Detection Monitoring - Analysis and Interpretations of Forest Health Data in the U.S.
Korean Forest Conservation Movement – Forest Health Symposium

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Introduction to Detection Monitoring in Forest Health

The daily business of the United States Forest Service's Forest Inventory and Analysis program is to monitor the status and trends in forest resources across all states, territories, and U.S. affiliated island governments. Part of this program includes Detection Monitoring, where permanent field plots are measured on a cyclic basis to detect change in forest health attributes.

Detection monitoring occurs at different scales depending on the attributes measured. Standard inventory data that include tree species, diameter, height, and site description are measured on plots with a spatial intensity of 1 plot per 2,400 hectares (phase 2). Additional forest health attributes are measured on special forest health plots at an intensity of 1 plot per 39,000 hectares (phase 3). The indicators described in this paper are measured on the forest health plots (phase 3).

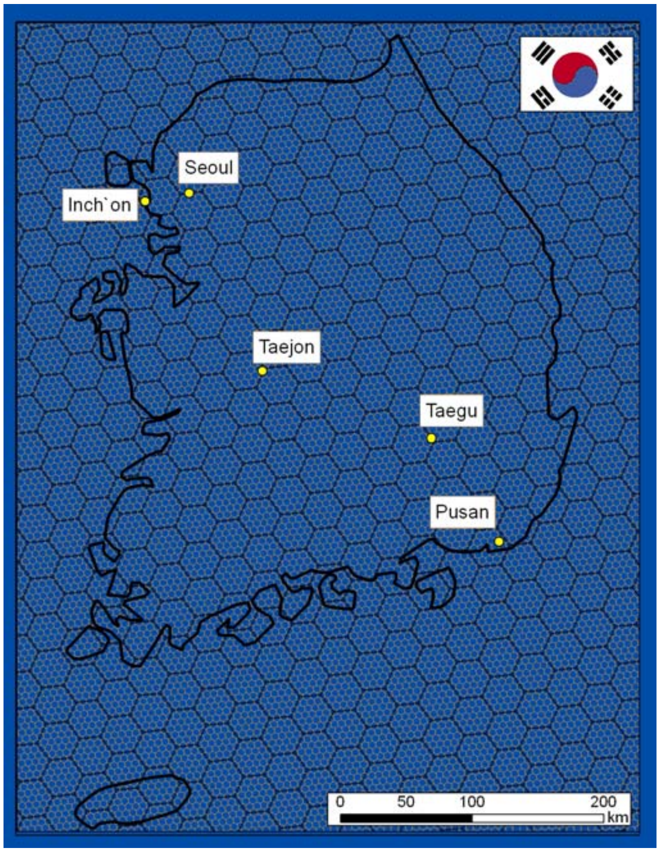
The standard inventory plots (phase 2) measure the status and changes in:

- Forest extent;
- Tree species abundance, volume, biomass, carbon mass;
- Tree species distribution;
- Age class distribution;
- Growth and mortality.

On the specialized forest health plots (phase 3), information is collected on:

- Tree crowns;
- Lichen communities;
- Soils;
- Ozone injury;
- Vegetation diversity and structure;
- Downed and dead wood on the forest floor.

To visualize the scale of inventory and forest health monitoring plots, the spatial intensity of standard inventory plots are represented by the small hexagons in the diagram. Forest health plots are located in each of the larger hexagons.



Forest health indicators measured at this broad scale are designed to be a first look at trends across ecosystems and must be summarized appropriately, taking into account the sample size. When trends are identified, special evaluation monitoring studies allow further investigation. This phased approach is an economical method to monitor forest health across large areas of forest. The indicators described below can be analyzed separately, but when combined and compared across indicators, they can help suggest appropriate methods that will assist in more detailed evaluation monitoring.

Tree crown condition

Why are tree crowns an indicator of forest health?

Tree crowns are a good indicator of stress for individual trees. When grouped into stands of trees, declining tree crowns can indicate a stand-wide stressor, such as insect outbreak, pathogens, climatic stress, soil toxicity, air quality degradation, and a wide variety of other large-scale stressors. Because tree crowns convert solar energy into food for the tree, severe impairment of this function can lead to spiraling decline. Reduced tree crowns have been shown to impair tree vigor and growth.

In addition to indicators of stress, the dimensions of tree crowns can be used to describe canopy fuel structure. Estimates of canopy bulk density are standard inputs into crown fuel models. Combined with canopy and understory layer information, they can be used to estimate fire spread both vertically and horizontally throughout a stand of trees.

Crown condition and structure can also be used to model wildlife habitat. Different species seek out different canopy characteristics for nesting, breeding, and obtaining food.

Who wants information about tree crowns?

Resource managers and pathologists need information on crown condition to predict mortality and detect possible insect and disease outbreak. Fuel managers and modelers use crown information to predict fire spread and fuels hazards. Wildlife biologists utilize crown information to associate species with favored canopy habitat.

What questions do forest managers and researchers ask about tree crown condition and canopy structure?

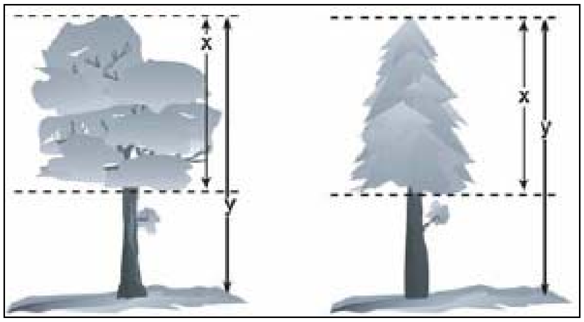
- What is the area of forest where tree crowns show signs of reduced density or dieback?
- Is there a spatial pattern to forest decline evidenced by reduced crown vigor?
- Are certain trees being differentially affected by pathogens according to their position in the canopy?
- On average, how continuous are canopy fuels in a region? Vertically? Horizontally?
- What is the average crown volume and surface to volume ratio for a forest type or region?
- Where is the optimal habitat for a certain species given a set of crown and canopy structure requirements?

How FIA approaches answering these questions

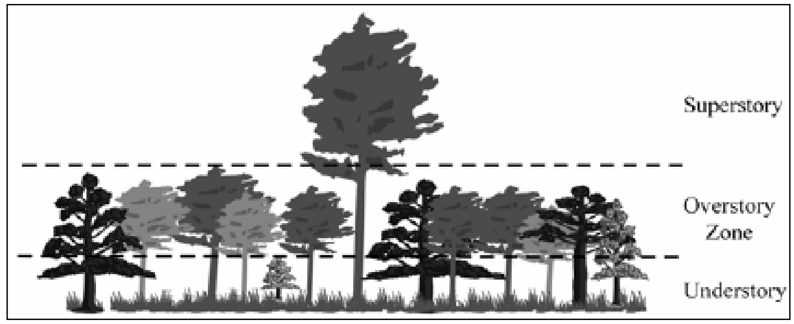
Tree crowns are measured for all live trees on the standard FIA forest health field plot. The crown indicator requires estimation of uncompacted crown ratio (see diagram), crown diameter (estimated via regression on height and stem diameter), crown density, crown dieback, foliage transparency, crown light exposure, crown position (see diagram), and crown vigor rating. Using these indicators, composite indicators are derived that include composite crown volume, crown surface area, crown production efficiency, and crown shape ratio (a ratio of crown diameter to crown length).

Analysis

Summary statistics can be used to determine the mean, median, standard deviation, and range of values for the crown condition variables. Histograms and cumulative distribution functions can be used to provide graphic information on the sampled population’s frequency distribution.



Crown Ratio = x / y



Canopy Position

Matching remeasured trees between time periods is one of the best ways to detect real change in the crown indicator variables through time. Analysis of variance and *t*-tests can be used to detect differences among groups for the same time period. Repeated measures analysis of variance can be used to detect differences in crown variables for two points or periods in time. These analyses are generally performed for the same species, but crown variables can be standardized to compare deviations from the mean among different species. Additionally, the crown variables can be used with other stand measurements to construct a model of expected crown condition, and then each variable can be compared as a deviation from that expected, modeled prediction. Surface estimation models, such as Kriging, can be use to generate continuous spatial estimates for the crown variables.

Example Products

Summary tables for the crown indicator variables are generated for each U.S. state's 5-year reports. These tables summarize crown vigor, crown density, dieback, foliage transparency, and changes for certain sizes of trees grouped by species. Graphs can be used to illustrate percentages of trees in different classes for each variable. Maps relating crown condition to tree basal area, growth, and mortality are also possible outputs. For example, crown dieback of hardwood trees could be mapped in relation to tree mortality according to region.

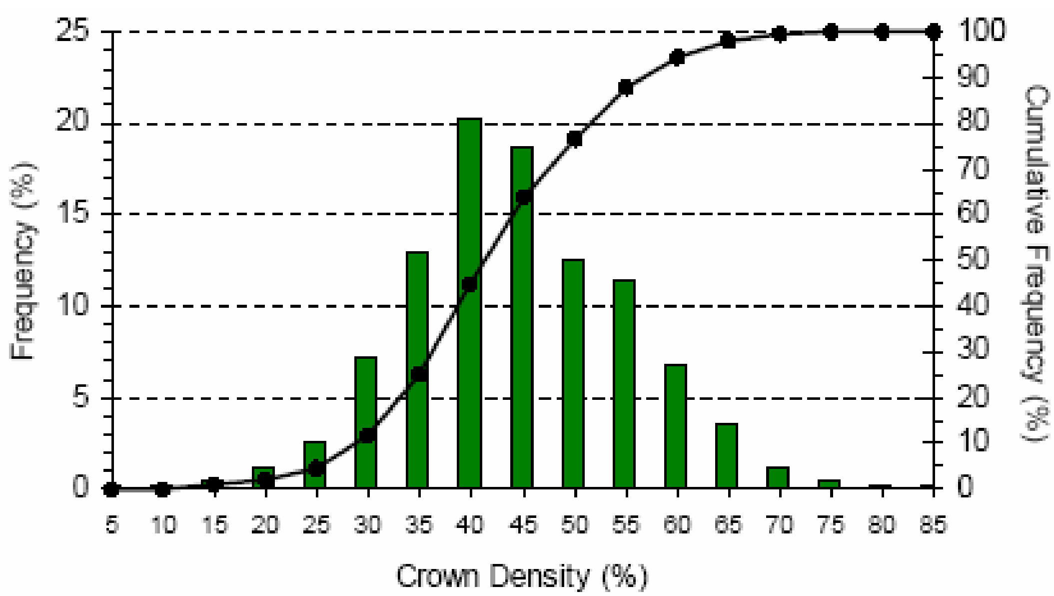


Table x. – Distribution of sapling crown vigor by species, [state], [year].

(Number of sampled saplings)

Species group	Crown Vigor Rating: Good	Fair	Poor	Total
Softwood species groups				
Eastern softwood species groups				
Longleaf and slash pines	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Loblolly and shortleaf pines	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Cypress	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Other eastern softwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Western softwood species groups	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Douglas-fir	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Ponderosa and Jeffrey pines	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Western woodland softwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Other western softwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx
All softwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Hardwood species groups				
Eastern hardwood species groups				
Select white oaks	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Select red oaks	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Other eastern hard hardwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Eastern noncommercial hardwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Western hardwood species groups	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Cottonwood and aspen	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Red alder	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Oak	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Other western hardwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Western woodland hardwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx
All hardwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx
All species groups	xx,xxx	xx,xxx	xx,xxx	xx,xxx

Notes:
Species are grouped in this example. When populating the actual tables, the Indicator Advisor recommends that species NOT be grouped.

Table x. – 5-year mean composite crown variable comparisons by species for all live trees, [state], [year].

Species group	1996 to 2000 panel totals				2001 to 2005 panel totals				5-year net change			
	Number of trees	Surface area	Crown Volume	Production efficiency	Number of trees	Surface area	Crown Volume	Production efficiency	Number of trees	Surface area	Crown Volume	Production efficiency
Softwood species groups												
Eastern softwood species grps												
Longleaf and slash pines	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Loblolly and shortleaf pines	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Cypress	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Other eastern softwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Western softwood species grps	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Douglas-fir	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Ponderosa and Jeffrey pines	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Western woodland softwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Other western softwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
All softwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Hardwood species groups												
Eastern hardwood species grps												
Select white oaks	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Select red oaks	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
.	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Other eastern hard hardwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Eastern noncomm hardwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Western hardwood species grps	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Cottonwood and aspen	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Red alder	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Oak	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Other western hardwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
Western woodland hardwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
All hardwoods	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx
All species groups	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx	xx,xxx

Lichen communities
Why are lichen communities of special interest for forest health?
Lichens absorb nutrients and water directly from the environment surrounding them on the branches of trees. Many air pollutants are absorbed and preserved in the tissues of lichens. Lichens act as an index of cumulative air quality. Certain lichen communities are found only in areas of good air quality, and others are found in areas with poor air quality; thus, the communities of lichens found in different areas can serve as an indicator of long-term air quality.

Macrolichen communities occur wherever there are trees and they are cheaper to monitor than installing a network of instruments to measure air quality. Lichen communities can also help supplement air quality instrumentation by allowing monitoring in remote areas and adding to the spatial resolution of existing air quality networks.

Lichens also play a significant role in fixing atmospheric nitrogen that can then be utilized by other plants and animals. Lichens provide a food source for many mammals and arthropods. Changes in the abundance of lichens translates into changes in the abundance of food for many forest organisms.

Lichen communities also function as an indicator of local climate. As with air quality, certain species and communities are only found in certain climates. Local lichen communities can extend the resolution of local climate networks measured through instrumentation.

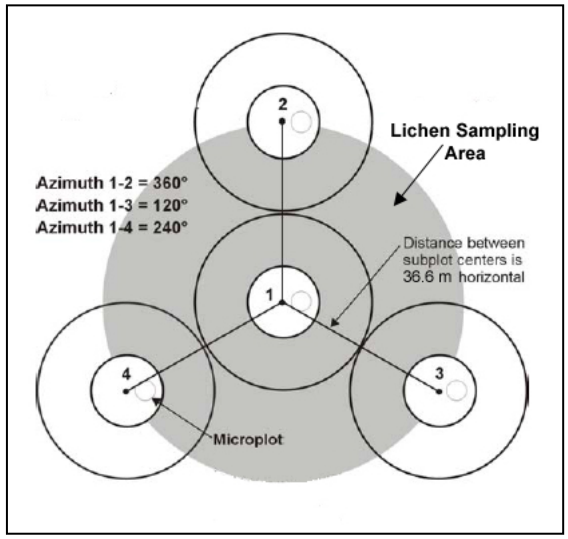
Who uses information about lichen communities?
Air quality researchers and monitoring agencies, like state-level departments of environmental quality and the federal Environmental Protection Agency, can supplement their instrumental networks with lichen community data. Researchers interested in vegetation diversity also use the lichen community data to investigate trends in community composition across gradients of climate and topography. Climate researchers use the lichen data to help intensify the resolution of local climate data.

What types of forest health questions can the lichen indicator help answer?

- What effect does air quality have on the diversity of species in forests?
- What is the spatial distribution of pollution tolerant lichen communities?
- Are there localized pollution effects that our air quality instrumentation networks do not reveal?
- How does community composition change across pollution gradients?
- What pollutants are lichens absorbing in different locations across the landscape?
- Are there localized climatic effects that our climate instrumentation networks do not reveal?
- As air quality changes, how do forest species and communities respond?

How does FIA try to answer these questions
FIA field crews collect lichen species and abundance data on FIA plots within a 36.6 meter radius circle that excludes the FIA subplots. A search is conducted for a minimum of 30 minutes and a maximum of 120 minutes to sample macrolichens occurring at a height from 1 meter to 2.4 meters on trees and on any fallen branches. Collectors are trained specialists but are not expert lichenologists. Training and certification ensures these specialists can identify lichens to the level of unique species. Specialists are expected to discern unique species for at least 65% of what an expert lichenologist would collect. Lichen specimens are sent to expert lichenologists for species identification. Tissue

samples from each species are sent to a laboratory for analysis of nitrogen (N), sulpuhur (S), and lead (Pb) content.



Analysis

Raw lichen data provides approximate diversity indices (alpha, beta, gamma diversity). These indices are approximate because the spatial sampling intensity is relatively low and lichen specialists may not capture the complete species diversity on a plot. Summary statistics are generated for the area of interest including the mean, range, and standard deviation for the variable of interest (e.g., abundance by species or groups of nitrogen tolerant species; species richness; N, S, and Pb tissue content).

Lichens on plots can be summarized by assigning a plot score based on that plot's species composition in comparison with all plots in a region or along a gradient. To assign these plot scores, a lichen gradient model must first be constructed that summarizes how lichen communities change across an air quality gradient and across a climatic gradient. Gradient models are developed using an independent set of systematic sample plots that include a diverse range of elevation, pollution, and climatic characteristics (temperature, precipitation, fog incidence; several models are available that estimate climatic characteristics based on a series of measurement stations and their topographic position). The lichen gradient models are constructed using nonmetric multidimensional scaling ordination (NMS in the computer program PC-ORD). The ordination groups plots with similar species composition along gradients of both air quality and climate. Once the gradient model has been created, the full set of plot data is used in the model to assign plot scores that link each plot to its location on the air quality and climatic gradients.

Trend analysis, comparing remeasured plots' species richness index, and their scores on air quality and climate gradients, can be conducted using non-parametric statistics (e.g. analysis of variance on ranked values).

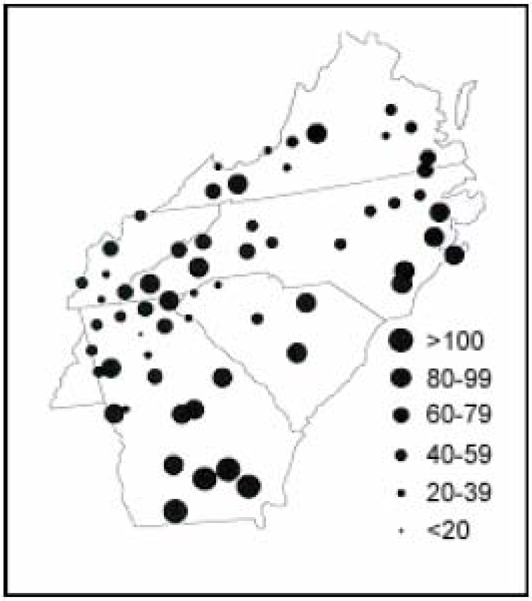
Indicator species analysis is also used to associate individual lichen species with clean, intermediate, and polluted plots, as well as climatic zones.

Example products

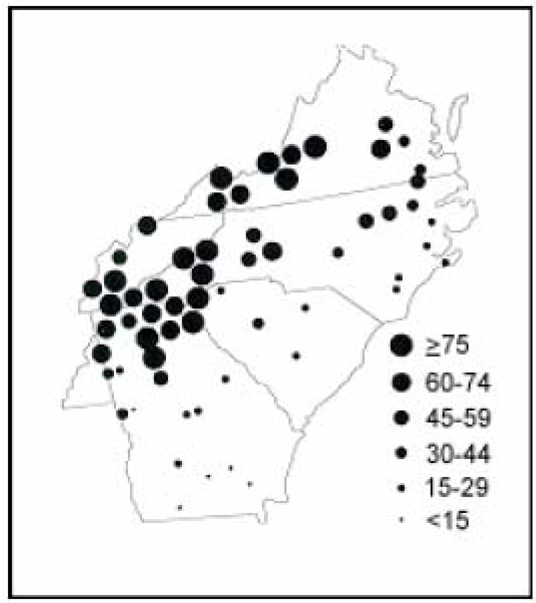
Gradient models have been developed for portions of the U.S. Results from California demonstrate a strong relationship between known air quality monitoring networks and lichen indicators. The gradients and plot scores on those gradients extends the network of pollution monitoring instruments to unpopulated areas and remote areas with high recreational use. Plot scores have revealed areas of high pollution near national parks and wild lands that see high automobile traffic.

Core products for 5-year state reports include tables of summary statistics, maps, and the gradient models. Species richness and abundance data are summarized regionally. Nitrophytic (nitrogen tolerant) species occurrence is associated with instrumental air quality data and summarized according to area of forest type.

Example products



Regional distribution of scores on the air quality gradient as expressed by the lichen community. Larger circles indicate better air quality. (Southeastern U.S.; Source: Lichen Fact Sheet: http://www.fia.fs.fed.us)



Regional distribution of scores on the climatic gradient as expressed by the lichen community. Larger circles indicate lichens associated with cooler climates. (Southeastern U.S.; Source: Lichen Fact Sheet: http://www.fia.fs.fed.us)

Table x. – Summary of lichen community indicator species richness, [year].

Parameter	ABC Region	State 1	State 2	State 3
Number of Plots	114	39	42	33
Number of Plots by Lichen Species Richness Category:1,3				
<6 species	30	13	5	12
6-15 species	67	21	29	17
16-25 species	16	5	8	3
>25 species	1	0	0	1
Range of Species Richness per plot (Low - High)	0 - 27	0 – 22	2 - 23	0 - 27
Average Lichen Species Richness per plot (alpha diversity)	9.53	8.64	11.26	8.36
Standard Deviation of Lichen Species Richness per plot	5.72	5.37	4.75	6.80
Species turnover rate (beta diversity)2	15.11	8.91	9.33	9.45
Total Number of Species per area (gamma diversity)	144	77	105	79

1Categories are based on a cumulative distribution function (CDF) of plot species richness for the SE gradient model.
2Beta diversity is calculated as gamma diversity divided by alpha diversity.
3Plots with no lichens ARE included.

FIA LICHEN COMMUNITY INDICATOR CORE TABLE 1 – SPECIES RICHNESS EXAMPLE (above):

Summary of lichen community indicator species richness parameters for YEARX in FIA ABC Region and ZQ Lichen Gradient Region and states State 1, State 2, and State 3. Species richness of plots varies with climate, air quality, and other plot characteristics such as tree species composition and stand age. Species richness also reflects completeness of species capture by field crew. In this example, average species richness is highest for State 2. Standard deviation and species turnover rate are highest for State 3, indicating greater differences in factors affecting lichen species richness than for other states in the region. Correlations with other plot vegetation and environmental variables would be needed to support assertions of causation for differences in lichen species richness. Estimates of total species richness of a region or subregion are strongly influenced (often in a nonlinear manner) by the number of plots sampled, so this parameter is appropriate for comparing between areas and years only when numbers of plots are very similar. Comparisons of parameters between years for the same areas are appropriate for trend analysis, while comparisons of parameters between areas within a region are appropriate for description of differences within a region.

Data like those in this table are available for any region or state in any year sampled, regardless of whether a regional gradient model is in place. Summaries of data for any geographic area represented by fewer than 20 plots should not be considered reliable, and summaries for geographic areas not representing appropriate ecological units should be interpreted with care

Table x. – Summary of lichen community indicator air quality index parameters, [year].

Parameter	ABC Region	State 1	State 2	State 3
Number of Plots Surveyed	114	39	42	33
Number of Plots by Air Quality Index Category: 1,2				
Lowest (poorest)	40	12	7	17
Intermediate	33	11	12	10
Highest (best)	38	15	23	0
Air Quality Index Extremes	-18.70 to 128.38	-18.70 to 118.70	7.62 to 128.38	-8.06 to 61.61
Average Score on Air Quality Index	59.14	60.48	74.24	33.78
Standard Deviation on Air Quality Index	36.42	41.64	31.58	18.15

1Categories are based on a cumulative distribution function (CDF) of plot air quality gradient scores for the SE gradient model.
2Plots with no lichens are NOT included.

FIA LICHEN COMMUNITY INDICATOR CORE TABLE 2 – AIR QUALITY INDEX SCORES. EXAMPLE (above):

Summary of lichen community indicator air quality index parameters for YEARX in FIA ABC Region and ZQ Lichen Gradient Region and states State 1, State 2, and State 3. Air quality scores are based upon a multivariate gradient model that uses variation in species composition to assess air quality and response to climate/environment. The primary axis of variation in most gradient models is a climatic axis in which community composition varies with environmental variables. Pollution is typically a secondary or tertiary axis. A subregion or state with a higher average score and/or more plots in higher air quality index categories has lichen communities characteristic of relatively cleaner air (better air quality) when compared either with other subregions/states or with the same area in other years. A subregion or state with a greater range in air quality extremes and/or a larger standard deviation of index scores has lichen communities characteristic of a greater range in air quality when compared either with other subregions/states or with the same area in other years. In this example, State 2 has lichen communities indicating better air quality on average than either State 1 or State 3, and State 1 has the greatest range in response of lichen communities to air quality.

Data like those in this table are available for a region or state and a sampled year only when a regional gradient model is in place. Summaries of data for any geographic area represented by fewer than 20 plots should not be considered reliable. Average and standard deviation of air quality index scores and distribution of plots in index categories for the entire region are useful primarily for comparison between years and with averages for internal subregions or states. Regional data should not be compared quantitatively with regional data for other lichen gradient regions until interregional calibrations have been performed.

Table x. – Summary of lichen community climate index parameters, [year].

Parameter	ABC Region	State 1	State 2	State 3
Number of Plots Surveyed	114	39	42	33
Number of Plots by Climate Index Category: 1,2				
Most coastal, S, warmest	38	18	16	0
Warm	23	12	11	0
Cool	25	4	11	10
Most mountainous, N, coolest	25	4	4	17
Climate Index Extremes	-11.69 to 120.37	-6.47 to 120.37	-11.69 to 90.49	60.60 to 112.90
Average Score on Climate Index	46.47	33.52	36.85	79.66
Standard Deviation on Climate Index	32.37	31.62	25.95	15.74

1Categories are based on a cumulative distribution function (CDF) of plot climate index gradient scores for the SE gradient model.
2Plots with no lichens are NOT included.

FIA LICHEN COMMUNITY INDICATOR CORE TABLE 3 – CLIMATE INDEX SCORES. EXAMPLE (above):

Summary of lichen community indicator climate index parameters for YEARX in FIA ABC Region and ZQ Lichen Gradient Region and states State 1, State 2, and State 3. Climatic scores are based upon a multivariate gradient model that uses variation in species composition to assess air quality and response to climate/environment. The primary axis of variation in most gradient models is a climatic axis in which community composition varies with environmental variables. A subregion or state with a higher average score and/or more plots with numerically larger climate index categories means that area has lichen communities characteristic of a relatively cooler climate when compared either with other subregions/states or with the same area in other years. A subregion or state with a greater range in climate extremes and/or a larger standard deviation of index scores shows more variable response of lichen communities to climate when compared either with other subregions/states or with the same area in other years. In this example State 3 has lichen communities characteristic of cooler climates than the other states, while State 1 has the greatest range in climate response of lichen communities.

Data like those in this table are available for a region or state and a sampled year only when a regional gradient model is in place. Data summaries for any geographic area represented by fewer than 20 plots should not be considered reliable, and summaries for geographic areas not representing appropriate ecological units should be interpreted with care. Average and standard deviation of climate index scores and distribution of plots in index categories for the entire region are useful primarily for comparison between years and with averages for internal subregions or states. Regional data should not be compared quantitatively with regional data for other lichen gradient regions until interregion calibrations have been performed.

Forest soils

Why are forest soils important to monitor?

To sustainably manage forests, information about the status and trends in soils is very important. Soils provide the direct contact with nutrients, microorganisms, and physical stability that trees require. Soils transport and filter water. Conservation of soil resources includes maintaining macro- and micronutrient exchange capacity, minimizing erosion and compaction, and protecting the physical properties of soils.

Soils provide habitat for ground-dwelling rodents, insects, fungi, and a wide range of other organisms that help in the process of bioturbation and nutrient cycling. The processes and organisms are fragile and can be degraded easily. Once degraded, the soils may not recover to their original state. Compaction and erosion are leading indicators of soil degradation. Monitoring for changes in soils helps us understand our impacts on soils in relation to the management of forests.

Who uses information about forest soils

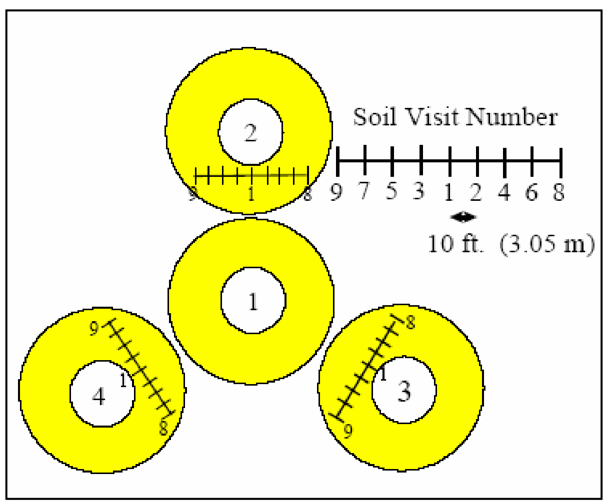
Forest managers are interested to know about changes in the ecosystem that will affect the growth and mortality of trees in their forests. Water quality managers need information on compaction, erosion, and toxins in soils to better manage the water supply. The Environmental Protection Agency needs information about the prevalence and persistence of soil and water toxins. The Natural Resource Conservation Service (NRCS) also monitors soil quality and suitability of different soils for various land uses. Soils information from the FIA analysis can help supplement and spatially intensify the work of these other agencies.

What are the typical questions FIA soils data can help answer?

- What percent of forest land is degraded by compaction?
- On what area of the forest is erosion a potential problem, and where?
- Are there significant concentrations of toxic metals associated with certain forest types?
- Are toxic metals associated with reductions in growth?
- How are macro- and micronutrient levels changing through time and across landscapes?
- How much carbon is being stored in soils?
- What is the spatial distribution of carbon and nitrogen in forests for the region?

How does FIA help answer question about forest soils?

Forest floor samples are collected by field crews on 3 points per plot. Mineral soil is sampled at one location and sent to a laboratory for analysis of chemical and physical properties. The mineral soil is divided into two depth samples: 0 – 10 cm, and 10 - 20 cm. The lab results for the mineral and forest floor samples include: bulk density, coarse fraction, pH, exchangeable cations (Na, K, Mg, Ca, Al, S), trace metals (Mn, Fe, Ni, Cu, Zn, Cd, Pb), total N, extractable P, and organic, inorganic, and total C. Erosion and compaction are surveyed on all subplots. The percent of bare soil, ground cover, compacted area, slope, slope length, types of compaction, and indicators of erosion are all recorded.



Analysis
Soils variables collected in the field and derived in the lab are averaged at the plot level. Summary statistics use the plot-level means to provide an overview of soils across a forest type or region. The range, mean, standard deviation, and distribution of values for the chemical analyses provide the foundation for comparison across forest types, regions, and for comparison at different points in time. Abrupt changes indicate there may be a problem that should be further investigated with more detailed, localized study at the evaluation monitoring level. It's important to note that soil chemistry and physical properties are variable over short distances. With this in mind, results should be interpreted and compared with long-term average soil characteristics.

Compaction can be summarized for a forest type or region by the percent of area experiencing the compaction. Changes in compaction can be correlated with changes in understory species composition, percent bare soil, and changes in evidence of erosion.

Erosion is estimated for the field plots using the Universal Soil Loss Equation (USLE) or the Water Erosion Prediction Project (WEPP) models. The percent bare soil, slope, length of slope, soil texture, and precipitation-event-strength are some of the inputs for these models to predict erosion. Within a climate zone, the percent bare soil and slope are often good indicators of relative erosion potential.

Example products
As with the other forest health indicators, soil variables are summarized for each state's 5-year report and in more detailed studies specific to a region, forest type, or special resource. Core tables and maps help explain the status and any changes occurring at the landscape scale. Maps help explain trends in soils across the landscape, such as, climate and elevation gradients. For example, spatial trends in soil carbon are often associated with an elevation gradient. Maps of erosion and compaction are often helpful showing the impact of development and recreation in forests as they relate to urbanized areas.

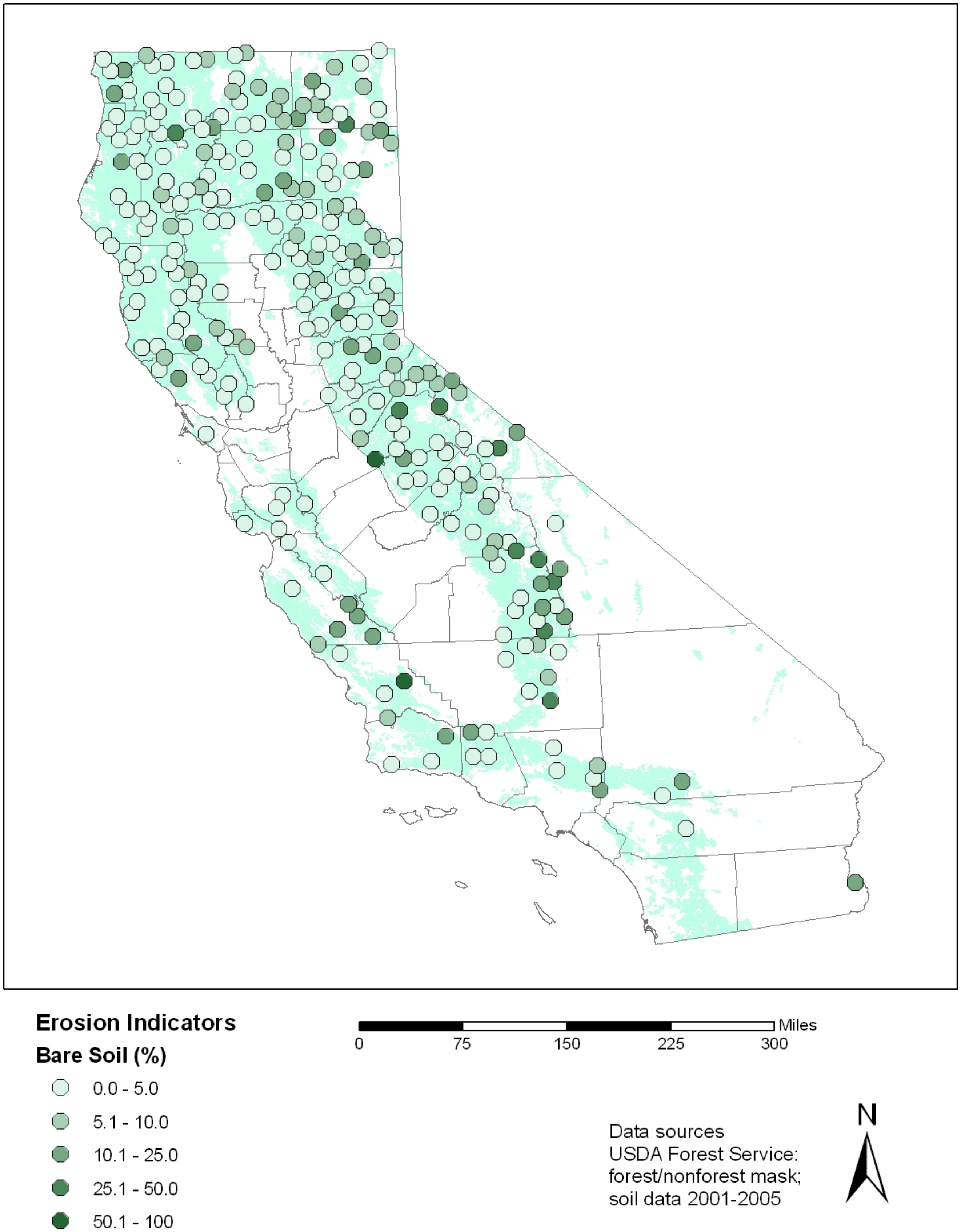

Erosion Indicators
Bare Soil (%)
0.0 - 5.0
5.1 - 10.0
10.1 - 25.0
25.1 - 50.0
50.1 - 100
0
75
150
225
300
Miles
Data sources
USDA Forest Service:
forest/nonforest mask;
soil data 2001-2005
N

Table 48a. – Properties of forest floor by forest type, Oregon, 2001, 2003 - 2005.

Soil Layer	Forest Type	Number of Samples	Moisture Content (Oven Dry Basis)	Forest Floor Thickness (cm)	Organic Carbon (percent)	Total Nitrogen (percent)
Forest Floor	Forest Type					
	Aspen	1	9.11	0.50	33.10	1.44
	Bigleaf maple	2	138.42	0.96	28.56	1.07
	California black oak	1	19.22	0.67	38.34	0.88
	California laurel	1	61.05	1.25	18.89	0.47
	Canyon live oak / interior live oak	1	14.50	3.58	36.20	0.63
	Cercocarpus woodland	1	5.40	1.13	38.40	1.15
	Douglas-fir	82	76.91	3.42	34.54	0.89
	Engelmann spruce	1	18.92	1.75	31.54	1.14
	Grand fir	7	12.57	1.93	34.81	0.97
	Lodgepole pine	19	22.51	1.64	39.19	0.77
	Mountain hemlock	5	39.93	1.41	40.12	1.03
	Noble fir	3	39.86	1.36	38.32	1.01
	Nonstocked	9	74.90	0.41	31.72	0.92
	Oregon white oak	4	10.86	0.96	29.01	0.96
	Pacific madrone	4	31.98	0.86	28.45	0.69
	Ponderosa pine	48	25.82	2.08	35.03	0.86
	Red alder	11	129.35	2.81	35.40	1.30
	Sitka spruce	2	100.24	10.25	44.82	1.44
	Subalpine fir	6	154.39	2.59	39.20	1.23
	Sugar pine	1	7.82	1.25	31.57	0.48
	Tanoak	4	76.37	1.85	39.67	0.85
	Western hemlock	7	166.14	4.55	41.75	1.29
	Western juniper	25	14.34	0.78	27.50	0.76
	Western white pine	1	21.10	3.75	43.46	0.65
	White fir	9	36.53	3.03	32.42	0.77

Table x. – Properties of mineral soils by forest type, Oregon, 2001, 2003 - 2005.

Soil Layer	Forest Type	Number of Samples	Texture (Most Common)	Moisture Content (Oven Dry Basis)	Coarse Fragments (Percent)	Bulk Density (g/cm^3)
Mineral	Forest Type					
(0-10 cm)	Aspen	1	Clayey	21.08	17.48	ND
	Bigleaf maple	2	Loamy	29.91	56.12	0.87
	California black oak	1	Clayey	9.83	42.30	1.19
	Canyon live oak / interior live oak	1	Coarse Sand	6.95	57.52	0.94
	Cercocarpus woodland	1	Sandy	2.67	64.13	ND
	Douglas-fir	76	Loamy	30.30	36.09	0.72
	Grand fir	7	Loamy	12.67	19.78	0.71
	Lodgepole pine	18	Sandy	15.15	12.16	0.68
	Mountain hemlock	3	Sandy	36.73	32.85	0.65
	Noble fir	3	Loamy	14.89	37.01	0.85
	Nonstocked	5	Clayey	17.21	18.04	0.83
	Oregon white oak	3	Clayey	15.27	39.09	1.13
	Pacific madrone	3	Clayey	12.80	43.24	1.14
	Ponderosa pine	41	Loamy	10.90	24.28	0.93
	Red alder	11	Clayey	44.51	25.24	0.60
	Sitka spruce	3	Clayey	40.34	2.62	1.18
	Subalpine fir	5	Loamy	22.87	22.52	0.71
	Sugar pine	1	Clayey	21.04	11.93	0.70
	Tanoak	3	Clayey	28.57	35.60	0.60
	Western hemlock	6	Loamy	62.55	42.07	0.43
	Western juniper	20	Loamy	9.62	16.49	0.96
	Western white pine	1	Sandy	22.77	9.77	0.33
	White fir	9	Loamy	13.08	25.14	0.75

Table x. – Chemical properties of mineral soil layers by forest type, Oregon, 2001, 2003-2005,

Soil Layer	Forest Type	Number of Samples	pH		Organic Carbon	Inorganic Carbon	Total Nitrogen	Extractable Phosphorus	Exchangeable Cations						Extractable Sulfur
			H_2O	$CaCl_2$	(%)	(%)	(%)	(mg/kg)	Na	K	Mg	Ca	Al	ECEC	(mg/kg)
									(cmolc/kg)						
Mineral 1	Forest Type														
(0-10 cm)	Aspen	1	5.92	5.20	8.94	0.35	0.81	127.00	0.00	676.65	219.50	2896.00	9.63	18.09	1.85
	Bigleaf maple	2	5.80	5.20	5.17	0.20	0.26	21.97	0.78	352.54	226.25	1714.50	37.17	11.73	2.33
	California black oak	1	5.64	4.88	3.31	0.18	0.11	5.90	3.32	105.81	350.40	1421.00	5.16	10.31	0.18
	Canyon live oak / interior live oak	1	6.30	5.77	5.59	0.38	0.18	43.75	7.63	465.20	303.30	2990.00	2.70	18.67	1.57
	Cercocarpus woodland	1	6.21	5.60	4.12	0.18	0.35	15.54	36.14	248.80	329.30	2782.00	0.00	17.38	1.48
	Douglas-fir	75	5.64	4.95	5.85	0.24	0.25	37.19	17.84	337.64	312.67	2001.90	108.25	14.71	6.60
	Grand fir	7	6.53	5.85	3.58	0.20	0.17	48.65	16.99	622.06	255.76	2579.88	2.20	16.67	10.68
	Lodgepole pine	19	5.87	5.07	3.43	0.16	0.13	66.13	15.44	256.32	107.74	840.23	23.73	6.07	3.07
	Mountain hemlock	2	5.19	4.51	2.99	0.19	0.09	35.55	1.07	45.61	8.30	181.47	55.28	1.71	5.34
	Noble fir	3	5.94	5.20	4.06	0.24	0.14	10.00	3.61	252.29	33.86	750.83	15.34	4.86	7.52
	Nonstocked	5	6.43	5.74	3.11	0.22	0.21	22.80	19.45	466.67	502.92	1974.46	33.01	15.63	3.04
	Oregon white oak	3	6.44	5.82	2.54	0.25	0.16	26.62	10.36	270.22	379.23	3493.13	1.73	21.30	2.70
	Pacific madrone	3	5.84	5.29	3.84	0.26	0.18	35.44	4.01	265.24	447.07	3210.33	4.15	20.44	2.20
	Ponderosa pine	41	6.26	5.57	3.06	0.18	0.15	52.69	15.89	526.45	345.09	2134.77	6.94	14.98	4.09
	Red alder	11	4.58	4.03	8.57	0.30	0.52	12.17	32.01	206.64	296.62	1150.58	431.89	13.65	10.56
	Sitka spruce	2	4.44	3.70	11.79	0.38	0.71	4.07	107.36	94.69	183.95	165.02	626.80	10.01	18.45
	Subalpine fir	5	6.05	5.37	6.70	0.26	0.38	30.80	5.48	488.58	199.53	2466.42	72.47	16.03	8.46
	Sugar pine	1	5.09	4.23	3.88	0.10	0.15	0.51	8.76	122.10	83.52	244.30	484.90	7.65	12.13
	Tanoak	3	4.92	4.18	6.04	0.19	0.25	3.33	14.44	99.24	50.63	153.21	312.10	4.97	10.93
	Western hemlock	6	4.98	4.27	15.47	0.37	0.64	6.04	25.06	238.16	333.50	1418.11	264.43	13.48	17.39
	Western juniper	19	6.52	5.91	2.90	0.19	0.24	28.10	27.05	450.50	511.08	2372.62	7.54	17.40	5.71
	Western white pine	1	5.05	4.24	9.84	0.09	0.20	23.55	2.71	147.90	20.15	220.20	51.99	2.23	13.24
	White fir	9	5.95	5.13	3.79	0.22	0.16	61.34	9.83	344.48	111.40	1167.91	17.11	7.86	4.48

Table x. – Chemical properties (trace elements) of forest floor and mineral soils by forest type, Oregon, 2001, 2003-2005,

Soil Layer	Forest Type	Number of Samples	Extractable Mn	Fe	Ni	Cu	Zn	Cd	Pb
			---------- mg/kg						----------
Mineral (0-10 cm)	Forest Type								
	Aspen	1	14.25	0.19	0.52	0.00	0.34	0.07	0.00
	Bigleaf maple	2	23.34	0.33	0.01	0.00	0.08	0.03	0.04
	California black oak	1	22.04	0.00	0.00	0.00	0.00	0.01	0.00
	Canyon live oak / interior live oak	1	18.06	0.00	0.00	0.00	0.01	0.12	0.00
	Cercocarpus woodland	1	4.60	0.00	0.00	0.00	0.11	0.06	0.00
	Douglas-fir	75	43.35	3.28	0.14	0.00	1.01	0.04	0.07
	Grand fir	7	22.90	0.30	0.04	0.00	0.12	0.03	0.00
	Lodgepole pine	19	22.58	0.49	0.04	0.00	0.41	0.04	0.14
	Mountain hemlock	2	21.94	0.28	0.00	0.00	0.45	0.00	0.01
	Noble fir	3	31.51	0.13	0.00	0.00	0.13	0.03	0.01
	Nonstocked	5	29.51	0.41	0.12	0.00	0.03	0.02	0.05
	Oregon white oak	3	8.40	0.00	0.18	0.00	0.00	0.06	0.12
	Pacific madrone	3	26.79	0.40	0.04	0.00	0.86	0.04	0.00
	Ponderosa pine	41	27.01	0.59	0.06	0.00	0.28	0.07	0.09
	Red alder	11	30.52	17.07	0.07	0.00	1.34	0.05	0.11
	Sitka spruce	2	1.58	68.39	0.38	0.00	0.59	0.09	0.00
	Subalpine fir	5	17.09	0.65	0.04	0.00	0.22	0.04	0.14
	Sugar pine	1	284.60	0.00	0.14	0.00	0.67	0.10	0.00
	Tanoak	3	31.78	1.67	0.36	0.00	0.65	0.04	0.00
	Western hemlock	6	57.37	6.88	0.24	0.00	4.06	0.04	0.28
	Western juniper	19	8.62	0.79	0.19	0.00	0.04	0.05	0.05
	Western white pine	1	33.94	0.00	0.00	0.00	1.47	0.06	0.34
	White fir	9	26.78	0.06	0.02	0.00	0.59	0.08	0.03

Table x. – Compaction, bare soil, and slope properties by forest type, Oregon, 2001, 2003-2005,

Forest Type	Number of Plots Sampled	Plots Reporting Compaction	Compacted Area per Plot (%)	Bare Soil Cover (%)	Slope (%)
Aspen	1	0	0	17.5	27.5
Bigleaf maple	2	1	18.75	3	25
California black oak	1	0	0	1	35
Canyon live oak / interior live oak	1	0	0	5	70
Cercocarpus woodland	1	0	0	30	50
Douglas-fir	69	26	7.13	5.16	40.77
Engelmann spruce	1	1	26.67	5.33	37.5
Grand fir	7	3	6.07	4.23	28.29
Lodgepole pine	18	5	3.12	20.11	10.56
Mountain hemlock	3	1	13.33	15.17	10.33
Noble fir	2	1	14.38	10.75	22.5
Nonstocked	11	2	4.66	29.25	27.29
Oregon white oak	4	1	18.75	4.94	27.5
Pacific madrone	2	0	0	2.5	55
Ponderosa pine	46	16	2.81	11.08	19.85
Red alder	8	3	14.17	18.63	40.67
Sitka spruce	1	0	0	1	0
Subalpine fir	5	1	0.25	5.47	47.5
Sugar pine	1	0	0	4	0
Tanoak	2	1	2.5	4.67	62.5
Western hemlock	5	3	27.33	11.68	48.4
Western juniper	25	9	2	23.61	18.68
Western white pine	1	0	0	2.33	18
White fir	9	4	6.97	10.92	15.75

Ozone injury

Why ozone is important

Ozone is toxic to humans and corrosive to metals, stone, and concrete. Ozone is frequently measured at phytotoxic levels. There are demonstrated negative impacts on plant growth. Ozone toxicity influences succession, species composition, and pest susceptibility. Injury is visible on the leaves and needles of plants. Ozone is widespread and background levels are increasing across the planet. Ground level ozone is generated through natural and human activities, but primarily through the exhaust of our vehicles and industries.

Who needs information on ozone injury?

In the U.S. air quality is monitored by the Environmental Protection Agency (EPA). The network for measuring ozone is expensive to maintain and easily supplemented by biomonitoring in locations where air quality is not directly measured. Forested and rural areas are often not served well by the direct measurement of air quality. Biomonitors allow the extension of air quality assessment. Forest managers are keenly interested in the data to help them relate incidence of dieback, mortality, insect outbreak, decreased growth, and other forest health concerns to possible causes.

What questions are we trying to answer with this indicator?

- How is foliar injury distributed across the landscape?
- How is foliar injury associated with climate and climatic gradients?
- How does ozone injury change through time and in relation to air quality controls?
- What is the relationship between measured ozone levels and plant injury?

Approach to answer the questions

FIA uses a biomonitoring approach to track ozone injury and relate it to measured ozone levels from ozone monitoring stations. A biomonitor is a living organism that is used to assess the impacts of an external force on that living organism. In this case, the leaves and needles of plants are used to monitor the cumulative effects of ozone on the particular species at a particular site. The FIA network of biomonitoring sites (biosites) is a representative sample across the landscape that is on a different grid of plots than traditional FIA plots. The grid of biosites is different because ozone is best monitored in open areas and by using specific indicator plants.

Analysis

To summarize ozone injury on the biosites, we calculate a biosite index (see box below). The biosite index is a measure of average injury for a biosite plot calculated as the amount of injury multiplied by the severity of the injury for each species and averaged for all species on a biosite. Each biosite is visited each year to rate the injury and calculate a biosite index.

The biosite index serves as the basis for further analysis and mapping. Biosite index is often further generalized for analysis by averaging the biosite index for a period of 3 to 5 years on a biosite. Fluctuations in climate among years can lead to variability in plant response to ozone, so an average biosite index is often a better representation of average ozone injury conditions. Generally, drought tends to result in less ozone damage because plants close their stomata under dry conditions and thus also reduce their internal exposure to ozone.

Injury index for each plant:
AMT = injury amount
SEV = injury severity

Injury index for each species:
N1 = the number of injured plants
N2 = the number of evaluated plants
A = N1 / N2
B = ∑[(AMT) (SEV)] / N1
Species Index = (A)(B)

Biosite injury index:
N3 = the number of evaluated species
Biosite Index = ∑(Species Index) / N3

Using the biosite index for biosites across a region, a map of injury can be built directly from the plots. Additionally, a surface map can be produced where values between plots are estimated using Kriging.

Correlation analysis can be used to evaluate associations between measured climate and landscape variables across a region (elevation, latitude, distance from the ocean, precipitation, temperature) and the biosite index. Multivariate and ordination techniques can help uncover relationships between the above regional variables and ozone injury.

Trend analysis and simple trend graphics can help answer questions about how ozone injury is changing over a period of years. Crosscorrelation between the biosite index and measured ozone concentrations will help reveal whether the relationship among ozone injury and measured concentrations are predictable through time. Trend analysis can also be used to investigate the response of plants to reductions in measured ozone as new ozone controls are initiated.

Succession of ozone tolerant plants can be gauged by looking at plant community composition through time and comparing the change to what would be expected under natural succession conditions. Because successional dynamics are inherently stochastic to some degree, it is important to look at possible changes in phenotypes of species remaining on a site throughout succession.

Example products
Ozone injury is summarized in core tables and maps for reports that are produced by each state in the U.S. every 5 years. The number of biosites and the estimated amount of forest land with visible ozone injury is summarized for each state according to the amount and severity of the damage. Injury can be further subdivided and reported for each of the indicator species. Maps of ozone biosite injury are also produced for a region using Kriging for the biosite index averaged over a period of 5 years.

Table x. – Number of ozone biomonitoring sites and summary of conditions of bioindicator species, [year].

Parameter	ABC Region	State 1	State 2	State 3	State 4	State 5	State 6	State 7
Number of plots	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Number of plots with injury	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Percent plots by biosite index category[1]								
0 to 4.9 (least injured)	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
5.0 to 14.9	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
15 to 24.9	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
>25 (most injured)	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Percent forestland by biosite index category[2]								
0 to 4.9 (least injured; air quality = good)	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
5.0 to 14.9	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
15 to 24.9	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
>25 (most injured; air quality = poor)	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Average biosite index score	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Average number of species per plot	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx
Number of plants evaluated	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx
Number of plants injured	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx
Number of plants evaluated by species[3]								
Blackberry (#injured in parenthesis)	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx
Eastern species (would be listed each on own line):	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx
black cherry, milkweed, yellow poplar, white ash, sassafras, spreading dogbane, big leaf aster, sweetgum, pin cherry	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx
Western species:	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx
ponderosa pine, quaking aspen, Scouler's willow, Jeffrey pine, red alder, ninebark, Pacific ninebark, huckleberry, blue elderberry, red elderberry, skunk bush, western wormwood, mugwort, evening primrose, mountain snowberry	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx	x,xxx

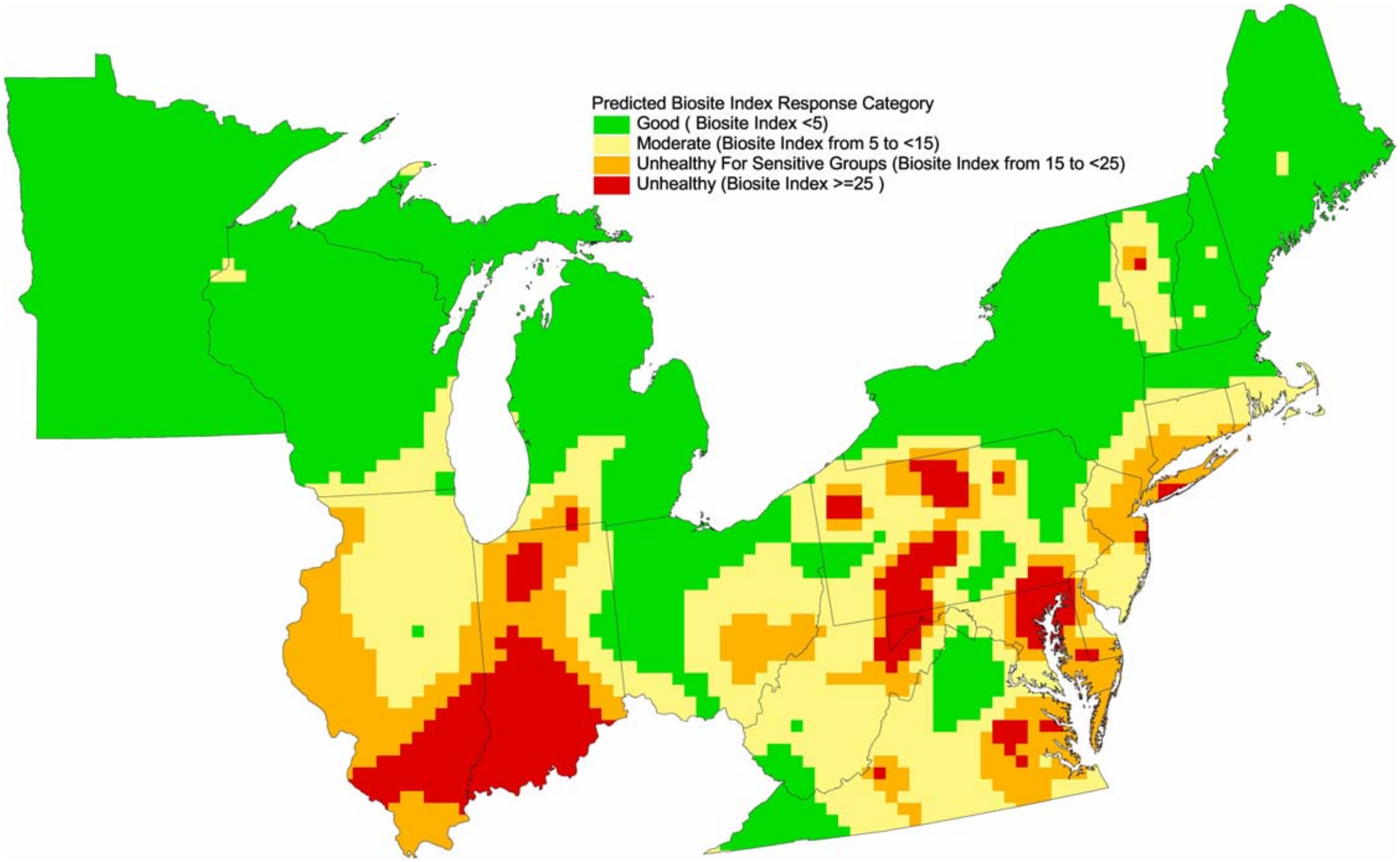


Figure x: Biosite Index Estimates and Risk in Northeastern States. Probable ozone injury and risk in the Northeast FIA region as determined by plot-level injury values (biosite index) averaged over a six-year period (1994-1999) and then categorized into four levels of risk (none, low, moderate, and high) defined in terms of the relative risk of tree or ecosystem-level disturbance to the forest resource from ambient ozone exposure. (Source: Ozone Fact Sheet: http://www.fia.fs.fed.us)

Vegetation Diversity and Structure

Why is vegetation diversity and structure important?

FIA's mission is to assess the status and change in forest resources through time. Part of this mission is to assess the status and trend in non-tree forest resources. These resources can include important medicinal plants, food, habitat, plants of cultural or aesthetic significance, potential fuels, non-native and invasive species, rare and endangered species, groundcover for watershed and erosion protection, genetic diversity, and many other valuable attributes.

Who needs information on plant diversity and community structure?

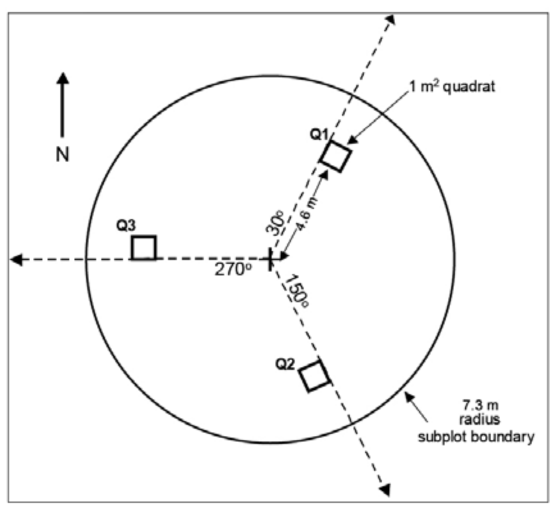
Forest managers require vegetation information to help them manage potential threats to native species, both plant and animal. Wildlife biologists are interested in knowing how much habitat is available to certain species, where that habitat is located and how habitat resources are changing. Fire managers are concerned with the amount and distribution of fuels, both horizontally and vertically, throughout forests. Fire modelers use this data to predict the potential spread of fire in an ecosystem. People who harvest non-tree forest products, such as berries, decorative products, and mushrooms, are interested in knowing where these plants can be found at the landscape scale. Vegetation ecologists use detailed information about the diversity and structure to help them make sense of the world and to help them classify vegetation types.

What questions can the vegetation diversity and structure indicator help answer?

- What is the horizontal and vertical structure of vegetation in various forest types?
- What species are found in certain types of forests?
- What species are associated with different climatic and landscape variables?
- How are fuels related to climatic and landscape gradients?
- How are fuels distributed, horizontally and vertically, in forests?
- Are invasive species changing the composition and structure of forests?
- How much suitable wildlife habitat is there for certain plant or animal species?
- What is the trend in wildlife habitat for certain species?
- What effect does vegetation cover have on erosion and water quality?
- How does disturbance affect plant community composition?

Approach to answer these questions

FIA field crews estimate the percentage vegetation cover by species and the vertical structure of vegetation by species and lifeform on forested subplots of the FIA phase 3 plot cluster. Ground cover is also estimated for each subplot. Three 1 m^2 quadrats are searched on each subplot to enumerate all species within them. Unknown plants are collected and later identified. Data are organized at the species and lifeform levels for each plot.



Analysis

Plant community composition, diversity (species richness and evenness), and structure are the key attributes to summarize for vegetation information on FIA forest health plots. Species

richness provides an index of the total number of species found for a given sampling system. Species evenness tells us how abundant each species is relative to the other species in the sample. A single plot can be compared through time to see how vegetation composition, diversity, and structure are changing with respect to disturbance and succession. At the landscape scale, data can be combined to look at the structure of vegetation and the typical plant communities that occur according to forest type.

Ordination methods can be used to help group like communities of vegetation based on species occurrences on plots across the landscape. The computer program PC-ORD is often used for ordination and clustering of plots and their respective plant species lists into meaningful associations. PC-ORD also provides the capability to investigate species/area relationships, graphing the cumulative number of species found as sample area is increased (species/area curves). This computer program is also used to resolve indicator species that may serve to help identify potential habitats.

Lifeforms of plants, whether trees, grasses, herbs, shrubs, or ferns, are used to estimate habitat according to height layers in a forest. Additionally, this information is useful to fire modelers to predict the potential laddering effects of fuels in understory vegetation. The canopy cover of each species is recorded as total cover for a field plot and also as the cover in each of three vertical layers. This information also provides information on the relative bulk density of fuels in each canopy layer.

Species spatial distributions, and their frequency and constancy across a landscape can be assessed with maps, simple summary statistics, and graphics. The constancy of a species and its relative abundance are often presented together to demonstrate how widespread a species is in relation to its relative dominance as vegetative cover.

Example products

Core tables for the vegetation indicator are produced for each state’s 5-year report. In addition to tables, maps are an important part of the vegetation indicator. Vegetation species range maps are used to help define potential habitat for a variety of species. Both presence/absence and the abundance of a species can be depicted in the maps. Through ordination techniques, classification systems can be developed to create vegetation types across a region.

Table x. – Species richness by ecological province, [state], [year].

Ecological Province	Average α per plot	Total (γ)	Community diversity (β)	Average number of native species/plot	Average number of introduced species/plot	Average total % cover by native species	Average total % cover by introduced species
	X	∑	B	x_n	x_i	Cc_n	Cc_i

Where: α = number of species on a plot, γ = total number of species reporting area, $\beta = \gamma$ / average α

Table x. – Number of plots with species showing significant changes in frequency (based on McNemar test), [state], [year].

Ecological Province	Community Type	# Plots with any changes	Native Species		Introduced Species		Both Native and Introduced	
			# Plots with increases	# Plots with decreases	# Plots with increases	# Plots with decreases	# Plots with increases	# Plots with decreases

Table x. – Species showing significant changes in frequency (based on McNemar test), [state], [year].

Ecological Province	Forest Type Group	Community Type	Species	Native (N) or Introduced (I)	Increase (↑) or Decrease (↓)

Table 44. – Mean percent vegetation cover by forest type group, layer and life form, all species (native and introduced), [state], [year].

		Layer 1 (0-2 ft)						Layer 2 (2-6 ft)						Layer 3 (6-16 ft)			Layer 4 (16+ ft)		
Forest Type Group	Community Type	Tree	Shrub	Forbs, excl. ferns	Fern	Grass	Total	Tree	Shrub	Forbs, excl. ferns	Fern	Grass	Total	Tree	Shrub	Total	Tree	Shrub	Total
East:		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
White / red / jack pine		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Spruce / fir		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Longleaf / slash pine		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Loblolly / shortleaf pine		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Oak / pine		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Oak / hickory		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Oak / gum / cypress		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Elm / ash / cottonwood		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Maple / beech / birch		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Aspen / birch		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Other forest types		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Non-stocked		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
East Total:		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
West:																			
Douglas-fir		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Ponderosa pine		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Western white pine		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Fir / spruce / mountain hemlock		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Lodgepole pine		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Hemlock / sitka spruce		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Western larch		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Redwood		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Pinyon / juniper		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Other western softwoods		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
California mixed conifer		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Aspen / birch		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Alder / maple		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Western oak		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Tanoak / laurel		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Other western hardwoods		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Other forest types		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Non-stocked		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
West Total:		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Tropical hardwoods		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Exotic softwoods		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
Exotic hardwoods		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
All forest type groups		xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x

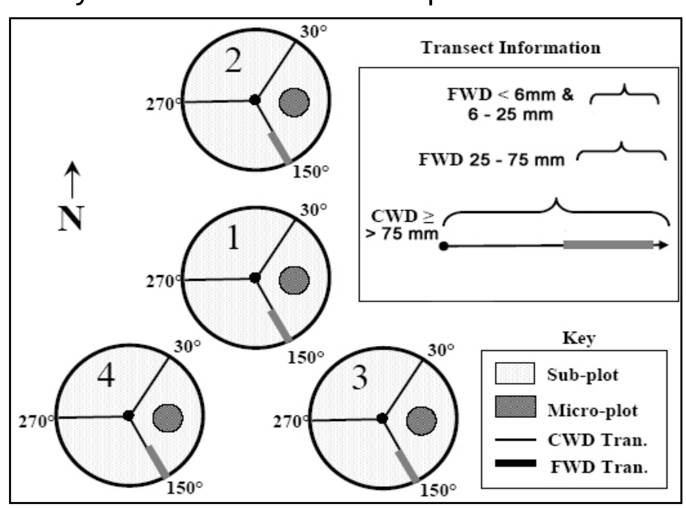
Dead wood

Why is dead wood important in forested ecosystems?
Dead wood plays an important role in the storage of carbon, nutrients, energy, and moisture in forests. Depending on climate, large pieces of dead wood can remain on the forest floor for several decades, acting as a slow-release mechanism for nutrients and carbon. In many forests, dead wood is a significant component of the carbon pool. Dead wood provides habitat and shelter for birds, mammals, reptiles, insects, decomposers, and serves as a seed bed in moist forests. The fungi growing on dead wood provides food for many animals. Dead wood can also be a major component of the fuels in a forest.

Who uses information about dead wood in forests?
Wildlife biologists and habitat modelers are interested in data on down woody materials. Understanding how much dead wood is used as habitat by a certain organism and how it is distributed across forests allows predictions of that organism's distribution. Scientists interested in accounting for carbon and its cycling through a forested ecosystem need information about the dead wood component of forests. Knowledge of amounts and storage time of dead wood carbon helps provide a better idea of how carbon mass changes in forests. Resource managers are concerned with fuel hazard in their forests. Knowing the dead wood abundance and distribution helps resource managers and fuel modelers to predict fire spread, fire severity, and to allocate fire fighting resources appropriately when planning for the fire season.

What are the common questions about the dead wood resource?
- What is the vertical, horizontal, and regional distribution of down wood in the ecosystem?
- How is down wood associated with other plot, regional, and climatic attributes?
- How much carbon is there in the down wood resource?
- How much fuel and in what fuel classes is there in down wood?
- How does dead wood amount and distribution vary among forest types?
- What species are found in areas with certain dead wood characteristics?

Approach to answer questions about down woody materials and dead wood
Field crews collect information about dead wood at a variety of locations on the FIA plot. The size classes for the dead wood sampled corresponds to the fuel-hour rating classes of 1, 10, 100, and 1000 hour drying times. Fine woody debris (FWD) is divided into three size classes and sampled using the line intersect method where different size classes are sampled on different length transects. The coarse woody debris (CWD; 1000+ hour fuels) is sampled on three transects per subplot, for a total of 12 transects with a combined length of 88 meters. In addition to the FWD and CWD, field crews measure the depth of the forest floor duff, forest litter, and the entire fuel bed depth at 12 points on the plot. The percent cover and the height of live and dead shrubs and herbs is



recorded for each micro-plot. Field crews also measure the dimensions of large piles of woody debris left on plots from cutting and other disturbances.

Analysis

The basis for estimating down wood in forests is the line intersect method for sampling and expansion to a larger area. Using the measurements taken on FIA plots, we can estimate the volume, weight, and number of pieces of coarse woody debris. For fine woody debris, we can estimate the volume and weight of the resource at the plot level. The duff and litter estimates are expanded to weight per unit area by multiplying their average depth with bulk density constants and then expanding the results based on the area the plot represents in the population. Debris piles are expanded by multiplying the volume estimated from field measurements (reduced by a packing ratio) with the area expansion factor, that is, the area the plot represents in the population.

Coarse woody debris varies in density depending on its stage of decay. Field crews rate the stage of decay for each piece of CWD using a 5-class scale. Biomass and carbon mass of CWD is reduced by multiplying by a factor that accounts for stage of decay.

Plot level estimates of FWD and CWD can be associated with other variables measured on field plots. For example, the amount of mortality or disturbance is often correlated with the amount of dead wood. In areas of frequent disturbance, dead wood may accumulate quickly, but may also persist for short periods depending on tree densities and decay rates. Moisture and elevation gradients are also possible explanations of differences in dead wood amounts across the landscape. Decay rates will vary with climate and elevation, and thus the retention of dead wood will vary with these landscape attributes. Forest type can also be associated with significant differences in dead wood in a region. Some forest types are made up of predominantly short-lived trees and will have fast rates of dead wood turnover. Stage of succession is also expected to influence dead wood accumulation with differences between short-lived pioneer successional sere and the longer-lived species in late successional sere.

Example products

Coarse and fine woody debris is summarized in the U.S. in state reports that are produced every 5 years. Core tables summarize the volume, biomass, carbon mass, and density of dead wood according to forest types, forest owner, and size class of the dead wood. Histograms and pie charts are used to graphically depict the frequency of dead wood according to size class. Maps can be used to summarize dead wood resources and size classes across regions. The raw and summarized data are used in fire models to produce fire hazard maps. Data are also used to model the occurrence of species requiring certain down wood characteristics in their habitat.

Table 41. – Average biomass, volume[1], and density[1] of down wood on forestland, by forest type group, and diameter class [state], [year].

Forest type group	Biomass, avg. tons/ac Diameter class[2] (inches) < 3	3 – 20	>= 20	Total	Volume[1], avg. ft^3/ac Diameter class[2] (inches) 3 – 20	>= 20	Total	Density[1], avg. pieces/ac Diameter class[2] (inches) 3 – 20	>= 20	Total
East:	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
White / red / jack pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Spruce / fir	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Longleaf / slash pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Loblolly / shortleaf pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Oak / pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Oak / hickory	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Oak / gum / cypress	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Elm / ash / cottonwood	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Maple / beech / birch	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Aspen / birch	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Other forest types	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Non-stocked	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
East Total:	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
West:										
Douglas-fir	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Ponderosa pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Western white pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Fir / spruce / mountain hemlock	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Lodgepole pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Hemlock / sitka spruce	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Western larch	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Redwood	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Pinyon / juniper	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Other western softwoods	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
California mixed conifer	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Aspen / birch	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Alder / maple	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Western oak	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Tanoak / laurel	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Other western hardwoods	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Other forest types	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Non-stocked	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
West Total:	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Tropical hardwoods	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Exotic softwoods	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Exotic hardwoods	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
All forest type groups	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x

[1] Volume and density estimates are only available for down wood >= 3 in. diameter at the point of intersection.

[2] The diameter classes are based on the diameter at the large end of the piece, except for decay class 5 pieces and the small diameter class (< 3"), which are based on the diameter at the point of intersection.

Table x. – Biomass and carbon mass of down wood[1] on forestland by forest type group and owner group [state], [year].

(In million tons)

	Owner group									
	US Forest Service		Other Federal		State and Local Government		Corporate		Other Private	
Forest type group	Biomass	Carbon	Biomass	Carbon	Biomass	Carbon	Biomass	Carbon	Biomass	Carbon
East:										
White / red / jack pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Spruce / fir	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Longleaf / slash pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Loblolly / shortleaf pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Oak / pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Oak / hickory	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Oak / gum / cypress	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Elm / ash / cottonwood	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Maple / beech / birch	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Aspen / birch	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Other forest types	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Non-stocked	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
East Total:	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
West:										
Douglas-fir	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Ponderosa pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Western white pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Fir / spruce / mountain hemlock	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Lodgepole pine	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Hemlock / sitka spruce	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Western larch	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Redwood	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Pinyon / juniper	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Other western softwoods	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
California mixed conifer	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Aspen / birch	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Alder / maple	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Western oak	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Tanoak / laurel	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Other western hardwoods	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Other forest types	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Non-stocked	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
West Total:	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Tropical hardwoods	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Exotic softwoods	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
Exotic hardwoods	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x
All forest type groups	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x	x,xxx.x

[1] Down wood includes all pieces with a diameter >= 3” at the point of intersection.