# Mapping and Modeling Forest Change in a Boreal Landscape


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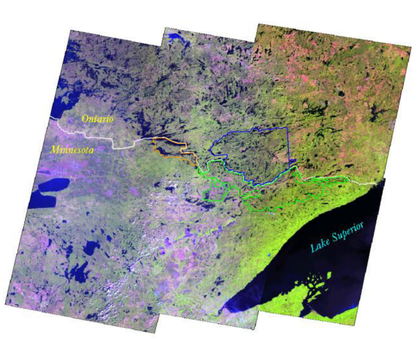
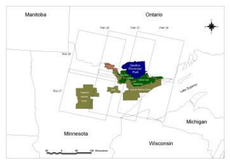
## Study Area




A




B

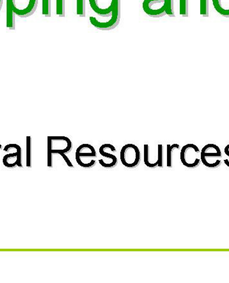
A) The full study area (145,560 km2) consists of six TM footprints which strattle the U.S./Canadian border. Cover type changes occurring between 1985, 1990, 1995, and 2000 are being classified.

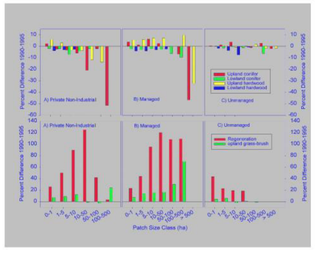
B) Results presented here are from a pilot study (27,495 km2) in northeastern Minnesota. Cover type changes between 1990 and 1995 were studied.

## Forest Structural Changes 1990-1995

Area of both upland and lowland conifer and lowland hardwood forest decreased for all patch size class categories, with the exception of small increases In upland conifer in the 0-1 ha patch class. Upland conifer had the greatest decrease (8%) in the largest size class (>500 ha) -- 34% of the upland conifer was in the this class in 1990. Upland hardwood increased in all patch size classes except >500 ha, which decreased 13%.

Early successional forest increased in all patch size classes. Upland grass-brush had the greatest increase (45%) in the >500 ha patch class.

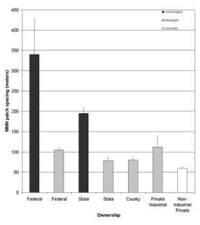




Changes in forest area between 1990 and 1995 varied considerably by management status. Private non-industrial (unknown management) and managed forest showed dramatic decreases in the >500 ha patch class resulting in increased fragmentation.

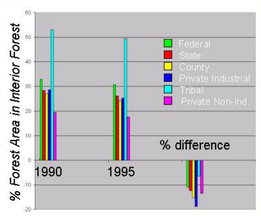
Early successional forest increases on private non-industrial lands were skewed toward smaller patch size classes (5-16 ha), while managed lands showed a trend toward larger patches.

PIF = private industrial forest
PNIF = private non-industrial forest
IFA = interior forest area




### Minnesota's Forest Structure -- Conclusions

- PIF greatest cut size, rate & spacing.
- PIF still maintained moderate IFA → organized management.
- PNIF smallest cut size, spacing & IFA → uncoordinated management.
- Tribal forest had highest IFA & lowest cut rate.
- Uncoordinated cutting patterns are responsible for high levels of forest fragmentation within Minnesota's forests.




## Why do we need to study it?

- Timber harvesting is one of the major factors altering the species composition, age class distribution, and carbon fluxes over much of forested North America.
- Timber harvesting in Minnesota is expected to increase by ~25% in the next several decades to supply increased fiber demand for paper mill expansions. Similar expansions are expected in adjacent northwestern Ontario.
- An increase of this magnitude in the rate of forest harvest is faster than the forest can be restored.

## Questions

- What is the current and historical rate of timber harvesting in northern Minnesota and southwestern Ontario?
- How does extensive timber harvesting impact land cover distribution in a boreal landscape?
- Will the current rates of timber harvesting cause problems in the near future?

## Landscape Laboratory

In contrast to the managed forested lands in this region, the 2.0 million hectares of the Boundary Waters Canoe Area (BWCA) and Voyageurs National Park (VNP) in Minnesota and adjacent Quetico Provincial Park in Ontario is the largest contiguous, forested wilderness area in North America. This wilderness landscape has its own disturbance regime generated mainly by large fires (Heinselman 1973) which is distinctly different from the anthropogenic disturbance regime imposed by timber harvesting immediately outside the BWCA-VNP-Quetico wilderness (Hall et al. 1991). Much of the forest is old-growth conifer, but there are large patches of early-mid successional forest as well. There is no other place in the 48 contiguous states where there are large, matched, forested landscapes with contrasting natural and anthropogenic disturbance regimes. Therefore, Minnesota and adjacent northwestern Ontario is a natural "landscape laboratory" for determining the impact of extensive timber harvesting on landscape structure in comparison with an equivalent large landscape of uncut forest subject only to a natural disturbance regime.

## Approach

We are using multitemporal data from Landsats 5 and 7 to classify forest cover (Wolter et al., 2002), then map the changes in the forest mosaic through time on a 5-year basis (1985, 1990, 1995, and 2000) to determine successional pathways under natural and managed disturbance regimes. Markov transition matrices are being developed from these data and analyzed using Markov theory (Pastor et al. 1993) to assess current trends in forest cover and steady state land cover distributions in order to help shape management policy at federal, state, and local levels.

## There are three key problems:

- What is the current state of the landscape?
- Where is it going?
- How long will it take to get there?

For a wilderness area, there is only natural disturbance regime:
- fires & wind throw
- beaver & insect

For a managed landscape, there is also
- human disturbance → timber harvest

## Mathematical Model

***Markov chain*** used to modeling the dynamic landscape.

A Markov chain is a stochastic process{ *Xn, n=0,1,2…*} that takes on a finite or countable number of possible values. We suppose that whenever the process is in state *i*, there is a fixed probability *Pij* that it will be in state *j* next. That is,

$$Pij = P\{Xn+1=j \mid Xn = in, Xn-1=in-1,\ldots,X0=i0\} = P\{Xn+1=j \mid Xn = i\}$$

for all states *i0,i1…in-1, i,j* and all *n*>=0.
Where *i0,i1,…,in* are different states (possible values) that the process would be in.

A Markov chain consists of a vector ***X*** of the distribution of land-covers at time ***t*** and a matrix ***P*** of transition probabilities of changes from each land-cover class to the others during a time period ***τ.***

$$X(t+\tau)=X(t)\,P(\tau)$$

**Transition matrix:**
*Pij* represents the probability that the process will make a transition into state *j* next when in state *i*. Then, *Pij>=0*, and $\sum_j P_{ij} = 1$, for all *i*'s. ***P*** denotes the matrix as follows:

$$P = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ p_{n1} & p_{2n} & \cdots & p_{nn} \end{pmatrix}$$

***X*** is a steady state vector, $\lambda_i$ are the eigenvalues of $P^T$ where the damping ratio $\rho = \lambda_1/\lambda_2$

**Rate of convergence** $r = X(t) = (-\ln\rho)X(0)e^{-t\ln\rho} = Ke^{-t\ln\rho}$ (*K* is a constant)

**95% convergence to steady state** is defined as 5% convergence rate, which is:

$$e^{-t\ln\rho} = 5\% = \frac{X(t)}{X(0)}$$

**The time (*T*) to get to 95% convergence:**

$$T = \frac{\ln 20}{\ln \rho}$$

## Model Results

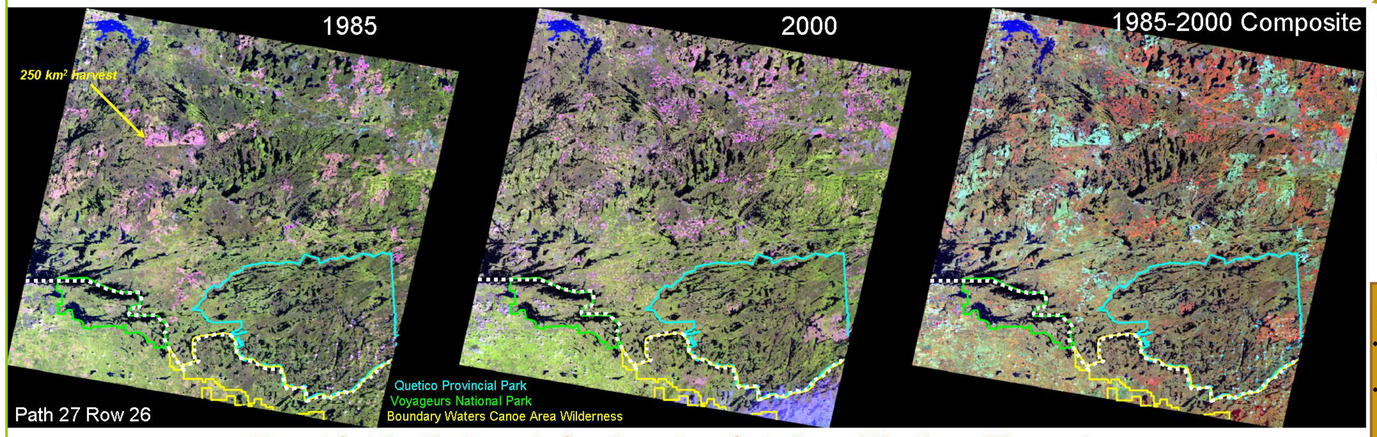
**1) Steady state comparison between wilderness and managed landscapes.**

| | forest | regen | up-grass | wetland | water | developed |
|---|---|---|---|---|---|---|
| Proportion in wilderness | 0.229506 | 0.034054 | 0.021588 | 0.042402 | 0.667842 | 0.004608 |
| Proportion in managed | 0.033853 | 0.194944 | 0.029725 | 0.059258 | 0.438778 | 0.243441 |

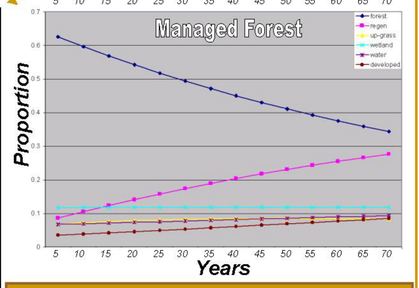
**2) Time to reach 95% convergence to steady state**

- Wilderness landscape → 467 time steps or 2325 years
- Managed landscape → 703.5 time steps or 3517.5 years

**3) Forest changes in the next 70 years:**








## Conclusions

- There are differences in dynamics between managed and wilderness forests.
- Within the next rotation (35y) 1/3 of the forested landscape will be in forest age classes less than 20 years old.
- Ultimately, developed land for non-forest uses will occupy ~25% of the landscape.

## Forest Cutting Patterns in Southwestern Ontario and Northern Minnesota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