Land Cover-Land Use Change-NASA Earth Science Program

Modeling Carbon Dynamics and Their Economic Implications in Two Forested Regions: Pacific Northwestern USA and Northwestern Russia.

- Project Overview
- Principal Investigator
- Co-Investigators
- Proposal
- Annual Reports
  - 1997-98
- Related Web Sites
- Acknowledgements




PROJECT OVERVIEW

Our proposed project is comparing two significant forest regions of the globe, the Pacific Northwest, USA and northwestern Russia with the overall objective of determining the relative importance of land-use versus biogeoclimatic factors in controlling spatial and temporal patterns of carbon dynamics. Our four specific objectives are: 1) Link remotely sensed and biogeoclimatic data to ecosystem models at three spatial scales (region, landscape, and stand) to predict changes in regional carbon stores, 2) Assess the major uncertainties introduced by complex and interactive natural processes and evaluate how these uncertainties propagate during the integration of scales, 3) Use this analysis system to compare the changes in carbon stores in the Pacific Northwest and northwestern Russia over the last 25 years, and 4) Link our carbon stores analysis system with forest market models to determine the economic consequences accompanying changes in carbon stores.

This research involves the continued integration of five highly complementary and interdependent carbon models into an overall regional analysis system. Each model addresses a particular process or pattern at a specific spatial scale, is linked to remotely sensed and biogeoclimatic data relevant to that scale, and will be tested with independent data from the Pacific Northwest and northwest Russia. Regional patterns of maximum potential carbon stores will be based on biogeoclimatic factors, potential vegetation, and maximum potential leaf area index. Landscape patterns of carbon flux will incorporate those constraints, but focus on the changes in carbon stores that result from changes in age structure caused by disturbances and the fate of carbon in forest products. Stand level patterns of carbon flux will incorporate the constraints of the previous two scales, but focus on the interactions of tree species, physiognomic forms, and small-scale disturbances (i.e., thinning) and their effects on successional changes in carbon stores. Once we have performed sensitivity analysis and corroborated the predictions of the separate system components, we will examine how uncertainty propagates in the overall analysis system, focusing on parameters and driving variables that the component models are most sensitive to and for which the largest uncertainty exists. Our analysis will also include a comparison of future scenarios of regional development for the next 25 years as a way to compare the overall "inertia" of these two regions to change in the current carbon flux.

Concurrent with assessing the uncertainty of our regional estimates, we are analyzing the economic implications of changing harvest rates and other management treatments (i.e., planting, precommercial thinning, commercial thinning) as well as the manufacturing efficiency and use of forest products. Each of these changes entails a cost of implementation as well as changes in the quantity, quality, and timing of forest harvests. Analysis of these costs will allow us to generate schedules of the marginal cost of carbon storage for each type and location (PNW versus Russia) of treatment. The final result will be calculations of the relative efficacy of various management options and improvements in processing efficiency that can help guide decision makers intent on managing carbon emissions from forests.

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PROPOSAL

1.0 Introduction

One of the most important questions facing ecologists today is the role of the biota in the global carbon (C) cycle. The fact that 1-3 Pg year-1 of the annual fossil fuel C release can not be accounted for (Post et al. 1990, Dale et al. 1991, Dixon et al. 1994) raises questions about our current understanding of this cycle. In particular, the failure to understand the role of forests at the regional and global scales may stem from a lack of regional scale C analysis (Dale et al. 1991, Solomon et al. 1993). To address this shortcoming, we propose to compare the C dynamics of two significant forest regions of the globe, the Pacific Northwest, USA (PNW) and northwestern Russia. These two regions are important to the global C cycle for different reasons. The PNW (defined here as western Oregon and Washington) is important because its potential to store C is several times higher than the global average. Thus its smaller aerial extent is offset by greater C density per unit area (Harmon et al. 1990). At the same time, the PNW is also a major region for timber production, a disturbance that has the potential to decrease C stores by almost an order of magnitude (Krankina & Harmon 1994). In contrast, Russian forests store less C per unit area, but taken as a whole comprise about 50% of the globe's boreal forests. Thus, low productivity is offset by a large aerial extent. Although largely thought to be sequestering C after harvest and disturbance (Kolchugina & Vinson 1993), Russian forests may be entering a phase of increased utilization for forest products which could make them future sources rather than sinks.

The proposed project builds upon three past studies. In the first, started in 1992, a team of US scientists (Cohen, Ferrell, Harmon, Homann, Sollins, and Wallin) with a combination of NASA Terrestrial Ecology Program, USDA Forest Service, and NSF-LTER funding has developed a hierarchial analysis system to assess the effects of forest management on C dynamics in western Oregon (Cohen et al. 1992, 1994, Wallin et al. in press). A second study was a NSF funded collaboration between Oregon State University (Harmon and Krankina) and the St. Petersburg Forest Academy (Chertov and Sennov) to examine the successional dynamics of live and dead wood in Russian boreal forests. This second study will provide an extensive database from which to parameterize stand level ecosystem models for Russia. The third study, about to end, is a NSF funded collaboration between Oregon State University (Harmon, Krankina, and McKee), USDA Forest Service (Cohen), the St. Petersburg Hydrological Institute (Kobak), Komarov Botanical Institute (Botch), St. Petersburg Forestry Academy (Chertov, Kuznezov, Soloviev), and the Russian Forest Inventory (Kukuyev and Treyfeld). As part of this effort we have held two separate 2 week workshops to formulate specific working plans to synthesize the Russian data needed to estimate regional C fluxes (http://lternet.edu/about/program/russia). This active collaboration with Russian colleagues (we have worked with each Russian investigator for at least 2 years) is producing the field data required to interpret satellite imagery and to parameterize, run, and test the models to be used in our proposed regional comparison. The proposed project will allow us to take full advantage of this long- term investment.

2.0 Objectives

Our main objective is to examine the major factors controlling the spatial and temporal patterns of C stores and fluxes within two major coniferous ecosystems: the PNW and northwestern Russia. This includes the living and the so-called "dead" part of the ecosystem (i.e., detritus and soils) as well as the C utilized by humans (i.e., lumber, paper). As part of this effort, we will compare the importance of biogeoclimatic, land-use, and economic factors between the two regions. In addressing our overall goal of estimating regional fluxes and their relation to economic output of these two regions, our analysis will emphasize the identification of major uncertainties within and between spatial scales.

Our specific objectives are: 1. Link remotely sensed and ground-based biogeoclimatic data to ecosystem models at three spatial scales (region, landscape, and stand) in an analysis system that predicts changes in regional C stores and identifies the major factors controlling ecosytem response to land-use change over the last 25 years. This work will involve the continued development and testing of three highly complementary and interdependent C models (RegionCarb, LandCarb, and StandCarb). 2. Assess the major uncertainties introduced into the analysis by complex and interactive natural processes and evaluate how those uncertainties propagate during the integration of scales. This objective will be achieved by sensitivity analysis of each model and measuring how the degree uncertainty propagates within the overall system of models and if this is magnified or decreased as spatial or temporal scales increase. 3. Use this analysis system to compare the changes in C stores for two significant forest regions in the globe over the last 25 years. Included in this objective will be an assessment of the "inertia" of these two systems to a change in the direction of the C flux. That is, how great does the change in recent trends in land- use have to be to convert a source region to a sink and vice versa. 4. Link our carbon stores analysis system with forest market models to determine the economic consequences accompanying changes in carbon stores. Because economic conditions for the two regions differ dramatically, separate market models for Russia and the PNW will be designed from existing models (e.g., Timber Assessment Market Model [TAMM], Adams & Hayes 1980).

3.0 Justification and Significance

Our proposed approach would address several shortcomings of past regional analyses (including our own!). First, by using remotely sensed and spatial biogeoclimatic data we will develop estimates that are spatially explicit, complete, and not overlapping. Second, we have made great efforts to consider all the components that store C including all live plant parts above- and belowground, all forms of detritus (including coarse woody debris), stable forms of soil C, and forest products. Third, our proposed project would help contribute to regional scale analysis of C fluxes by providing an example of a state-of-the-art approach. Finally, by comparing two important forest regions we will be testing the flexibility of our analysis system and allow us to explore ways in which regional results can be aggregated for global scale analyses.

Our proposed project would also make a significant contribution to testing a methodology to corroborate predictions and reduce the uncertainty of regional C fluxes. In ideal circumstances C fluxes would be measured directly, but with current technologies direct measurements are difficult at the spatial or temporal scales required. Solving fluxes from mass balance of C inventories is theoretically possible at regional scales, but not practical given that many key pools have not been included and that inventories are often inconsistent in space and time. A practical, sound alternative is to integrate satellite imargery, ground data, and models at several spatial scales using a hierarchical approach. This has several key advantages. The hierarchical approach lends itself to the corroboration of key aspects of C sequestration at the most appropriate scales. By dividing the problem hierarchically, the analysis is computationally more efficient. The hierarchical approach also has the advantage of focusing on the scale at which processes and controls interact. This focus is one of the keys to identifying the scale at which uncertainty enters into the analysis and how this uncertainty is propagated. Finally, our research would enhance the C stores models by linking them to economic models. Once these linkages are made, the feasibility and efficacy of various forest practices and industry investment plans that influence C flux can be assessed. Moreover, comparisons of economic costs between the U.S. and Russia will provide guidance on the best use of management and investment dollars for enhanced C sequestration.

4.0 Hypotheses

Our comparison of the PNW and northwestern Russia will be organized around four working hypotheses: 1. Disturbance severity and frequency exert a major control on C stores and flux rates in both forest regions. Due to the dominance of second-growth forests and low harvest rates, the St. Petersburg region is currently a net sink of atmospheric C. In contrast, the PNW forests are net sources of atmospheric C because uptake by second-growth forests is lower than releases from recently harvested old-growth and secondary forests. 2. Water balance is the major controlling variable of maximum potential C stores in both regions. In the PNW water is in short supply during the growing season, while in Russia precipitation substantially exceeds potential evapotranspiration thus excessive water can reduce forest productivity if drainage is insufficient. 3. Slow regrowth after disturbance, caused by the replacement of conifers by smaller or shorter lived species, is limiting C sequestration in both regions. This hypothesis is based on the assumption that, for both regions, conifer forest has the greatest potential to sequester C. We will test this assumption through an analysis of field data and by varying the species composition in our models to test which gives the highest rates of C sequestration. 4. Improvements in the efficiency of forest products processing will yield net economic benefits and result in decreased harvesting in Russian forests. This hypothesis is based on studies suggesting that the Russian wood processing industry is very inefficient and that efficiency gains could be made at low costs (Nilsson et al. 1992, Whitsell 1994). Diminishing marginal returns suggest investments in Russia will yield greater increases in efficiency than those invested in the more mature and modern production facilities in the PNW.

5.0 Study Areas

The two study areas represent contrasts in potential productivity, land-use patterns, and economic systems. The St. Petersburg region is located in the forest zone of northwest Russia, with closed forest comprising 53% of the land area. It has a long history of agricultural and forest management dating from the 18th century. The Russian economic system is currently in a state of transition with high uncertainty. Nevertheless, it is likely that Russia will increasingly use market based prices to direct economic activity implying its forest products industry will increasingly resemble its European and U.S counterparts. Therefore this region has the potential to enter a period of increased timber harvest. In contrast, the PNW forests are just ending a long-term period of heavy timber harvest of primary forests, in which a significant amount of C has been released to the atmosphere (Harmon et al. 1990, Wallin et al. in press, Cohen et al. in press). A recent, major shift in policy on public lands (where timber harvest has been reduced) has increased the rate of harvest on private lands, maintaining overall regional harvest levels over the short-term. The degree this shifting of harvests is sustainable ecologically or economically is uncertain because it means progressivley shorter forest rotations.

6.0 Proposed Research

We will use our multiscale analysis system, linking a set of simulation models with remotely sensed data analysis and biogeoclimatic data to assess the regional flux of C. In addition, we will begin to include an economic analysis into our overall system. For the purposes of this study we define three nested scales of interest: stand, landscape, and regional (Table 2). We start the following description of our multiple scale modeling strategy with the landscape scale as that has been the focus of our past work. This analysis will be linked to the regional scale by "looking upward" to determine the degree biogeoclimatic factors (temperature, precipitation, radiation, soil water holding capacity, and potential vegetation) determine maximum potential stores of C, as well as production and decomposition rates. The landscape scale analysis will be linked to the stand scale by "looking downward" to examine how species mixtures, physiognomic form, and small scale management actions (e.g., planting, thinning) influence the rate C accumulation occurs over succession. For each scale we describe the simulation models, as well as the remotely sensed and other spatial data required to estimate C stores and fluxes. We then describe the tests that will be used to corroborate the remote sensing and/or the simulation analyses (Tables 3 and 4). The final section gives examples of the types of analyses and regional comparisons that will be performed once these steps have been completed.

6.1 Landscape Scale. At the landscape level, we will use the LandCarb model reconstruct the effects of the past natural fire cycle, insect outbreaks, and observed changes in land-use patterns on C flux over the last 25 years. The primary purpose of LandCarb is to examine implications of landscape-level patterns and processes such as forest clearing. Fluxes in this model are solved as changes in live biomass, detritus, and forest products pools over time. At the heart of LandCarb is a Richard's function (Cooper 1983), that predicts live biomass at each point in succession. This model is linked to the other scales because the maximum potential biomass for a given location is determined by RegionCarb, while rates of increase over time are determined by StandCarb. LandCarb considers all forms of detritus in aggregate and assumes that C stores in mineral soil are relatively stable compared to the detritus pools. Detrital stores are predicted dynamically with inputs from litterfall (a constant proportion of live biomass) and stand level disturbances being offset by decomposition and combustion. RegionCarb is used to estimate the influence of abiotic environment on decomposition. StandCarb is used to estimate the effect of species on decomposition rate and litter production rates. Wallin is currently performing a sensitivity analysis of LandCarb. As LandCarb aggregates all live and detritus pools, we plan to compare its temporal trends to those of StandCarb to assess the size of aggregation errors. Another model, Harvest, will be used to predict the mass of detritus left after timber harvest based on utilization standards, species, tree age and size (Harmon et al. 1996a, http://www.fsl.orst.edu/lter/data/studies/ml01/ml01fmt.htm). We have already parameterized Harvest for the PNW and as part of our NSF related work are currently parameterizing it for northwestern Russian forests. The model will be used to predict the proportion of C removed based on forest type and age, time period being considered, and land ownership.

Although our earlier version of LandCarb did not include fluxes from mineral soil C (there is an ongoing debate on the degree this is altered by most forest practices; see Johnson 1992), we plan to include fluxes from this pool in our new work. We will therefore modify LandCarb so that "stable" C, produced after extensive decomposition, is added to the mineral soil C pool. We will use maps of mineral soil C over the two study areas to estimate the initial store of C in this pool. The decomposition rate of this pool will then be set so that when mature to old-growth forests are present the mineral soil C pool is in balance.

Changes in the production of detritus caused by disturbance, species replacement, or increased growth rates would therefore change the C stores in this more stable pool. In the PNW, we will use the Statsgo database (Soil conservation Service 1991) to map the regional C stores in mineral soil. Statsgo is compiled at 1:250,000 scale and designed to be used primarily for planning, management and monitoring at the region, multistate, state, and river-basin scale. Oregon and Washington Statsgo represent our PNW study area by several hundred spatially explicit map units, i.e., at a scale that is quite coarse compared with remote- sensing or DEM data. Ongoing work by Homann is evaluating the consistancy of Statsgo with other soils data (Homann et al. 1995). For northwest Russia, extensive soil data (ca. 1000 soil pits) and maps exist and these will be compiled by our Russian collaborator Chertov. A preliminary subset of these data show substantial differences in soil C stores among forest types. Therefore forest type GIS layers will be coupled with average stores values to map soil C distribution. Peat is a major store of C in the St. Petersburg region and will be included in the LandCarb model of that region. Dr. Botch has compiled the location and store of C in each major bog, mire, and wetland in this area. We are currently collaborating with her to explore the use of TM data to map all peatlands in this region.

To complete C flux estimates, we will account for the C stored in forest products. Including this component is absolutely crucial to understanding whether a region is a C sink or source (Dewar 1991, Kurz et al. 1992, Turner et al. 1995). The model to be used in this effort, ForProd, has recently been completed and parameterized for the PNW (Harmon et al. 1996b) and for northwestern Russia (Soloviev). This model tracks the fate of harvested C through manufacturing, use, and disposal as 6 pools (paper, mulch, short-term structures, long-term structures, dumps, and landfills).

To link C flux in the forest products sector to their economic consequences, we will use models based on cost (supply) and consumption (demand) relationships to compute the producer and consumer surpluses associated with the major forest products (lumber, plywood, paper and pulp). For the PNW these models will be adaptations of existing models such as the TAMM (Adams & Haynes, 1980) and PAPYRUS (Gilles & Buongiorno 1987). Similar models will be developed to reflect conditions in Russia with parameters estimated from historic data from Russia and the Soviet Union. Since this system does not represent free market conditions, the econometric techniques apropos disequilibrium conditions will be used (Fair & Jaffee 1972, Chang 1992). Estimates of production efficiency in forest products in Russia and the PNW can be obtained by parametric (Kerkvliet 1991) and nonparametric methods (Hseu and Buongiorno 1995). The key parameters of forest product market models are likely to be supply responses to changes in harvest levels and species composition as well as demand responses to changes in price. The supply responses generated by our forest product market models will be compared to similar existing models of regional and global timber markets (Sedjo and Lyon, 1996). Large uncertainty will likely surround demand responses of the Russian market model. Some corroboration is possible by comparisons with similar measures obtained by other means and for other regions (FAO 1986). Similarily, estimated changes in efficiency of the Russian forest products industry can be compared to practices in adjacent countries (e.g., Finland).

Remote sensing plays a key role in generating the spatial databases on land cover and change needed to integrate C stores estimated from the LandCarb model. Methods used to map land cover in the PNW and in northwest Russia are a combination of statistical clustering and regression analysis using Landsat imagery in conjunction with ground and airphoto reference data (Cohen & Spies 1992, Cohen et al. 1995). With the most recent TM data available, a cover map is produced of vegetation classes that are aligned along a successional gradient from recently disturbed forest to old-growth forest and correspond to changes in C stores. Thus far, we have completed cover mapping for all of western Oregon, from the high Cascades Range to the Oregon Coast Range. We plan to expand this effort to include western Washington and begin using this method in Russia. The map produced thus far contains six forest vegetation classes: two early-successional pre-canopy closure classes, with relatively low biomass, an early-successional closed canopy mixed hardwood-conifer shrub class, and three classes of closed canopy conifer seral stages. Ground data were used to determine the age range of each of these classes; the time required for each class to progress to later successional classes is estimated assuming all stands follow the "average" successional rates indicated by these time intervals. In future work, we propose to move away from this approach and determine how each disturbed area deviates from this average rate of succession (see section 6.3). Although these six classes are sufficient to accurately capture biomass accumulation in the Oregon Cascades, they are not adequate for the Oregon Coast Range where the mixed shrub class also includes hardwood-conifer mixtures of several seral stages with varying amounts of biomass. As the forests of northwestern Russia also contain expansive areas of hardwood-conifer mixtures, we will improve our cover mapping at both sites, as follows. For the closed mixed class, a Gram-Schmidt Orthogonalization procedure (G- SO) will be used (Jackson 1983) to derive a hardwood-conifer mixture index. This index will then be segmented into a mimimum of three mixture classes. One of these classes, a pure hardwood condition will be further separated into shrub and tree categories. The other classes will have increasing amounts of conifer cover and biomass. This procedure has been extensively tested in the Coast Range as part of a recently completed MS thesis (Maiersperger & Cohen), where, using a reference data base from several hundred forest stands, the Oregon Coast Range was represented with ten classes and an overall mapping accuracy near 80 %. For mapping of Russian forests, we will conduct a similar analysis using TM data and the extensive forest inventory database made available from the Northwest Forest Inventory Regional Office in St. Petersburg (Triefeld).

In addition to mapping the location and extent of vegetation cover classes, remote sensing data will be used to map stand replacing disturbances. Thus far we have completed our disturbance mapping over all of western Oregon using multi-temporal Landsat MSS and TM data from 1972 to near-present at roughly 5 year intervals. We plan a similar analysis in western Washington and northwestern Russia. Our methods for mapping and error assessment thoroughly documented in Cohen et al. (in review, Appendix), involve an unsupervised classification of multitemporal difference images. Because the spectral properties of recently disturbed forest are at one end and the mid- to late- successional forests (i.e., the most likely to be clearcut harvested) are at the other end of the brightness and greenness continua, the detection of severely disturbed forests is virtually unambiguous. Consequently, disturbance mapping accuracy in western Oregon forests exceeds 90% (Cohen et al. in review).

Whereas a clearcut harvest regime was the norm in PNW forests, recent policy changes have led to an increase of selective logging on public lands. In northwestern Russia, management prescriptions have long included a significant amount of selective harvest, as well as clearcutting. Thus, it is now essential that we begin mapping disturbances that cause partial stand replacement. Although we will test a number of multitemporal image analysis strategies (e.g., image differencing, principal components analysis, change vector analysis, etc.), we expect that the G-SO procedure will provide efficient, robust, and accurate results for regional disturbance mapping across a spectrum of disturbance severities and types, including harvest, wildfire, and insects (e.g., Collins & Woodcock 1994). Because we are attempting to map disturbances more subtle than clearcuts, we will use the relative radiometric normalization procedure of Hall et al. (1991) for MSS data that we have successfully adapted for TM data (Franklin et al. 1995). To assess non-clearcut disturbance mapping errors in Russia, we will use the Russian

Inventory database which maps stands with partial harvest and insect damage.

In our PNW work, error rates for all vegetation and age class maps have been determined using independent airphoto and ground reference data. We will continue to perform these checks as new areas within this study area are processed. In the St. Petersburg, Russia area we will compare our maps to those derived by the Northwest Forest Inventory Regional Office. These maps, which show the species, age, diameter, height, volume, and site productivity are linked to a computerized database for the 1993 inventory of 15,000 mapped stands. Dr. Treyfeld of the Northwest Forest Inventory Regional Office has already provided us with these data for three ranger districts representative of the St. Petersburg region.

The corroboration of the landscape scale analysis will emphasize aggregations of stands in watersheds, counties, or other large areas. This is because corroborating the successional trends in C accumulation will be conducted on the StandCarb model and corroborating the regional patterns of maximum potential productivity will be conducted on the RegionCarb model. The unique features of the landscape analysis to be tested are the location, rate, and area of disturbance, the amount of C harvested, and the amount of C within landscapes, watersheds or other subregional areas. Several data bases can be used to corroborate these predictions. In both study areas, existing maps and spatial databases will be compared to the Landsat derived estimates of the location and area harvested. In another test, the amount of C harvested across the study area for each time interval predicted by LandCarb can be aggregated for various administrative units (counties and Forest Service and BLM Ranger Districts) and compared to timber harvest statistics compiled for these units. These volumes will be converted to C using the conversion factors of Harmon et al. (1996b). As none of these harvest records were used during model development or the remote sensing work they provide an independent assessment of both methods. This test also serves as a check on the accuracy of our estimates of inputs to the forest products sector. In another test of the LandCarb model, we will use forest inventory data at the county level to corroborate our estimates of live C stores for several periods (e.g., Gedney et al. 1986). We will perform similar tests in the Russian study area using the maps and databases outlined above to test the amount of live C stores.

6.2 Regional Scale. At the regional scale, the RegionCarb model, currently being planned by Harmon, will be used to estimate the effects of radiation, temperature, water balance, physiognomic structure, and species on the maximum potential stores of live and dead C (i.e., in the absence of disturbance). We will use RegionCarb to assess our second working hypothesis. This model is similar to Forest-BGC (Running & Coughlan 1988), but estimates maximum C stores as well as net primary production (NPP). The constraints of radiation, temperature, water balance, physiognomic structure, and species on production and decomposition is similar between RegionCarb and StandCarb. The main distinction is that while StandCarb examines transient changes during succession, RegionCarb only considers the steady-state condition of undisturbed vegetation. Once corroborated, RegionCarb will be used to create a spatial database of maximum live and dead C stores as well as abiotic indices of production and decomposition rates. These data layers will be used to parameterize the LandCarb model described above. We will also compare the maximum live and detritus C stores predicted by RegionCarb to those predicted by StandCarb to confirm that these two models reach similar steady-state solutions.

A key variable required to estimate potential NPP and maximum C stores is the maximum potential leaf area index (LAI). Although remote sensing analysis has been used in the past to estimate large-scale, current patterns of LAI, we need to estimate the maximum potential LAI. Additionally, remotely sensed spectral indices tend to saturate above a LAI of approximately 5 m2 m-2, but older forests in the PNW may have values up to 15 m2 m-2. For these reasons this well established method will not serve our needs. Our alternative is to map the potential extent of major life forms that have different maximum potential LAI (e.g., alpine tundra, bogs, grassland, shrubland, deciduous forest, conifer forest). We can then assign maximum potential leaf area indices derived from existing field measurements to the map units which can be thought of as "C production subregions." Identifying and mapping these C production subregions will involve multiple data bases, including Landsat imagery, and various GIS data such as elevation and topography, ecoregions, climate, and geology. We will first develop this method for the PNW region and then apply the final method to the St. Petersburg region. Using maps of vegetation change derived from the multi- temporal Landsat data, we will mask out harvests since 1972 from most current vegetation classification derived from TM data. The 1972 vegetation map derived from MSS data will then be used to "add" back in the vegetation condition prior to harvest. This composite, multi-date vegetation map will represent as near to a primary forest vegetation map for the region as one could derive from satellite imagery. Nonetheless, the boundary between mapping units may have been fragmented or altered by harvest prior to 1972. We will therefore check these boundaries against elevation, climatic, soil, topographic, and geographic limits.

In addition to the remotely sensed data, the regional level analysis will require information on the distribution of the dominant potential vegetation, soil water holding capacity and climatic variables such as monthly temperature, precipitation, and radiation. Dominant potential vegetation in the PNW will be derived from the Franklin and Dryness map (1973). Similar maps exist for the St. Petersburg region. In the PNW, regional data layers of mean monthly temperature have been generated using a model developed by Turner and Marks (1993). Monthly precipitation surfaces for the region have been generated using the PRISM model (Daly et al. 1994). Solar radiation will be predicted from a modified version of the models developed by Bonan (1988) . This PNW version is operational and has been used to predict spatial patterns of monthly direct, diffuse, and total short wave radiation at the H. J. Andrews LTER (http://www.fsl.orst.edu/lter/data/software/solarrad.htm). We will use this model to predict patterns of monthly direct, diffuse, and total short wave radiation for both regions from digital elevation models. Climatic spatial databases will also be developed for the St. Petersburg region (Kobak) from long-term climatic records of 16 stations for which we have an electronic copy of temperature, precipitation, and radiation data for the last 30 years.

For the PNW, soil water holding capacity will be determined from the Oregon and Washington state soil geographic data bases (Statsgo; Soil Conservation Service 1991). The adequacy of this soils information for our purposes will be compared with soil water holding capacity calculated from Statsgo textural properties (Rawls et al. 1982). To determine amount of uncertainty arising through compilation of Statsgo, Statsgo soil water holding capacity for two individual counties will be compared with soil water holding capacity from digitized county soil surveys upon which Statsgo was based. If Statsgo soil water holding capacity deviates considerably from the county soil-survey soil water holding capacity, we will test the application of a topographic index (Zheng et al. 1995) to adjust the Statsgo values to conform to county values. If this is approach is successful, we will apply it to the entire region. For the Russian study area, we will explore the use of the soil pit data being compiled by Dr. Chertov to predict soil water holding capacity in conjuction with existing soil texture maps. Soil drainage is an important control of production and decomposition in the St. Petersburg area. We will therefore assess the use of forest inventory maps to locate areas with excessive moisture.

Corroboration of the RegionCarb model will involve point data and spatially explicit data. Maps of site index such as that of Isaacs (1949) or new maps derived from Statsgo will be used to check the predicted regional spatial pattern of NPP. Although these maps and data bases focus on bole production, they should indicate the regional levels of productivity and the degree climate versus soils limits productivity. Similar maps will be developed for the St. Petersburg region based on the Forest Inventory database that can be used for the same types of tests. The predicted maximum C stores will be checked in the PNW against an old-growth C survey that we are currently conducting with EPA funding. During summer of 1995, we measured the C stored in trees, understory vegetation, woody detritus, and soils for 37 old-growth stands that span a wide range of climatic and soil conditions. Although old- growth stands are less common in the Russian study area, our Russian colleagues (Kobak) are compiling data that will be used to conduct similar tests.

6.3 Stand Scale. Stand scale controls on the C cycle will be explored using StandCarb, a multi-life form, stand scale model developed by Harmon et al. (1996c, Appendix). This model is best described as a hybrid between a gap succession model (e.g., Zelig; Urban & Shugart 1992) and an ecosystem process model (e.g, Century; Parton et al. 1987). The purpose of StandCarb is to explore the effects of colonization success, species succession, and disturbance severity (e.g., clear-cut versus thinning) on C sequestration. This model considers three life forms (i.e., herbs, shrubs, and trees), which grow in a stand comprised of 100-500 cells that interact through shading. The model simulates C stores in 6 live pools, 6 corresponding detritus pools, and one stable soil C pool. In addition to including three life forms, the model includes tree species succession, and allows for thinning or partial stocking of trees. The overall abiotic and biotic controls of StandCarb are similar to the RegionCarb model. Therefore the spatial databases on biogeoclimatic variables used for RegionCarb can be used to drive StandCarb. The programming and User's Manual of this model have been completed and a manuscript for Ecological Modelling is being prepared. Once corroborated, StandCarb will be used to test the effect of disturbance severity, species substitutions, and successional trajectories on C stores and fluxes. This will allow us to assess our second and third working hypotheses (see section 4.0). We will also use StandCarb to parameterize the LandCarb model.

The role of the remote sensing analysis at the stand scale will be to identify areas prone to prolonged shrub and hardwood occupancy versus those that are rapidly occupied by conifers. Distinguishing the spatial extent and location of these successional trajectories is important because both live biomass and detritus accumulation rates are highly dependent on the life forms present (i.e., herb, versus shrubs versus hardwoods versus conifers). For example, we had assumed that disturbed stands would progress to the closed canopy, conifer-dominated conditions within 20 to 40 years. Our earlier change detection research, however, indicates extensive areas of harvested forest appear to have remained in shrub-field or hardwood canopy states for an extended period (Cohen et al. in press). Preliminary analysis indicates these areas may be larger C sources to the atmosphere than originally estimated (Wallin et al. in press), but until we understand the factors controlling rates of successional development this uncertainty can not be fully addressed.

We propose to build an empirical understanding of these controls, and to develop a model that uses historical Landsat imagery to map the successional trajectory of early- successional stands. A preliminary analysis has been completed over the 6,400 ha area H.J. Andrews Experimental Forest in the Oregon Cascades as part of an MS thesis (Nesje & Cohen). Three statistically distinct successional trajectories (rapid recovery, <20 yr; expected recovery, 20 to 40 yr; and slow recovery, >40 yr) were identified by overlaying harvest date and current vegetation cover, and tracking successional development from harvest to closed canopy conifer condition using airphotos. From these data, logistic regression models were developed to predict the trajectory as a function of topographic aspect and elevation, and treatment factors such as planting and burning. Models based on biogeoclimatic and site treatment factors without inclusion of harvest date are important, because for applying these models to a broad region we cannot expect to have a comprehensive harvest date map for all disturbed stands. It is also unlikely that we will have site treatment factor data, so we need to test if land ownership can serve as a proxy for this information.

The proposed research will expand the geographic scope beyond the H.J. Andrews Experimental Forest to develop more robust models for the whole PNW region and for Russia, and will incorporate historic Landsat data. As we are capable of mapping vegetation cover over a set of successional development stages (see section 6.1), we assume that using a multitemporal, radiometrically normalized image data set we can construct temporal-spectral trajectories that are closely aligned with the successional trajectories identified by our current models. If this is true, we can use measures derived from the historic Landsat data archive as independent variables in our succession models. For stands harvested since 1972, we will have a direct observation of harvest date, and for stands harvested prior to 1972, we will have a record of spectral development for the past 25 or so years. By classifying the rate of succession on the landscape, we will then be able to assess the effect of these trajectories on C stores using the StandCarb model. This will allow us to assess our third working hypothesis (see section 4.0). The spatial data layers generated by this analysis will also be used to stratify the biomass accumulation rates required by the LandCarb model. By comparing the observed rates of succession to each of the successional trajectory classes, we will test the sensitivity of the landscape level behavior to uncertainty generated at the stand level in both regions.

Corroboration of the StandCarb model will use a number of existing databases that describe successional and spatial trends in C stores. Although we will first focus on testing StandCarb in the PNW, similar sets of data exist for the St. Petersburg region to use in similar corroboration tests. In the PNW, we will compare live C stores gathered from three sets of permanent plots to those predicted by the model. In this and the other tests, we will run the StandCarb model using the regional data bases on temperature, precipitation, radiation, and soil water holding capacity. Time series data exist for nine coastal Tsuga heterophylla/Picea sitchensis stands (60 years of observation), 30 Pseudotsuga menziesii stands (50-70 years of observation), and 8 higher elevation Abies procera stands (20 years of observation). Measurements on tree mass and mortality have been conducted at 5 years intervals over these periods of observation (Franklin & DeBell 1988, Harcombe et al. 1990, Greene et al. 1992). Many of these stands also have woody detritus measurements for the last observation period that can be used to test the detritus predictions. A second dataset that can be used to test StandCarb is a chronosequence of Pseudotsuga menziesii and Tsuga heterophylla stands that covers a range of 70-1000 years of age (Spies et al. 1988). The third set of data that can be used to test StandCarb is a one time sample of Pseudotsuga menziesii stands that were disturbed by fire 50 to 70 years ago (Acker et al. 1994). In each of these areas, data on live and dead wood biomass have been recorded with the purpose of comparing locations with complete forest destruction to partial forest destruction. The final set of data will be used to test the accumulation rates of C during the early stages of succession. These live biomass data exist for several clear-cut watersheds at the H. J. Andrews Experimental Forest and have periodic measurements every 2 to 3 years over a 20 to 30 year observation period (Halpern 1989). Each of these sets of data has not been used to parameterize StandCarb, and will therefore independently test different aspects of the model behavior.

6.4 Regional Analysis and Comparisons. In addition to meeting our objective of assessing C stores and fluxes our project will serve as the basis of other assessments. Once we have performed sensitivity analysis and corroborated the predictions of the separate system components described above, we will examine how uncertainty propagates in the overall analysis system. This overall sensitivity analysis will be performed by identifying the parameters that the component models are most sensitive to and for which the largest uncertainty exists. Model parameters with large uncertainty for which the model is not sensitive or parameters with a great deal of certainty but for which there is a large sensitivity would be of secondary importance. Once these parameters have been identified, we will vary these parameters within their expected range of uncertainty to generate an envelope of uncertainty for the overall analysis. A complementary approach will be to modify these model parameters to the point where the overall behavior of the system is changed. In the case of the PNW this will mean modifying these parameters until the source is reduced to a sink. In the case of NW Russia this will mean modifying the parameters until the sink is converted to a source. One can then assess the degree these parameter changes fall within the expected uncertainty and hence determine the degree of confidence the direction of C flux is estimated correctly.

Our analysis would also include a comparison of future scenarios of regional development for the next 25 years as a way to evaluate our first working hypothesis. Projecting current trends in harvest rates and management treatments (planting and thinning) would constitute the base-case. We would then, modify the rate of harvesting, thinning, and planting success by a factor of 2 and compare the results of these scenarios to the base-case in terms of C stores and economic implications. We will also compare the overall "inertia" of these two systems to change in C sequestration by modifying the driving variables until the system behavior switches (this is distinct from the modification of parameters described in the paragraph above). For example, we will modify the rates of timber harvest, conversion of forest land to agriculture or urban use, rates of succession, and underlying biogeoclimatic factors (e.g., increased or decreased drainage in NW Russia) until PNW switches from a source to a sink and vice versa for northwestern Russia. This will identify the magnitude of change required to alter the system from a source to a sink, or a sink to a source. We can then assess the economic and policy implications of these changes to determine the degree they are reasonable alternative futures.

Concurrent with testing for system "inertia", we will analyze the economic consequence of changing harvest rates and other management treatments (i.e., planting, precommercial thinning, commercial thinning). Each simulated change entails a cost of implementation as well as changes in the quantity, quality (e.g., species composition), and timing of forest harvests. These variations in turn affect the supply of lumber, plywood, and pulp and paper. By incorporating these supply changes into the forest product market models, increases or decreases in economic surpluses (net of treatment costs) can be calculated. We will change treatment levels incrementally and match carbon storage consequences with the associated economic consequences. This will allow us to generate schedules of the marginal cost of carbon storage for each type and location (PNW versus Russia) of treatment. Similar schedules of marginal costs can be generated for changes in the efficiency of the forest products industry, especially in Russia. The final result will be calculations of the relative efficacy of various management options and improvements in processing efficiency by level and location.

7.0 Potential End Users

Our proposed project has a number of potential users. First, the data on land use change itself would be a valuable resource for assessments of potential habitat of organisms and effects of forest fragmentation. Second, our system, in combination with field checking, would be more efficient than the current Russian forest inventory which relies on ground survey of all stands. Our system would also complement the US forest surveys, which are not complete in aerial coverage or C pools. Our system may also form the basis of future regional assessments conducted by countries or states to determine the current flux of

C (Appendix). Finally, Working Group III of the International Panel on Climate Change has recently agreed that economic cost benefit analysis can help guide decision makers intent on global agreements to manage carbon emmissions (www.enep.ch/ipcc/ipcc-0.html). Our calculations of relative marginal costs of carbon storage by treatment type, level, and location may be useful in choosing the least costly regional and global policies to manage carbon stores.

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ANNUAL REPORTS

General Progress 1997-98

Our general progress has been excellent over the last year. Funding for the project was received officially in September 1997. However, in anticipation of these funds we continued to make trips to Russia, have planning sessions, and to answer methodological questions that underlie our work. This has resulted in a total of 8 publications and 3 manuscripts, mostly in the area of remote sensing. In the next year we expect the balance to move more toward carbon and economic analyzes.

The overall strategy outlined in our proposal is working, although whenever we can improve a method or make it more efficient we take the opportunity. This is particularly true for the remote sensing project as the amount of data processing is extremely large. Communication between the Corvallis and Bellingham PI's has been very good, in part because we have held quarterly meetings. It has proven more difficult to keep close contact with our Russian colleagues, but we manage to maintain weekly to monthly communication with our main collaborator, Dr. Treyfeld. In summary, we see no major problems ahead and anticipate making more excellent progress in the upcoming year.

Remote Sensing

Western Oregon Land Cover Mapping. Recent remote sensing activity has been focused on the TM-based mapping of land cover in western Oregon. Our approach builds upon previous efforts, but has been adapted and refined to yield more information and to address the problems inherent in regional scale, multi-scene mapping. Portions of nine TM scenes from 1988 were used in the mapping effort (Figure 1).

A combination of unsupervised classification and GIS mapping was used to develop a first level classification of the study area (Figure 2). Pixels within the forest class were then modeled in a continuous fashion to produce estimates of the following vegetation attributes: 1) percent green vegetation cover, 2) percent conifer cover, and 3) visible crown diameter of conifers (in areas with 70-100% conifer cover). The fourth and final attribute, conifer age (also in areas with 70-100% conifer cover), is currently in process. The predictive equations were developed using regression techniques with air photo or ground survey data serving as a reference. Figures 4 to 6 illustrate the databases developed for green vegetation, conifer cover, and conifer size. The problem of differing radiometric properties between scenes was ameliorated by an applied normalization process. For any given vegetation attribute, the predicted values from a source scene were used to "train" the spectra of an adjacent destination scene. This results in a new predictive model with slope and intercept parameters adjusted to calibrate the destination scene predictions. Between-scene diagnostics, combined scene independent validation, and seamless map products demonstrate the effectiveness of the procedure. Completion of the western Oregon land cover mapping is slated for early May, and a manuscript documenting the process is in the draft stages.

Western Oregon Disturbance Mapping. Earlier work produced a stand replacement disturbance map for the periods 1972-77, 1977-84, 1984-88, and 1988-91 for western Oregon. Using the same techniques (Cohen et al., 1998), the 1991-1995 period has recently been added to the disturbance map (Figure 7). The map indicates the different locations of disturbances (fires are in the south) as well as the pattern of land ownership (clustered harvest on private and State lands versus diffuse cutting on Federal lands). Additionally, a new accuracy assessment for the map has been completed.

Data Acquisition for Western Washington and Northwestern Russia. Eighteen TM scenes and three MSS scenes have been ordered to complete the spatial and temporal coverage necessary for remote sensing activities in western Washington and northwestern Russia. Forest inventory polygons have been acquired for Russia to use as ground reference. An example of the Russian inventory data registered to TM imagery appears in Figure 8. A framework for reference data collection in Washington has been established, and these data will be acquired during the summer months of 1998.

Rates of Succession. Dr. Cohen is major advisor to a Ph.D. student (Yang Zhiqiang) who will be examining the extent and causes of variations in the rates of succession in the Pacific Northwest. This subproject will concentration on the Willamette basin, the largest in the study area. Photointerpretation will used to estimate the cover of major cover types (e.g., shrubs, hardwoods, and conifers) and the rate of change over the last 50 years. Rates of succession between the cover types will then be correlated to physical features and site treatment.

Carbon Modeling

Stand Level Modeling. In the past year, two manuscripts on carbon modeling have been completed. The first, which describes our stand level carbon model (STANDCARB), has been submitted to Ecological Modelling. The second, which describes the effects of various sylvicultural treatments is awaiting final revisions before submission to Ecological Applications. Two major conclusions come from the latter work:

1) increasing the length of time between harvests is the most important factor increasing carbon stores in the ecosystem (Figure 9 and 10). Interestingly, increasing the rotation length up to 90 years also increases the stores of forest products, indicating that society can continue to have forest products needs met while carbon sequestration in forest regions increases.

2) the intensive harvesting and site preparation methods currently in use greatly decrease the ability of the ecosystem to store carbon. As with increasing rotation length, some of the less intensive sylvicultural systems also produce more forest products than the intensive ones (Figure 11).

In addition to publishing past work, we are revising the STANDCARB model to include a number of new silvicultural treatments (selective cutting of species, herbiciding, timber salvage) and hypotheses on ecosystem controls. Perhaps the most important control we have added is a hydraulic limitation linked to tree height. We found that the initial version of STANDCARB overestimated old-growth biomass. By means of sensitivity analysis we eliminated all other possibilities such as increased autotrophic respiration and mortality; these parameters have to be increased far beyond the observed values to put old-growth biomass at the correct level. While we consider the hydraulic limitation a working hypothesis at this point, it does allow the model to more reasonably predict old-growth biomass than the initial version. In cooperation with a graduate student, Michele Pruyn, we are continuing to perform sensitivity analysis on the STANDCARB model. Michele will also examine many of the assumptions the model uses to predict autotrophic respiration including the variation among species, ages, and positions within the tree stems.

Potential Maximum Carbon Stores. Warren Cohen and Mark Harmon are co-major professors for a PhD student (Erica Hoffa) that is examining how to predict the maximum carbon stores as a function of climate, soils, and producer species. At this point we are prototyping a very simple model on a spreadsheet. We hope to start programming the full spatial model this summer. Another area we are exploring with Erica is how predicting carbon dynamics at the regional level could be simplified. Scaling our stand level results to the landscape level has given us some new insights that we plan to explore in the next year. Our approach will to use the disturbance/land-use regime within a landscape to help modify the maximum values predicted without disturbance. If we can achieve this goal, it might be possible to use the work at broader scales (the pattern of NPP globally) in combination with regional disturbance/land-use regimes to predict current trends globally.

Soil Stores of Carbon. The use of soil spatial data bases in this project to provide information about soil carbon and soil water holding capacity is contingent upon the validity of the data bases. In the publication “Regional Soil Organic Carbon Storage Estimates for Western Oregon by Multiple

Approaches" (Homann et al., 1998, in press), we compared six approaches of estimating soil organic C (kg C m-2, not including the surface organic horizon; hereafter called soil C) and its spatial pattern in the mountainous, largely forested western Oregon region. The approaches were (i) Natural Resources Conservation Service (NRCS) pedons, (ii) other pedons, (iii) the State Soil Geographic Data Base (STATSGO), (iv) the United Nations Soil Map of the World, (v) the National Soil Geographic Data Base, and (vi) an ecosystem-complex map. Agreement between approaches varied with scale. For the entire region (~105 km2), estimates of average soil C varied from 4.3 to 6.8 kg C m-2 for the 0- to 20-cm depth and from 12.1 to 16.9 kg C m-2 for the 0- to 100-cm depth. At the subregional scale (~104 km2), all approaches indicated higher soil C in the coastal area than in the inland southern area, but relative amounts in other subregions varied among the approaches. At the subsubregional scale (~103 km2), soil C was consistent between individual STATSGO map units and NRCS pedons within those map units, but there was less agreement with other pedons. Lack of perfect agreement indicates uncertainty in the distribution of soil properties across regions, but the general consistency among approaches suggests that the STATSGO data base is an adequate source of soil spatial information for this project. STATSGO represents the most detailed basis for spatially weighting soil attribute information for regions of the USA.

Economic Analysis

Silvicultural Treatments. We are still in the preliminary stages concerning economic analysis, but that is quite appropriate at this point. Joe Kerkvliet and Mark Harmon have been collaborating to adapt the existing carbon models so they produce economically meaningful output. Thus far we have concentrated on the STANDCARB model with the aim of producing information on the number, size, and volume of individual species harvested. This in combination with the monetary value of certain types of wood and the cost of various silvicultural treatments should allow us to examine which treatments are cost effective.

The Substitution Question. Another area we plan to explore is the carbon trade-off in substituting steel, concrete, and other non-wood material for forest products. Current analysis by Perez-Garcia and Oliver from the University of Washington suggests that more carbon is released by using non-wood materials. Their analysis has a number of questionable assumptions concerning the longevity different materials (concrete lasts longer than wood), the energy costs associated with manufacture (they used 1970's values) as well as the extraction and transportation (these were not counted). We plan to reanalyze this question in the next year as it has very important implications for how the forest sector relates to the overall industrial balance of carbon.

Russian Collaboration

In June of 1997 Joe Kerkvliet and Mark Harmon met with the Russian collaborators in St. Petersburg. Unfortunately Olga Krankina was not able to attend because of visa problems. The most significant new progress was on the economic front as we established a collaboration with Dr. Gresnov, an economist at the St. Petersburg Forest Academy. We are currently working out a formal agreement between the St. Petersburg Forest Academy and Oregon State University that will allow access to forestry related economics data from Russia. Our interactions with the rest of our Russian colleagues mostly involved the continued development of book chapters describing the climate, forests, soils, peatlands, and forest products of the St. Petersburg region.

Three of us (Harmon, Krankina, and Kerkvliet) will return to St. Petersburg this summer to continue our meetings on the Russian part of the project. We expect to start making significant progress in this region on the remote sensing front in the next year. In addition to these plans, we are hoping to secure funding from NSF to host a workshop in Corvallis to conclude the first phase of the collaborative effort. We hope to synthesize these results in a book, hopefully in the LTER series being published by Oxford Press.

Publications Resulting from LCLUC-0018, Grant# NAG5-6242

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RELATED WEB SITES

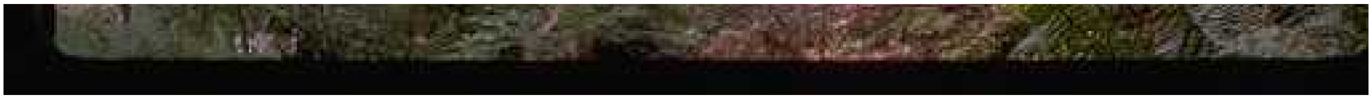
- NASA's Land-Cover Land-Use Change Program
- Pacific Northwest: Regional Carbon Stores
- Pacific Northwest: Land-Cover Land-Use Change

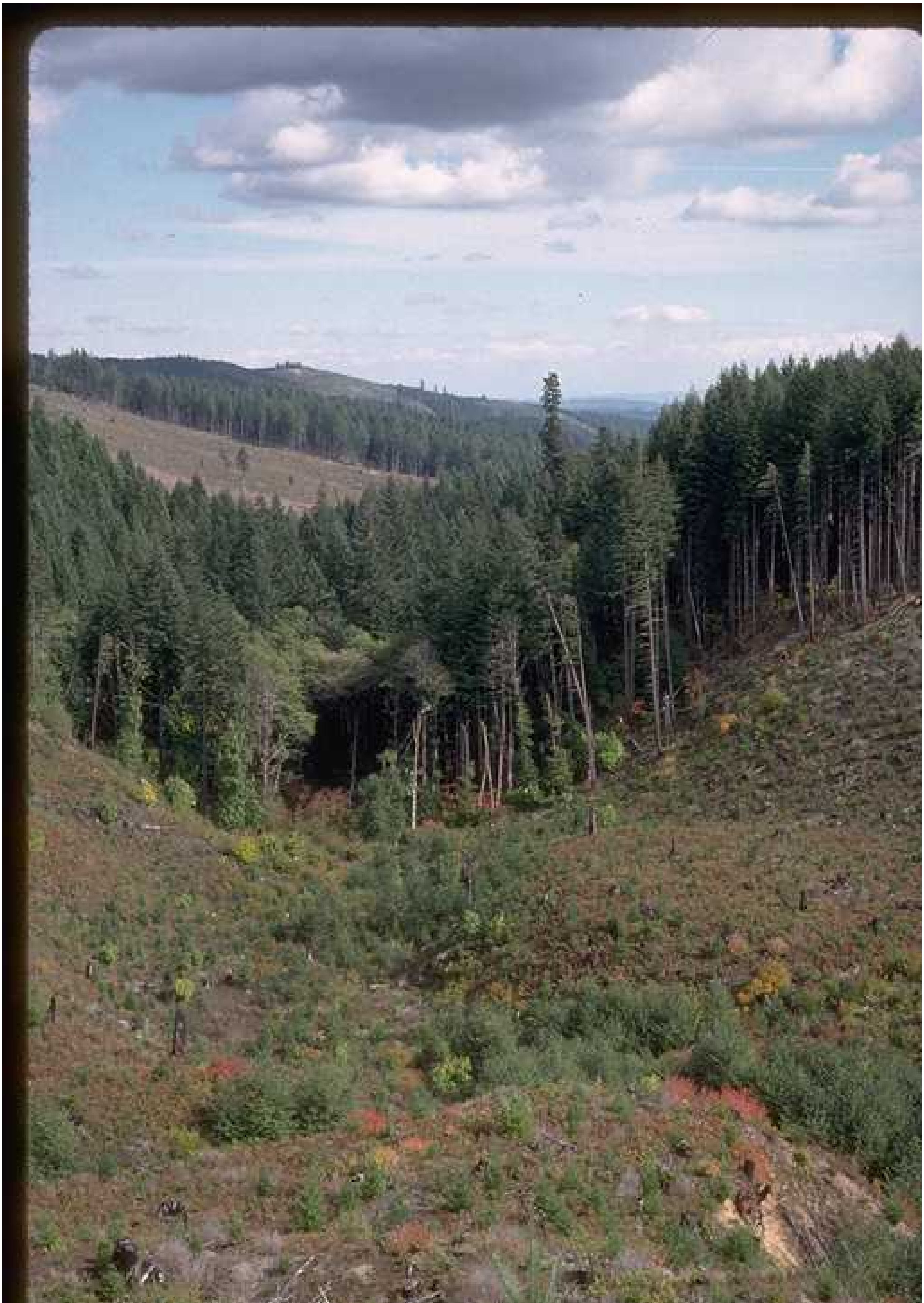
ACKNOWLEDGEMENTS

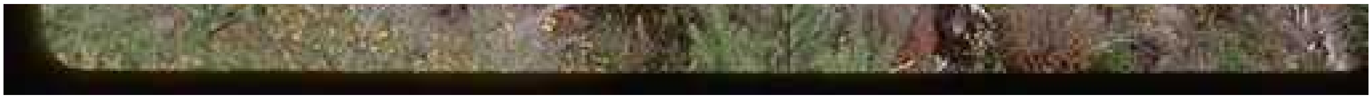
This research being funded in part from NASA Earth Science by grant # NAG5-6242 as part of the Land

Cover-Land -Use Change Program.


FMC







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Professional Interests/Activities:

General Interests:

Forest ecology

Andrews LTER Component Study Areas:

VEG
CAR
DIS

Andrews LTER Regionalization Study Areas:

Carbon Stores

Vegetation Succession

Current Projects:

Predicting woody detritus dynamics in forests

Assessing the impact of forest practices of carbon stores of forests

Long-term decomposition dynamics of leaf and root litter

Intersite LTER/International Activities:

Long-Term Intersite Decomposition Experiment Team

Comparison of carbon stores in two conifer ecosystems: PNW and NW Russia

Representative Publications:

- Harmon, Mark E.; Ferrell, William K.; Franklin, Jerry F. 1990. Effects on carbon storage of conversion of old-growth forests to young forests. Science. 247: 699-702.
- Harmon, Mark E.; Garman, Steven L.; Ferrell, William K. 1996. Modeling historical patterns of tree utilization in the Pacific Northwest: carbon sequestration implications. Ecological Applications. 6(2): 641-652.
- Harmon, Mark E.; Sexton, Jay. 1995. Water balance of conifer logs in early stages of decomposition. Plant and Soil. 172: 141-152.

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Principle Collaborators:

Professional Interests/Activities:

General Interests:

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Andrews LTER Component Study Areas:

VEG
CAR
DIS

Andrews LTER Regionalization Study Areas:

Disturbance

Carbon Stores

Intersite LTER/International Activities:

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BS, 1977, Forest Management, St. Petersburg Forest Academy,St. Petersburg, Russia

Roles/Affiliations:

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SAF

Principle Collaborators:

Mark E. Harmon, Warren B. Cohen

Professional Interests/Activities:

General Interests:

Forest management, forest ecology, woody detritus, carbon cycling, Russian forestry, non-timber forest products

Andrews LTER Component Study Areas:

VEG
CAR

Andrews LTER Regionalization Study Areas:

Vegetation Succession

Current Projects:

Carbon accumulation, storage, and release by woody detritus in the forests of Russia

Intersite LTER/International Activities:

Collaboration with St. Petersburg Forest Academy, Komarov Botanical Institute, State Hydrological Institute (all in St. Petersburg, Russia)

Representative Publications:

- Krankina, O. N.; Harmon, M. E. 1995. Dynamics of the dead wood carbon pool in northwestern Russian boreal forests. Water, Air and Soil Pollution. 82: 227-238.

Personal Stats:

Hometown: St. Petersburg, Russia

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Background Information

David O. Wallin received degrees in biology from Juniata College (B.S.; 1978) and the College of William and Mary (M.A.; 1982) and a degree in environmental sciences from the University of Virginia (Ph.D.; 1990). Between 1990 and 1995, he worked as a Research Associate and Research Assistant Professor in the Department of Forest Sciences at Oregon State University. Dr. Wallin's research focuses on the regional-scale study of land-use effects on the structure and function of forest ecosystems. His work is heavily dependent on the use of simulation models and satellite remote sensing. Retrospective studies have involved the use of fire history data to reconstruct landscape structure prior to European settlement. These results provide a useful frame of reference for evaluating current landscape structure and conditions that might be generated by alternative future management scenarios. He is also involved in studies that use satellite remote sensing to document changes in the structure of Pacific Northwest forests since 1972. The synoptic overview provided by these satellite data makes it possible to quantify differences in forest structure on both public and private lands. Dr. Wallin and his colleagues have developed a series of models that use these satellite data to evaluate the consequences of forest change for vertebrate diversity and the regional carbon budget. He is also involved in comparative studies of land-use effects on forest structure in other parts of the world.

Teaching

ENVR 325 Fundamentals of Ecology
ENVR 407/507 Terrestrial Ecology
ENVR 435a/535a Landscape Ecology
ENVR 497b/597b Landscape Ecology Lab
ENVR & GEOL 442/542_Introduction to Remote Sensing
ENVR 599 Ecosystem Management Seminar

Selected Publications

Wallin, D.O., Harmon, M.E., Cohen, W.B., Fiorella, M. and Ferrell, W.K. 1996a. Use of remote sensing to model land use effects on carbon flux in forests of the Pacific Northwest, USA. -- Pages 219-237 In: Gholz, H.L., Nakane, K. and Shimoda, H. (eds). The use of remote sensing in the modeling of forest productivity at scales from the stand to the globe. Kluwer Academic Publishers, Dordrecht, The Netherlands. ISBN 0- 7923-4278-X

Wallin, D.O., F.J. Swanson, B. Marks, J. Kertis and J. Cissel. 1996b. Comparison of managed and pre-settlement landscape dynamics in forests of the Pacific Northwest, U.S.A.. Forest Ecology and Management 85:291- 310.

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Wallin, D.O., C.C.H. Elliott, H.H. Shugart, C.J. Tucker and F. Wilhelmi. 1992. Satellite remote sensing of breeding habitat for an African weaver-bird. Landscape Ecology 7(2):87-99.

Ongoing Research

A variety of research projects are currently underway in my Spatial Analysis and Landscape Ecology Lab

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H.J. Andrews Formats Catalog

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ML01

HARVEST model

- **PI: Harmon, Mark**
- **Dates of study: -**
- **Other researchers: Garman,Steve**

```
STUDY PURPOSE/GOALS:                                FULL ABSTRACT
  This model, called HARVEST, predicts the mass of woody debris
  left after timber harvest in Pacific Northwest forests.  Inputs
  to the model include the species, diameter and age distribution
  of trees, the minimum tree size to be harvested, the minimum top
  diameter, stump height, and slope steepness.  Model output
  includes the absolute and proportion of bole biomass removed as
  well as that left as stumps, tops, breakage, and decay.  The
  model also predicts the biomass of non-merchantable parts such as
  branches, coarse roots and fine roots left after harvest.  The
  model was used to predict changes in the biomass left after
  harvest in Pacific Northwest forests from 1920 to the present
  (Harmon et al. in review).


Format Titles
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1  Biomass regression coefficients              FILE FORMAT
   (massin.tab)
2  Stump, decay and breakage parameters         FILE FORMAT
   (params.tab)
3  Chapman-Richards height-dbh coefficients     FILE FORMAT
   (richina.tab)
4  Kozak taper coefficients (taperou.tab)       FILE FORMAT
5  List of possible species (species.tab)       FILE FORMAT
6  Stand data                                   FILE FORMAT
7  Final output file                            FILE FORMAT
```

feedback.txt - file containing comments by users of the data

TOP of PAGE	**Contact our** Data Manager	LTER Network Office
Andrews HOMEPAGE	**Maintained by** Webmaster	**Last Modified:** *04/29/99*

About the Solar Radiation Model. This model estimates the solar radiation input to a site based on its latitude, elevation, aspect, slope, and cloud cover. The effects of topographic shading are not included in this version of these programs. The first program, SolarRad, is used for a single location. The second program, SolarImg, is used for a multiple locations in a grid . Both programs are coded in C and can be used either in a DOS or a UNIX environment.

These programs have several potential uses. The first is to supply estimates of solar radiation required to run simulation models (Urban 1993, Harmon et al. in review). The second is to combine with other climatic data such as temperature to estimate other climatic variables such as Potential Evapotranspiration (Jensen and Haise 1963). The sun angle data can also be used to determine the effect of topographic shading, the passage of light through canopies (Urban 1993) or the effects of one patch of trees on another (Harmon et al in review).

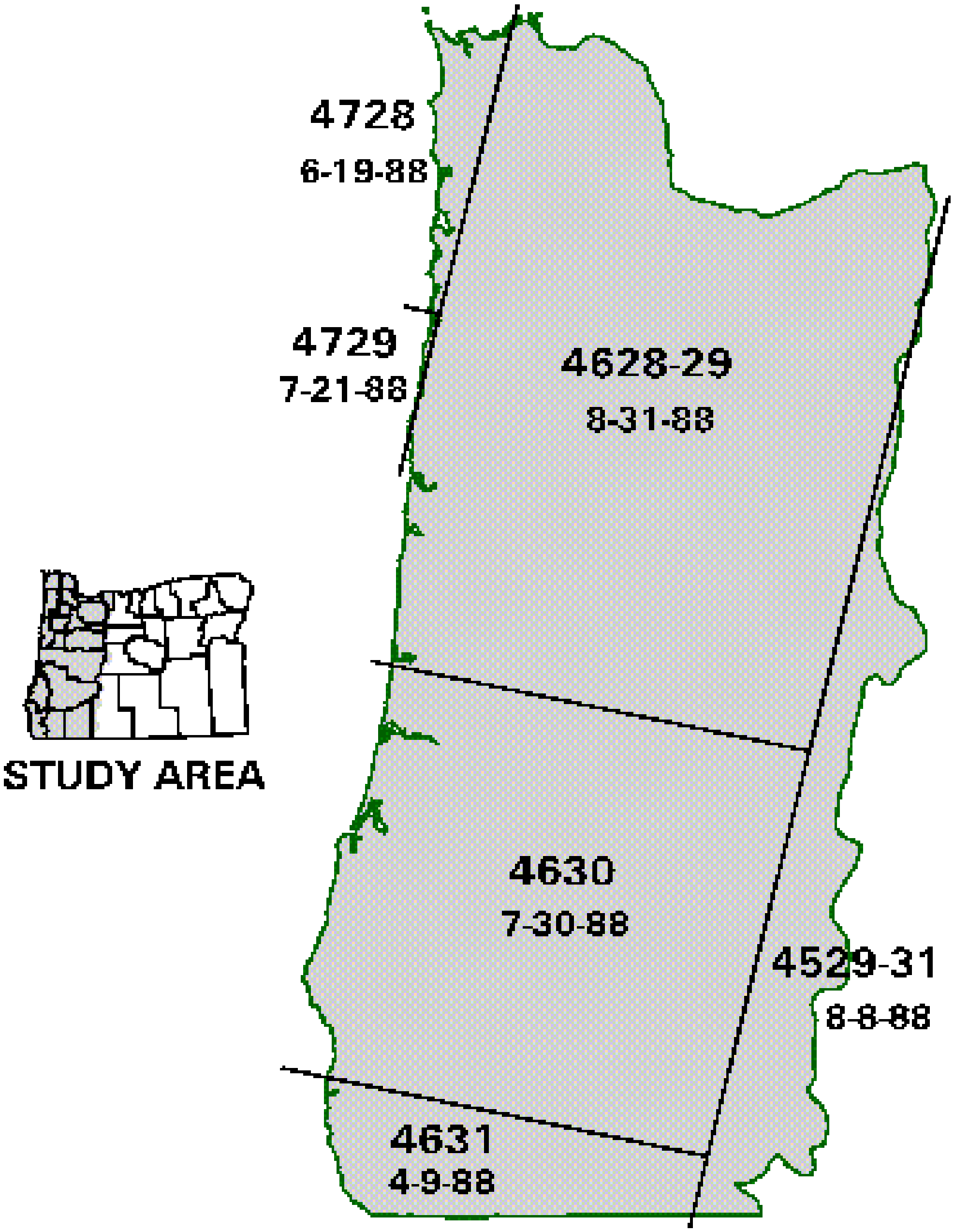
Sample products:

- Average Daily Beam Radiation
- Average Daily Total Radiation

Full documentation and source code is available on line. For more information contact Mark Harmon.

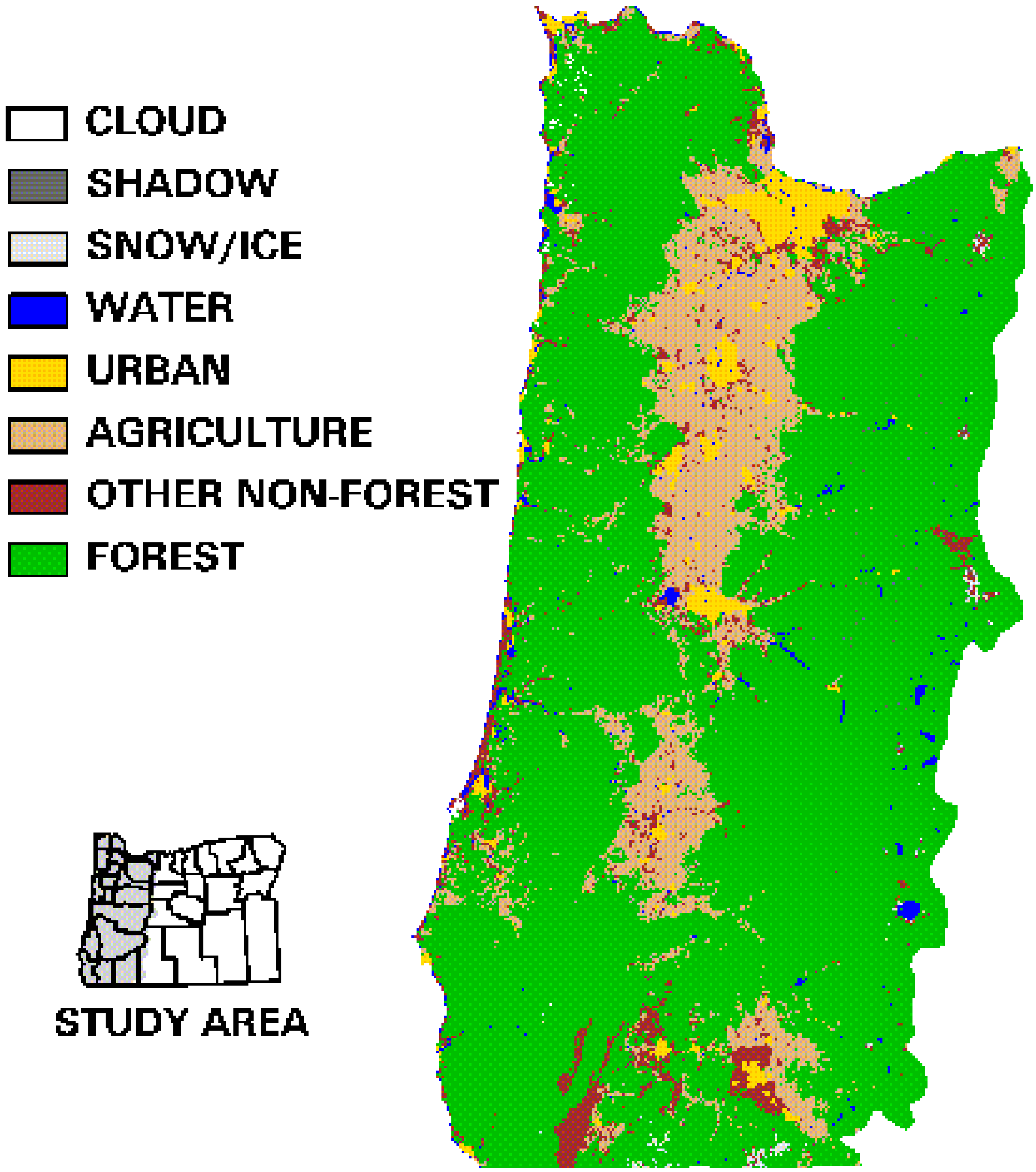
1988 WESTERN OREGON LAND COVER

LANDSAT TM SCENES

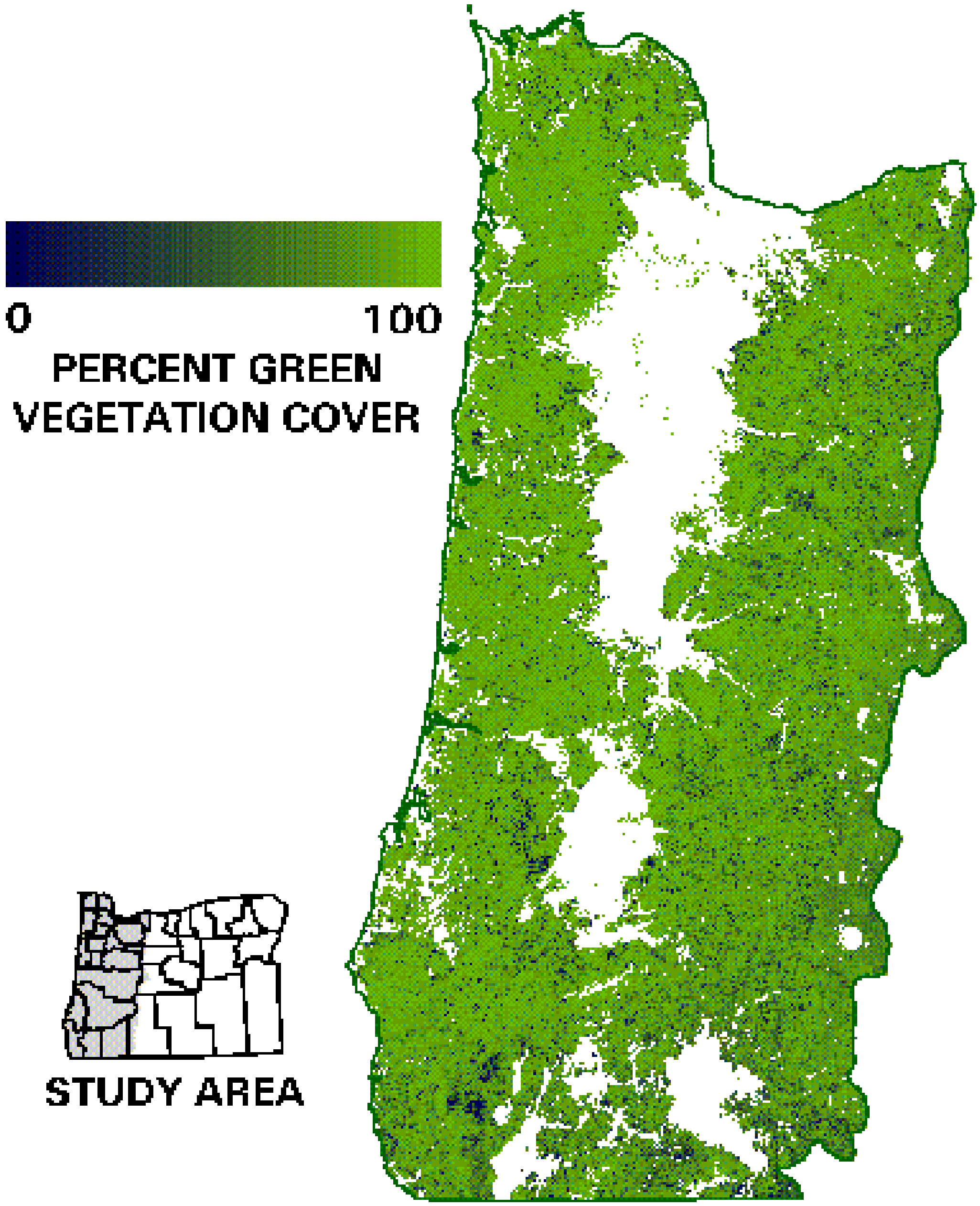


1988 WESTERN OREGON LAND COVER

FIRST LEVEL CLASSIFICATION

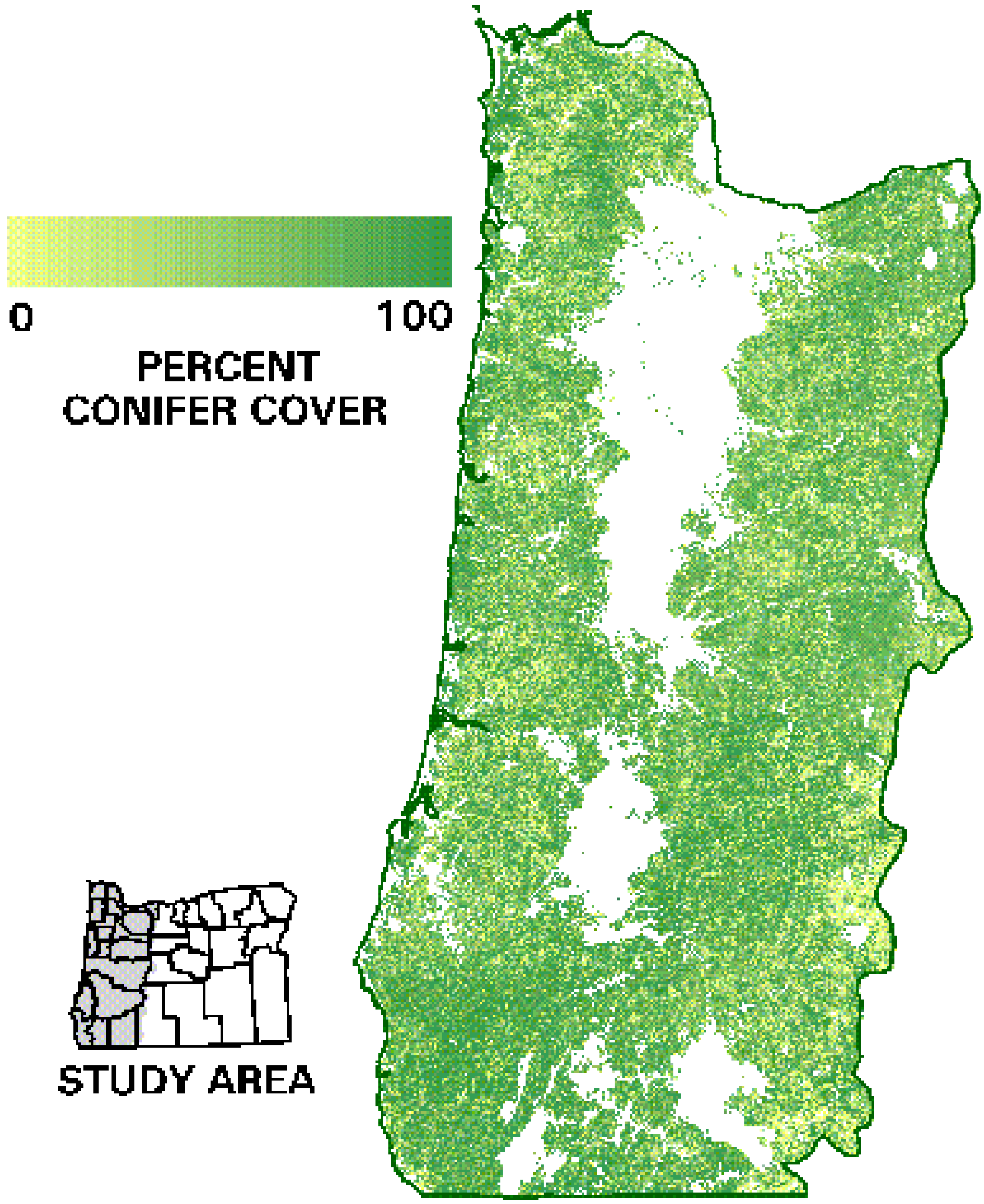


1988 WESTERN OREGON LAND COVER
PERCENT GREEN VEGETATION COVER

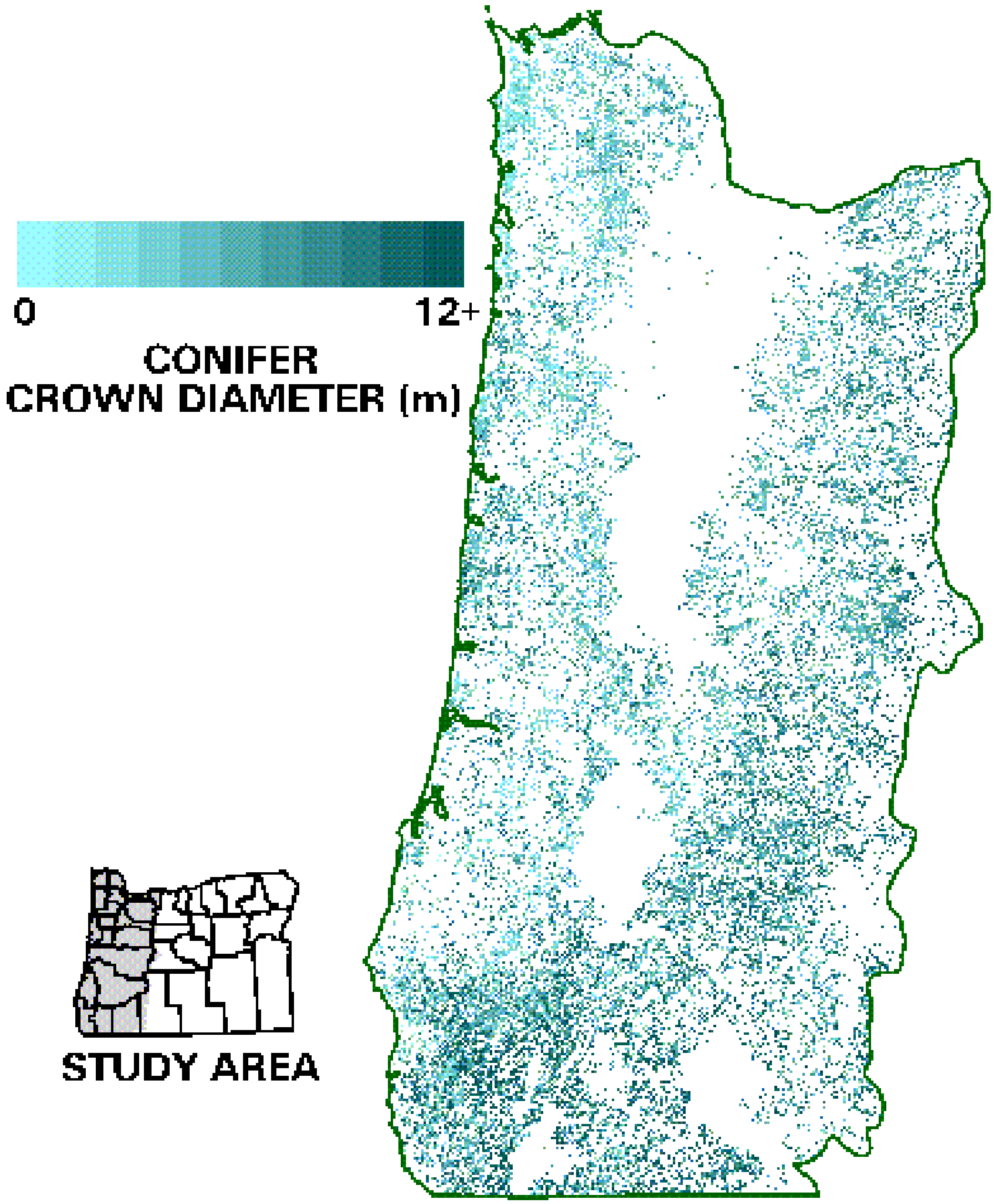


1988 WESTERN OREGON LAND COVER

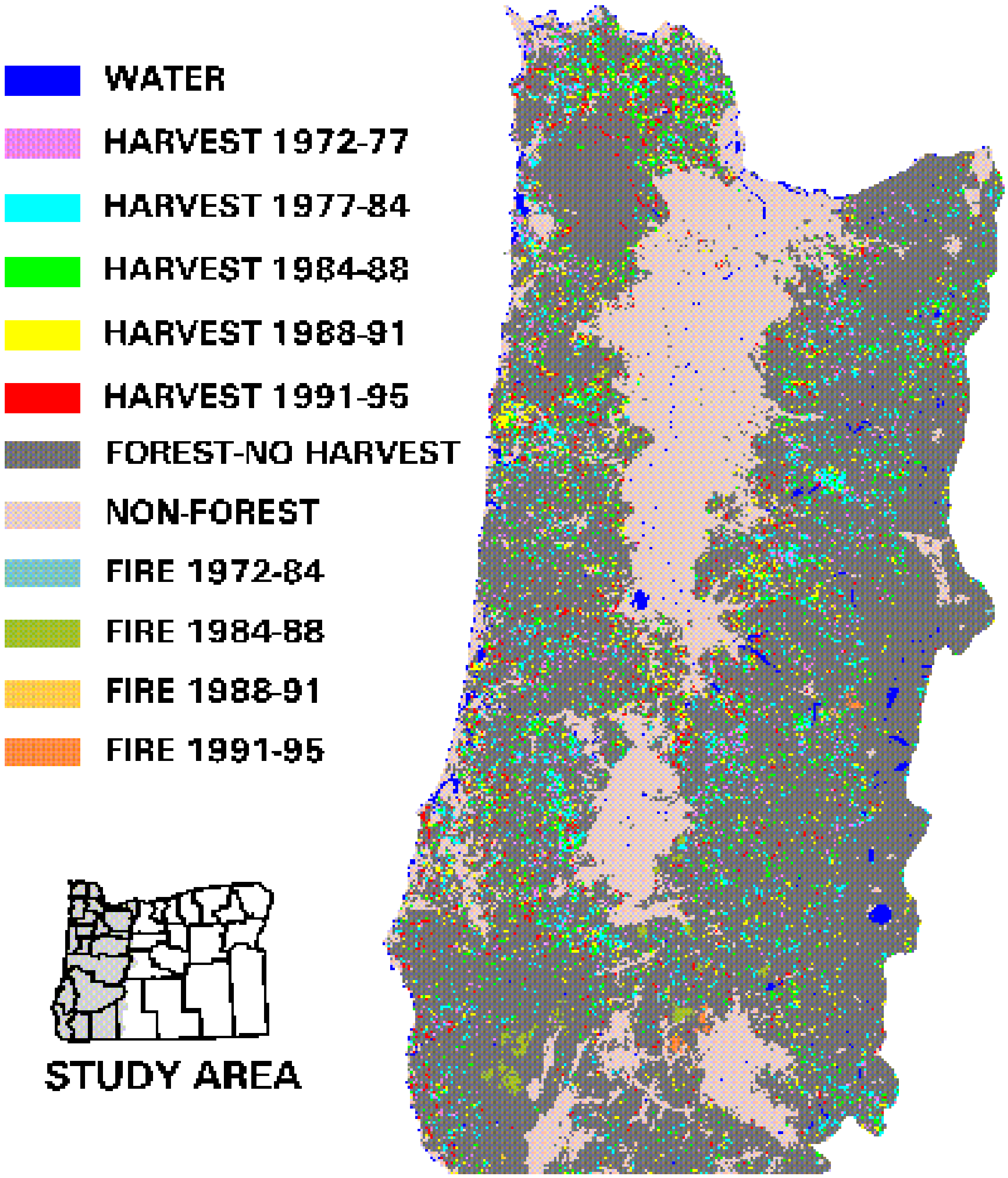
PERCENT CONIFER COVER



1988 WESTERN OREGON LAND COVER
CONIFER SIZE
(IN AREAS WITH 70-100% CONIFER COVER)



STAND REPLACEMENT DISTURBANCE WITHIN WESTERN OREGON: 1972-1995



Land
Cover
Land
Use
Change

LCLUC is an interdisciplinary scientific theme within NASA s Earth Science Enterprise (ESE). The ultimate vision of this program is to develop the capability to perform repeated global inventories of land-use and land-cover from space, to develop the scientific understanding and models necessary to simulate the processes taking place, and evaluate the consequences of observed and predicted changes. The underlying philosophy of the ESE LCLUC Program is to further the understanding of the consequences of land-use and land-cover changes for continued provision of ecological goods and services.

For descriptions of LCLUC studies, click here

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Proposals due September 29, 1999

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Carbon Dynamics in the Pacific Northwest Region

Mark E. Harmon

Introduction

We have been examining the C dynamics of the Pacific Northwest, USA (PNW) since 1990. The PNW is important because its potential to store C per unit area is several times higher than the global average. Thus its smaller aerial extent is offset by greater C density per unit area (Harmon et al. 1990). At the same time, the PNW is also a major region for timber production, a disturbance that has the potential to decrease C stores by almost an order of magnitude (Krankina & Harmon 1994).

Our main objective in this work is to examine the major factors controlling the spatial and temporal patterns of C stores and fluxes within the PNW. This includes the living and the so- called "dead" part of the ecosystem (i.e., detritus and soils) as well as the C utilized by humans (i.e., lumber, paper). Our specific objectives are: 1. Link remotely sensed and ground-based biogeoclimatic data to ecosystem models at three spatial scales (region, landscape, and stand) in an analysis system that predicts changes in regional C stores. 2. Assess the major uncertainties introduced into the analysis and evaluate how those uncertainties propagate during the integration of scales. 3. Use this analysis system to assess the changes in C stores over the last 25 years.

Spatial and Temporal Extent

Our work in the past 5 years has been conducted on the 1.2 million ha central Cascades study area. This area was used to develop our overall analysis strategy and rigorously test the remote sensing approaches used. We are currently attempting to expand this analysis to the entire area of forest land west of the Cascade Crest in Oregon and Washington (10 million ha). The spatial resolution of this work is approximately 0.08 ha or the pixel size of Thematic Mapper (TM) imagery. Our analysis has emphasized the last 25 years of land-use, largely because that is the period for which satellite imagery is available. Temporal resolution of the analysis is restricted by the availability of TM; we examine land-use change on a 4-5 year interval, but in principle an annual interval could be used.

Justification

One of the most important questions facing ecologists today is the role of the biota in the global carbon (C) cycle. The fact that 1-3 Pg year-1 of the annual fossil fuel C release can not be accounted for raises questions about our current understanding of this cycle. Our project addresses several shortcomings of past regional analyses. First, by using remotely sensed and spatial biogeoclimatic data we can develop estimates that are spatially explicit, complete, and not overlapping. Second, we have made great efforts to consider all the components that store C including all live plant parts above- and belowground, all forms of detritus (including coarse woody debris), stable forms of soil C, and forest products. Third, our project is testing a methodology to corroborate predictions and reduce the uncertainty of regional C fluxes by integrating satellite imagery, ground data, written records of forest product use, and models at several spatial scales using a hierarchical approach.

History of Project

This project started in 1992 when a team of LTER and Forest Service scientists with a combination of NASA Terrestrial Ecology Program, USDA Forest Service, and NSF-LTER funding began developing a hierarchical analysis system to assess the effects of forest management on C dynamics in western Oregon (Cohen et al. 1992, 1994, Wallin et al. in press) In 1994 we began a NSF funded collaboration between Oregon State University, USDA Forest Service, the St. Petersburg Hydrological Institute, Komarov Botanical Institute, St. Petersburg Forestry Academy, and the Russian Forest Inventory to compare the carbon dynamics of the PNW to northwest Russia.

Participants

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Olga N. Krankina, Department of Forest Science
Barbara Marks, Department of Forest Science
Art McKee, Department of Forest Science
Phil Sollins, Department of Forest Science
David Turner, Department of Forest Science
David O. Wallin, Western Washington University

Basic Approach

For the purposes of this project we have defined three nested scales of interest: stand, landscape, and regional. Our landscape analysis is linked to the regional scale by "looking upward" to determine the degree biogeoclimatic factors (temperature, precipitation, radiation, soil water holding capacity, and potential vegetation) determine maximum potential stores of C, as well as production and decomposition rates. The landscape scale analysis is linked to the stand scale by "looking downward" to examine how species mixtures, physiognomic form, and management actions (e.g., planting, thinning) influence the rate C accumulation occurs over succession.

At the landscape level, we use the LandCarb model to reconstruct the effects of the past natural fire cycle, insect outbreaks, and observed land-use patterns on C flux over the last 25 years. Remote sensing plays a key role in generating the spatial databases on land cover and land-use change needed to integrate C stores estimated from the LandCarb model. LandCarb is linked to the two other scales because the maximum potential biomass for a given location is determined by the RegionCarb model, while rates of increase over time are determined by the StandCarb model. Another model, Harvest, is used to predict the mass of detritus left after timber harvest based on utilization standards, species, tree age and size (Harmon et al. 1996a) To complete C flux estimates, we account for the C stored in forest products using the model ForProd (Harmon et al. 1996b). This model tracks the fate of harvested C through manufacturing, use, and disposal as 6 pools (paper, mulch, short-term structures, long-term structures, dumps, and landfills).

At the regional scale, we are developing a model called RegionCarb to estimate the effects of radiation, temperature, water balance, physiognomic structure, and species on the maximum potential stores of live and dead C (i.e., in the absence of disturbance). The constraints of radiation, temperature, water balance, physiognomic structure, and species on production and decomposition are similar between RegionCarb and StandCarb. The main distinction is that while StandCarb examines transient changes during succession, RegionCarb only considers the steady-state condition of undisturbed vegetation. We are also using the Statsgo database to begin mapping the regional C stores in mineral soil (Homann et al. 1995).

Stand scale controls on the C cycle are being explored using StandCarb, a multi-life form, stand scale model developed by Harmon et al. (1996c). This model is best described as a hybrid between a gap succession model (e.g., Zelig) and an ecosystem process model (e.g., Century). The purpose of StandCarb is to explore the effects of colonization success, species succession, and disturbance severity (e.g., clear-cut versus thinning) on C sequestration. This model considers three life forms (i.e., herbs, shrubs, and trees), which grow in a stand comprised of 100-500 cells that interact through shading. The model simulates C stores in 6 live pools, 6 corresponding detritus pools, and one stable soil C pool. In addition to including three life forms, the model includes tree species succession, and allows for thinning or partial stocking of trees. The overall abiotic and biotic controls of StandCarb are similar to the RegionCarb model. Our plan is to compare the predictions from this model to production and stores data gathered in the H. J. Andrews LTER Permanent Plot Network. The role of remote sensing at the stand scale is to identify areas prone to prolonged shrub and hardwood occupancy versus those that are rapidly occupied by conifers. Distinguishing the spatial extent and location of these successional trajectories is important because both live biomass and detritus accumulation rates are highly dependent on the life forms present (i.e., herb, versus shrubs versus hardwoods versus conifers).

Key Findings

The most significant results from our past work are summarized in Cohen et al. (in press). We have thus far derived carbon flux results from a 1.2 million ha intensive study area in the central Oregon Cascades Range. Of this area, 68% was forest land, and 15% of this forest land was harvested between 1972 and 1991. During that time period, the total flux to the atmosphere was 17.5 x 1012 g C. Live and detrital stores have both decreased, whereas forest products and other offsite uses have increased throughout the study period. On balance, the forests of this 1.2 million ha area have been a net source to the atmosphere of 1.1 x 106 C ha-1 yr-1.

With respect to the global C budget, what do these results suggest? Since the intensive study area is representative of the 10.4 million ha Pacific Northwest region of western Oregon and Washington, extrapolation over the full region suggests that there was a flux over the past two decades of 11.8 x 1012 g C yr-1 from the region to the atmosphere. This amount is somewhat less than the estimate of Harmon et al. (1990), who suggested the amount was somewhere between 15.25 and 18.5 x 1012 g C yr-1 over the past 100 yr.

Future Directions

Once we have performed sensitivity analysis and corroborated the predictions of the separate system components described above, we plan to examine how uncertainty propagates in the overall analysis system. We would also like to compare future scenarios of regional development for the next 25 to 100 years, projecting current trends in harvest rates and management treatments (planting and thinning) as a base-case. We can then assess the economic and policy implications of these changes to determine the degree they are reasonable alternatives.

Acknowledgements

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USDA Forest Service, Pacific Northwest Research Station
NSF-LTER, BSR-9011663
NSF-International Studies, DEB-9416821
The Pacific Forest Trust, Boonville, CA.

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Homann, P.S., P. Sollins, H.N. Chappell, and A.G. Stangenberger. 1995. Soil organic carbon in a mountainous, forested region: Relation to site characteristics. Soil Science Society of America Journal 59:1468-1475.

Krankina, O. N., Harmon M. E. 1994. The impact of intensive forest management on carbon stores in forest ecosystems. World Resource Review 6:161-177.

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Land Cover and Land Cover Change in the Pacific Northwest Region of the United States

Warren B. Cohen

Introduction

Closed canopy mature and old-growth conifer-dominated forests of the Pacific Northwest (PNW) region of the United States have high ecological, commodity and non-commodity values and, not surprisingly, their conservation and management have been extremely controversial. A major contributor to the controversy has been lack of information about the amount and distribution of these ecosystems over the landscape. Recognizing this, both public land management agencies and conservation groups have been using satellite imagery to estimate the amount, and map the locations, of old forest systems on public lands in the PNW region. Although these independent efforts demonstrate the potential value of remote sensing as a management tool in the PNW, and may have narrowed the uncertainty about the amount of mature and old forest in the region, the estimates differ by as much as over 100 percent depending on the definition used and the public planning unit surveyed (Cohen et al. 1995). These differences in estimates are partially due to differences in definitions, with the remainder probably a result of major differences in data sources and methodologies used. While these application experiences are valuable to help define the role of remote sensing in management of PNW ecosystems, a strong research component is needed to test, compare, and explore potentially useful data sources and methods, and to provide detailed descriptions of methods and accuracy in the scientific literature.

An emerging issue in the PNW region is the recovery of harvested forest; in particular, whether disturbed stands are rapidly returning to the expected condition of closed canopy conifer forest, or are remaining as early successional brush fields for extended periods. Remote sensing, particularly with the use of satellite images, holds considerable promise to assist in mapping the distribution of forest conditions in the region and resolve controversies about the conservation and management of old forest ecosystems. Even more fundamentally, research can help bring about an understanding of the basic reflectance characteristics of ecosystems in the region, and how these characteristics change with forest structure and composition. Such directed research can also help identify important limitations in the application of different types of current satellite data and methods of analysis, an thus lead to effective use of remote sensing in modeling forest ecological processes.

Spatial and Temporal Extent

Much of the remote sensing research in the PNW region has been conducted over a 1.2 million ha central Cascades study area . However, we recently have expanded our analyses to the full area west of the crest of the Cascades in Oregon, and expect to soon work within the full area west of the Cascades in the State of Washington. The spatial resolution of this work is roughly 25 m, associated with the resolution of Landsat Thematic Mapper data. The temporal extent of our analyses are roughly equivalent to the period for which Landsat data exist (1972-present). Our analyses are directed at developing land cover and cover and cover change maps at roughly five- year intervals over this time period. Maps developed for periods prior to 1984, were derived from Landsat Multispectral Scanner (MSS) data resampled to a spatial resolution of 50 m.

History of Project

This work began in 1989 with funds from the USDA Forest Service Region 6 Headquarters and the PNW Research Station to determine what closed canopy conifer information could be derived from various sources of image data (Cohen et al. 1990, Cohen and Spies 1992, Cohen 1994). In 1992 the research was greatly expanded to develop methods for mapping land cover and cover change over the full western halves of Oregon and Washington with support from NASA's Terrestrial Ecology Program, and the HJ Andrews LTER program. The intent was to link the map data with carbon dynamics models (Cohen et al. 1992 & 1994, Wallin et al. 1996, Cohen et al. 1996). Whereas we initially concentrated exclusively on forest land, we now are working to map agricultural lands in the region as well, with funding from the EPA in Corvallis.

Key Participants

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Basic Approach

Methods used to map land cover in the PNW are a combination of statistical clustering and regression analysis using Landsat imagery in conjunction with ground and airphoto reference data (Cohen and Spies 1992, Cohen et al. 1995). With the most recent TM data available, a cover map is produced of vegetation classes that are aligned along a successional gradient from recently disturbed forest to old-growth forest and correspond to changes in major biophysical processes. The map produced thus far contains six forest vegetation classes: two early-successional pre- canopy closure classes, with relatively low biomass, an early-successional closed canopy mixed hardwood-conifer shrub class, and three classes of closed canopy conifer seral stages (Figure 1). Although these six classes are sufficient to accurately capture biomass accumulation in the Oregon Cascades, they are not adequate for the Oregon Coast Range where the mixed shrub class also includes hardwood-conifer mixtures of several seral stages with varying amounts of biomass. We are improving our cover mapping at both sites by deriving a Hardwood-Conifer Mixture Index, which is then segmented into a mimimum of three mixture classes (Maiersperger, Cohen, and Ganio, in review). One of these classes, a pure hardwood condition is further separated into shrub and tree categories. The other classes have increasing amounts of conifer cover and biomass. This procedure has been extensively tested in the Coast Range and will soon be expanded to the full region of study.

In addition to mapping the location and extent of vegetation cover classes, remote sensing data are used to map stand replacing disturbances (Figure 2). Thus far we have completed our disturbance mapping over all of western Oregon using multi-temporal Landsat MSS and TM data from 1972 to near-present at roughly 5 year intervals. Our methods for mapping and error assessment, thoroughly documented in Cohen et al. (in review), involve an unsupervised classification of multitemporal difference images. Because the spectral properties of recently disturbed forest are at one end and the mid- to late-successional forests (i.e., the most likely to be clearcut harvested) are at the other end of the brightness and greenness continua, the detection of severely disturbed forests is virtually unambiguous. Consequently, disturbance mapping accuracy in western Oregon forests exceeds 90%.

To identify areas prone to prolonged shrub and hardwood occupancy versus those that are rapidly occupied by conifers, we are building an empirical understanding of biogeophysical controls that incorporates historical Landsat imagery to map the successional trajectory of early-successional stands. A preliminary analysis has been completed over the 6,400 ha area H.J. Andrews Experimental Forest in the Oregon Cascades. Three statistically distinct successional trajectories (rapid recovery, <20 yr; expected recovery, 20 to 40 yr; and slow recovery, >40 yr) were identified by overlaying harvest date and current vegetation cover, and tracking successional development from harvest to closed canopy conifer condition using airphotos. From these data, logistic regression models were developed to predict the trajectory as a function of topographic aspect and elevation, and treatment factors such as planting and burning. Models based on biogeoclimatic and site treatment factors without inclusion of harvest date are important, because for applying these models to a broad region we cannot expect to have a comprehensive harvest date map for all disturbed stands. It is also unlikely that we will have site treatment factor data, so we need to test if land ownership can serve as a proxy for this information.

Key Findings

Over our intensive study area of 1.2 million ha on the west side of the Oregon Cascade Range, we estimated and mapped forest age and structure in 1988 with an overall accuracy of 82 %. Unsupervised classification enabled several forest classes to be defined in terms of percent cover: open (0-30 %), semi-open (30-85 %), closed mix (>85 %, of which at least 10 % is comprised of non-conifer species), and closed conifer (>85 %, of which less than 10 % is non-conifer). These classes represented nearly distinct spectral groups. Within the closed canopy conifer class, three age and structural classes could be distinguished using regression analysis (e.g., young, mature, and old-growth). The multi-ownership study area consisted of 76 % forestland. Of the total forestland, 70 % was closed canopy conifer, with 42 % being in a mature or old-growth state. Forests administered by the USDI Bureau of Land Management (BLM) and the USDA Forest Service, but protected by congressional and administrative mandates from harvest, were 10 % of the total forestland. Of the protected category, only 60 % was mature and old-growth forest. Unprotected BLM and Forest Service lands accounted for 53 % of the forestland in this study (8 % and 45 %, respectively). Of the unprotected category, the BLM had 63 %, and the Forest Service had 49 %, respectively, of their holdings in a pre-canopy closure and young conifer condition. Thirty-five percent of the forestland was privately owned, and consisted of 73 % pre- canopy closure and young conifer forest stands. Of all mature and old-growth forest, 22 % was found on private land, 7 % on unprotected BLM land, 55 % on unprotected Forest Service land, and 15 % on protected land.

Over the same study area, we demonstrated that forest harvest activity in a dense conifer forest region can be accurately mapped using a temporal sequence of Landsat images. With statistical cluster analysis of individual date pairs of images (i.e., 1972 & 1976, 1976 & 1984, 1984 & 1988, 1988 & 1991, 1991 & 1993), we achieved a map accuracy well in excess of 90 % after merging the date-pair maps. A considerably more economical method that involves simultaneous analysis of the full temporal data set yielded a harvest map matching the merged harvest map on greater than 90 % of the total number of pixels mapped for a 1.2 million hectare area. Error assessments were done in a number of ways, and included the use of digital ground-based reference data, airphotos, and evaluation of the input Landsat images themselves. Use of the Landsat images for error assessment probably gives the best representation of "true" map accuracy, as the contrast between dense forest and clearcut is so great.

Future Directions

Much of our attention is now directed at determining how to best use remote sensing in developing an understanding of controls over successional properties in the PNW region. Proposed research will expand the geographic scope beyond the H.J. Andrews Experimental Forest to develop more robust models for the whole PNW region, and will incorporate historic Landsat data. As we are capable of mapping vegetation cover over a set of successional development stages, we assume that using a multitemporal, radiometrically normalized image data set we can construct temporal-spectral trajectories that are closely aligned with the successional trajectories identified by our current models. If this is true, we can use measures derived from the historic Landsat data archive as independent variables in our succession models. For stands harvested since 1972, we will have a direct observation of harvest date, and for stands harvested prior to 1972, we will have a record of spectral development for the past 25 or so years. Another important direction for our remote sensing research is to use a variety of image data sources to determine what data sets used in unison can best provide map information on successional and disturbance (both severe and subtle) processes in the forested portions of the PNW region. In particular, we are experimenting with multitemporal AVIRIS hyperspectral data, SLICER laser altimeter data, and ADAR high spatial resolution aircraft digital data.

Funding sources

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