Criterion 3 – Maintenance of Ecosystem Health and Vitality

Indicator 17 – Area and percentage of forest land with diminished biological components indicative of changes in fundamental ecological processes and/or ecological continuity.

by

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Introduction

The rationale for Indicator 17 is to evaluate the status of fundamental ecological processes that are essential to continued forest ecosystem health and vitality. However, because it is extremely difficult to measure most ecological processes directly, the indicator is framed in terms of the conditions of biological components of the forest ecosystem that reflect the state of those fundamental ecological processes.

A number of the metrics that may be incorporated into Indicator 17 are also elements of other indicators. These metrics (ex. biodiversity, forest productivity, insects and pathogens, soils) typically are elements of other indicators because they are important in and of themselves. They are also relevant to Indicator 17 because they provide some information about underlying ecological processes.

In some cases those biological components that may be incorporated into Indicator 17 may directly reflect a change in ecological processes or ecological continuity (ex. reduction in species diversity). In other cases, the relationship between biological components measured and the underlying ecological processes are much less direct.

Clearly, since forest ecosystems include the entire suite of forest biota, not just trees, data relating to the entire range of forest species could be incorporated into this indicator. Indeed, the Montreal Process Technical Advisory Committee noted that "the indicator should be considered as an integrated measure of component influences and should not rely on only one component." (Roundtable on Sustainable Forests 2000). However, the data that could actually be utilized in the present analysis are much more limited. The relationships between many elements of forest ecosystems and ecological processes are still poorly understood. Much of the intensive ecological research that has occurred was done on small scales, and it is unclear how to apply the research to large-scale ecological monitoring. There are also many ecological processes on which we have little or no data.

The data available for this report on a national scale coverage relates almost exclusively to trees. At some point in the future, information on other forest biota needs to be incorporated into this indicator. Monitoring of some other elements of forest ecosystems is being implemented through the Forest Health Monitoring (FHM) program. Monitoring of understory vegetation will eventually provide information on changes in understory communities, biodiversity, and invasive exotics. Lichen monitoring will eventually serve as an indicator of climate change and air pollution effects on this community and (possibly) on the fungal community. Monitoring of down woody debris will provide information on fuel loading affecting fire cycles, wildlife habitat, and carbon cycling. None of these indicators have been implemented fully or widely enough or long enough to provide data usable in this analysis.

Data on other biological components may also be available from a variety of other sources. Further work is needed to locate and evaluate other datasets for possible inclusion in this indicator at a later date.

Limitations

At present there are significant limitations on the analyses that can be performed and the conclusions that can be drawn for this indicator.

The Roundtable Discussion on Sustainable Forests identified three key scientific problems that currently limit the application of this indicator:

- There is an inadequate understanding of links between indicators and fundamental ecological processes.
- There is a poor ability to scale up from sites where processes are understood to larger ecological units.
- There is a poor ability to make temporal projections.

(Roundtable on Sustainable Forests 2000)

Linkages

Indicator 17 deals with diminished biological components indicative of changes in fundamental ecological processes and ecological continuity. However there is a lack of basic research linking biological components that are measurable on large spatial scales with changes in fundamental ecological processes. Much of the intensive research on ecological processes has been done on very small spatial scales.

As already mentioned, this indicator also incorporates elements of other indicators (ex. biodiversity, insects and diseases, productivity, soils – nutrient cycling, carbon). Therefore, all of the limitations associated with the analyses of those indicators carry over to this one. “This indicator relies on assessments and ‘spin-offs’ from other analyses.” (Roundtable on Sustainable Forests 2000) Once these metrics are better understood in their own right, research is needed to determine what they tell us about fundamental processes.

Lack of baseline data

Data is being collected on a variety of characteristics of U.S. forests. However, in many cases baseline information is lacking. We do not know what indicator values are “normal for healthy forests” of various forest types. We also do not know the normal range of variation for indicator levels in response to cycles in weather patterns, wildlife population levels, insect population levels, etc. Without such a baseline, it is difficult to interpret the data being collected.

In some cases, small scale, intensive ecological studies have determined how changes to ecological processes affect measurable biological components of the forest system. For example, we know that changes to a fundamental ecological process, such as nutrient cycling will be manifested in deteriorating crown condition. However, poor crown condition may also be caused by a variety of natural stressors while the fundamental ecological process remains intact. Thus, in most cases those indicators, measured on a regional scale, can at best indicate areas where fundamental ecological processes MAY have been altered.

Further work is needed to generalize research done on smaller scales or in single forest types, to relate metrics used for national monitoring to ecological processes and to determine a baselines.

Data

Data relating to tree crown condition, growth, and mortality used in this analysis comes from the Forest Health Monitoring Program database. The FHM program is a multi-agency, cooperative effort to determine the health status, changes, and long-term, large-scale trends for forest ecosystems in the United States. The USDA Forest Service cooperates with State forestry and agricultural agencies to conduct FHM activities.

Plot data used in these analyses were collected as part of FHM Detection Monitoring. FHM detection monitoring plots were phased in state by state with the oldest plots in New England having been established in 1990. As of 1999 FHM plots had been established 32 states.

The States and the years in which FHM plot data were collected are found in Table 1.

Table 1. The years plot data were collected in each state through 1999

Years Data Collected	States
1990-99	CT, MA, ME, NH, RI, VT
1991-99	AL, DE, GA, MD, NJ, VA
1992-99	CA, CO
1994-99	MI, MN, WI
1995-99	WV
1995,1998-99	PA
1996-99	ID, IN
1997-99	IL, OR, WA, WY
1998-99	NC, SC
1999	MO, NV, NY, TN, UT

Plots established for Detection Monitoring covered all forested lands except riparian forests less than 100 feet wide. A hexagonal network of permanent, fixed-area plots were located 27 km apart with potentially 4600 forested plots in the United States (White and others 1992). Each year a systematic sample (called a “panel”) of one-fourth of the plots was measured. In addition, one-third of the plots from the previous year’s panel (called the overlap) were remeasured. This four-year rotating panel design resulted in one-third of the permanent plots being measured each year.

A great variety of forest health data is collected on FHM plots. For more details about the variables measured in the field, see the Forest Health Monitoring and Forest Inventory and Analysis Field Methods Guides (USDA Forest Service 1998, 1999, 2000a, 2000b).

In 2000, the plot activities of the Detection Monitoring component were integrated with the Forest Inventory and Analysis (FIA) program. Former FHM plots will continue to be measured by FIA on a modified schedule.

Data relating to fire regimes and fire condition class comes from the USDA Forest Service Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, Montana. Their national scale maps, data tables, GIS coverages, and data documentation are available at: http://www.fs.fed.us/fire/fuelman/.

Data incorporated into this analysis of Indicator 17:

Crown condition

Tree crown condition is an important indicator of individual tree and forest stand health. Generally, trees with large, full crowns have the potential to maximize gross photosynthesis because they are able to capture a large portion of the solar radiation available during the growing season. Changes to fundamental ecological processes such as soil nutrient cycling which negatively impact forest productivity and tree health will ultimately be reflected in diminished crown condition. However, deteriorating crown condition may also occur in response to a variety of stressors, both biotic and abiotic, natural and anthropogenic, chronic or transient. Abiotic stressors that can affect crown condition include air pollution and extreme weather (e.g. drought or extreme winter weather). Biotic stressors include native and introduced insects and pathogens (BFH 2000). The crown response to stressors may vary depending upon the particular stressors and tree species, complicating efforts to determine causal relationships. Thus, crown condition alone cannot be used as an indicator of changes to fundamental ecological processes. At best it can be used to identify areas where changes to ecological processes may have occurred and where further investigation is needed.

FHM measures several variables that relate to amount and fullness of foliage and the vigor of the apical growing points of the crown. Two of these variables are the mortality of the terminal twigs in the sun-exposed portions of tree crowns (dieback) and the transparency of the foliage of the whole tree crown to sunlight (i.e., sparseness of the crown foliage). Crown dieback is recorded as the percent mortality of the terminal portion of branches that are greater than 1 inch in diameter and in the upper, sun-exposed portion of the crown (Burkman and others 1995). Foliar transparency is recorded as the percent of sky visible through the live, normally foliated portion of the crown. Both are determined via ocular estimates to the nearest 5 percent.

These two variables can be combined to produce a composite foliage index for each tree. Using a variation of the method proposed by Zarnoch, Stolte, and Binns[1] and Zarnoch, Bechtold, and Stolte [2], an index, hereafter referred to as the ZB-index is given by the formula:

$$Z = (1 - (1 - \frac{T}{100})(1 - \frac{D}{100}))$$

where

Z = ZB-index

T = percent transparency

[1] Zarnoch, S.J.; Stolte, K.W.; and Binns, R. Chapter 6 – Crown Condition. In: Lewis, T.E; Conkling, B.L., eds. Forest Health Monitoring Southeast Loblolly/Shortleaf Pine Demonstration Final Report. Unpublished manuscript.

[2] Zarnoch, S.J.; Bechtold, W.A.; and Stolte, K.W. Crown condition as an indicator of forest health. Manuscript in review.

D = percent dieback

The ZB-index represents the amount by which the foliage of the tree is reduced relative to an ideal "fully foliated" tree having the same crown diameter, live crown ratio, and crown density (other crown variables measured by FHM) (See footnotes 1 and 2). For example, a tree having Z = 0.25 would have 75% of the foliage that the ideal fully foliated tree would have.

The components of the ZB-index can also be analyzed independently. *2001 Forest Health Monitoring National Technical Report* (Conkling and others In Press) provides independent analyses of foliar transparency and dieback for hardwoods and softwoods. Since different species have different crown responses to various environmental stressors, such analyses by species group may enable crown condition to be used as a more direct indicator of changes to ecological processes.

For each ecoregion section (Bailey 1995) the average ZB-index was estimated using a generalized least-squares (GLS) mixed modeling procedure (Smith and Conkling In Press, Conkling and others In Press), utilizing current as well as all prior plot measurements to estimate simultaneously the current status as well as the periodic annual change in the index. Periodic annual change is defined as the total change observed over the period from plot establishment to the present put on an annual basis.

Since baseline data is lacking, at present there is no way to know exactly what ZB-index values should be expected in a "healthy" forest for various forest types, so the current status estimates are of limited value. However, the annual change estimates identify areas where crown condition is improving or deteriorating.

Figure 1 shows the average annual change in ZB-index values by ecoregion section for those areas where there was sufficient FHM plot data to run the analysis.

Tree mortality

Tree mortality is a natural part of any forest ecosystem. Using tree mensuration data from FHM plots, it is possible to estimate the annual mortality, in terms of wood volume per acre, based on the trees and saplings that have died since plot establishment. However, since different forest types, growing under very different conditions grow at different rates, a simple measure of mortality volume is not a good measure of forest health on a national basis. For example, a greater tree volume might die in a healthy forest in the southeast than the total standing volume of some dry western forests. A more useful national mortality indicator is the ratio of annual mortality volume to gross volume growth (MRATIO). An MRATIO value greater than one indicates that mortality is exceeding growth and live standing volume is actually decreasing. MRATIO's were calculated for each ecoregion section from independently derived gross growth and mortality rates (Details on the method are documented in *2001 Forest Health Monitoring National Technical Report* (Conkling and others In Press).

The MRATIO can be large if a mature forest is senescing and losing a cohort of older trees. If forests are not naturally senescing, a high MRATIO (greater than 0.6) may indicate high mortality due to some acute cause (insects or pathogens) or generally deteriorating forest health conditions. To further analyze tree mortality, the ratio of the average dead tree diameter to the average live tree diameter (DDLD ratio) was also calculated for each plot where mortality occurred. Low (much less than 1) DDLD ratios usually indicate competition induced mortality typical of young, vigorous stands, while high ratios (much greater than 1) indicate mortality associated with senescence or some external factors such as insects or disease (Smith and Conkling In Press). The DDLD ratio is most useful for analyzing mortality in regions that also have high MRATIO's. High DDLD values in regions with very low MRATIO's may indicate small areas experiencing high mortality of large trees or locations where the death of a single large tree (such as a remnant pine in a young hardwood stand) produced a deceptively high DDLD.

Figure 2 shows the MRATIO values by ecoregion section, representing the annual mortality over the time period from the earliest plot establishment in each section through 1999, and the plot values of the DDLD ratio for the most recent measurement of the plot. Areas of highest mortality relative to growth were apparent in the Central Till Plains, Beech-Maple Section (222H) in Illinois; the Interior Low Plateau, Shawnee Hills Section (222D) in Indiana; and the Northern California Coast Ranges Section (M261B) in northwest California. In these ecoregion sections mortality volume actually exceeded growth volumes.

Mortality relative to growth was also high (greater than 0.6 in fig. 2) in northern Michigan and Wisconsin (the Northern Great Lakes Section, 212H). Similar numbers were calculated for parts of central and eastern Washington and Oregon in the Eastern Cascades Section (M242C) and the Blue Mountains Section (M332G), and for parts of central and eastern Idaho in the Idaho Batholith Section (M332A), Challis Volcanics Section (M332F), Northwestern Basin and Range Section (342B), and Owyhee Uplands Section (342C).

Table 2 provides the summary mortality statistics by ecoregion section. The reader can use these statistics to obtain further insights into what is occurring in particular regions of interest. For example, in the Northern California Coast Ranges (section M261B), only 7 of 15 plots experienced any mortality. The MRATIO is high, but so is its standard error, indicating high uncertainty in the estimate of mortality relative to growth. DDLD values ranged from 0.243 to 7.018, and total mortality volume on plots that experienced mortality ranged from 1.8 to 4049.1 cu. ft per acre. These statistics indicated that on some plots very large trees are dying. This may be due to a number of causes. Past management may have produced a large percentage of older stands that are senescing, insects or pathogens may be affecting key tree species, or more generalized stressors may be creating broader forest health problems. More detailed study on a regional scale is needed to ascertain the underlying causes of this mortality.

Tree mortality is a natural part of any forest ecosystem. Yet, high MRATIO values may indicate changes in fundamental ecological processes that have increased mortality relative to growth (or that have significantly reduced annual growth) in a particular area. A high MRATIO may also mean that past management or land use in a region has produced an imbalance in the age classes of forests in a region. In such a case there may be ecological impacts to having a large proportion of the stands in a region becoming senescent at the same time.

Fire Condition Class

Fire is a powerful, selective regulatory mechanism in forest ecosystems. It is a natural part of the environment, and fire-affected ecosystems depend on a particular frequency and intensity of fire. These ecosystems will remain in their natural state only if the fire regime they are adapted to is present (Kimmins 1987). The frequency and intensity of burning depends on the buildup of fuels, weather conditions, and the occurrence of ignition sources. Historically, most fires were started by lightning strikes. Figure 3 displays the historic (pre-European) fire regimes (Fire Sciences Laboratory 2001b).

Historical fire regimes are described in terms of frequency and severity and represent pre-European settlement, historical fire processes. Fire regimes I and II represent frequent fire return intervals. The 0-35+ years/low severity fire regime (I) occurs mostly on forested land. The 0-35+years/stand-replacement regime (II) occurs mostly on grasslands and shrublands. Fire regimes III, IV, and V have longer fire return intervals and occur on forestlands, shrublands, and grasslands.

Humans have altered historic fire regimes through fire suppression, tree harvesting, and prescribed burning. Influencing either the frequency or intensity of natural fires can change the species composition and age structure of a fire-adapted community, as well as soil characteristics (Kimmins 1987).

Current condition classes categorize departure from historic fire regimes based on five ecosystem attributes (Fire Sciences Laboratory 2001a) (Table 3). The five attributes are disturbance regimes, disturbance agents, smoke production, hydrologic function, and vegetative attributes. Current condition class 1 represents a minor deviation from ecological conditions compatible with historic fire regimes. Condition class 2 represents a moderate deviation from ecological conditions compatible with historic fire regimes. Restoration of historic fire regimes would require some silvicultural treatment. For example, ponderosa pine stands in the Southwest were historically adapted to low severity frequent fire to maintain understory diversity and an open canopy structure. Without frequent low severity fire, ponderosa pine stands can become extremely dense. Covington and others (1997) suggest thinning these stands to densities similar to historic ones and establishing a 2 to 7 year low intensity fire cycle. Current condition class 3 represents a significant deviation from ecological conditions compatible with historic fire regimes. These areas would require significant management activities such as harvesting and replanting to restore the historic fire regimes. For example, lodgepole pine in the Northern Rockies is adapted to severe infrequent fire with periodic low severity fires between severe fire events. In the absence of this fire regime shade tolerant species such as Douglas-fir and sub-alpine fir eventually replace lodgepole pine. To restore lodgepole pine to areas that have been replaced by shade tolerant species, the shade tolerant species can be harvested and the area replanted in lodgepole pine (Monnig and Byler 1992).

Table 3 –Descriptions of Current Condition Classes

Condition class	Attributes	Examples of appropriate management options
Condition Class 1	• Fire regimes are within or near an historical range. • The risk of losing key ecosystem components is low. • Fire frequencies have departed from historical frequencies by no more than one return interval. • Vegetation attributes (species composition and structure) are intact and functioning within an historical range.	Where appropriate, these areas can be maintained within the historical fire regime by treatments such as fire use.
Condition Class 2	• Fire regimes have been moderately altered from their historical range. • The risk of losing key ecosystem components has increased to moderate. • Fire frequencies have departed (either increased or decreased) from historical frequencies by more than one return interval. This results in moderate changes to one or more of the following: fire size, frequency, intensity, severity, or landscape patterns. • Vegetation attributes have been moderately altered from their historical range.	Where appropriate, these areas may need moderate levels of restoration treatments, such as fire use and hand or mechanical treatments, to be restored to the historical fire regime.
Condition Class 3	• Fire regimes have been significantly altered from their historical range. • The risk of losing key ecosystem components is high. • Fire frequencies have departed from historical frequencies by multiple return intervals. This results in dramatic changes to one or more of the following: fire size, frequency, intensity, severity, or landscape patterns. • Vegetation attributes have been significantly altered from their historical range.	Where appropriate, these areas may need high levels of restoration treatments, such as hand or mechanical treatments. These treatments may be necessary before fire is used to restore the historical fire regime.

(Source: http://www.fs.fed.us/fire/fuelman/curcond2000/def.html)

Forested areas in each historic fire regime have been altered to various degrees (Table 4).

Table 4 – Area and percent forest by historic fire regimes and current condition class for lands under all ownerships in the U.S.

Historic fire regime	Area (acres) by condition class			
	Class 1	Class 2	Class 3	Total
0-35 years Low severity	150,131,492 39.7%	151,365,381 40.0%	76,871,080 20.3%	378,358,953
0-35 years Stand replacement	7,053,528 46.8%	3,184,158 21.1%	4,825,167 32.0%	15,062,853
35-100+ years Mixed severity	38,117,754 22.9%	84,093,861 50.6%	43,918,735 26.4%	166,130,350
35-100+ years Stand replacement	15,618,100 28.9%	8,512,675 15.7%	29,921,867 55.4%	54,052,642
200+ years Stand replacement	44,649,668 70.6%	13,706,766 21.7%	4,901,519 7.7%	63,257,953
Total	255,570,542 37.8%	260,853,841 38.5%	160,438,368 23.7%	676,862,751

(Source: http://www.fs.fed.us/fire/fuelman/)

The fire Condition Class GIS layer from the Fire Sciences Laboratory was overlaid with a map of forest cover of the U.S. to produce a map of the currently forested area of the U.S. by condition class. This map is shown in figure 4. From this GIS analysis, it was possible to determine the percent of forested area in each Current Condition Class by RPA Region (Table 5).

Table 5 - RPA Regions by Fire Current Condition Class -- Forested area only

Region	Class 1	Class 2	Class 3
Northern	22.3%	43.3%	34.4%
Southern	69.8%	19.3%	10.9%
Rocky Mtn.	28.1%	46.3%	25.6%
Pacific Coast*	21.9%	50.1%	28.0%
Total	38.7%	37.5%	23.8%

*Analysis does not include the forested areas of Alaska or Hawaii.

Data available for forested areas of National Forest System lands provide further insights as to the spatial distribution of areas that have undergone significant changes in forest condition due to fire exclusion (Table 6). The largest percentage of National Forest System lands with Current Condition Class 3 occur in the Northern and Pacific Coast RPA Regions.

Table 6 – Land area and proportion of National Forest lands in Current Condition Class 3 by RPA and USDA Forest Service Region

RPA Region	USDA Forest Service Region(s)	Total forest area (acres)	Total forest in current condition class 3	
			Acres	Percent
Northern	Eastern (R-9)	19,285,597	8,675,766	45.0
Southern	Southern (R-8)	22,003,231	1,928,141	8.8
Rocky Mountain	Northern (R-1)	23,562,695	8,447,691	35.9
	Rocky Mountain Region (R-2)	18,505,991	4,793,046	25.9
	Southwestern Region (R-3)	15,180,981	6,518,807	42.9
	Intermountain Region (R-4)	26,066,582	4,032,711	15.5
	Total	83,316,249	23,792,255	28.6
Pacific Coast	Pacific Southwest (R-5)	18,912,477	7,824,251	41.4
	Pacific Northwest (R-6)	25,299,331	8,210,963	32.5
	Total	44,211,808	16,035,214	36.3
All RPA Regions	All USDA Forest Service Regions	168,816,885	50,431,376	29.9

Of particular concern are forest lands in Condition Class 3 and the 0-35 year, low severity fire regime (Table 7). Due to the altered fire regime on these lands, the effects of a fire occurring today would probably be very different, in terms of fire size, frequency, intensity, severity, and landscape patterns, than what would have occurred prior to European settlement.

Table 7 – Land area and proportion of National Forest lands in Fire Regime I and Current Condition class 3 by RPA Region

RPA Region	Total forest area in 0-35 low severity historic fire regime (acres)	Total forest area (acres)	Total forest in 0-35 year low severity historic fire regime and condition class 3	
			Acres	Percent
Northern	5,100,192	19,285,597	3,041,090	59.6
Southern	20,235,955	22,003,231	1,885,392	9.3
Rocky Mountain	32,438,856	83,316,249	10,950,590	33.8
Pacific Coast	21,636,784	44,211,808	12,934,577	59.8
All RPA Regions	79,411,787	154,201,273	28,811,649	36.3

On National Forest lands nationwide, 36.3 percent of the land that had historically been in the 0-35 year, low severity fire regime is in Condition Class 3. In the Northern and Pacific Coast RPA regions almost 60 percent of the National Forest land historically in that fire regime is in Condition Class 3.

In order to analyze fire condition class together with crown condition and mortality, fire condition class needed to be summarized by ecoregion section. To do this the forested area by condition class data layer was overlaid with a map of Bailey's ecoregion sections, and the percent of forested area in each ecoregion section that was in Condition Class 3 was determined.

The resulting map is shown in figure 5.

Additional data for future analyses

Several other FHM datasets were considered for inclusion in this analysis. They were not used in the final analysis either because the available data did not yet approach a national coverage or because no appropriate method of analyzing the data for inclusion in this indicator has been determined. Information about these data is included here because they are potentially useful for future analyses. Some of these data are summarized to the ecoregion section level and presented in map and/or tabular form.

Tree damage

Because of the lack of linkages, lack of thresholds, difficulty in interpreting damage, the FHM damage data were not used to determine values for indicator 17 in this report. However, information about the damage data collected nationally is included here in order to more fully document the data sets that may be useful for future analyses. Additional information about the FHM damage monitoring may be found in the *2001 Forest Health Monitoring National Technical Report* (Conkling and others In Press). Damage data was collected by FHM from 1994-1999. With responsibility for Forest Health Monitoring plots transferred to FIA in 2000, the damage indicator was also implemented on all FIA annual inventory sample plots. The quantity of damage data available is expected to increase rapidly in coming years.

According to the FHM monitoring protocol, tree damage is recorded if it is considered serious enough to increase the probability that a tree will be infected by lethal pathogens (such as open wounds or broken branches), that a tree will die prematurely (presence of pathogenic conks, cankers, or broken roots), or that the growth and/or reproduction of the tree will be seriously depressed (such as high defoliation or broken branches). To be recorded, damages must meet or exceed set thresholds; i.e., greater than 20 percent bole circumference with an open wound; greater than 30 percent of the foliage damaged more than 50 percent (Mielke and others 1995). Therefore, a score of zero does not necessarily mean that a tree is free of damage. Insect pests or pathogens may be present on sample plots and even affecting long-term forest productivity but will not be recorded unless levels exceed the predetermined thresholds.

A damage severity index (DSI) score was determined for each damaged tree. The DSI score is determined based on three variables measured in the field: the type of damage symptom, the location of the damage on the tree, and the severity of the damage (Mielke, 1999). The severity of the symptom is simply an estimate of the area affected. A DSI score was assigned to each damage based on these three variables according to look-up tables (Table 8). The index value associated with each particular combination of damage type, location, and severity was determined following several workshops of Federal, State, and university experts in forest pathology and entomology[3].

[3] Mielke, M.E. Personal communication, 30 May 2001.

Table 8 - Sample damage severity index values by type, location and severity rating.

Damage types 1 and 3 (Cankers/galls and Wounds)

Severity	**Location**						
(Percent of circumference affected)	**Roots**	**Roots, stump, Lower bole**	**Lower bole**	**Lower and upper bole**	**Upper bole**	**Crown-stem**	**Branches**
20-29	20	20	20	20	20	10	5
30-39	30	30	30	30	30	15	10
40-49	40	40	40	40	40	20	15
50-59	50	50	50	50	50	25	25
60-69	60	60	60	60	60	30	40
70-79	70	70	70	70	70	35	55
80-89	80	80	80	80	80	40	70
90-99	90	90	90	90	90	45	85

Up to three damages per tree can be scored. The scale runs from 0 to theoretical maximum of 300, with zero indicating no damage above the minimum threshold being recorded and 300 indicating three damages of maximum severity. In fact, individual tree damage index scores rarely exceed 90; trees usually die before their damage level gets much higher. Tree scores were aggregated to plot-level scores (plot-level mean) for hardwoods and softwoods. In general, a high damage index indicated multiple damages, severe types of damage, and/or extensive damage with the damages occurring near the base of the tree. A plot-level DSI can be calculated by averaging the individual tree scores.

The plot level DSIs were calculated using the most recent measurement of each forested plot through 1999. These are presented as the plot values on the map in figures 6 and 7.

Because damage can occur as either a tree-level or a stand-level phenomenon and the large majority of trees in US forest show no damage (see footnote 3), it is difficult to find a meaningful way to summarize damage on an ecoregion section basis. In order to identify those areas experiencing relatively high damage, a plot-level DSI threshold of 15 was selected (see footnote 3). For the plot-level DSI to be 15 or greater, either a number of trees on the plot would have to have experienced very severe damage, possibly of a level to cause mortality in the near future, or lower severity damage would have to be widespread on the plot. Either situation would perhaps merit attention, especially if the plot average values were consistently high throughout an ecoregion section. The percentage of plots with DSI scores of 15 or more was calculated for each ecoregion section and shown on the maps in figures 6 and 7.

Interpreting tree damage and its relationship to forest health is complex because tree damage is the result of a number of different causes. Some of them are anthropogenic, some are part of the natural disturbance regime, and some are natural processes whose impacts have been altered by forest management practices.

Tables 9 and 10 provide damage summary statistics by ecoregion section. These tables together with the above maps permit the reader to further interpret the tree damage in ecoregion sections of interest.

Other approaches to analyzing damage data need to be developed. To better interpret these data, it may be necessary to analyze individual tree species. It may be possible to set thresholds for interpreting damage levels to individual trees based on what is known about the pests and pathogens specific to each species. Then the damage status of various species could be aggregated over geographic areas. This work may involve integrating the damage data with other (regional) data sets relating to causal agents (i.e. insects, pathogens, storms).

Lichen bioindicator

Lichens are a group of non-vascular plant-like organisms that grow on a variety of substrates including soil, rocks, and trees. Lichens are symbiotic combinations of fungi and algae; the fungi absorb mineral nutrients (primarily from the air and also from the substrate) and supply structural support while the algae conduct photosynthesis.

FHM samples lichen species growing on woody plants (live stems and branches as well as woody debris) in the sample plot. Field crews rate the relative abundance of each lichen species on a plot. They collect samples of each species, which are later identified by a lichen specialist. Plot-level lichen species richness, evenness, and overall diversity can then be calculated. Lichen species richness is often correlated with several variables that can affect the forest ecosystem including air quality, climate, forest type, forest successional status, and management status. In general, higher numbers of lichen species are found in cooler, moister areas, and in areas with the best air quality. Within similar forest types (i.e., at smaller spatial scales such as ecoregion sections), higher lichen diversity tends to be strongly associated with later successional status and greater structural diversity. (Neitlich and McCune 1997, McCune 1993)

Figure 8 shows the total lichen species richness by ecoregion section using FHM data from 1994 through 1999. Forest cover is only shown within the States in which FHM lichen plots had been established. The numeric labels on the map give the number of lichen plots in each ecoregion section. In several ecoregion sections the number of lichen plots is probably not yet sufficient to adequately characterize lichen species richness. No species richness values are shown for ecoregion sections having less than 5 lichen plots. Total species richness values may also be significantly underestimated for those ecoregion sections with less than 10 lichen plots. Also, in extremely arid zones, much of the lichen community often is found growing on rocky substrates rather than as epiphytes. In such areas FHM may only be sampling a small fraction of the total lichen community.

Table 11 contains the total species richness by ecoregion section as well as the mean, maximum, minimum, and median species richness at the plot level. The percentage of species on the median plot, also presented in the table, gives an indication of the portion of the total ecoregion species richness that you may find on a “typical” plot.

Because lichens lack an epidermis, cuticle, and stomata, they cannot control gas exchange with the atmosphere and are therefore especially sensitive to air pollution (Stolte and others 1993). Sulfur and nitrogen oxides, hydrogen fluoride, and metal and organic toxins are particularly harmful. Lichens are also susceptible to, and good indicators of, wet and dry deposition of sulfates, nitrates, other sources of acidification, and ammonium. They are sensitive to long-term changes in temperatures and moisture, and therefore are also good indicators of changing climatic and forest stand conditions.

Unlike most fungi, lichens are always directly exposed to the atmosphere. Soil fungi are generally well buffered by the soil system from the effects of air pollution and from extremes of temperature. Since lichens are exposed directly to the atmosphere, they may be able to serve as an early warning signal of changes that may later occur in the soil fungal community as a result of air pollution or climate change.

Preliminary analysis of the lichen data together with other environmental data indicate that there are several issues of concern. Primary among these are blackout zones (areas lacking in lichen species that one would expect to find given the forest stand and climate conditions) for cyanolichens and other pollution-sensitive taxa, community degradation due to excess N deposition, and depressed species richness over large areas of the Northeast. Blackout zones for the otherwise conspicuous cyanolichen flora of the Pacific Northwest have been observed in the vicinity of large urban areas such as Seattle and Portland, and throughout the Columbia Gorge, a National Scenic Area (Neitlich and others 1999). Nitrification, primarily due to agricultural inputs, has created a bloom of nitrophilous taxa (primarily the orange *Xanthoria* genus) in and near the Central Valley of California (Neitlich and others 1999). This bloom has apparently suppressed the growth of other native taxa. And lastly, throughout large sections of the Northeast—from the Ohio Valley eastward to New York, Pennsylvania and southern New England—the species richness is far lower than might be expected under clean air conditions. Presumably this is a long-term, regional pollution effect. However, the correlation of background air pollution levels with regional climate variables makes it difficult to extract a regional gradient of air pollution response independent of climate response.[4]

In order to use lichens as an environmental indicator, it is necessary to develop a model that relates lichen species composition to the environmental variables of interest (e.g. air quality). Such a gradient model produces a score for the environmental variable based on the lichen community on each plot. To date gradient models for the lichen bioindicator have been developed for Colorado and the Southeastern U.S. Gradient models are under development for the Northeast, the Pacific Northwest, and California. Since the gradient models for different areas were derived independently, additional calibration studies must be conducted to compare gradient scores across regions.

For Colorado, the gradient model that was developed assigns an air quality score to each plot based on the relative abundance of pollution tolerant and pollution intolerant lichen species adjusted for the effects of elevation, which is closely tied to moisture and temperature (McCune and others 1998). The plot values of the Colorado air quality scores are shown in figure 9. The

[4] Personal Communication. 2001. Susan Will-Wolf, Department of Botany, University of Wisconsin, 430 Lincoln Drive, Madison, WI, 53706.

plots with the lowest air quality scores were generally located in or downwind from urban or industrialized areas.

For the southeastern U.S., the gradient model was developed using ordination techniques and gradient analysis on the lichen species data. Two major gradients were found to explain the variation in species composition. One corresponds to macroclimate (warm and dry to cool and wet); the other corresponds to air quality (McCune and others 1997). The plot values on the two gradients are shown in figures 10-A and 10-B. Figure 10-A shows the climate gradient reflected in the lichen species occurrence, with the low values (indicating hotter conditions) being found to the south and high values (indicating cooler conditions) being found to the north or at higher elevations. In figure 10-B the poorer air quality scores are generally located in northwestern Virginia and in the more urbanized northern and central parts of Virginia, Georgia, and Alabama.

The data available at present can serve as baseline data for monitoring long-term changes in climate and air quality. Given what is known about lichen growth rates and their sensitivity to the environment, changes in the lichen community could be expected to provide evidence of any deterioration in air quality over a period of several years. Since lichens are not always good colonizers, any indication of improving air quality would take longer to manifest itself. Indication of global climate change might take even longer.

Research is ongoing to develop gradient models for the lichen communities in other parts of the country and to refine the existing models (Neitlich and others 1999). In the Northeast, the correlation of background air pollution levels with regional climate variables has necessitated the development of a relatively complex air pollution gradient model (still being refined) to explain the observed differences in lichen community composition. In the West, data from tissue analysis of lichen specimens has shown that the gradient model serves as a very good predictor of the amount of pollutants that actually affect the lichens and are taken up by them[5]. The tissue analysis data as well as atmospheric deposition data are being used to refine that model[6]. Since the gradient models for different areas were derived independently, it will be necessary to calibrate the models across regions before lichen bioindicator scores can be used nationally as a component of Indicator 17.

The *FIA Lichens Community Indicator* webpage, http://www.wmrs.edu/lichen/ , contains more information about lichen data collected nationally, reports and publications relating to the lichen indicator, and links to the FIA/FHM lichen data sets.

Further information about the lichen bioindicator as well as data and preliminary analysis results for Alaska and the Pacific Northwest are available at the *USDA Forest Service Pacific Northwest and Alaska Regions Lichens and Air Quality Home Page,* http://www.NACSE.ORG/lichenair/, and the *R6 Lichens Home Page*, http://www.fs.fed.us/r6/aq/lichen/.

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[5] Personal communication. 2001. Peter Neitlich, National Park Service, P.O. Box 220, Nome, AK, 99762.
[6] USDA Forest Service. Date unknown. USDA Forest Service Pacific Northwest Region Lichens and Air Quality Home Page. http://www.NACSE.ORG/lichenair/

Methods

Crown condition and mortality were first analyzed separately. As described above, using generalized least squares models, estimates of the MRATIO and annual change in the ZB-index were made for each ecoregion section in which there were sufficient FHM plots measured.

The fire Condition Class GIS layer was overlaid with a map of forest cover of the U.S. to produce a GIS data layer of the forested area that was in Condition Class 3. This data was overlaid with a map of Bailey's ecoregion sections, and the percent of forested area in each ecoregion section that was in Condition Class 3 was determined.

Integration of Measures of Biological Components

The mortality, crown, and fire analyses were combined in a straightforward manner. An ecoregion section was considered to have diminished biological components that may be indicative of changes in fundamental ecological processes if the annual increase in the ZB-index was 0.015 per year or greater, the MRATIO was 0.60 or greater, or more than half of the forested area of the ecoregion section was in fire Condition Class 3.

ArcView GIS was then used to calculate the forest area meeting at least one of those criteria. This forest area was considered to be "possibly affected." For each RPA region, the percent of forest area possibly affected (out of the area of all ecoregion sections for which the analysis could be completed) was determined. Applying this percentage to the total forest area in each RPA region can give an estimate of the total affected area in each region.

The percent of the total forest area in each RPA region represented by those ecoregion sections for which the analysis could be performed is shown in Table 12. Because FHM plot data were not available from all 50 states, the area evaluated may not always be representative of entire RPA regions. The coverage of the available FHM data was best in the North. The area evaluated is most representative of the entire RPA region in the North. Data was available from states spanning the region from east to west with relatively few gaps. In the Pacific Coast, data was available from Washington, Oregon, and California, but not from Alaska and Hawaii. In the Interior West, no data was available from most of the states of the region, but data was available from 3 of the 4 states having the most forest area. In the South, the data is probably the most unbalanced geographically. All of the data is from the eastern portion of that region.

Results and conclusions

The individual components used to analyze indicator 17 are shown graphically in figures 1, 2, and 5, and the percentage of area meeting the thresholds used in the analysis can be seen in tables 5, 13 and 14.

The percent of forest area affected by diminished biological components possibly indicative of changes in fundamental ecological processes is shown in Table 15 and presented graphically in Figure 11. Overall, approximately 20 percent of the forested area of the coterminus 48 States was found to have diminished biological components according to the metrics used in this analysis. These areas are mostly concentrated in the Lake States and in the northwestern U.S. In several of these areas, especially northern Minnesota and the Eastern Cascades of Washington and Oregon, mortality is high and a large proportion of the forest is in Condition Class 3. This suggests that high mortality may be producing high fuel loads for fire or that fire suppression and/or other past management may have produced a large proportion of over-mature, senescent stands.

Table 15 also shows that there was insufficient data to analyze over a third of the forested area of the U.S. for this indicator. It is possible to estimate the status of the area for which data is lacking. For each RPA region and for the entire U.S., we can calculate the percent of forested area affected by diminished biological components considering only those States from which data were available. If we assume that the forests of those States are representative of all forests in each RPA region and the U.S. as a whole (See the discussion of available data in the previous section for why this may not be true in all cases), these percentages are our best estimates of the percent of forested area affected by diminished biological components for each RPA region and for all U.S. forests.

The results of this calculation are shown in Table 16. About 23 percent of U.S. forests are estimated to have diminished biological components. The North and Pacific Coast RPA regions have the greatest percent of affected forest. The South has none.

Lack of baseline data, lack of information regarding the natural variability of the metrics used, and lack of complete understanding of the linkages between components of the forest system and ecological processes limit the conclusions that can be drawn from this analysis. Therefore, we cannot say that there actually have been changes in fundamental ecological processes in those area identified as "having diminished biological components."

It is fairly certain that those regions are experiencing stressors that are affecting tree health and productivity. Those areas also **MAY** be experiencing changes in fundamental ecological processes.

In those regions where the indicators fall below the thresholds used, we have no evidence of diminished biological components indicative of changes in fundamental ecological processes and/or ecological continuity **from FHM tree data or Fire Sciences Laboratory data**. Since data relating to other components of the forest were not used, we can make not judgments as to the condition of other elements of the forest ecosystems. Data relating to other components of forest ecosystems will need to be incorporated into future analyses to obtain a more accurate estimate of the status of this indicator.

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