LONG-TERM DATASETS AND SYNTHESIS OF TRENDS AND VARIATION IN LANDSCAPE LCLUC ACROSS THE RUSSIAN FAR EAST AND CENTRAL SIBERIA

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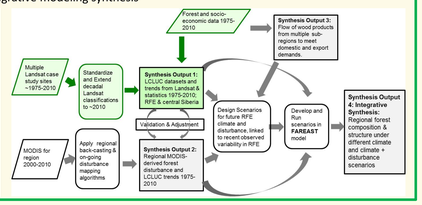
OBJECTIVE

This poster reports on progress on one of three objectives and products for our LCLUC synthesis project focusing on boreal forest change in the Russian Far East and Central Siberia. A set of team members have focused on completing long-term time series datasets of: a) landscape-level Landsat LCLUC classifications b) landscape-level spatial datasets (roads and urban infrastructures), and c) accompanying province-level statistical variables. This work involved redefining and merging diverse existing Landsat classifications from multiple institutions, completing new classifications to extend previous time series of LCLUC data to 2010, and generating the accompanying spatial and socio-economic statistical datasets. The map (below) shows the multiple Landsat case study sites within the broader study region (orange outline), within our integrative modeling synthesis objective (magenta) and within the ecoregions of Northern Eurasia. The flow chart shows the steps involved in completing this Synthesis Output 1 (green), as well as its important connections to the overall project and final integrative modeling synthesis



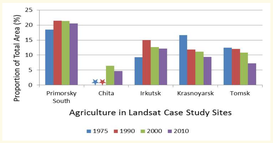
LONGTERM DATASETS SYNTHESIS

- **Landsat Land-Cover/Land-Use Time Series Classifications:** We updated seven Landsat case study sites classification data, merging data from two separate institutions. All sites were classified for 2010 following a common class scheme. All sites have disturbance data (Burn and Cut) for four time series dates at approximately decadal eras: 1975, 1990, 2000, and 2010. Five sites have complete times series classifications for twelve different land-cover and disturbance classes for these same four decadal dates (Bergen et al. 2013. Site Reports; Loboda et al. Site Reports).
- **Infrastructure Time Series Mapping:** We compiled all new time series spatial data for A) Transportation and B) Urban infrastructure in eight case study sites. This data was compiled from a combination of Russian topographic maps and Landsat imagery for all sites all dates (Bergen et al. 2013. Road and Urban Reports).
- **Statistical Time Series:** We compiled Russian statistical data at the province level from multiple sources for a number of socio-economic variables. Provinces included Kamchatka, Khabarovsk, Primorsky, Amur, Chita (Zabaykalsk), Irkutsk, Krasnoyarsk and Tomsk. Time series were analyzed for relationships including correlations (not shown) between forestry and other socio-economic variables (Newell and Simeone, in press; Park 2013).

SYNTHESIS FINDINGS BY LCLUC ACTIVITY

- **Logging:** Prior work had shown that logging in RFE (Kamchatka) and three Central Siberia sites had dropped sharply after 1990. New results for additional RFE sites and updated to 2010 suggest that logging rates have not significantly increased and have not re-attained Soviet-era levels. Logging patterns were largely different between the RFE and Central Siberia. RFE logging was difficult to distinguish via Landsat, occurring as fewer, smaller clearcuts or as selective logging, the latter especially in the mixed forest of Primorsky_S. Central Siberia logging continued either in large landscape patches or as dense checkerboard patterns conforming to 1994 regulations.
- **Fire:** Results of fire occurrence compared with logging highlight the dominance of fire as the main agent of regional-scale disturbance in the forests of the RFE and Central Siberia. Statistics derived from the sites depict the potential for fire to dominate disturbance over large portions of landscapes. Conversely, in all sites, recent Cut has never exceeded 5% by area, and has been decreasing over the 1975-2010 study period. An exception is Krasnoyarsk with low fire occurrence and high earlier logging rates.
- **Regeneration & Succession**: In the RFE Landsat sites Conifer/Mixed forests appear to be stable or slightly increasing. In the Central Siberian sites, Conifer/Mixed appears to mostly continue to decrease. In the RFE sites Deciduous may have decreased slightly over time; whereas in the Central Siberian sites it has mostly consistently increased. Fire drives most change in forest type with the exception of highly logged Tomsk/Krasnoyarsk. Change in forest species mix is likely occurring due to selective removal of species such as Oak in southern RFE. This is corroborated by export and trade statistics.
- **Urban** areas were mapped from Russian topographic maps and Landsat and showed that most were small villages and change in area was negligible 1975-2010. However our statistical compilations showed extensive out-migrations especially from the RFE and our other work has documented that this has come mostly from small villages (with in-migration towards the west and to large urban centers). Thus a combination of both remotely sensed data and population statistics are needed to fully explain urban LCLUC, especially in the RFE.
- **Transportation** networks: While populations have declined, updating of roads maps via Landsat times series shows that transportation infrastructure has increased. In particular forest road density has increased in all sites since 1990. The Sikhote and Primorsky_N sites (our most remote forested sites) has had the greatest increase, and this increase was in forest roads. Given the relatively minor level of identifiable clearcuts in the Sikhote and other RFE sites, we expect that forest roads are a proxy for increase in selective harvest or salvage harvest after fire, confirming different approaches to forest harvest between RFE and Central Siberia.
- **Agriculture** LCLUC at the province level showed that drops in agriculture output (e.g. grains) generally mirrored the temporal trend of forest industry wood production. Results of Landsat analyses of the case study sites were somewhat heterogeneous. Areas in Central Siberia and including Chita continued to experience some agriculture abandonment into 2010. Patterns diverged between Central Siberia and RFE sites: agriculture appeared to increase slightly in both the Amur site and the Primorsky_South site, both of which are adjacent or share borders with China and where the Chinese side of the border is dominantly agricultural. In addition these sites border ecotonal changes. Overall this suggests that agriculture may still be declining in more marginal areas.

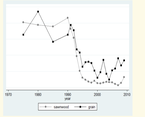
AGRICULTURE

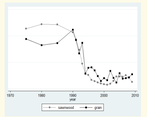


Research Questions: Our work investigated whether agricultural abandonment was present in the range of study sites and whether this trend was consistent over time. Earlier results had suggested that, in Central Siberia, that abandonment of collective farming areas had contributed to forest regrowth. However, the trends in RFE Landsat sites agriculture were unknown, as were trends after 2000.

Approach: Agriculture was mapped by used pixel-based Landsat classifications at all dates for the Primorsky_S site, as well as updated to 2010 for most other sites. We also collected and analyzed province level statistical data for all site locations.

Findings: Landsat-derived LCLUC due to agriculture showed mostly consistent trends over the range of sites and over time (above center). For sites in Central Siberia, agriculture has continued to decrease up through 2010. However, within the sites nearest to the border with China, agriculture in *some* areas appears to have increased. In the Primorsky_S site wetlands had been significantly reclaimed for agriculture, much of which apparently took place prior to 1975, but has increased since that time (below). This appears to be a localized political border or ecotone phenomenon as both Landsat-derived statistics the provincial statistics show decreases in agriculture. Overall, province-level statistical data showed a significant decrease in agricultural activity beginning in ~1990 and continuing to remain lower (though fluctuating) up through 2010 (panel upper right figure).



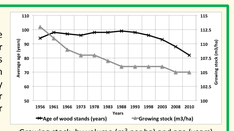


Above: Time series statistics showing similar patterns over time for sawnwood production and grain production in Amur (L) and Chita (R; entire) provinces

Primorsky_S site - local example of typical agriculture expansion between 1975 and 2010 near China border in reclaimed vegetated wetlands (agriculture shown in brown)

FOREST TYPES, REGNERATION & SUCCESSION

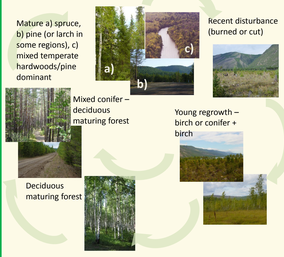
Research Questions: Official statistics for Russia show an overall trend of decrease in forest age accompanied by a more evident reduction in growing stock volume. Our prior work has shown that the boreal forests of the RFE and Central Siberian regions are dynamic and may be changing. Fundamental to interpretation of this LCLUC is an understanding of the forest itself – its species, communities and disturbance, recovery and succession regimes. We sought to synthesize these characteristics within our Landsat case sites in terms of trends over time 1975-2010 and variation over geographic space spanning from the Russian Far East (RFE) to Central Siberia.



Growing stock, by volume (m^3 per ha) and age (years)
Source: FAO 2012; Newell and Simeone, in press.

Approach: We completed multiple time series of Landsat forest- and land-cover classifications in order to understand the change in forests over time at the landscape scale. We complemented this with research into the compositions of those forests, their structure and their ecological dynamics.

Trends over time



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

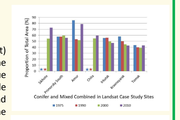
Recent disturbance (burned or cut)

Mixed conifer – deciduous maturing forest

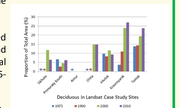
Young regrowth – birch or conifer + birch

Deciduous maturing forest

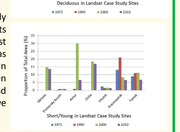
Conifer & Mixed forest: Results from the Landsat sites (right) show that in the RFE sites plus Chita (now Zabaykalsk) the proportion of Conifer and Mixed Forest either fluctuated due to large fires (Sikhote and Amur) or stayed nearly stable (Primorsky_south). In Central Siberian sites, Conifer and Mixed forest mostly decreased over the 1975-2010 time period due large-scale preferential logging in these types.



Deciduous forest: Deciduous appears to have decreased slightly in RFE sites. Deciduous is stable in Chita and fluctuates somewhat in Irkutsk. In the remaining Central Siberian sites, Deciduous has steadily increased from 1975-2010 – due to recovery from earlier extensive logging.

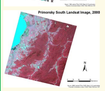


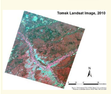
Short/Young: Short/Young vegetation is present in steady moderate amounts in Sikhote (post-fire) but small amounts in Primorsky_south (little fire and small or selective harvest gaps). Widespread post-fire regeneration in Amur was observed as Young forest succeeded to Mixed forest. In Central Siberia in all sites, Short/Young increased between 1975-1990 (due to high earlier rates of logging and subsequent regeneration) but has since decreased in relative proportion. ★ = no data or in progress rather than 0%



(Bergen et al, Loboda et al., Site Reports)

Variation over East-West





Mature forest composition: Forests in topographically zonal Sikhote and Primorsky_N sites (Left, top) are dominated by spruce-fir at higher elevations (Right, top) and mixed conifer at lower zones. In Primorsky_S (Left, middle), mixed Korean pine and temperature deciduous forests are dominant mature types. The complexity of this latter forest is the greatest of all of the sites (Right, bottom) The northern Amur site is dominated by larch and the Chita site by mixed pine-larch (structure similar to middle figure). In the Krasnoyarsk and Tomsk sites, dark conifer forests consist of denser (than northern RFE) spruce-fir-Siberian pine and light coniferous Scots pine.

Disturbance regimes: In the more northern mountainous RFE sites (Sikhote and Primorsky_N), fire is the dominant disturbance regime observable via Landsat. In the Primorsky_S, temperate forest region fire is absent over the time series and logging (likely selective) is either minor or non-observable via Landsat. Amur and Irkutsk have been significantly impacted by fire over the 1975-2010 time period. In the Central Siberian sites, fire has occurred but large industrial clearcuts also occurred before 1975 and over the 1975-2010 period, readily observable via Landsat.

Forest regeneration and succession: Burned areas in the RFE appear to be slower in regenerating post-fire, in particular more northerly sites such as Sikhote and Primorsky_N. In northern RFE sites, birch regeneration harbors spruce in its understory which eventually becomes dominant, especially in mountainous areas. In Primorsky_S, birch is the dominant post-disturbance species, however Korean pine will regenerate in gaps. In Irkutsk, regeneration is birch-dominant mixed with larch or scots pine. In Krasnoyarsk or Tomsk, birch regeneration is widespread.

(Figures from Krestov et al. 2003)

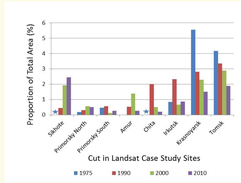
DISTURBANCE – LOGGING

Research Questions: Prior Landsat work in Central Siberia had shown that forest harvest (logging) land use had been higher prior to 1990 and dropped from 1990-2000, mirroring official statistics. We were interested to determine if this phenomenon also occurred in the Russian Far East (RFE) Landsat sites. In addition, for all sites from the RFE to Central Siberia we sought to learn if the temporal trend of diminished logging had continued through 2010 or if there had been a recovery of logging activity on our forested Landsat case site landscapes. Finally, we were interested to see if temporal trends in remote sensing–derived LCLUC from localized case sites followed similar patterns as provincial official statistics as well to observe any correlations between key statistical trends relating forestry output to other socioeconomic variables.

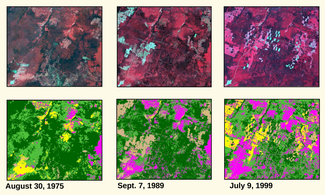
Approach: We identified logging (Cuts) in the form of small to large patches of cleared forest on 30-m **Landsat** TM/ETM+ and on 60-m MSS. In most sites this class was identified using supervised classification with a maximum likelihood classifier. For the Primorsky_N site manual methods were used. The classifications provide information on forest that was harvested either during the year of image observation or fairly recently prior. After 1-2 years cleared areas typically would have some increased herbaceous or shrub cover and were mapped as Short/Young Vegetation class. Cuts were identified in most sites for ~1975, 1990, 2000 and 2010 decadal dates. We also collected and compiled official Russian statistics on several variables related to the forest industry and other industries for which we could find a reasonably consistent time series. Finally we looked at statistical correlations between some of the forest time series and those of other population and industry trajectories (not shown, Park 2013).

Trends over time

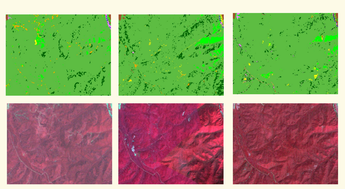
Results: Results from the Landsat case study sites (right) show that for most sites that the proportion of the landscapes classed as Cut dropped after 1990. Time series of statistics at the province level for wood removal and sawnwood show this temporal trend as well (below). Another major component of variation over time has been the pattern of harvest. Prior to 1975 and up through 1994 there is evidence of very large conglomerated landscape-scale harvest patches (below, upper figure). In 1994 the (then) new Russian forest code established a maximum cut size of 50 ha and in non-contiguous patches for industrial forests (below). Landsat remote sensing observations suggest that the latter regulation has been followed often but not always nor in all sites.



(Bergen et al, Loboda et al., Site Reports)



Variation in harvest patterns over time and between RFE and East Siberia. **Left:** Central Siberia large landscape-scale harvests supplanted by small (<50 ha) clearcuts after 1994. **Right:** RFE small patches. Logging statistics in Primorsky Krai indicate wood/log removal, however little evidence is observed by Landsat suggesting very small patches and/or selective harvest of valuable tree species from mixed forests (e.g. Oak).



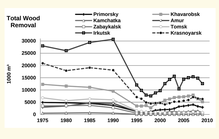
Water
Mature Conifer
Mature Mixed
Mature Deciduous
Short/Young Regeneration
Cut

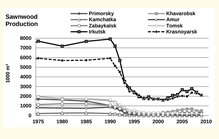
Variation over East-West

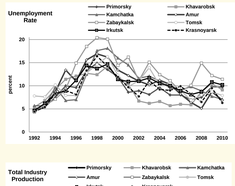
Results: A closer look at the Russian statistics after 1990 suggests that the provinces with historically highest levels of logging (Khabarovsk, Krasnoyarsk and Irkutsk have rebounded more in terms of Wood Production in the past decade. However, statistics for Sawnwood show distinctly higher recovery for Central Siberian provinces vs. RFE provinces, suggesting greater export of raw logs from the RFE rather than value-added sawnwood. Results from the Landsat case study sites (left) suggest slightly greater renewed presence of logging in the more Eastern sites. Another major component of variation East-West has been the type of harvest. RFE sites from 1975 to 2010 show less of either the very large landscape-scale cuts OR the patchwork of regulated non-contiguous clearcuts associated with the 1994 regulations. Instead, most RFE sites show small irregular cuts over most time periods.

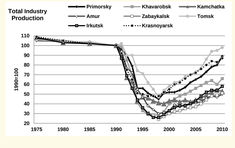
Relationships to Socio-Economic factors

Findings: Time series we have compiled of Russian statistics also suggest that total wood production has increased somewhat after 2000. However the increase in sawnwood production is not as great, especially in RFE provinces. This may suggest more export of raw logs vs. sawn wood. Industrial roundwood export statistics appear to show this trend as well, in particular showing a strong increase in roundwood export to China, but dropping after tariffs instituted.





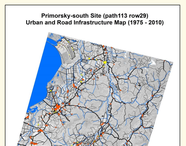




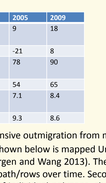
DEVELOPMENT – URBAN

Research Questions: Little work has been completed to analyze **urban** LCLUC using remote sensing in Central Siberia and RFE. Therefore, we asked how much and what types (classes) of urban changes have occurred in the study sites, how this has changed over time, and how it may be patterned over the range of sites

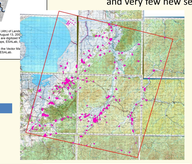
Approach: Because prior work had shown that most 'urban' areas in the study sites were small, often under forest cover and/or often interspersed with vegetated agricultural areas, our approach used detailed Russian topographic maps & class scheme to initially locate, map and classify urban polygons. We then adjusted or updated these polygons based on overlay and comparison with Landsat imagery for each scene/date in our time (e.g. below left). Because change in size of urban areas observed via remote sensing cannot show population gain or loss, we also relied on compilation of Russian statistics to provide a more complete picture of human population dynamics in the RFE and Central Siberia. Time series statistics on population were compiled from multiple Russian Sources .

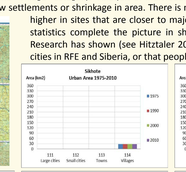


Year	1992	1995	2000	2005	2009
Net Migration Russia (per 1000 persons)	18	44	25	9	18
Net Migration Study Region	-135	-85	-56	-21	8
Total Production Russia (1990=100)	75	55	57	78	90
Total Production Study Region	78	47	43	54	65
Unemployment Russia (percentage)	5.1	9.6	10.5	7.1	8.4
Unemployment Study Region	5.3	9.6	12.9	9.3	8.6



Findings: Our province-level statistics show extensive outmigration from many parts of Siberia and the RFE after dissolution of the USSR through at least 2005 (above; Park 2013). Shown below is mapped Urban area by class by Landsat case site over time derived from topographic maps and Landsat imagery (Bergen and Wang 2013). The most evident result is that there is very little change in Urban area in any of the Landsat case study site path/rows over time. Second, the great majority of Urban in the primarily forested path/rows is in the "Village" category. Analysis of individual polygons shows some minor growth – almost all to *existing* Villages and very few new settlements or shrinkage in area. There is no discernable E-W pattern, however density of villages appears to be higher in sites that are closer to major urban centers outside of the Landsat case sites. Again, population statistics complete the picture in showing that populations in Urban areas have declined (Park 2013). Research has shown (see Hitztaler 2004) that most population migration was from rural areas to regional cities in RFE and Siberia, or that people left the area altogether to migrate to Western Russia.

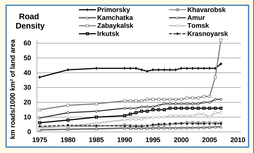


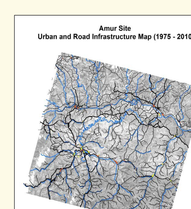


DEVELOPMENT – TRANSPORTATION INFRASTRUCTURE

Research Questions: As our above results show, areas (km²) of Urban have stayed steady but human populations have declined. Thus we were interested in whether transportation infrastructure had also stayed steady. We were also interested in patterns across our West-East set of sites and in what types of roads were being built.

Approach: Our approach to mapping transportation infrastructure and change used detailed Russian topographic maps & their roads class scheme. We then adjusted or updated these line segments based on overlay and comparison with each scene/date in our **Landsat** time series for all sites (below). We also compiled province-level statistics





Findings: All of the eight study sites for which time series roads data (below) were created showed an *increase* in roads between each date (Bergen et al 2013). Although some of the previous roads may no longer be active, new roads appeared between each year in the time series in every study site. Most of the growth occurred between the years 1975 and 1990 and was *mostly forest road growth*. Figures below display growth in km of roads for each road type for the years 1990, 2000, and 2010. Most increase after 1990 was also *forest road growth*. This was consistent among sites in both Central Siberia and the RFE with the exception of Amur (part of this site is in China).

The Sikhote (our most 'remote' and forested site in the RFE), Primorsky_N, and Amur sites have seen the greatest and most recent forest road growth since 1990 (these sites also have the lowest urban density, see above Urban section). The Amur site is our site that straddles both Russia and China.

DISTURBANCE - FIRE

Landsat observes stand-replacing fires such as that on the hillcrest above. Many fires however are ground fires; thus the prevalence of all fire is greater than observed by Landsat and quantified in our time series statistics.

Research questions: An overarching question of the larger synthesis study is what are the respective contributions of human and natural disturbance and their influence on forested landscapes?

Approach: We used the Landsat case sites to also map Burns at the dates in our time series. Burns included any area relatively freshly burned such that regeneration had not significantly progressed. [similarly Cut captures any freshly logged areas, not yet significantly regenerated, likely the current or past several years]. Thus the total amount of area burned between our decadal time series dates would likely be higher than the area reported at each single date.

Findings: Fire is the dominant disturbance in the boreal forests of the study region and the Landsat case study sites results support this (Right). Statistics derived from the sites depict the potential for fire to dominate disturbance over large portions of landscapes. Conversely, in all sites, Cut has never exceeded 5%, is consistently lower and has been decreasing over the 1975-2010 study period. Only in Krasnoyarsk and Tomsk, sites of extensive industrial Soviet-era logging has forest harvest approached the impact of a moderate fire season. The fire charts also remind that fire is a spatially and temporally more stochastic process. Only high temporal resolution regional mapping (such as from MODIS or AVHRR) can provide the fuller data on fire rates and extent.

(Bergen et al, Loboda et al., Site Reports)

Left: Amur 1987

Below: Amur 2010

Below: Irkutsk 2010

Left: Sikhote 2005

Above: Chita 2000

SOURCES

Photos by: L. Peterson, T. Loboda and K. Bergen

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