Ozone Bioindicator Sampling and Estimation

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1.0 Introduction

1.1 Overview of the Ozone Indicator

Ozone interacts with forest ecosystems, causing visible injury and alterations in species composition and pest interactions (Chappelka and Samuelson 1998, Miller and others 1996). It is the only regional gaseous air pollutant that has been measured at known phytotoxic levels at both remote and urbanized forest locations (U.S. EPA 1996a and 1996b). The importance of ozone as a forest stressor is illustrated by its inclusion in the Montréal Process Criteria and Indicators (Montreal Process 1995) where the percent forest exhibiting negative impacts from air pollutants such as ozone is an indicator of the overall forest health and vitality. Coulston and others (2004) point out that the ozone biomonitoring data of the USDA Forest Service Forest Inventory and Analysis Program (FIA) are the only source of information available that documents plant injury from air pollution using consistent protocols. The goal of our document is to describe the ozone bioindicator and suggest analytical techniques appropriate for FIA ozone biomonitoring data.

The ozone bioindicator provides a biological index of ozone stress to plants using consistent protocols on a nationwide system of biomonitoring sites. Ozone biomonitoring is part of the FIA Phase 3 sample (USDA Forest Service 2005) and is based on the documentation of visible foliar injury to known ozone-sensitive plant species under conditions of ambient exposure. The field methods, site variables, and site-level biosite index were developed with support from the scientific research community (Smith 1995), and the sampling procedures and analytical techniques have been reviewed in the scientific literature (Coulston and others 2003, Smith and others 2003).

Although ozone biomonitoring is part of the Phase 3 (forest health) sample, the biomonitoring grid and the FIA base grid are independent and information is collected on a different population from other FIA phase 2 (P2) and phase 3 (P3) measurements (see section 2.0). One primary use of these data is Detection Monitoring (DM), which identifies forested areas that may be at risk from some stressor or disturbance. These areas may then become candidates for Evaluation Monitoring (EM). Vose (2000) defined risk analysis as the process of quantifying, either qualitatively or quantitatively, the probability and the potential impacts of some risk. DM analyses using the ozone biomonitoring data are both qualitative and quantitative and fall under the category of risk analysis.

Throughout this document the word “site” or “biosite” will be used to refer to the ground location where the FIA field crews collect ozone indicator data and the word “plot” will be used to refer to the FIA ground sample plots for which the estimation procedures apply. Our objective here is to provide guidance on presenting annual summaries of the ozone biomonitoring data and performing risk analysis for DM.

1.2 Detection Monitoring

The FIA ozone biomonitoring program is designed to detect and monitor plant-damaging concentrations of ozone in the natural environment. Information gathered at ozone biomonitoring sites identifies whether conditions exist (ozone, light, moisture, relative humidity) for plant injury to occur. This information can be used to report national and regional trends in ozone injury to plants and to identify areas of concern for closer evaluation. The biomonitoring grid is independent of the FIA base grid (Figure 1). Therefore, spatial interpolation is one method to predict potential risk of ozone injury on the ground plots. Interpolated biosite values are classified into four response categories that are used to define and describe possible impact (i.e., risk) to the forest resource from ambient ozone exposure (Table 1). These categories also provide an indication of ozone relative air quality with respect to a plant receptor. The categorizations of the biosite index are qualitative, but have received positive reviews in the scientific literature (Coulston and others 2003, Smith and others 2003).

The categorized and interpolated biosite values, along with the presence and abundance of ozone- sensitive tree species found on FIA P2/P3 ground plots, are used to develop species-specific risk maps of ozone stress. These maps are then used to identify localized areas of moderate to high risk where Evaluation Monitoring (EM) studies are warranted. This approach is documented in Coulston and others (2003).

1.3 Evaluation Monitoring

When regional or national analyses of detection-level data indicate areas of potential impact on forest productivity and sustainability, these areas are evaluated through the implementation of additional studies on an intensified grid. For example, the biomonitoring data may indicate a band of high ozone stress across a State or region, which may prompt the regional analyst to ask if the finding is real or some artifact of data collection. The next logical step is an evaluation study to take a closer look at the area of concern. For the ozone indicator, an evaluation study should include an intensified sampling grid and an analysis of air quality and environmental data that influence plant response to ozone. It may also be important to examine species distribution maps available from FIA regional archives. An example of DM identifying a potential problem area and EM verifying the problem is illustrated by Coulston and others (2003) and Skelly and others (2003), respectively.

1.4 Key References

Biomonitoring: Biomonitoring has been used since the 1960s in numerous smaller field studies to assess pollutant stress. What is new and significant about the FIA biomonitoring program is its national scope and the successful implementation of national standards for training, field procedures, quality assurance, data analysis, and reporting.
Key references: Berry and Hepting 1964, Chappelka and others 1997, Feder 1978, Heck 1968, Hildebrand and others 1996, Kohut and others 1997, Lewis and Conkling 1994, Neufeld and others 1992, Pronos and Vogler 1981.

Bioindicator species: The FIA list of ozone bioindicator species was gleaned from various sources including the peer-reviewed scientific literature, interagency reports, and communications with Federal and university researchers experienced in ozone biomonitoring. Selected species are common across a variety of forest types, easy to identify and distinguish from similar species, and sensitive to ozone based on a combination of field evidence and causative fumigation experiments. The eastern bioindicator species have a long history of

application in ozone field studies. The western bioindicator species have not been as well tested under natural conditions of ozone exposure, but have all received enough testing to justify inclusion in the FIA program.
Key references: East: Krupa and others 1998, Skelly and others 1987, Skelly 2000. West: Brace and others 1999, Campbell and others 2000, Duriscoe and Temple 1996, Mavity and others 1995, Temple 2000. East and West: U.S. Department of the Interior 2003.

Biosite index: The Horsfall-Barrett (HB) rating scale used to assess ozone injury in the field is based on a technique developed for plant disease research. Since the 1940s, it has been used repeatedly in the field evaluation of ozone-induced foliar injury. Details on the formulation of the plot-level biosite index (BI) are presented in section 3.2. The index developed for the FIA program is new, but it has been widely adopted by cooperating researchers at various institutions and published in the scientific literature.
Key references: Horsfall and Barrett 1945, Horsfall and Cowling 1978, Smith and others 2003.

Classification scheme for the biosite index: The classification scheme for the FIA biosite index has been reviewed in the scientific literature and applied in a published assessment of ozone injury to eastern forest tree species.
Key references: Coulston and others 2003, Smith and others 2003.

Interpolation techniques: Plot-level attributes required for population estimates are developed by spatial interpolation of the biosite data. Spatial interpolation techniques are widely used in the analysis of air pollution, environmental, and ecological data. The approach used for the ozone indicator has been reviewed in the scientific literature and applied in a published assessment of ozone injury to eastern forest tree species.
Key references: Coulston and others 2003, Cressie 1993, Cressie and Ver Hoff 1993, Isaaks and Srivastava 1989, Lefohn and Pinkerton 1988.

Status and change estimation: There are several references for valid estimation techniques; however, Bechtold and Patterson (2005) provide a review and recommendations specifically for FIA data.
Key reference: Bechtold and Patterson (2005)

2.0 Biomonitoring and Data Collection

Ozone sampling occurs on a unique national grid independent of the P2 and P3 plot system. The ozone grid enhances quality assurance for this indicator by allowing greater flexibility in plot location on the ground and greater sampling intensity in areas believed to be at high risk for ozone impact (Smith and others 2001). The grid design generates differing sampling intensities across the landscape based on the best available information on air quality regimes.

The ozone grid is purposive both at the grid level and at the biosite. Biosite location on the ground is deliberately chosen first for ease of access and second for optimal size, species, and plant counts. The ozone biomonitoring sites vary in size and do not have set boundaries. They are defined by the presence of ozone-sensitive bioindicator species indigenous to each FIA region. There must be one biosite per polygon on the national ozone biomonitoring grid. Some

States use an intensified ozone grid so two or more biosites may be located in each polygon on the base grid. Biosite locations are mapped, geographic coordinates are recorded, and the same sites are evaluated every year. Ozone injury and our ability to detect that injury increase over the course of the field season. For this reason, the sampling window for the ozone indicator is limited to 3 weeks (from late-July to mid-August) within which the indicator is considered stable. This minimizes variability and the error associated with the data collection system.

The sampling rules for the ozone biosites are as follows. Biosites are wide-open areas, at least one acre in size, within or alongside forested areas. Each site must contain at least 30 individual plants of at least two bioindicator species. If not enough plants are available at one location, two nearby open areas, within 3 miles of each other, may be combined to maximize plant counts. Biosite locations must be easy to access, and they must be free of significant soil compaction and other human-made disturbance. Additional guidelines are available in the Field Methods Guide (USDA Forest Service 2000).

The characteristics of each site are described in terms of the size of the open area, elevation, terrain position, aspect, soil drainage, soil depth, and site disturbance. If characteristics vary significantly across the biosite, then the area where most of the bioindicator species are growing is described and variations are recorded on the site map and notes. When two nearby open areas are used, each location is described separately.

Up to 30 plants of each species are randomly selected for injury evaluation. Plants less than 12 inches in height, suppressed, shaded, or with more than half the crown out of reach are not evaluated. The approximate locations of the plants used for evaluations are drawn on the site map so that the same population of plants is evaluated on return visits to the biosite. The entire open area is sampled until 30 plants of two (ideally, three or more) species have been evaluated.

Quality assurance (QA) procedures dictate that the ozone injury symptom must be verified for each injured species on each plot. Crews collect a minimum of three injured leaves from a random sample of individual plants that show obvious ozone injury, and they mail pressed leaf samples to a regional expert for review. Three leaves from each injured species are subject to microscopic examination. Injury is validated for all samples that show a characteristic color and injury pattern for ozone and that are otherwise free of confounding signs and symptoms of other mimicking stress agents (e.g., insects, disease, mites, or weather). If the symptoms are not typical of ozone injury, then the field data associated with the invalidated leaf voucher are zeroed out. Furthermore, if a leaf voucher is missing and unable to be validated, then the field data associated with the missing voucher are flagged so they cannot be used in data summaries or analyses.

The ozone indicator is included in the FIA National QA Plan (USDA Forest Service 2004). Just before the sampling window, ozone training and certification sessions are held in each region. A minimum of 10 biosites per region are blind checked every year (5 to 6 percent of the total biosites in each region). The ozone remeasurement data have been evaluated on two occasions, once in 1999 and again in 2003 (Pollard and Smith 2001, Pollard 2004). Inconsistent results with two eastern bioindicator species reported in Pollard and Smith (2001) were corrected by improvements to the ozone training session. Results from the 2003 review indicate the biosite data are robust and field crews in all regions are able to meet data quality expectations for the ozone indicator.

3.0 Point-in-time Estimation

3.1 Plant-level Estimates

At each ozone biosite, 30 individual plants of two bioindicator species, and between 10 and 30 individual plants of additional bioindicator species are evaluated for ozone injury. Each plant is rated for the proportion of leaves with ozone injury (injury amount) and the mean severity of symptoms (injury severity) using a modified Horsfall-Barratt scale with break points at 0, 6, 25, 50, 75, and 100 percent (Horsfall and Cowling 1978, USDA Forest Service 1999). This scale uses class break points that correspond to the ability of the human eye to distinguish gradations of healthy and unhealthy leaf tissue.

3.2 Biosite Index and Proportion Injured Plants

For each biosite, the percent injured plants and a biosite index are calculated based on the injury amount and severity scores. The proportion injured is $I_p=n_i/n_t$ where I_p is the proportion of plants injured, n_i is the number of injured plants (i.e., amount of injury $\neq 0$), n_t=the total number of plants evaluated. The biosite index is the average score (amount $*$ severity) for each species averaged across all species on the biosite multiplied by 1,000 to allow risk categories to be defined by integers (Table 1). The biosite index is calculated

$$BI = 1000\left(m^{-1} \sum_{j=1}^{m} n_j^{-1} \sum_{p=1}^{n_j \geq 10} a_{pj} s_{pj} \right)$$

where

BI = biosite index

m = number of species evaluated

n_j =number of plants of the j^{th} species evaluated

a_{pj} =proportion of injured leaves on the p^{th} plant of the j^{th} species

s_{pj} =average severity of injury on the p^{th} plant of the j^{th} species

Biosite summary statistics on the ozone indicator are generated annually and loaded to three ozone data summary tables in each FIA region. Tabular data include species and site counts and calculated mean injury indices from the first year each State implemented the ozone indicator up to the current year. For some regions it is important to group States with similar air quality regimes together and keep them separate from neighboring States with distinctly different air quality regimes. A map of biosite level values will also be produced for illustration. Tables and figures illustrating these types of products are included in section 6.1.

3.3 Status Estimation

FIA plot-level attributes required for population estimates can be developed by spatial interpolation of data collected from the biosites. Each ozone season is unique, influenced by variable ozone levels, weather, windflow, and precipitation patterns. Therefore, it is important to use 5-year averages of the biosite index to generate a truly representative estimate of ozone stress. Thus, a 5-year moving average is used:

$\hat{B}_t = \sum_{t=-(n-1)}^{0} \frac{B_t}{n}$ where

$\hat{B}_t$ = the 5-year average estimate for a biosite plot value at time t
B_t = biosite plot value at time t
t = time in years ranging from $t = 0$ (the current year) to year $t - n$
n = number of plot measurements (maximum of 5)

$\hat{B}_t$ will be used in the spatial interpolation. Spatial interpolation techniques are widely used (e.g., see Cressie and Ver Hoff 1993) and air pollution variables are commonly interpolated. For example, Lefohn and Pinkerton (1988) interpolated ambient ozone concentrations to characterize forested areas of the United States. Coulston and others (2003) interpolated data from ozone biomonitoring sites to characterize risk to northeastern tree species. For a review of spatial statistics, see Cressie 1993.

3.3.1 Spatial Interpolation of the Biosite Index

Many spatial interpolation techniques are available. In this document we discuss the procedures for kriging, inverse distance weighting, and cross-validation, but as work proceeds with the ozone indicator, other methods such as universal kriging, splining, and spatial regression may be implemented. Spatial interpolation is performed to create a map of ozone risk to plants. This map is used to, among other things, classify ozone injury risk for FIA P2/P3 plots. Many spatial interpolation techniques require analysts to make assumptions (e.g., stationarity). We assume analysts are aware of both the theoretical and practical considerations associated with each interpolation technique.

Using kriging, a standard interpolation technique, requires at least three steps to interpolate a surface. First, the empirical semivariogram is calculated. Second, the empirical semivariogram is modeled. With parameters from the modeled semivariogram, the kriging equations can be used. The semivariance between values for a particular lag distance h is $\gamma(h)=1/(2N(h))\Sigma(v_i-v_j)^2$ where N is the number of pairs (i, j) and v_i-v_j is the difference between the values of pair (i, j). It is one-half the average squared difference between values a particular distance apart. Several model types can be used to model the empirical semivariogram. They include the Gaussian model, wave model, and exponential model. Gaussian models tend to account for strong spatial relationships at short distances while wave models account for periodicity in spatial relationships. Matern class models may also be used when flexibility near h=0 is desired. See Hoeting and others (2006) for more information on semivariogram model selection.

After the semivariogram has been modeled, ordinary kriging can be used to interpolate between values. Ordinary kriging is a weighted average such that $\hat{V}_0 = \sum_{i=1}^{n} w_i V_i$ where $\hat{V}_0$ is the estimate at unmeasured location 0, w is the weight of each i observation, and V_i is the value of each i observation. The weights sum to 1 and are determined by minimizing the estimation error. The estimation variance is $S^2_0=w_i\gamma(s_i-s_0) + \lambda$ where $\gamma(s_i-s_0)$ is the modeled semivariance for the distance between s_i and s_0; λ is the Lagrange multiplier from solving the linear system of equations for minimum estimation error.

Analysts may choose to use the inverse distance squared weighting interpolation method (IDW). Estimates are made by:

$$\hat{\mathrm{V}}_0 = \frac{\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{d}_{0\mathrm{i}}^{-2} \mathrm{v}_\mathrm{i}}{\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{d}_{0\mathrm{i}}^{-2}}$$

where $\hat{V}_0$ is the estimate at unmeasured location *0*, d_{0i} is the distance from the i^{th} biosite to location *0*, and v_i is the value at biosite *i*. Under the assumption of intrinsic stationarity, the estimation variance is:

$$S_0^2 = -\sum_i \sum_j \left(\frac{d_{0i}^{-2}}{\sum d_{0i}^{-2}} \right) \left(\frac{d_{0j}^{-2}}{\sum d_{0j}^{-2}} \right) \gamma(s_i - s_j) + \sum_i \left(\frac{d_{0i}^{-2}}{\sum_i d_{0i}^{-2}} \right) 2\gamma(s_i - s_0) .$$

Cross-validation is a method to quantify and compare various models (e.g., kriging and IDW). It can also be used to decide among variogram models (e.g., spherical, Gaussian). The cross-validation technique is implemented sequentially by removing each v_i one at a time and then estimating v_i based on the spatial model (e.g., IDW) and the remaining *n*-1 observations. If this is done sequentially for all *i* =1,.,.,.,*n* observations in the sample, the estimates can then be compared to the actual values using several standard summary statistics (Prediction error sum of squares – PRESS statistics).

The PRESS statistics are the values analysts may use to decide on which interpolation model performs the best for their particular situation. One PRESS statistic is the average squared deviation $= \mathrm{n}^{-1} \sum_\mathrm{i} (\mathrm{v}_\mathrm{i} - \hat{\mathrm{v}}_{-\mathrm{i}})^2$ where $\hat{v}_{-i}$ is the prediction of v_i from the rest of the data. This value should be relatively small if the model fits well. Another summary statistic is the mean of standardized PRESS residuals = $n^{-1} \sum_i (v_i - \hat{v}_{-i}) / \sqrt{S_{(-i)}{}^2}$ where $S_{(-i)}{}^2$ is the estimation variance for $\hat{v}_{-i}$. This quantity should be close to zero if the model fits well. The root mean squared prediction residuals also provide a measure of model aptness. This is calculated by $\sqrt{n^{-1} \sum_i \left(v_i - \hat{v}_{-i} / \sqrt{S_{(-i)}{}^2} \right)^2}$ and will be approximately one if the spatial model fits well. An analyst should create several interpolated maps using the various options for the IDW and kriging. For example, analysts may choose to create an IDW map based on the 12 nearest neighbors rather than all neighbors. Analysts may also decide to try several variogram models (e.g., spherical, Gaussian) with the kriging technique. The resultant maps can then be compared based on the PRESS statistics, and the analysts can decide on the most appropriate map.

Once an appropriate spatial model has been selected, biosite index values will be estimated for all P2 and P3 plots by intersecting the map of interpolated values with P2 and P3 plot locations (e.g., Figure 2). This will result in a biosite index value estimate for each P2 and P3 plot (e.g., Table 2).

3.3.2 Estimating Status for Forested Areas

Bioindicator attributes will be estimated yearly for all FIA plots, using the procedures described above. The attributes will then be merged with the other plot attributes. Population estimates include (1) the proportion of forest land in each biosite index category by region, ecoregion, and State; (2) the acres of forest land in each biosite index category by region, ecoregion, and State; and (3) the volume of ozone susceptible species in each biosite index category by region, ecoregion, and State. Population estimates will be made using the procedures presented by Bechtold and Patterson (2005).

The following description uses the same equations and terminology as used in "Sample-Based Estimators Used by the Forest Inventory and Analysis National Information System" (chapter 4 in Bechtold and Patterson 2005). In general terms, each P2 plot (and tree) will be assigned a biosite index category (Table 1) based on spatial interpolation that will be considered a plot (and tree) attribute. Each plot is assigned to one stratum from phase 1 (e.g., forest, nonforest). To estimate the proportion of forest land in biosite index category 4, an indicator function (δ) would be used. In this case, the indicator function would equal 1 if the attribute (biosite index category) is in the domain *d* (biosite index = 4) of interest, or 0 otherwise. The portion of each plot in the domain of interest is then

$$P_{hid} = \frac{\sum_{j}^{4}\sum_{k}^{K_{hij}} a_{mhijk}\delta_{hijkd}}{a_m \overline{p}_{mh}} \quad \text{where}$$

P_{hid} = proportion of plot *i* in the domain of interest *d*, for plots assigned to stratum *h*, adjusted for stratum *h* plots that overlap the population boundary

a_{mhijk} = mapped area (acres) of subplot (macroplot) *j* covering condition *k* on plot *i* assigned to stratum *h*. (Area is computed using the largest area mapped, which is the subplot except in the Pacific Northwest (PNW) where the macroplot or 1-ha circle is used.)

δ_{hijkd} = zero-one domain indicator function, which is 1 if condition *k* on subplot (macroplot) *j* of plot *i* assigned to stratum *h* belongs to the domain of interest *d*

K_{hij} = the number of conditions that exist on subplot (macroplot) *j* of plot *i* assigned to stratum *h*

a_m = total area of the largest plot on which area attributes are mapped (i.e., four times the subplot or macroplot area)

$\overline{p}_{mh}$ = mean proportion of stratum *h* mapped plot areas falling within the population ($\overline{p}_{mh}$ is generally 1 unless the plot is partially outside the population. If this situation arises, see Bechtold and Patterson 2005.)

The estimated proportion of forest land in strata *h* and domain *d* is simply the average of the plot values.

$$\overline{P_{hd}} = \frac{\sum_{i}^{n_h} P_{hid}}{n_h}$$

The total area in the domain of interest is then

$$\hat{A}_d = A_T \sum_{h}^{H} W_h \overline{P_{hd}} = A_T \overline{P_d} \quad \text{where}$$

A_T = total area in the population in acres
$\overline{P}_d$ = estimated proportion of the population in the domain of interest d
W_h = weight for stratum h, that is, the proportion of the population area, A_T, that is in stratum h

A similar procedure is used to estimate the volume of susceptible tree species in each ozone biosite index category. Tables 1 and 2 in section 6.2 provide a preliminary list of tree and shrub species susceptible to ozone injury. As an example, suppose the attribute of interest was the total volume of loblolly pine in biosite index category 4. The following is used to estimate the attribute of interest on a per unit area basis:

$$y_{hid} = \frac{\sum_{j}^{4}\sum_{t} y_{hijt}\delta_{hijtd}}{a_o \overline{p}_{oh}} \quad \text{where}$$

y_{hijt} = attribute of interest for tree t on macroplot, subplot or microplot j of plot i assigned to stratum h
δ_{hijtd} = zero-one domain indicator function, which is 1 if tree t on subplot j of plot i assigned to stratum h belongs to the domain of interest d
a_o = total area normally used to observe the attribute of interest on a plot, that is, four times the microplot, subplot, or macroplot area

$$\overline{p}_{oh} = \sum_{i}^{n_h}\sum_{j}^{4}\sum_{k}^{K_{hij}} \frac{a_{ohijk}\delta_{hijk}}{a_o n_h} = \frac{1}{a_o n_h}\sum_{i}^{n_h}\sum_{j}^{4}\sum_{k}^{K_{hij}} a_{ohijk}\delta_{hijk}$$

= mean proportion of stratum h observed-plot areas falling within the population where, a_{ohijk} = area normally used to observe the attribute of interest (microplot, subplot or macroplot j) covering condition k on plot i assigned to stratum h.

These values are then averaged across each i plot

$$\overline{Y_{hd}} = \frac{\sum_{i}^{n_h} y_{hid}}{n_h}$$

The total for the attribute of interest in the domain of interest is then

$$\hat{Y}_d = A_T \sum_{h}^{H} W_h \overline{Y_{hd}} = A_T \overline{Y_d}$$

See section 6.1 for example output.

4.0 Discussion

Here we present one method to perform DM by classifying each FIA plot based on an interpolated map of ozone injury risk. The purpose of this activity is to identify candidate areas for EM. As with other DM activities, there is a high noise to signal ratio and there may be a relatively high rate of false positives. For this reason, EM is an essential part of the process. The map of ozone injury risk does have unquantified error. However, other maps used to classify FIA plots (e.g., ecoregion sections, counties) also have unquantified error. When the information is used at its intended resolution, unquantified errors may be overlooked. For the ozone bioindicator, error propagation can be overlooked for DM activities. However, error propagation cannot be overlooked if one is trying to make a statistical inference about the relationship between growth rates and ozone injury.

The purpose of this document is to describe the analytical techniques used with the ozone indicator. We provided background material on ozone, examples of biosite summary statistics, a description of spatial interpolation, and methods to estimate status and change in forested areas with respect to the occurrence of ozone injury from ambient ozone concentrations. Section 6.1 includes examples of each expected output. Section 6.2 provides a current list of tree and shrub species susceptible to ozone. Section 6.3 contains several additional documents to assist FIA analysts with ozone data access and management. The list in section 6.2 will be updated as more information becomes available. The interpolation techniques may be improved over time, and other methods of estimating change (e.g., spatio-temporal kriging) may also be investigated. Periodic recommendations to analysts will be made as results for QA analyses become available. There is also a companion ozone bioindicator user guide (Smith and others – in review) that analysts are encouraged to consult for additional guidance on interpreting ozone biomonitoring data and reporting on the issue of ozone and forest health for the FIA program.

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Table 1. Classification scheme for the FIA biosite index[1]

Biosite index	Bioindicator response	Assumption of risk	Possible impact	Relative air quality[2]
0 - < 5	Little or no foliar injury	None	Visible injury to highly sensitive species, e.g., black cherry.	Good
5 - < 15	Light to moderate foliar injury	Low	Visible injury to moderately sensitive species, e.g., tulip poplar.	Moderate
15 - < 25	Moderate to severe foliar injury	Moderate	Visible and invisible injury. Tree-level response.[3]	Unhealthy for sensitive species
≥ 25	Severe foliar injury	High	Visible and invisible injury. Ecosystem-level response.[3]	Unhealthy

[1] The categorizations of the biosite index are subjective and based solely on expert opinion.

[2] Relative ozone air quality from a plant's perspective. See: EPA-456/F-99-002 July 1999; http://www.airnow.gov.

[3] According to the EPA's Proposed Guidelines for Ecological Risk Assessment (Federal Register 61 (175) 47552-47631).

Table 2. Example of interpolated biosite index values for P2 and P3 plots

Plot number	Biosite index	Injured plants (%)
27120110311029	13.8	15.8
27120110311156	16.1	18.0
27120110319064	0.1	1.1
27120110319251	20.8	40.8
27120110319361	19.9	25.0
27120110319385	9.7	10.4
27120110712093	1.7	3.8
27120110712438	8.4	8.0
27120110712720	6.1	7.9
27120110712907	24.5	30.8
27120110713096	10.6	10.0
27120110713107	20.9	14.5
27120110713459	14.0	12.9
27120110759099	13.6	6.8
27120110759237	2.8	5.0

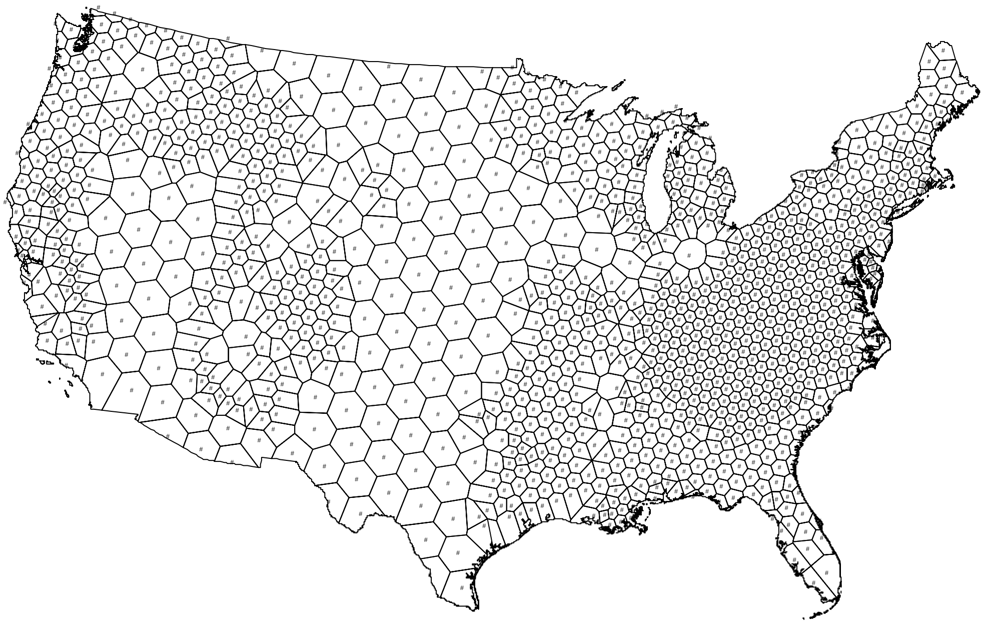

Figure 1. FIA ozone biomonitoring grid developed from the Environmental Monitoring and Assessment Program (EMAP) base grid (White and others 1992). The grid has four sampling intensities based on sensitive species and ambient ozone concentrations (see: Smith and others 2001 for more details).

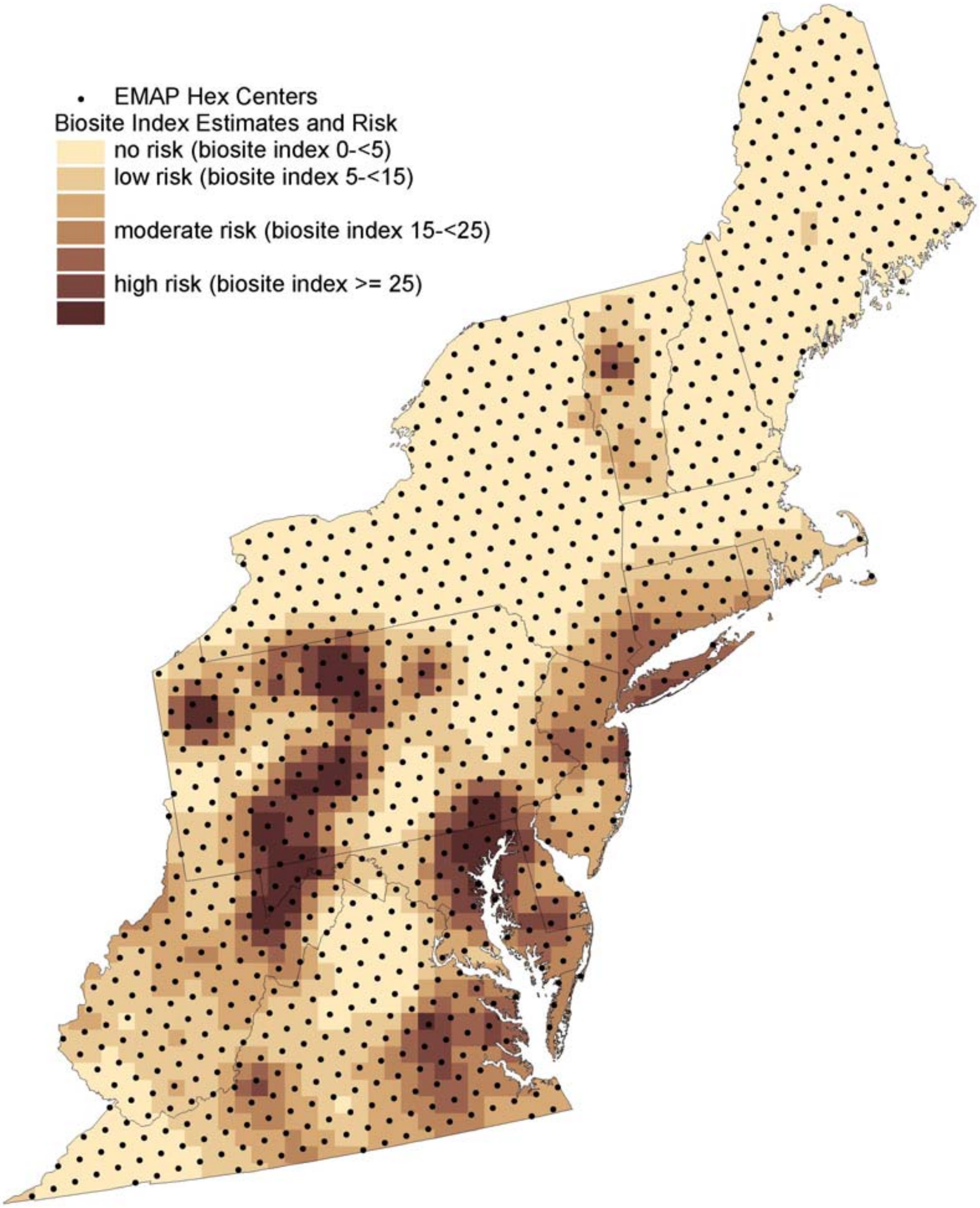

Figure 2. Example of block kriging and intersecting Environmental Monitoring and Assessment Program (EMAP) hex centers.

6.0 Appendices

The appendices include supplementary information on the ozone indicator. Section 6.1 includes examples of output tables and maps suitable for FIA State reports. Section 6.2 includes ozone sensitivity tables for trees and shrubs, information that is needed for risk assessment analysis, and section 6.3 provides information on ozone data in the FIA national information management system (NIMS) and FIA public data base (FIADB), as well as contact information for individuals most familiar with the ozone biomonitoring program in FIA.

6.1 Examples of output tables and maps for annual and multiyear summary reports:

Table 1. State-level summary statistics

	State X -Biomonitoring Program								
Parameter	1994	1995	1996	1997	1998	1999	2000	2001	2002
Number of biosites evaluated	xx	xx	xx	xx	xx	xx	xx	xx	xx
Number of biosites with injury	x	xx	x	x	xx	x	x	xx	xx
Average biosite injury score[1]	x.x	x.x	x.x	x.x	x.x	x.x	x.x	x.x	x.x
Percent biosites with BI = 0 to 4.9[2]	xx	xx	xx	xx	xx	xx	xx	xx	xx
Percent biosites with BI = 5 to 14.9	xx	xx	xx	xx	xx	xx	xx	xx	xx
Percent biosites with BI = 15 to 24.9	xx	xx	xx	xx	xx	xx	xx	xx	xx
Percent biosites with BI >= 25	xx	xx	xx	xx	xx	xx	xx	xx	xx
Average number of species per biosite	x	x	x	x	x	x	x	x	x
Number of plants evaluated	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxx
Number of plants injured	x	xx	xx	xx	xxx	x	x	xxx	x
Percent sample plants by HB category[3]									
0 = no injury	xx	xx	xx	xx	xx	xx	xx	xx	xx
1 = 1 to 6%	xx	xx	xx	xx	xx	xx	xx	xx	xx
2 = 7 to 25%	x	x	x	x	x	x	x	x	x
3 = 26 to 50%	x	x	x	x	x	-	x	x	x
4 = 51 to 75%	-	x	-	x	x	-	x	x	-
5 = >75%	-	x	-	x	-	-	x	x	-
Number of plants evaluated by species									
Species1 (#injured in parentheses)	x (x)	x(x)	x(x)	x(x)	x(x)	-	x(x)	x(x)	x(x)
Species2, etc.	-	x	x(x)	x(x)	x(x)	x	xx	x(x)	x

Table 2. Region-level summary statistics

	ABC Region - Biomonitoring Program								
Parameter	1994	1995	1996	1997	1998	1999	2000	2001	2002
Number of biosites evaluated	xx	xx	xx	xx	xx	xx	xx	xx	xx
Number of biosites with injury	x	xx	x	x	xx	x	x	xx	xx
Number of plants evaluated	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxx
Number of plants injured	x	xx	xx	xx	xxx	x	x	xxx	x
Average biosite injury score[1]	x.x	x.x	x.x	x.x	x.x	x.x	x.x	x.x	x.x
Percent biosites with BI = 0 to 4.9[2]	xx	xx	xx	xx	xx	xx	xx	xx	xx
Percent biosites with BI = 5 to 14.9	xx	xx	xx	xx	xx	xx	xx	xx	xx
Percent biosites with BI = 15 to 24.9	xx	xx	xx	xx	xx	xx	xx	xx	xx
Percent biosites with BI >= 25	xx	xx	xx	xx	xx	xx	xx	xx	xx
Average number of species per biosite	x	x	x	x	x	x	x	x	x
Number of plants evaluated	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxx
Number of plants injured	x	xx	xx	xx	xxx	x	x	xxx	x
Percent sample plants by HB category[3]									
0 = no injury	xx	xx	xx	xx	xx	xx	xx	xx	xx
1 = 1 to 6%	xx	xx	xx	xx	xx	xx	xx	xx	xx
2 = 7 to 25%	x	x	x	x	x	x	x	x	x
3 = 26 to 50%	x	x	x	x	x	-	x	x	x
4 = 51 to 75%	-	x	-	x	x	-	x	x	-
5 = >75%	-	x	-	x	-	-	x	x	-
Number of plants evaluated by species									
Species1 (#injured in parentheses)	x (x)	x(x)	x(x)	x(x)	x(x)	-	x(x)	x(x)	x(x)
Species2,etc.	-	x	x(x)	x(x)	x(x)	x	xx	x(x)	x

[1] The biosite index is based on the average injury score (amount*severity) for each species averaged across all species on the biosite.

[2] Biosite categories represent a relative measure of tree-level response to ambient ozone exposure (see table 1 in the main body of the text).

[3] HB = injury severity is an estimate of the mean severity of symptoms on injured foliage (0 = no injury; 1=1-6%; 2 = 7- 25%; 3 = 26-50%; 4 = 51-75%; 5 >75%). Calculated percents are rounded to the nearest whole number. Terms are further described in the text.

**Standard errors can be presented, as needed, for the calculated variables.*

Note: Tables 1 and 2 provide an example of site-level summary statistics from State X and Region ABC. These two tables are core products for the ozone indicator. The summarized values show the base data used to generate the plot-level and population-level estimates as described in the text of this document. Individual States may choose to use the regional table as a basis of comparison to their summary statistics. Smaller States may choose to use the regional table for reports.

Table 3. Number of biomonitoring sites evaluated for ozone-induced foliar symptoms, number of plants sampled, and percent of sampled plants in each injury severity category by year and subregion in FIA-North

Subregion and year[1]	No. of biosites evaluated	No. of plants sampled	Injury severity categories[2]					
			0	1	2	3	4	5
			Percent of sampled plants					
Lake States								
1996	95	3,880	99	1	<1	<1	0	0
1997	104	4,584	99	1	<1	<1	0	<1
1998	160	9,012	97	2	1	<1	<1	<1
1999	143	10,949	97	2	1	<1	<1	<1
2000	160	12,647	97	2	1	<1	<1	<1
New England								
1996	92	4,245	89	5	4	2	<1	<1
1997	91	4,248	93	3	3	1	<1	<1
1998	98	5,460	90	4	4	2	<1	<1
1999	96	5,057	97	1	1	<1	<1	<1
2000	87	4,850	96	2	2	<1	<1	0
North Central								
1996	8	589	67	6	7	4	7	9
1997	19	1,180	77	3	9	6	4	<1
1998	36	1,580	72	5	10	9	4	<1
1999	45	3,387	90	4	3	2	1	<1
2000	131	8,688	92	4	3	1	<1	<1
Mid-Atlantic								
1996	34	1,244	82	5	5	5	2	1
1997	60	2,908	93	2	2	2	1	<1
1998	170	6,384	78	5	7	5	3	2
1999	191	10,941	97	1	1	1	<1	<1
2000	182	12,762	93	2	2	1	1	<1

[1] Subregions are defined as follows: Lake States = MI, MN, WI; New England = CT, ME, MA, NH, RI, VT; North Central = IL, IN, IA, MO; Mid-Atlantic = DE, MD, NJ, OH, PA, WV.

[2] Injury severity is an estimate of the mean severity of symptoms on injured foliage (0 = no injury; 1=1-6%; 2 = 7- 25%; 3 = 26-50%; 4 = 51-75%; 5 >75%). Calculated percents are rounded to the nearest whole number.

<u>Note</u>: Table 3 is an example of site-level summary statistics using real data. It is sometimes useful to summarize ozone bioindicator data by multi-State groupings. For example, in the Northeast, it is informative to separate New England and New York from the Mid-Atlantic States because they tend to have dramatically different air quality regimes. Reporting a single regionwide injury index may mask gradations in air quality across the landscape and make it difficult to assess changes in the ozone indicator over time.

Table 4. Population estimates for the ozone indicator including acres of forest land and volume of ozone-susceptible tree species in each biosite index category by State and county in Region ABC. Real data for Delaware (2002) are presented.

State	Cnty	Biosite Index[1]							
		<5	5 - <15	15 - <25	≥25	<5	5 - <15	15 - <25	≥25
		Acres of Forest Land				Volume of Susceptible Species			
10	1	0	97,356	56,338	11,119	xxx	xxx	xxx	xxx
10	3	0	3,954	71,164	69,434	xxx	xxx	xxx	xxx
10	5	0	7,166	97,356	35,088	xxx	xxx	xxx	xxx
State 2	1	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
State 2	2	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
State 2	3	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
State 3	1	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
State 3	2	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
State 3	3	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx

[1] The biosite index is based on interpolated values (see section 3.3.1 for details). Biosite categories represent a relative measure of tree-level response to ambient ozone exposure (see table 1 in the main body of the text).

I can help by adding no, low, mod, and high risk to this table even if a **foot note.** Larger states will want to use 'Area of forest land' in (million acres), and 'volume of susceptible species' in (million cubic feet). For smaller states the 'Area of forest land' may be used straight up as 'Acres of forest land'.

Note: This map of ozone risk to plants is a core product for the ozone indicator. In this example, biosite index values were averaged across the 4-year sampling period from 1999 to 2002 and then geostatistical procedures were used to create an interpolated bioindicator response surface across the landscape (see section 3.3 of this document). The interpolated data are classified into color-based gradations of response representing low risk of probable ozone injury to forests (green), moderate risk (yellow), and high risk (red). These categories also provide an indication of ozone relative air quality with respect to a plant receptor (see table 1 in the main body of the text). Intensified sampling is recommended where high ozone stress coincides with the spatial distribution of ozone-sensitive tree species. Refer to section 6.2 for more information on the ozone sensitivity of tree species.

The ozone risk map is used to estimate bioindicator attributes for all FIA plots using the procedures described in section 3.3.1. BI attributes are merged with other FIA plot attributes to generate population estimates such as those presented in section 6.1, table 4. Population estimates are made using procedures presented by Bechtold and Patterson (2005).

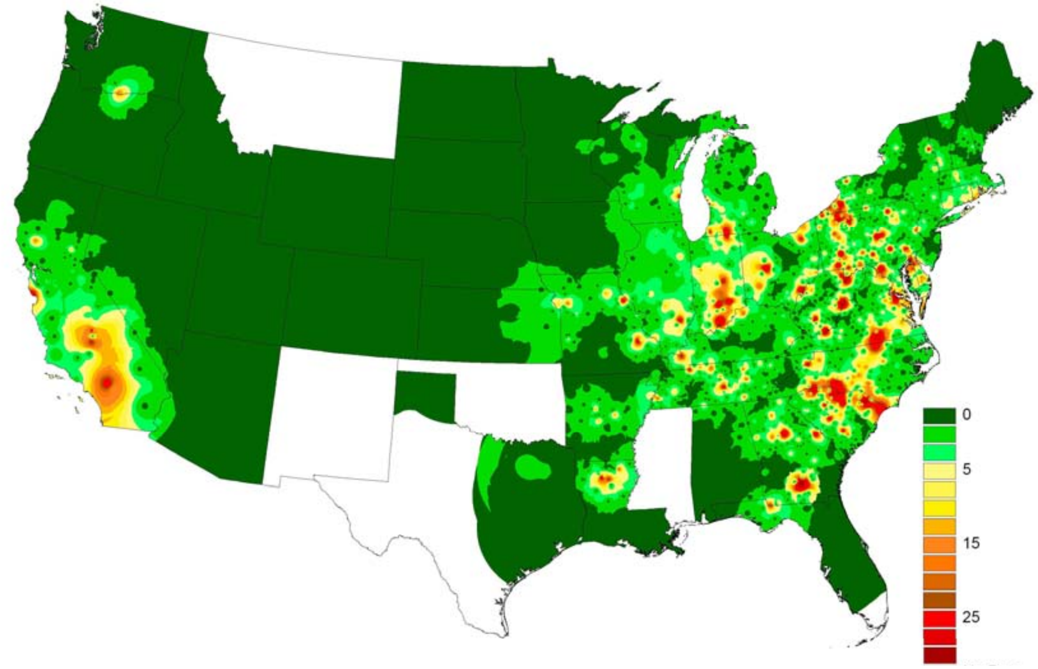

Figure 1. National map of ozone risk to plants. Categorized values are derived from the 1999-2002 biosite data.

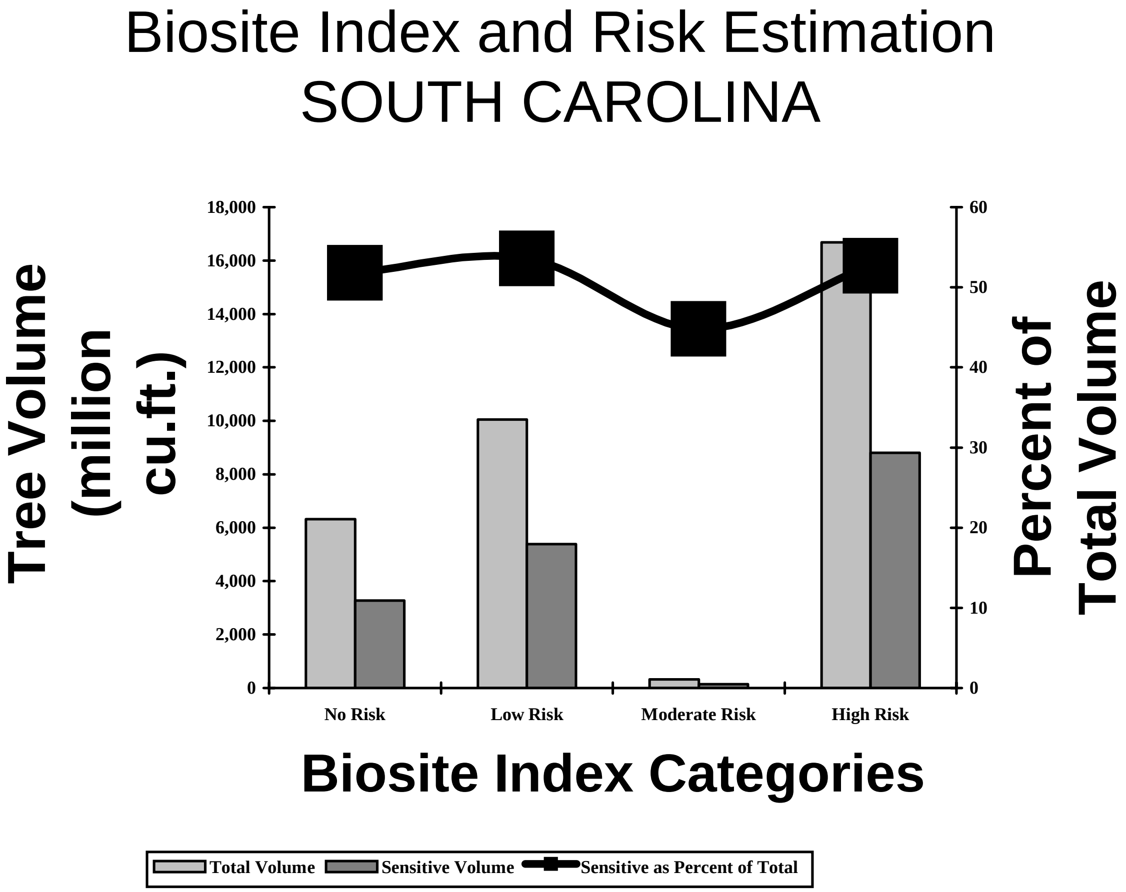

Figure 2. Total tree volume, tree volume for ozone-sensitive trees, and sensitive volume as a percent of total volume by ozone risk category for South Carolina (2002).

Note: The data presented in figure 2 provide an example of ozone risk estimation at the State level. Biosite categories on the x axis represent the risk of probable ozone injury to ozone-sensitive tree species in South Carolina in 2002. More than 16 million cubic feet of tree volume falls into the high risk zone in South Carolina, and 53 percent of this total includes tree species that are ozone sensitive.

In this example, estimates are presented in terms of tree volume. However, other useful population estimates include the proportion of forest land and the acres of forest land in each biosite index category. Refer to section 3.3 for the procedures used to estimate bioindicator attributes for forested areas.

6.2 Ozone sensitivity of tree and shrub species:

The abbreviations used to assign sensitivity in the following tables are as follows: Sen = ozone sensitive, ModSen = moderately sensitive, InSen = ozone insensitive, Unk = unknown ozone sensitivity because there is evidence from different observers that is conflicting. Regional analysts should review both tables because species listed as eastern may be found in limited areas in western States and visa versa. Additional ozone sensitivity listings of non-woody, forest species can be found at: http://www2.nature.nps.gov/air/Pubs/pdf/BaltFinalReport1.pdf.

Table 1. List of eastern tree and shrub species and their ozone sensitivity.
Table 2. List of western tree and shrub species and their ozone sensitivity.

Table 1. List of eastern tree and shrub species and their ozone sensitivity

Eastern Species		Sensitivity	Citation
balsam fir	*Abies balsamea*	InSen[1]	Smith 1981
boxelder	*Acer negundo*	ModSen[1]	Smith 1981
striped maple	*Acer pensylvanicum*	Unk	
red maple	*Acer rubrum*	Sen	Eckert et al. 1999
silver maple	*Acer saccharinum*	Unk	USDI 2003
sugar maple	*Acer saccharum*	InSen	Renfro 1987-1992
mountain maple	*Acer spicatum*	Unk	
Ohio buckeye	*Aesculus glabra*	Unk	USDI 2003
yellow buckeye	*Aesculus octandra*	Sen[2]	USDI 2003
tree-of-heaven	*Ailanthus altissima*	Sen[2]	USDI 2003
speckled alder	*Alnus rugosa*	Sen[2]	USDI 2003
serviceberry	*Amelanchier arborea*	Sen	Renfro 1987-1992
Allegheny seviceberry	*Amelanchierlaevis*	Unk	USDI 2003
pawpaw	*Asimina triloba*	Unk	
yellow birch	*Betula alleghaniensis*	Sen	Renfro 1987-1992
sweet birch	*Betula lenta*	Unk	
paper birch	*Betula papyifera*	ModSen	Eckert et al. 1999
gray birch	*Betula populifolia*	ModSen	Eckert et al. 1999
bitternut hickory	*Carya cordiformis*	Unk	
pignut hickory	*Carya glabra*	Unk	
shagbark hickory	*Carya ovata*	Unk	
hickory sp.	*Carya sp.*	Unk	
mockernut hickory	*Carya tomentosa*	Unk	
hackberry	*Celtis occidentalis*	Unk	
common buttonbush	*Cephalanthus occidentalis*	Unk	USDI 2003
eastern redbud	*Cercis canadensis*	ModSen, Sen[2]	Renfro 1987-1992, USDI 2003
yellowwood	*Cladrastis lutea*	Unk	USDI 2003
Virgin's bower	*Clematis virginiana*	Sen[2]	USDI 2003
flowering dogwood	*Cornus florida*	ModSen	Renfro 1987-1992
American hazelnut	*Corylus americana*	Sen[2]	USDI 2003
Hawthorn	*Crataegus sp.*	Sen[3]	Krupa et al. 1998
common persimmon	*Diospyros virginiana*	Unk	
American beech	*Fagus grandifolia*	Unk	
white ash	*Fraxinus americana*	Sen	Skelly 2000
black ash	*Fraxinus nigra*	Sen[3]	Krupa et al. 1998
green ash	*Fraxinus pennsylvanica*	Sen	Krupa and Manning 1988
black huckleberry	*Gaylussacia baccata*	Sen[2]	USDI 2003

witch-hazel	*Hamamelis virginiana*	Unk	USDI 2003
American holly	*Ilex opaca*	InSen[1]	Smith 1981
black walnut	*Juglans nigra*	Unk	
eastern redcedar	*Juniperus virginiana*	Unk	
tamarack (native)	*Larix laricina*	Unk	
sweetgum	*Liquidambar stryraciflua*	Sen	Krupa et al. 1998
spicebush	*Lindera benzoin*	Unk	USDI 2003
yellow-poplar	*Liriodendron tulipifera*	Sen	Krupa and Manning 1988
maleberry	*Lyonia ligustrina*	Sen[2]	USDI 2003
cucumbertree	*Magnolia acuminata*	Unk	
apple sp.	*Malus sp.*	Unk	
blackgum	*Nyssa sylvatica*	ModSen	Renfro 1987-1992
sourwood	*Oxydendrum arboreum*	ModSen	Renfro 1987-1992
Virginia creeper	*Parthenocissus quinquefolia*	Sen[2]	USDI 2003

Table 1 continued:

sweet mock orange	*Philadelphus coronarius*	Sen[2]	USDI 2003
Norway spruce	*Picea abies*	InSen[1]	Smith 1981
white spruce	*Picea glauca*	InSen[1]	Smith 1981
black spruce	*Picea mariana*	Unk	
red spruce	*Picea rubens*	InSen	Eckert et al. 1999
Jack pine	*Pinus banksiana*	Sen[2]	USDI 2003
shortleaf pine	*Pinus echinata*	ModSen[1]	Smith 1981
table mountain pine	*Pinus pungens*	Sen	Renfro 1987-1992
red pine	*Pinus resinosa*	InSen[1]	Smith 1981
pitch pine	*Pinus rigida*	InSen, Sen[2]	Eckert et al. 1999, USDI 2003
eastern white pine	*Pinus strobus*	Sen	Krupa and Manning 1988
Scotch pine	*Pinus sylvestris*	ModSen[1]	Smith 1981
loblolly pine	*Pinus taeda*	Sen	Taylor 1994
Virginia pine	*Pinus virginiana*	ModSen, Sen[2]	Renfro 1987-1992, USDI 2003
American sycamore	*Platanus occidentalis*	Sen	Krupa and Manning 1988
balsam poplar	*Populus balsamifera*	Sen[3]	Krupa et al. 1998
eastern cottonwood	*Populus deltoides*	Sen[3]	Krupa et al. 1998
bigtooth aspen	*Populus grandidentata*	Sen[3]	Krupa et al. 1998
quaking aspen	*Populus tremuloides*	Sen	Krupa and Manning 1988
wild plum	*Prunus americana*	Unk	USDI 2003
pin cherry	*Prunus pensylvanica*	ModSen	Renfro 1987-1992
black cherry	*Prunus serotina*	Sen	Krupa and Manning 1988
choke cherry	*Prunus virginiana*	ModSen	Renfro 1987-1992
white oak	*Quercus alba*	InSen	Renfro 1987-1992
scarlet oak	*Quercus coccinea*	ModSen[1]	Smith 1981
northern pin oak	*Quercus ellipsoidalis*	ModSen[1]	Smith 1981
southern red oak	*Quercus falcata*	Unk	
shingle oak	*Quercus imbricaria*	InSen[1]	Smith 1981
bur oak	*Quercus macrocarpa*	InSen[1]	Smith 1981
pin oak	*Quercus palustris*	ModSen[1]	Smith 1981
willow oak	*Quercus phellos*	Unk	
chestnut oak	*Quercus prinus*	Unk	
northern red oak	*Quercus rubra*	InSen	Eckert et al. 1999
post oak	*Quercus stellata*	Unk	
black oak	*Quercus velutina*	ModSen[1]	Smith 1981
winged sumac	*Rhus copallina*	Sen[2]	USDI 2003
black locust	*Robina pseudoacacia*	ModSen, Sen[2]	Renfro 1987-1992, USDI 2003
Allegheny blackberry	*Rubus allegheniensis*	Sen[2]	USDI 2003
thornless blackberry	*Rubus canadensis*	Sen[2]	USDI 2003
sand blackberry	*Rubus cuneifolius*	Sen[2]	USDI 2003

black willow	*Salix nigra*	Unk	
American elder	*Sambucus canadensis*	Sen[2]	USDI 2003
sassafras	*Sassafras albidum*	Sen	Krupa et al. 1998
common snowberry	*Symphoricarpos albus*	Sen[2]	USDI 2003
northern white-cedar	*Thuja occidentalis*	InSen	Eckert et al. 1999
American basswood	*Tilia americana*	InSen[1]	Smith 1981
Chinese tallow	*Triadica sebifera*	Sen[2]	USDI 2003
eastern hemlock	*Tsuga canadensis*	InSen	Renfro 1987-1992
American elm	*Ulmus americana*	Unk	
slippery elm	*Ulmus rubra*	Unk	
northern fox grape	*Vitis labrusca*	Sen[2]	USDI 2003

[1] Based on relative sensitivity to acute ozone exposure.
[2] Based on sensitivity to ambient ozone concentrations in the field and exposure chamber.
[3] Based on relative sensitivity of genus, not species.

Table 2. List of Western Tree and Shrub Species and their Ozone Sensitivity

Western Species		Sensitivity	Citation
red alder	*Alnus rubra*	Sen[3]	Brace et al. 1996
Sitka alder	*Alnus sinuata*	Sen	Brace et al. 1996
western serviceberry	*Amelanchier alnifolia*	ModSen[3]	Brace et al. 1996
single-leaf ash	*Fraxinus anomala*	Sen[4]	USDI 2003
twinberry	*Lonicera involucrata*	Sen[4]	USDA 2003
lodgepole pine	*Pinus contorta*[1]	ModSen[3]	Brace et al. 1996
Jeffrey pine	*Pinus jeffreyi*	Sen	Miller et al. 1996
ponderosa pine	*Pinus ponderosa*[2]	Sen	Smith 1981
Monterey pine	*Pinus radiata*	Sen[4]	USDI 2003
Pacific ninebark	*Physocarpus capitatus*	Sen[3]	Brace et al. 1996
mallow ninebark	*Physocarpus malvaceus*	Sen[3]	Brace et al. 1996
Fremont cottonwood	*Populus fremontii*	Sen[4]	USDI 2003
quaking aspen	*Populus tremuloides*	Sen	Smith 1981
black cottonwood	*Populus trichocarpa*	ModSen[3]	Brace et al. 1996
Douglas-fir	*Pseudotsuga menziesii*	ModSen[3]	Brace et al. 1996
California black oak	*Quercus kelloggii*	ModSen	Miller et al. 1996
skunk bush	*Rhus trilobata*	Sen	Temple 2000
thimbleberry	*Rubus parviflorus*	Sen[4]	USDI 2003
Gooding’s willow	*Salix gooddingii*	Sen[4]	USDI 2003
Scouler’s willow	*Salix scouleriana*	Sen[4]	Brace et al. 1996
willow sp.	*Salix sp.*	ModSen[5]	Krupa and Manning 1988
blue elderberry	*Sambucus mexicana*	Sen	Temple 2000
red elderberry	*Sambucus racemosa*	ModSen[3]	Brace et al. 1996
common snowberry	*Symphoricarpos albus*	Sen[4]	USDI 2003
snowberry sp.	*Symphoricarpos sp*	Sen[5]	Smith 1981
western hemlock	*Tsuga heterophylla*	ModSen[3]	Brace et al. 1996
huckleberry	*Vaccinium membranaceum*	Sen[4]	USDI 2003
huckleberry sp.	*Vaccinium sp.*	ModSen[3]	Brace et al. 1996

[1] *Pinus contorta* var. *latifolia*.
[2] *Pinus ponderosa* var. *ponderosa*.
[3] Based on relative sensitivity to acute ozone exposure.
[4] Based on sensitivity to ambient ozone concentrations in the field and exposure chamber.
[5] Based on relative sensitivity of genus, not species.

6.3 Documents for Ozone Information Management

Documents to assist FIA Regional Analysts with ozone information management:
1. Flow of Ozone Data from the Field to the FIA Information Management System
2. Ozone Standard Summary Tables in the FIA Data Base (FIADB)
3. Formulation of the Biosite Index
4. SAS Code for Biosite Tables and Maps
5. Contact List for Ozone Data Management

To obtain the following documents, e-mail: Gretchen Smith at gcsmith@forwild.umass.edu

1. Computation specifications for derived ozone data in FHM
2. Ozone bioindicator attribute definitions for FIADB
3. Ozone data collection start dates by State and year.
4. Crosswalk tables for tracking changes to the ozone sample from 1994 to the present.
5. Sample biosite field map
6. National ozone risk map for the sampling period 1994-1998
7. National ozone risk map for the sampling period 1999-2002
8. National map of the 7-year average ozone exposure 1996-2002

Flow of Ozone Data from the Field to FIA Information Management

The goals of ozone information management are to clean up the ozone data files collected by the field crews, correct the regular crew and QA crew data files so they are compatible with the leaf voucher data, and generate ozone summary statistics suitable for further analysis and reporting. The summary statistics are used to generate an ozone risk map and population metrics as described in the main body of this document.

Step 1:
Each Regional Analyst works with the raw data file entered by the field crew and the validation file created by the National Indicator Advisor**.**

Step 2:
The Regional Analyst/P3 Data Processor in each region takes the raw data files entered by the field crew and the validation file created by the National Indicator Advisor and loads both into NIMS (National Information Management System). The P3 LAB system-checker program determines errors between the validation file and the raw data. Differences between these two files must be resolved at the regional level through direct communication between the National Indicator Advisor and the Regional Analyst. Error resolution requires changes to both the raw data file and the validation file.

> Note: It is sometimes helpful to resolve differences between these two files before loading the data into NIMS. Software to assist with this process is available. Once the data are loaded, the checker program is used as a final edit.

Step 3:
The Regional Analyst/P3 Data Processor in each region runs the P3 LAB system-report program on the validated ozone data. The report program creates three ozone standard summary tables: OZONE_PLOT_SUMMARY, OZONE_SPECIES_SUMMARY, and OZONE_BIOSITE_SUMMARY.

Step 4:
The Regional Anaylst/P3 Data Processor contacts Brian Cordova, FIA-IM, at: cordovab@unlv.nevada.edu. Each region's data is captured and placed on the national NIMS web site. Sensitive information is stripped (NULLED), and the remaining information is posted on the national FIA data base (FIADB) P3 web site and the FIADB Data Mart which is the data distribution system to the public.

> Note: Step 2 instructs the Regional Analyst to load the data into NIMS. Until the new TALLY program is completed, the raw TALLY files are parsed using TALLY Cracker and inserted into the LOAD tables in NIMS. The data are moved from the LOAD tables to the NIMS tables through the front-end, which is a graphical interface used to load and drop data, run computations and reports, etc. The front-end is again used to load the validation file and create a report of any errors. In the future, Step 4 will be a direct upload to the NIMS FIA-P3 web site via the front-end interface.

Additional Steps:
The NIMS ozone summary tables provide biosite summary statistics suitable for preliminary reports at the State and regional levels (see 6.1 Output Tables and Maps). SAS routines are available that generate additional summary statistics from the validated ozone files. For example, one routine generates all the necessary values to create a summary table that presents numbers of biosites evaluated, number of plants sampled by species, and percentage of sampled plants in each injury severity category. Another SAS routine is available that generates a biosite list with presence or absence of ozone injury to use for an ozone site distribution map. This map is useful for tracking changes over time in the number and distribution of plus ozone sites across a State or region.

The OZONE_BIOSITE_SUMMARY table includes the plot-level ozone injury index referred to as the Biosite Index (BI). Using a 5-year rolling average of the BI, an FIA Spatial Data Analyst creates the national risk map of probable ozone injury. A new map is produced every year. This map surface is stored in the FIADB Data Mart so that it can be extracted by Regional Analysts, in whole or in part, as needed. FIA Spatial Data Services uses the national map to generate an estimated BI value for every P2 ground plot. This biosite attribute is added to the larger P2 table of plot attributes in the FIADB Data Mart. This will allow FIA analysts to examine relationships between bioindicator attributes and other indicators of tree growth, forest health, and condition. FIA Spatial Data Services also maintains a master list of geographical coordinates for the ozone sampling grid and crosswalk tables that link biosites on the FHM-P3 grid (1994-2001) to biosites on the FIA Ozone Grid (2002-present).

Analysts responsible for 5-year reports or comprehensive regional reports should refer to the main body of the text of this document for detailed guidance on the analytical techniques used to generate FIA P2 plot-level metrics of the ozone data. The companion user guide for the ozone indicator provides (1) examples of output tables and maps using real data, and (2) additional interpretive guidance on the issues associated with ozone air quality and forest health.

Three Ozone Standard Summary Tables in the FIA Data Base

Ozone Species Summary Table

Statecd	number(2)	not null
countycd	number(2)	not null
p3hex	number(7)	not null
p3plot	number(1)	not null
plot	number(8)	not null
measyear	number(4)	not null
bio_species_cd	number	not null
amount_maximum	number	not null
amount_minimum	number	not null
amount_mean	number	not null
severity_maximum	number	not null
severity_minimum	number	not null
severity_mean	number	not null
plants_inj_cnt	number	not null
plants_eval_cnt	number	not null
plants_ratio	number	not null
bio_species_sum	number	not null
bio_species_index	number	not null
elev	number	not null
pltsize	number	not null
aspect	number	not null
terrpos	number	not null
soildpth	number	not null
soildrn	number	not null
soildrn	number	not null
plotwet	number	not null
pltdstrb	number	not null

Ozone Plot Summary Table

Statecd	number(2)	not null
countycd	number(2)	not null
p3hex	number(7)	not null
p3plot	number(1)	not null
plot	number(8)	not null
measyear	number(4)	not null
species_eval_cnt	number	not null
biosite_index	number	not null
elev	number	not null
pltsize	number	not null
aspect	number	not null
terrpos	number	not null
soildpth	number	not null
soildrn	number	not null
soildrn	number	not null
plotwet	number	not null
pltdstrb	number	not null

Ozone Biosite Summary Table

Statecd	number(2)	not null
countycd	number(2)	not null
p3hex	number(7)	not null
location_cnt	number(1)	not null
plot	number(8)	not null
measyear	number(4)	not null
plant_inj_cnt	number	not null
plant_eval_cnt	number	not null
plant_ratio	number	not null
species_eval_cnt	number	not null
biosite_index***	number	not null
svrty_class_zero	number	not null
svrty_class_one	number	not null
svrty_class_two	number	not null
svrty_class_three	number	not null
svrty_class_four	number	not null
svrty_class_five	number	not null

***See notes on the formulation of the biosite_index on the following page.

Formulation of the Biosite Index (BI)

Note: The ozone indicator site-level biosite index was formulated with the assistance of David Randall, Statistician for the USDA Forest Service Northeastern Area, Washington Office.

Notes on the formulation:
There are 3 components to the formulation: (1) the amount of injury, (2) the severity of injury, and (3) the incidence of injury on the site. The formulation selected associates these three components at the individual plant level. This suggests that the ozone injury response of each individual plant is important. This is biological reality and better than lumping all species together.

The calculation is intuitive. A mean value is calculated that truly represents a proportion of the population at both the plant level and the species level. An arithmetic mean is then taken for the "n" species on the plot.

Notes on method:
Each plant observed by the field crew is rated for the percent of the plant that is injured (i.e., injury amount) and the average severity of injury (i.e., injury severity) using a modified Horsfall-Barrett scale with breakpoints at 6, 25, 50, 75, and 100 percent. This information is used to calculate an injury value for each plant, a mean value for each species, and an overall site mean. The incidence of injury on the site is also considered. The formulation is based on the fact that each individual plant has a unique response to ozone that is dependent on the genotype and microhabitat at the time of exposure.

For each plant:

AMT = injury amount
SEV = injury severity

For each species:

N_1 = the number of injured plants
N_2 = the number of evaluated plants
$A = N_1 / N_2$
$B = \sum[(AMT)(SEV)] / N_1$
Species_Index = (A)(B)

For each biosite (hexagon number):

N_3 = the number of evaluated species
Biosite_Index = $\sum$(Species_Index) / N_3

Notes on transforming crew values from the ordinal scale to the percent scale:

In the field, the crews estimate the percent injury to the plant and then assign ordinal values that reflect 5 broad classes of injury as follows: 0 = no injury; 1 = 1-6% injury; 2 = 7-25% injury; 3 = 26-50% injury; 4 = 51-75% injury; and 5 = ≥75% injury.

In the office, the ordinal codes recorded by the field crews are converted to percentage values representing the midpoint of each injury class as follows: 0 = 0; 1 = 3.5%; 2 = 16%; 3 = 38%; 4 = 63%; and 5 = 88%. Theoretically, the site-value has a range from zero to 100. In reality, the highest values are less than 25 and most are less than 5. A site with no injury has an index of zero.

The measurement intervals on the two scales are different. The intervals on the ordinal scale are equal; those on the percent scale are not. Midpoint values are used rather than ordinal values for the site-level index because (1) the midpoint percentage values bring the reader back to the original scale used by the field crew to rate the injured plants; (2) the percentage values have some intuitive biological relevance, unlike the ordinal scale, which was developed largely as a matter of convenience for the field crews; and (3) readers relate more easily to the percentage values than the ordinal scale.

It is understood that the data transformation introduces some error or misrepresentation into the reporting of the Biosite_Index. Nevertheless, as long as the reader knows how the biosite-value was calculated, the midpoint percentage is still preferable because it provides a more meaningful image of ozone injury than would be provided by the ordinal scale.

SAS CODE: Biosite Tables
The following routine will generate summary statistics similar to those presented in section 6.1, Table 3.

- The number of plots evaluated by State
- The number of plants sampled by State
- The percent of sampled plants in each HB injury severity class by State

This is a highly defensible presentation of the ozone indicator data for State and regional reports.

```
/**** filename o3_summary.sas    Jan 2004   Barbara O'Connell****/
/****Program to produce percent injured by severity by State  *****/
/*** must first run vouch03.sas, biovch03.sas, and biocor03.sas to create corrected data set****/

options ls=95 ps=1000 obs=max;

libname perm 'c:\_barbo\2003\analysis\ozone\';

data o3sum03;  set perm.biocor03;  *biocor03 is raw tally files corrected as per validation data;
   if qa_stat=1;  *include only the regular crew data;
   if severity =. then severity=0;
   if amount>0 then nplants=1;

proc sort data=o3sum03; by State hex_num;
proc freq data=o3sum03;
tables severity/norow nocol nofreq nocum;
by State;
weight nplants;
title1 '2003 Ozone Severity';

proc summary data=o3sum03;  * to get the number of plots surveyed per State;
   class hex_num;
   id State;
   output out=all03;
data all03;  set all03;  total=_freq_;  drop _type_ _freq_;
proc sort data=all03;
by State hex_num;
proc summary data=all03;
class State;
var hex_num;
output out=noplots n=;
proc print;
title1 '2003 Ozone plots';

proc summary data=o3sum03;  * to get the number of plants sampled;
class State;
var nplants;
output out=spcnt sum=;
proc print;
title1 '2003 Nbr. of Plants Sampled';
run;
```

Note: The SAS routine was written by Barbara M. O’Connell, Forester, USDA Forest Service, Northern Research Station, FIA, Newtown Square, PA.

SAS CODE: Maps

The following routine will generate summary statistics that can be used to create a State or regional map of ozone biomonitoring sites with and without ozone injury. This type of map is useful for documenting status and change in the number and distribution of biosites with ozone injury across a State or region.

```
/**** filename biomap03.sas    March 1998   ****/
/***  updated Jan 2004   Barbara O'Connell****/
/*** must first run vouch03.sas, biovch03.sas, and biocor03.sas to create corrected data set****/

options ls=95 ps=1000 obs=max;

libname perm 'c:\_barbo\2003\analysis\ozone\';

data bio03;  set perm.biocor03;
  if qa_stat=1;  *include only the regular crew data;

proc summary nway data=bio03;  *to create hex_num data set;
  class hex_num;
  id State;
  output out=all;

data all;  set all;  drop _type_ _freq_;

proc sort data=all;  by hex_num ;

data temp;  set bio03;  if amount > .5;  *include only injured data;

proc summary nway data=temp;  *to create data set with hex avg injury and total nbr damaged;
  var amount severity;
  class hex_num ;
  output out=damaged mean= ;

data damaged;  set damaged;  damaged=_freq_; drop _type_ _freq_;
proc sort data=damaged; by hex_num;
data summary;
  merge all damaged;
  by hex_num ;
 if damaged=. then damaged=0; if amount < .5 then amount=0;
 if severity < .5 then severity=0;
data final; set summary;
if amount = 0 then infect=2;
if amount > .5 then infect=1;

proc sort;
by State hex_num;

proc print r;

title1 'FHM 2003 Bioindicator';
title2 'no. of plants with injury and avg amount/severity per plot';
title4 'injury: 1=injury detected 2=no injury';
var State hex_num infect damaged amount severity;

run;
```

Note: The SAS routine was written by Barbara M. O'Connell, Forester, USDA Forest Service, Northern Research Station, FIA, Newtown Square, PA.

<u>Contact List for Ozone Data Management</u>

National Indicator Advisors:
John Coulston, FS – Southern Research Station. Knoxville, TN, jcoulston@fs.fed.us
Gretchen Smith, UMass-Amherst, gcsmith@forwild.umass.edu

Information Management: For access to validated data files, summary statistics, and map products.
Brian Cordova, UNLV, cordovab@unlv.nevada.edu
Chuck Liff, FS – Rocky Mountain Research Station. Ogden, UT, cliff@fs.fed.us
John Coulston, FS – Southern Research Station. Knoxville, TN, jcoulston@fs.fed.us

National QA: For information on QA analyses of the field data at the national level.
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Bill Smith, FS – RTP. bdsmith@fs.fed.us

Regional Analysts: For information on analyses and reports and for access to regional files.
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<u>Where to find more information on the biomonitoring program and ozone data.</u>

http://fiaozone.net/ This site includes a library of information on the ozone indicator for trainers and data users.
http://fhm.fs.fed.us/ This is the FHM home page. It includes fact sheets for all of the P3 forest health indicators.
http://fia.fs.fed.us/ This is the FIA home page. Click on 'FIA Tools and Data' for access to ozone field data, standard ozone summary tables, and the FIADB ozone user guide for field attributes. Click on 'FIA Library' for access to the ozone field manual.

FIA uses the Oracle Database Management System to process and store the ozone indicator data (also called NIMS – National Information Management System). Raw data from field-collected tally files and sample voucher validation files are loaded onto five standard tables (OZONE_PLOT_TBL, OZONE_VISIT, OZONE_SPECIES, OZONE_PLOT_NOTES, and OZONE_VALIDATION). Further processing computes indices and creates three standard summary tables (OZONE_BIOSITE_SUMMARY, OZONE_PLOT_SUMMARY, and OZONE_SPECIES_SUMMARY), which are used as the presentation data in the FIADB (FIA database) after sensitive information has been stripped. The database structure is such that flat files can be easily produced for users who do not have access to, or the capability of, database management on their own computers. ASCII data files (1994 to present), two core ozone maps, and a core list of ozone sensitive tree and shrub species are available for download from the FIADB Data Mart (the data distribution system to the public). The first map product is the national ozone risk map which provides an interpolated surface of probable ozone injury across the landscape. The second map product is an interpolated surface of ambient ozone concentrations. Data users select their area of interest (e.g., state, region, or eco-region) from these two map products, and use the procedures outlined in the ozone estimation document to calculate and interpret population metrics for the ozone indicator. If you have trouble accessing web sites or data files, contact the national ozone advisor, the FIA analyst in your region, or Brian Cordova at cordovab@unlv.nevada.edu.