

Indicators of Ecological Effects of Air Quality
Analysis Subcommittee Meeting Summary
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Note: In this summary, the text focuses on topics that will be investigated for possible customized analysis work. The table at the end provides a view of the broad suite of topics addressed through subcommittee discussions – topics listed in the first (blue) column will be investigated through literature review; topics listed in the third (pink) column will be described in a “Research Needs” section of the final project report.

The objective of the Analysis subcommittee meeting was to identify opportunities to incrementally strengthen the scientific link between metrics of air pollution exposure and ecological response through customized analyses, including:

- linkages across atmospheric nitrogen and sulfur deposition, ‘primary’ acidification and enrichment effects, and a suite of ‘secondary’ effects on organisms, species and ecosystems;
- linkages among ambient ozone concentration, foliar injury, and plant physiological responses;
- linkages among contemporary atmospheric mercury deposition, transformations in terrestrial and aquatic systems, and bioaccumulation.

The Analysis subcommittee provided additional technical insight for the list of potential indicator metrics generated through previous subcommittee discussions, focusing its attention on metrics that require additional synthesis or quantitative analysis. Contaminant-specific discussions of potential customized analysis projects are summarized below. A few cross-cutting topics emerged:

- Developing stratified ecosystem reporting categories. To produce ecological indicator metrics that are sensitive to changes in air quality over management-relevant timeframes, yet also relate to the majority of affected ecosystems, it may be useful to stratify reporting by ecosystem characteristics relevant to ecological sensitivity and rates of pollutant transfer/transformation. This is an evolution of earlier ideas for focusing indicator metrics on ecosystems in which atmospheric deposition is the primary pollutant exposure pathway. This approach may enable distinct tracking of changes across slow and fast responding systems.
- Parsing out confounding factors. In addition to air pollutants, many ecological endpoints are commonly affected by a suite of other stressors, such as climate change, disturbance patterns and management activities, which can obscure or amplify signals of air pollution effects. Proposed indicators should account for these interactions and enable users to parse out ecological responses to changes in air quality.

- Optimizing geographic scale of reporting. Spatial variability in air pollutant exposure/deposition and ecological response presents challenges in defining appropriate geographic scales for indicator metrics. For example, coarse-scale data may be applied more universally and produce strategic level indicators while fine-scale data may be applied more locally and produce tactical level indicators. Indicators should be optimized to avoid obscuring important spatial patterns such as variation in watershed sensitivity.
- Optimizing temporal scale of reporting. Temporal variability in air pollutant exposure/deposition generates variable ecological responses. Pollutant exposure may vary seasonally or interannually and ecological effects may be acute or chronic. Pollutant transfer to aquatic systems may represent contemporary or historical air emissions and there may be non-trivial lag time between changes in air quality and changes in ecological endpoints. These patterns require clearly articulated rationales for indicator design choices.
- Translating across biogeochemical and biological endpoints. Existing models can estimate changes in chemical conditions in response to changes in pollutant loading. Other models can estimate changes in biota in response to changes in chemical conditions. New approaches are emerging to translate across these two spheres of modeling activity, however new tools may not yet be ready to inform this indicator design project.

A full list of potential indicator metrics for acidification, nitrogen enrichment, ozone-induced plant injury and methylation/bioaccumulation of mercury are listed in the table at the end. The first column (in blue) lists ecological effects for which viable indicator metric will be developed through literature synthesis. The second column (in yellow) lists ecological effects for which customized analyses may be needed to formulate a suitable indicator metric – these are described in the contaminant-specific sections below. The third column (in pink) lists ecological effects that require substantial additional research to enable indicator development and will be described in a *Research Needs* section of the final report.

Nitrogen and Sulfur

Two aspects of nitrogen enrichment emerged as candidates for customized analysis: linking terrestrial, freshwater and coastal systems and quantifying change in community structure.

Potential projects:

- Linking atmospheric nitrogen deposition to coastal nitrogen loading and eutrophication. This is a subject of substantial policy/management interest that presents non-trivial scientific challenges. Several federal agencies and numerous researchers, using a variety of quantitative approaches, have developed estimates of the relative contribution of atmospheric nitrogen to coastal eutrophication (confounding factors include non-atmospheric nitrogen sources, watershed properties, climate, land use, etc.) In order to propose a nationally-relevant indicator metric for this ecological effect of atmospheric nitrogen deposition (e.g., change in nitrogen levels in coastal waters, change in dissolved oxygen, change in chlorophyll a) further progress in synthesizing and/or scaling up existing watershed-level work may be needed and may be feasible within the context of this project.
- Linking atmospheric nitrogen deposition to change in community structure. The Ecological Change subcommittee recommended investigating the potential for using biota such as lichens in terrestrial systems and diatoms in aquatic systems as 'sentinels' of ecological effects of nitrogen enrichment. While significant research has focused on lichens and diatoms, further

synthesis may be needed to delineate strategies for using changes in abundance or chemical composition as indicators of changing air quality.

- Developing stratified reporting categories (as discussed on page 1). Although we are interested in potential effects of nitrogen and sulfur deposition on all ecosystems, the most rapid responses to changes in air quality would be anticipated in ecosystems with low resilience to nitrogen and sulfur addition (e.g., acid-sensitive systems, nitrogen-limited systems). Specialized analysis may be needed to define appropriate geographic reporting categories.

Ozone

The effect of chronic elevated ozone levels on plant productivity was identified as a candidate for customized analysis.

Potential projects:

- Linking ambient ozone concentrations to changes in plant physiology. To track the ecological effects of chronic elevated ozone levels, the Analysis subcommittee recommended further investigation of the potential of remote sensing data to detect patterns of ozone effects on plant chlorophyll levels and water use efficiency. If feasible, this approach represents a possible opportunity to factor out climatic effects (i.e., effect of moisture/temperature on stomata and gas exchange) and/or ambient CO₂ concentrations from ozone exposure effects.
- Linking ambient ozone concentrations to changes in forest species composition. The Analysis subcommittee also supported scanning FIA data for long-term patterns of decline of ozone-sensitive tree species and investigating corroborating evidence of effects of chronic elevated background ozone levels on plant communities. This approach would look for correlation between spatial patterns of peak or cumulative ozone exposure and spatial patterns of decline in ozone-sensitive species (based on established databases of species sensitivity). Note that it will be necessary to parse out confounding factors such as temperature, moisture, fire and pest outbreaks.
- Developing stratified reporting categories (as discussed on page 1). Although we are interested in potential effects of ozone on all vegetated ecosystems, the most rapid responses to changes in ambient ozone concentration would be anticipated in ecosystems with high or continuous exposure levels. Specialized analysis may be needed to define appropriate geographic reporting categories.

Mercury

Spatial variation in mercury transfer/transformation emerged as a candidate for customized analysis¹.

Potential projects:

- Developing stratified reporting categories (as discussed on page 1). Although we are interested in potential effects of mercury in all receiving watersheds, the most rapid responses to changes in atmospheric mercury deposition would be anticipated in watersheds that rapidly transfer mercury to aquatic systems and that efficiently produce methylated mercury. Significant research exists to support the development of watershed categories that exhibit different mercury transfer rates and methylation capacity, but additional work may be needed to synthesize existing knowledge and to define watershed categories. Potential factors for

¹ It was noted that, “The most loaded systems are not necessarily the most impacted systems.”

watershed category definition include land-to-water ratio, soil type, depth of hydrologic flow path, abundance of wetlands and chemical conditions (pH, sulfur, organics, etc.)

Next Steps

In the coming weeks, the Heinz Center will scope out specific options for customized analyses and seek input from the project Steering Committee. Subsequently, indicator development work will occur on two tracks: (1) metric development through literature review, and (2) customized data analysis by contracted specialists. Also during this time, we will investigate the availability of existing data systems to support recommended indicator metrics. Findings from model analyses, data investigations and an on-going literature review will be housed in a comprehensive report that proposes a refined list of ecological indicators of air quality.

Ecological Effects		Lit review to identify best metric	Possible customized analysis	Research Needs in report	
NITROGEN AND SULFUR DEPOSITION					
Acidification	Terrestrial	Change in base cation status in forest soils (e.g., base saturation; BC:Al ratio)		Change in relative productivity, acid-sensitive biota	
		Change in forest soil pH			
	Freshwater	Change in ANC in streams, lakes, ponds		Change in relative productivity, acid-sensitive biota	
		Change in sulfate in streams, lakes, ponds			
Nitrogen enrichment	Terrestrial	Change in C:N ratio in soil organic matter	Change in community structure (lichen abundance or chemical composition; grass species dominance)	Altered chemical cycles (N uptake; N volatilization; relative net nitrification; litter decomposition/accumulation)	
		Change in foliar N:P ratio or or N:productivity		Alteration of N-sensitive species/features, seedling root:shoot ratio, ratio of nitrophilic/phobic species, mycorrhizae, etc.	
		Change in streamwater nitrogen status (e.g., nitrate, total nitrogen, N:P ratio; DIN:Total P ratio, DON:DIN ratio)		Altered disturbance regimes, e.g., hydrology, fire frequency (with change in species mix); pest outbreaks; invasive species	
				Change in species composition (red:sugar maple ratio; fungi:bacteria ratio; hetero:autotrophic nitrifiers)	
	Freshwater		Change in community structure (diatoms)	Change in species composition, abundance (nitrophilous algae; fish)	
	Coastal systems			Change in total nitrogen	
				Change in dissolved oxygen	
				Change in Chlorophyll a (abundance, timing)	
AMBIENT OZONE					
Plant injury	Terrestrial	Foliar injury (e.g., lesions, leaf senescence) in forests, croplands and grass/shrublands	Change in plant physiology, e.g., yield (cropped systems); chlorophyll/water use efficiency in forests (spectral 'red shift')		
			Changes in species composition (ozone-sensitive species in forests)		
MERCURY DEPOSITION					
Methylation	Aquatic	Change in MeHg:Total Hg ratio in wetlands		Change in MeHg:Total Hg ratio in streams, coastal systems	
Bioaccumulation	Terrestrial			Change in total Hg in tissues (blood/egg) of invertivores	
	Aquatic	Change in MeHg in young-of-the-year fish tissues			
Change in total Hg in tissues of piscivores (mature fish)					