PNW
Pacific Northwest Research Station

Science FINDINGS

issue fifty-six / september 2003

INSIDE

"Science affects the way we think together."

Lewis Thomas

SEEING THE TREES FOR THE FOREST: MAPPING VEGETATION BIODIVERSITY IN COASTAL OREGON FORESTS

"Like the universal fascination with moving water, or the dance of a fire's flame, maps hold some primal attraction for the human animal."

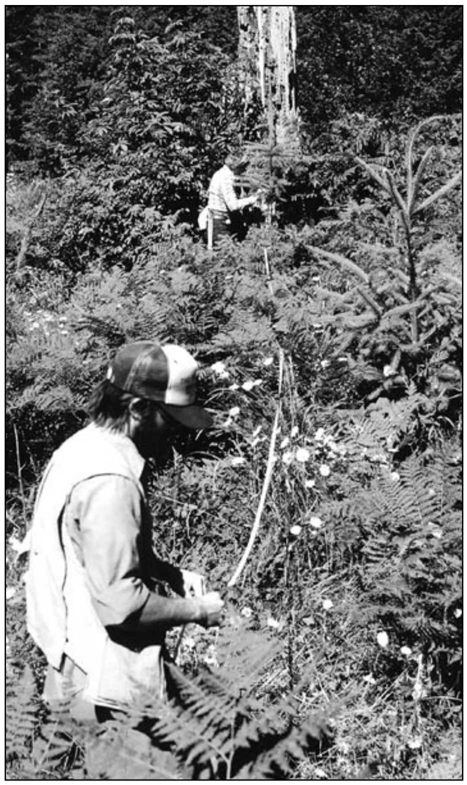
D. Aberley, *Boundaries of Home*

The challenge of integrating Landsat satellite imagery with ground-based field plot data is unending. The process is replete with dead ends, loaded with mathematical and statistical nightmares, and likely to generate terminal eye rolls in the most patient of researchers. The payoff, however, is mighty.

Prior to 1972, aerial photos were widely used to map forest cover types across large regions. But in the 1960s "in-place" (map-based) inventories had been abandoned as too expensive, and the plot-based approach was adopted. Field plots, however, were only ever as good as their geographic extent: no fieldwork on earth could cover every inch of ground. But with the increasing accessibility and decreasing cost of satellite imagery, a vast new data resource was opened up. "Every inch of ground" became a tempting possibility.

The research and policy possibilities of remote sensing were among the drivers of the Coastal Landscape Analysis and Modeling Study (CLAMS), a bioregional assessment project focused on the Coast Range Province of Oregon. Modeling vegetation by using both remotely sensed data and field plot data would be central.

"As with any modeling approach, the design was driven by the objectives of the users, and by the constraints of the technology," says



Credit: J.L. Ohmann

Field plots, although expensive to establish and maintain, are equally valuable components with satellite imagery of efforts to map whole landscapes digitally.

Janet Ohmann, a research forest ecologist with the Pacific Northwest Research Station in Corvallis, Oregon. "In this case, we were up against the limitations of satellite imagery. So if we're interested in forest structure, and the satellite is only giving us general information about the forest canopy, we need those field data more than ever to verify our conclusions about more detailed characteristics of the forest."

IN SUMMARY

In order to address policy issues relating to biodiversity, productivity, and sustainability, we need detailed understanding of forest vegetation at broad geographic and time scales. Most existing maps developed from satellite imagery describe only general characteristics of the upper canopy. Detailed vegetation data are available from regional grids of field plots, but the data are not spatially complete—they do not cover an entire area of interest.

Regardless of these limitations, forest policymakers and stakeholders want information about current forest conditions that is spatially explicit (mappable), spans all ownerships, and is rich in detail, including tree species, sizes, and densities. Scientists studying regional vegetation patterns and dynamics require similar data for their research.

The Gradient Nearest Neighbor method for mapping vegetation is a breakthrough for regional assessments. Field plot, remotely sensed, and environmental data are integrated into a single digital map. At the regional scale, the method shows an impressive level of accuracy, suggesting its potential for strategic regional planning across ownerships.

Of course, the CLAMS team **was** interested in forest structure. The study's wish list also included forest species composition, age classes, land use change, ownership, topography, and environmental gradients from the coastal maritime forests to the dry inland valleys. Every inch of ground. The quest for a mapping approach became a process of elimination, and lots of approaches didn't pan out.

"In the end we used components that were not new individually, we just put them together in a new way," Ohmann explains. For the database development and spatial analysis work of CLAMS, she teamed up with Matt Gregory, an Oregon State University faculty research assistant in the Department of Forest Science. Several other scientists on the interagency and interdisciplinary CLAMS team contributed valuable ideas.

KEY FINDINGS

- The Gradient Nearest Neighbor (GNN) method of vegetation mapping integrates field plot, remotely sensed, and environmental data into a single digital map. GNN uses multivariate gradient analysis and imputation to assign a list of tree species, densities, and sizes to each pixel in a regional map.
- GNN analyses revealed that variation in tree species composition was strongly linked to physical environment and relatively unaffected by forest management activities. Forest structure, defined by average tree size and density, was strongly associated with disturbance history and landownership patterns.
- Mid-successional, closed-canopy forests dominate the coastal landscape. Older forest, along with legacies of snags and down dead wood, is concentrated on federal lands; diverse young "natural" forest has been lost on all ownerships. Foothill oak woodlands and hardwood trees are most abundant on nonindustrial private lands.
- Evaluation at regional and site scales suggests that GNN maps are appropriately used for regional-level planning, policy analysis, and research, not to guide local management decisions.

HOW DO WE TACKLE THIS MONSTER?

In case no one has noticed, the issues involved in managing forests are growing alarmingly complex, or appropriately complex, depending on your viewpoint. The array of ecological and commodity values and their interactions is daunting to any manager, landowner, or interested citizen. It is quite apparent that land use decisions, environmental constraints, and ecological processes constantly interact to influence the spatial pattern of forested land cover.

"Therefore issues such as biodiversity conservation, long-term productivity and sustainability, and global climate change require consideration of broad geographic scales, from landscapes to whole regions, and long time frames, from decades to centuries," Ohmann says.

Policy analysis considers the distribution of forest resources and uses across multiple ownerships, as well as landscape patterns and forest conditions over time. Regional assessments are starting to rely on simulation modeling to examine landscape change. Vegetation maps are needed to support these simulation models.

Most existing regional maps of forest cover are based on classified satellite imagery, Ohmann explains. "Although these data are spatially complete, their information content is limited to general characteristics of the upper forest canopy. Few examples exist of integrating this imagery with field plot and environmental data for ecological modeling and understanding at the regional scale."

The Gradient Nearest Neighbor (GNN) method Ohmann developed uses multivariate analysis—dealing with many variables at the same time—to assign a list of tree species, densities, and sizes to each pixel in a regional map. For the first time in forest assessment, this allows us to integrate remote sensing, field data, and environmental data into a single digital map. Breakthrough.

So OK, to achieve this you take tree lists from field data, and include one tree list in each mapped pixel? Given that a CLAMS pixel is 25 meters on a side, that's a boatload of tree lists. How does this work?

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
P.O. Box 3890
Portland, Oregon 97208
(503) 808-2137

Sherri Richardson Dodge, Editor
srichardsondodge@fs.fed.us

Send new subscriptions and change of address information to pnw_pnwpubs@fs.fed.us

Keith Routman, layout
kroutman@fs.fed.us

USDA United States Department of Agriculture

Forest Service

Science Findings is online at:

http://www.fs.fed.us/pnw

The site includes our new **Science Update**—scientific knowledge for pressing decisions about controversial natural resource and environmental issues.

TEAMING GRADIENTS AND IMPUTATION

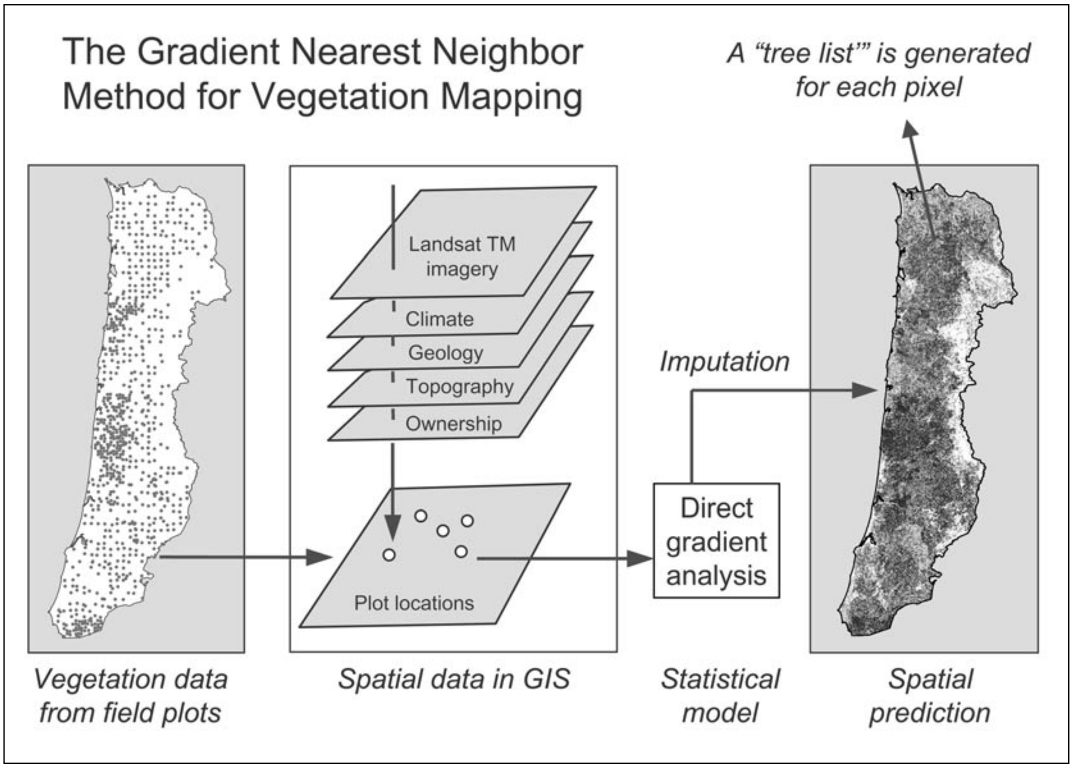
A technique called direct gradient analysis is used to quantify relations between vegetation and environment for a sample of field plot locations. This helps establish variations in tree species composition and structure at different elevations and climates, topographic positions, and disturbance histories.

Imputation is a statistical analysis tool for incomplete data, whereby measured values are assigned to sites lacking such data. The GNN method, then, refers to the practice of giving a pixel the attributes of the plot that is most likely to be similar in terms of environmental and spectral characteristics. Think of it as a best computer guess, after a lot of input from researchers. A tree list specifies what species, densities, and sizes of trees are likely to occur at any given site, based on ground measurements taken on field plots. Tree lists can be imputed to sites that have not been sampled in the field.

"Direct gradient analysis and predictive vegetation mapping rest on the premise that vegetation pattern can be predicted from mapped environmental data," Ohmann explains. "Predictive models are based on various hypotheses as to how environmental factors control the distribution of species and communities of trees and plants."

For the CLAMS project, field plot data were obtained from the Current Vegetation Survey (CVS) of the USDA Forest Service and USDI Bureau of Land Management; and the Forest Inventory and Analysis (FIA) and Old-Growth Study of the Pacific Northwest Research Station.

Gradient analysis and imputation were the existing tools that Ohmann and Gregory put together in a new way for the CLAMS project. They built their ideas on other researchers' efforts and questions, some of which contributed, some of which did not suit their needs. And they relied, of course, on the growing computing power available to them to come up with the digital parts of the answers. Not surprisingly, computational speed for simulation modeling is increasing by orders of magnitude. Ohmann recalls that a model run took 2 days at the beginning of the CLAMS project 5 years ago. It now takes 2 hours, making a huge difference in how quickly "What-if?" scenarios can be produced and evaluated, or sensitivity analysis can be conducted.



Direct gradient analysis quantifies relations between vegetation and environment for a sample of field plot locations. Imputation statistically assigns measured values to sites lacking such data. A tree list specifies what species, densities, and sizes of trees are likely to occur at any given site, based on ground measurements taken on field plots. Tree lists can be imputed to sites that have not been sampled in the field.

OBJECTIVES UNDER CLAMS

The purpose of the GNN study within the CLAMS project was to characterize, both quantitatively and spatially, the current patterns of forest vegetation in the Oregon coastal province. Under that general rubric, specific objectives were threefold. First, researchers wanted to quantify environmental and disturbance factors associated with regional gradients of tree species composition and structure.

Second, they were to develop GIS-based analytical tools and models to integrate field plot, remotely sensed, and mapped environmental data to map current vegetation. And third, they were to produce maps of current vegetation that are model predictions. The resulting vegetation map is used in landscape simulations that project vegetation change as far out in time as 100 years.

"The current vegetation map had to have sufficient fine-scale heterogeneity to support the models of habitat capability for focal wildlife and plant species being used in CLAMS," Ohmann says. "To be ecologically realistic, we tried to develop a method of dealing with multiple variables that would both predict and maintain the integrity of different assemblages of tree species and structures." Their model also needed to interact with other models—wildlife, aquatic habitat, and forest dynamics.

In its mapped predictions, the study sought to represent the full range of variability in the area's forest vegetation. Researchers also worked on simultaneously mapping multiple vegetation attributes that vary individually and continuously, rather than separate, static vegetation classes.

EVALUATING RESULTS ACROSS THE LANDSCAPE

The predictive accuracy of the GNN method was tested at the regional and the site levels.

"The relative proportions of forest conditions across the province predicted by GNN very closely matched those estimated by systematic grids of inventory plots," Ohmann says. "This agreement was not necessarily expected, even though the GNN model was based on a subset of the inventory plots. In addition, the mapped GNN predictions reproduced the sampled range of variability in vegetation across the province very closely." Furthermore, the GNN approach does a reasonable job of portraying fine-scale heterogeneity, Ohmann says.

At the site level, a map of 10 vegetation classes defined by species composition, density, and size class was 88 percent accurate within one class. Classification accuracy improved when fewer classes were used. Mapped predictions were most accurate for tree species whose distributions are geographically limited and strongly associated with climate, such as Oregon white oak and Sitka spruce.

The ability to predict a given vegetation attribute with GNN, she points out, is limited by the response variables used to develop the underlying model. These response variables, or summary measures, can be selected by the researchers and tailored to study objectives.

"Improving prediction accuracy for some vegetation attributes may come at the cost of reduced accuracy for others, and it is possible to optimize the model for particular attributes," she says. In other words, one model may best predict the location of recent clearcuts or old-growth forest, but a different model would be specified to predict the distributions of individual tree species. "Similarly, perfect accuracy for multiple vegetation attributes in the GNN predictions is impossible, because two plots never are exactly alike nor are the vegetation and explanatory factors perfectly correlated."

It is important to note, she says, that there is a danger that the fine spatial resolution and detailed information content of the GNN predictions may imply a higher level of precision than actually exists. "We stress that vegetation maps produced with GNN are appropriately used for strategic-level planning and policy analysis, not to guide local management decisions."

In time, she believes, as the technology improves and other kinds of remote sensing data become more affordable, the challenge of accuracy at finer scales may gradually be met.

Credit: R.J. Pabst

Foothill oak woodlands and hardwood trees are most abundant on private nonindustrial lands due to both environmental and past forest management effects. These forest types are unprotected by existing forest policies and land use laws.

LANDSCAPE-LEVEL BIODIVERSITY FINDINGS WITH GNN

The analyses generated by the GNN-created maps revealed a variety of new data about Oregon's coastal province. For example, variations in tree species composition are strongly linked to physical environment and relatively unaffected (at least so far) by management activities. In other words, Ohmann explains, tree species changed along a climate gradient from the maritime coast to the inland valleys and with elevation, but were little affected by management activities. Therefore we see that tree species still occupy essentially the same ranges now as they did before timber harvesting began in the late 1800s.

Forest structure, on the other hand—defined by tree size and density—was strongly associated with disturbance history, especially human disturbance, as reflected in the satellite data and by land ownership patterns.

"The map revealed that mid-successional, closed-canopy conifer forests dominated the coastal landscape. Older forest was concentrated on federal lands, and over 90 percent of foothill oak woodlands are on private lands," Ohmann observes.

A number of key biodiversity issues came to light in the map, she notes. There has been a loss of diverse young forest on all ownerships. Young stands in the current landscape have regenerated after clearcutting and other intensive forest management activities and typically lack the legacy of scattered large live and dead trees that remain after natural disturbances such as wildfire and wind. Conservation of diverse young forests has received little attention in forest policy.

Large live trees, snags, and down dead wood are present on all forest lands throughout coastal Oregon, but are most abundant on public lands. Many of these trees are legacy from previously harvested or burned old-growth forest, and their presence in future landscapes is uncertain. In contrast, foothill oak woodlands and hardwood trees are most

WRITER'S PROFILE

Sally Duncan is a science communications analyst and writer specializing in natural resource issues. She is currently a Ph.D. candidate in Environmental Sciences at Oregon State University in Corvallis.

abundant on private nonindustrial lands owing to both environmental and past forest management effects. Since these tree types are underrepresented on public lands and in reserves, they are unprotected by existing forest policies and land use laws, Ohmann notes.

"Our findings do suggest that some aspects of biodiversity are affected more by physical environment than by land management practices," Ohmann says. "Regional conservation planning for forest plant species therefore needs to consider protection across broad-scale environmental gradients such as climate and elevation. Conservation efforts focused on forest structure and thus wildlife habitat, in contrast, need to consider landownership and the effects of forest management practices."

LAND MANAGEMENT IMPLICATIONS

- Regional conservation for forest plant species needs to consider broad-scale environmental gradients; efforts focused on forest structure and wildlife habitat need to emphasize management practices and ownership patterns.
- Foothill oak woodlands are unprotected by existing forest policies and land use laws, and are underrepresented on public lands and in reserves.
- Existing large live trees and dead wood are legacies from previously harvested old-growth forests and have an uncertain future.
- Because the GNN method represents vegetation attributes in the map as individual continuous variables, user-defined classification schemes can be developed and constructed for specific purposes.

ADVANTAGES OF GNN FOR INTEGRATED ASSESSMENTS

Unlike many other mapping techniques, the integration of gradient analysis and imputation gives the GNN approach several distinct advantages in bioregional assessment projects.

First, information content is high, because each individual pixel contains a list of trees by species, size, and density. "Because the vegetation data are preserved at this most basic level of detail, user-defined classification schemes can be applied, maps constructed, and accuracy assessed for specific analytical purposes," Ohmann points out.

Second, because of the imputation of a single nearest-neighbor plot to each pixel, the closely related variations among predicted species and structures within map units are ecologically realistic. Likewise, the range of variability present in the sampled stands is maintained in the mapped predictions. Thus if the field plots are representative of the entire regional landscape, the GNN procedure and maps will reflect the inherent variability of the region.

Although single-species models often will yield better predictions than multispecies models for the same species, it is also true that methods that model the response of single species lose information about the co-occurrence of multiple species within samples, Ohmann notes. The GNN approach, she says, ensures that predicted plant communities are realistic assemblages of species and structures.

Direct gradient analysis in itself contributes to knowledge about regional ecological gradients, so the ongoing science endeavor is enhanced. And finally, the current vegetation model supports other models, such as wildlife, stand, and landscape dynamics, within the CLAMS study.

OTHER USES FOR GNN

Although the GNN approach was developed specifically for the CLAMS project, it appears that it could be successfully applied to other regions, so long as a representative sample of georegistered field plots and mapped spectral and environmental data are available. Already, biodiversity analyses of the GNN-based maps have been used to address criteria and indicators of sustainability under the Montreal Process for the Oregon Department of Forestry's forestry program for Oregon assessment.

In addition, a recently funded 3-year study is applying GNN to mapping of forest vegetation and fuels in Washington, Oregon, and California. Results of this research, Ohmann says, will provide input to models that assess fuel loadings and fire risk at the strategic level for broad regions.

"The GNN maps also provide new opportunities for assessing the distribution of ecological and economic values across land ownerships and policy objectives, and potentially for identifying new ways to accommodate competing interests within a region," she says.

Under the umbrella of CLAMS, the maps are used to evaluate various policy alternatives that address key issues in forest management, across ownerships. Although the GNN approach may not yet be perfectly accurate at local scales, its value as a regional assessment tool surely returns the investment in dead ends and eye rolls.

FOR FURTHER READING

Ohmann, J.L.; Gregory, M.J. 2002. *Predictive mapping of forest composition and structure with direct gradient analysis and nearest-neighbor imputation in coastal Oregon, U.S.A.* Canadian Journal of Forest Resources. 32: 725–741.

Spies, T.A.; Reeves, G.H.; Burnett, K.M. [and others]. 2002. *Assessing the ecological consequences of forest policies in a multi-ownership province in Oregon.* In Liu, J.; Taylor, W.W.; eds. *Integrating landscape ecology into natural resource management.* Cambridge, United Kingdom: Cambridge University Press.

Wimberly, M.C.; Ohmann, J.L. In review. *A multi-scale assessment of human and environmental constraints on forest landscape dynamics.* Landscape Ecology.

Science
FINDINGS

U.S. Department of Agriculture
Pacific Northwest Research Station
333 SW First Avenue
P.O. Box 3890
Portland, OR 97208-3890

Official Business
Penalty for Private Use, $300

PRSRT STD
US POSTAGE
PAID
PORTLAND OR
PERMIT N0 G-40

SCIENTIST PROFILE

JANET OHMANN is a research forest ecologist with the Ecosystem Processes Program of the Pacific Northwest Research Station, USDA Forest Service. She earned B.A. and M.F. degrees from Duke University and a Ph.D. in forest ecology from Oregon State University. Before coming to the Forestry Sciences Laboratory in Corvallis, she worked several years for the Forest Inventory and Analysis Program in Portland, developing methods for the ecological basis for extensive forest inventory and analysis. Her current research focuses on understanding broad-scale patterns and dynamics of plant species and communities and their relationships with environment and disturbance in Pacific Northwest forests.

Ohmann can be reached at:

Pacific Northwest Research Station/USDA Forest Service
Forestry Sciences Laboratory
3200 SW Jefferson Way
Corvallis, OR 97331-4401
Phone: (541) 750-7487
E-mail: johmann@fs.fed.us

COLLABORATORS

Matthew J. Gregory, Oregon State University (OSU)

Coastal Landscape Analysis and Modeling Study team (PNW Research Station, OSU, PNW Region, Oregon Dept. of Forestry)

Forest Inventory and Analysis Program (PNW Research Station)