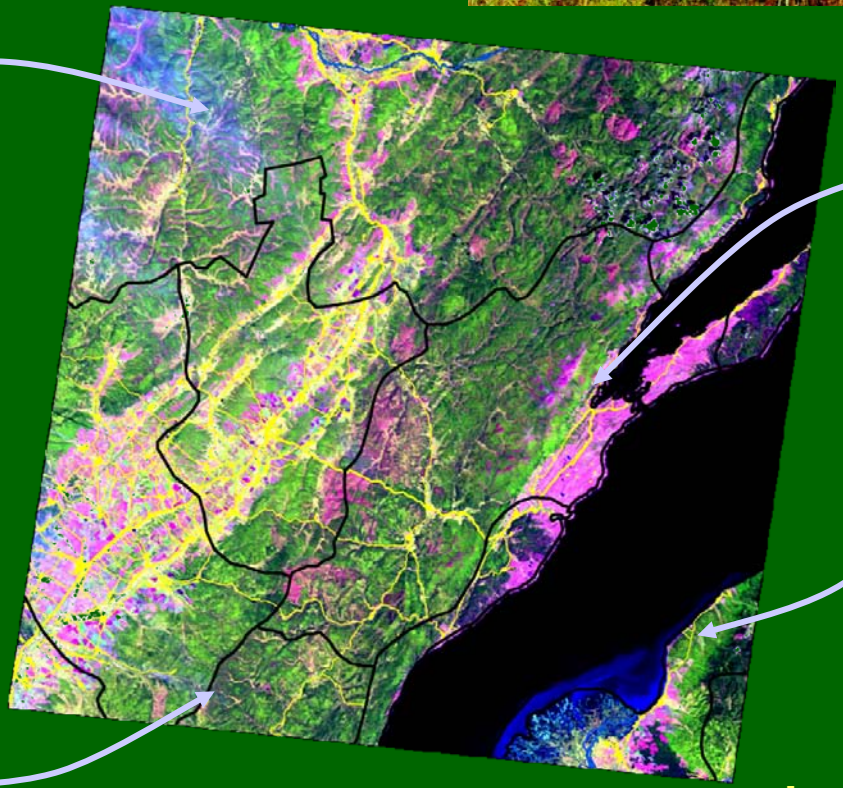


. . .and their Russian Scientist Collaborators

Forest Types in the Region

Spruce/Fir/ Siberian Pine (*Pinus siberica*)

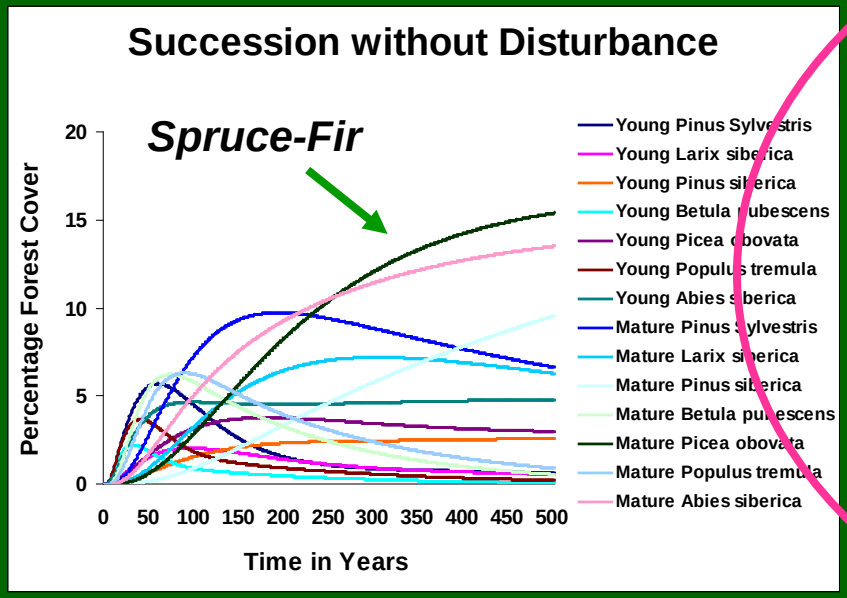
Aspen/birch



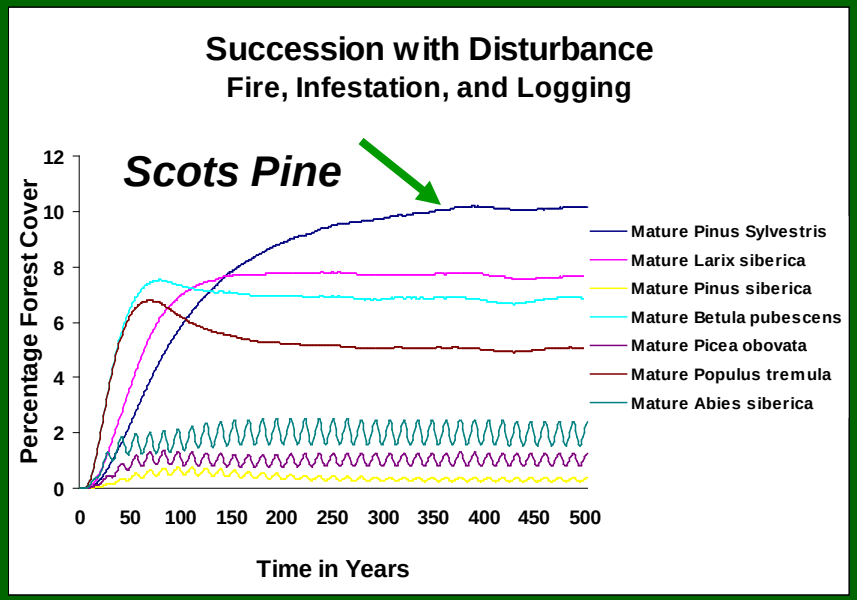
Scots Pine (*Pinus sylvestris*)

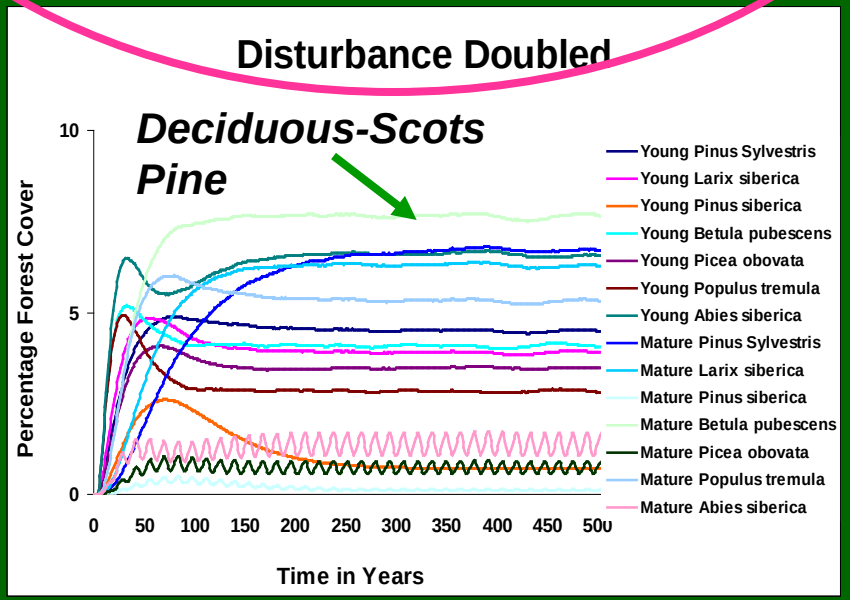
Larch

Modeled Forest Composition Over Time
(University of Virginia Model, 1998)



Disturbance Regimes:
- Fire
- Logging
- Insects



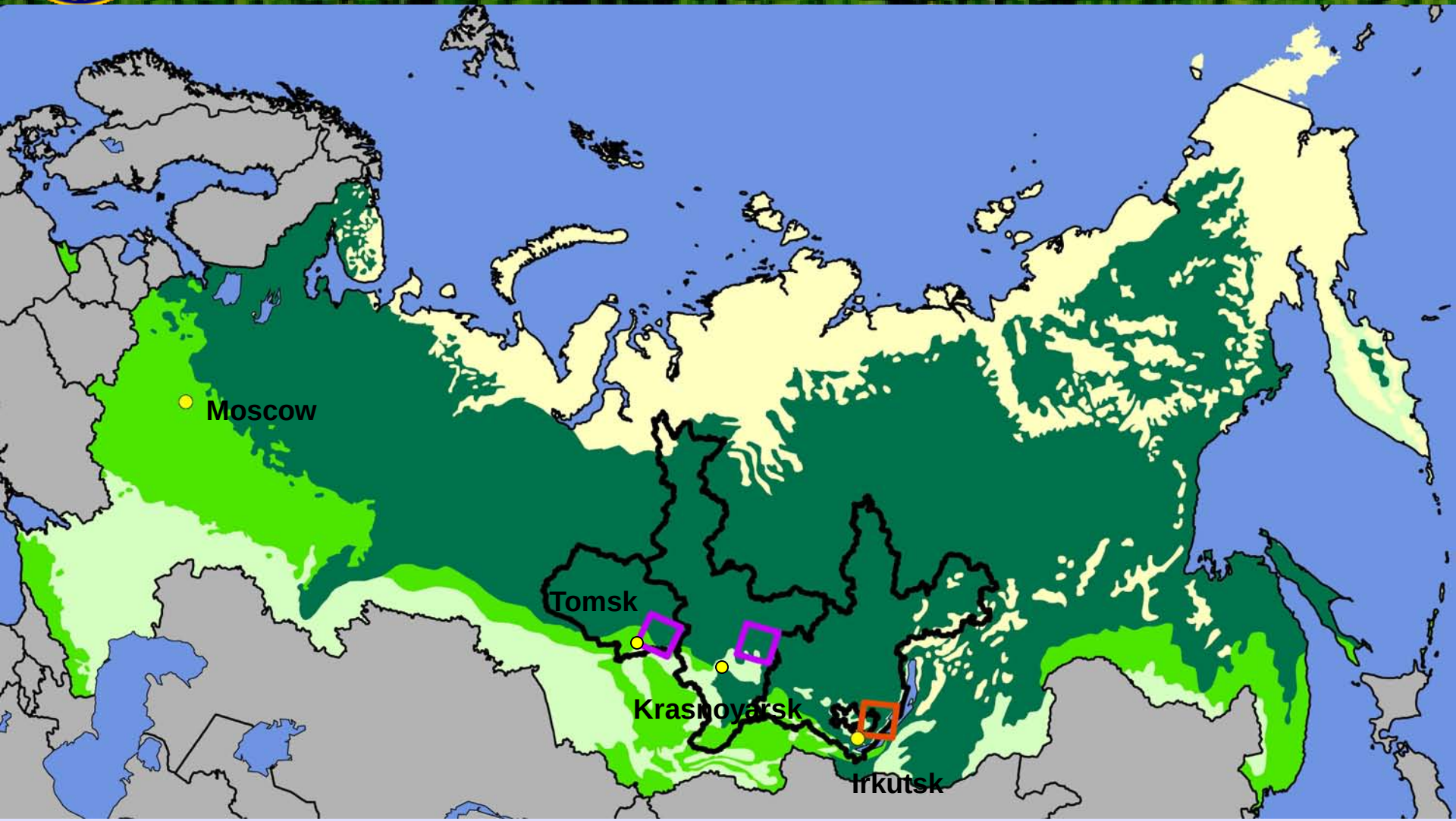


Goal of this NASA Land-Cover Land-Use Change (LCLUC) Project

- Our goal is to analyze land-cover/land-use change in Central Siberia boreal forests, including prior to and after the socio-economic change that accompanied the dissolution of the Soviet Union:
  - Is land-cover changing?
  - Is forest composition and age changing?
  - Is carbon storage changing?

- We are doing this using:
  - time-series Landsat satellite remote sensing data 1975-2000
  - time-series Russian statistical data 1975-2000
  - constructing new spatial diagnostic models of LCLUC and carbon

The Study Region in Central Siberia



The Questions/Objectives that Drove our Analysis Methods

I. What is occurring 1975-2000 in terms of socio-economic change?

II. How is land-cover changing? 1975-2000

a. Within the forest class, how is forest composition and age changing?

III. How may land-cover change in the future?

IV. How is carbon storage changing?

1975-2000

2000- future

I. GIS Creation for Spatial Analysis of Socio-Economic & Environmental Variables

Source: We digitized all relevant features on the 1:200,000 Russian Topographic Maps for the 3 study sites (Irkutsk site shown here)

Legend

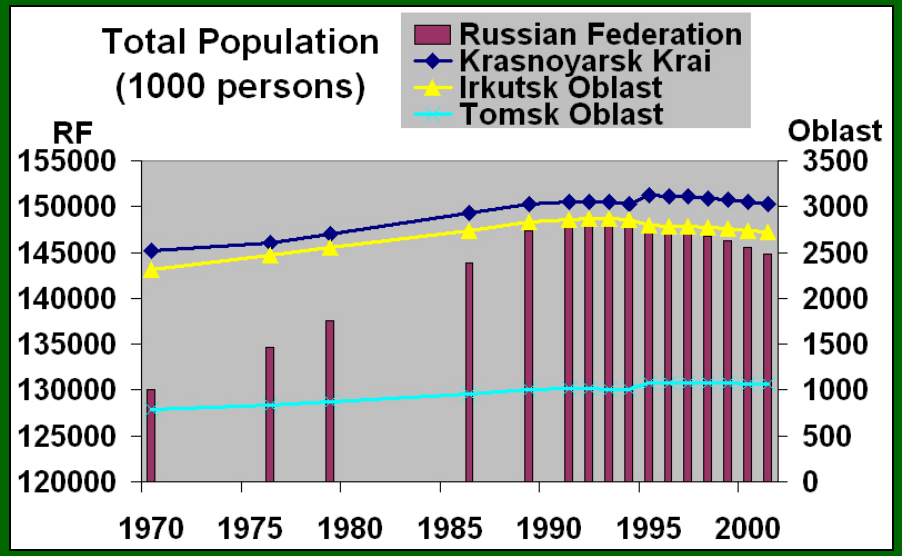
- Settlements
- Utilities
- Roads
- Rivers
- Lakes

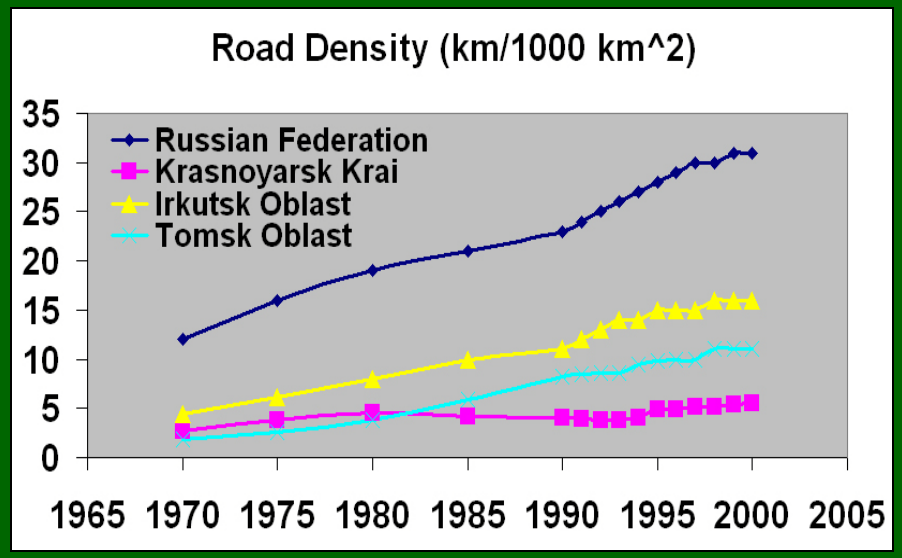
I. What is Occuring in Terms of Socio-Economic Change?
Socio-Economic Data Gathering

- Country level statistics were compiled from Goskomstat of Russia
- Local and Regional statistics were gathered and compiled by project scientists working at the *RAS Institute of Economics Forestry Group* in the *Novosibirsk Akademgorodok*

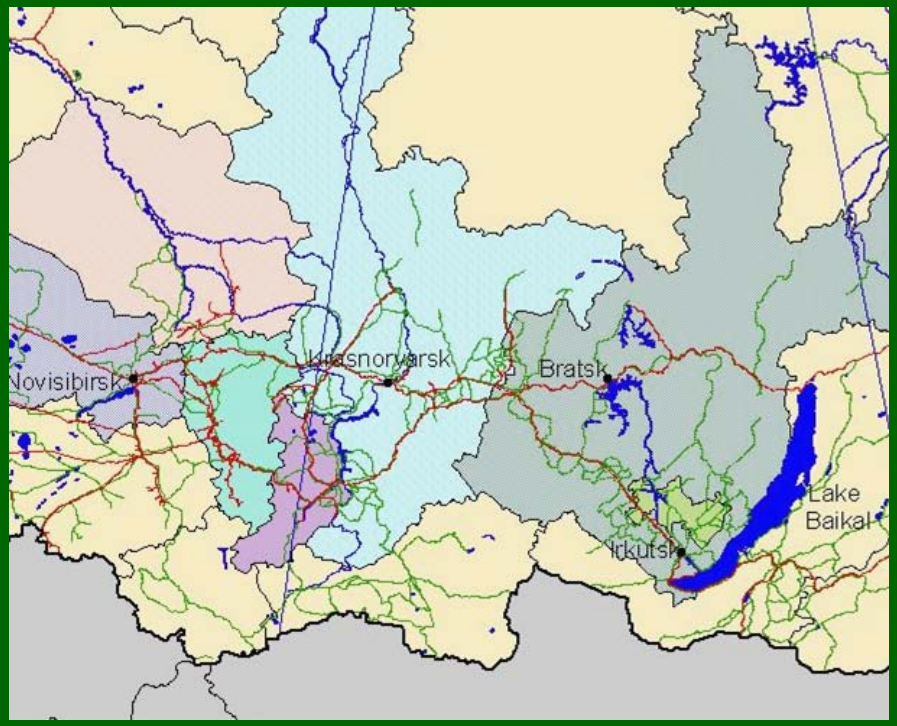
Akademgorodok - a town of Science in Siberia

I. Selected Socio-Economic Population-Infrastructure Variables Results

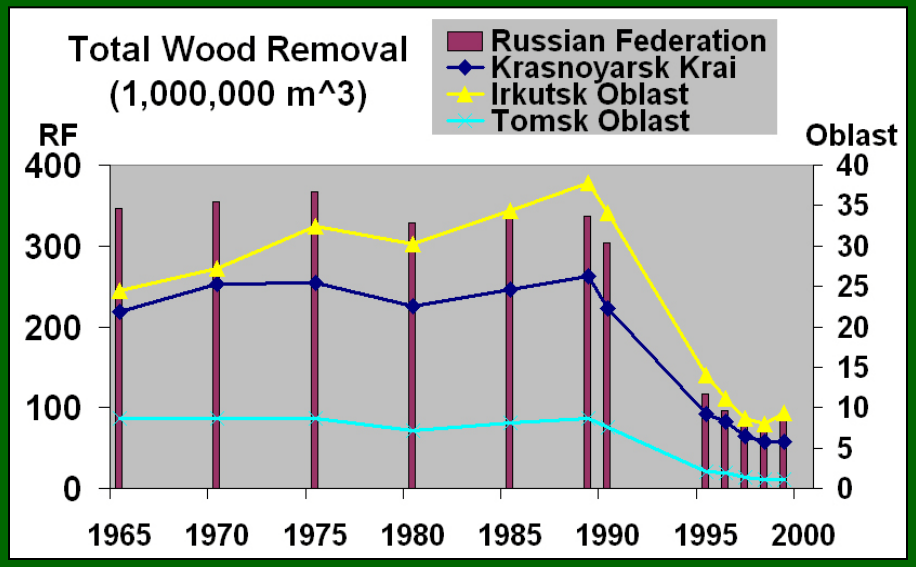


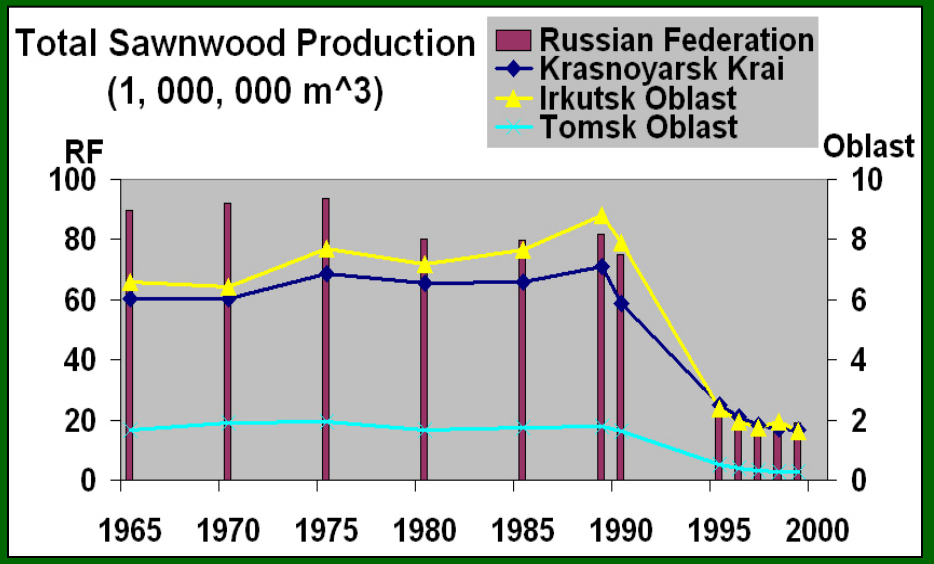


- **Population in Central Siberia is decreasing slightly, following the same trend as the Russian Federation**
- **At the same time, some infrastructure in this remote region is clearly increasing**



I. Selected Forest Sector Socio-Economic Variables Results





- **Official forest sector productivity, including wood removal (harvest) and sawn wood production decreased dramatically in 1990 (to < 1/4 of former productivity), again paralleling Russian Federation trends**

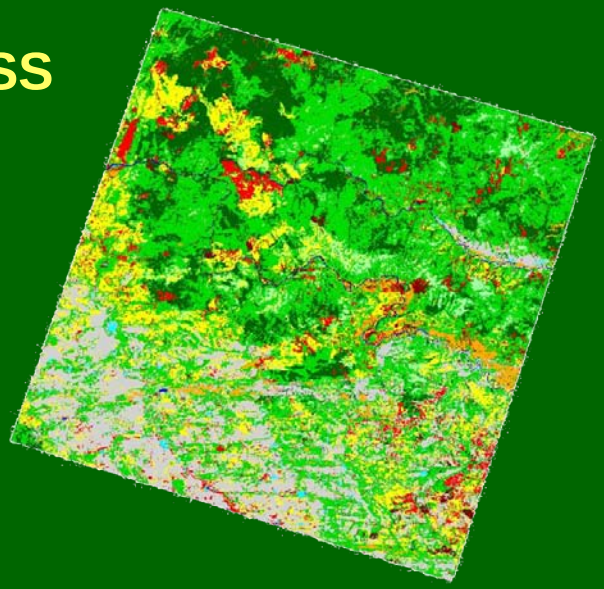
- **Forest sector productivity has increased very slightly in the past several years**

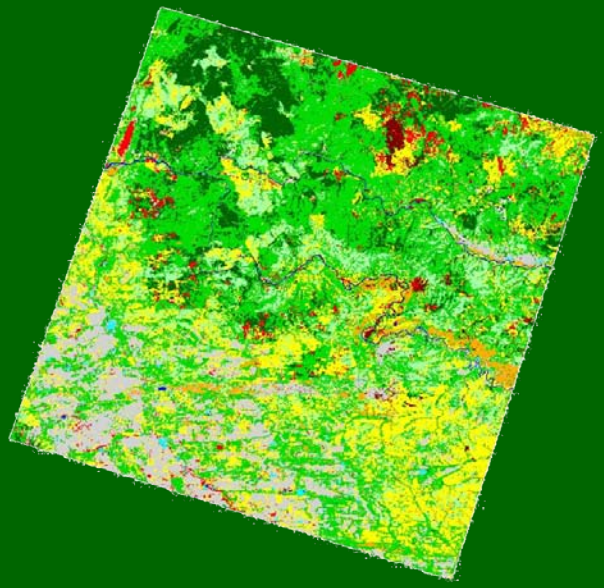
II. How is Land-Cover Changing?

- Time series Landsat data were acquired, processed, and analysed for land-cover and land-cover change
  - Three case study sites, each the footprint of a single Landsat scene (185 x 185 km)
  - Three time periods (three images) per case study site: 1975, 1990, 2000 (cloud-free Landsat rare)
  - Analysis involved (for nine scenes):
    - Preprocessing: georectification, cloud-removal, some mosaicing
    - Land-cover classification
    - Post-classification change detection
    - Accuracy assessment
    - Analysis of results

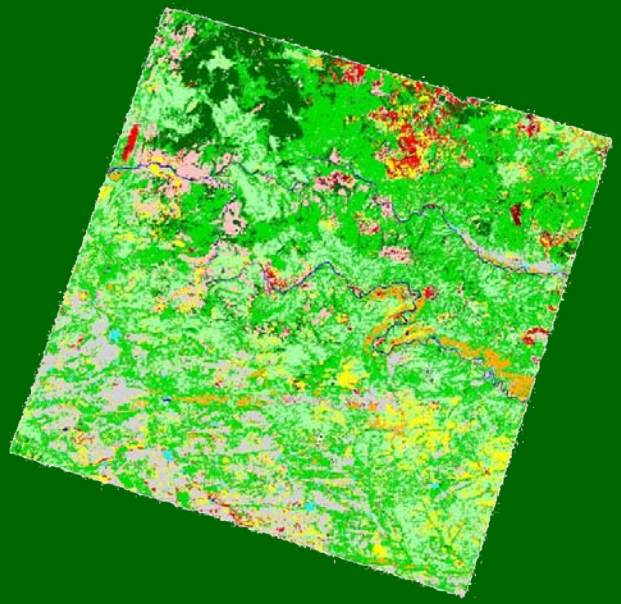
II. Land-Cover Change in the Krasnoyarsk Case Study Site 1974-2000

Landsat MSS
6/26/1974
P152R20





Landsat TM
7/2/1989 (W)
P142R20
& 7/7/1990 (E)
P140R20

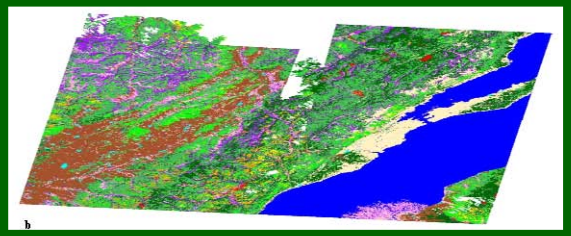


Landsat ETM+
8/18/2000
P141R20

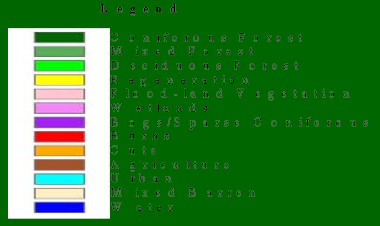
- coniferous forest
- deciduous forest
- mixed forest
- regeneration
- fresh-cut/bare
- fresh-burn
- insect damage
- water
- agriculture
- wetland
- urban

II. Land-Cover Change in the Irkutsk Case Study Site 1974-2000

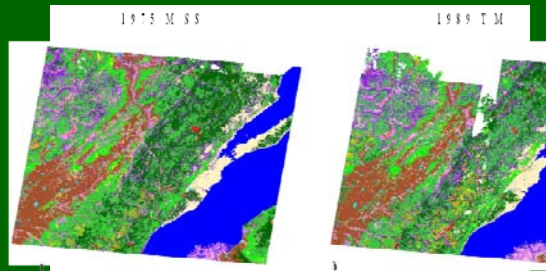
Landsat MSS
6/21/1975
P143R23

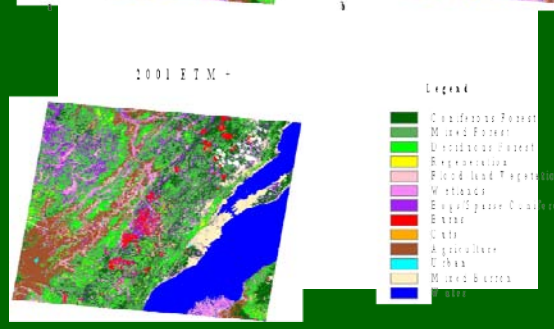


Landsat TM
7/2/1989 (N)
P133R23
& 8/21/1989 (S)
P132R23



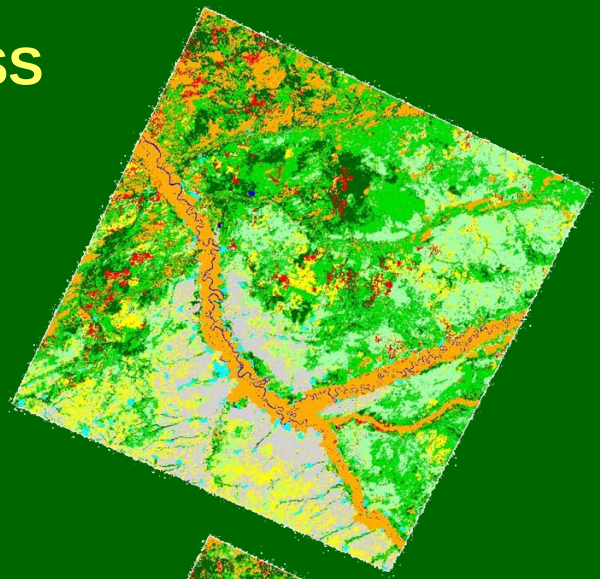
Landsat ETM+
8/13/2001
P133/R23



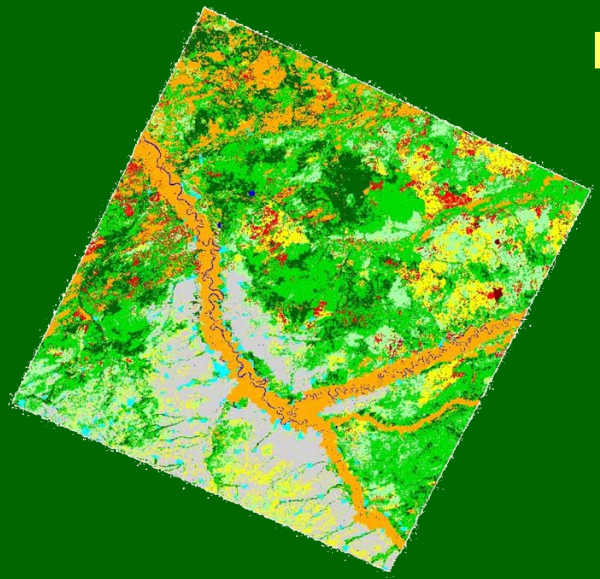


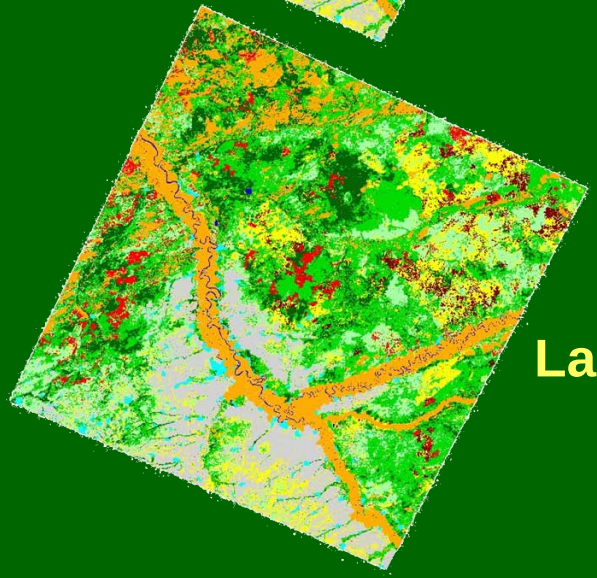
II. Land-Cover Change in the Tomsk Case Study Site 1974-2000

Landsat MSS
8/30/1975
P159R20



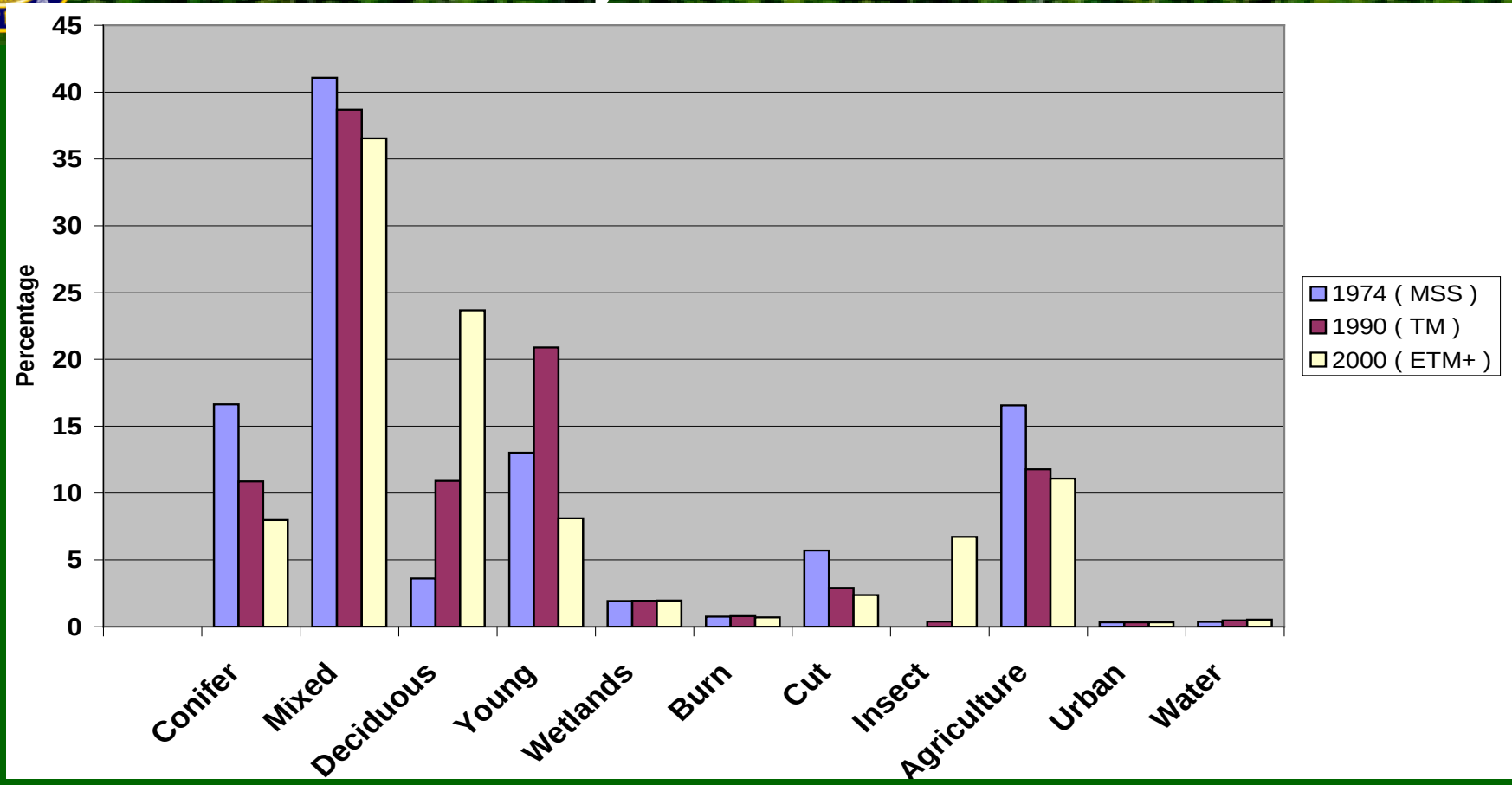
Landsat TM
9/7/1989
P147R20





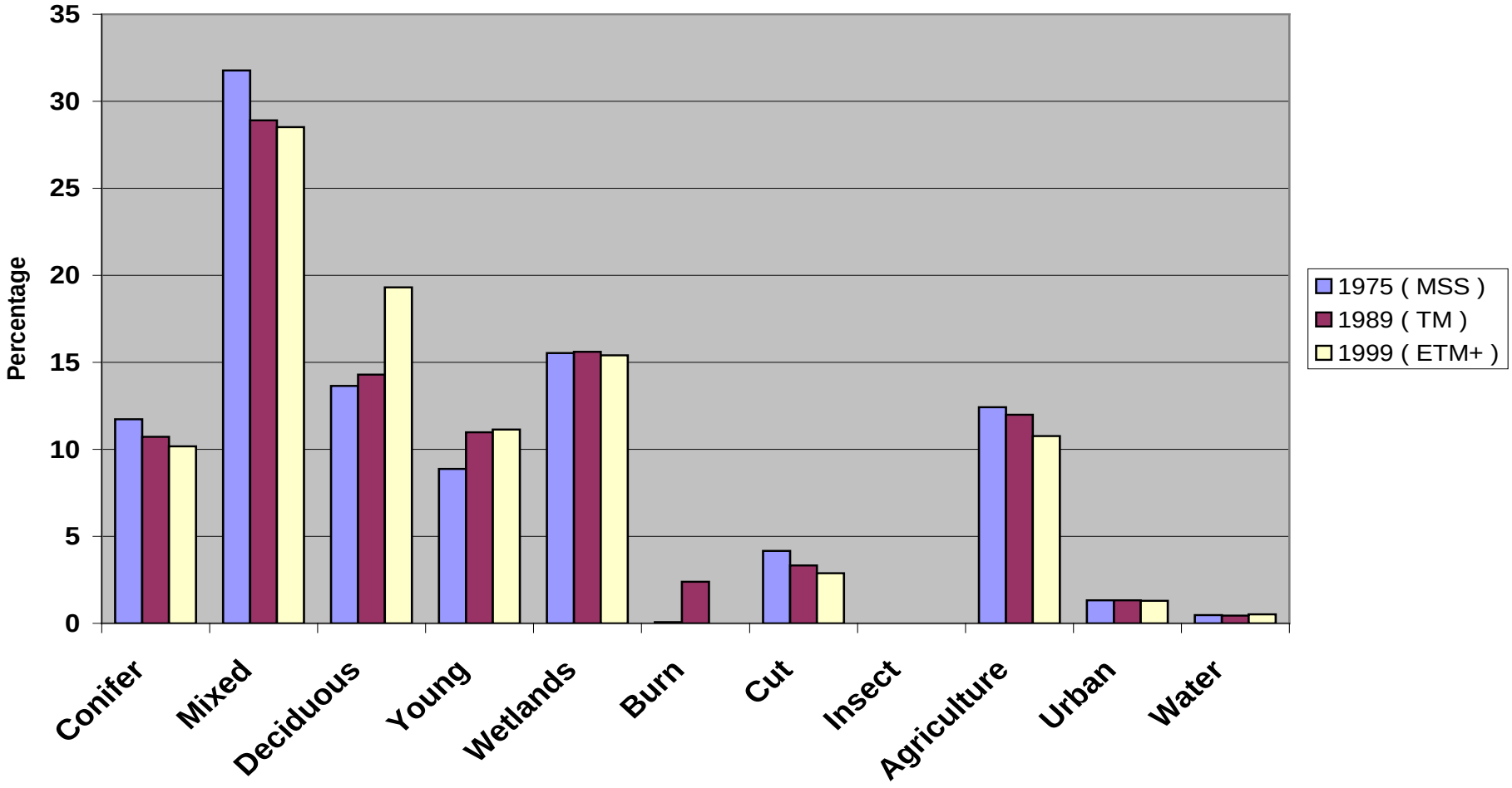
Landsat ETM+
7/9/1999
P147R20

II. Land-Cover Change in the Krasnoyarsk Case Study Site 1974-2000 Results



Landsat-derived statistics 1975-2000 in case study sites show that significantly reduced forest harvest, increased collective farm abandonment, growing deciduous forests, and insects/fire are changing the *amount*, *age*, and *type* of forest on the landscape with implications for carbon storage.

II. Land-Cover Change in the Tomsk Case Study Site 1974-2000 Results



Landsat-derived statistics 1974-1999 in case study sites show that reduced forest harvest, collective farm abandonment, growth of deciduous forests and fire are changing the *amount*, *age*, and *type* of forest on the landscape with implications for carbon storage.

II. Land-Cover Change Selected Conclusions

- **Land-Cover**
  - **Forest harvest decreased 1990-2000; however it had already been decreasing in the study sites 1975-1990**
  - **Agricultural abandonment underway by 1990, and continues to 2000**
  - **Urban, wetland, bare categories are not as dynamic (e.g. urbanization not a major issue)**
  - **Major insect damage seen in one site**
  - **Fire - need more (annual) data to more fully assess impact**

II. Land-Cover Change Conclusions

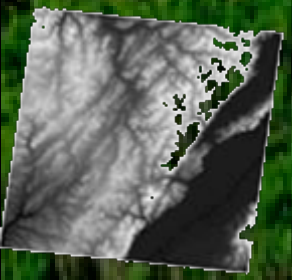
- **Forest Type and Age**
  - Previous primary forest had a much greater proportion of “dark coniferous” (spruce/fir/Siberian pine)
  - Forest harvest currently occurs primarily in mature spruce-fir forest or pine-mixed forests. Likely significant cutting prior to 1975.
  - The late 20th century forest is dominated by pine-mixed (*Pinus sylvestris*) or deciduous forest types and deciduous is increasing
  - After fire or logging the deciduous component remains dominant up to 70-100 years, then the stand begins to succeed to conifer
  - The areal percentage of coniferous and mixed forests is declining 1975-2000 while the areal percentage of deciduous is increasing. Possible reasons:
    - Regrowth from prior logging moving into deciduous
    - Continuing agricultural abandonment
    - Reduced but continued logging in conifer forest type
    - Fire occurrence in pine-mixed forests
    - Climate change?

III. What May Land-Cover Look Like in the Future

- **Construct "diagnostic" spatial-temporal land-cover change models for each study site using:**
  - ***Logistic Regression Analysis*** **- create probability maps, land-cover, terrain, and other environmental variables from GIS**
  - ***Markov*** **model process based on transition probabilities from Landsat-derived land-cover change data from 1975-1990 and 1990-2000**
  - ***Cellular Automata*** **method incorporating spatial dependencies**
  - **Future scenarios - ~2013 based on 1975-1990 data and based on 1990-2000 data**
  - **Compare actual and modeled current conditions**

LOGISTIC REGRESSION ANALYSIS: effects of terrain on land cover

Independent Variables



TERRAIN
- **Elevation**
- **Slope**
- Aspect
- Topographic Wetness Index

INFRASTRUCTURE
- **Distance to roads**
- Distance to rivers
- **Distance to Settlements**

LAND COVER
Presence/Absence
- Coniferous Forest
- Mixed Forest
- Deciduous Forest

Land cover Probability

- **Coniferous Forest**
- Mixed Forest
- Deciduous Forest
- Regeneration
- Bogs
- Bogs
- Wetland/Floodland Vegetation
- Burns
- Cuts
- Agriculture

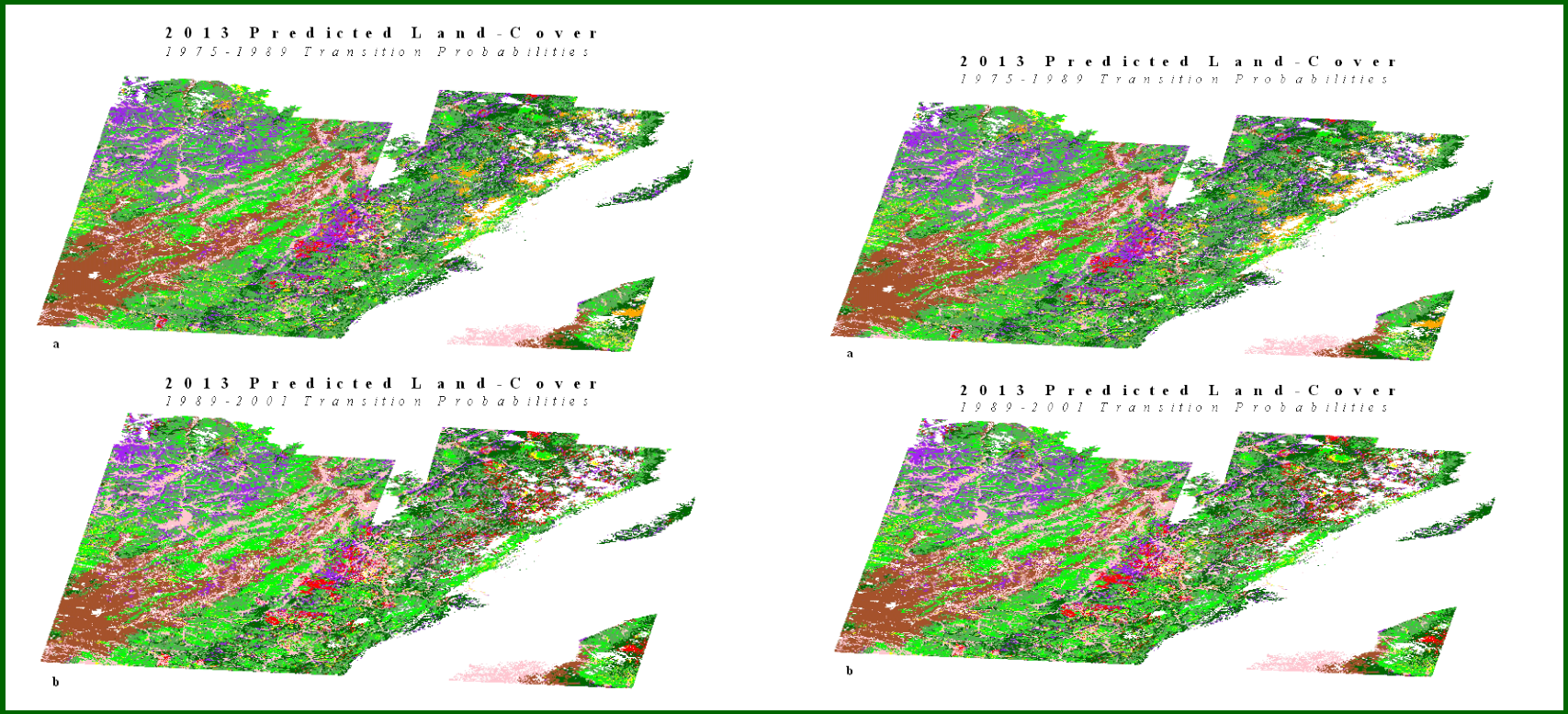
MARKOV CHAIN ANALYSIS: transition probabilities

CELLULAR AUTOMATA: incorporating space into transitions

III. 2013 Predicted Land Cover

1975-1989 Transition Probabilities

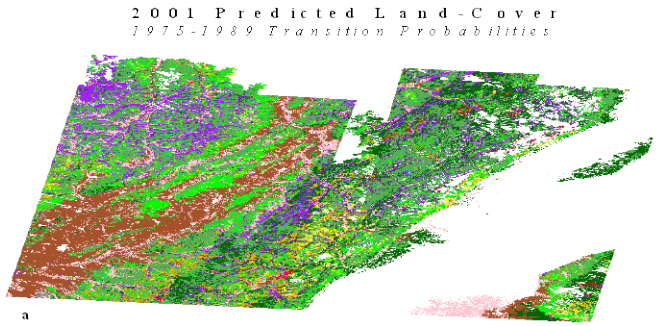
1989-2001 Transition Probabilities



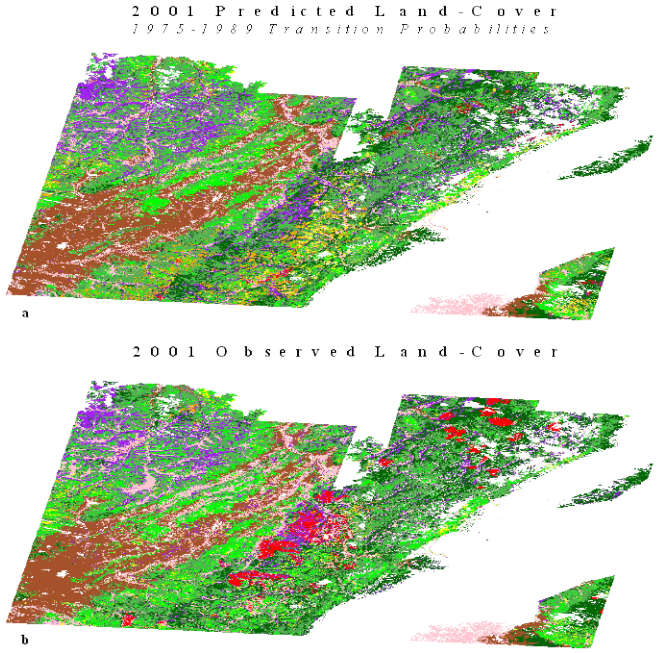
- Coniferous Forest
- Mixed Forest
- Deciduous Forest
- Regeneration
- Flood-land Vegetation
- Wetlands
- Bogs/Sparse Coniferous
- Burns
- Cuts
- Agriculture

III. 2001 Predicted and Observed Land Cover

2001 Predicted Land Cover



2001 Observed Land Cover

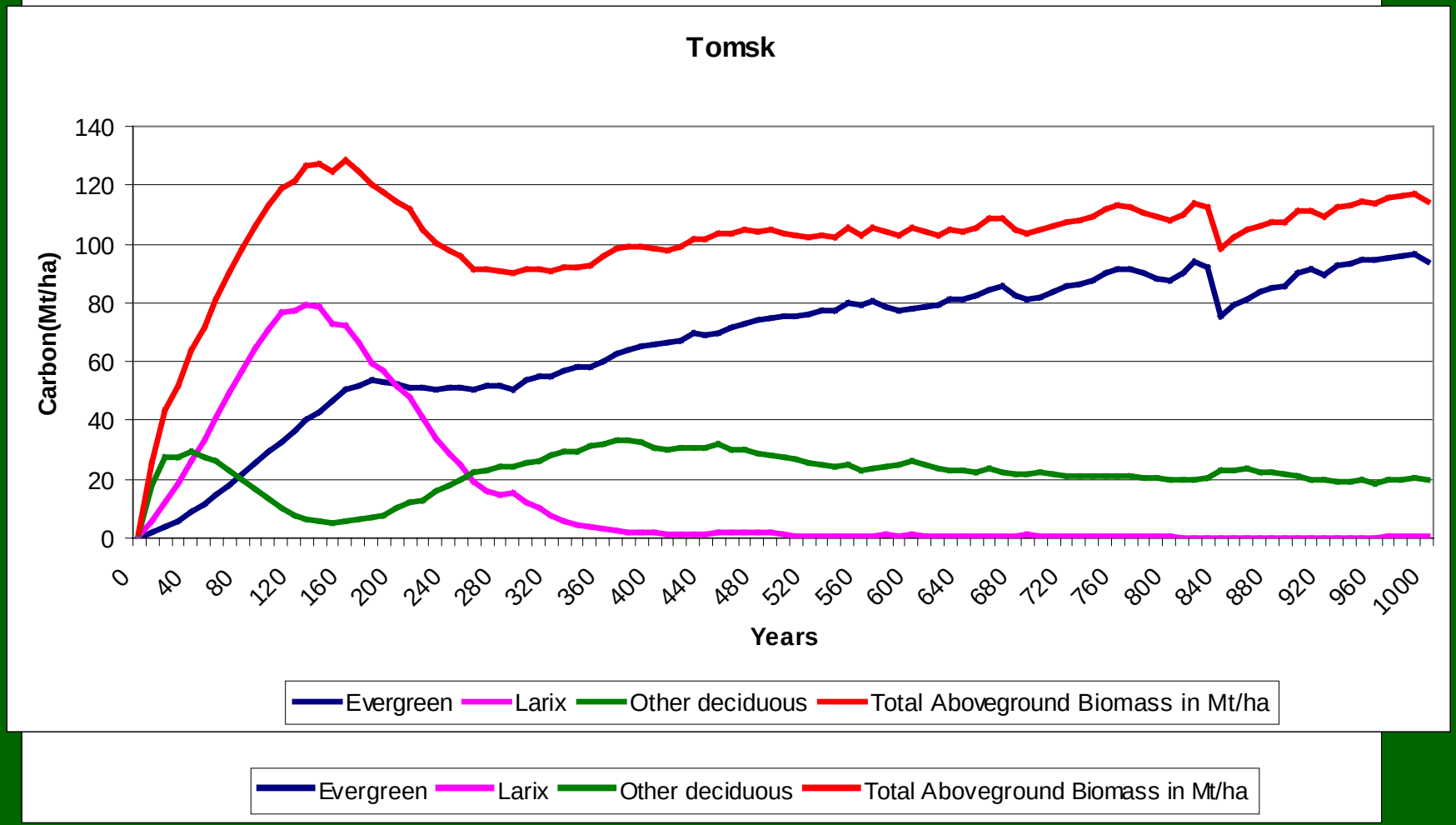


- Coniferous Forest
- Mixed Forest
- Deciduous Forest
- Regeneration
- Flood-land Vegetation
- Wetlands
- Bogs/Sparse Coniferous
- Burns
- Cuts
- Agriculture

IV. How is Carbon Changing?

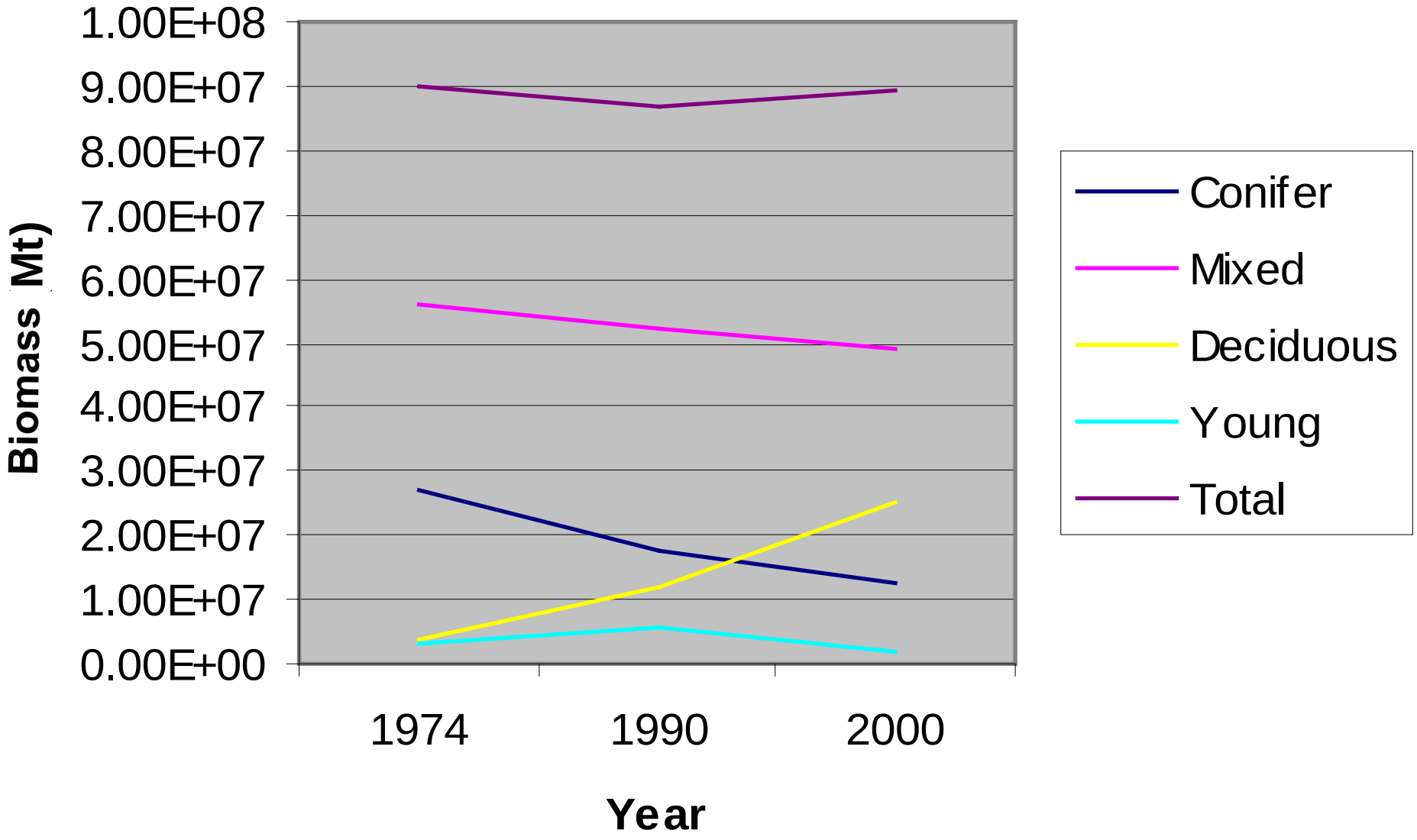
- Carbon Model of University of Virginia (Hank Shugart et al)
  - based on previously measured field plots in Central Siberian forests over range of the ages and compositions on the landscape
- Run model for our LCLUC study sites (Tomsk, Krasnoyarsk, Irkutsk)
- Output carbon values for each forest component plus total from time 0 - 600 years+
- Assign carbon values to land-cover categories used for remote sensing analysis at each of the three time periods
- Calculate carbon storage in each of the land-cover types, over each time period for each site
- Visualize change in Carbon storage

IV. Regional Carbon Behavior output from UVA Carbon Model for Siberian Forests

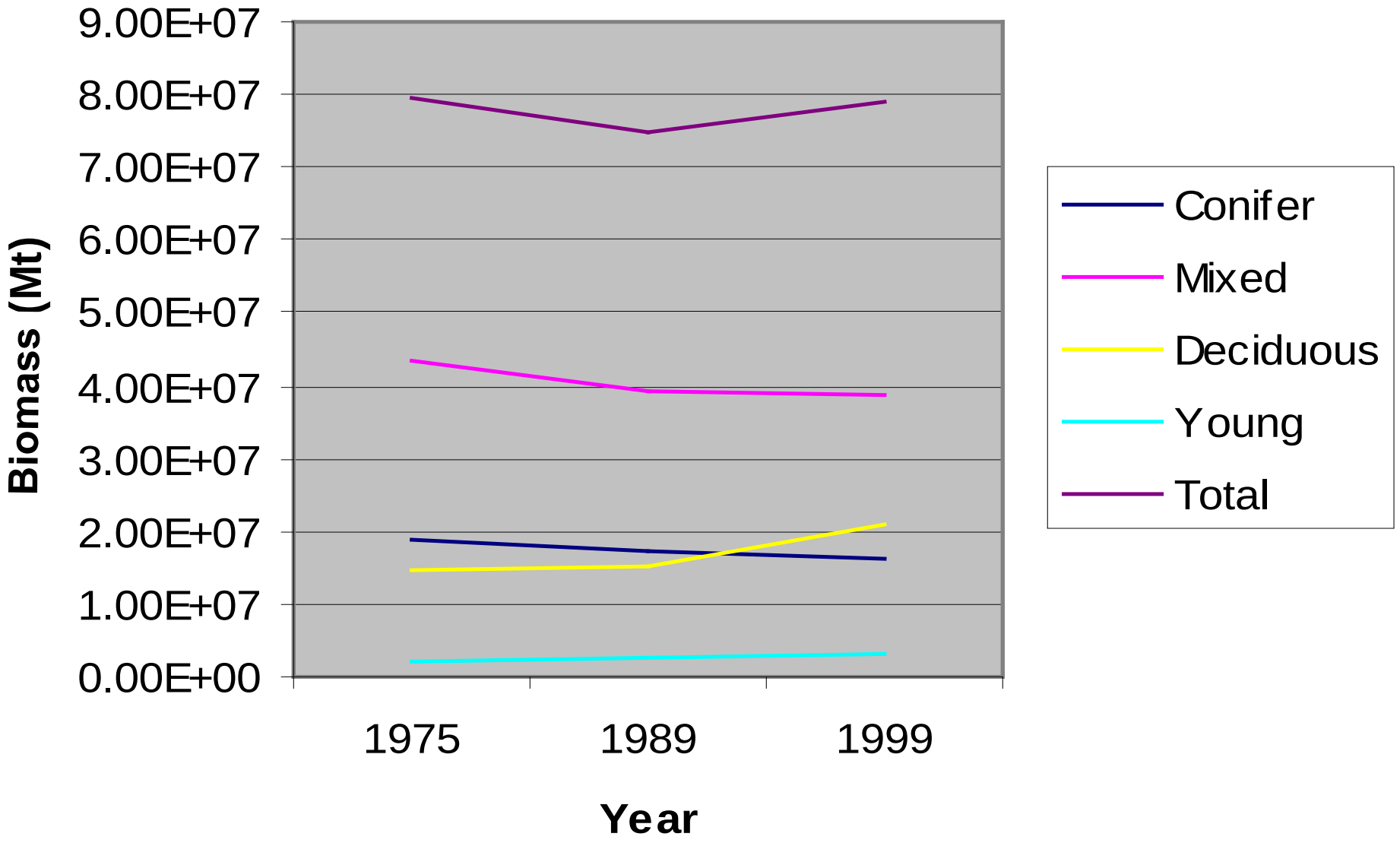


Evergreen Larix Other deciduous Total Aboveground Biomass in Mt/ha

IV. Krasnoyarsk: Change in Carbon Stored in Major Forest Types 1974-2000: Draft Results



IV. Tomsk: Change in Carbon Stored in Major Forest Types 1974-2000: Draft Results



IV: Tentative Results on Carbon

- Carbon stored appears to be increasing in the deciduous type and decreasing in the other forest types
- Increasing carbon stored in deciduous is probably the result of land-cover change and disturbance, from abandoned agriculture and logging (human activities) and from fire.
- Region probably is a carbon sink at this time. Carbon sink may be from reduced logging and increased re-growth
- Annual productivity is high up to ~100 years, then declines significantly (show slide). Younger (< 100 years) forests have a greater *rate* of carbon accumulation
- Plan to simulate (model) potential future carbon stores

Our To Do List

- **Final steps**
  - Complete final analysis of carbon storage for each of the three sites
  - Finish simulation of future scenarios
  - Add additional fire data in
  - Statistical correlation of socio-economic variables with remote sensing derived land-cover change
  - Synthesis and reporting

- **Data Sharing**
  - Make our test sites, extensive GIS data, statistical data, and remote sensing data available to the research communities

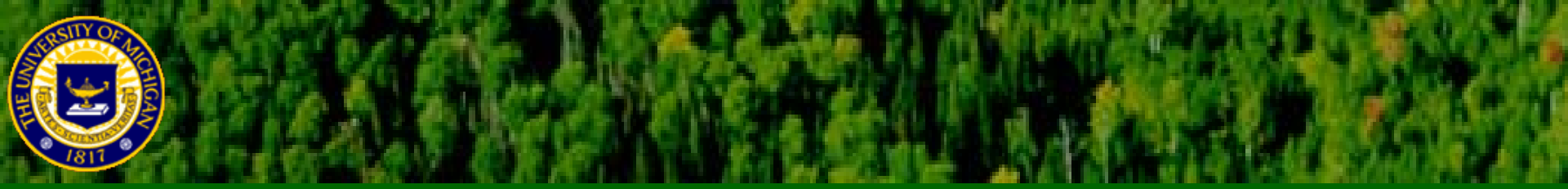
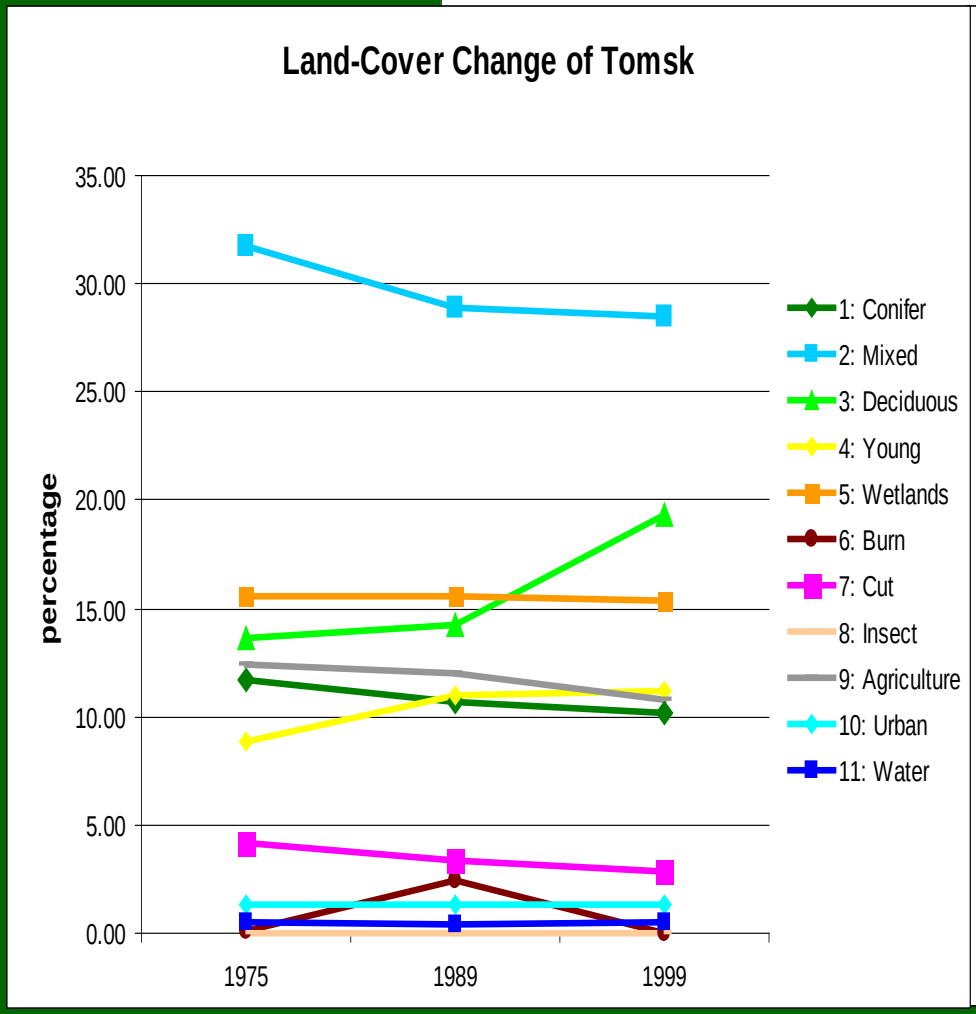
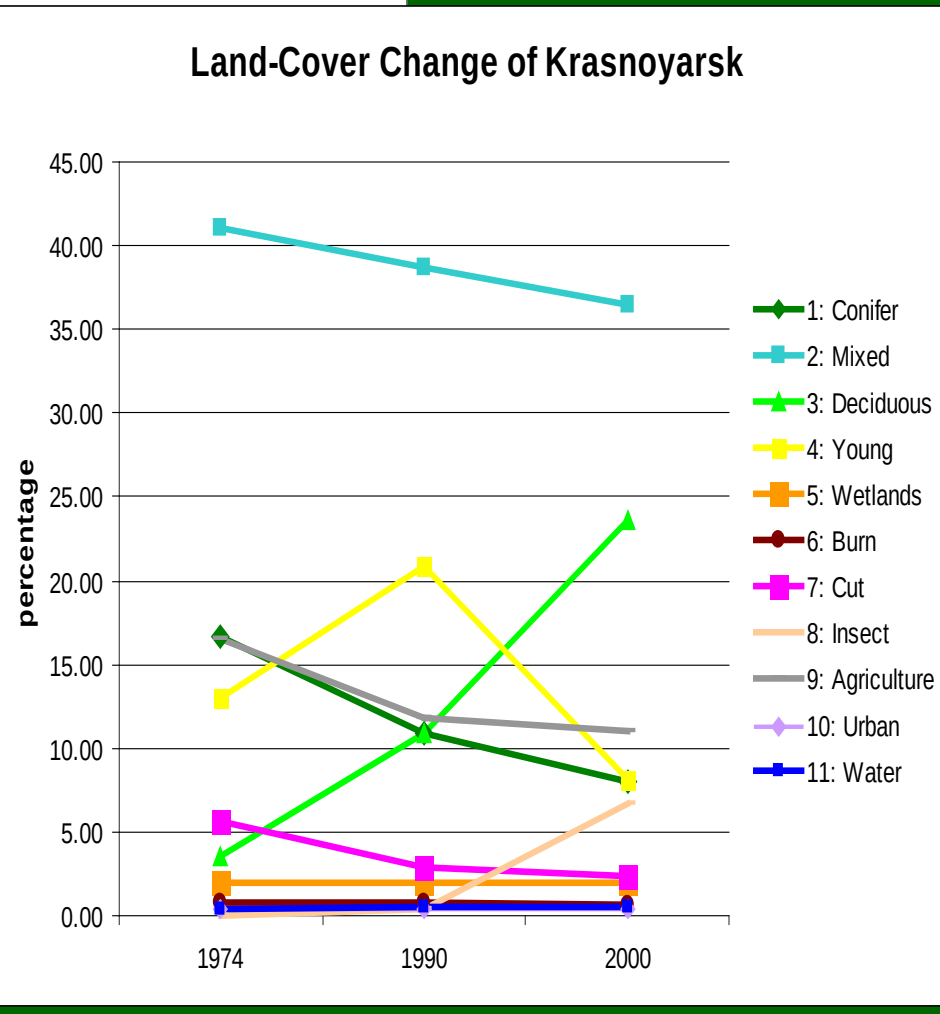
Community Research To Do List

- One of the first LCLUC studies in Siberian Russia. Continue the effort.
- Potential to develop *process* models that would link to our land-cover change spatial CA-Markov models. Agent based models?
  - Learn from LBA about process modeling. What is the same, what is different in tropical vs. boreal forests processes modeling?
- Continue to develop and provide better time-series fire location data on a yearly basis (including back to 1975)
- Develop research on the impact of agricultural abandonment in Russia on regional-global carbon (FOOD-related Grand Challenge!)
- Study carbon FLUX and rates of accumulation in addition to STORAGE
- Role of climate change in the trend toward deciduous?
- Landsat extremely important. Also invest in cloud-free data sources (e.g. fine scale radar-lidar)
- Couple what we've learned with Landsat with MODIS NPP and Fire datasets
- Use GIS/RS/Statistical datasets we have compiled

Acknowledgments

- This work on the Siberian Boreal forest is supported by the NASA Land-Cover Land-Use Change Program.

- The authors would like to thank Dr. Garik Gutman (NASA LCLUC), Chris Justice (UMD, LCLUC), Eugene Vaganov (RAS, Krasnoyarsk), and many members of Siberian Branch of the Russian Academy of Sciences, and officers of local forest management organizations.



III. Change in Forest Composition and Age 1974-2000 Results