Lichens, Ozone, and Forest Health – Exploring Cross-indicator Analyses with FIA Data

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Abstract: *Does air pollution risk represented by a lichen bioindicator of air pollution, an ozone bioindicator, or a combination of both, correlate with forest health as reflected by condition of tree crowns and other variables? We conducted pilot analyses to answer this question using Forest Inventory and Analysis (FIA) data from the Sierra Nevada region of California and the New England region; they have very different environments. We started by addressing procedural and statistical issues. Several steps were required to assemble data sets for addressing this question. Currently, incomplete data availability limits the ability of an analyst not affiliated with the FIA program to conduct similar investigations. Statistical issues include data characteristics, data screening for suitability, and how to combine different variables in the same analysis. We calculated combined plot-level air pollution risk indexes from lichens and ozone data, and combined plot-level 'forest stress' indexes from two or more tree health indicators. Consultations with other FIA indicator advisors and with FIA analysts having experience with the tree variables we used were extremely important. For the Sierra Nevada region no significant correlations were found between pollution risk and 'forest stress' indexes. The next step there is to decide whether it seems worthwhile to pursue other related avenues investigating the same question. For the New England states, some correlations were significant but so weak that their biological relevance is questionable. For one of three ecoregion subgroups examined, correlations were significant and strong enough to warrant follow-up studies. In general we concluded that crown dieback and vigor variables were more useful than other tree variables, and summarizing to plot-level based on tree basal area was more useful than using tree counts. Development of more sophisticated plot-level indexes of 'forest stress' should be part of all follow-up investigations.*

Keywords: Air pollution, bioindicator, California, forest health, forest stress, lichens, ozone, Phase 3, risk index, tree crowns, tree mortality, New England

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Introduction

We decided to explore whether estimated air pollution risk in forests (represented by a lichen bioindicator of air pollution, an ozone bioindicator, or a combination of both) correlates with forest health as reflected by condition of tree crowns and other variables. The U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program (FIA) collects both tree mensuration data and data addressing forest ecosystem health on a subset of its full national grid (phase 3 or P3 plots). Lichens are included in the program as useful forest health indicators for air quality impact, biodiversity, and forest ecosystem integrity. An ozone bioindicator is included to help assess the level of this known risk to some vascular plants. A number of variables included in the program can be used to assess tree health on FIA plots, including growth and mortality, crown condition, and tree damage variables (FIA 2008f).

We conducted pilot analyses to answer our question using FIA data from the Greater Sierra Nevada region of California and the New England region (including New York state) – parts of the USA with very different environments. Since this is a very preliminary investigation, our project included evaluation of the procedural and statistical issues involved in asking such a question. What steps are required to assemble data sets for addressing this question? How might these steps be seen by a data user from outside the Forest Service trying to do similar analyses based on FIA data available online? What statistical issues arise related to using the different indicators in the same analyses? What issues arise when we attempt to generate a combined air pollution response index from lichens and ozone indexes, or a combined plot-level 'forest stress' index from two or more tree variables? When and where are consultations critical - with FIA Indicator Advisors and FIA Analysts having experience with these variables?

Our starting assumption was that air pollution tracked by lichen air quality indexes and the ozone bioindicator index might contribute to low-level stress that would render trees more susceptible to reduced health or damage from other agents. It is possible this might happen well below levels of air pollution that would directly damage most trees.

Selected variables

We selected several FIA variables for our pilot project. These variables are primary or derived variables related to either pollution risk or tree health. Most are defined in online FIA documents. Other published documents linked to the FIA program explain how to use and interpret the variables.

Pollution risk variables

We used two different kinds of pollution risk variables. Lichens are sensitive to several kinds of Nitrogen- and Sulfur-based air pollutants, and lichen air quality indexes track response of lichens to all of these pollutants together. The ozone interpolated biotic index (IBI) is calculated based on response of sensitive vascular plants; it assesses potential risk from only this single pollutant. Both lichen air quality indexes and the ozone IBI apply to an entire FIA plot.

Lichen air quality indexes: Lichen air quality indexes are based on lichen species composition at sites, are derived from models specific to a particular geographic region (Will-Wolf and Neitlich in review), and apply only within that region. They are not currently defined in online FIA database documentation; users refer to published descriptions of each model and to Will-Wolf (in review) for guides to usage. Lichens are sensitive to two major classes of air pollution: 1) mostly neutral pH/alkaline N pollution from agricultural sources (figure 1A), and 2) acidic N and S pollution that comes primarily from urban and industrial sources (figure 1B). In addition, N from both sources can have a fertilizing effect on the ecosystem. Responses of lichens to the two classes of pollution differ, and the most important kind of pollution may differ between regions (Will-Wolf et al. in review). Thus lichen air quality indexes from different regions may reflect response to different kinds of air pollution. In both regions included in this study, a higher index number indicates poorer air quality.

A **B**

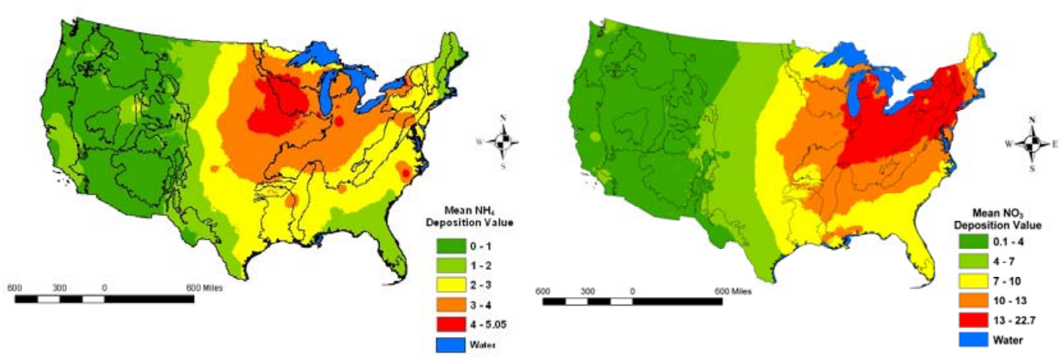

Figure 1: Pollution wet deposition modeled from 1998-2004 National Atmospheric Deposition Program data (Coulston and others 2004). Black lines mark boundaries of ecoregion groups (some noted in figures 3 and 4). **A.** NH_4^+ represents effects of agriculture; **B.** NO_3^- represents urban/ industrial effects. Note amounts for both are much higher in the East. Reproduced from Will-Wolf et al. (in review).

Greater Sierra Nevada (GSN) region of California – The published Lichen Air Quality index (LichenAirGSN for this project) for this region (Jovan & McCune 2006) tracks mostly response to neutral/alkaline agricultural nitrogen pollution (Fenn et al 2003, Jovan 2008). The amount of pollution in this region is underestimated in figure 1 because those maps are based only on wet deposition and dry deposition is an important contributor there (Fenn et al. 2008).

New England (NE) region – This region has two provisional Lichen Air Quality indexes (Will-Wolf unpublished) that track response primarily to acidic urban/industrial pollution. LichenAirNE-A is relative abundance of eight pollution-tolerant lichen indicator species, and LichenAirNE-B is the former index adjusted for latitude. The latter takes into account north-south gradients in climate as well as regional background air pollution (figure 1), leaving this index more responsive to relative local pollution level regardless of regional context.

Ozone interpolated biosite index (IBI): This index is based on level of damage to sensitive species at special field plots. It is calculated by spatial interpolation for FIA plots (FIA 2008a). It is diagnostic for one pollutant, and is applicable and comparable across the country (Coulston et al. 2004, Smith et al. 2007); ozone risk is quite similar for the two pilot project regions (figure 2). A higher number indicates greater potential risk for ozone injury.

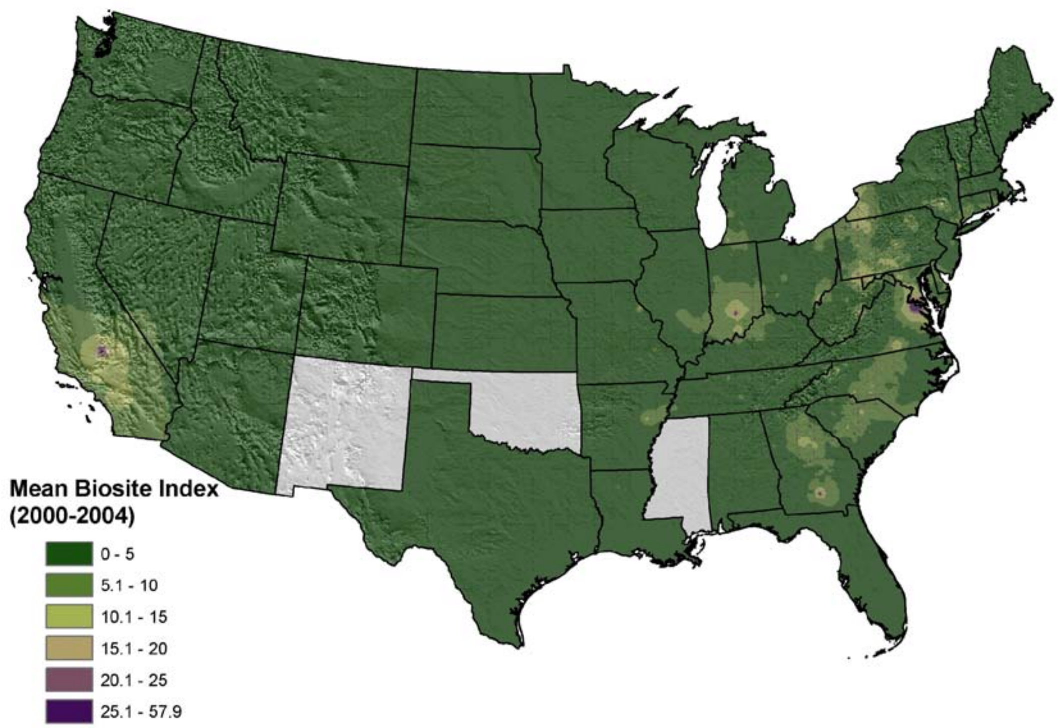

Figure 2: This map of Ozone Interpolated Biosite Index (IBI) illustrates estimated risk of ozone injury (map by John Coulston).

Tree health variables

Crown condition, growth, mortality, and damage are all classes of FIA tree variables (FIA 2008b) that are good candidates for evaluating tree health. Relatively few plots for which we have lichens data also have damage data, so we did not consider damage variables further. We needed to aggregate values representing tree health across all trees at the plot into 'forest stress' indexes for comparison with pollution risk indexes. For this pilot study, we conducted no calibration based on species of tree. In most cases stressed trees were expressed as proportion of either total number of trees or total basal area at the plot. Total basal area was also used as a surrogate for stand age.

Crown variables: From crown condition documents (Bechtold and Randolph 2007, Schomaker et al. 2007) and consultation with current crowns indicator advisors William Bechtold and KaDonna Randolph, we identified several crown variables suitable to represent tree stress. Our 'stressed tree' cutoff levels are based on both advice from Bechtold and Randolph and on previous work by others; our choices of cutoff levels are our responsibility alone.

Crown dieback (trees ≥5in/12.7cm diameter) – This variable may be aggregated across species to plot-level. It is considered a strong 'tree stress' indicator. Both average dieback and proportion of trees with dieback ≥10% (indicating stress) are calculated for 'forest stress' indexes.

Crown vigor (trees <5in/12.7cm diameter) – This variable may be aggregated across species to plot-level. This is considered a strong 'tree stress' indicator. Proportion of small trees (saplings) in vigor class 3 (indicating stress) is calculated for a 'forest stress' index.

Crown density (trees ≥5in/12.7cm diameter) – Density for healthy trees varies by species, so this variable should be related to a species standard before aggregating to plot-level. Steinman et al. (2000) used crown density ≤35% as a conservative indicator of a stressed tree, so we used proportion of trees stressed based on this cutoff value as a weak 'forest stress' index.

Foliage transparency (trees ≥5in/12.7cm diameter) – Density for healthy trees varies by species, so this variable should be related to species standard before aggregating to plot-level. Steinman et al. (2000) used foliage transparency ≥35% as a conservative indicator of a stressed tree, so we used proportion of trees stressed based on this cutoff value as a weak 'forest stress' index.

Growth: Growth for healthy trees varies by species, so this variable should be related to a species standard before aggregating to plot-level. We found no examples in literature for reasonably conservative indicators of a stressed tree based on growth alone, so we did not pursue this variable further.

Mortality: – This variable may be aggregated across species to plot-level. We calculated the proportion of trees that died up to 5 years before an inventory year as an estimate of tree stress, to be consistent with mortality variable definitions (FIA 2008b). Expected mortality might vary with stand age (Bechtold, pers. comm.), so the proportion might need to be adjusted for stand age. Also, mortality became an optional variable to report starting in 2003, and some states did not report this after 2002. For both these reasons, we consider this a weak 'forest stress' index.

Data for analysis

Data were assembled for the two pilot study areas, then were screened for a variety of issues. Plot variables were assembled from screened data. Data sets were assembled in Excel (2003); statistical analyses used SPSS (2007).

Study areas

The Greater Sierra Nevada region of California (figure 3) is mostly one ecoregion province. Lichens data are available from 1998-2001 and 2003.

The New England states (figure 4) include Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. This region is much larger than the California region; we investigated patterns both for the whole region and for three ecoregion group subdivisions from another project (Will-Wolf et al. in review). Lichens data are available from 1994 and 1998-2004.

Assembling data sets

FIA data are in the public domain (FIA 2008c) and are made available in a timely manner, but difficulties reconciling some data matching issues mean not all measured data used for this project are currently available to the public online. No 2000-2002 data are currently available online, pending resolution of data matching issues. Neither lichen nor ozone indexes (derived variables) are archived in the central database and posted online, pending development of FIA database structures for derived variables. They must be obtained by both FIA and public data users from lichen indicator advisors (currently the coauthors of this document) or the FIA region. It is assumed that both database and data matching issues that limit data availability online are temporary; all data will eventually be publicly available in some form.

We started with a list of all plots in each region for which lichens data are available. Plots were screened based on the following criteria. Plots with no lichens found (cannot calculate a lichens air quality index for them) or with flags for poor fit to the regional model were excluded. Eastern plots with live tree basal area (BA) below 5 m^2/ha (21.8 ft^2/ac) were excluded; their lichen air quality indexes might be biased due to limited substrate (no BA cutoff needed for western plots; Will-Wolf in review). Some plots were excluded because tree data were not easily available. Plots with fewer than 3 trees rated for crowns were excluded as giving inadequate representation of forest health. An ozone IBI can be calculated by interpolation for all our plots; no screening was needed based on ozone data.

Lichen air quality index values for the greater Sierra Nevada region of California were calculated by Sarah Jovan. Two provisional lichen air quality indexes for the New England region were calculated by Susan Will-Wolf. The ozone IBI was calculated via interpolation for all project plots by John Coulston using exact plot locations. Tree data were extracted from FIA database files and FHM legacy database files mostly by Randy Morin, and also by Susan Will-Wolf.

Available lichen plots and plots excluded based on lichen data criteria are summarized in table 1; plots excluded based on tree data and remaining plots available for this project are summarized in table 2. Plots in four ecoregion subgroups of the New England region are listed in table 2.

Table 1: Lichen plots available and excluded based on lichen data screening.

	Lichen plots: years	**No lichens; plots excluded**	**Plots surveyed in 2 years; 1 year excluded**	**Plots excluded - tree BA too low[a]**
California Sierra Nevada region	146 plots: 1998-2001, 2003	3	9[b]	
New England region	668 plots: 1994, 1998-2004	4	71[c]	53

[a]NE plots only; lichen air quality index might be biased.

[b]1998 plots retained

[c]plots from several later years retained

Table 2: Lichen plots available and excluded based on tree data screening.

	Plots with lichens data[a]	**Plots excluded: tree data unavailable**	**Plots excluded: too few trees rated for crowns**	**Plots used for this project**
California Sierra Nevada region	134	2 plots: 1998-2001 25 plots: 2003	8	99
New England region	540	4 plots: 1994-1999 178 plots: 2000-2002	6	352
Adirondacks subregion				146
Laurentian subregion				125
Eastern Deciduous subregion				80
Appalachian subregion				1

[a]Plots remaining from table 1.

Assembling plot variables

We used single variables calculated from the program databases as described above. We also used composite variables calculated from combining different single variables. For composite variables we used different approaches depending on the variables used. Our calculation procedures took into account a number of statistical issues; we outline these first.

Statistical issues: To avoid bias in our cross-indicator analyses, we modified differently-scaled variables to be used in the same statistical procedure. We tried two 'low tech' options to equalize scales for variables. One choice was to add and/or multiply values of some variables by constants to match ranges of the other variables to be used in the same analysis. A second choice was to rank-transform all variables to equalize ranges. This second choice at the same time corrects for any problems with data distributions.

Pollution - lichen and ozone plot indexes: These are the single or composite variables we used for analysis. We used the same approach for all three LichenAir… indexes in both regions. Since high values of both lichen and ozone indexes suggest higher pollution risk, we added them together for a composite index. We tried three kinds of composite pollution index, one with original indexes weighted equally, and others with one or the other weighted double. One set of indexes was calculated using modified variable range – these are listed below. A second parallel set of variables was calculated using rank-transformed data.

- LichenAir… [region suffix]: Range modified to match Ozone IBI in region.
- OzoneIBI: No region suffix needed; IBI is nationally consistent.
- LichenAir…+OzoneIBI: Composite index from simple addition.
- 2xLichenAir…+OzoneIBI: Composite index, LichenAir… weighted double.
- LichenAir…+2xOzoneIBI: Composite index, OzoneIBI weighted double.

Forest stress - crowns and mortality plot variables: Most of the forest stress indexes are composite variables; only average crown dieback seems a useful single index. All variables are calculated so that a higher value suggests greater stress on the forest at the plot. We found that % recent mortality (based on counts or BA of trees) in either region was not correlated with total plot BA, our best estimator for stand age.

- AvgDbk is Average Crown dieback class (for all trees rated) – a single variable

All composite variables are % of trees ('Ct' for count added after % in variable name) or % of basal area ('BA' added after % in variable name) on a plot with various combinations of variables indicating tree stress. Since numerator and denominator were in the same units and numbers were converted to unitless proportions, there was no need to rescale values for composite variables.

- %...DbkVgr are proportion (live trees only) showing stress based on crown dieback or crown vigor class cutoffs. These are strong combined forest stress indexes.
- %...DbkVgrM are proportion (all trees) showing stress based on crown dieback or crown vigor class cutoffs or recent mortality. These are slightly weaker combined forest stress indexes, since mortality was not available for all years.
- %...Stress are proportion (all trees) showing stress based on any of the crown variable cutoffs or recent mortality. No extra weighting was given based on multiple indications of stress to a tree. These are weak combined forest stress indexes, since mortality was not available for all years and crown density and foliage transparency should be compared with species standards.

Greater Sierra Nevada Region Analyses

Sierras results

No correlation of any of the pollution risk indexes with any 'forest stress' index was significant. The strongest was a Spearman rank correlation of *rho* = 0.157 (p=0.121, $rho^2 \approx 0.03$) for [2 x rank of LichenAirGSN + rank of OzoneIBI] with [%BA-DbkVgr (crown dieback ≥10% or crown vigor code 3)].

Despite the lack of significant results, we observed some patterns worth reporting qualitatively to support possible future work. Correlations were stronger for composite pollution risk variables based on ranked data than for composite variables with LichenAirGSN rescaled to match OzoneIBI. Correlations were stronger for LichenAirGSN than for OzoneIBI, as were those for combined indexes weighting LichenAirGSN more heavily. Combined pollution risk indexes gave slightly stronger correlations than either single index. Correlations with 'forest stress' indexes based on crown dieback or vigor (the strongest of our tree stress variables) were stronger than others. Correlations with 'forest stress' indexes based on BA were stronger than those based on tree counts. Composite pollution risk variables from ranked data gave stronger correlations than those from rescaled data, and nonparametric correlations were mostly stronger than parametric correlations. These findings suggest probably most variables failed to meet assumptions for parametric statistics (not tested).

Sierras discussion

The Greater Sierra Nevada region appears to have relatively low S and N air pollution as compared with the New England region (figure 1). However, dry deposition has been shown to be a strong source of S and N pollution more important than wet deposition in West Coast states (Fenn et al 2003, 2008). Moisture may actually mitigate pollution effects on lichens there (Jovan and

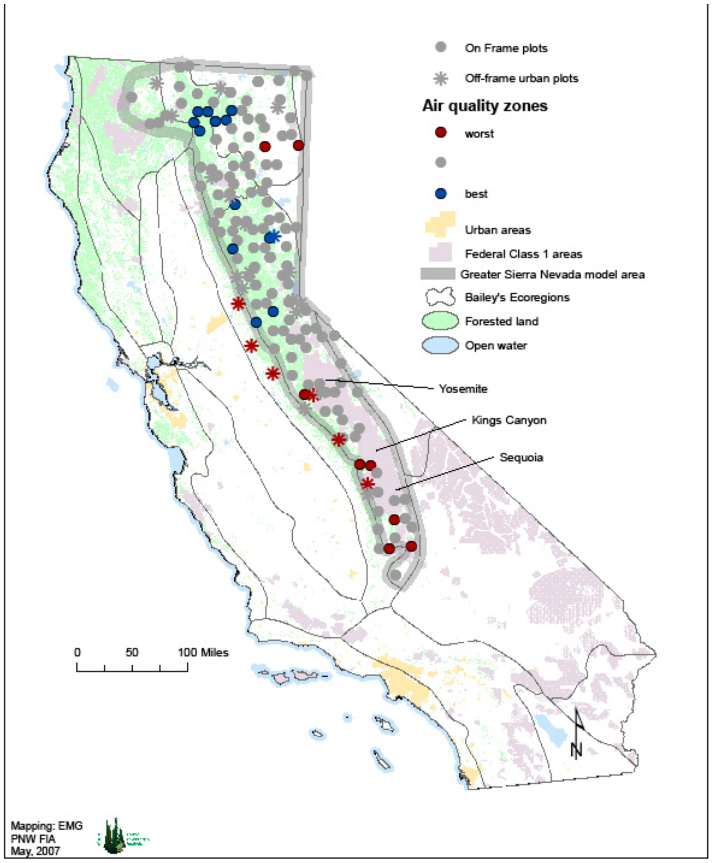

Figure 3: Greater Sierra Nevada Region of California. Data used in this project are from standard (on-frame) FIA plots. Figure modified from Jovan (2008)

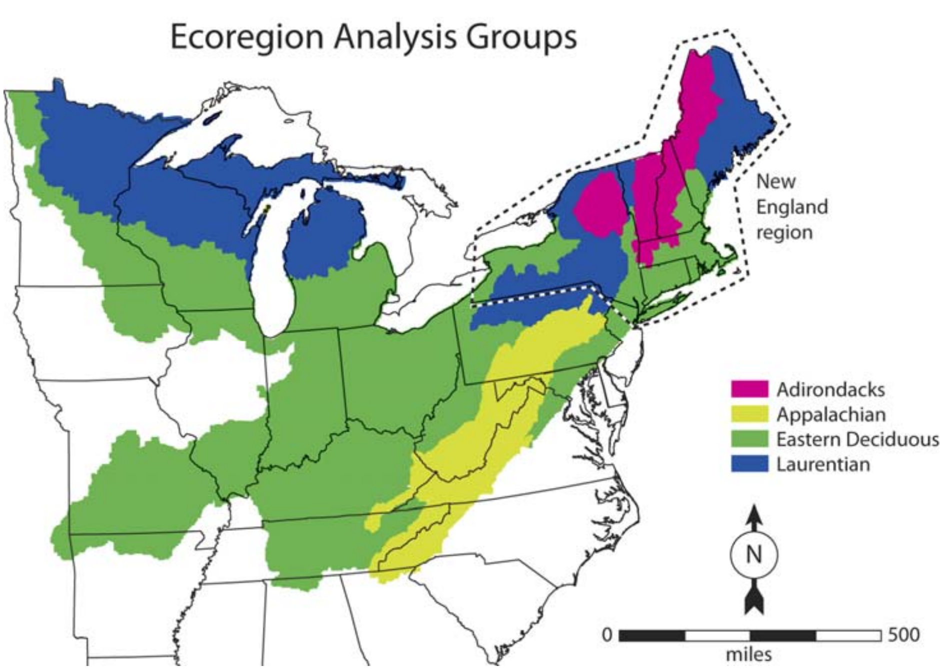

Figure 4: New England region with ecoregion subgroups. (modified from Will-Wolf et al. in review).

Carlsberg 2006). So the apparently lower pollution loads shown in figure 1 for the West Coast as compared with the Northeast might be somewhat misleading. LichenAirGSN is primarily an index of response to agricultural nitrogen pollution (Jovan and McCune 2006).

The Sierras and New England regions appear to have similar ozone risk (figure 2). Ozone is one of several variables correlated with effects on lichens in an adjacent region of California (Jovan and McCune 2005).

Clearly our simple approaches are not adequate to establish there is potential for pollution risk variables to be related to forest stress in this region. Since most of the N pollution is related to agriculture, it may be having a mostly fertilizing effect on forests that is not reflected in our selected measures of tree stress. It might be useful to test more sophisticated estimation of tree stress on a plot. For instance, it might for this small region be useful and not too difficult to calculate tree stress and growth indexes by comparing with species-based standards and aggregate those to plot level for correlation with pollution risk. The presence of so many federal class 1 areas in this region (figure 3) is a reason further research should be conducted on correlation between pollution risk and forest stress indexes, even with little support from this pilot study.

New England Region Analyses

A brief summary of New England region analyses is followed by summaries of results for three ecoregion subgroups (figure 4).

New England region results

New England entire region: A few correlations of ‘forest stress’ indexes with LichenAirNE-B or composite indexes that include it were statistically significant or approached significance (table 3) for the New England region as a whole. The variation in variables accounted for by the correlations was no more than 1-2% (estimated by r^2); these results have little biological importance. More variation was accounted for by the best nonsignificant correlation for the Greater Sierra Nevada region. Statistical significance for the weak NE region results stems from the large sample size. Correlations for pollution risk indexes and ‘forest stress’ indexes not included in table 3 were much weaker than those shown.

Despite few significant results and the lack of any biologically important results, we observed some patterns worth reporting qualitatively to support possible future work. LichenAirNE-B in general gave stronger correlations with ‘forest stress’ indexes than did LichenAirNE-A, suggesting that it is important to control for the effect of regional gradients in climate and air pollution. Correlations were also stronger for LichenAirNE-B than for OzoneIBI or any combined indexes. The one combined index that approached significance included LichenAirNE-B weighted double (table 3). These patterns suggest forest stress is potentially more strongly related to urban/industrial pollution than to ozone risk. Correlations with 'forest stress' indexes based on crown dieback or vigor were stronger than others. Parametric correlations were stronger than non-parametric correlations. Combined pollution risk indexes based on rescaled data gave stronger correlations than those based on ranked data. Both patterns suggest assumptions for parametric statistics were probably met for New England region data (not tested).

Table 3: New England region: Pearson correlations between selected pollution risk and 'forest stress' indexes. Correlation coefficients are followed by probability. We include r^2 in parentheses to indicate percent of variation involved in the correlation. Dashes indicate lack of significant results.

'Forest stress' indexes	Pollution risk indexes	
N = 352	**LichenAirNE-B**	**2 x LichenAirNE-B +OzoneIBI**
AvgDBK	0.126 p=0.018 (r^2=0.02)	0.102 p=0.055 (r^2=0.01)
%BA-DbkVgr	0.107 p=0.044 (r^2=0.01)	-
%BA-DbkVgrM	0.118 p=0.027 (r^2=0.01)	-

Table 4: Eastern Deciduous ecoregion group: Pearson correlations between selected pollution risk and 'forest stress' indexes. Correlation coefficients are followed by probability. A p>0.01 is considered significant; a 0.01<p<0.1 is considered approaching to weakly significant. We include r^2 in parentheses to indicate percent of variation involved in the correlation.

'Forest stress' indexes	Pollution risk indexes	
N = 80	**LichenAirNE-B**	**2 x LichenAirNE-B +OzoneIBI**
AvgDBK	0.240 p=0.032 (r^2=0.06)	0.205 p=0.068 (r^2=0.04)
%BA-DbkVgr	0.341 p=0.002 (r^2=0.12)	0.284 p=0.011 (r^2=0.08)
%BA-DbkVgrM	0.328 p=0.003 (r^2=0.11)	0.273 p=0.014 (r^2=0.07)
%Ct-Stress	0.280 p=0.017 (r^2=0.08)	0.233 p=0.038 (r^2=0.05)
%BA-Stress	0.270 p=0.016 (r^2=0.07)	0.228 p=0.042 (r^2=0.05)

New England ecoregion groups: Based on results for the entire region, we correlated only LichenAirNE-B, Ozone IBI, and combined indexes with 'forest stress' indexes within three ecoregion groups. After excluding plots, only one plot remained in the Appalachian ecoregion. For the Adirondacks and Laurentian ecoregions, all correlations were weaker than for the entire region, and no additional or contrary patterns were observed. So we consider them no further.

For the Eastern Deciduous ecoregion there were several significant correlations. The two strongest correlations accounted for 11-12% of variation between the two indexes; these are strong enough to perhaps approach biological relevance (table 4). The strongest correlation still shows a fairly weak relationship (figure 5), but it does suggest pollution may indeed be a relevant contributor to stress on forests in this region.

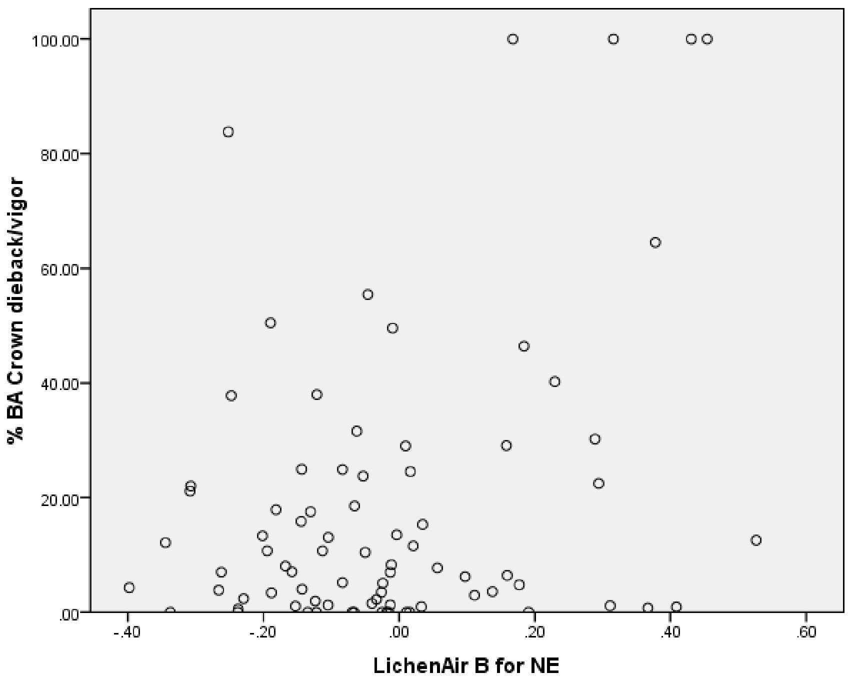

Figure 5: Scatterplot for the 80 Eastern Deciduous ecoregion group plots of LichenAirNE-B vs. %BA-DbkVgr (% of live tree BA with crown dieback ≥10% or crown vigor code 3). The Pearson correlation for this strongest of the within-group relationships (table 4) is 0.341, $p=0.002$, $r^2=0.12$.

In general, LichenAirNE-B and combined pollution risk indexes with LichenAirNE-B weighted double had stronger correlations with 'forest stress' indexes than did OzoneIBI and other combined pollution risk indexes. Correlations with LichenAirNE-B were always stronger than for combined pollution indexes. Correlations based on rescaled data were stronger than those based on ranked data. 'Forest stress' indexes based on BA mostly gave stronger correlations than those based on tree counts. The combined index %BA-DbkVgr (from crown dieback and crown vigor, our two best 'tree stress' variables) gave the strongest correlation with pollution risk of all the 'forest stress' indexes for the Eastern Deciduous ecoregion subgroup.

New England region – discussion

For the New England region as a whole and for two of the ecoregion subgroups, the answer to our question is similar to that for the Sierras. Clearly our simple approaches are not adequate to establish there is potential for pollution risk variables to be related to forest stress in most of this region.

In contrast, for the Eastern Deciduous ecoregion subgroup there does indeed appear to be at least some relationship of pollution risk indexes to our simple ‘forest stress’ indexes. The Eastern Deciduous subregion is subject to heavier pollution loads than the other two subregions, while the Laurentian subregion probably has the widest range of pollution loads (compare figures 1 and 4). Our results suggest absolute pollution load might be the more important factor promoting the finding of a significant correlation between pollution risk indexes and ‘forest stress’ indexes.

More sophisticated estimation of tree stress on the plot would certainly be useful to calculate. It would for the entire NE region be much more difficult to calculate tree stress and growth indexes by comparing with species-based standards because there are many more tree species recorded in the region. Another possibility might be for the %...Stress indexes to weight contribution of a single tree based on number of stress indications for that tree.

Conclusions and follow-up

This very preliminary pilot study suggests simple approaches to linking pollution risk indexes to forest stress may not work in most regions. However they do show some promise in one subregion with relatively high levels of pollution. Our study was somewhat limited by data availability, and it benefited greatly from consultation with other FIA experts. It does seem it would be worthwhile to pursue development of more sensitive forest stress indicators in follow-up studies.

Data availability and consultation

Limited data availability did affect our project. Temporary unavailability of the ozone and lichen indexes online was a minor inconvenience easily overcome with consultation. Ozone data were made available rapidly, and all lichen data were available to the authors from previous projects. Substantially more tree and lichens data will be available for analysis after existing data mismatches are resolved, especially for 2000-2002 data. Data collected before 2000, when FHM plot data collection was transferred to the FIA program, were one-half to two thirds of the data available and suitable for our pilot study. Any further documentation of changes and online crosswalks between data sets for the years 1994 to present will enhance the value of all current data for analysis.

Assembling the data sets and data screening were by far the most time-consuming steps for this project. Online tools for selecting and sorting FIA data according to user-defined criteria would substantially aid both FIA and outside analysts to pursue a variety of exploratory investigations. Database scripts for calculating plot-level summaries such as BA, number of trees, and forest composition summaries would aid investigation of plot-level forest health questions.

Consultation with FIA indicator experts about variables other than lichens indexes was critical to the success of this project. Even after all data availability issues are resolved, researchers both inside and outside the FIA program would benefit from substantial consultation with FIA personnel to ask similar questions using FIA data. Online documents explaining use of the ozone indicator were completely adequate to support investigating our question. Consultations with ozone indicator advisor John Coulston (FIA-Southern Region; ~3 hrs; consulted, provided data and maps) and past advisor Gretchen Smith (University of Massachusetts-Amhearst; ~1 hr; consulted) were essential to guide us to ask the right questions and to obtain data. Consultation with crown indicator advisors William Bechtold (FIA-Southern Region; ~1.5 hrs) and KaDonna Randolph (FIA-Southern Region; ~1 hr) was very important to supplement information available in online documents about appropriate use of crown variables. Bechtold also advised on use of growth and mortality variables; little information was available online about appropriate use of these variables for estimating plot-level forest health. Randall Morin (FIA-Northern Region; ~2-3 hr; consulted, provided map and 2000-2002 tree data) consulted on historical use of crown variables and mortality to assess forest stress, and consulted on efficient management of tree data. Elizabeth LaPoint (FIA-Northern Region; ~1 hr) provided crosswalk tables for linking lichens data with tree data (1994-2002 data especially).

Evaluation of project for follow-up

We recommend follow-up investigation soon of linkage between pollution risk and forest stress for the Eastern Deciduous ecoregion, since we found evidence for such linkage in that subgroup of the New England region. There was no evidence from our simple pilot study for such a linkage in the other regions and subregions we investigated.

Results of our pilot project suggest that crown dieback and crown vigor seem to be the best variables to use for calculating plot-level ‘forest stress’ indexes related to pollution risk. Calculating these indexes based on % BA of trees appears to be better than calculating based on % of tree counts. More sophisticated estimation of plot-level forest stress seems essential to address our question in most regions. Relating crown density and foliage transparency to standards for each species seems a logical, but very time-consuming step to take. In some areas it might be worthwhile to try using different cutoff standards for conifers vs hardwoods. Another possibility is to weight contribution of single trees to plot-level indexes based on the number of stress indications recorded for each tree.

Use of damage variables should be investigated where possible. Calculation of % BA of trees with any kind of damage avoids problems with identifying cause of damage or number of damages. With this approach FHM legacy data and all other available damage data would be appropriate to combine and use in analyses for this purpose.

We found that in the Greater Sierra Nevada region combination pollution indexes seemed better. However, in the New England region a single pollution index seemed to work better. This suggests a general approach will need to be adapted for different regions; neither one kind of pollution risk index, nor one kind of 'forest stress' index is likely to work best for all regions of the USA.

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