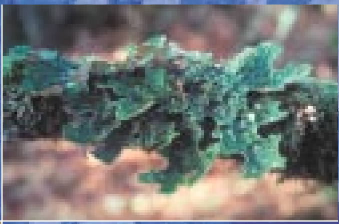
Forest Health Indicators

Forest Inventory and Analysis Program



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INTRODUCTION

Forest Inventory and Analysis. The Forest Service Forest Inventory and Analysis (FIA) Program is the Nation's continuous forest census. Since 1930, we have collected, analyzed, and reported information on the status and trends of America's forests: how much forest exists, where it exists, who owns it, and how it is changing – growing, dying, or being harvested. In response to widening customer interests, the FIA Program is developing a core program that will be implemented in the same manner on all U.S. forest lands. It includes sampling an extended suite of forest health indicators. The purpose of this brochure is to describe these health indicators: what we are measuring, why we believe these measurements are important, how we collect and interpret the data, and examples of what we have found to date. The FIA indicators discussed in this brochure are:

- Crown Condition
- Ozone Injury
- Tree Damage
- Tree Mortality
- Lichen Communities
- Down Woody Debris
- Vegetation Diversity and Structure
- Soil Condition

These indicators were developed and initially measured by the Forest Health Monitoring (FHM) Program in the 1990s. In 1999, they were transferred to FIA and now are a subset of the FIA sample grid (one forest health plot for every 16 standard FIA plots). On the forest health plots, core FIA measurements (for example, height, diameter, species) are made, as well as the forest health measurements.

FIA Customers and Data Users. The FIA Program has a diverse and growing set of customers that are interested not only in reports and analyses produced by FIA, but also in using the actual FIA data itself. Congress, State legislators, and State foresters have long used FIA information as a basis for formulating sound forest policy. Forest industry, environmental organizations, and a wide range of private consultants use FIA information for business planning. Government and academic researchers use FIA data as a basis for further research. And land managers at all levels are relying on FIA data for a strategic look at forest resources and as a basis for forest planning at the strategic scale. All of these users have expressed interest in the broader suite of FIA measures that includes indicators of forest health.

FIA also contributes data and analyses to a variety of national and global assessments. FIA data address at least 38 of the 67 Criteria and Indicators of Sustainability for reporting under the Montreal Process. FIA data are key for producing the reports required by the Resource Planning Act and are increasingly being used to support regional resource assessments used as a basis for forest planning.

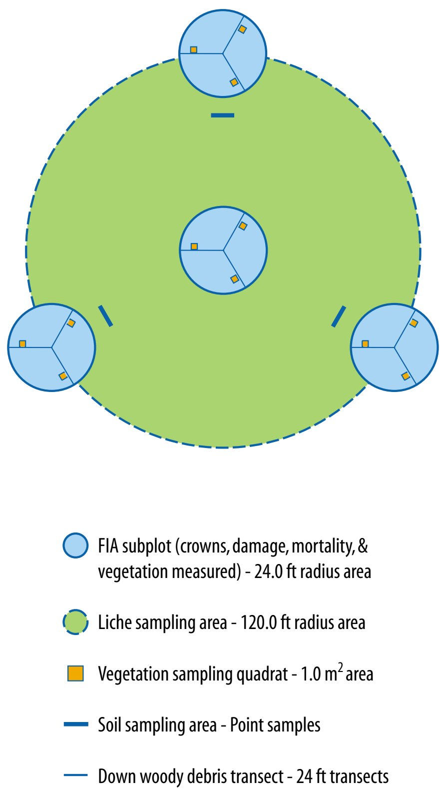
Researchers and policymakers are using FIA data about forest soils, down woody debris, and tree biomass to estimate carbon budgets and to model the potential for carbon sequestration under different management scenarios. The fire management community is using the forest structure and down woody debris data to identify areas at highest risk of catastrophic fire and opportunities for preventative treatments. Land managers use understory vegetation data to track increases of invasive species. Many partners use FIA data on ozone injury, lichen community composition, tree damage, and tree crown condition to report, as required by several international treaties, on overall forest health and probable impacts of air quality and acid deposition.

Brochure Format. The majority of this brochure is devoted to descriptions of each forest health indicator. Each indicator is featured on two facing pages with the following sections:

- **What is the indicator?**
- **Why is it important?**
- **How is it measured?**
- **How can the data be used?**

More Information. For more detailed information about the FIA Program and the forest health indicators, including field methods, please visit the FIA Web site at **http://fia.fs.fed.us.** Information about the FHM Program is available at **http://www.na.fs.fed.us/spfo/fhm/.**

FIA Plot Design for Forest Health Indicators



Crown Condition

What Is the Crown Condition Indicator? The crown indicator is based on the amount, condition, and distribution of foliage, branches, and growing tips of trees (see photo below). There are five components of the crown indicator:

- *Ratio* – the length of the tree with branches, divided by the total tree height.
- *Density* – a visual estimate of the fullness of the crown, based on the amount of skylight blocked from view by leaves, branches, bole, and fruits.
- *Foliar transparency* – an estimate of the amount of skylight seen in the foliage parts of branches.
- *Dieback* – the death of the sun-exposed, growing twigs in the upper crown.
- *Diameter* – the width of the tree crown. It is estimated with models.

Why Is the Crown Indicator Important? In addition to being aesthetically pleasing, tree crowns provide shade, temperature moderation, and food and habitat for many organisms. They also are a source of fuel for wildfires. Crowns give a quick evaluation of general tree health. Healthy, full crowns suggest carbon is being stored; the tree is growing; and there are no serious impacts from pathogens, air pollutants, or insects.

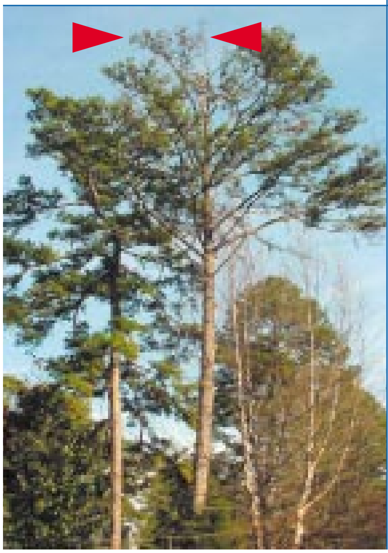


PHOTO BY KENNETH STOLTE

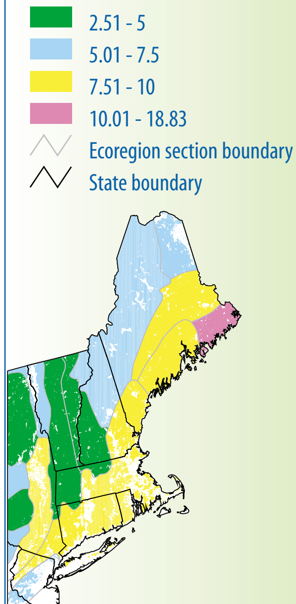
High foliage transparency (left arrow) and dieback (right arrow) of a pine tree under stress; note healthy crowns of other pines.

How Is the Crown Indicator Measured? Two people stand – at different angles with the most open views of the crown – one tree-length away from the tree being evaluated. Visual estimates of each crown indicator are recorded in percentage classes (0-5 percent, 5-10 percent, …95-100 percent) for each tree. Consensus is reached on each indicator using visual guides for standardization.

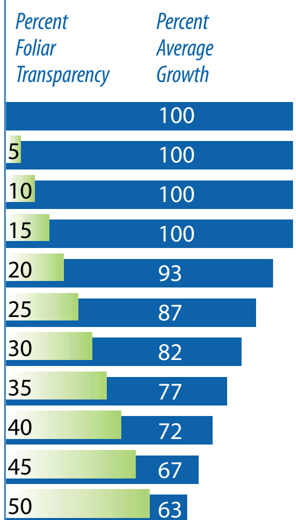
How Can Crown Indicator Data Be Used? The crown condition indicator is a good general indicator of tree health and can be used to:

- Monitor visible changes in crown condition
- Relate crown condition to tree growth or resilience to stressors such as insects and diseases.
- Evaluate suitability of stand for wildlife and bird species.
- Provide data to estimate risk of catastrophic crown fires.
- Serve as an indicator of soil fertility and toxicity.
- Serve as an indicator of climate change

Softwood dieback: 1999 status



Dieback on Softwoods in Northeastern United States. By ecological units, 1999 data.



Relationship between foliar transparency and growth of pines. 1993-99 data. Foliar Transparency ≥ 20 percent was associated with reduced growth.

Ozone Injury

What Is the Ozone Injury Indicator? A number of plant species are sensitive to ozone exposures above normal background levels. These bioindicator species exhibit an upper surface foliar injury symptom that can easily be distinguished from other foliar injuries and quantified. Ozone bioindicator species are monitored in all U.S. forests.

Why Is the Ozone Injury Indicator Important? Elevated ozone exposures are an air-quality problem that has great potential to affect human health, as well as forest health and productivity over large areas. Injury to bioindicator plants shows us where ozone exposures in forests are high enough to cause plant injury, and gives estimates of the relative severity of exposures. They also show where the highest probability of reduced growth; reduced resilience to insects, pathogens, drought, and other stressors; and increased mortality might be occurring.

How Is the Ozone Injury Indicator Measured? The ozone indicator is not sampled on FIA plots because specific site and plant species requirements must be met that may not be present on the FIA plot. Ozone biomonitoring sites are located in forest openings where three or more bioindicator species are found. In forests where ozone exposures are very high and sensitive species are common, increased numbers of sites are located. The plants are rated for foliar injury symptoms during the peak of ozone injury (mid-to-late summer), before fall colors mask ozone foliar symptoms. The severity of foliar injury is expressed in an Ozone Injury Score (OIS) – 0 to 4.9 (no or minute injury), 5 to 24.9 (low to moderate injury), and greater than 25 (severe injury). FIA analysts use consecutive 5-year periods with variable ozone exposures, weather, wind flow, and precipitation patterns to examine regional trends in OIS over the long term.

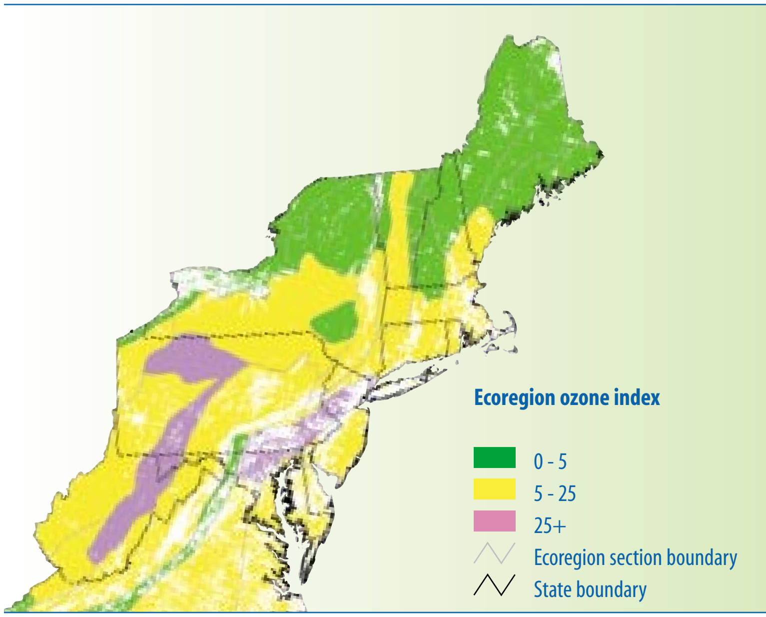
PHOTO BY GRETCHEN SMITH

Severe ozone injury on tulip poplar leaf.

How Can Ozone Injury Data Be Used? Ozone injury data can identify forested areas where ozone exposures are high and where other necessary conditions for injury (e.g., adequate light, nutrition, and moisture) are also present. Ozone injury data can be used to:

- Identify areas in forests where ozone injury is high.
- Relate the severity of ozone injury to changes in growth, mortality, or diversity.
- Relate the severity of ozone injury to increased sensitivity to biotic and abiotic stressors.
- Relate the severity of ozone injury to changes in animals or insects dependent on ozone-sensitive bioindicator species (for example, the Monarch butterfly is dependent on common milkweed, a bioindicator species).

Ozone Index Scores in Northeastern United States. By ecological unit, 1994-99 data.



Tree Damage

What Is the Damage Indicator? The damage indicator is the measurement of the type, location, and severity of injury caused by diseases, insects, storms, and various human activities. Some examples of damages recorded are open wounds, signs of advanced decay, cankers, and broken boles, roots, or branches.

Why Is the Damage Indicator Important? Damage caused by a variety of natural and human-caused sources affects growth and development of trees. Identifying unexpected or unexplained damage is intended to trigger further investigation into causal agents and tree responses. Information from this indicator should help answer questions about roles of biotic and abiotic stressors and how they affect biological conditions and processes within the forest community.

How Is the Damage Indicator Measured? Damage data are collected on all FIA plots. A maximum of two different damages may be recorded per tree. Individual damages are characterized by type or kind of damage, the location on the tree where the damage occurs, and the severity of the damage.

In general, damages are considered more serious when they are found on lower parts of the tree and large areas of tree are affected. Damages must meet minimum thresholds to be recorded. Therefore, zero damage recorded means there were no damages observed that met the minimum injury threshold. Cause or causes of damage are not collected as part of the core damage measurements. Methods for matching causal agents with observed damage and useful data sources are under discussion in FIA.

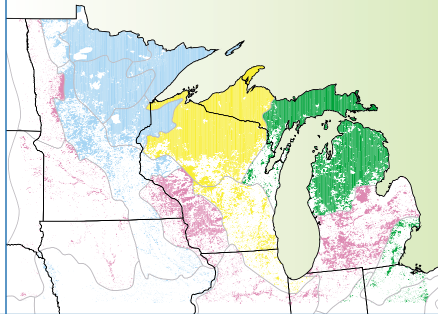
Open wound on sweetgum tree caused by beavers.

PHOTO BY KENNETH STOLTE

Damage Severity Index (DSI) for hardwoods in the Great Lakes area. By ecological units, 1999 data. Further analysis is needed to define relationships between DSI and growth or mortality.

Percentage of plots having mean plot hardwood DSI of 15 or greater

- 0 - 10
- 10.1 - 10
- 20.1 - 30
- 30.1 - 50
- Ecoregion section boundary
- State boundary



How Can Damage Data Be Used? Damage data are collected to:

- Assess the damage severity index (DSI) for each plot. DSIs are calculated from the three damage components: type, location, and severity. In general, a high DSI indicates multiple damages, severe types of damage, and/or a lot of damage occurring near the bottom of the tree. DSI values less than 15 indicate trees with minimal damage that are likely to be a normal occurrence in fairly healthy stands. The DSI results are usually separated by tree species because of the biological differences between species.
- Evaluate what forests or proportions of forests are at risk of reduced growth and/or increased mortality due to the damages observed.
- Determine how the life, development, or survival of the forest is affected by the level of damages observed.

Tree Mortality

What Is the Tree Mortality Indicator? The tree mortality indicator is the number, size, and volume of trees that have died since the previous measurement on an FIA plot. It provides information on whether changes in abiotic or biotic stressors or stand development are creating conditions less favorable for tree growth and survival.

Why Is the Tree Mortality Indicator Important? Mortality is an essential part of all healthy forest ecosystems. It contributes to ecosystem functioning and diversity by creating dead material for nutrient recycling, creating openings that result in mosaics of species and ages, and providing habitat for wildlife. Mortality may also reduce productivity of forests being managed for wood production and increase risk of wildfire. Changes in the rates and amounts of mortality require close scrutiny to separate “normal” or acceptable levels of mortality from unusual or unacceptable levels. Analysis of affected species, their ages, disturbance history in the area, and the cause of mortality are essential information for land managers and policymakers.

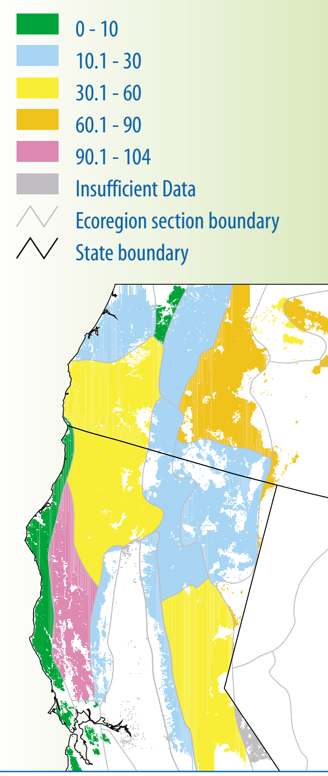
How Is the Tree Mortality Indicator Measured? Tree mortality is the measurement of diameter and height of trees that have died on FIA plots from one measurement cycle to the next. The cause of the mortality is recorded when it can be determined.

Mortality data are most meaningful when compared to growth data from the same plots. The volume of trees that died – mortality volume (mv) – is divided by the volume gained in growth (gv) of the live trees. A mv/gv value greater than 1.0 means there was a net loss of wood volume on the plot. A related method compares the average size (diameter) of the trees that have died (dd) to the size of remaining live trees (ld). A dd/ld ratio greater than 1.0 means the average size of dead trees is larger then the average size of living trees.

Port-orford-cedar killed by a root disease in southwestern Oregon.

PHOTO BY TOM IRACI.

How Can Tree Mortality Indicator Data Be Used? The tree mortality indicator measures a key forest process and therefore has a number of uses. It can identify:



Mortality in southern Oregon and northern California. By ecological units, 1992-99 data. The cause of the high mortality in coastal northern California is currently under review.

- High mortality areas – FIA plot data can be used with insect and disease survey data to better determine the geographic extent of mortality, track trends, and determine causes.
- Habitat suitability for wildlife.
- Areas of high fuel loading and fire spread risk.
- Carbon cycling patterns.
- Sustainability of stand developmental patterns.
- Climate change.

Lichen Communities

What Is the Lichen Communities Indicator? Lichens are an association of fungi and algae that grow on a variety of substrates including trees. They have a number of important forest functions, including cycling of nutrients and providing forage and habitat for a variety of wildlife. Because of their physiology, lichens are responsive to environmental stresses such as air pollution and climate change, making them useful as indicators of both. They also are indicators of forest ecosystem biodiversity.

Why Is the Lichen Communities Indicator Important? Lichen community composition and changes in composition can provide information about changes in air quality, climate, and biological processes. For example, not finding a pollution-sensitive species in an area where it is expected can indicate the presence or past presence of pollutants. Finding many nitrogen-loving species in an area can indicate high nitrogen deposition, which may also affect other components of the ecosystem, such as water quality. Diversity and abundance of lichens is also affected by forest type, age, density, and spatial arrangement of trees and other vegetation.

How Are Lichen Communities Measured? The indicator has two data collection parts – collecting samples for species identification (to determine number of different species per plot) and estimating species abundance (the number of times each species occurs). Samples are collected from woody plants (conifers and hardwood trees and shrubs above 0.5

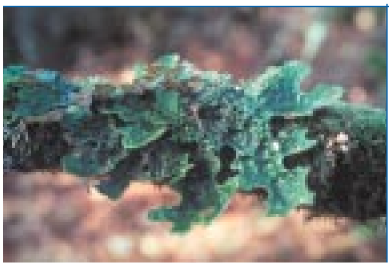
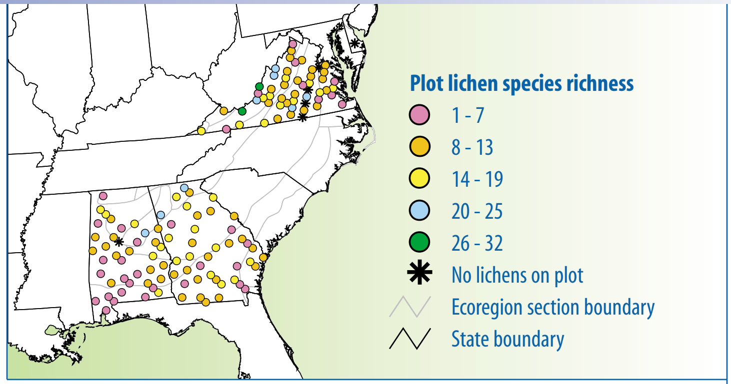


PHOTO BY BRUCE MCCUNE

Pollution-sensitive lichen, Lobaria pulmonaria.



Lichen richness in Southeastern United States. By plot, 1993-98 data. Analysis and use of gradient models help determine if lower species richness in these States is due to air pollution, climate, forest structure, or other causes. North and South Carolina were measured in 1999; their measurements will expand the analysis in this region.

meters) and recently fallen trunks and branches. Samples are mailed to an expert for identification. Abundance within the lichen plot is recorded for each species. Other data are recorded to describe the plot such as percent canopy cover, percent gaps, and dominant tree and shrub species. This information is combined with FIA tree data, environmental data, and measures of lichen community composition to suggest causes for variations in the lichen communities.

How Can Lichen Data Be Used? Two main uses of lichen indicator data are determining lichen abundance and diversity and identifying the relationships among lichens, climate, and air pollution. Lichen community data can be used to:

- Determine species abundance and richness by plot.
- Determine regional diversity – number of species recorded in a large region, such as an ecoregion section.
- Develop biotic indexes – indexes based on lichen community data from plots along pollution and climate gradients across large regions. Gradient models have been developed for Colorado and the Southeastern United States. Models for other locations are under development.

Down Woody Debris

What Is the Down Woody Debris Indicator? The down woody debris (DWD) indicator is the measurement of fallen trees, dead branches, and large fragments of wood on the forest floor. Small branches less than 3 inches in diameter are measured as fine woody debris, while larger branches and down trees are measured as coarse woody debris. DWD records the species, shapes, sizes, holes, and stages of decay.

Why Is the Down Woody Debris Indicator Important? Down woody debris is an important element of productive and biologically diverse forests. It is an important component of forest productivity, wildlife habitat, fuel loading, soil erosion, and carbon storage. As DWD decomposes, the soil is enriched with organic matter, nutrients, and moisture. Larger down tree boles provide dens for wildlife. Both large and small debris provide shelter and food for insects; germination sites for tree, herb, and shrub species; a substrate for fungi and microorganisms; and long-term storage for water, carbon, and other nutrients.

How Is the Down Woody Debris Indicator Measured? Three transect lines on each of four subplots radiate out from subplot center and extend to subplot edge. All down wood greater than 3 inches in diameter crossed by the transect line are measured for bole diameter, length, stage of decay, species, and presence of hollow cavities. Fine woody debris is recorded as the number of pieces less than 3 inches in diameter in different size classes. Large piles of coarse woody debris are treated as a unit based on the size and shape of the pile.

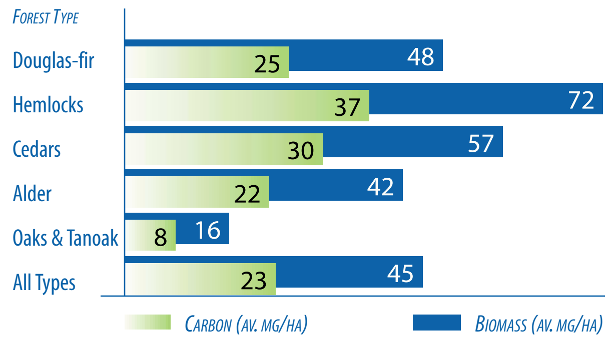
PHOTO BY KENNETH STOLTE

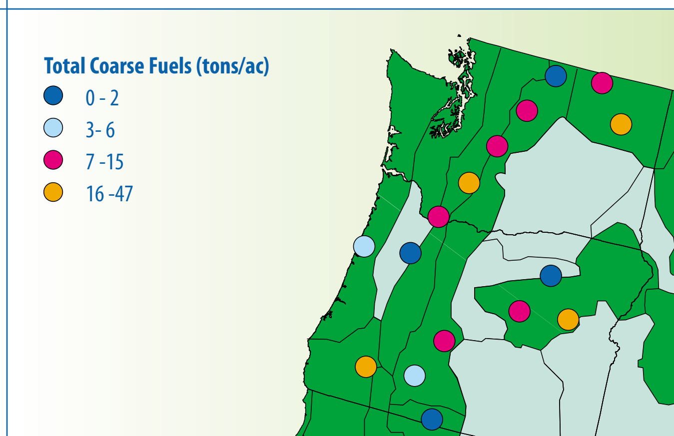
Down logs and smaller woody debris.

How Can Down Woody Debris Data Be Used? DWD data relate to a number of forest ecosystem processes and hence provide multiple and varied uses in analyzing forest health. DWD data can help evaluate:

- Biomass, carbon, and nutrient storage.
- Fuel loading and fire spread – down woody debris fuels can be classed by species groups, state-of-decay groups, and log sizes.
- Wildlife habitat – type and amount of down wood available or used as habitat.
- Soil stabilization.

Biomass and carbon in coarse woody debris in western Oregon. *1991 – 98 data. Average biomass and carbon was highest in hemlock forest types.*





Total coarse fuels in Oregon and Washington. *1998 pilot study data. Coarse woody debris is highly variable from plot to plot due to factors such as forest type, climate, and disturbance history.*

Vegetation Diversity and Structure

What Is the Vegetation Indicator? The vegetation indicator measures the type, abundance, and vertical position of vascular plant species on FIA forest health plots. It inventories and monitors the status, changes, and trends in plant species richness and abundance, and the vertical structure of the forest vegetation.

Why Is the Vegetation Indicator Important? The vegetation indicator produces information on native plant diversity; spread of invasive exotic species; fuel loading and fire-spread rates; food and habitat for wildlife; carbon cycling; and the impacts of acid rain, nitrogen deposition, ozone, and climate change effects. It will be useful in evaluating the risk of soil erosion, resistance and recovery from disturbance, and providing data to type plot vegetation by locally defined communities.

How Is the Vegetation Indicator Measured? Vegetation is measured using a multiple-scale nested approach. All trees, shrubs, herbs, grasses, vines, ferns, and fern allies are identified and quantified on three permanently positioned 1m² quadrats on each subplot. The general characteristics of the forest floor, such as litter, moss, bare ground, and rocks are also recorded. The rest of the subplot is then searched for additional species. For each species on the subplot, cover is estimated and the vertical layer (0-2, 2-6, 6-16, >16 ft) where the majority of the foliage occurs is recorded. Unknown species are collected near the plot, then pressed, dried, labeled, and mailed to a qualified herbarium for identification.

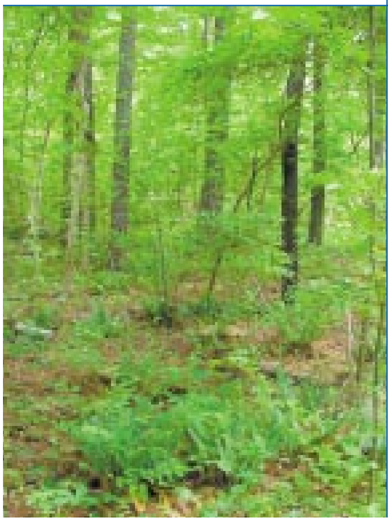


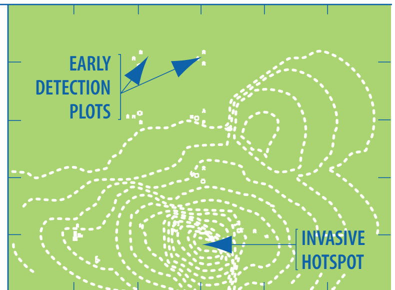
PHOTO BY KENNETH STOLTE.

Understory plant diversity and vertical layering in a mixed hardwood-pine forest.

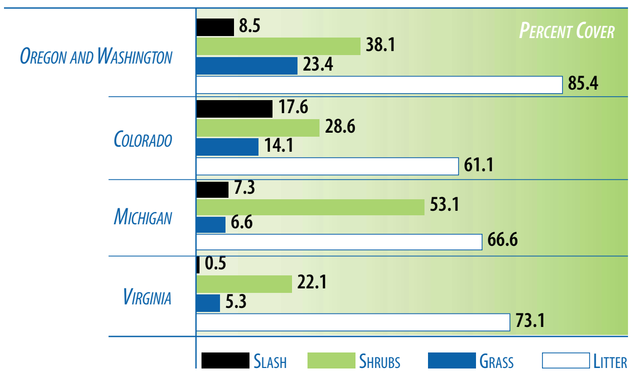
How Can Vegetation Indicator Data Be Used? The vegetation indicator data can be used in many ways. Some of the most common uses will be to:

- Monitor native diversity in the understory.
- Track the spread of exotic invasive plants and impacts on native species.
- Relate vegetation changes to soil chemical and physical changes, ozone exposures, and climate change.
- Evaluate amount, extent, and suitability of wildlife habitat.
- Provide data for fuel loading and fire spread risk.

Spread of invasive species. *1998-99 pilot study data. A model was used to determine the likely origin of invasive species (invasive hotspot) and areas where the species is next likely to spread (early detection plots).*



Fuel abundance by plant type in five States. *1998 - 2000 pilot study data.*



Soil Condition

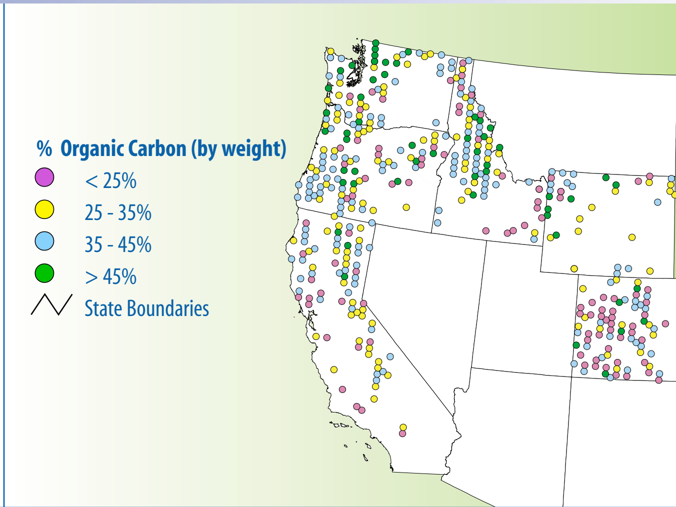
What Is the Soil Condition Indicator? The soil condition indicator is designed to collect data about erosion, compaction, and important physical and chemical soil properties. These data establish baseline values that can be used to characterize soil status on all forest land across the United States, and can be used with subsequent measurements to identify and evaluate change. The chemical and physical properties include nutrient information, such as the amount of exchangeable cations (e.g., calcium, magnesium, potassium, and phosphorus); pH level; carbon and nitrogen; toxics such as heavy metals; and the bulk density (weight of soil per unit volume).

Why Is the Soil Condition Indicator Important? Soils are important to forest land because vegetation depends on the five basic environmental factors that soils provide – nutrients, water, air, heat, and mechanical support. Chemical and physical data provide information about the physical and fertility status of forest soil and are used in many ecological models at different spatial scales of the forest ecosystem, such as in estimates of the forest carbon budget.

How Is the Soil Condition Indicator Measured? Soil measurements are made in both the field and laboratory and are divided into three categories – soil erosion, compaction, and soil sampling. Samples for analysis are collected from the forest floor (litter layer and O-horizon) and from underlying mineral soil in two equal increments down to about 8 inches. These soil samples are analyzed for chemical and physical properties in laboratories.

Soil sample collection.

PHOTO BY BARBARA CONKLING.



Mean organic carbon concentrations in forest floor soils of the Western United States. By plot, 1998 and 1999 data. Plot to plot differences can be caused by climate, forest, and understory vegetation.

How Can Soil Condition Indicator Data Be Used? There are three main components to the data:

- Chemical and physical information—to evaluate characteristics, such as fertility; potential of the soil system to accommodate stressors, such as acid precipitation or heavy metals; bulk density; and carbon. The ability to measure soil carbon content consistently on a national set of forest plots will contribute greatly to current information about how forest soils store and release carbon.
- Soil erosion information—to assess the potential for accelerated erosion in response to management practices or naturally occurring events. For example, the Watershed Erosion Prediction Project (WEPP) model (Elliot and others 2000), currently being evaluated for use with the soils plot data, makes erosion predictions for different forest ages and disturbance types.
- Soil compaction information—to assess the status and changes in the amount of compaction and the type observed, such as ruts, trails, or areas. Compaction can be caused, for example, by repeated passage of heavy machinery or vehicles.

QUALITY ASSURANCE PROGRAM

What Is the Quality Assurance Program? The FIA continuous quality management program is designed to control, correct, and document measurement uncertainty. This process utilizes quality control (QC) and quality assurance (QA) techniques to continually improve field and laboratory measurements. The program includes extensive training, auditing, and timely feedback to field crews. FIA is also working to include the QA process in information management, data analysis, and reporting. The overall QA program has many components, including a carefully planned, executed, and documented training program for each crew member. The training program requires crew members to pass both written and field tests in order to be certified to collect data.

Two main kinds of checks or audits are done during data collection: (1) those done by a qualified QA crew that has the data collected by the field crews and checks it in the field themselves (field crew may or may not be present during the check) and (2) a qualified QA crew performs a complete plot reinstallation and remeasurement of a previously measured plot (field crew is not there and does not know which plot will be remeasured).

Why Is QA Important? The QA checks provide different kinds of information to help improve data collection and to document the quality of the data collected. This information helps FIA analysts determine if data are appropriate for particular analysis techniques and models.

How Are QA Data Used? One use of the complete plot reinstallation and remeasurement data is performance evaluation of the crews. The absolute magnitude of the differences (bias) between field crews and QA crews is compared to measurement quality objectives specified for each measurement. For example, in 1999, the average percent of trees measured that met the measurement quality objectives in all regions for all crown measurements (hardwoods and softwoods) was about 89 percent, with values ranging from 67 percent to 100 percent. These analyses help in data interpretation and in identifying problems in data collection that then leads to solutions.

GLOSSARY

Bioindicator plant – A plant that exhibits a unique, detectable, visible injury response when exposed to a particular stressor.

Core measurements – Measurements that must be made on all FIA plots using the FIA Field Methods Guide procedures.

Ecological unit – An area characterized by similar climate, soils, and topography. Grouped at various spatial scales, such as region, domain, province, section, land unit, and land type.

Exotic species – Nonnative species of plants or animals that often are invasive, competing with native species for space, nutrients, or light.

Forest land – Land that is at least 10 percent stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated.

FIA plot design – A fixed-area plot where most FIA measurements are collected without damage to the plot, and data can be stratified in analysis by forest types, disturbances, etc.

Hardwood – A dicotyledonous tree, usually broad-leaved and deciduous.

Lichen – Nonvascular organism that is a symbiotic combination of a fungus and algae. The fungus attaches to a variety of substrates such as trees, rocks, and soil. The algae get nutrients and water directly from the air and makes sugar for growth of both.

Nonforest land – Land that does not support or has never supported forests, and lands formerly forested where use for timber management is precluded by development for other uses.

pH (soil) – The degree of acidity or alkalinity of a soil.

Quality assurance – The overall system of management activities designed to assure quality data.

Quality control – Operational techniques and activities that are used to control the data acquisition process.

Softwood – A coniferous tree, usually evergreen, having needles or scale-like leaves.

Stressor – An agent that causes a plant to suffer damage or stress or be killed. Stressors can be living (biotic) – such as insects, diseases, mammals, or competing vegetation – or nonliving (abiotic) – such as chemical pollutants or weather extremes.

Tree – An individual of a tree species with a diameter at breast height or diameter at the root collar that is greater than or equal to 5.0 inches.

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