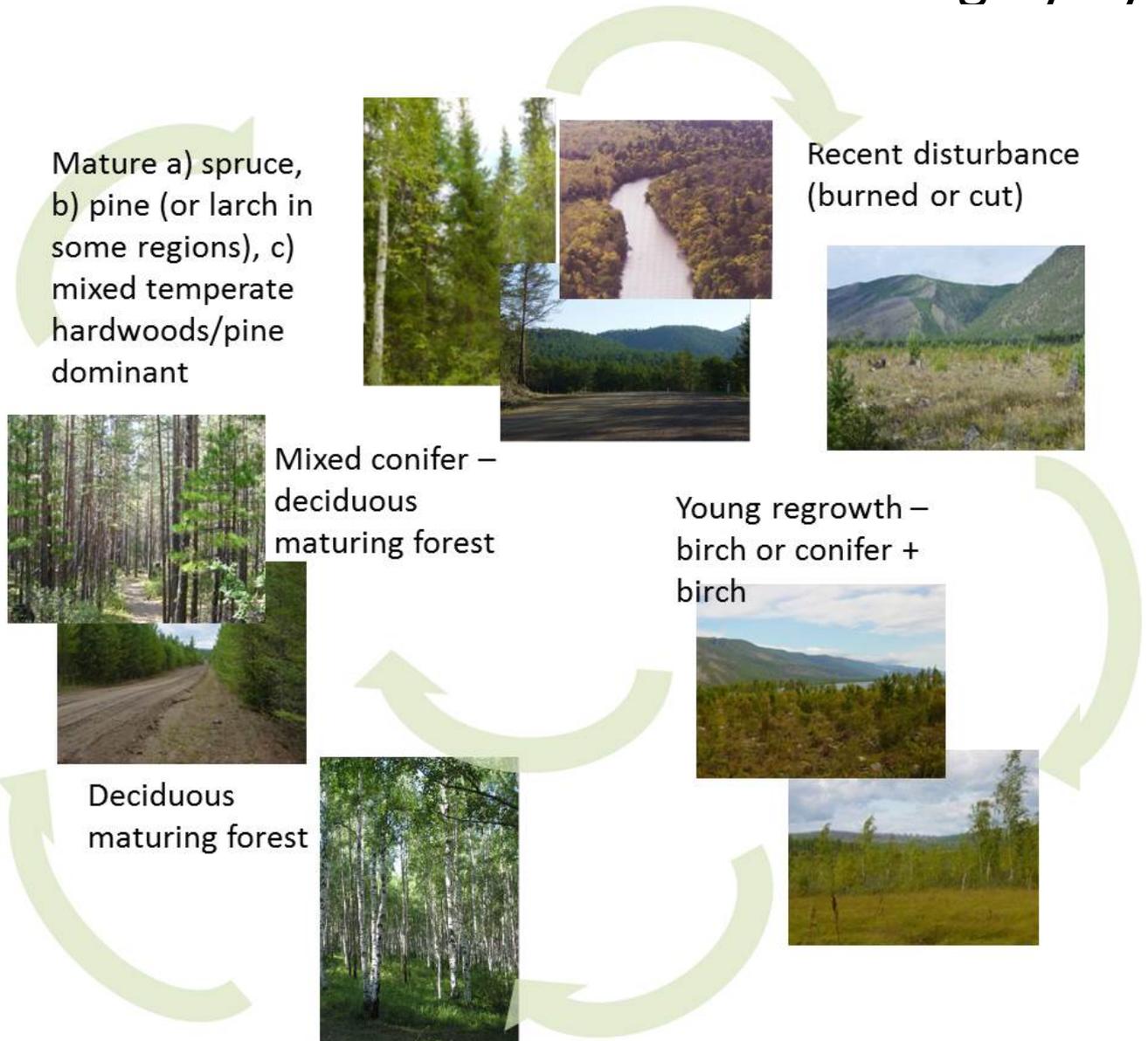# LCLUC Synthesis: Forested Land-Cover and Land-Use Change in the Russian Far East & Central Siberia Under the Combined Drivers Of Climate and Socio-Economic Transformation

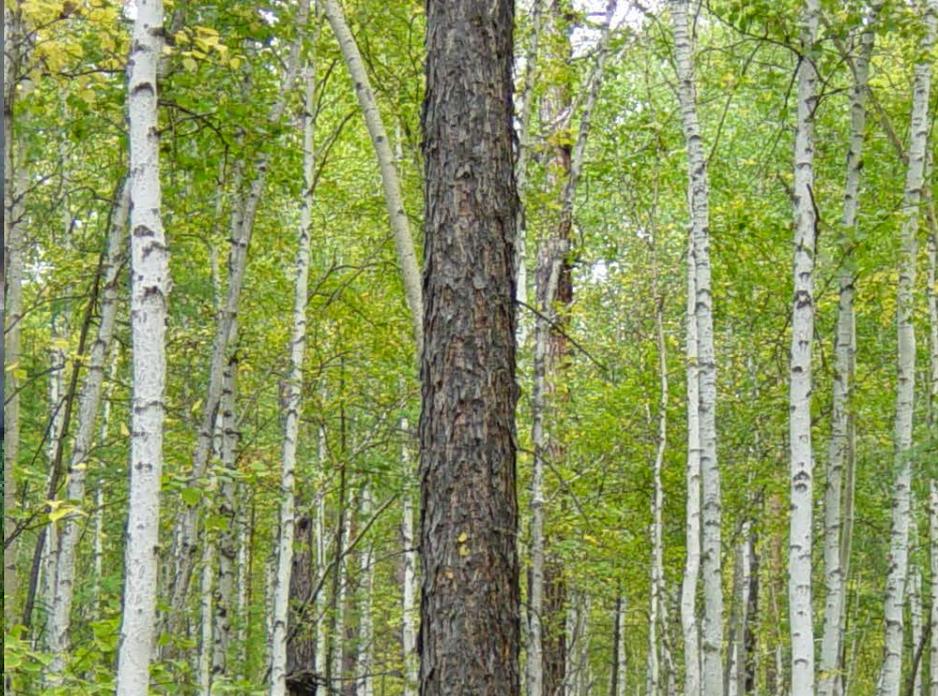U.S. Multi-Institution Synthesis Team

❖ Kathleen Bergen, Josh Newell, Dan Brown, Stephanie Hitztaler:

University of Michigan

❖ Tatiana Loboda, Guoqing Sun: *University of Maryland*

❖ Hank Shugart, Jacquelyn Shuman: *University of Virginia*
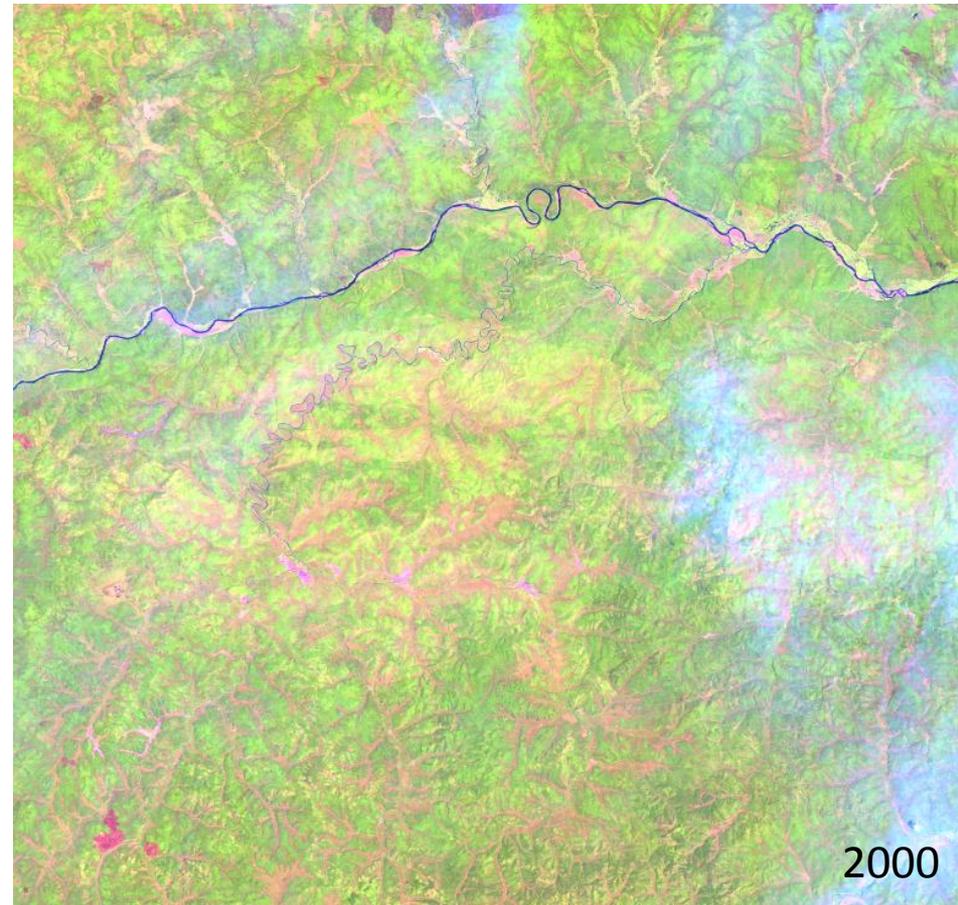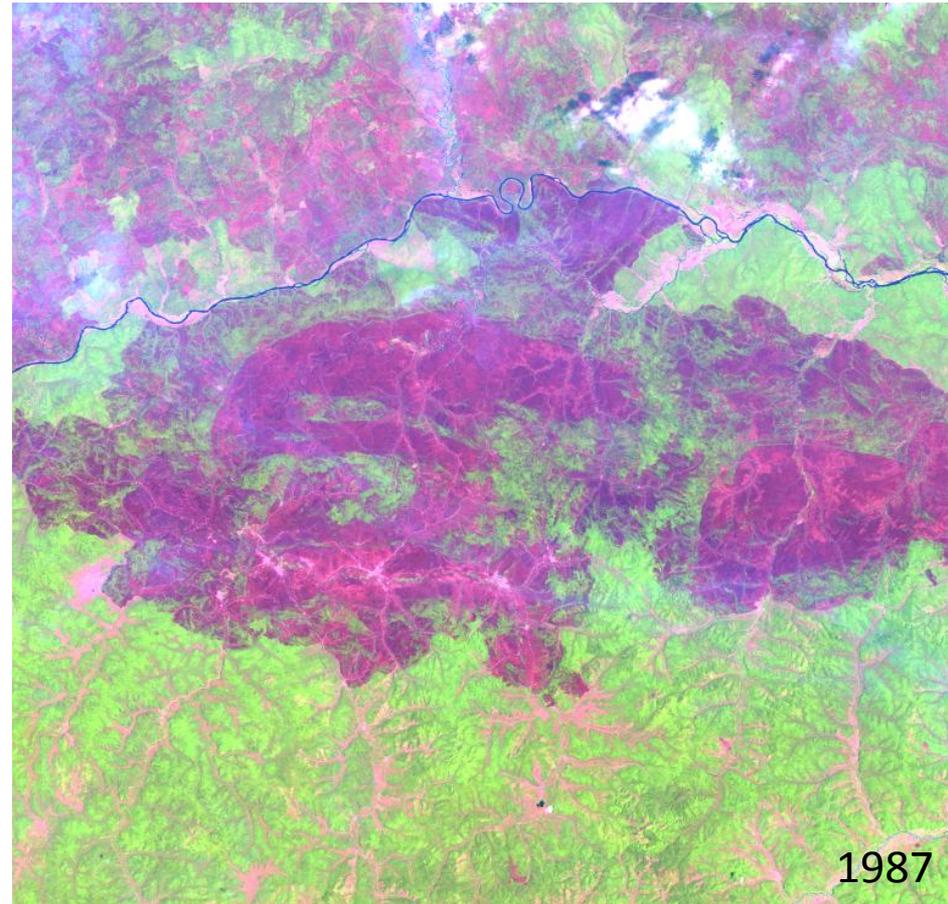
❖ Olga Krankina: *Oregon State University*

Motivation

Boreal forests of northeastern Eurasia are highly dynamic:

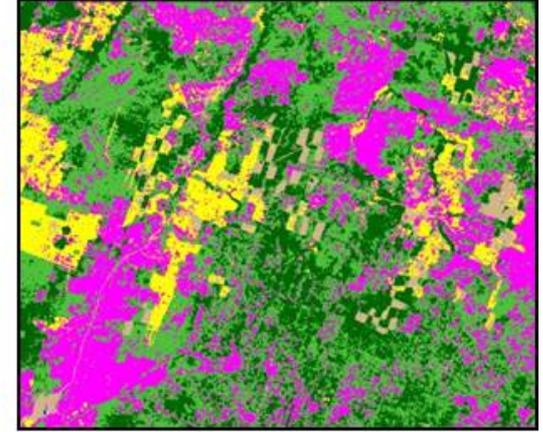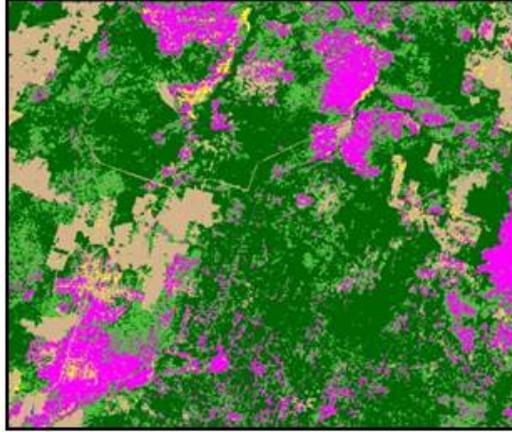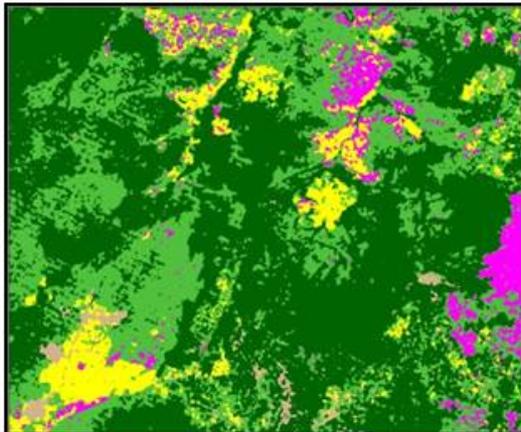Mature a) spruce, b) pine (or larch in some regions), c) mixed temperate hardwoods/pine dominant

Recent disturbance (burned or cut)

Mixed conifer – deciduous maturing forest

Young regrowth – birch or conifer + birch

Deciduous maturing forest

Fire

Fire : Amur site path/row 122/023 185X185km

1987

2000

Harvest

Harvest (logging)

August 30, 1975   Sept. 7, 1989   July 9, 1999

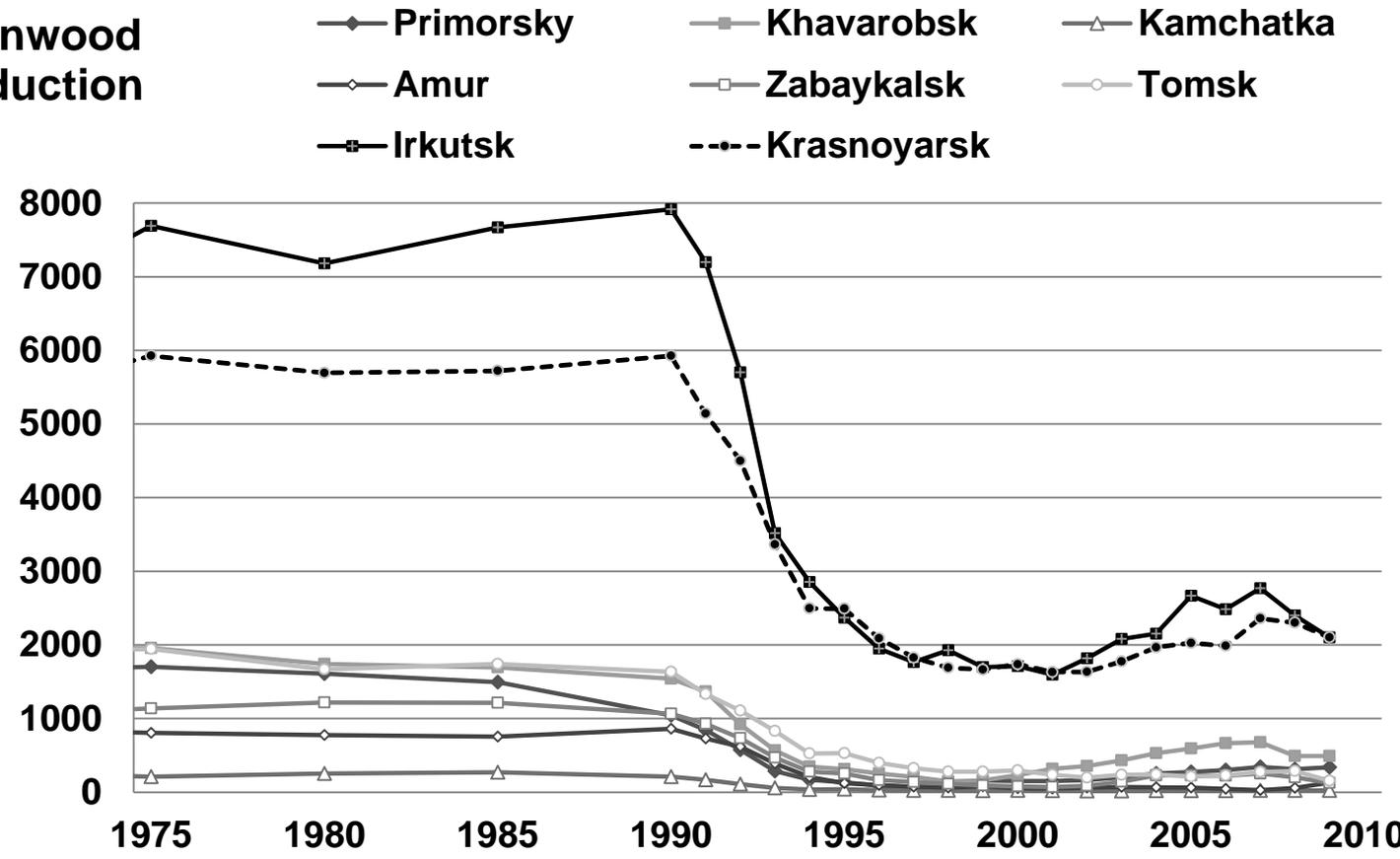|			
■ Water		■ Deciduous	
■ Mature Conifer		■ Short/Young regeneration	
■ Mature/maturing Mixed		■ Cut	

"Everything was good, but it didn't last for long."

Former logging village of Kravche

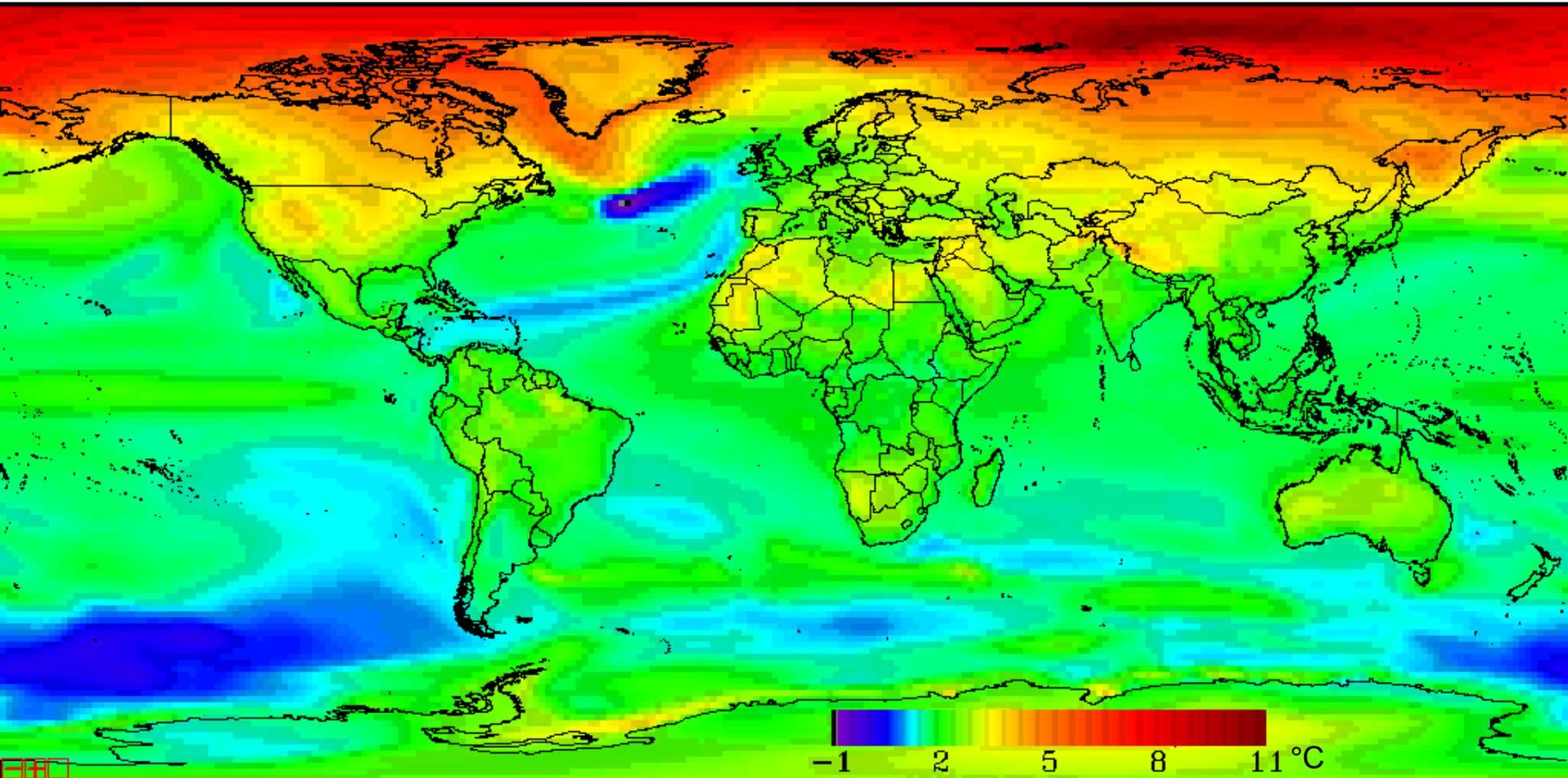# Significant and abrupt changes in demographics and resource use

Year	1992	1995	2000	2005	2009
Net Migration Ru... 1000 persons)					
Net Migration Stu...					
Total Production (1990=100)					
Total Production Region					
Unemployment R... (percentage)					
Unemployment S... Region					

Sawnwood Production

Legend: Primorsky, Khavarobsk, Kamchatka, Amur, Zabaykalsk, Tomsk, Irkutsk, Krasnoyarsk

Y-axis: 1000 m³

Climate change

Mean temperature increase for the 2040-2069 relative to 1961-1990 under A1B scenarios produced by NCAR-CCSM3

Research Questions

- **Synthesis Research Questions:**

  How have human-driven disturbances (logging, settlement) related to use of forest resources, combined with natural and other disturbances (fire, insects, agriculture), created the landscapes of the region over the past 35 years?

  - Do trends through 2000 continue into the present?
  - How do they vary across and between the Russian Far East and central Siberia?
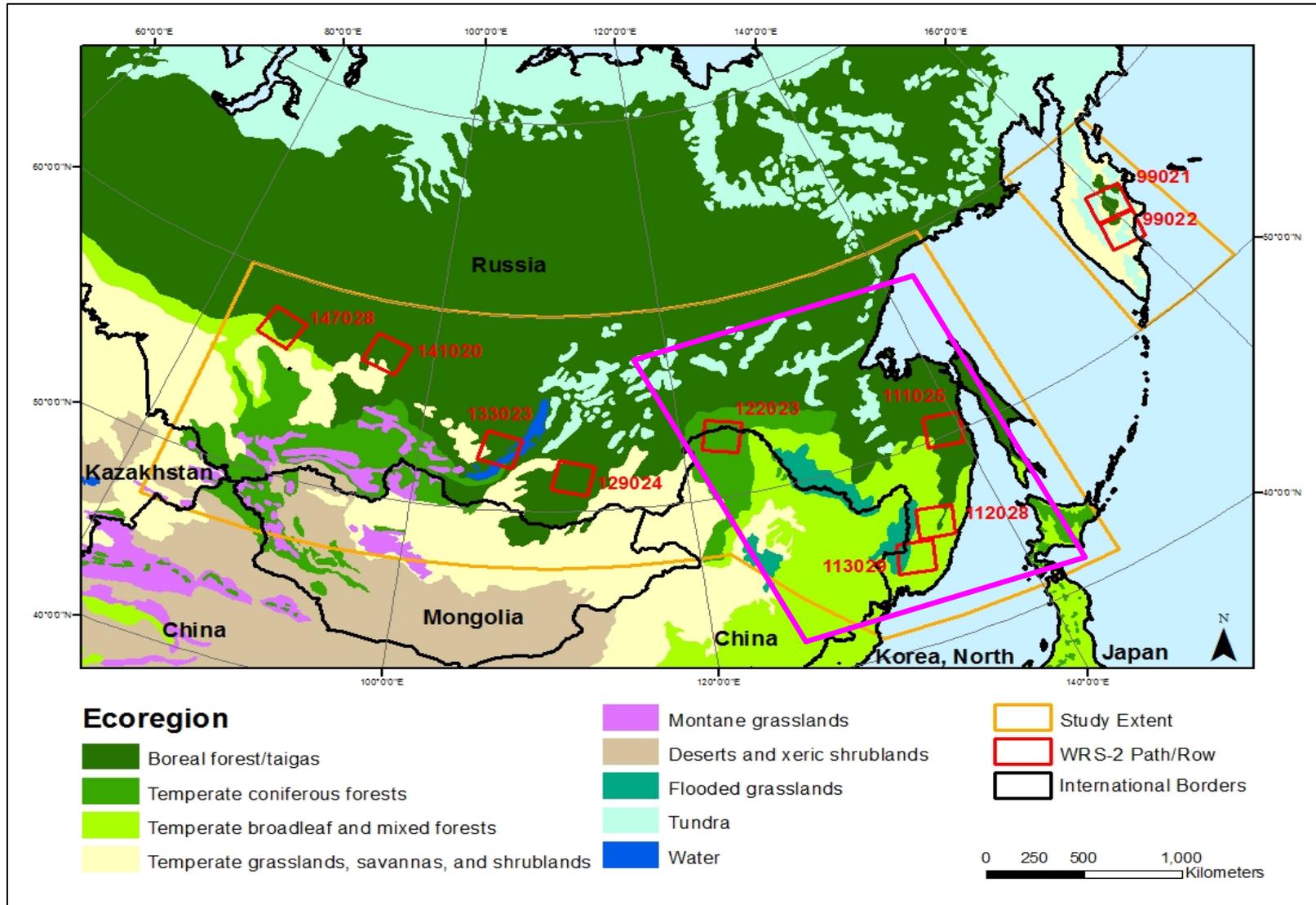 - How have outside drivers (e.g. export/trade) influenced LCLU?

  How might they change in the future?

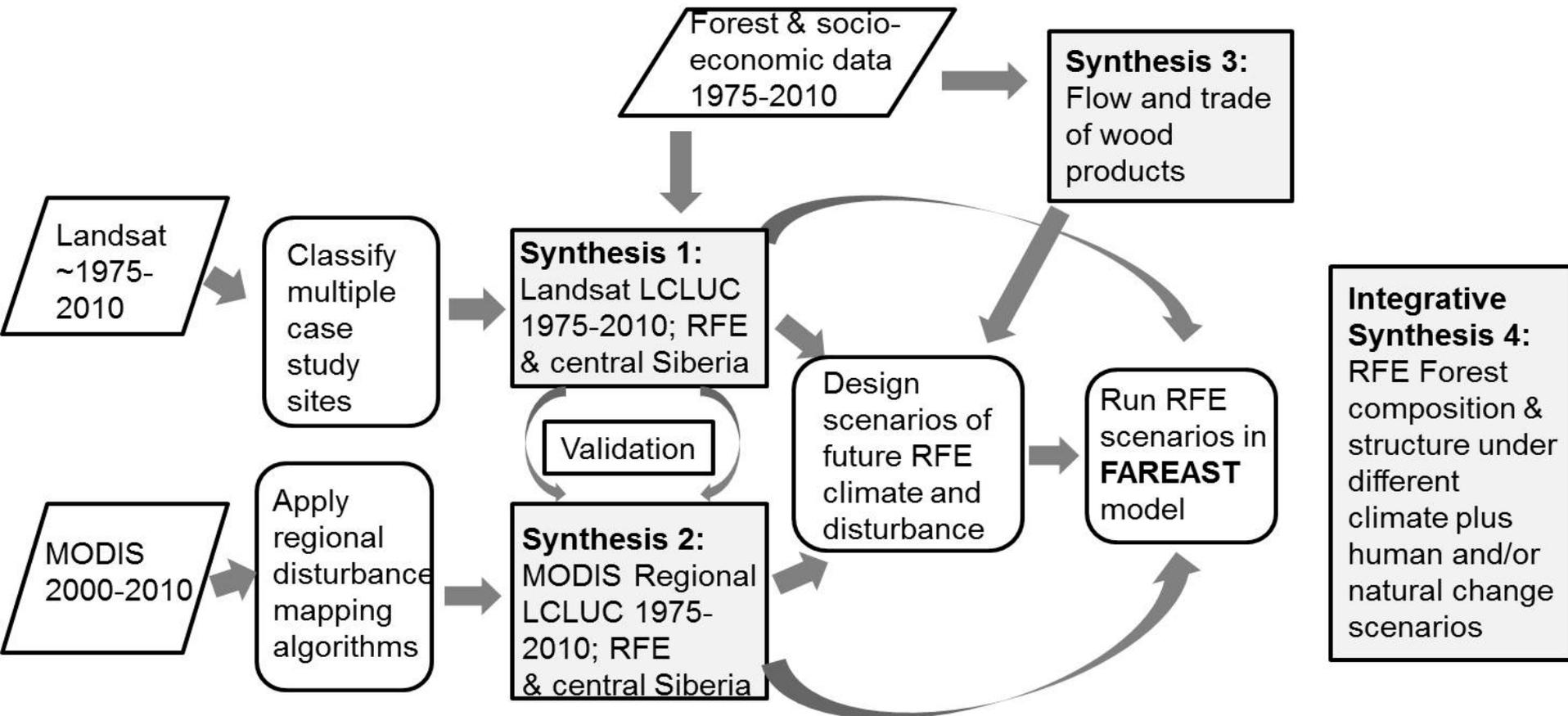 - In particular due to: logging, fire, climate

Two Synthesis Regions:

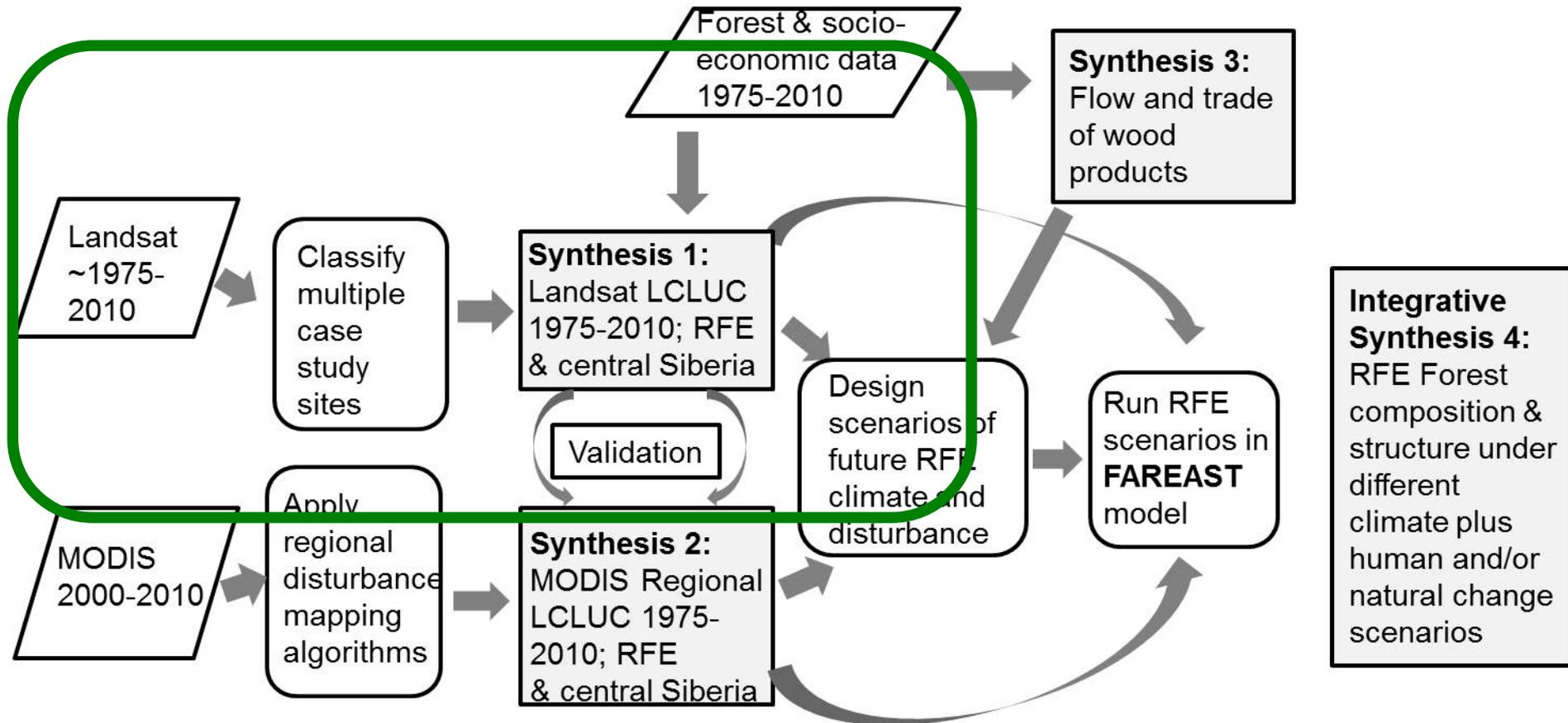1. Data & LCLUC Synthesis: Russian Far East & Central Siberia
2. Integrative Modeling Synthesis: Russian Far East

Integrated Synthesis Approach

Forest & socio-economic data 1975-2010

Synthesis 3: Flow and trade of wood products

Landsat ~1975-2010

Classify multiple case study sites

Synthesis 1: Landsat LCLUC 1975-2010; RFE & central Siberia

Validation

MODIS 2000-2010

Apply regional disturbance mapping algorithms

Synthesis 2: MODIS Regional LCLUC 1975-2010; RFE & central Siberia

Design scenarios of future RFE climate and disturbance

Run RFE scenarios in **FAREAST** model

Integrative Synthesis 4: RFE Forest composition & structure under different climate plus human and/or natural change scenarios
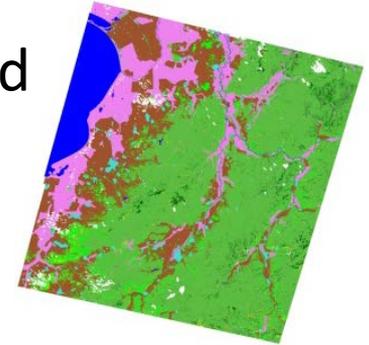
Synthesis 1: Long-term Landsat Case Study Sites LCLUC

# Results: Long-term Datasets Synthesis

- LCLUC Time Series classifications 1975, 1990, 2000 and 2010 eras:
  - Burn & Cut disturbance– 8 sites (i.e. Landsat path/rows)
  - Multiple forest- and land-cover classes – 5 sites
    - Bergen et al (2013) *LCLUC Site Reports*
   - Loboda, Sun, et al (20-- ongoing) *LCLUC Site Reports*.

- Infrastructure Time Series Mapping:
  - Transportation : 1975, 1990, 2000, 2010 – 8 sites
  - Urban: 1975, 1990, 2000, 2010 – 8 sites
    - Bergen et al (2013) *Transportation and Urban Site Reports*.
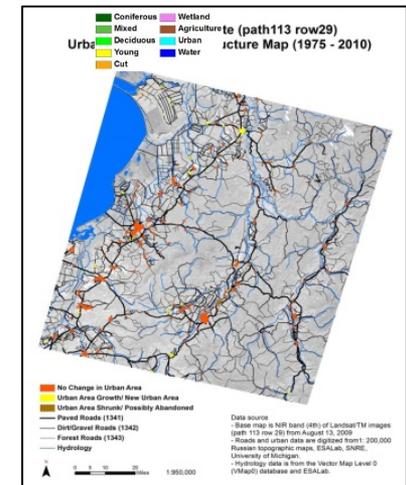
- Statistical Time Series:
  - Multiple province-level socio-economic variables 1975-2010 annually (RFE and Central Siberia) (
    - Park, (2013) MS thesis Univ. Michigan.
  - Forest trade/export 1950s-2010, annually (Russia-wide & international)
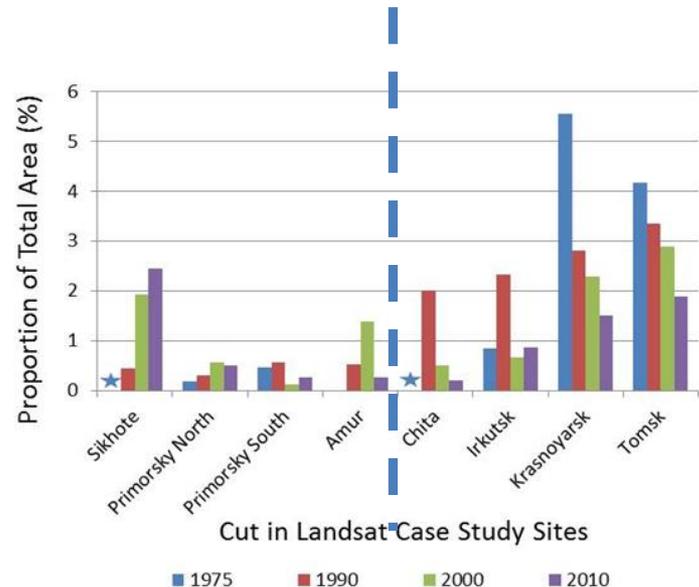   - (Newell and Simeone, *in press*).
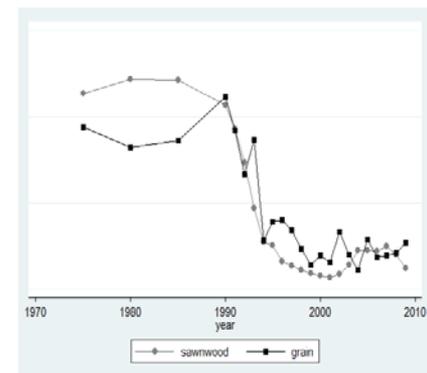
Results: Disturbances

- **Fire** – *The* disturbance at the regional scale
    - Higher in our mountainous sites and further east (RFE &Irkutsk)
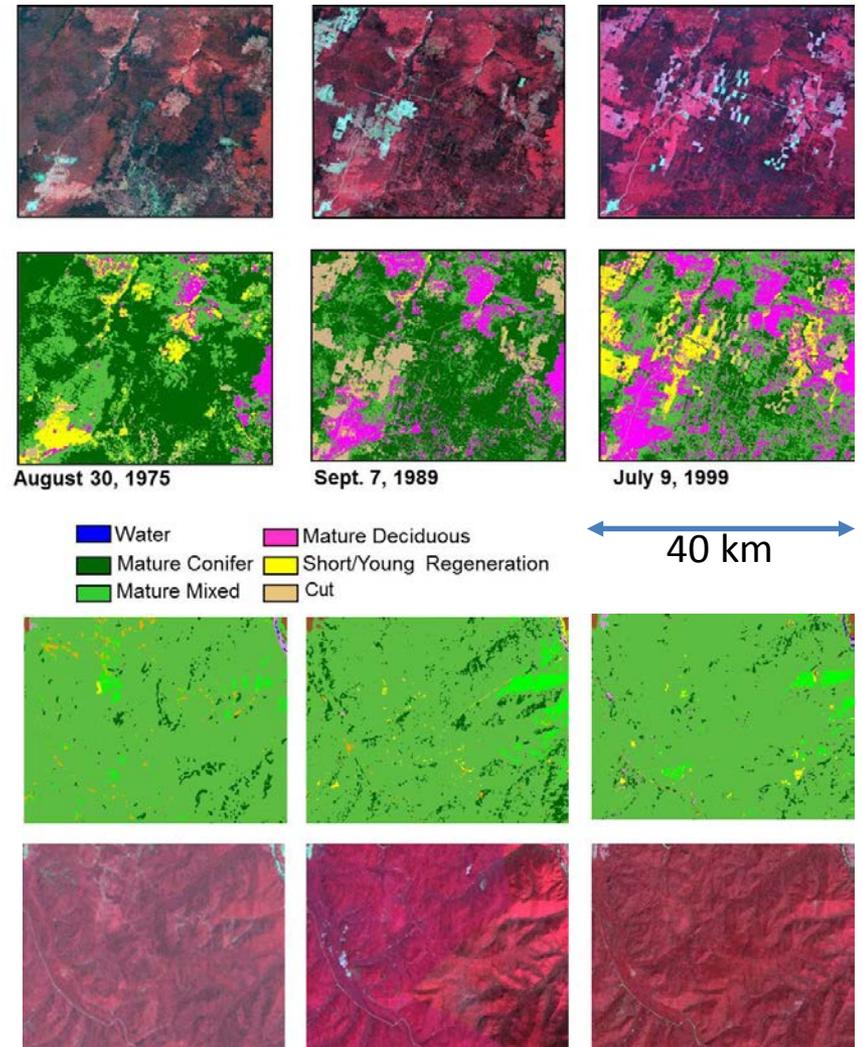   - Highest logging sites in central Siberia had lowest fire

Burn in Landsat Case Study Sites
■ 1975 ■ 1990 ■ 2000 ■ 2010

Cut in Landsat Case Study Sites
■ 1975 ■ 1990 ■ 2000 ■ 2010
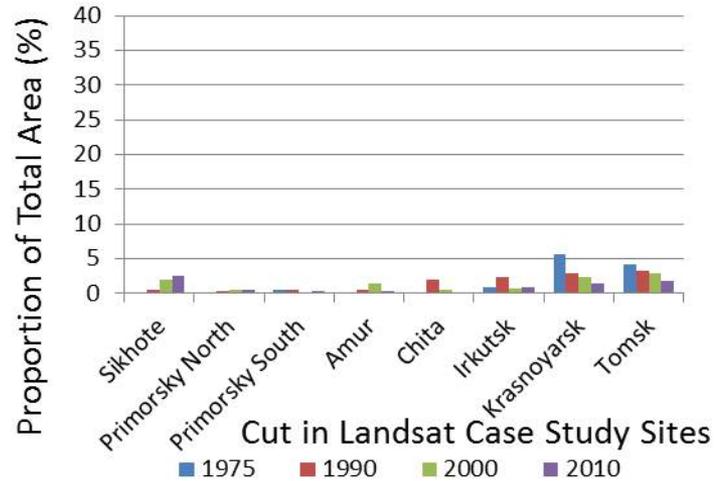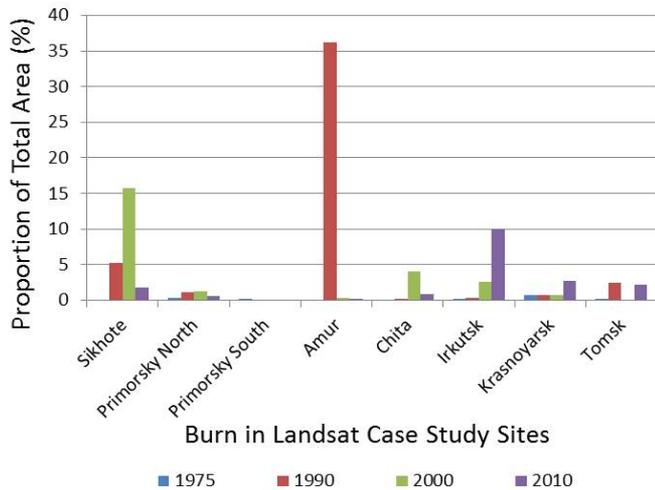
- **Logging** – impacts the landscape scale

    - Central Siberia ⬇ over time

    - RFE ⬆ or ⬇ over time

    - But: this is logging as observed
by Landsat

Cut in Landsat Case Study Sites
■ 1975 ■ 1990 ■ 2000 ■ 2010

Sources: Bergen et al. 2013; Loboda, Sun, et al. 20--.
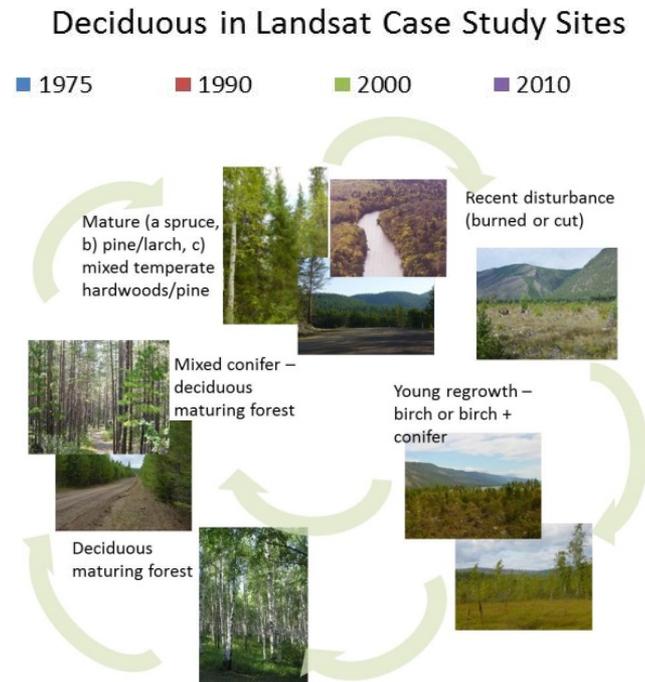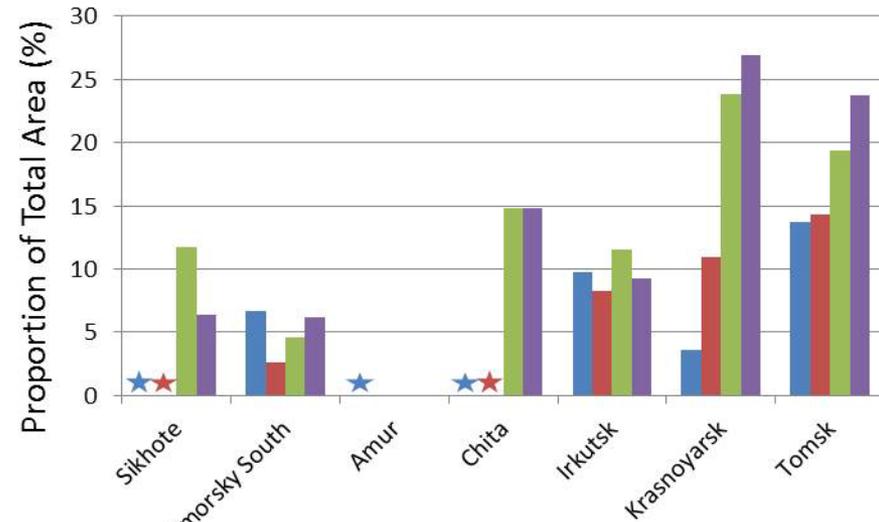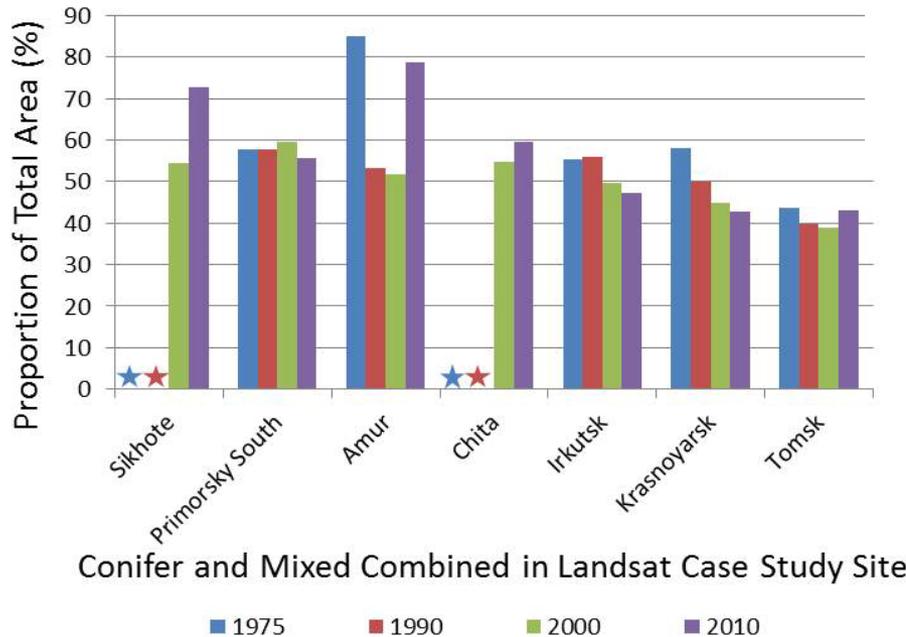
Results: Regional patterns of harvest

- ## Central Siberia
  - large or conglomerate patches → *forest age and composition*

- ## RFE
  - small patches + removal of key species → *forest species diversity + habitat quality* but little patchiness observed

  - *Landsat resolution is insufficient to map selective harvest*
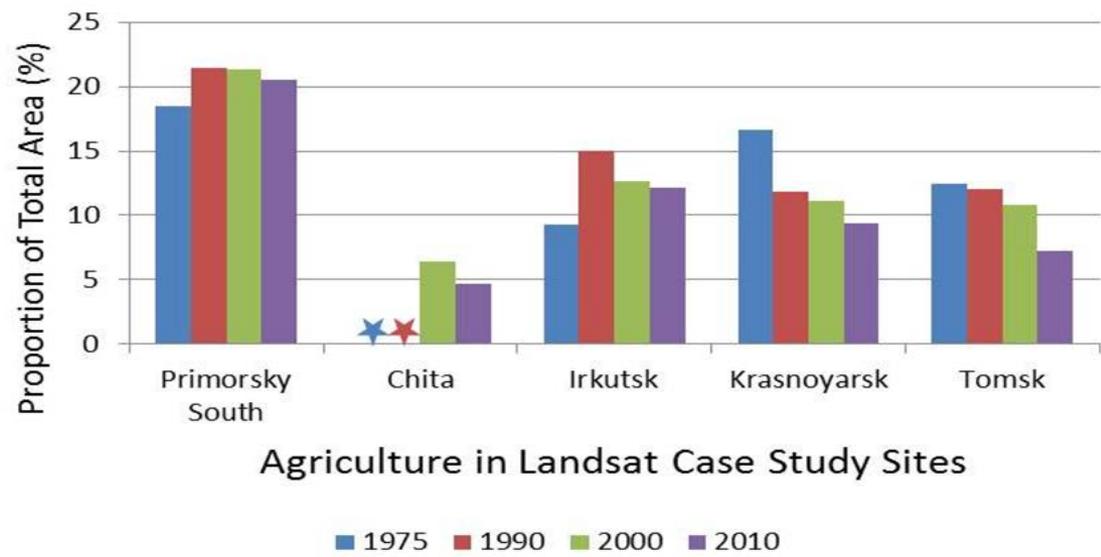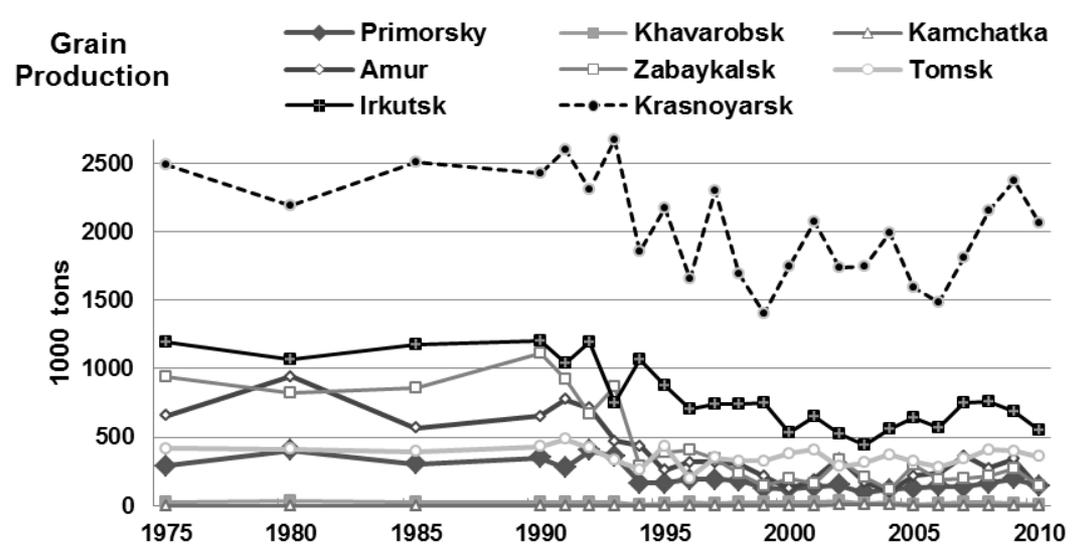 - *Roads added as logging proxies in RFE*

Sources: Bergen et al. 2013.

August 30, 1975   Sept. 7, 1989   July 9, 1999

- Water
- Mature Conifer
- Mature Mixed
- Mature Deciduous
- Short/Young Regeneration
- Cut

40 km

Time series (~1970, 1990, 2000) of two logged Leskhoz showing typical landscape patterns
Top: central Siberia (Tomsk)
Bottom: RFE (Primorsky)

Results: Regeneration/Succession

- **Central Siberia**:
  - slight to large increases in deciduous (birch) forests
- **RFE:**
  - vary strongly due to topography + climate/ecoregion → birch/aspen vs. pine/larch

Deciduous in Landsat Case Study Sites

■ 1975   ■ 1990   ■ 2000   ■ 2010

Conifer and Mixed Combined in Landsat Case Study Site

■ 1975   ■ 1990   ■ 2000   ■ 2010

Mature (a spruce, b) pine/larch, c) mixed temperate hardwoods/pine

Recent disturbance (burned or cut)

Mixed conifer – deciduous maturing forest

Young regrowth – birch or birch + conifer

Deciduous maturing forest

Sources: Bergen et al., site reports; Loboda et al., site reports; Park 2013.

Results: Agriculture

Agriculture in Landsat Case Study Sites

Sources: Bergen et al., site reports; Loboda et al., site reports; Park 2013.
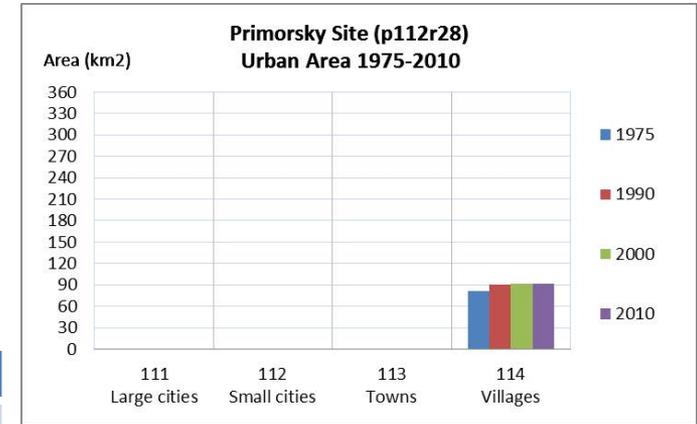
Results: Built-up areas

- **Urban:**

  AREA is stable over time but:
  - Most Urban in ALL case sites are "Villages"
  - Large scale abandonment and outward migration

Year	1992	1995	2000	2005	2009
Net Migration Russia (per 1000 persons)	18	44	25	9	18
Net Migration Study Region	-135	-85	-56	-21	8

Primorsky Site (p112r28) Urban Area 1975-2010

- **Roads**

  A large amount of road building after ~1980 in RFE
  - Almost all are *forest roads class* in Russia + *multi-purpose* roads in Russia/China site
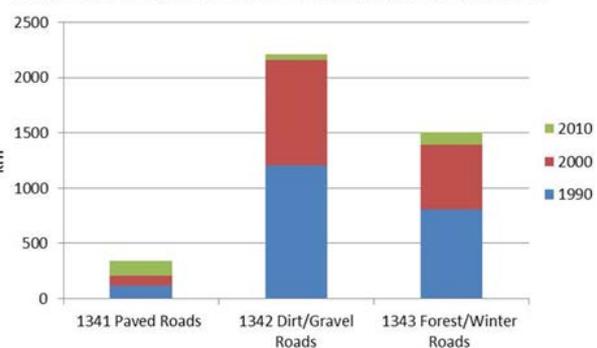
Sources: Bergen at al (2013) Urban and Transportation Reports
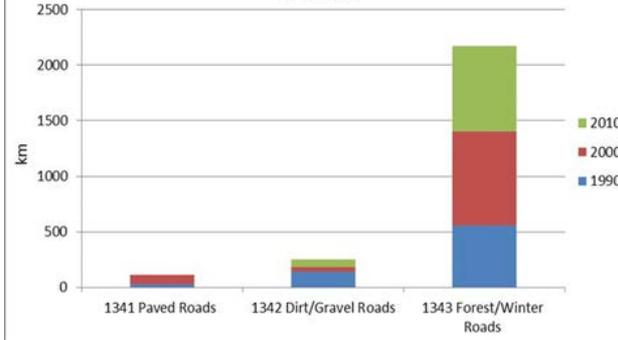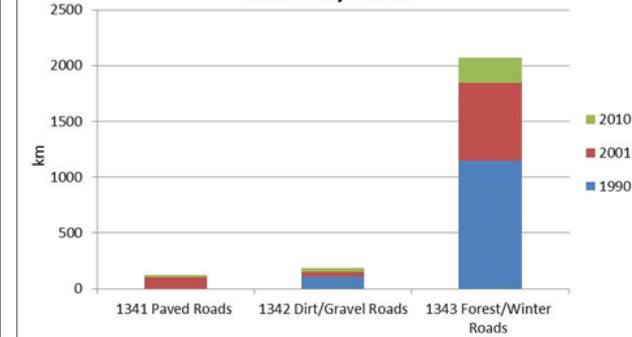
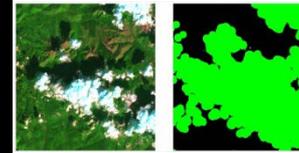# Synthesis 2: Regional MODIS Disturbance Backcasting & Mapping
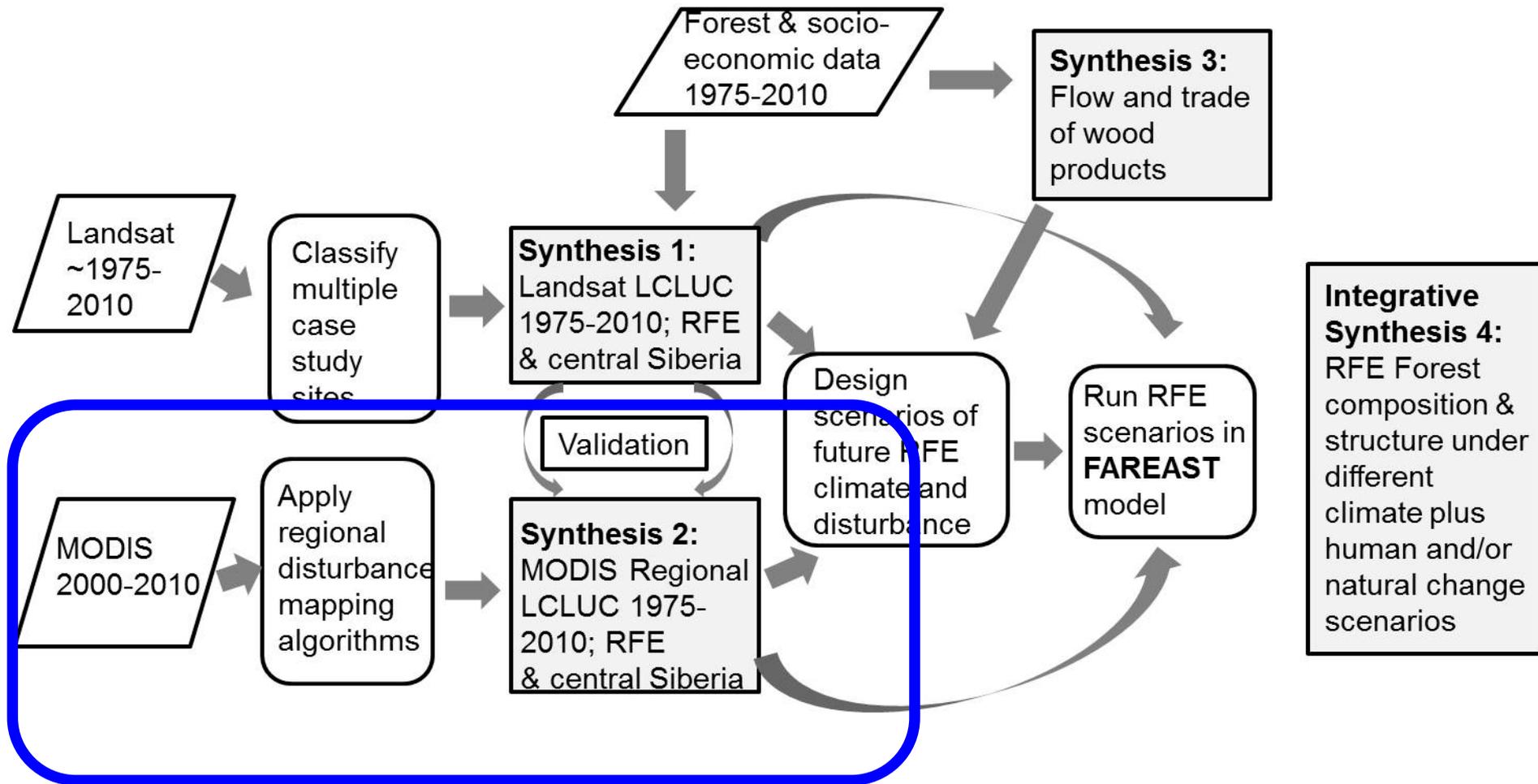
Objective 2: Reconstructing Forest Disturbances

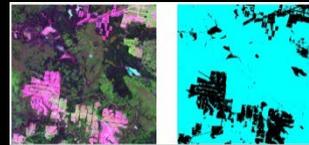Randomized sample of <u>Landsat</u> stacks

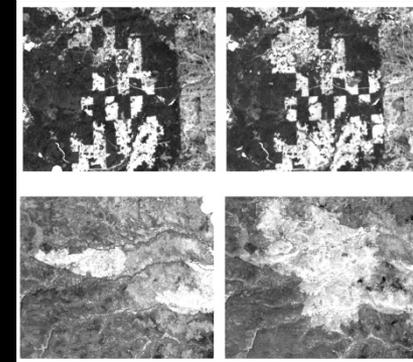LEDAPS-based Landsat TM/ETM+ surface reflectance

Cloud/shadow/water masking

Mature forest masking

Disturbance Index

MODIS data sets:
MCD43A4
Nadir BRDF adjusted reflectance
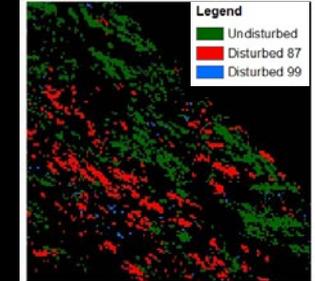MOD/MYD11A2
Land Surface Temperature

MODIS-based metrics :
yearly max, min, mean of Jun, Jul, Aug for surface reflectance Bands 1-6, NDVI, NBR, daytime & nighttime temperature)
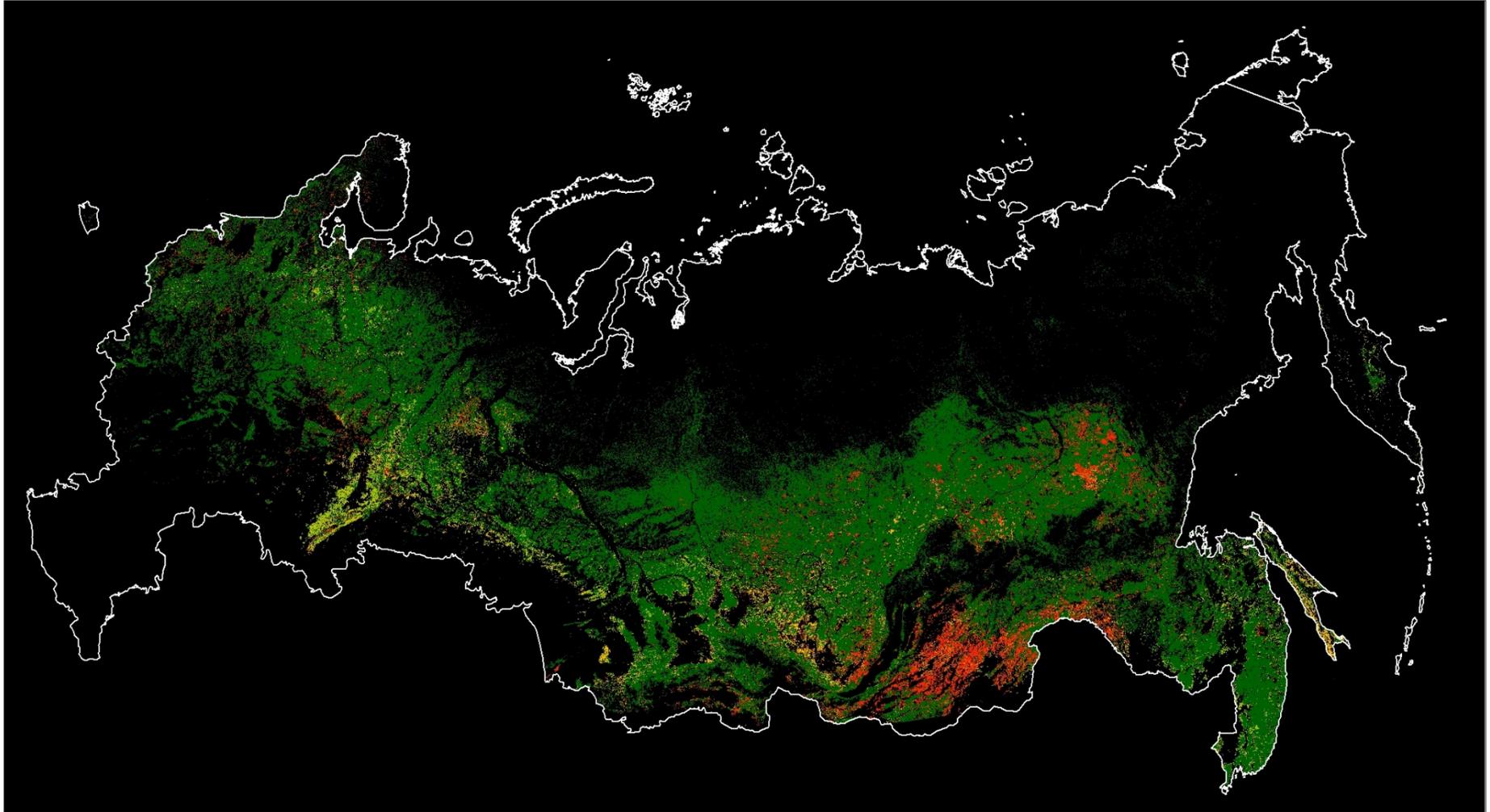
MODIS Training Sample

Legend
Undisturbed
Disturbed 87
Disturbed 99

Decision-tree classifier

Past disturbance map

Source: Loboda 2013

Stand age distribution year 2000

Stand Age

⬛ Unclassified	🟧 6-10
🟩 >16	🟥 1-5
🟨 11-16	

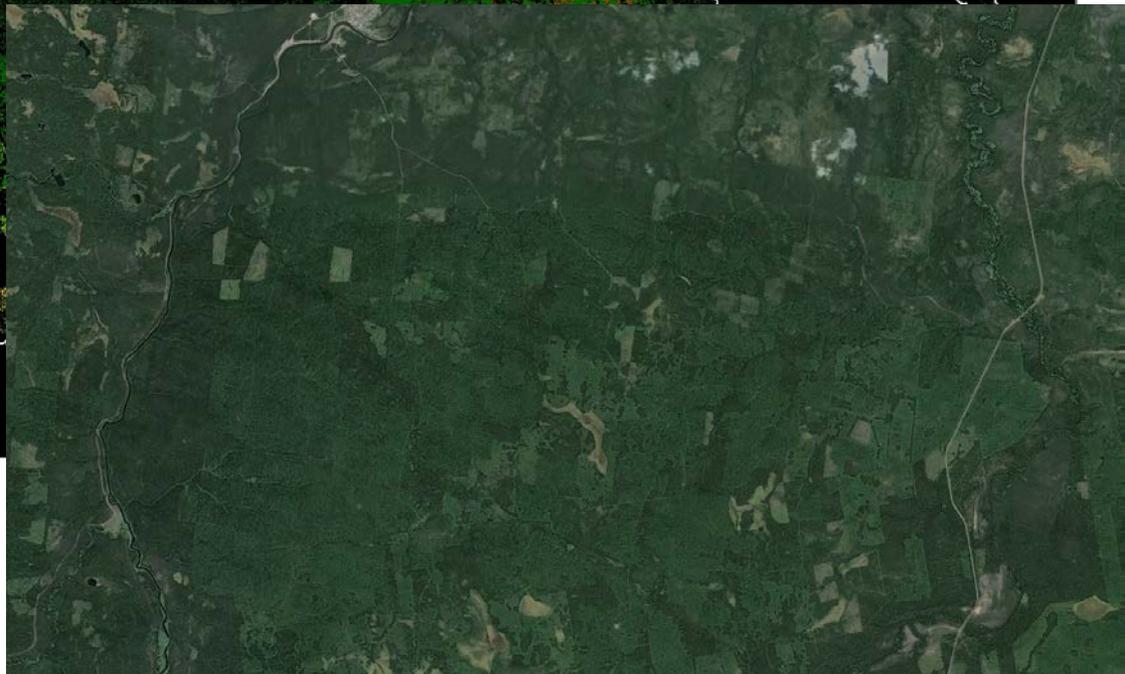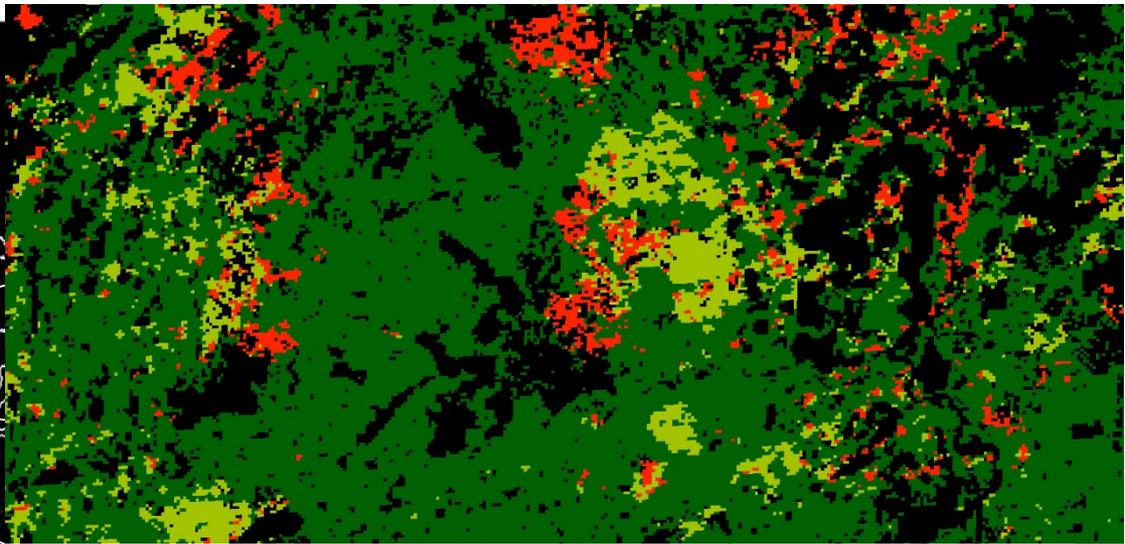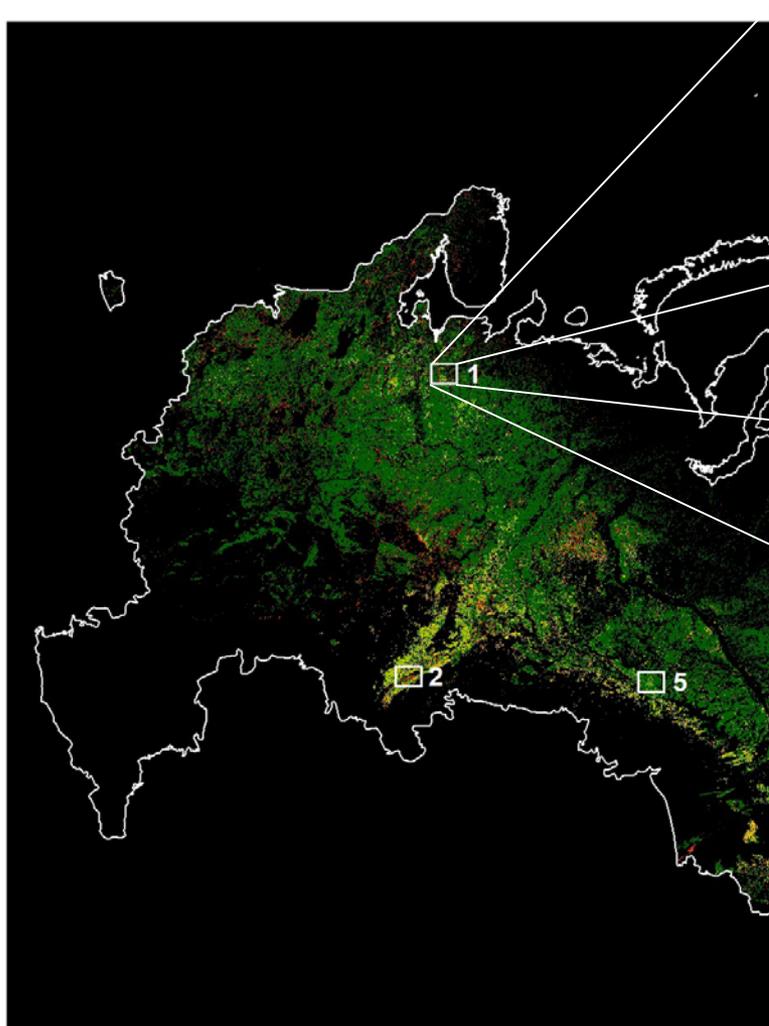0   305   610   1,220   1,830   2,440
Kilometers

N

Stand age distribution year 2000

Stand Age

▮ Unclassified	▮ 6-10
▮ >16	▮ 1-5
▮ 11-16	

Stand Age

- Unclassified (black)
- >16 (dark green)
- 11-16 (light green)
- 6-10 (yellow/gold)
- 1-5 (red)

	Unclassified		6-10
	>16		1-5
	11-16		

0   305   610   1,220   1,830   2,440
Kilometers

N

⬛ Unclassified	🟧 6-10	
🟩 >16	🟥 1-5	
🟨 11-16		

N

0	305	610	1,220	1,830	2,440

Kilometers

Stand Age

⬛	Unclassified	🟧	6-10
🟩	>16	🟥	1-5
🟨	11-16		

0   305   610   1,220   1,830   2,440
Kilometers
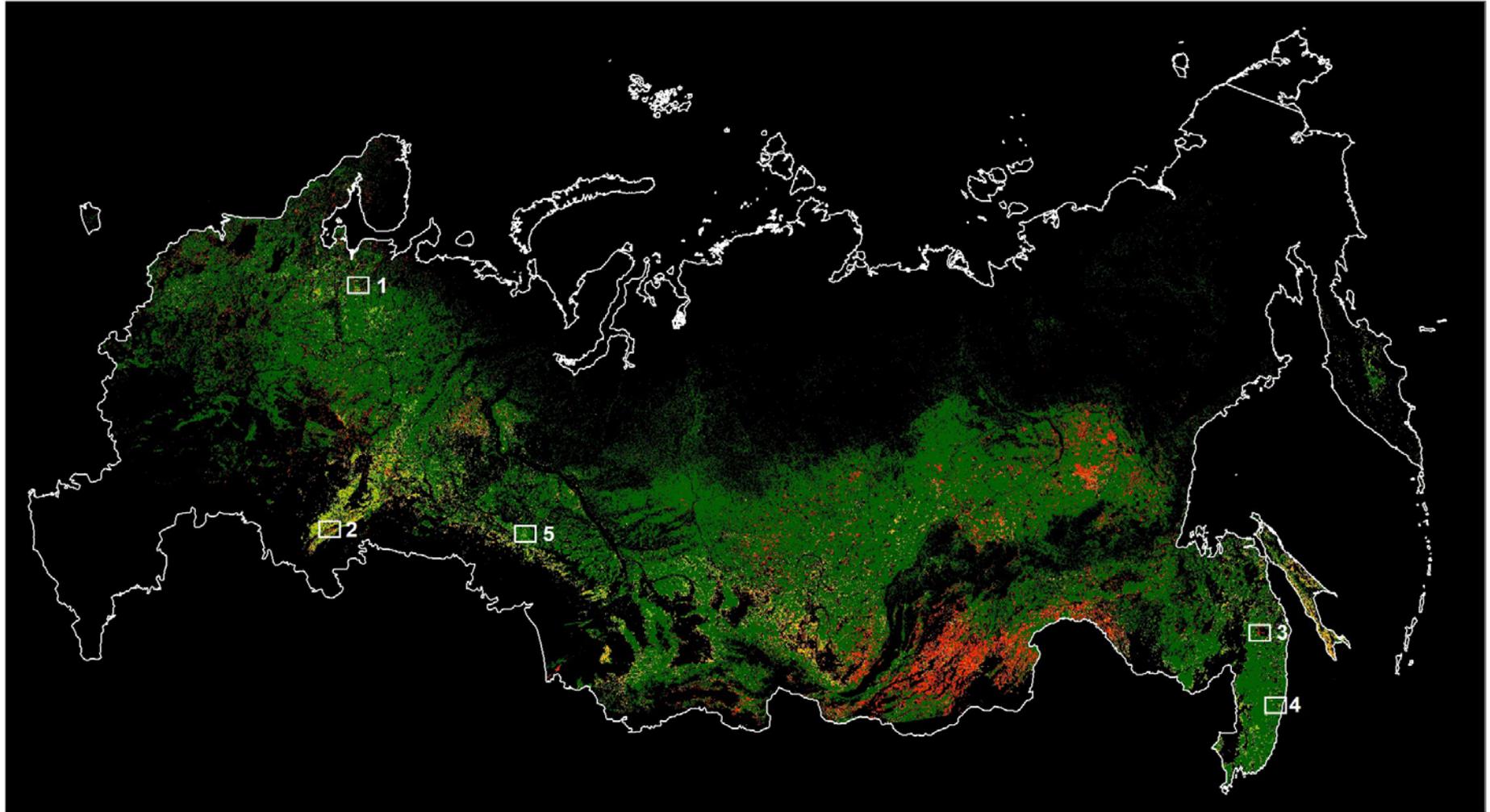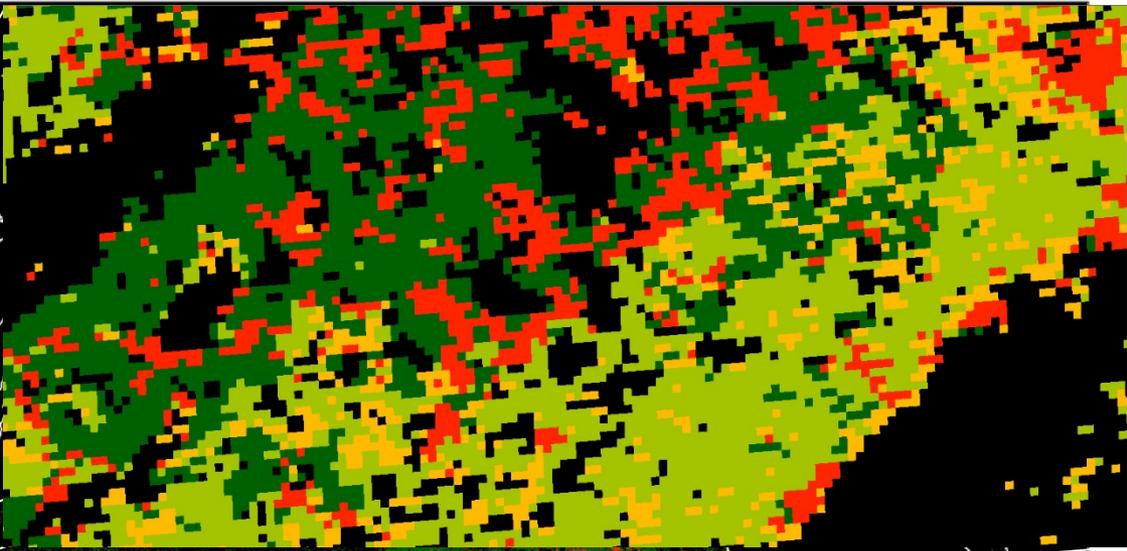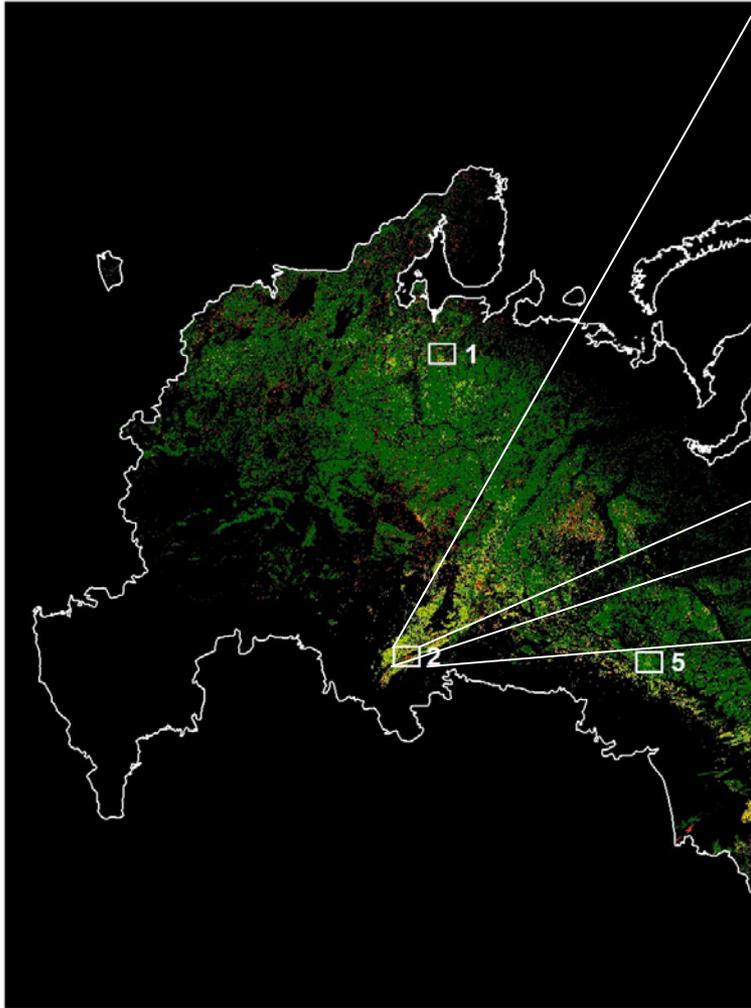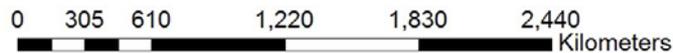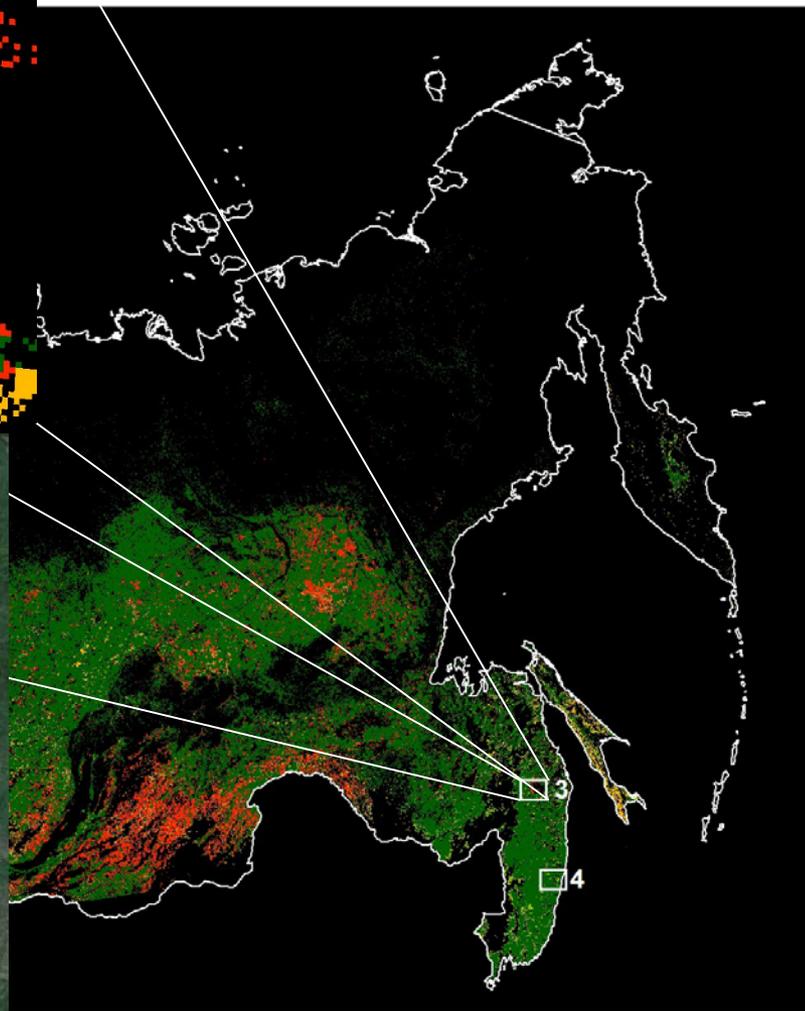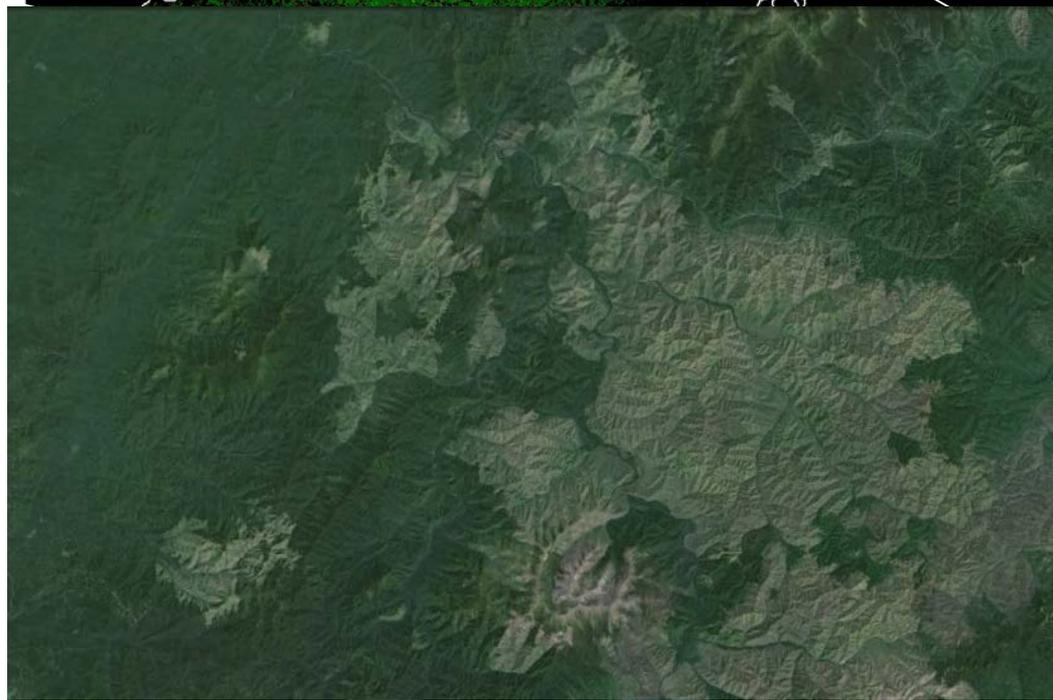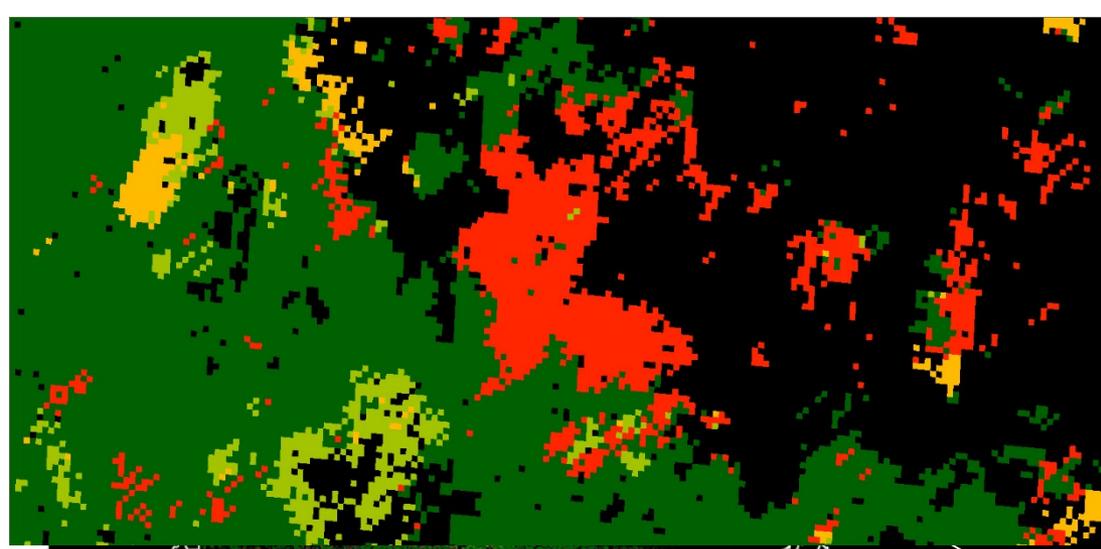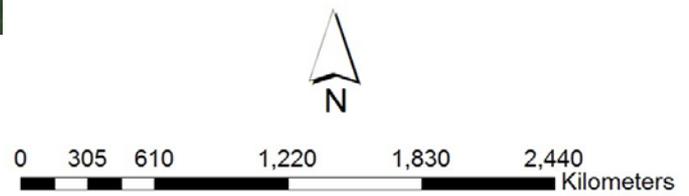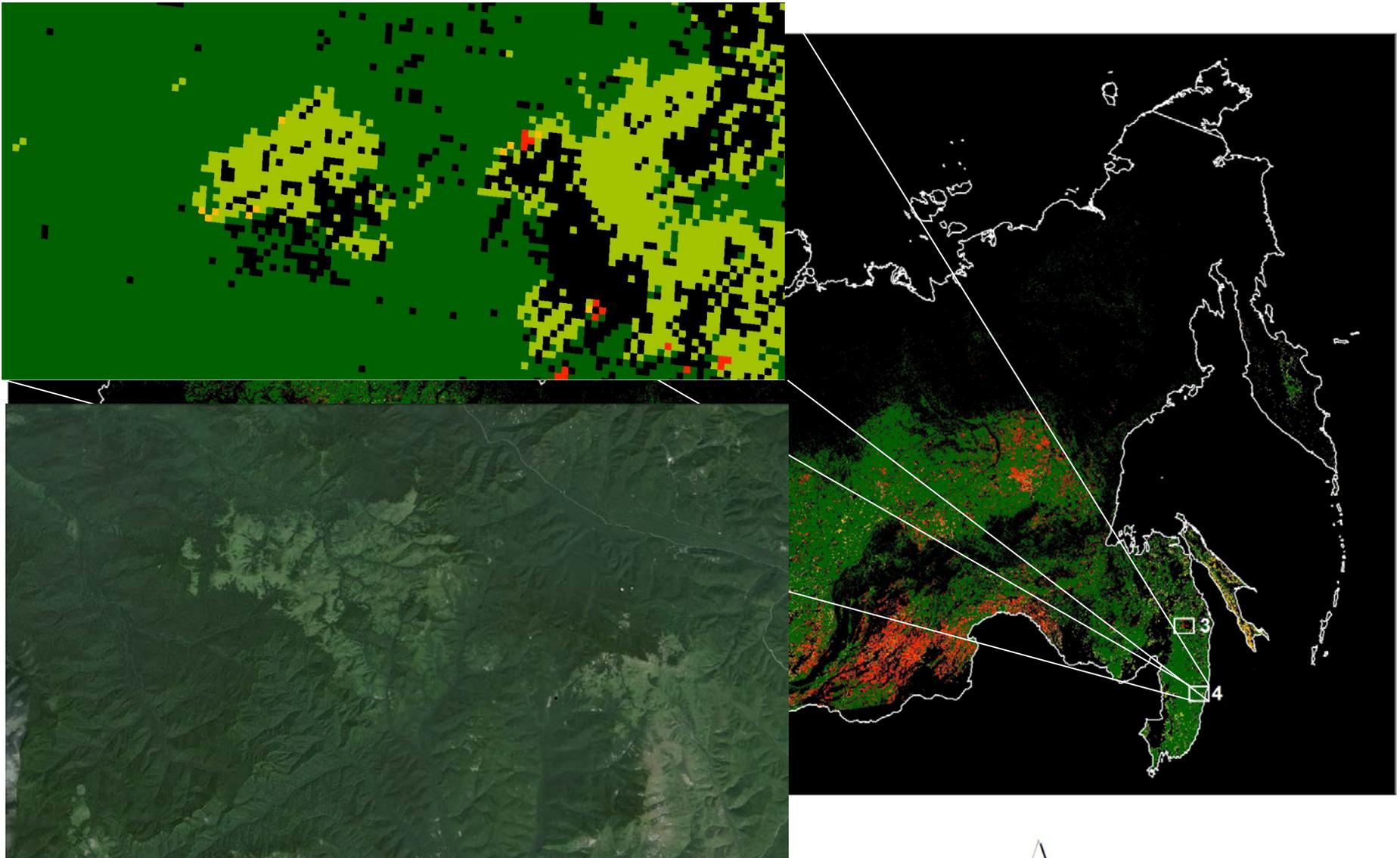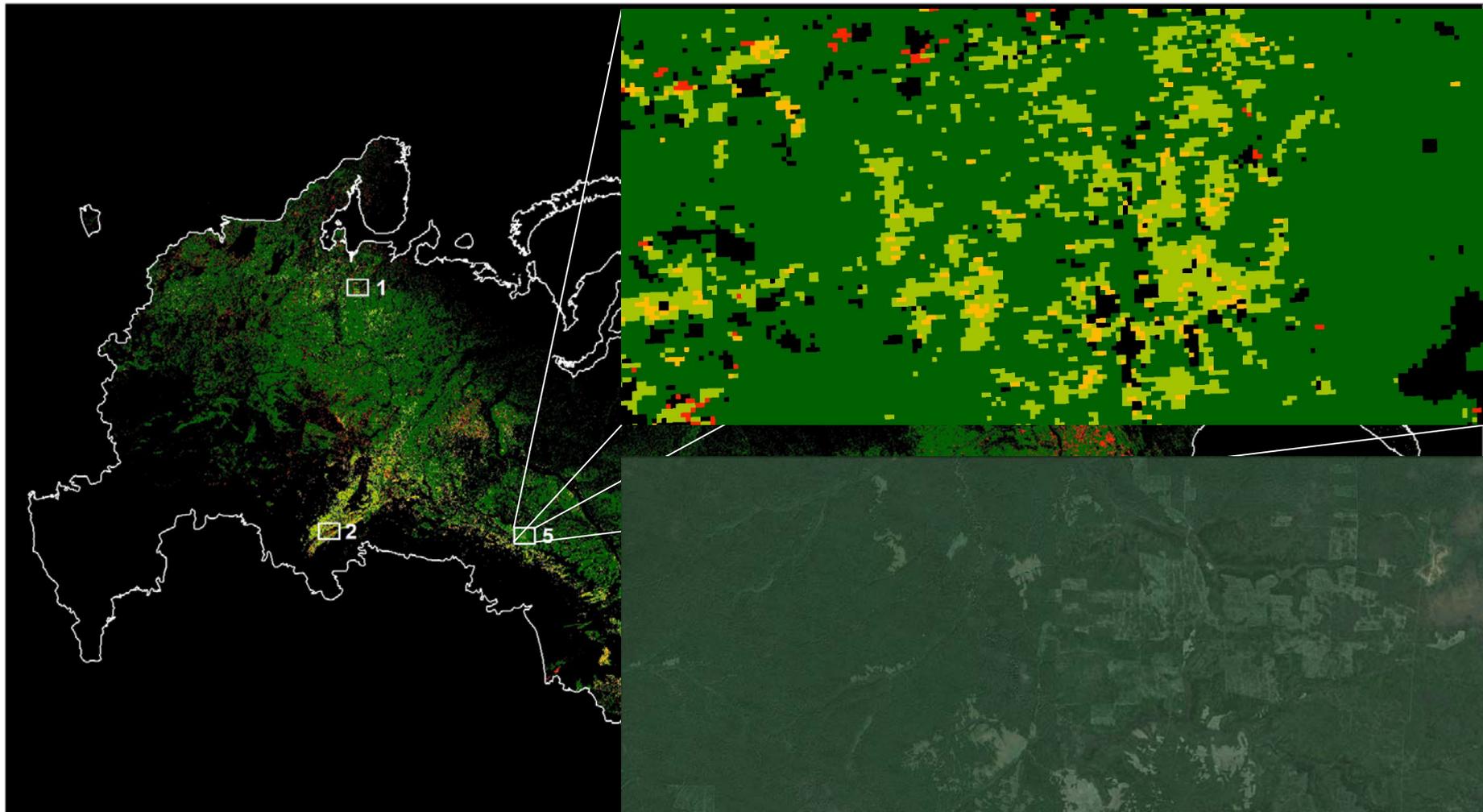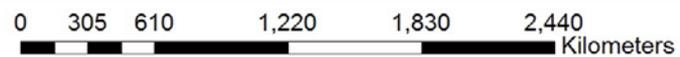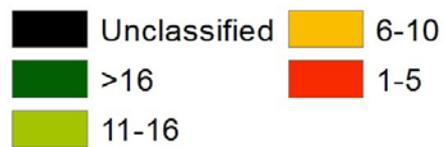
Stand age distribution year 2000
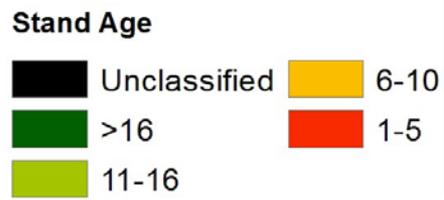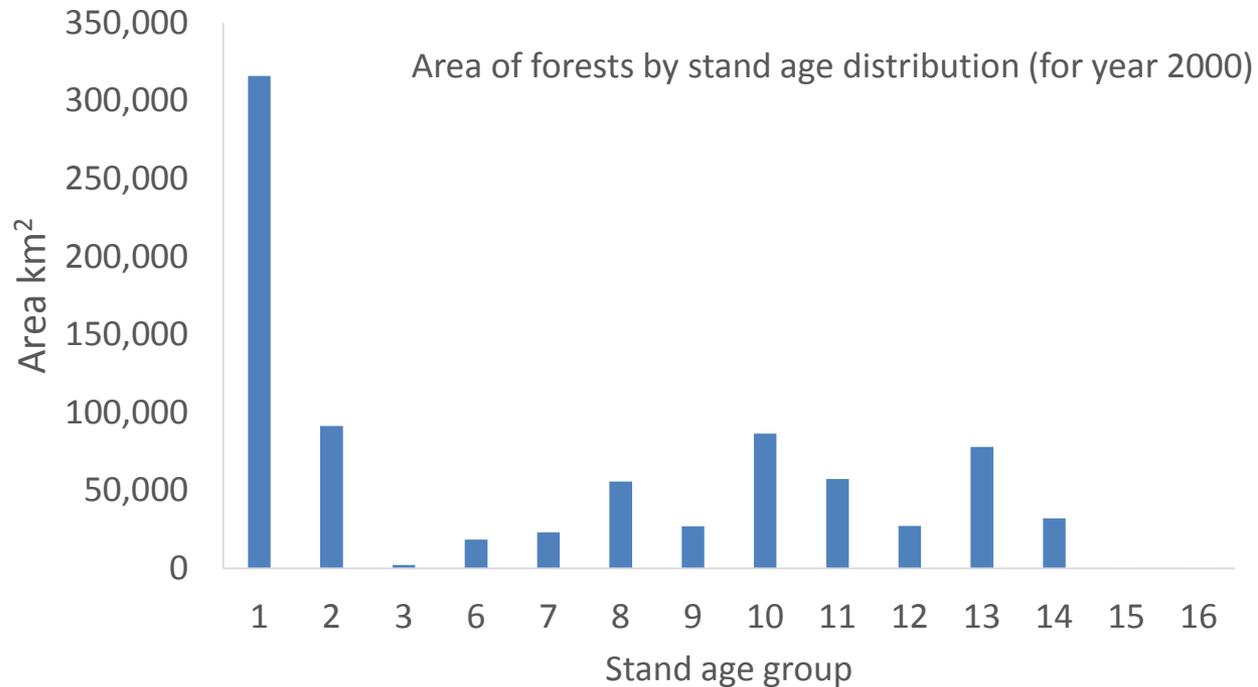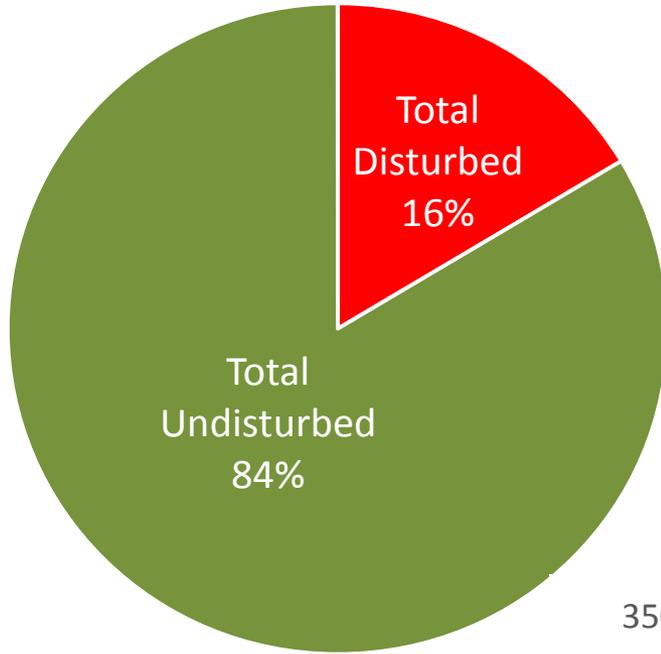
Stand age distribution year 2011

Stand Age

Unclassified	11-15
>27	6-10
21-27	1-5
16-20	

N

0 305 610 1,220 1,830 2,440
Kilometers
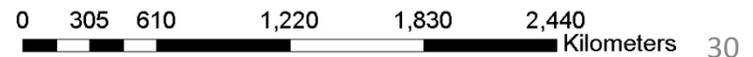
Synthesis 3: Resource Flows & Timber Trade
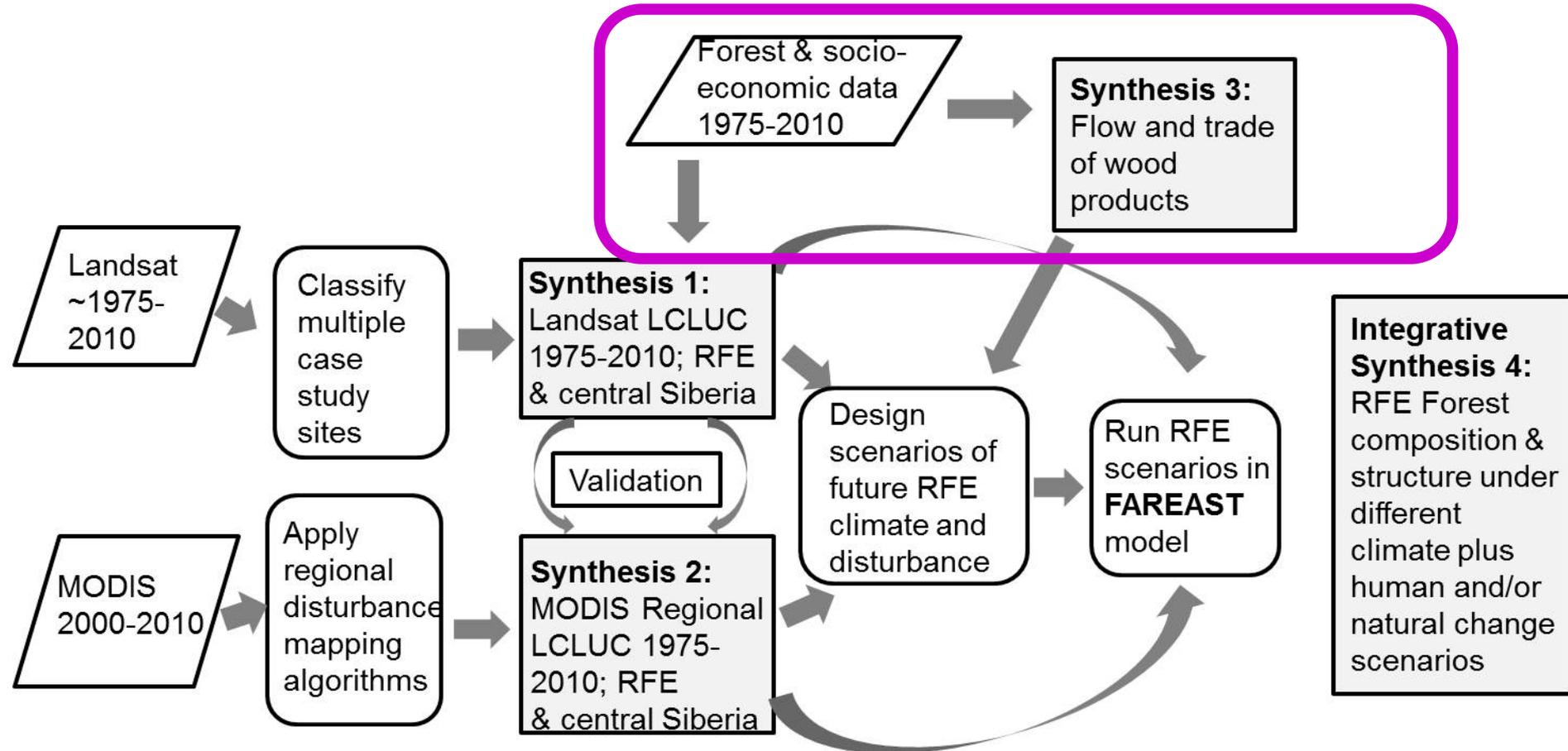
Timber Production 1946-2012 by major Russian federal district
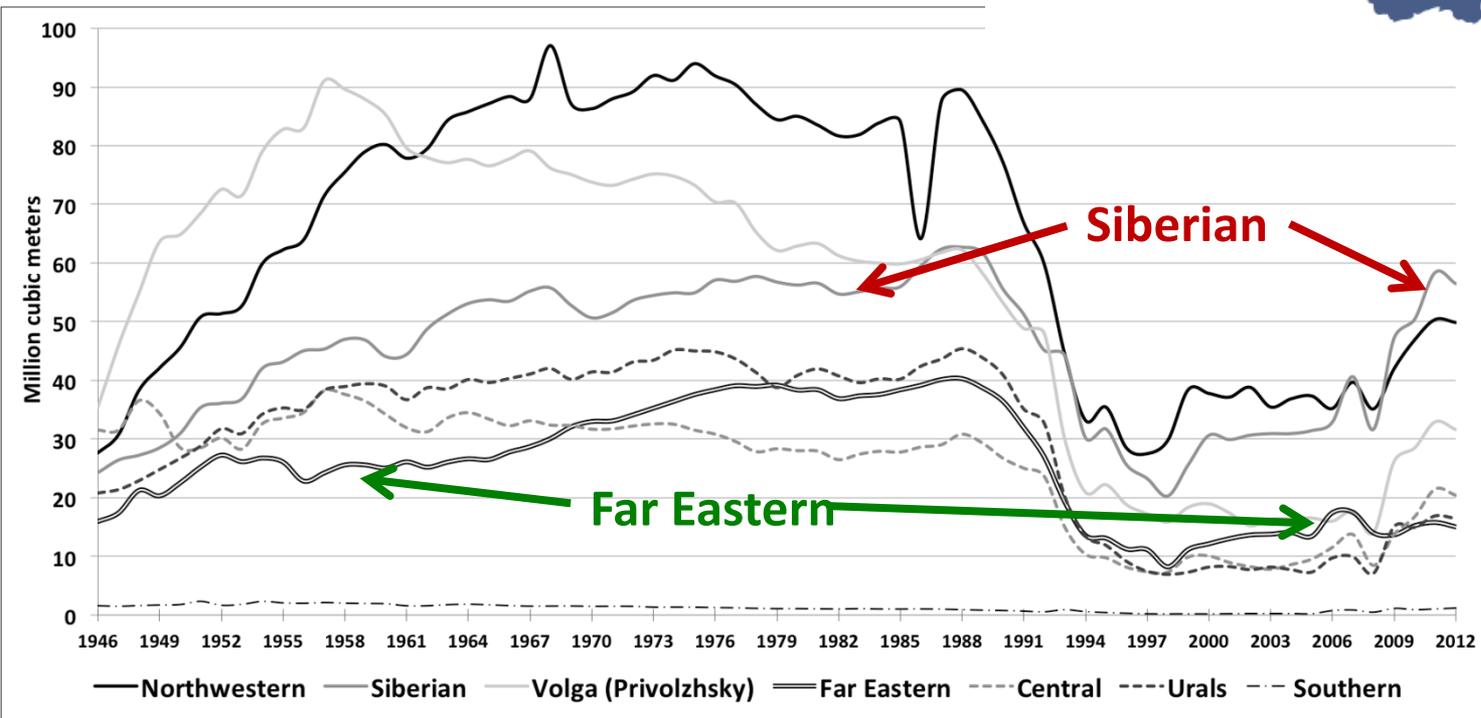
Sources: Compiled by the authors based on data from IIASA (2007) and Russian Federation Federal Statistics Division (2013), including the FIRA database (2013) and EMISS database (2013); Newell and Simeone, in press.

Major export markets for Russian forest products, 1962–2006
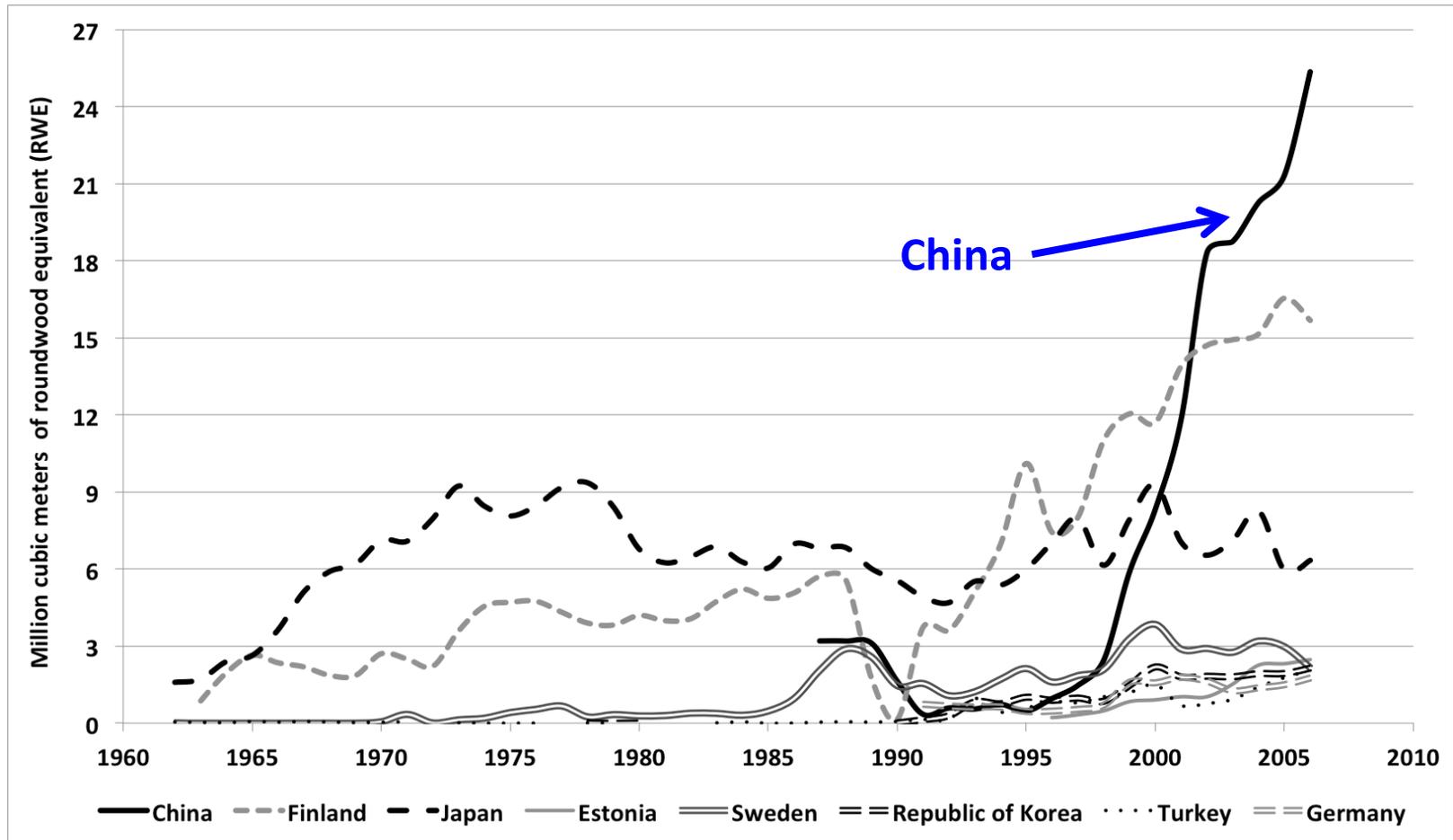
Sources: Forest Products Trade Flow Database of the European Forest Institute
(EFI) 2009; Newell and Simeone, in press)

Hotspots of forest harvest export to China

- Southerly shift in harvest intensity within the RFE in post-Soviet era
  - ↑ in Primorsky Krai and Khabarovsky Krai
  - ↓ in northern RFE provinces

  →

  Major ecological impacts

- Both RFE and Central Siberian provinces are strongly influenced by the Chinese market

Top four Russian Provinces in 2011	Province proportion of total Russian roundwood exports to China
Khabarovsk	33%
Irkutsk	22%
Primorsky	11%
Krasnoyarsk	10%

Source: Newell and Simeone, in press

Intact forests and protected areas in Primorsky

Russian Wood Products Exports to China 2008
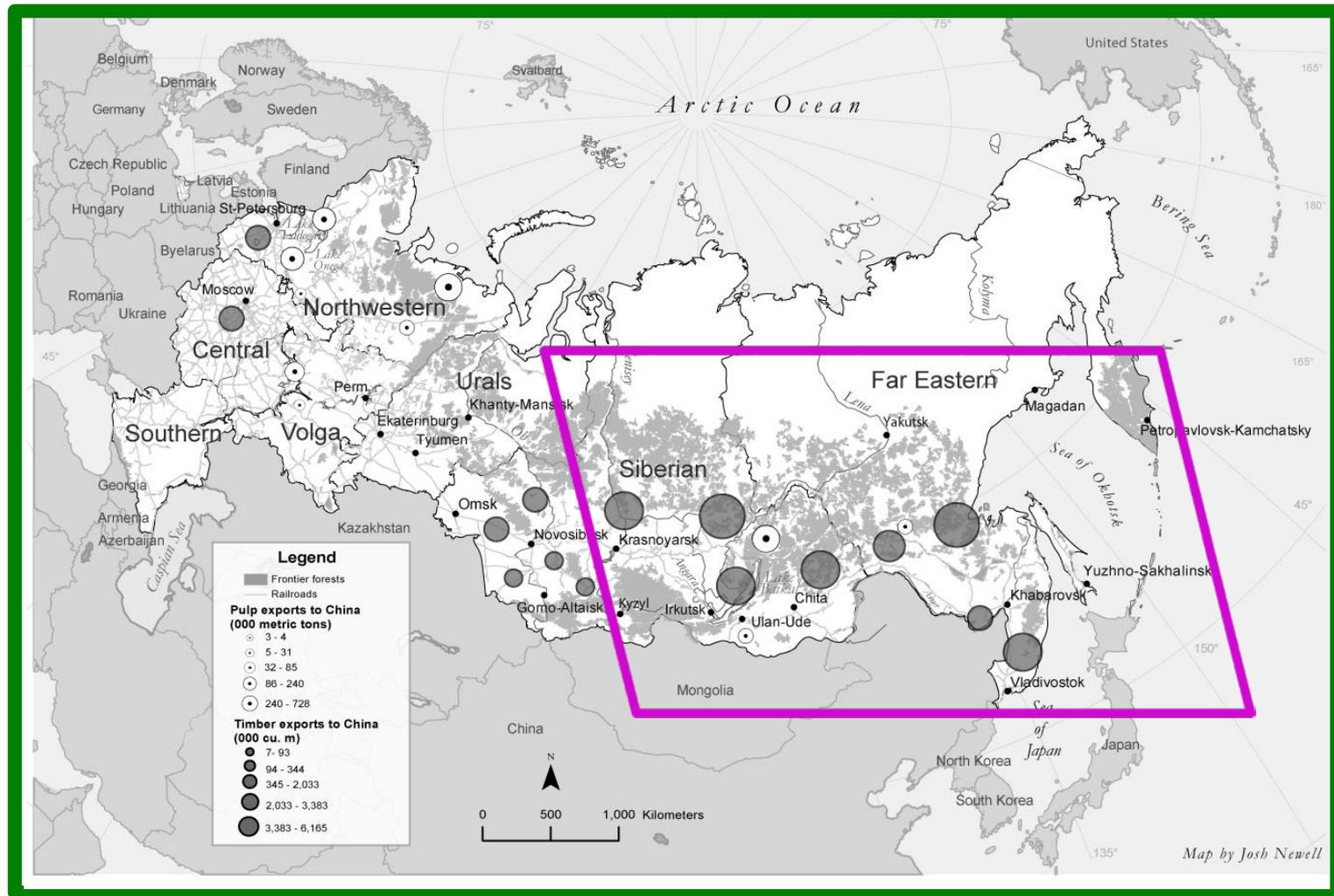
Source: Map by J.P. Newell; spatial datasets from ESRI and World Resources Institute. Russian-Chinese export data from M-Info Consulting Company, 2009.

Integrative Synthesis Modeling

Forest & socio-economic data 1975-2010

Synthesis 3: Flow and trade of wood products

Landsat ~1975-2010

Classify multiple case study sites

Synthesis 1: Landsat LCLUC 1975-2010; RFE & central Siberia

Validation

MODIS 2000-2010

Apply regional disturbance mapping algorithms

Synthesis 2: MODIS Regional LCLUC 1975-2010; RFE & central Siberia

Design scenarios of future RFE climate and disturbance

Run RFE scenarios in **FAREAST** model

Integrative Synthesis 4: RFE Forest composition & structure under different climate plus human and/or natural change scenarios

Initialize UVAFME to "current age" based on Past Disturbance map

Primorsky South Leskhozs

Primorsky North Leskhozs
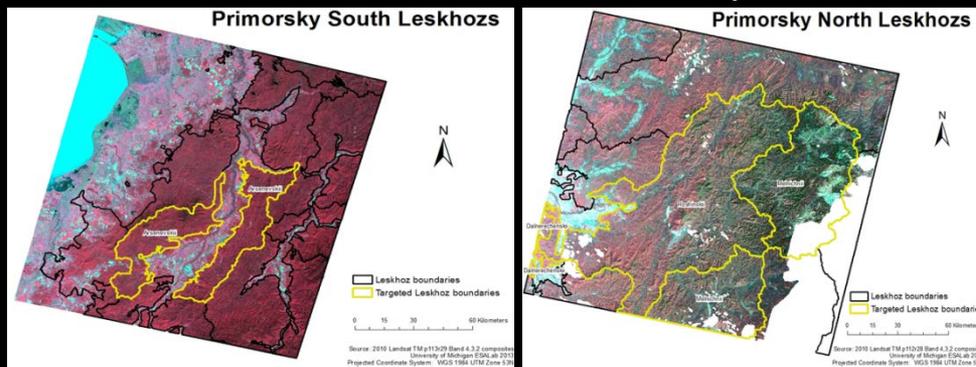
Apply local parameters:
Fire probability
Harvest rates:
clear cut vs. selective, and species specific

UVAFME simulation Current and future climate

Scenarios:
Current conditions ,no harvest
Current, harvest
Current, harvest and fire
Future, no harvest
Future, harvest
Future, harvest and fire
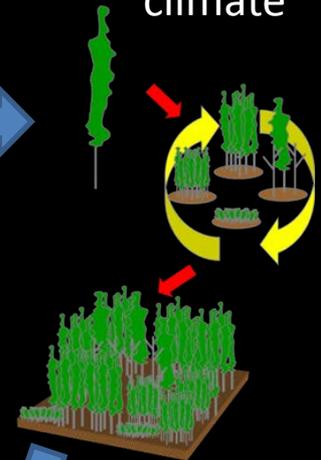
Output: Change in Forest type by scenario

UVAFME year 2000 biomes
UVAFME A1B year 2095 biomes
UVAFME A2 year 2095 biomes

Broad leaf deciduous
Dark needle leaf
Light needle leaf
Small leaf deciduous
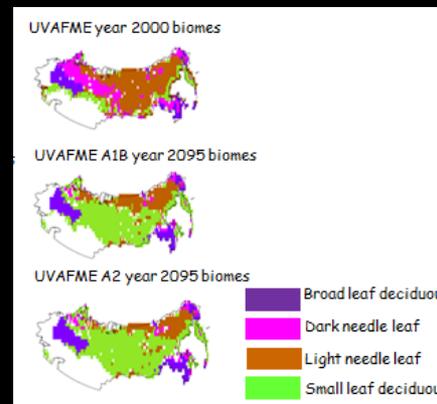
Output: Detail Composition and Biomass change
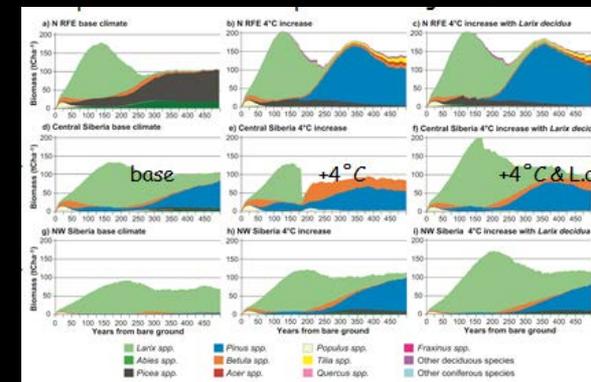
University of Virginia Forest Model Enhanced

Yan, X. and Shugart, H.H. (2005) FAREAST: a forest gap model to simulate dynamics and patterns of eastern Eurasian forests. *Journal of Biogeography,* 32:1641-1658.
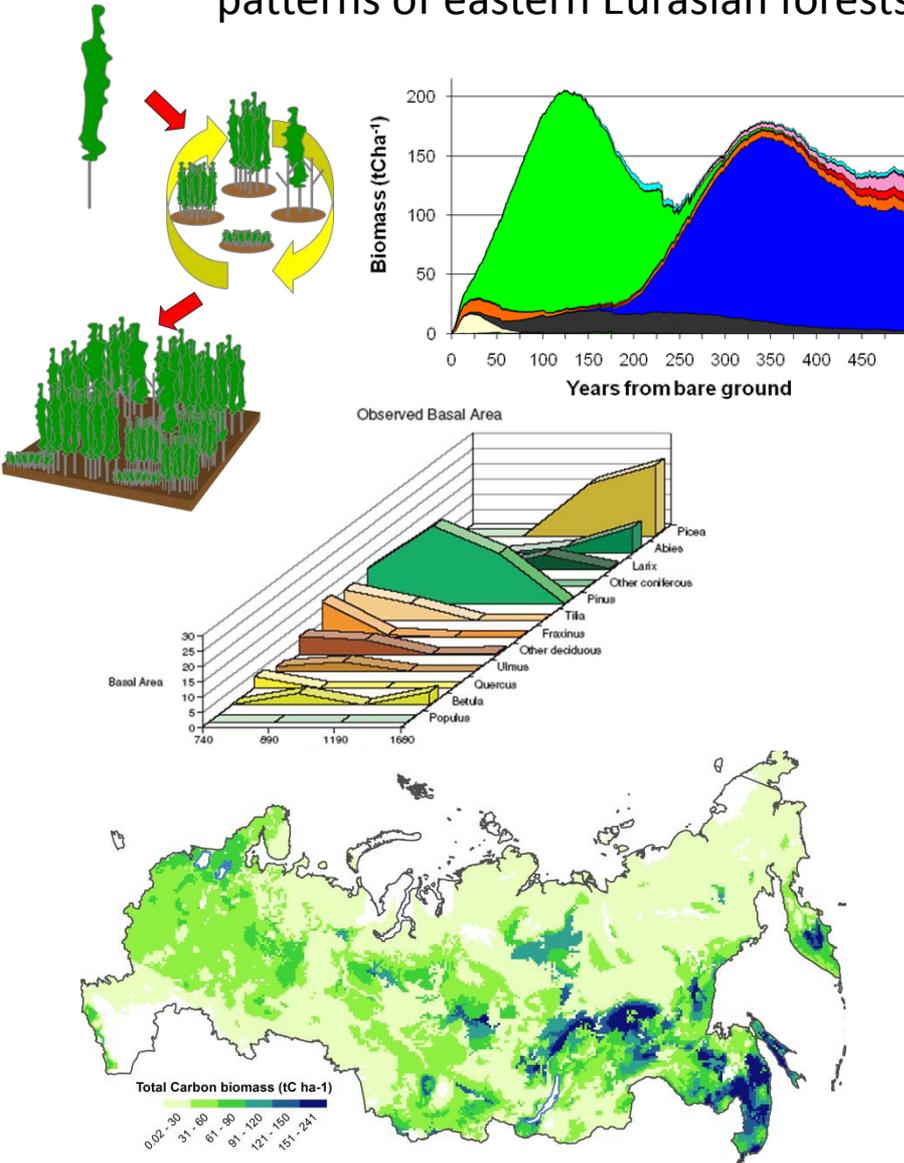
- Individual based model of forest ecosystem

- Trees influenced by soil nutrients and water, climate, and canopy

- Species niche parameters drive competition (growth rates, regeneration needs, sizes, longevities)

- Forest community and species response to climate and disturbance regimes

Species distribution in current climate (without disturbance in model)

UVAFME

Legend:
- 0 (white)
- 1 (grey)
- 2 *Pinus sibirica*
- 3 *Abies sibirica*
- 4 *Picea spp.*
- 5 *Larix spp.*
- 6 *Pinus sylvestris*
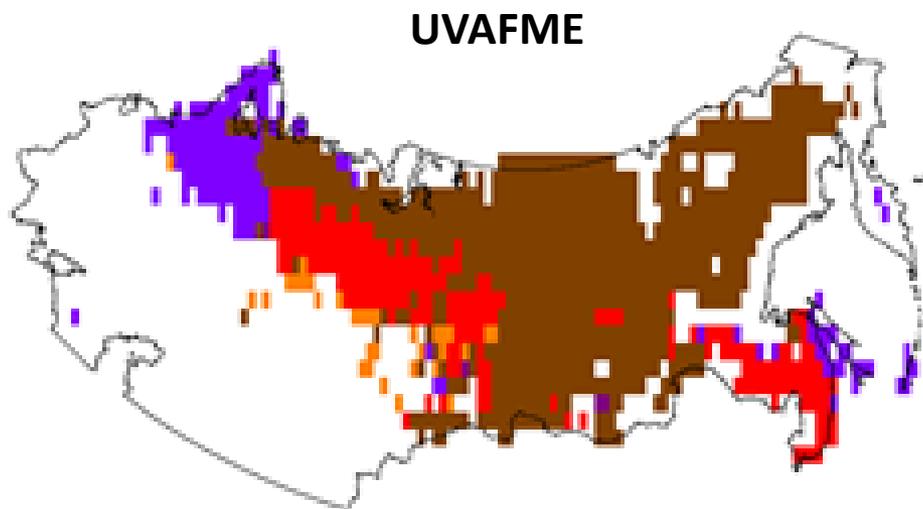
Isaev (1990)

- UVAFME species defined as one with greatest biomass per grid cell after 500 years

- UVAFME agrees with species distribution and type from Isaev (1990)

- Kappa statistic low (0.23) due to disturbance in observation map

- Stand age and disturbance important at local level

Shuman et al (in review) CJFR
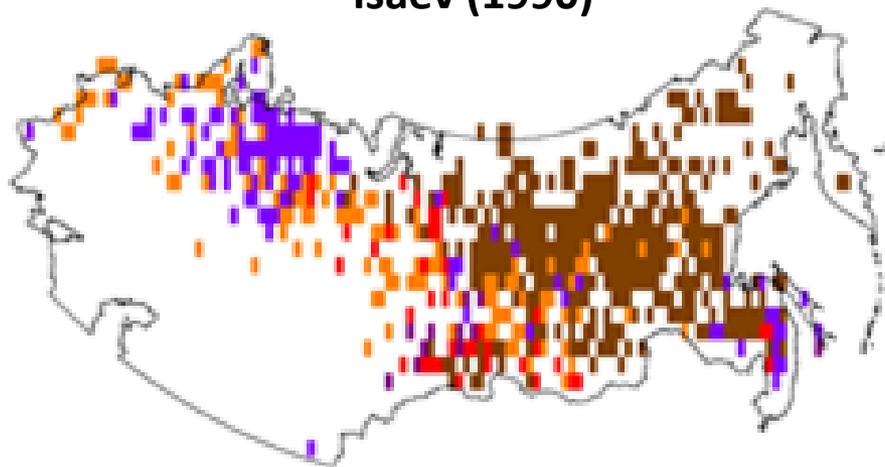
For each point, given data on climate and soil, UVAFME simulates the growth, death and mortality of individual trees on a small plot to assemble and produce change in a forest.

High diversity NRFE

Low diversity Central Siberia

Low diversity NW Siberia

Shuman, J.K. *et al.* (2011) *Global Change Biology*
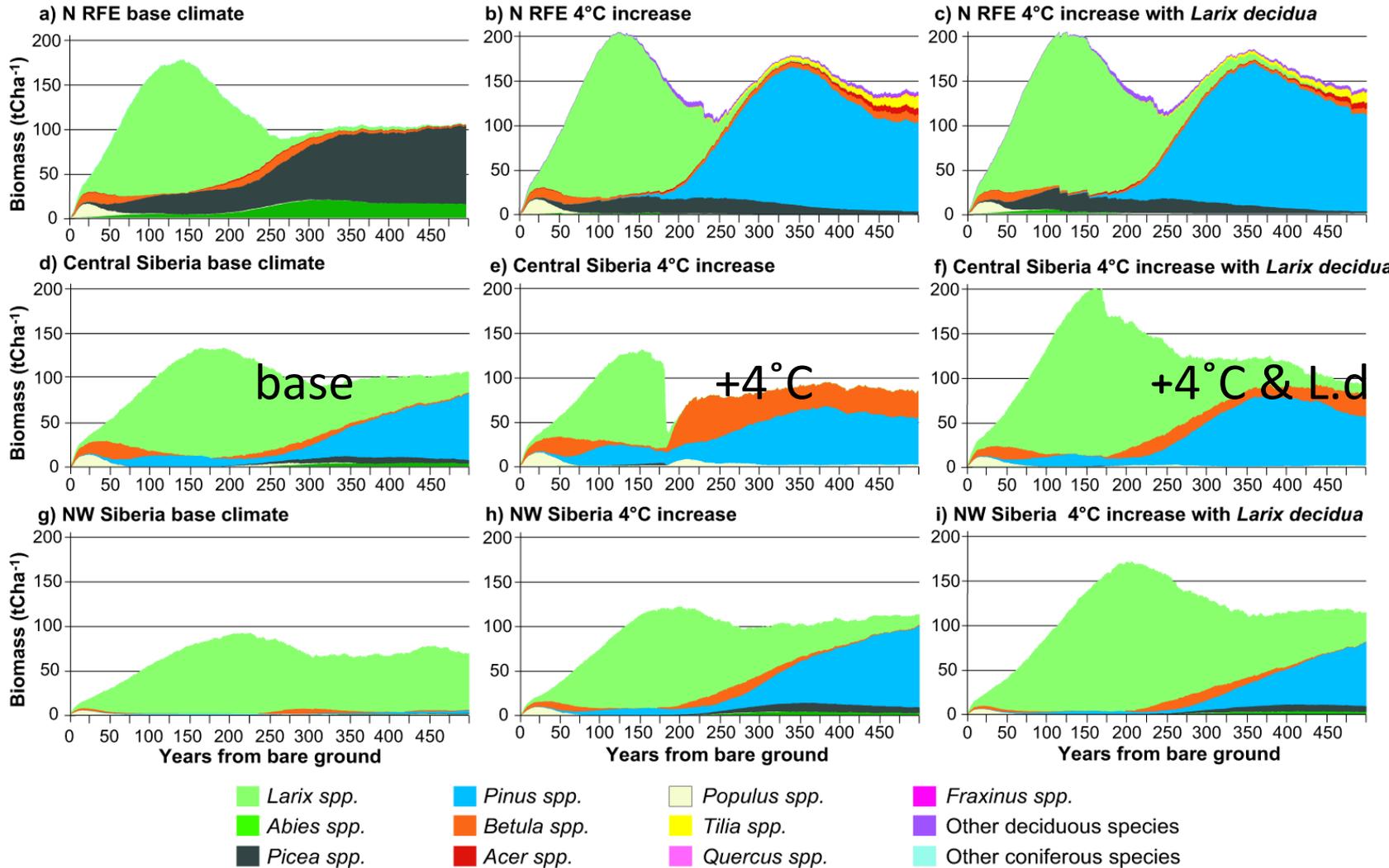
Response of mixed-age forest

Current climate conditions at year 100

NCAR CCSM sres A1B at year 100
(2X CO_2, altered temp and precip)

Larix species biomass
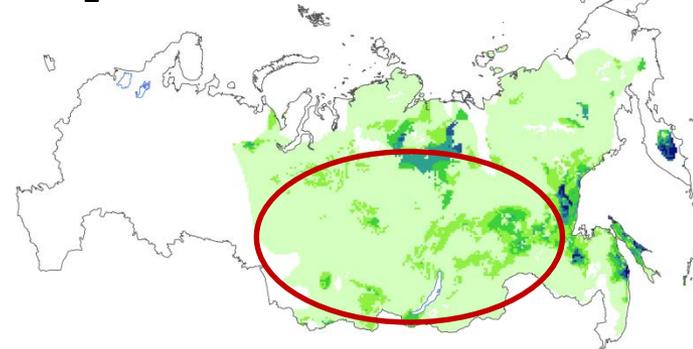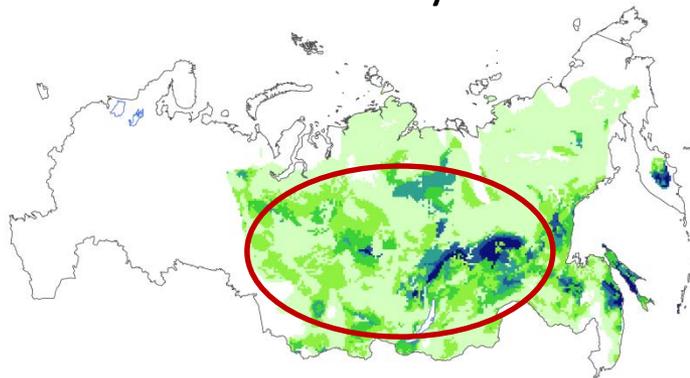
Broad-leaved deciduous species biomass

Total mixed species biomass

Carbon biomass (tC ha-1)
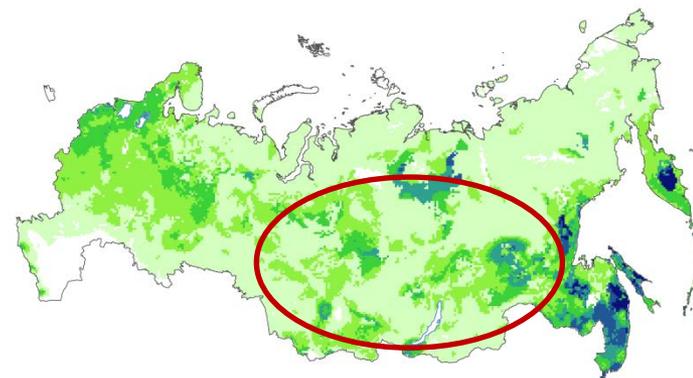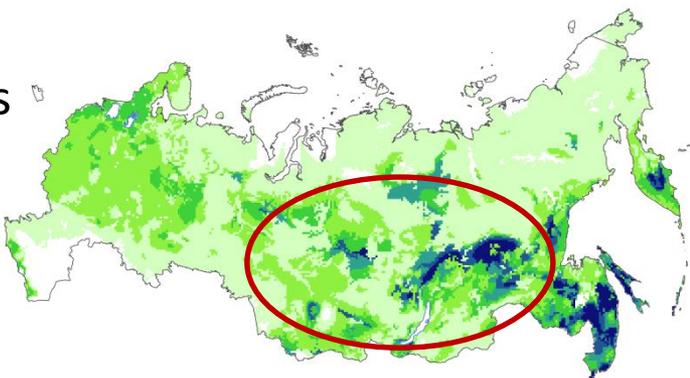
0.02 - 30   31 - 60   61 - 90   91 - 120   121 - 150   151 - 241
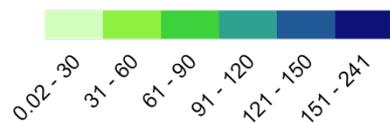
Response of mixed-age forest change in total carbon (tC per hectare)

A1B change from year 2000 to year 2095
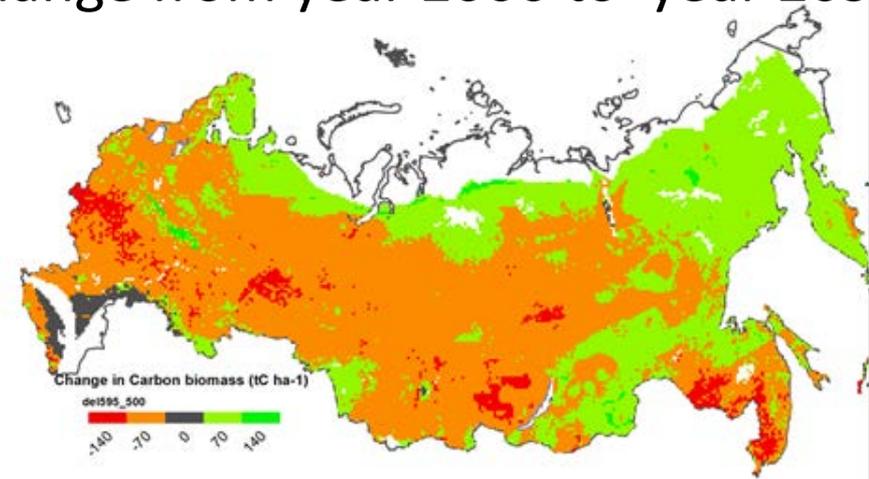
Total loss of 0.678 Petagrams

A2 change from year 2000 to year 2095
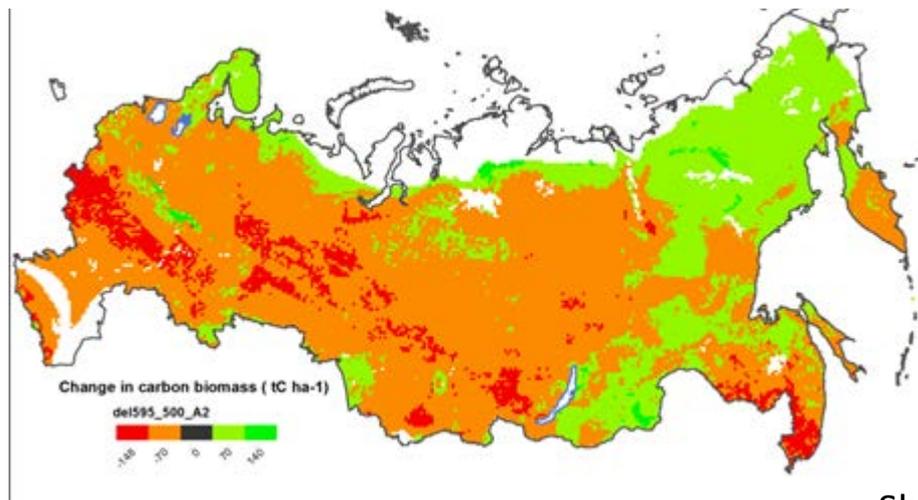
Total loss of 1.131 Petagrams

Shuman et al (in review) CJFR

Example of Estimated Biomass for selected case study sites from UVAFME outputs combined with Landsat-based LCLUC

LCLUC	Tomsk		Krasnoyarsk		Irkutsk	
	Area (%)	Area-weighted Δbiomass	Area (%)	Area-weighted Δbiomass	Area (%)	Area-weighted Δbiomass
Forest disturbance	4.82	-3.45	11.37	-4.98	3.98	-3.59
Forest regrowth	15.25	+6.46	20.91	+11.35	9.00	+3.11
Total		**+3.01**		**+6.37**		**-0.48**
Constant	75.35	–	60.75	–	74.26	–
Unknown	4.52	-0.34	6.97	+0.34	12.76	-1.87

- The total is the sum of Δ biomass between post-Soviet years 1990 and 2000 Disturbance and regrowth from Landsat analysis

Modified from Zhao, Bergen, Brown & Shugart 2009.

Integrated Synthesis Approach
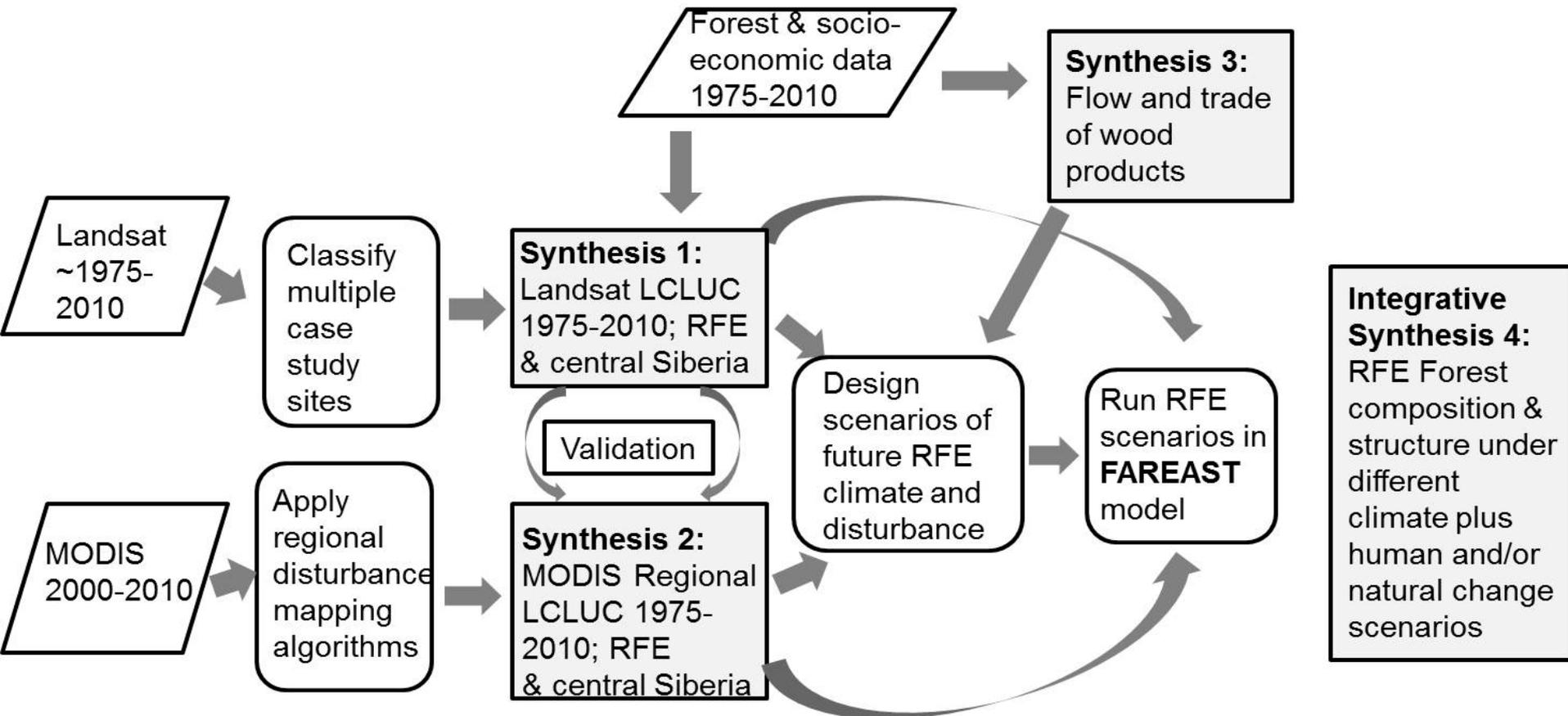
Project –related publications I

JOURNAL ARTICLES AND BOOKS

Chen, D., Loboda, T.V., Hall, A., Channan, S. (in review). Long-term record of sampled disturbances in Northern Eurasian boreal forest from pre-2000 Landsat data. *Remote Sensing.*

Hitztaler, S. and **K. Bergen** (2013) Mapping Resource Use over a Russian Landscape: An Integrated Look at Harvesting of a Non-Timber Forest Product in Central Kamchatka. *Environmental Research Letters,*

8: 045020.

Newell, J. and **J. Simeone** (in press). Russia's forests in a global economy: How consumption drives environmental change. In-press at *Eurasian Geography and Economics*.

Newell, J. (2004) *The Russian Far East: A Reference Guide for Conservation and Development*. McKinleyville, CA: Daniel & Daniel. 466 pages.

Shuman, J.K., Tchebakova N., Parfenova E., Soja A., Shugart H., Ershov D. and **Holcomb K.** (in review) Forest Forecasting with Multiple Ecosystem Models in the Boreal Forests of Russia. *Canadian Journal of Forest Research*.

Shuman J.K., Shugart H. and **Krankina O**. (2013) Assessment of carbon stores in tree biomass for two management scenarios in Russia. *Environmental Research Letters*. 8, 045019 (9pp)

Shuman J.K., Shugart H. and **O'Halloran, T.** (2011) Sensitivity of Siberian larch forests to climate change. *Global Change Biology.* 17:2370-2384

Zhao, T., Bergen, K.M., Brown, D.G., and **H. Shugart**. 2009. Scale-Dependence in Quantification of Land-Cover Change and Biomass in Siberian Boreal Forests. *Landscape Ecology,* 24: 1299-1313.

Project-related publications II

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Bergen, K., Estrada, J., Johnson, T. (2013), *Landsat LCLUC Site Reports for Krasnoyarsk, Tomsk, Irkutsk, Primorsky*, University of Michigan SNRE, Ann Arbor.

Bergen, K. and **Wang, Y.** (2013), *Urban LCLUC RFE & Central Siberia Report*, University of Michigan SNRE, Ann Arbor.

Bergen, K., Johnson, T. and **Wang, Y**. (2013), *Transportation Infrastructure RFE & Central Siberia Report*, University of Michigan SNRE, Ann Arbor.

Loboda, T., Sun, G. et al (20-- ongoing), *Landsat LCLUC Site Reports for Amur, Chita, Sikhote*, University of Maryland.

GRADUATE STUDENT THESES

Johnson, T. (2014), *Improvement in Landsat Land-Cover Change Results using Time Series Classifications and Multi-temporal Land-Cover Classification and Accuracy Comparison Using a Rule-Based Logic: a Case Study in Southern Primorsky Krai, Russia*; M.S. Thesis University of Michigan, SNRE, Ann Arbor.

Park, K. (2013) *A Spatial-Temporal Analysis (1975-2010) of the Timber Industry in the Russian Far East and Siberia*, M.S. Thesis University of Michigan.

PHOTOGRAPHS

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