2002 Progress Report for the NASA Land Cover Land Use Change Program

Monitoring Forest Response to Past and Future Global Change in Greater Yellowstone

Principle Investigators

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1 May April 2002

Background

Have the forests of Greater Yellowstone responded to global change in recent decades?
What have been the consequences of past forest change for carbon, fire, and biodiversity?
Can a monitoring strategy be designed to allow early detection of future change?

Understanding past global change provides an important context for designing monitoring protocols to detect future change. New data from the Greater Yellowstone Ecosystem indicate that vegetation change has been dramatic over the last century. Conifer forests have both increased in density and expanded into previously unforested areas. Concurrently, hardwood, shrubland, and grassland habitats have declined. Fire exclusion by humans may explain these forest dynamics. However, pilot dendrochronological studies of tree growth rates suggest climate variability has also contributed to conifer expansion. These vegetation dynamics appear to have important implications for carbon sequestration, fire and risk to humans, and biodiversity. The responsiveness of vegetation to past land use and climate, and the climate changes predicted for the GYE in the future, suggest that the GYE is an important site for monitoring for early detection of global change. The objectives of the this study are:

1. Quantify change in forest cover, density, and composition across the GYE during 1950-2000.
2. Assess the consequences of this change for carbon sequestration and biodiversity.
3. Devise a monitoring strategy to detect future change in forests of the GYE.

We are quantifying change in forest composition and structure over the GYE for 1975-2000 using Landsat imagery calibrated with reference data from aerial photographs and for rapid change transects for 1950-2000 using aerial photographs. The consequences of these changes for carbon accumulation will be quantified by estimating carbon storage for each cover type based on allometric relationships and field data. Habitat functions will be used to estimate change in the abundances of several bird and shrub species. A monitoring strategy will be developed for locations of rapid change and for the GYE as a whole.

Key Words: Research – biodiversity, change detection, carbon cycling
Geographical Area - North America, temperate forest
Remote Sensing – aerial photographs, Landsat
Methods/Scales – GIS, regional scale

Questions, Goals, Approaches

Questions
NASA ESE Science Questions Addressed: Land cover/use change; consequences of change in land cover/use.

Proportion of Study Devoted to Social Science: 0%

Proportion of Study Devoted to Key Themes: carbon -25 %; water - 0%, nutrients -0 %, GOFC - 50%, biodiversity – 25%.

Goals
Proposed Timetable

Task	2000				2001				2002			
	S	S	F	W	S	S	F	W	S	S	F	W
Aerial photo reference data	---	---										
Reclassify cover type maps for 1975, 1985, 1994		---	---									
Select rapid change transects		---										
Collect field data along rapid change transects					---	---			---	---		
Develop methods for assessing consequences					---	---	---	---	---	---		
Finalize Landsat classification methods and do cover maps for 1950, 1975, 1985, 1994, 2000								---	---	---	---	---
Analyze consequences of vegetation change								---	---	---	---	---
Make results available											---	---

Progress During Period

Aerial photo reference data collection and Rapid Change Transects

- Completed purchase of aerial photos and completed reference data collection for two of three Landsat scenes for the years 1939, 1971, 1985, 1994. A total of >2000 points were sampled across 12 transects.
- Initiated interpretation of aerial photos for the third (and final) Landsat scene.

Analysis of rates of change in conifer cover from aerial photo data

- We analyzed direction and magnitude of change in percent cover of conifer for the reference data collected for Landsat scene one. This was done in total and by elevation class, aspect, topographic convergence index, and distance from conifer. The net change in percent conifer during 1971-99 among stands that were not logged or clearcut was an increase of 3.7%. Among stands that changed in conifer cover, three times as many increased in conifer cover as decreased in cover. The change was greatest near lower treeline (5% average increase). Change was greatest on northerly and easterly aspects.

Field sampling of stand structure and composition.

- Detailed data on vegetation structure and composition were collected for 100 stands stratified by cover type, seral stage, and percent conifer. These samples were taken from the areas covered by Landsat scene one and the northern portion of Landsat scene two.

Accuracy assessment of classification of percent conifer.

- The key variable of interest in the study is percent conifer and change in percent conifer. We first evaluated the ability to quantify from spectral data percent conifer in 10% increments for the 1999 time period. Landsat ETM+ images were obtained for an early growing season date (July), late growing season date (September), and for winter (December). Univariate analyses were done for each band for each date and for change in each band between dates. A "best multivariate" model was also developed and validated against "hold-back" data.
- We found strong linear relationships between percent conifer and several individual bands and difference in individual bands between seasons. Band 5, the mid-infrared band, which is sensitive to moisture in plants, was most strongly correlated with percent conifer. The best multivariate model explained 71% of the variation and included July band 3, July band 5, Sept. Band 7, July-Sept band 7, Dec.-July band 1, and Dec.-July band 4. Validation against hold back reference data resulted in a coefficient of determination of .72 between predicted and observed in 10 % increments of conifer cover.

Accuracy assessment of classification of change in percent conifer.

- We then evaluated the ability to quantify from spectral data change in percent conifer between 1985 and 1999. This is the period for which finer resolution (<=30 m) Landsat data are available. The key question is whether rates of change in conifer cover (over this relatively short time for forest dynamics) are greater than classification error in detecting the change spectrally. Hence, we developed univariate and multivariate models of change in conifer cover between 1985 and 1999 and validated these against hold-back reference data.
- We specifically assessed the ability to detect changes in conifer cover in the range of 10-30%. Most reference stands that changed in conifer cover increased or decreased less than 30%. The best model for increase in conifer cover explained 34% of the variation. The best model for decrease in conifer cover explained 26% of the variation.

Mapping of percent change in conifer across Scene one for 1985-1999.

- A pilot analysis of change across all of Scene one was done. Percent conifer was mapped from spectral data for 1999. A threshold denoting change was established. This threshold was applied as a filter to the 1985 image to identify places that differed in percent conifer from the 1999 image. These "change" pixels were classified for 1985. The 1999 and 1985 images were "differenced" to determine the location and magnitude of change.
- This pilot analysis was done to refine methods. It was completed before the best predictive models were developed. The analysis will be redone using best predictive models.

Additional Resources

- Obtain funding for related studies. These are listed under Products.
- A Masters of Science thesis on fire and climate history was completed under a related project. This study provides an excellence context on fire, climate, and forest dynamics between 1600 and present.

Evaluation of Original Approach and Methods

We have learned that aerial photos are an excellent data source for quantifying rates of change in conifer cover. We originally proposed to use photos from the 1970s to 1999. We have determined that photos from 1939 are available and usable. Hence, we have expanded the aerial photo analyses to both produce reference data for satellite classification and to quantify change in forests for 1939-1999. Beyond total rates of change, these data also allow quantification of rates of change by landscape setting. The average rate of change for 1971-99 was a 3.6% increase in percent conifer and many samples increase by 10% to 20%. Conifer encroachment and densification are most rapid at lower treeline and on northeasterly aspects.

We have also learned that conifer cover can be quantified with Landsat ETM+ for a given year with relatively good accuracy (72% accuracy for 10% cover classes). However, the rate of change in conifer cover during 1985-1999, while considerable on the time scale of forest dynamics, is not large relative to the error in our classification of change from Landsat TM and ETM+ data. Our conclusion is that our satellite-derived maps of change for the period of 1985-1999 will not be sufficiently accurate for the magnitude of change that has occurred in the study area. We will do a similar analysis with Landsat MSS 1975 to Landsat ETM+ for 1999. However, the coarser (80-m) resolution of the MSS data will not likely result in higher accuracies.

Consequently, we will use Landsat-based change analysis for mapping over the landscape cover types and coarse-scale changes in seral stage and conifer cover (e.g., under logging, burning, reforestation). We predict fine-scale changes in conifer cover over the study area using statistical models involving biophysical factors.

We expect that consequences of change in conifer for carbon and biodiversity will be effectively quantified.

Narrative Statement on Progress

The study is fully on schedule in this second year of the three-year funding period. The research team is working well together. Aerial photo acquisition and interpretation, satellite classification of vegetation, accuracy assessments, and field studies are proceeding as scheduled. Funds have been generated for companion studies. Several publications and presentations were completed.

New Findings

- Preliminary analyses indicate that conifer forests have increased in cover by 3.6% on average during 1971-1999 across the one-third of the study area analyzed to date.
- Forest change is strongly related to biophysical setting. Conifer encroachment is most rapid at lower tree line, on northeasterly aspects, and in close proximity to existing conifer stands. Forest densification is most rapid at lower elevations. Monitoring to detect future forest change should focus on these biophysical settings.
- Percent conifer can be mapped from Landsat ETM+ imagery for one time period with reasonably good accuracy (72% for 10% increments).
- Quantifying change in conifer cover for the period of satellite data availability (1973 to present) will be difficult. Forest change, thought fast for forest dynamics, is slow relative to the accuracies that can be derived from Landsat TM and ETM+ data for the 1985-present period. Landsat MSS is available back to 1973. However, the coarser resolution of these data will also likely inhibit its utility for detecting changes of the magnitude of those in GYE. We expect that use of both spectral data and biophysical data will allow the goals of the study to be met.
- A companion study found that fires were frequent (ca 35 year return interval) in lower treeline forests from 1600 to the mid 1800s. Few fires have occurred there after. These findings suggest that the conifer expansion we have documented is partially resulting from fire exclusion by humans.

New Products

- Preliminary maps of conifer forest change in a portion of the GYE.
- Graphics summarizing long-term climate indices for the GYE.

Proposals Funded

Hansen. A.J. and R. Defries. Land Use Change Around Protected Areas in LCLUC Sites: Synthesis of Rates, Consequences for Biodiversity, and Monitoring Strategies. NASA Land Cover Land Use Program. $550,000. 2001-2003.

Hansen, A.J. A decision support system to understand interactions between wildfire and rural residential development. USGS. $92,000. 2002

Brown, K. and A. Hansen. A Landscape Approach to Aspen Restoration: Understanding the Role of Biophysical Setting in Aspen Community Dynamics. USFS Northern Rockies Fire Lab. $35,000.

Graumlich, L. Dynamics of Climate, Fire, and Land Use in the Greater Yellowstone Ecosystem, US Dept. of Agriculture NRI, $65,000.

Graumlich, L. Precipitation variability in the Greater Yellowstone Region as inferred from 1000+ tree-ring records. National Science Foundation, Earth System History Program. $239,000

Hansen, A.J., B. Maxwell, R. Rasker. Demographic Change in the New West: Exurban Development Around Nature Reserves. EPA. $400,000.

Hansen, A. and J. Rotella. Riparian Habitat Dynamics and Wildlife along the Upper Yellowstone River. US Army Corps of Engineers. $115,567.

Hansen, A.J, and R. Waring. Biodiversity hotspots in the Pacific and Inland Northwest. National Council on Air and Stream Improvement. $125,000.

Presentations

Graumlich, L., et al. Dynamics of Mountain Ecosystems. Ecological Society of America Annual Meeting. August 2001.

Hansen, A.J. et al. Spatial Patterns of Conifer Forest Expansion in Greater Yellowstone. Ecological Society of America Annual Meeting. August 2001.

Hansen, A.J. et al. Spatial Patterns of Conifer Forest Expansion in Greater Yellowstone. NASA LCLUC Annual Science Meeting. October 2001.

Hansen, A.J. et al. Changing Forests of Yellowstone: Conifer Expansion and Aspen Decline under Global Change. December 2001.

Powell, S., et al. Conifer forest expansion and densification in the Greater Yellowstone Ecosystem: detection and quantification over a 15-year time period Annual meeting of International Association of Landscape Ecology. April 2001.

Publications

Hansen, A.J., R. Rasker, B. Maxwell, J.J. Rotella, A. Wright, U. Langner, W. Cohen, R. Lawrence, J. Johnson. 2002. Ecology and socioeconomics in the New West: A case study from Greater Yellowstone. BioScience 52(2)151-168.

Hansen, A.J., and J.J. Rotella. 2002. Biophysical factors, land use, and species viability in and around nature reserves. Conservation Biology. In Press.

Joyce, L., A.J. Hansen. 2002. Climate change: Ecosystem restructuring, natural disturbances and land use. Trans. 66th North American Wildlife and Natural Resources Conference. In press.

Kramer, M.G., A.J. Hansen, M. Taper, and E. Kissinger. 2001. Abiotic controls on windthrow and pattern and process of forest development on Kuiu Island, Alaska. Ecology 82(10):2749-2768.

Hansen, A.J., R.P. Neilson, V. Dale, C. Flather, L. Iverson, D. J. Currie, S. Shafer, R. Cook, P. Bartlein. 2001. Global Change in Forests: Interactions among Biodiversity, Climate, and Land Use. BioScience 51(9):765-779.

Hansen, A.J., and V. Dale. 2001. Biodiversity in U.S. Forests Under Global Climate Change. Ecosystems (4):161-163.

Burrough, P.A., J.P. Wilson, P.F.M. van Gaans, A.J. Hansen. 2001. Fuzzy k-means classification of topo-climatic data as an aid to forest mapping in the Greater Yellowstone Area, USA. Landscape Ecology 16(6):523-546.