National Park Service
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Natural Resource Stewardship and Science

Air Quality and Ecosystem Services Workshop Report

Santa Monica Mountains National Recreation Area, Thousand Oaks, CA – February 24-26, 2015

Natural Resource Report NPS/ NRSS/ARD/NRR—2016/1107

"When the plants you haven't heard of go…
the animals you like will start fading, too."
-Elizabeth Farnsworth

ON THE COVER
Santa Monica Mountains National Recreation Area, taken in December, 2011 by Tamara Blett, National Park Service

Air Quality and Ecosystem Services Workshop Report

Santa Monica Mountains National Recreation Area, Thousand Oaks, CA – February 24-26, 2015

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Executive Summary

The main objective of this workshop was to link well documented air pollution critical loads (CLs) to specific final ecosystem goods and services (FEGS) defined by the FEGS Classification System. The workshop took place on February 24-26, 2015, at Santa Monica Mountains Natural Recreation Area, in Thousand Oaks, California. Workshop participants included scientists, resource managers, and policy makers with expertise in aquatic ecology, water and soil biogeochemistry, plant physiology, modeling of environmental effects of pollution, and economics.

Participants were split into one of four groups, Terrestrial Eutrophication, Terrestrial Acidification, Aquatic Eutrophication, or Aquatic Acidification to explore the ecological relationships between a change in a biological indicator due to air pollution and the resulting change in a FEGS. Each group was comprised of scientists with expertise in the CL science, as well as economists familiar with ecosystem service classification approaches.

To complete this task, groups constructed a series of chains linking a biological indicator responding to the exceedance of a critical load, to an ecological production function consisting of cause-and-effect steps, to an ecological endpoint valued by humans, to the different human use groups that interact with the final endpoint. This was done within the Final Ecosystem Goods and Services Classification System which provided structure and terminology that will allow the results to be used broadly by management agencies.

We developed a total of 1046 chains that linked to 66 unique FEGS Metrics and impacted 26 Beneficiary groups. Each link in the chain was given a Strength of Science score to qualitatively assess the amount of information supporting the relationships. The number of chains varied among groups due to the methods each group used in their analysis.

The work products developed by the small groups had two very different audiences: complex diagrams to provide details of interest to scientists and subject matter experts, and simple stories for management and public audiences. This dual approach was important as the stories are able to refine the complex interactions into a few discrete steps ending in a biological unit that produced emotional connection and resonance with the audience. The stories and the detailed diagrams are valuable products from this workshop which, when used in combination, can serve to fill the gaps between science and policy in connecting air quality and ecosystem services.

Participants uniformly praised the workshop products as demonstrating significant progress in making connections between air pollution induced acidification and eutrophication, and ecosystem services, and felt that the chains had great potential in setting the foundation for future work which could provide information the EPA needed to help set secondary NAAQS standards.

Now that this workshop has achieved preliminary progress on the “supply side” using the FEGS-CS tool, the data is positioned to be linked to a National Ecosystem Services Classification System (NESCS) or similar tool to facilitate quantification and valuation (the “demand side”) of the natural systems that provide ecosystem services.

INTRODUCTION

Purpose of the Workshop

The purpose of this workshop was to identify links between atmospheric deposition effects on sensitive natural resources and the ecosystem services they provide. While substantial information on the effects of acidification and eutrophication in aquatic and terrestrial ecosystems has been published,[1] little work had previously been done in establishing the links between specific air quality effects on plants, animals, soils, algae and waters to the humans who use or enjoy them.

Environmental policy and management decisions must often consider how changes to the environment affect human welfare. Scientists, land managers and policy makers have increasingly been using ecosystem services to describe the benefits provided by nature and valued by society.[2,3] This workshop was developed to establish a rich landscape of multiple and varied links between biological indicators of air pollution and their end users, or beneficiaries, such that the ecological "*supply side*" of this process could be better understood. This process is useful because it advances communication of the science by translating air pollution impacts on ecosystems into terms that the public can more easily understand and value. It also provides information allowing land managers and policy makers to assess whether air pollutants are causing adverse impacts to ecosystems.

The workshop took place on February 24-26, 2015, at Santa Monica Mountains Natural Recreation Area, in Thousand Oaks, California. Workshop participants included scientists, resource managers, and policy makers with expertise in aquatic ecology, water and soil biogeochemistry, plant physiology, modeling of environmental effects of pollution, and economics (Appendix A).

Background

Nitrogen (N) and sulfur (S) deposition are airborne pollutants deposited to the earth through either wet process (such as rain and snow) or dry processes (such as dust, particles, and gasses). N and S impacts on environmental chemistry, and ultimately to aquatic and terrestrial biota are described through the use of critical loads (CL). A critical load is the *"quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge.*[4]" Critical loads have been identified for several key biological indicators (components of the ecosystem sensitive to N and S additions). The objective of the workshop was to connect these indicators to ecosystem services.

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[1] Greaver, T.L., Sullivan, T.J., Herrick, J.D., Barber, M.C., Baron, J.S., Cosby, B.J., Deerhake, M.E., et al. (2012). Ecological effects of nitrogen and sulfur air pollution in the US: What do we know? *Frontiers in Ecology and the Environment*, 10 (7):365-372.

[2] Compton, J E. Harrison, J.A., Dennis, R.L., Greaver, T.L., Hill, B.H., Jordan, S.J., Walker, H., and Campbell, H.V. 2011. Ecosystem services altered by human changes in the nitrogen cycle: a new perspective for US decision making. Ecology Letters 14: 804-815

[3] Sullivan, T.J. 2012 Combining ecosystem service and critical load concepts for resource management and public policy. Water 4: 905-913: doi: 10.3390/w4040905

[4] Nilsson, J. and P. Grennfelt, eds. 1988. Critical Loads for Sulphur and Nitrogen. UNECE Nordic Council Workshop report, Skokloster, Sweden, 19e24. Miljorapport 1988: 15. Nordic Council of Ministers, Copenhagen.

The Critical Loads of Atmospheric Deposition Science Committee (CLAD) of the National Atmospheric Deposition Program (NADP) has developed a national database of critical loads for S and N. The database is a compilation of critical loads representing acidification and excess nitrogen impacts to natural resources across the continental Unites States. The database includes both empirically derived and calculated critical loads for a variety of biological indicators including the impacts of surface water chemistry on aquatic biota and the impacts of excess nitrogen on lichen community structure, forest health, and biodiversity. This database, as well as other recently published critical load information, was used to build the links between critical loads and ecosystem services. These connections are particularly important because they are of interest to the United States Environmental Protection Agency (USEPA) for use in describing the rationale for developing National Ambient Air Quality Secondary Standards and to federal land management agencies in communicating to the public about the consequences of air pollution damage to sensitive resources.

A defined list of biological indicators for which critical loads have been developed was used in this workshop. Participants' expertise and knowledge of the published literature was used to document or hypothesize how deposition excess (CL exceedance) alters these indicators in a cascade of ways that could ultimately impact human benefits. Critical load exceedance (determined by comparing current deposition levels to CLs) is a measure that may be used by the USEPA, National Park Service (NPS), the U.S. Forest Service (FS) and other groups to define the point at which ecosystems may be first affected by pollutants.

For the purposes of the workshop we used the well-documented Final Ecosystem Goods and Services Classification System (FEGS-CS, developed by USEPA to identify why the CL biological indicators do, or should, matter to humans.[5] Final Ecosystem Goods and Services (FEGS) are *"the components of nature, directly enjoyed, consumed, or used to yield human well-being.*[6]" FEGS-CS is a tool designed to be used by environmental and land management policy makers to develop the *supply-side* information on the natural systems that provide ecosystem services. This information then feeds into the National Ecosystem Services Classification System (NESCS), which emphasizes the *demand-side* classification, and represents one way of supporting the identification of ecosystem service changes to facilitate subsequent steps of quantification and valuation.[7] This workshop utilized the expertise of the participants to create an ecological production function, a series of cause-and-effect steps that link change in a biological indicator associated with a CL to an ecological endpoint valued by humans. Using the FEGS-CS, the ecological endpoint was associated with distinct potential beneficiary groups. FEGS provides a foundation from which these links can be further

[5] DH Landers and Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

[6] Boyd, J. and Banzhaf, S. 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63: 616-626. Doi: 10.1016/j.ecolecon.2007.01.002

[7] United States Environmental Protection Agency. 2014. *National Ecosystem Services Classification System (NESCS): Framework Design and Policy Application.* Draft Report.

identified and explored in the future to develop *demand-side* economic assessments addressing the effects of N and S air pollution on natural resources of specific value to society.

Air pollution affects many components of natural systems, however, for the purposes of this workshop we intentionally limited our scope to the impacts of acidification and eutrophication resulting from nitrogen and sulfur air pollution. Air quality issues considered beyond the scope of this workshop included: human health, ozone damage, mercury methylation and visibility.

Workshop Objectives

1. Create specific links from critical loads endpoints (e.g. abundance of sensitive lichen species, high-elevation lake chemistry, grassland biodiversity, etc.) to benefits and human beneficiaries (e.g. livestock grazers, eco-tourism businesses, artists, students, etc.) of pollution-sensitive natural resources using the "final ecosystem goods and services" (FEGS) framework.
2. Utilize standardized definitions and processes, as defined by the FEGS-CS approach, to describe what biophysical processes or endpoints are "lost" when air pollution levels result in damage to ecosystems and relate these "losses" to final impacts on ecosystem goods and services.
3. Utilize the subject matter expertise of participants to identify the strength of science describing relationships between air quality impacts and ecosystem services within ecological production functions.
4. Identify gaps in our knowledge that impede making necessary links between biological indicators and FEGS and identify areas where biophysical data exists, but where further analysis is needed to get from CLs endpoints to ecosystem services endpoints.
5. Produce a workshop report and a journal article that describe critical loads/ecosystem services links in ways that will be useful to the current USEPA secondary national ambient air quality standards development review process and federal land management agency land management planning processes.
6. Provide a forum to assemble subject matter experts from four federal agencies (USEPA, FS, NPS, USGS), universities, and research firms with expertise in air quality critical loads and/or ecosystems services who would not ordinarily interact together, in order to develop collaborative and comprehensive products.

This report summarizes the presentations given to the participants at the start of the workshop to introduce the concepts of critical loads of air pollutants, FEGS, ecological production functions, and beneficiary groups. We then report on the relationships between bioindicators and FEGS developed by each of the four groups. We conclude with a synthesis of results and report on how effective the FEGS-CS worked in flushing out relationships between critical loads and end users.

HISTORY AND BACKGROUND OF ECOSYSTEM SERVICES

Presented by Jim Boyd (Resources for the Future), Summarized by Amanda M. Nahlik (Kenyon College)

All people directly or indirectly rely on the goods and services provided by the environment, and we strive to recognize the multitude of those benefits provided– what many now call "ecosystem services." The concept of ecosystem services was intended to connect ecological status and changes to social well-being, and because ecosystem services are the goods and services that people use, it would be useful for the impacts on ecosystems from air pollution to be better understood by the public. However, despite the notion of ecosystem services being well-received and prominently used as a focus for research, one of the most challenging aspects is that there is virtually no standardization of terminology, definitions, or classification approaches.[8]

In 2007, Boyd and Banzhaf offered a solution to these issues by introducing the concept of *final* ecosystem services as "*the components of nature, directly enjoyed, consumed, or used to yield human well-being*.[9]" This concept was refined and rebranded into Final Ecosystem Goods and Services (FEGS) over a series of interdisciplinary workshops held by the USEPA and Jim Boyd, with the objective of operationalizing and applying the definition of FEGS to different aquatic ecosystems[10,11].

FEGS can be thought of as measurable "boundary objects" or "points of contact" between the disciplines of natural and social scientists, allowing them to work together to incorporate aspects of both specialties into an ecosystem services framework. This is important because the ecosystem services concept is innately transdisciplinary. The FEGS successfully bridge natural and social sciences because they are the transition between an environmental production function, i.e., ecological structure and processes, and an economic production function, i.e., human interaction and human wellbeing (Figure 1). Furthermore, FEGS serve as quantifiable units to link natural and social sciences.

Consider the example of surface water pH. How would you explain the social value of increased or decreased surface water pH to your neighbor? You might start by explaining why pH matters. Natural scientists have many answers to this, one of which may be because it indicates "condition" which may be water quality and habitat status. Would your neighbor understand or care about this? Perhaps not. Then, why does water quality and habitat condition matter? Possibly because it affects

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[8] Nahlik AM, Kentula ME, Fennessy MS, Landers DH. 2012. *Where is the consensus? A proposed foundation for moving ecosystem service concepts into practice*. Ecological Economics 77: 27-35.
[9] Boyd JW, Banzhaf S. 2007. *What are ecosystem services? The need for standardized environmental accounting units*. Ecological Economics 63: 616-626.
[10] Ringold PL, Boyd JW, Landers D, Weber M. 2009. *Report from the Workshop on Indicators of Final Ecosystem Services for Streams*. U.S. Environmental Protection Agency. Report Number EPA/600/R-09/137. 56 pp.
[11] Ringold PL, Nahlik AM, Boyd JW, Bernard D. 2011. *Report from the Workshop on Indicators of Final Ecosystem Goods and Services for Wetlands and Estuaries*. US Environmental Protection Agency. Report Number EPA/600/X-11/014. 73 pp.

changes in the abundance of a fish species your neighbor targets while angling – something your neighbor *does* understand and value. So pH is intermediate to the FEGS, which is the abundance of a fish species. FEGS are environmental commodities that require little subsequent translation and, as such, they are understandable and relevant to the public.

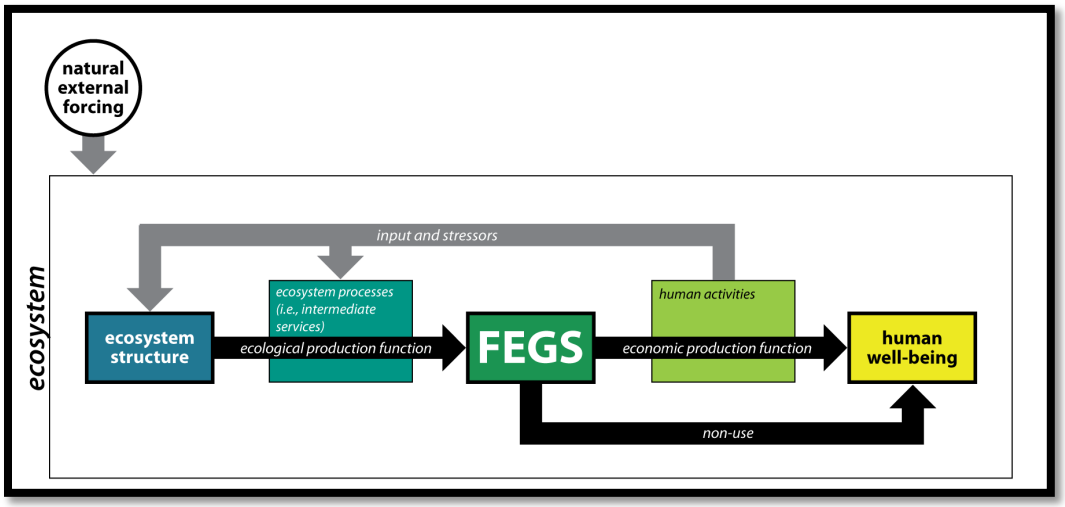

Figure 1. Conceptual diagram of the production and consumption of FEGS

It is worth noting that beneficiaries, or users that have particular use-interests, must directly interact with the Final Ecosystem Good or Service in the environment. Once human capital has been added to the FEGS to receive a benefit, the good or service is considered part of the economic production function, for which there may be other, secondary beneficiaries. For example, acidification (a stressor) affects tree growth and mortality, which in turn results in a shift of tree species available to foresters, from species desirable for creating durable wood products, such as baseball bats, to less desirable tree species. At the point that the foresters harvest the wood, the wood is no longer a FEGS – it is an economic product that is clearly defined by the North American Industrial Classification System (NAICS). Beneficiaries downstream of the environment (i.e., in the economic production function) mill the wood, sell it to baseball bat manufacturers and provide the completed products (baseball bats) to professional and non-professional teams. Although baseball players are affected by lesser-quality bats, they are not a primary FEGS beneficiary, nor are baseball bats considered FEGS. While making economic connections are important to evaluating human well-being, this workshop was primarily focused on the ecological production functions and FEGS identification.

There are instances when environmental entities are both inputs to FEGS (intermediate services), and final ends in themselves (FEGS). For example, in Figure 2, seagrass may be a FEGS to one user, such as someone who collects that seagrass to make baskets, but the seagrass is also an input into crab abundance, a FEGS for another user, such as a commercial fishery. This illustrates the importance of understanding the user, or the beneficiary. This is also important because use of seagrass as a FEGS may reduce the availability of seagrass to serve as habitat for crabs, so in order to avoid double-counting, you have to also understand the interplay between the two FEGS categories.

Thus, in many ways, seagrass in situ is not the final good, rather, harvested seagrass is the FEGS, which affects the availability of seagrass for the other FEGS which might be crab harvests.

Understanding who or what group is directly interacting with the FEGS by enjoying, consuming, or utilizing the environmental component is critical to distinguishing intermediate services from FEGS.

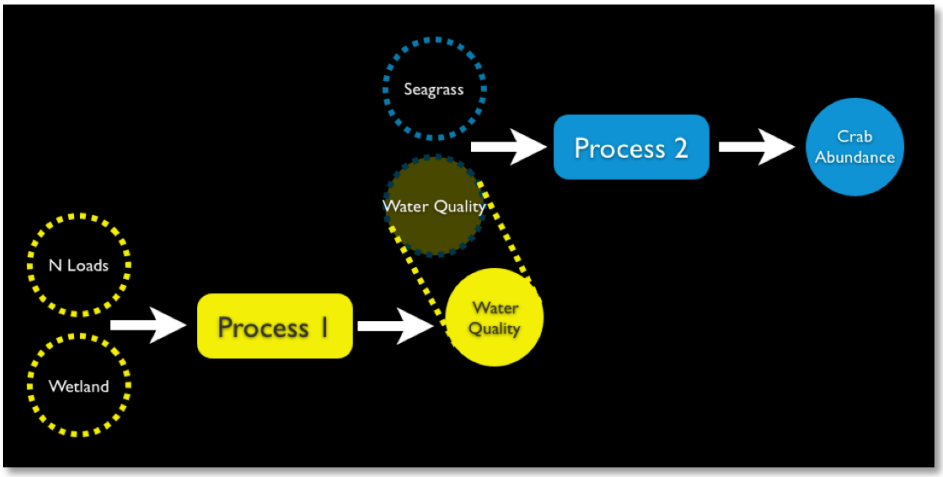

Figure 2. An example of how inputs can be intermediate services or FEGS depending on the beneficiary

APPLYING FINAL ECOSYSTEM GOODS AND SERVICES (FEGS)

Presented by Dixon H. Landers (USEPA), Summarized by Amanda M. Nahlik (Kenyon College)

To quantify the supply of ecosystem services on the ground (stocks) or changes in ecosystem services (flows) due to stressors, ecologists have to know what biophysical indicators to measure. What to measure depends on the beneficiary and what they directly utilize, consume, or enjoy from the environment. For example, a variety of methods are available to ecologists to measure water in a meaningful ecosystem-service-relevant way, but first it is critical to know how the water is being used. Knowing whether the water is being used for irrigation or for drinking makes the difference between measuring water quantity and harmful chemicals in the water (water quality).

The definition of FEGS inherently provides simple guidelines for identifying ecosystem services and the beneficiaries in a meaningful, systematic, and measureable way. The FEGS definition has two key components: the environment and the beneficiary (Figure 3). By hypothesizing what people (beneficiaries) care about for a particular ecosystem, we are able to identify the FEGS, which is a comprehensive description that combines the Environmental Class, the Beneficiary Category, and the ecosystem service.

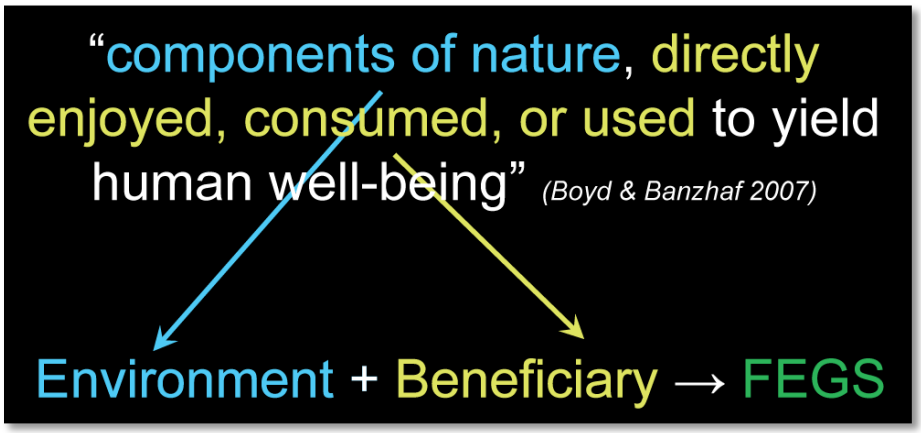

Figure 3. The definition of Final Ecosystem Goods as Services (FEGS) deconstructed into its key components

We use guiding questions to identify FEGS. For example, consider people who recreationally collect edibles from the environment for their own personal consumption (Figure 4). First we put them into an environment, say, the shore. We start by asking, "Do Recreational Food Pickers and Gatherers utilize Estuaries and Near Shore Marine environments? The answer of course is, "Yes". Then, we ask, "What do they utilize to obtain a benefit and why?" The answer is flora and fauna, such as seaweed, kelp, mussels, or crabs, which are edible organisms that can be collected for personal use. Therefore, the FEGS can be described as "flora and fauna provided by estuaries and near shore marine environments to recreational food pickers and gathers." Ecologists can measure the

population of mussels, for example, to estimate potential service provision at a location, and economists can value those mussels using a variety of methods depending on their use (or non-use).

Figure 4. An example of how FEGS can be identified using the definition and guiding questions

Over some years and with the help of many experts from multiple fields and disciplines, Landers and Nahlik established Environmental Classes and Beneficiary Categories that could be applied globally, then systematically identified a finite number, 338, of measurable and meaningful FEGS. The results of these efforts was the Final Ecosystem Goods and Services Classification System (FEGS-CS)[12,13] as well as documents describing how FEGS were developed and are applied. It also provides FEGS Matrices, which were collectively designed to be a resource and tool for practitioners to consistently identify and communicate FEGS.

[12] Landers DH, Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). U.S. Environmental Protection Agency Office of Research and Development. Report Number EPA/600/R-13/ORD-004914. 108 pp.

[13] The USEPA Final Ecosystem Goods and Services Classification System (FEGS-CS) Report can be downloaded from http://gispub.epa.gov/FEGS/. Additionally, FEGS Matrices available on this website can be customized to a user's interests.

CRITICAL LOADS OVERVIEW

Summary of presentation by Tamara Blett (NPS Air Resources Division)

Air pollution induced changes in natural resources can be profound and sometimes irreversible. Hundreds of studies show that nitrogen and sulfur deposition, as a result of air pollution from combustion and other sources, has altered sensitive resources in national parks and other natural areas across the country (Figure 5). When air pollution begins to impact the health of ecosystems, subtle changes often occur first in microscopic, hidden, or lesser-known parts of the environment such as aquatic diatoms, lichens, macroinvertebrates, or mycorrhizae abundance. Therefore, scientists studying air pollution effects on ecosystems are particularly challenged with explaining the function and value that these early indicators of environmental harm have, because the public benefit may not be obvious or direct. Making this connection between early indicators of ecosystem health and ecosystem services is important not only for communicating to the general public, but also for understanding how air quality policy-decisions may directly impact people.

Figure 5. Aquatic acidification alters pH and acid neutralizing capacity which negatively impacts ecosystem function.

Ecosystem effects from nitrogen and sulfur can be grouped into four categories: aquatic acidification, aquatic eutrophication, terrestrial acidification, and terrestrial eutrophication (Figure 6, Table 1) although in reality, air pollution impacts do not always neatly or discretely remain within each boundary. Biological indicators that show early negative impacts from air pollution in each of these four categories have been extensively studied by scientists. Research has shown that deposition of nitrogen and sulfur air pollution leads to changes in the chemistry of soil, water or air that in turn affects the health, growth or viability of biota. Critical thresholds of these chemical variables link air pollutant loads to unique biological indicator responses (Table 1).

For example, acid neutralizing capacity (ANC), pH, and nitrate (NO_3) are the most commonly used chemical variables for surface waters because thresholds are often known at which aquatic biota, such as phytoplankton or fish begin to be affected. Base saturation and calcium to aluminum ratios (Ca/Al) are the most commonly used chemical variables for soils, because threshold exceedances can be linked to declines in forest health, changes in biodiversity of plant communities, and other effects.

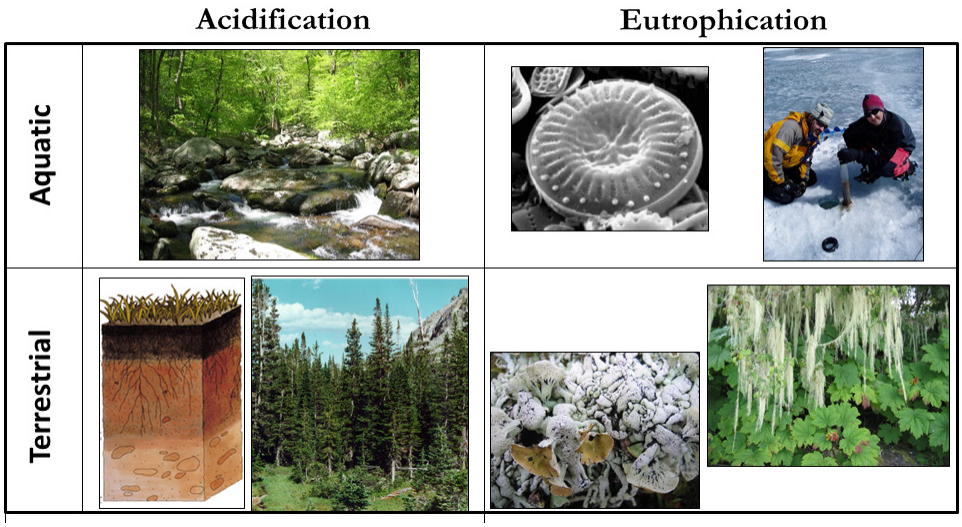

Figure 6. Biological indicators of air pollution effects generally fall into one of four categories; acidification or eutrophication of aquatic and terrestrial ecosystems. Acidification has traditionally been more of an issue for the eastern US, while eutrophication is emerging as an issue for the western US.

The chemical variables (or criteria) are very important because they are used as proxies or indicators of likely biological responses when assessing ecosystem impacts. Critical loads (CL) vary widely because biological indicators respond differently to different levels of air pollution depending on their sensitivity to pollution as well as physical, biological, and chemical environments. Not only do the pollution levels at which biota respond vary widely, but how they response (linear, exponential, etc.) can vary. This means that setting a specific CL, although based on science, can still be a judgment call based on what level of protection is desired; some responses will be rapid and obvious and some may be subtle or gradual.

Land managers often select from a variety of critical loads in a national park or national forest to highlight the "most sensitive" systems that they can then monitor for significant harmful effects. They define "significant harmful effects" as those that alter natural structure of the biological community by reducing the size of a specific species' population, changing ecosystem function, or significantly altering the health or condition of sensitive ecosystem components. While land managers are most interested in "healthy natural ecosystems" and the critical load that preserves or restores them, state and federal air regulators are more often interested in determining what levels of ecosystem change constitute adversity to public welfare. Critical loads can therefore be developed for a variety of endpoints depending on the how the desired outcome is defined (Figure 7).

Table 1. An example of some relationships between ecosystems, biological indicators and responses, chemical variables and atmospheric pollutant loads.

Disturbance	**Acidification**				**Excess N / Eutrophication**		
Receptor	**Terrestrial**		**Aquatic**		**Terrestrial**		**Aquatic**
Biological Indicator	Sugar Maple	Red Spruce	Brook Trout	Fish species	Grass Species changes increase fire	Lichen species diversity	Diatom Species shifts
Critical Biological Indicator Response	Reduced growth and seedling success	Biomass or root growth reduced	Loss of health and reproductive capability	Reduced number of fish species	Arid land grass increases	Loss of sensitive lichen species	Species loss, biodiversity decrease
Chemical Variable	Soil % Base Saturation	Soil water Ca/Al ratio	Stream water ANC	Stream water pH	Soil C/N, %N in soil, biomass productivity	%N in the common 'wolf lichen'	Lake water NO3
Critical Chemical Limit	< 10%	< 10:1	< 20 µeq/L	< 6.0	1000 kg/ha biomass productivity	1% N	1.0 mg/L NO3-N
Atmospheric Pollutant	SO4, NO3, NH4				NO3, NH4		
Critical Pollutant Load	Varies	Varies	Varies	Varies	3.2 kg/ha/yr	3.1 kg/ha/yr	1.5 kg/ha/yr

Critical loads have been estimated and mapped at a national scale for a variety of ecosystem effects, including surface water acidification, forest soil acidification, lichen community impacts, and excess nutrient enrichment impacts on biota.[14] These maps provide initial estimates of sensitivity to air pollution for key resources across most natural areas of the country.

The critical loads can also be used in concert with deposition estimates to identify areas where CLs are exceeded, thereby identifying potential areas of damage or impact to sensitive natural resources. Sources of reasonable deposition estimates at geographic scales from 4-12 km nationwide include atmospheric model output (from the Community Multi-scale Air Quality model [CMAQ]), pollution deposition monitoring networks (National Trends Network[NTN], Clean Air Status and Trends Network [CASTNET]), and hybrid approaches such as the total deposition ("TDep") map products from NADP.

For this workshop, well-established biological indicators with existing CLs were used as starting points in a process created specifically to link CLs and ecosystem services. These biological indicators include: aquatic biota (macroinvertebrates and fish), diatoms, lichens, herbaceous plants, invasive grasses and forests (trees).

14 http://nadp.isws.illinois.edu/committees/clad/

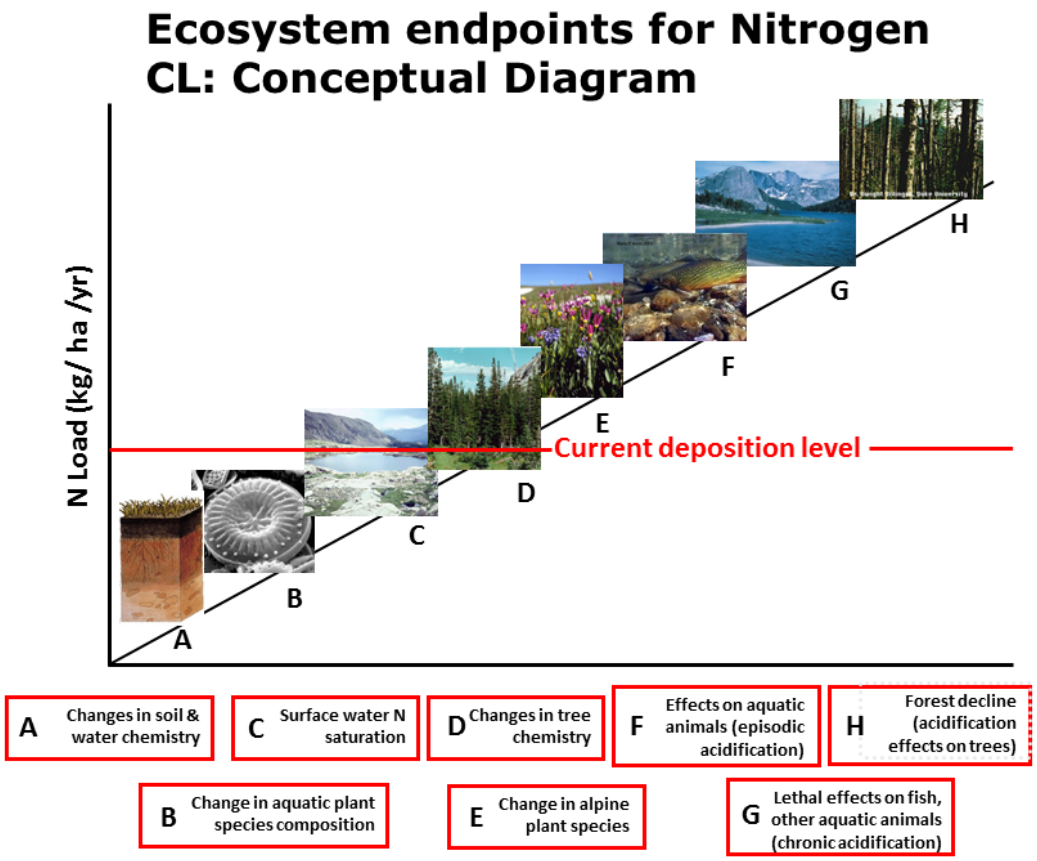

Figure 7. This conceptual diagram illustrates how critical loads are unique for specific biological indicators and endpoints. Note that relationships between increasing nitrogen and effects on individual indicators is not always linear, and can change over time.

SETTING THE STAGE FOR REGULATORY ACTION: WHAT DOES EPA NEED?

Summary of Presentation by Randy Waite, Christine Davis, Tara Greaver (EPA)

Secondary National Ambient Air Quality Standards (NAAQS) are air chemistry values set to protect public welfare. Unlike the primary standards, which are developed to protect human health, the secondary standards account for known or anticipated adverse effects on components of nature such as soils, water, crops, vegetation, animals, and wildlife, as well as economic values, personal comfort, and well-being. The Office of Air Quality Planning and Standards, which is responsible for reviewing and setting the NAAQS, is now using an ecosystem services framework to describe, quantify, and in a few cases, monetize the effects of air pollutants on public welfare. This process is on a 5-year cycle and includes an integrated science assessment providing a comprehensive review, synthesis, and evaluation of the most policy-relevant science since the last review; a risk and exposure assessment, which develops quantitative characterizations of exposures and associated risks to the environment; and a policy assessment which is a staff analysis of the scientific basis for various policy options. All of these steps must be completed before proposal of a new NAAQS.

An important consideration in developing the risk and policy assessments is the identification and assessment of effects that are known or anticipated to have adverse effects on public welfare. Figure 8 illustrates a conceptual model of the pathway from ambient air concentrations to the policy decision based on welfare effects using recreational fishing as an example.

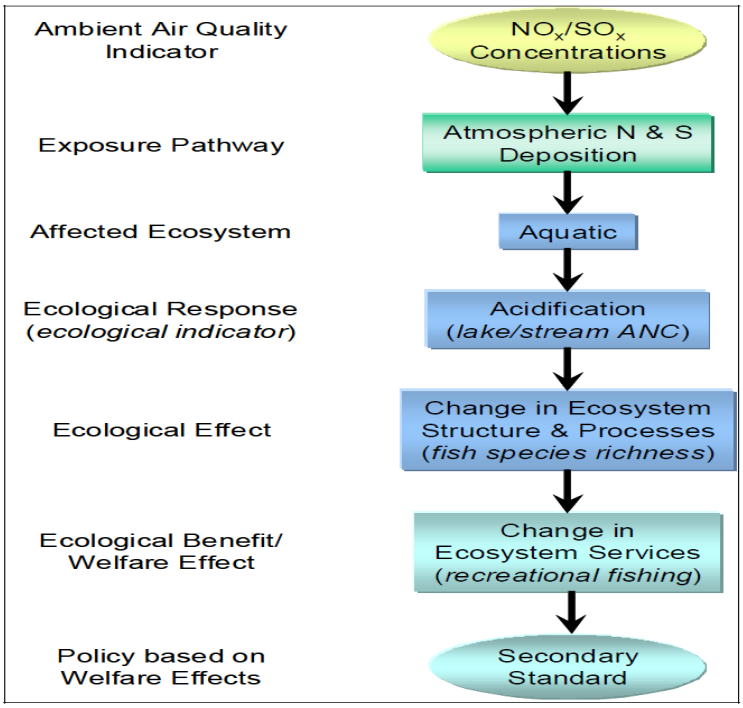

Figure 8. Conceptual model of relationships leading to an effect on public welfare.

The previous combined review of the secondary standards for oxides of nitrogen and sulfur (NO_x and SO_x) evaluated information on four major effects categories: aquatic acidification, terrestrial acidification, aquatic eutrophication, and terrestrial nutrient enrichment. The review also introduced the use of an ecosystem services framework to provide an evaluation of adversity to public welfare.[15] The science assessment for the current review has identified case studies and species of interest for evaluation of ecological and ecosystem services effects for the various endpoints identified in the previous review cycle. The risk assessment is in the planning stage and will be informed by the science assessment and analyze effects of current concentrations of NO_x and SO_x for their risks to ecology and public welfare to inform the policy assessment's review of the policy options available to address those effects.

The products of the AQES workshop will inform the science and risk assessments with regard to the relationships between critical loads and effects on ecosystem services and help to provide a public welfare context for the EPA Administrator. Particularly, the workshop products useful for the risk assessment include identifying quantified relationships between deposition rates and ecological effects, and between ecological effects and Final Ecosystem Goods and Services.

[15] Rea A.W., Davis C., Evans D.A., Heninger B.T., and Van Houtven, G. 2012. *Using Ecosystem Services to Inform Decisions on U.S. Air Quality Standards*. Environ. Sci. Technol., 2012, 46 (12), pp 6481–6488

PROCESS: CREATING "CHAINS" FROM CRITICAL LOAD BIOLOGICAL INDICATORS THROUGH ECOLOGICAL PRODUCTION FUNCTIONS TO FINAL ECOSYSTEM GOODS AND SERVICES

Methods

The main objective of this workshop was to link well documented critical loads (CLs) to specific final ecosystem goods and services (FEGS) defined by the FEGS Classification System. Although CLs allow us to characterize the point at which ecosystem functions, processes, and characteristics of a biological indicator begin to be impaired, this does not necessarily equate to a specific level of impairment of an ecosystem service. It was therefore necessary to go through a process that linked biological indicators (e.g. diatoms, macroinvertebrates, fish) to the ecological condition(s) that support specific final ecosystem goods and services (Figure 9). Ecological production functions are the series of cause-and-effect steps that link change in a biological indicator associated with a CL to an ecological endpoint valued by humans. An example of one possible pathway is shown in Figure 10. The entirety of the links between a single biological indicator, each step in the ecological production function, and each potential beneficiary is called a *chain*. The challenge for workshop participants was to develop a number of plausible chains that linked a CL exceedance for a particular biological indicator to impacts on the ecological conditions that humans need, value, or appreciate; FEGS. Each chain was recorded in a spreadsheet template to ensure that each group maintained a similar format so that future analyses could be completed among groups (Table 2).

Small groups worked together to generate as many chains as possible based on the four ecological effects of pollution that have well defined critical loads: aquatic acidification, aquatic eutrophication, terrestrial acidification, and terrestrial eutrophication (Figure 11). Groups understood that there would be some overlap between ecological effects addressed by the four sectors (for example acidification and eutrophication both affect surface water chemistry, diatoms, and other biota), so some group members rotated to provide input and expertise where needed. Each group was comprised of scientists with expertise in the CL science, as well as economists familiar with ecosystem service classification systems. A facilitator was assigned to each group to keep the process moving and present work group products to the full group. A rapporteur for each group was responsible for taking notes, documenting discussions and rationale for the decisions made by the group, and was also responsible for populating the spreadsheet template to ensure that all relevant cells were filled out.

The groups generally worked through the process in the same way, following these steps:

1. Groups would examine the list of the available CL biological indicators and associated assessment criteria to determine which were applicable to their area of concern (aquatic vs. terrestrial, acidification vs. eutrophication).

2. Groups then created an ecological production function by identifying the cascading ecosystem effects of the change in the biological indicator. All decisions regarding the ecological chains were recorded in notes and the effects were recorded in the spreadsheet.

3. This metric was then associated with a potential beneficiary from the FEGS Classification System (FEGS-CS). A modified FEGS-CS (Table 3) was created specifically for the workshop to include only those environmental subclasses and beneficiary categories pertinent to the available CLs.

4. The process was somewhat iterative and groups approached identifying the chains by working in both directions. For example, most worked from the biological indicators through the chains, ending with FEGS. Some groups would also start with the FEGS and work "backwards" to make sure all relevant FEGS were addressed. Later sections of this report will describe what each group accomplished along with their approach.

5. A spreadsheet template was provided to facilitate recording all pertinent information for each section of the chain, including CLs, ecological production function and FEGS information (Table 2). Each group was asked to record a qualitative assessment of known evidence supporting each link of the chain.

6. A Strength of Science (SOS) score was used to track the type of evidence linking changes in air quality to changes in the biological indicator (SOS – CL) and the evidence supporting each cause-effect relationship along ecological production function (SOS – Effect). SOS Scores are qualitative with values of High (multiple, strong, consistent lines of published scientific evidence), Medium (limited scientific evidence, or inconsistent/conflicting evidence in multiple lines), and Low (expert opinion but no published scientific evidence or site specific data with unknown transferability to other sites).

7. The final step in the Workshop Process was to have participants select a subset of key chains for each biological indicator and tell a story linking the effects of exceeding CLs to FEGS. Examples are presented in the conclusion of the report (Boxes 1-4).

If the groups had time, they were asked to discuss and identify metrics that could be used to characterize the change in ecosystem services that occurs when critical loads are exceeded. Metrics might include: (1) ways to express or quantify the effects of incremental changes in deposition on critical load exceedance (considering magnitude and extent), ecological condition, and the associated ecosystem service; and (2) consideration of how to account for the extent to which deposition vs. other stressors affect the ecological condition (e.g. the effect of N on diatoms can result in algal blooms in lakes, but so can excess phosphorus, increases in temperature, decreases in precipitation, etc.). While discussion in some of the groups touched on these topics, there was not sufficient time during the workshop to develop a comprehensive assessment of these types of metrics.

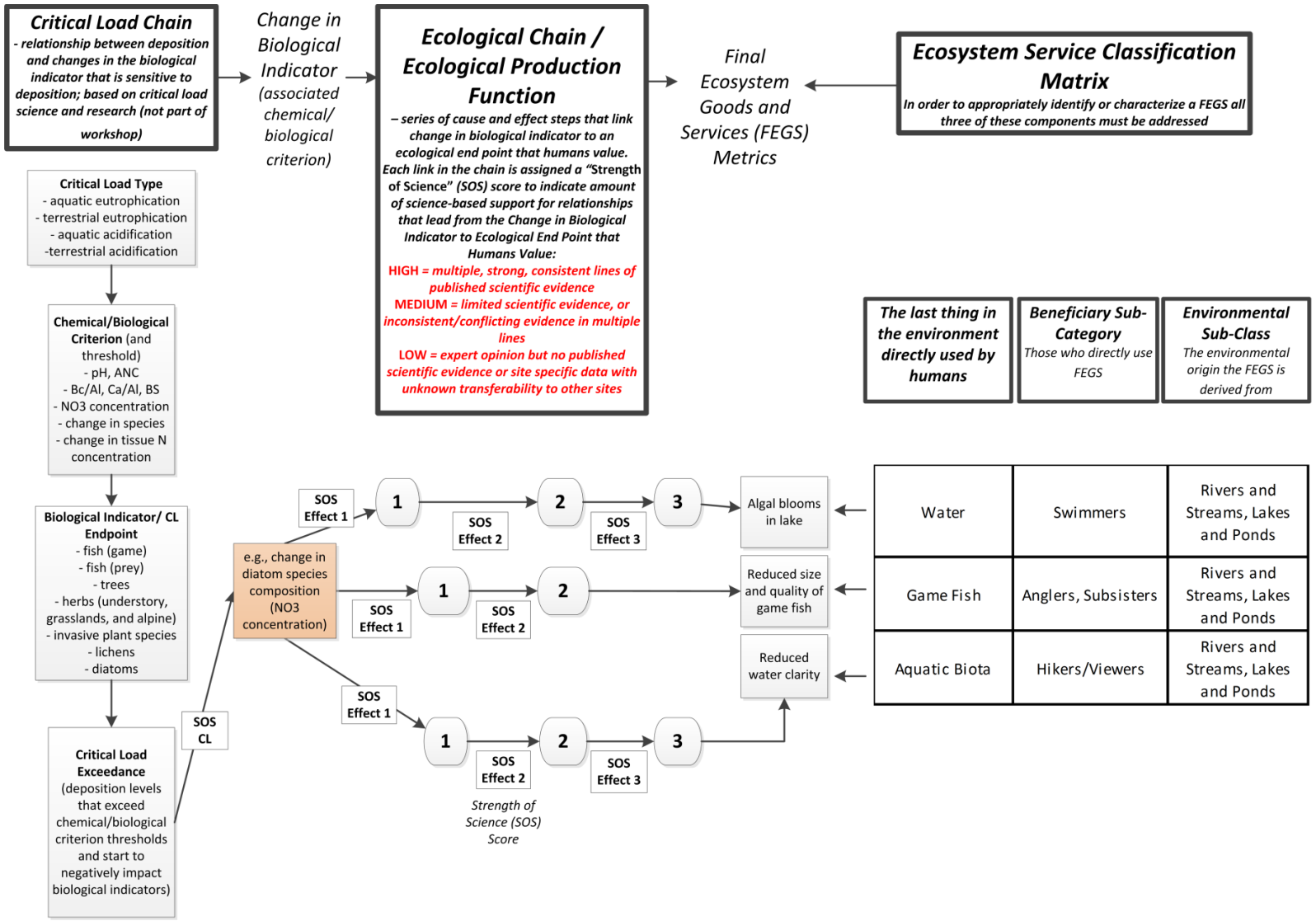

Figure 9. Diagram showing links between CL, ecological chains or production functions and FEGS. This handout was provided to workshop participants to help them conceptualize how critical loads and ecosystem services might be linked.

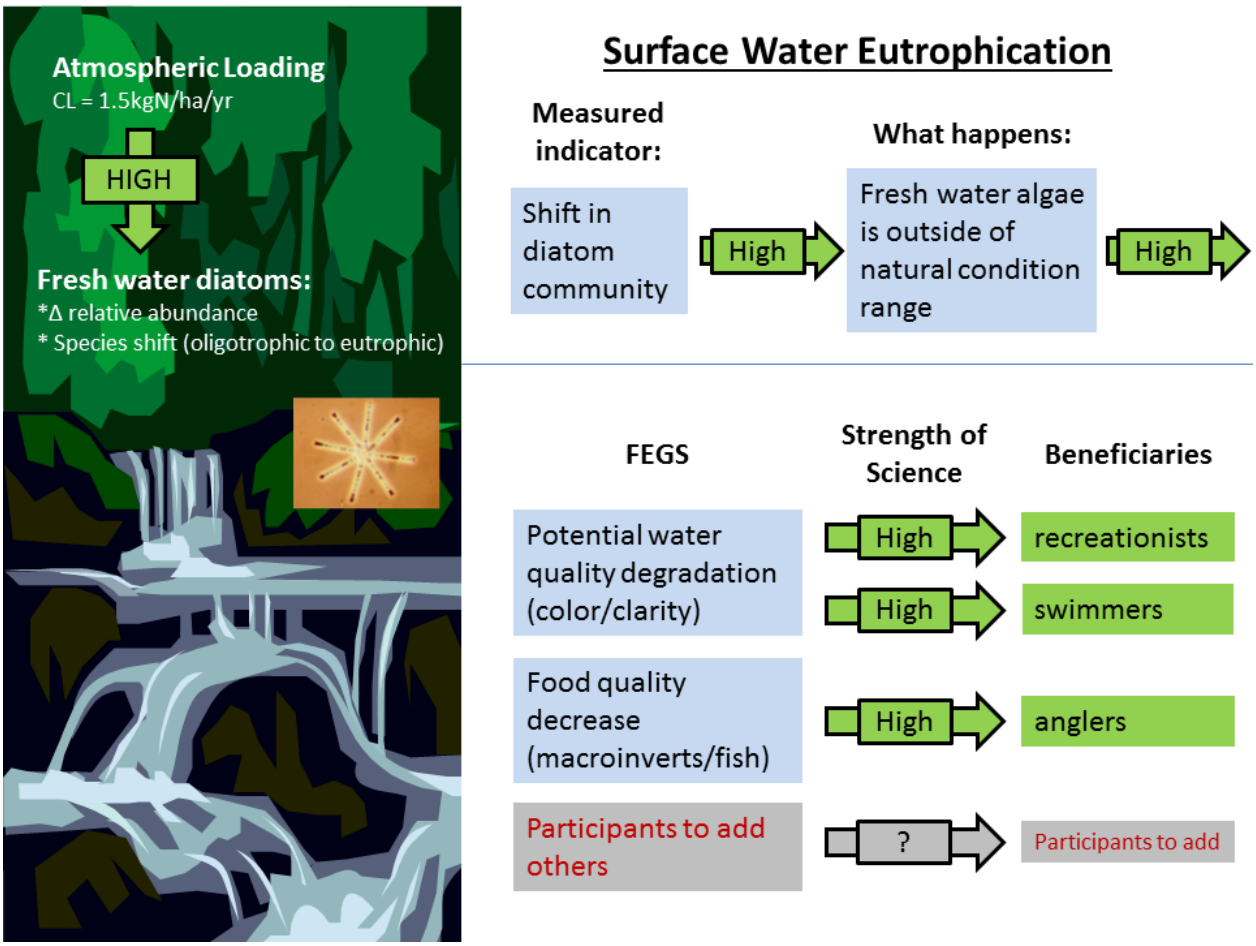

Figure 10. Example of one possible pathway or ecological chain for changes in diatoms, a biological indicator of aquatic eutrophication. The final link of the EPF was linked to a FEGS metric which was identified as the final ecosystem product used by humans. This handout was provided to workshop participants to help them envision the potential components of a “chain” linking biological indicators to beneficiaries.

Ecological Effects:

- Aquatic Acidification
- Aquatic Eutrophication
- Terrestrial Acidification
- Terrestrial Eutrophication

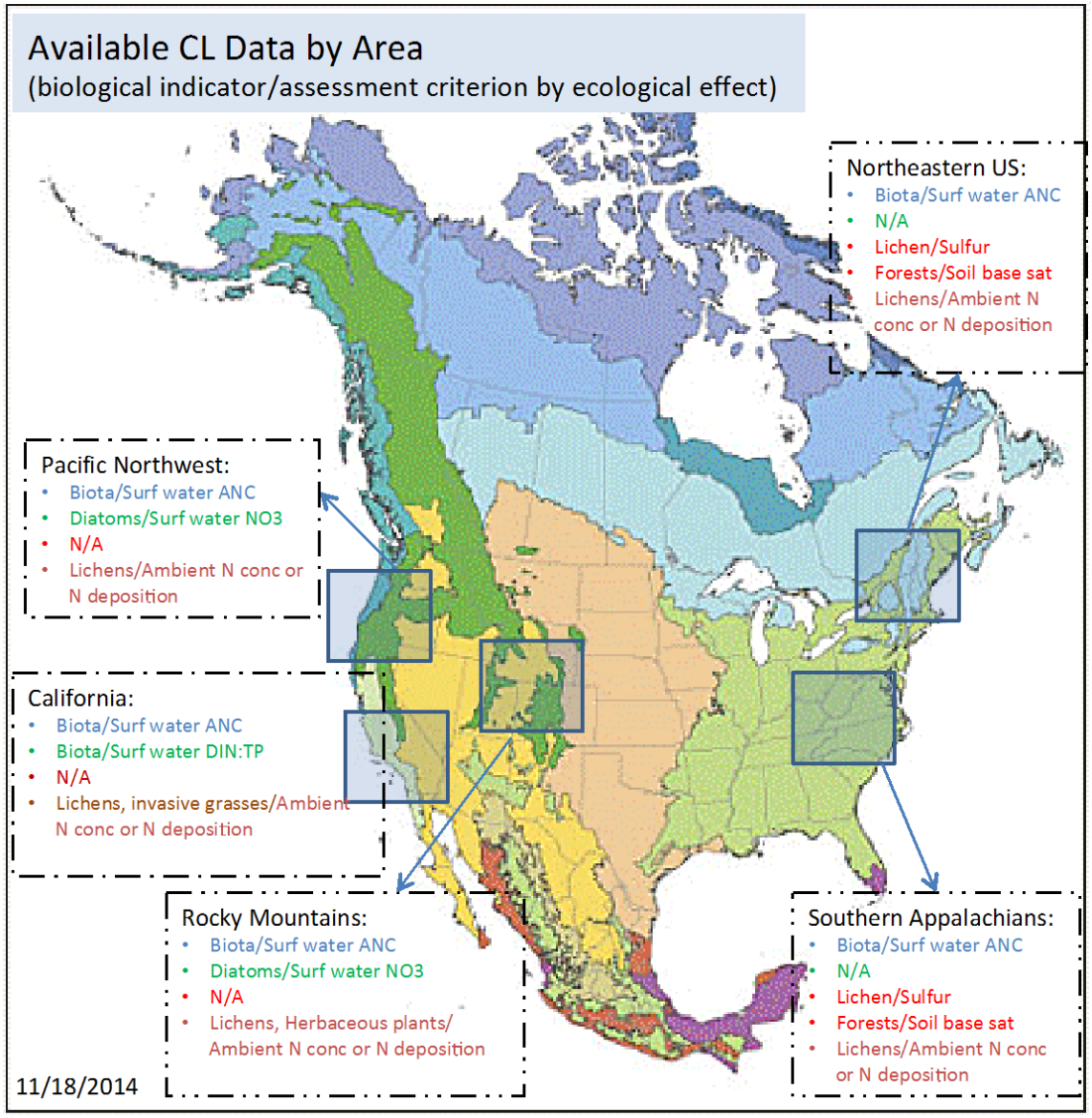

Figure 11. Map showing suites of critical loads and related information considered most reliable for each of five regions of the US. N/A indicates the information is not available for that region.

Table 2. Example of the template that was provided to each workgroup for recording the "chains" of information they generated.

Critical Loads Information							Ecological Production Function Information							FEGS-CS Information						Day 3
Ecological Effect	**Chemical/ Biological Criterion**	**Chemical/ Biological Criterion Threshold (and location if known)**	**Biological Indicator/ CL Endpoint**	**Change in Biological Indicator / CL End point**	**Critical Load in kg/ha (and location/region if known)**	**SOS - CL**	**Effect #1**	**SOS - Effect #1**	**Effect #2**	**SOS – Effect #2**	**Effect #3**	**SOS - Effect #3**	**SOR - EPF**	**FEGS Metric**	**Last Thing in Env. Directly Used by Humans**	**Beneficiary sub category (direct FEGS user)**	**Environ. Sub-Class**	**Regional restriction of FEGS?**	**Metric Measurement options**	**FESGS - SOS score - direct link between air quality and measured metric(s)?**
Aquatic Eutrophication	water NO3 concentration	1.0 mg/L NO3	diatom	change in species composition		High							High	Change in biodiversity or natural presence in the env. of diatom spp.	Aquatic biota / Water	Experiencers and Viewers / Spiritual and Ceremonial / People Who Care	Lakes	no	diatom sp. biodiversity-	High
"	"	"	"	"		"	Macro-invertebrate spp. shifts from change in food quality	Low	Fish condition / size of game fish shifts from change in food quality	Low			Low	Reduced size of game fish	Game fish	Anglers	Lakes	no	Fish surveys - measure size of game fish, diatom species, surface water nitrate, N deposition.	Low
"	"	"	"	"		"	"	"	Fish species diversity shifts from change in food quality	Low			Low	Reduced avail. of desired spp. of game fish	Game fish	Anglers	Lakes	no	Fish surveys - Biodiversity - electroshocking?	Low
"	"	"	"	"		"	"	"	Fish species diversity shifts from change in food quality	Low			Low	Change in biodiversity of fish spp.	Fish	Experiencers and Viewers / Spiritual and Ceremonial / People Who Care	Lakes	no	Fish sp. Biodiversity	Low
"	"	"	"	"		"	"	"	Condition / diversity of fish as prey shifts from change in food quality	Low	Piscivore birds decline	Low	Low	Bird health / numbers declines	Bird	Experiencers and Viewers (Birdwatchers)	Lakes	no	Bird health measures	Low

Table 3. Modified FEGS-CS matrix used for the workshop.

Beneficiary Categories and Sub-Categories	FINAL ECOSYSTEM GOODS AND SERVICE (FEGS) IDENTIFIED FOR EACH ENVIRONMENTAL SUB-CLASS							
	Rivers and Streams	Wetlands	Lakes and Ponds	Forests	Grasslands	Scrubland/ Shrubland	Tundra	Ice and Snow
Agriculture								
Aquaculturists	presence of the environment, water	presence of the environment, water	presence of the environment, water					
Livestock Grazers	water, flora		water	water, flora, open space	flora, open space	flora, open space		
Foresters				soil, open space				
Commerical/Industrial								
Food Extractors	flora, fauna	flora, fauna	flora, fauna	flora, fauna, fungi	flora, fauna, fungi	flora	flora, fauna	
Timber, Fiber, Ornamental Extractors	fiber, natural materials	timber, fiber, natural materials	natural materials	fiber, natural materials, timber	fiber, natural materials	timber, fiber, natural materials	fiber, natural materials	
Resource Dependent Businesses	presence of the environment							
Pharmaceutical and Food Supplement Suppliers	flora, fauna	flora, fauna	flora, fauna	flora, fauna, fungi	flora, fauna, fungi	flora		
Subsistence								
Water Subsisters	water		water					water
Food Subsisters	flora, fauna	flora, fauna	flora, fauna	flora, fauna, fungi	flora, fauna, fungi	flora, fauna	flora, fauna	fauna
Timber, Fiber, and Fur/Hide Subsisters	fiber, fauna	timber, fiber, natural materials	fiber, fauna	timber, fiber, fauna	timber, fiber, fauna	timber, fiber, fauna	timber, fiber, fauna	fauna
Recreational								
Experiencers and Viewers	presence of the environment, viewscapes, flora, fauna, sounds and scents	presence of the environment, viewscapes, flora, fauna, sounds and scents	presence of the environment, viewscapes, flora, fauna, sounds and scents	presence of the environment, viewscapes, flora, fauna, fungi, sounds and scents	presence of the environment, viewscapes, flora, fauna, fungi, sounds and scents	presence of the environment, viewscapes, flora, fauna, fungi, sounds and scents	presence of the environment, viewscapes, flora, fauna, sounds and scents	presence of the environment, viewscapes, fauna, sounds and scents
Food Pickers and Gatherers	flora, fauna	flora, fauna	flora, fauna	flora, fauna, fungi	flora, fauna, fungi	flora, fauna	flora	
Hunters	fauna	fauna	fauna	fauna	fauna	fauna	fauna	fauna
Anglers	fish	fish	fish					
Waders, Swimmers, and Divers	presence of the environment	presence of the environment	presence of the environment					
Boaters	presence of the environment, water	presence of the environment, water	presence of the environment, water					
Inspirational								
Spritual and Ceremonial Participants and Participants of Celebration	presence of the environment							
Aritsts	presence of the environment, viewscapes, sounds and scents, natural materials	presence of the environment, viewscapes, sounds and scents, natural materials	presence of the environment, viewscapes, sounds and scents, natural materials	presence of the environment, viewscapes, sounds and scents, natural materials	presence of the environment, viewscapes, sounds and scents, natural materials	presence of the environment, viewscapes, sounds and scents, natural materials	presence of the environment, viewscapes, sounds and scents, natural materials	presence of the environment, viewscapes, sounds and scents, natural materials
Learning								
Eduators and Students	presence of the environment							
Researchers	presence of the environment							
Non-Use								
People Who Care (Existence)	presence of the environment							
People Who Care (Option/Bequest)	presence of the environment							

Workshop Rules

Given participants had not previously worked closely together, this workshop followed the below "rules."

Do:

- Feel empowered to (slightly!) modify the process if it is not working (but check with workshop leaders first since we want consistency in output between groups). For example, drawing a diagram before filling out the spreadsheet might be helpful.
- Keep good notes!
- Use "Bin" flip chart pages if needed to track important things outside of our immediate scope here (e.g., communication needs, data gaps, future challenges).
- Translate science jargon and acronyms into plain language to communicate in terms that the public will understand.
- Include everyone and ask for input from all group members.
- Keep it light, have fun.

Do not:

- Get stuck in long discussions about ecological processes.
- Mistake "intermediate" ecosystem services for "final" ecosystem services.
- Make a laundry list of all the ways that air pollution impacts ecosystems (stick to those for which we have CLs, at least regionally).

Workshop Pre-planning

Workshop organizers developed a steering committee about nine months in advance; this group met approximately monthly. The steering committee planned workshop logistics, tested ideas on group members outside our own disciplines to determine how best to present unfamiliar content (e.g., ecological information to economists and vice versa), and developed and refined process diagrams and spreadsheets from which the small groups would conduct their work during the meeting. Background information was also provided as "pre-work" for the participants to familiarize themselves with material before they arrived.

Securing a workshop sponsor to provide travel funding and on-site meals was imperative, and this was provided by a Research Coordination Network (RCN) grant of the National Foundation (award DEB-1049744) to the University of Maryland Center for Environmental Science. This RCN project on reactive nitrogen in the environment is a project of the International Nitrogen Initiative.

A site sponsor was also critical to the success of this meeting; meeting rooms, supplies, transportation, field trip planning and interpretation were provided by staff at the Santa Monica Mountains National Recreation Area. We carefully selected participants based on their subject matter expertise needed to fill a specific role at the meeting and demonstrated success in team-based meetings. We also strove for a balance of early career, mid-career, and late career scientists as participants (Appendix A).

RESULTS

Spreadsheet Description

Each of the four breakout groups developed spreadsheets describing the categories linking ecological effects of air pollution on specific biological indicators to final ecosystem goods and services. Each spreadsheet contains three sections: critical loads information, ecological production function (EPF) information, and Final Ecosystem Goods and Services (FEGS) information (Table 4). An example entry from each group is provided in Tables 7-9. The information in the three tables are connected across rows but are presented as three separate tables to increase readability.

Table 4. Framework of how examples of the spreadsheet are represented in Tables 7-9. To increase readability, columns from the tables were split into three sections, but should be read across tables. Colors in the table match the box diagrams in group write ups

Critical Loads Information	Ecological Production Function Information	FEGS Information
Table 7	Table 8	Table 9

- *Critical Loads Information* included categories for ecological effects, chemical/biological criterion, chemical and biological criterion threshold, biological indicator/critical loads endpoint, change in biological indicator, critical load (kg/ha/yr), and strength of the science for developing the critical load. Each group entered their critical load information slightly differently. An example of how this data was entered into the matrix is in Table 7.
- *Ecological Production Function Information* included a description of up to four effect links and the strength of science between each link. These were entered into the matrix as seen in Table 8. A FEGS metric was identified for each end member of the ecological production function. If the EPF was fewer than four steps, the remaining cells were left empty and the FEGS metric was associated with the final effect. This is represented by the arrows in the spreadsheet tables below.
- *FEGS Information* included categories for: FEGS metric (the last thing in the environment directly used by humans), direct FEGS user, beneficiary category, environment sub-class, regional restriction of FEGS, metric measurement, and FEGS strength of science score. An example of this information is represented in Table 9. See the list of definitions in Appendix C for further explanations of terms.
- *Strength of Science Scores* were developed for each Critical Load (SOS – CL) and each effect in the EPF (SOS – Effect). These scores allow us to identify the strength of each chain and identify knowledge gaps.

Critical Load Bioindicators

Each group pooled their knowledge to identify measureable bioindicators that responded to nitrogen and sulfur deposition. Each bioindicator was linked to either a critical load of nitrogen deposition or a chemical criterion (e.g., ANC) that is influenced by deposition. All critical load values are backed by scientific literature. Some groups only addressed a handful of biological indicators and fully fleshed out all the pathways that could be associated with an indicator. Others identified a variety of different

indicators and pathways and made note that each of the pathways could represent a larger set of species specific chains.

Chains

Overall, 1045 unique chains were identified linking an ecosystem response to air quality to a beneficiary type (Table 5). Each chain was entered into the matrix as an individual line to allow for sorting and counting. The aquatic eutrophication group had the most chains, 637, because most chains in this group were counted four times in different environmental sub-classes (wetland, rivers and streams, estuaries, and lakes). The terrestrial eutrophication group developed 213 chains, the terrestrial acidification group developed 130 chains, and the aquatic acidification group developed 66 chains. There was considerable discrepancy in the number of chains developed depending on whether the group decided to do separate chains for individual species and environments.

Although the goals and outcomes were similar between groups, the process adopted by each group was unique. Each group had their own criteria for including chains in their table, but since time was limited, some groups did not fully explore all of the links that could have been made with beneficiaries. Therefore, the total number of links is towards the lower end of what is possible if every theoretical chain was more fully explored. The total number of chains does not represent the relative importance of each ecological response to air quality, but instead is a product of the methods used by each group. The methods each group took are further explored in their individual sections below.

Table 5. Total number of CL Bioindicators, FEGS Metrics, Beneficiary groups, and chains identified by each working group.

Group	CL Bioindicators	FEGS Metrics	Beneficiaries	Chains
Terrestrial Eutrophication	10	37	15	213
Terrestrial Acidification	2	12	9	130
Aquatic Eutrophication	1	9	19	637
Aquatic Acidification	7	8	16	66

Examples of chains from each group are presented in Tables 7-9. A complete set of all of the spreadsheets developed within each group at the workshop will be available via a web link at the NPS- Integration of Resource Management Applications (IRMA) site as a companion product to this workshop report.[16]

Final Ecosystem Goods and Services

There were 66 unique FEGS identified as end products of the ecological production functions. These FEGS generally fell into one of four classes (Table 6). During the chain building process, each group used slightly different terminology when identifying their FEGS which lead to similar metric being described in different ways (e.g., abundance of desirable wildlife, abundance of hunted mammals, deer abundance). Instead of categorizing the FEGS Metrics into bins, we have left them as described to capture the variety and scientific certainty that the groups intended. In the future, these values may be categorized to improve analyses. Each metric was also associated with the last thing in the

[16]https://irma.nps.gov/App/Reference/Profile/2225739

environment used by humans, so that specific chains can be extracted from the spreadsheet if the user is only concerned with a particular resource (e.g., forests).

Table 6. How to measure different classes of FEGS

Interaction type	FEGS type	Measurement
Non-use	Existence – General (Stewardship)	Change relative to reference
Non-use	Existence – Specific (T&E / Species of Concern)	Presence/Absence; extinction risk
Use	Passive Enjoyment (Aesthetics)	Abundance; variety
Use	Resource Harvesting / Consumption	Abundance

Beneficiaries

In total, the groups identified 26 separate beneficiaries to the FEGS modified by air pollution. In addition to the original 22 beneficiary subcategories, the groups also added All Humans, Land Managers, Traditional Medicine, and Water Treatment Plant Operator. All Humans was meant to encompass the impacts that the ecosystem has on global factors (e.g., C storage and clean air). All groups identified Land Managers as a category that interacted with resources in a different manner than a general user and had much broader interests. Traditional Medicine was separated from Pharmaceutical and Food Supplement Suppliers in order to highlight the link with certain cultures. Lastly, Water Treatment Plant Operator was separated from Resource Dependent Businesses, since it is a public utility and would operate under different regulations than a typical resource extraction business.

The most common beneficiary type was Experiencers and Viewers, which was associated with 120 different chains. The total number of chains ending in each beneficiary is displayed in Figure 12.

Table 7. Critical loads section of the spreadsheet. Selected biological indicators/critical load endpoints are shown here to illustrate the process. The ecological production functions stemming from the changes in biological criterion are reported in Table 8.

Ecological Effect	Chemical/ Biological Criterion	Chemical and Biological Criterion threshold (and location if known)	Biological Indicator/ CL Endpoint	Change in Biological Indicator / CL End point	Change in Biological Indicator / CL End point (kg/ha/yr)	SOS - CL
Terrestrial Eutrophication	Coastal Sage Scrub	Western US	Invasive Grass Cover	Increase grass to forb ratio and increase in total biomass	11	High
Terrestrial Eutrophication	Sagebrush-Steppe	Arid Northwest	Invasive Grass Cover	Increase in grass to forb ratio	11	Low
Terrestrial Eutrophication	Serpentine grasslands	West	Invasive Grass Cover	Increase in grass to forb ratio	11	High
Terrestrial Eutrophication	Hardwood, Coniferous Forests	West	Forest Productivity	Increase in Ponderosa Pine mortality	1-21	High
Aquatic Eutrophication	water NO_3 concentration	1.0 mg/L NO_3	Diatom	change in species composition	1.5	High
Aquatic Eutrophication	water NO_3 concentration	1.0 mg/L NO_3	Diatom	change in species composition	1.5	High
Aquatic Eutrophication	water NO_3 concentration	1.0 mg/L NO_3	Diatom	change in species composition	1.5	High
Terrestrial Acidification	Base Cation/Al ratio	10	Balsam Fir	Reduced regeneration		High
Terrestrial Acidification	Base Cation/Al ratio	10	Balsam Fir	Reduced regeneration		High
Terrestrial Acidification	Base Cation/Al ratio	10	White Ash	Increased mortality		High
Aquatic Acidification	Acid Neutralizing Capacity	ANC of 50	Brook Trout	Change in the probability of brook trout presence/absence, abundance, and size		High
Aquatic Acidification	Acid Neutralizing Capacity	ANC of 50	Macrophytes	Macrophytes		High
Aquatic Acidification	Acid Neutralizing Capacity	ANC of 50	Mollusks	Freshwater Mollusks		High
Aquatic Acidification	Acid Neutralizing Capacity	ANC of 50	Otters and Minks	Otters and Minks		High

Ecological Production Function

Table 8. Ecological production function section of the spreadsheet. Selected chains are shown here to illustrate the process. The FEGS Metrics and Beneficiaries associated with each ecological production function are reported in Table 9.

Critical Load Information							FEGS Classification
Effect #1	**SOS - Effect #1**	**Effect #2**	**SOS - Effect #2**	**Effect #3**	**SOS - Effect #3**	**SOR - EPF**	
Increased Fuel Load (invasive grass biomass)	High	Increased Fire Frequency	High				
Decreased forage quality	High	Shift in wildlife composition	Low				
Decreased Bay Checkerspot Butterfly Abundance	High						
Decrease in habitat quality	High						
Algal abundance	Not reported	Food chain effects	Not reported				
Algal abundance	Not reported	Submerged Aquatic Vegetation	Not reported	Fauna	Not reported		
Food web effects	Not reported	Small fish/ macroinvertebrates	Not reported				
Reduced habitat for snowshoe hares	Medium						
Reduced habitat for ruffed and spruce grouse	Medium						
Decreased pH	High	Increased Al	High	Decrease Brook Trout because of mortality and decreased production	High		
Decreased pH	High	Changing abundance and species richness of macrophytes	Medium				
Inferred change in Ca from ANC	High	Affects shellfish shell formation	High	Decline and absence in shell fish	High		
Change in ANC	High	Decrease in fish abundance	High	Change in mammals	High		

Table 9. FEGS-CL section of the spreadsheet. Selected beneficiary endpoints are shown here to illustrate the process.

	FEGS Metric	Last Thing in Environment Directly Used by Humans	Beneficiary sub category (direct FEGS user)	Environment Sub-Class	Regional restriction of FEGS?	Metric Measurement Options
	Increased fire risk	Landscape	Residential Property Owners	Shrubland	West	
	Abundance of desirable wildlife	Wildlife	Hunters	Shrubland	West	
	Abundance of Bay Checkerspot butterfly	Bay Checkerspot Butterfly	People who care (Existence)	Grasslands	West	
		Landscape	Experiencers and Viewers	Forest	East	
	Change in favored species composition	Fauna affected by algal bloom	Anglers	Lakes	No	
	Change in favored species composition	Fauna affected by change Submerged Aquatic Vegetation	Food Subsisters	Rivers & Streams	No	
	Large fish & large invertebrates	Large fish & large invertebrates	Food Extractors	Rivers & Streams	No	
	Reduced snowshoe hare	Mammal	Experiencers and Viewers	Forest	Balsam Fir Distribution	
	Reduced bird abundance (certain species)	Bird	Experiencers and Viewers	Forest	Balsam Fir Distribution	
	Reduced Timber, fiber [baseball bats, guitars, fine tools, cabinets]	White Ash	Timber, Fiber, Ornamental Extractors	Forest	White Ash Distribution	
Ecological Production Function	Probability of Brook Trout Presence, Loss of age class	Brook Trout	Resource Dependent Businesses	Lakes & Ponds, Rivers & Streams	Restricted to Brook Trout ranges	Indirect-ANC; Direct- presence / absence, abundance, size
	Change in aquatic macrophyte diversity	Aquatic vegetation diversity	Educators and Students	Lakes & Ponds, Rivers & Streams	May not apply to high elevation systems where macrophages are not present	Water ANC
	Probability of Shellfish Presence and Abundance	Freshwater shellfish	Land Managers	Lakes & Ponds, Rivers & Streams		Water ANC
	Mammals	Otters and Minks	Spiritual and Ceremonial Participants and Participants of Celebration	Lakes & Ponds, Rivers & Streams		Water ANC

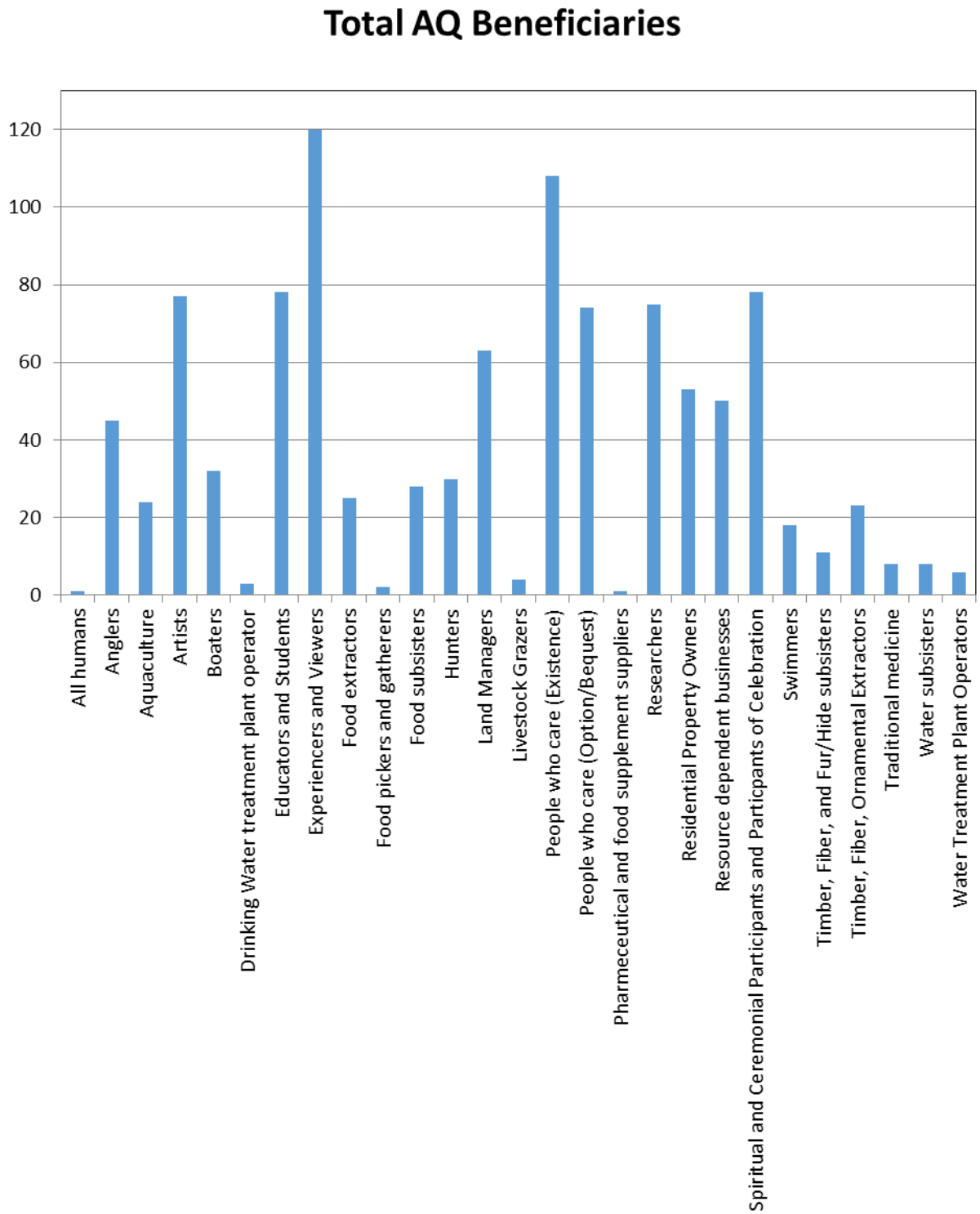

Figure 12. Total number of chains, identified by all groups that link air quality impacts in terrestrial or aquatic ecosystems to beneficiaries.

Workgroup #1: Terrestrial Eutrophication

Chris Clark (Facilitator), Mike Bell (Rapporteur), Eric Davidson, Christine Davis, Laurence Jones, Mark Fenn, Linda Geiser, Jim Boyd, Jana Compton.

Process

In the terrestrial eutrophication section, we began by listing numerous specific responses to nitrogen eutrophication on terrestrial ecosystems. This was essentially a brainstorming session of all the expertise in the group to compile a comprehensive set of eutrophication responses. We then recognized that several responses were variants of one another and/or could be combined into broader categories of response. For example, the specific responses "loss of native herbaceous plant species," and "increase in grass abundance," are both different forms of the category of responses named "change in herbaceous community composition." Another example, instead of focusing on individual tree responses within a forest, we combined all potential responses into "Tree species responses," that were not listed specifically except in the case of particular chains we wanted to highlight. Critical loads are usually but not always defined at the biological response level rather than the category, but the category is a useful construct for organizing in this context.

Following this brainstorming and categorization, we generated 12 categories of effect, seven of which had published critical loads. Of those with published critical loads, we then created chains of subsequent responses linking the initial response to nitrogen (N) to a Final Ecosystem Goods and Service (FEGS). We then linked beneficiaries to each FEGS within the spreadsheet.

As we studied the links in our chains we realized that within each category the critical loads needed to be differentiated by region. For example, "changes in community composition" in the southwest corresponds to increases in grass and subsequently fire risk, which has a very different set of FEGS compared with the East, where reductions in forbs and changes in plant species with ectomycorrhizal symbiont, are the associated changes in community composition. Thus, we separated our regions into the Western and Eastern US. Furthermore, we determined that it was not appropriate to use a critical load for lichen biodiversity loss developed in a mesic environment for lichen biodiversity in a dry environment, as environmental and physical characteristics of a region greatly influence the critical load, thus we broke our regions down as ecosystems. The East was divided into two ecosystems (Deciduous Forest and Evergreen Forest), and the West into seven ecosystems (Coastal Sage Scrub, Desert, Southwest Evergreen Forest, Northwest Evergreen Forest, Grassland, Sagebrush Steppe, and Serpentine Grassland).

Within each ecosystem we developed a series of chains that began at a common critical load, which we labeled 'fans'. Our fan diagrams highlighted the complex interactions within a system based on the initial biological response to exceeding a critical load. We tried to separate out responses by critical load values so that in the future this could be used to identify how many FEGS are affected by surpassing a new load level per region. Each chain represented a direct relationship between critical load exceedance and FEGS metric.

Challenges

We had many discussions on how to incorporate the "biodiversity effect" from deposition as well as how to quantify the "People Who Care" beneficiary. The biodiversity effect represents several concepts. It includes the idea that if one species is lost, even if it does not have a cascading effect, it should still be counted as a significant loss. The biodiversity effect also includes the concept that a diverse assemblage of interacting species is important in and of itself, in addition to the constituent species that make up the assemblage, and separate from the known services that are derived for human benefit.

The problem we identified with the "People Who Care" beneficiary group is that technically different people/organizations can care strongly about specific species that occur before the final link of the chain. This was covered in the introduction about double counting, but most of our resources were non-consumptive use. For example, to refrain from of overproducing chains, we could have linked an increase in invasive grasses to (1) Decrease in insects (2) Decrease in wildflowers (3) Decrease in small mammals (4) Decrease in large mammals, but for the most part we just wrote "Change in vegetation community relative to reference" (or something similar) and avoided breaking out each of the chains individually. We generally chose to only follow the path that had an endpoint with the highest number of beneficiaries.

The other issue we encountered was how to incorporate changes in biogeochemical cycling and the formation of greenhouse gases (GHG) as products of increased deposition. Many of the processes identified would lead to an increase in N_2O, CH_4, or CO_2 released from the system. This could have broad impacts, but because a critical load for these effects is not defined, they were beyond the scope of the analyses but were highlighted for future study. We also note that GHG emissions, by themselves, are difficult to tie to beneficiary-specific welfare. Instead, GHG emissions are an intermediate biophysical outcome that has a variety of subsequent, more "final" biophysical consequences, such as changes in species abundance and distribution, flood risks, etc. So even if changed GHG emissions could be quantified it would still be necessary to translate those changes into subsequent biophysical outcomes.

Chains

In total we identified 213 chains linked to 37 FEGS that affect 15 different beneficiaries (Figure 18). The eastern ecosystems had a heavy focus on general forest tree species. Researchers Kevin Horn and Quinn Thomas are currently completing a CL analysis on 114 tree species to assign critical loads at the species level for changes in growth and mortality[17]. Due to the incomplete analysis, effects of tree species were lumped into a general category and the total number of chains for that region were significantly reduced. The west on the other hand had 7 developed ecosystems that produced the majority of the chains. Below we discuss the links between exceeding a critical load and the impact on beneficiaries within 3 of the 9 ecosystems. We present both the fan diagrams and a single chain, to highlight both broad and simple relationships, so that eutrophication can be related to the maximum number of beneficiaries.

[17] Horn, K.J. et al, in review

Type Conversion of Coastal Sage Scrub Habitat

We used coastal sage scrub (CSS) to represent shrubland communities in the southwest US that are water limited and generally influenced by high levels of dry deposition. Within CSS communities the increase in invasive grass cover (CL=11 kg/ha/yr) can lead to an increase in fire frequency due to highly flammable exotic grasses outcompeting perennial vegetation after the initial burn (Figure 13). Frequent fires can burn through the areas as exotic grass biomass accumulates causing type conversion of CSS habitat to invaded grassland (Figure 14). As exotic grass cover and N deposition increase, the mycorrhizal community also shifts (CL=7.8 to 9.2 kg/ha/yr), leading to an enhanced competitive edge for grass species. The type conversion process can be accelerated through an increase in herbivory as well as a loss of root biomass that are both associated with increased N deposition. This can make the perennial species more susceptible to summer drought, increase stand die off, and limit recovery post disturbance. These responses have been measured in the field, but the critical load is currently unknown (CL=X kg/ha/yr) The loss of perennial CSS vegetation not only reduces habitat for the endangered California gnatcatcher (as well as many other species) but also increases the fire risk to nearby infrastructure.

As an endangered species, the California gnatcatcher is highly valuable as an indicator species of ecosystem health for land managers as well as a highly desirable attraction for birders. The increased fire frequency can have a large negative effect on homeowners, not only increasing the risk of property damage, but also transforming the viewscapes from individual properties. Additionally, the loss of shrubs can increase the risk of mudslides due to a decrease in soil stability.

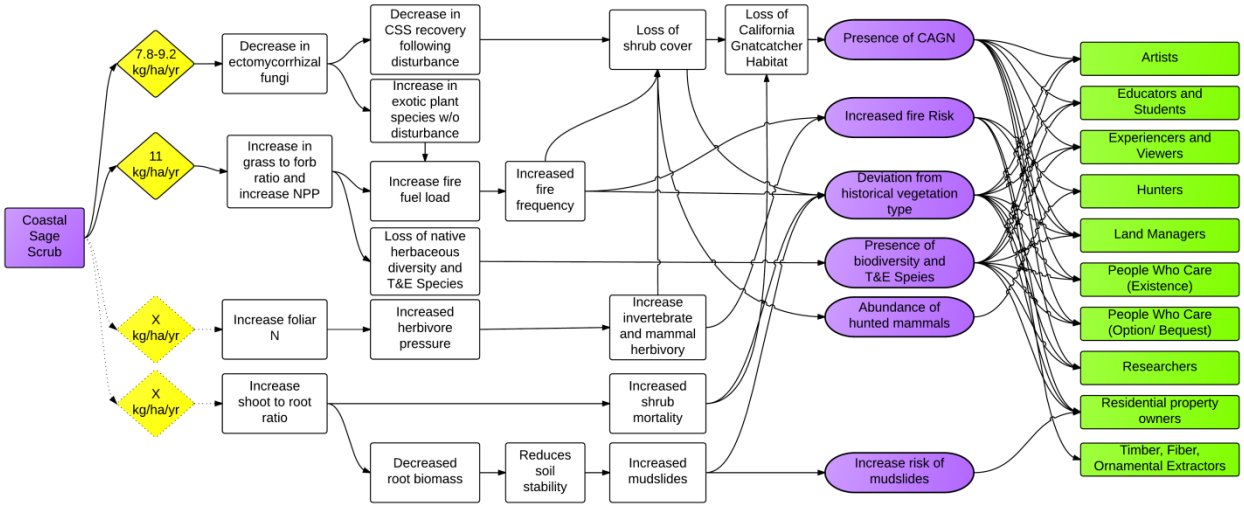

Figure 13. Fan diagram showing all identified chains for the coastal sage scrub ecosystem. Yellow diamonds show accepted critical load values for the biological indicator. Dotted lines represent currently undetermined critical loads.

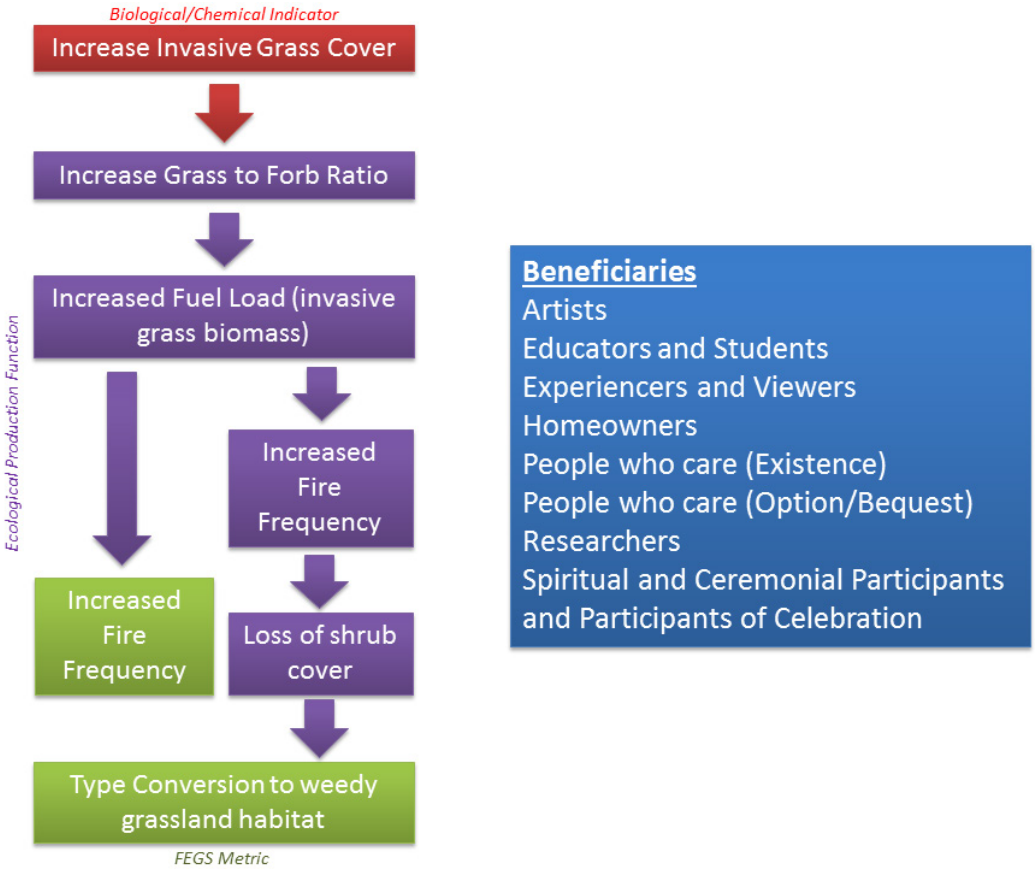

Figure 14. An increase in invasive grass biomass can lead to increased fire frequency which prevents recovery of natural habitat.

Specific Tree Responses in Forests

Eastern forest systems are under pressure from high amounts of N deposition. The forested area in the eastern US covers a large spatial range and contains a diverse assemblage of tree species that vary from north to south and east to west. These ecosystems have a history of resource extraction for either food or timber making them a valuable economic resource. As diversity is high, responses to N vary across the region both at the soil level and the tree species level (Figure 15).

At a tree species level, responses to N have been identified by using US Forest Service Forest Inventory Analysis data. Each species in this analysis has a different suite of resource extraction uses and species interactions, so we have included a generic chain with the link "Decrease in tree species A" pointing to another link "Decrease in tree species Z." This captures the preliminary results of the study indicating that there are a variety of trees that have a critical load between 1 and 21 kg/ha/yr (Figure 15). One species that has shown significant declines with increased deposition is the white pine (Figure 16). The loss of the pine from the forest decreases timber production and habitat for a diverse group of animals. The loss of faunal diversity and the presence of dead and dying trees decrease the aesthetic value of the ecosystem, affecting Homeowners and Experiences and Viewers alike, as well as increases the likelihood that management action will be needed by Land Managers and reduces scientific opportunity to Researchers.

One of the mechanisms for the loss of some tree species is hypothesized to be a change in the soil microbial community. There have been measured decreases in ectomycorrhizal fungi (CL=5 to 10 kg/ha/yr) which can lead to community shifts towards trees that utilize endomycorrhizal fungi. Alternatively, the increase in soil N can lead to an overall decrease in mycorrhizal associations which leads to a decrease in uptake of other nutrients and decreases forest growth and regeneration. The resulting increased bacteria to fungal ratio can decrease decomposition rates and alter carbon storage within the system. These changes have been measured in the forest, but there has yet to be a direct link to soil biochemistry and community shifts.

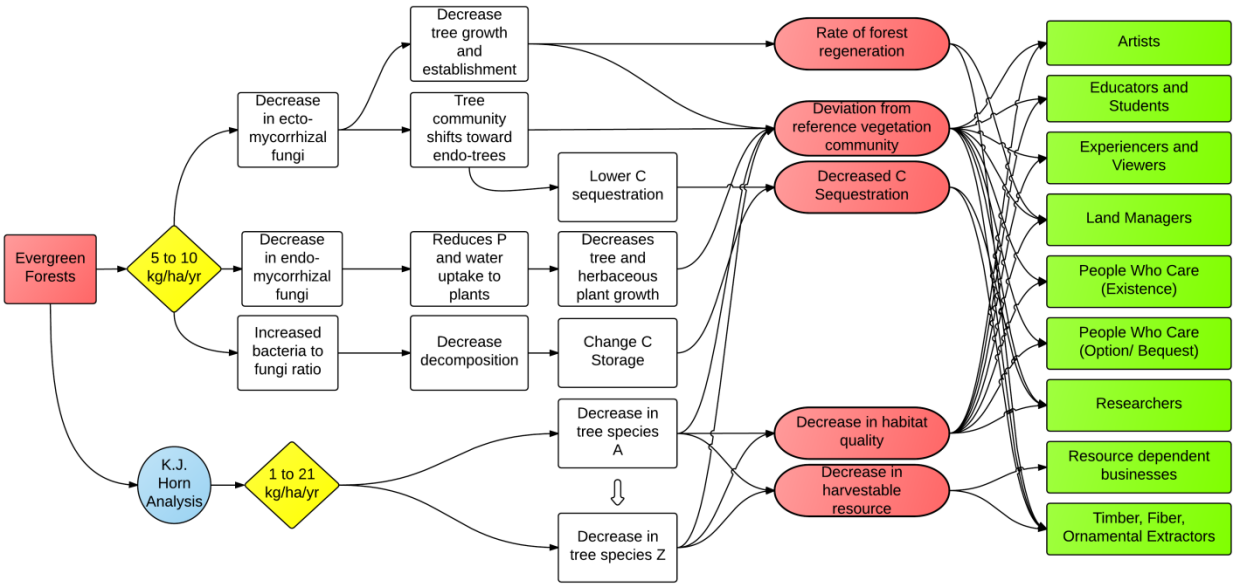

Figure 15. Fan diagram showing chains for the eastern forest region. Yellow diamonds are accepted critical load values for the biological indicator. The blue circle represents chains to be developed by ongoing analyses.

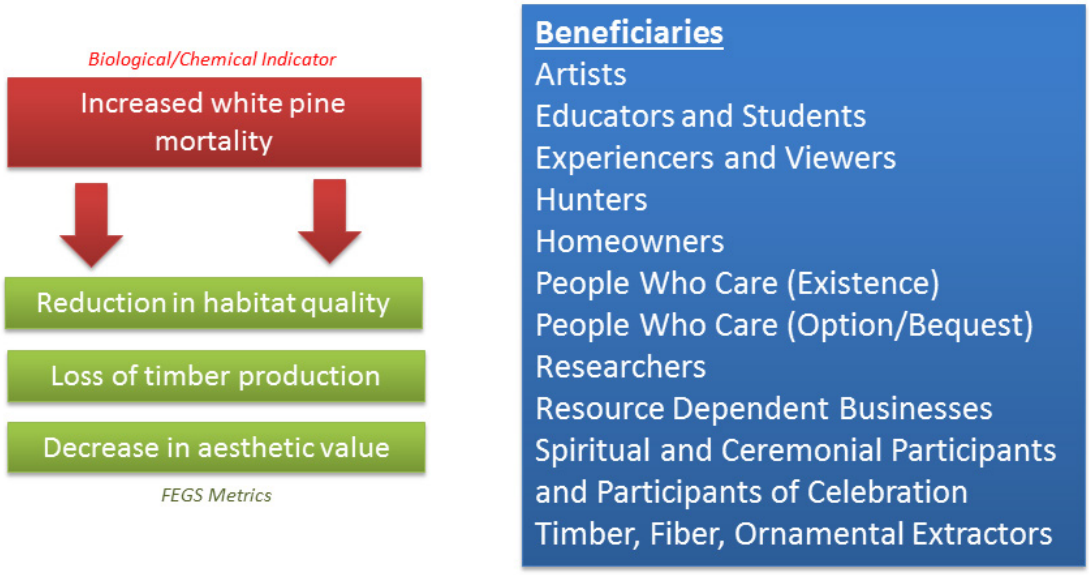

Figure 16. The loss of a single tree species can impact many FEGS.

Cascading Effects of Lichen Loss

Lichens have been identified as being highly responsive to increased atmospheric N and have been considered for use as a national indicator for N and S deposition effects. In high deposition areas in the eastern US and southwestern US most sensitive lichen species have already disappeared from the ecosystem. Within the Pacific Northwest, forest lichens are highly tied to ecosystem function and are at risk due to N deposition (CL=1.5 kg/ha/yr). This system has a very tightly knit ecosystem tying lichen communities to spotted owl populations, among other species, that affect a broad array of FEGS and beneficiaries (Figure 17). Lichens provides forage and nesting material for the insects and small mammals (including the flying squirrel) that are food sources for the spotted owl (Figure 18). Currently deposition levels have not surpassed the critical load for lichen community changes in spotted owl habitat, but identifying areas of concern will help us prevent future damage. Therefore it is essential to preserve the few remaining areas where sensitive lichen species still occur by maintaining low levels of N deposition and stemming significant ecosystem loss before it accelerates.

As an indicator species of old growth forests and a federally listed endangered species, the spotted owl is a highly recognizable species in the region and one that has long been associated with conservation in the Pacific Northwest. This makes the species linked to many beneficiaries as people are highly invested in its presence and survival. The small mammals that rely on lichens are also the primary distributors of hypogeus fungi, all of which form ectomycorrhizal relationships with trees that are essential to tree nutrition and drought tolerance. Thus, the loss of lichen species could potentially adversely affect the growth and production of timber species, leading to a decrease in harvestable wood.

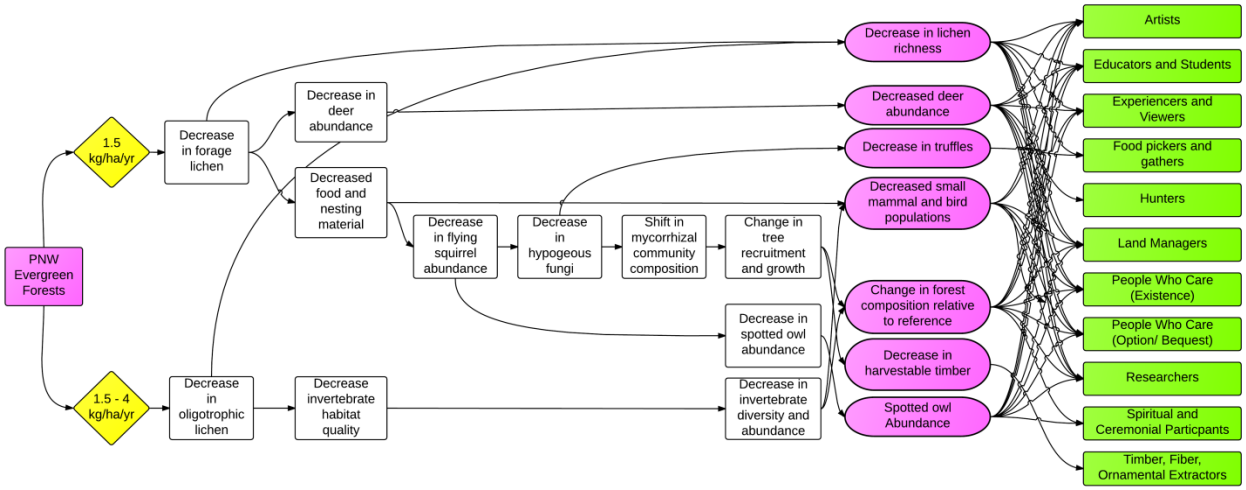

Figure 17. Fan diagram showing chains for the Pacific northwest region. Yellow diamonds are accepted critical load values for the biological indicator.

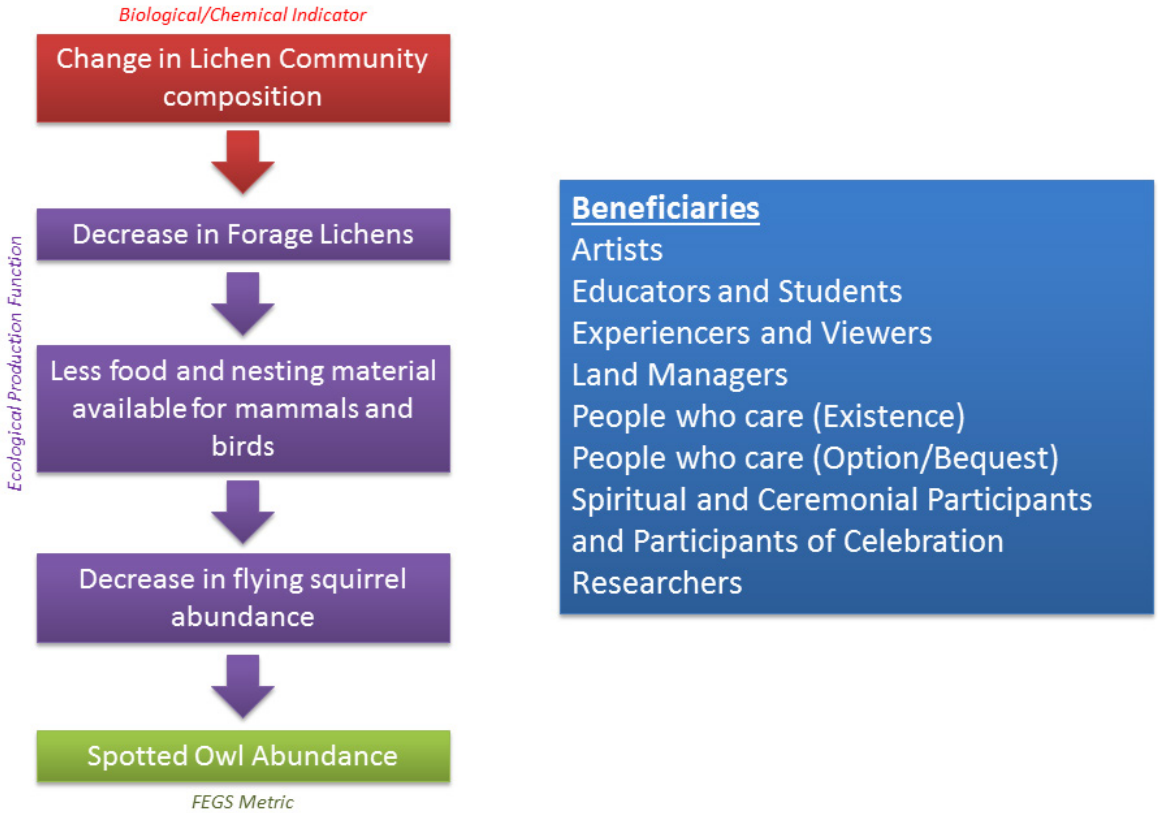

Figure 18. A single chain of responses demonstrates the near exclusive reliance of an endangered, top level predator, upon prey that in turn relies upon highly air-pollution sensitive lichens for winter forage. Thus small increases in nitrogen deposition can impact food web dynamics.

Full Chain Diagram

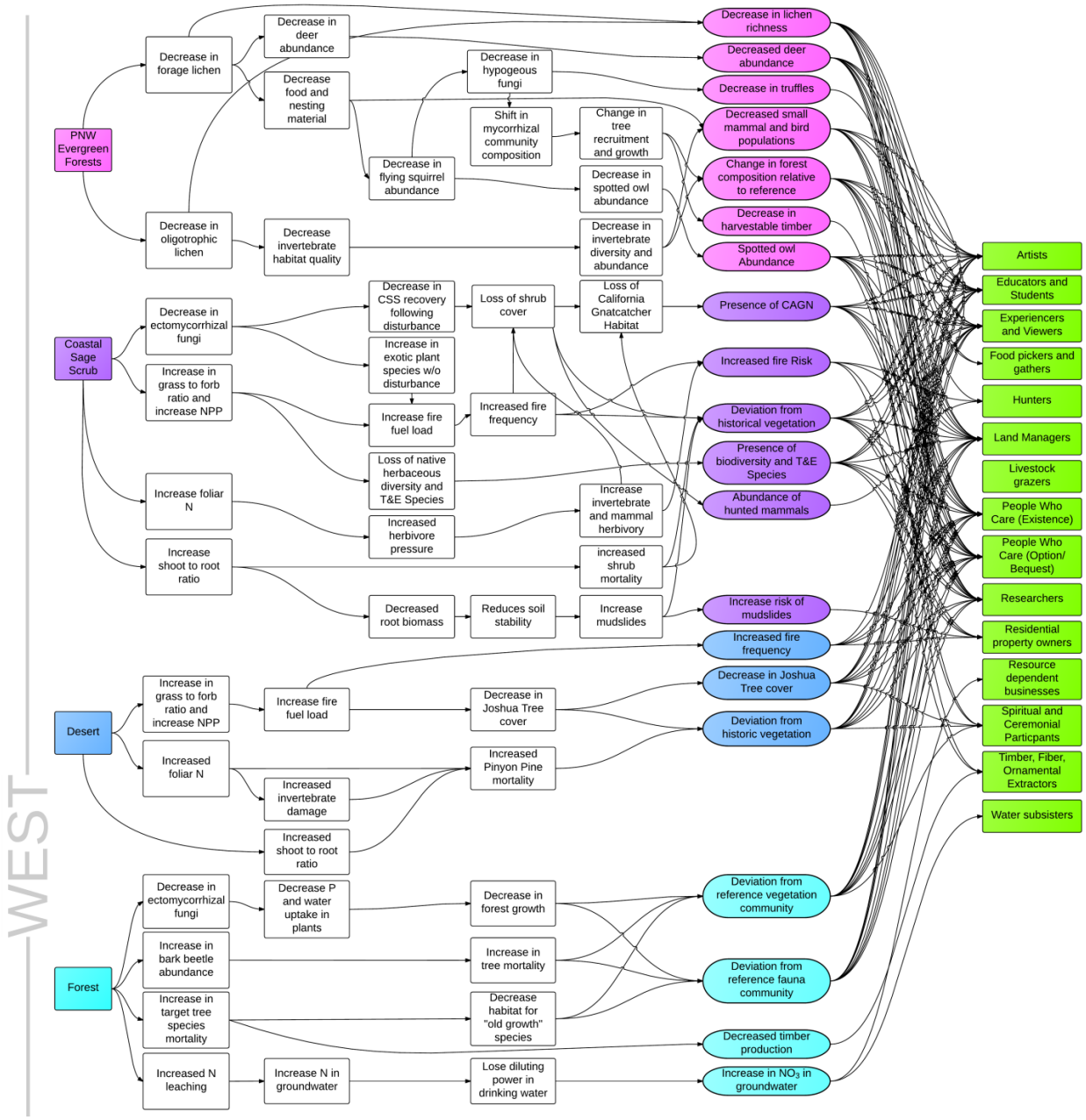

Figure 19. Links between FEGS and their beneficiaries for ecosystem process impacted by terrestrial eutrophication illustrate the extensive and profound ecological connections between air pollution sensitive components of the ecosystem and processes and products upon which humans rely. Ecosystem production functions are separated into regions and ecosystem type.

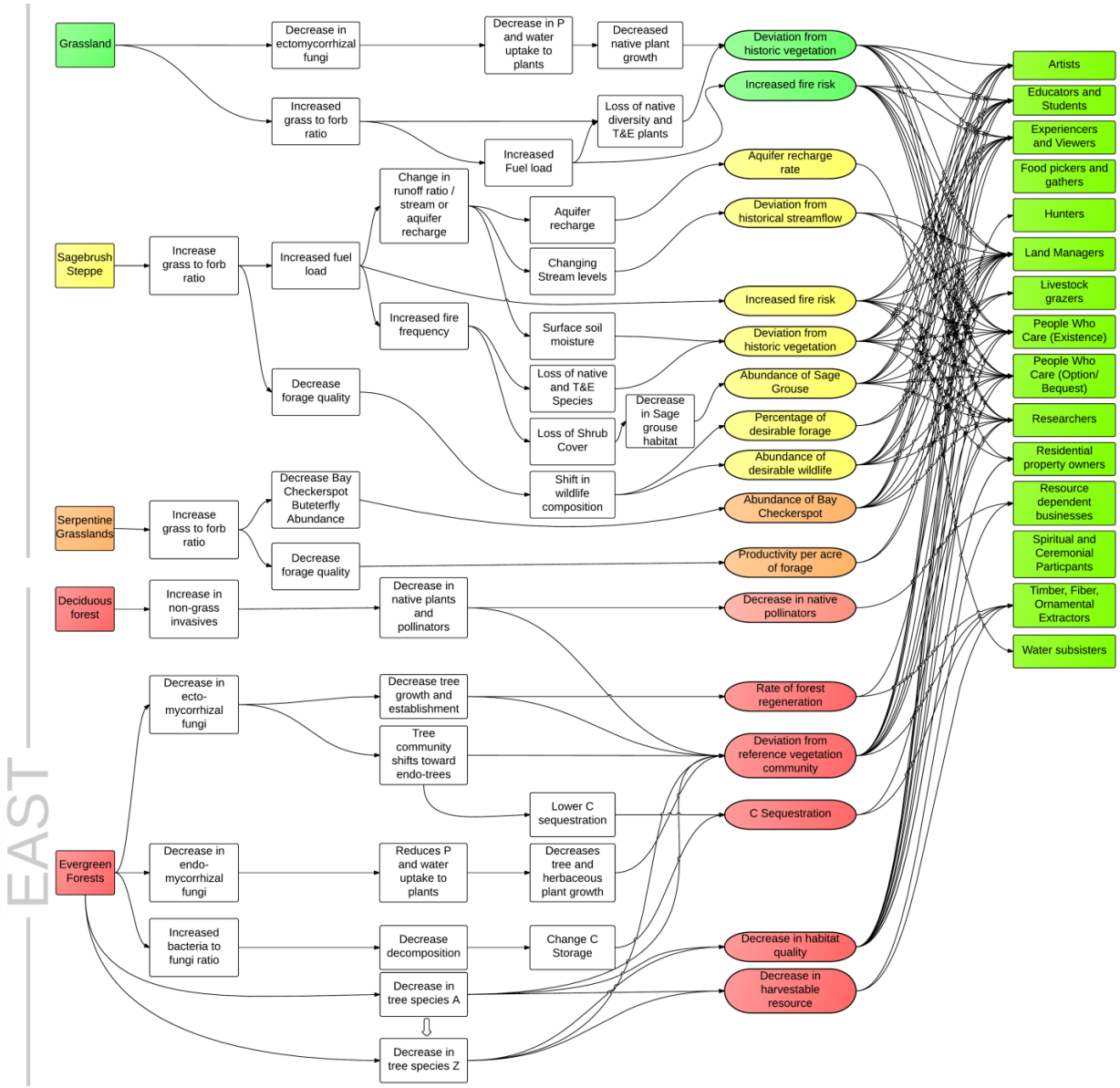

Figure 20. Links between FEGS and their beneficiaries for ecosystem process impacted by terrestrial eutrophication illustrate the extensive and profound ecological connections between air pollution sensitive components of the ecosystem and processes and products upon which humans rely. Ecosystem production functions are separated into regions and ecosystem type.

Workgroup #2: Terrestrial Acidification

Irina Irvine (Facilitator), Robert Sabo (Rapporteur), Lawrence Jones, Jen Phelan, Tara Greaver, George Van Houtven.

Process

The Terrestrial Acidification group began by identifying the species that are listed within the EPA Integrated Science Assessments as being sensitive to NO_x and SO_x. From this list, we selected one deciduous tree, white ash (*Fraxinus americana*), and one evergreen tree, balsam fir (*Abies balsamea*), as "representative" species for acid deposition effects. They both have wide spatial ranges and specific apparent impacts. Chains for other acid sensitive species (e.g., sugar maple, red spruce) were not developed due to lack of time and similarity to other chains.

The sensitivities of white ash and balsam fir to the acidifying impacts of N and S deposition were identified by Duarte et al.[18] who showed that both species exhibited negative growth in response to exceedances of critical loads of acidity. A similar response of balsam fir (growth reductions as N deposition increased) was demonstrated by Thomas et al.[19] in their analysis of growth responses in 19 eastern states, which was further confirmed by a nation-wide analysis conducted by Horn et al.[17] Conversely, these regional and national analyses reported an increase in growth with N deposition for white ash.[19] An increase in white ash growth with N deposition in one set of studies, is not necessarily inconsistent with a decrease in growth following exceedance of a critical load for acidification. These differences may be due to a combination of factors including different analysis scales, and the sensitivity of the sites to N deposition causing eutrophic or acidifying conditions for white ash. Further study is needed to advance our understanding of these multiple processes that simultaneously operate in any given ecosystem.

As we were focused on acidification, we made the chemical criterion a base cation/aluminum ratio of 10:1; the ratio at which negative effects of acidification accelerate. This is the most accurate way to understand and monitor acidification, but does not directly relate to acid deposition as various components can contribute to the change in base cation/aluminum ratio. The direct impact of deposition on these systems will be determined by climate, soil type, and past disturbance. Further research needs to be conducted to develop a clearer understanding of how ecosystem attributes buffer acid accumulation in streams.

We felt that it was important to have a highly relatable FEGS for each ecological production function. We developed stories to relate balsam fir to the decline of snowshoe hares (a charismatic species) and white ash to baseball (America's pastime).

Challenges

One of the big challenges we faced was dealing with redundancy within the ecological production functions. The first issue was that each biological indicator can have multiple responses to deposition

[18] Duarte, N., L.H. Pardo, and M.J. Robin-Abbott. 2013. Susceptibility of Forests in the Northeastern USA to Nitrogen and Sulfur Deposition: Critical Load Exceedance and Forest Health. Water, Air, & Soil Pollution 224:1-21.
[19] Thomas, R.Q., C.D. Canham, K.C. Weathers, and C.L. Goodale. 2010. Increased tree carbon storage in response to nitrogen deposition in the US. Nature Geosci 3:13-17.

(e.g., increased mortality, reduced regeneration, reduced growth leading to total reduced biomass) that all have the same FEGS (e.g., reduced snowshoe hare abundance). The second level of redundancy was that multiple tree species are experiencing the same chains (e.g., all species that are sensitive are experiencing reduced biomass, etc). The change in survival of each tree species may impact a different fauna species that use the trees for forage and habitat. Each species responding to the loss of habitat could be a FEGS as birders, hunters, and botanists each have their own focus during their exploration of the wilderness. We avoided creating chains for individual species out of the interest in time.

A second challenge was how to deal with FEGS offered by the forest as a unit. Forests offer "downstream" benefits of clean air, clean water, and carbon sequestration that impact all humans. On a tree by tree basis, this impact would be negligible, but at the forest level it would be large.

Chains

We identified 120 chains linked to 12 FEGS that affect nine beneficiary groups. As stated before, there is the potential to create significantly more chains focused around new focal species and splitting forage and habitat species into individual nodes.

We focused our analysis on two FEGS that managers and visitors have an emotional connection to; snowshoe hares and baseball.

<u>Balsam fir/Snowshoe Hare</u>

In addition to its $17,000,000 Christmas tree and essential oils industries, the balsam fir provides forage and habitat for the snowshoe hare. As the crown of the fir decreases due to reduced growth rate and increased crown dieback, the amount of cover available for the snowshoe hare to hide within decreases, increasing predation. The loss of forage also reduces the reproductive rate of the hare, leading to a decline in reproductive success. These act in concert to diminish local populations (Figure 20).

The loss of balsam fir trees directly impacts timber harvesting, Christmas tree farms, and the collection of Oleo resin. These direct resources influence the financial output of the ecosystem. The indirect beneficiaries are Experiencers and Viewers and Hunters who are reliant on the presence of the snow shoe hare, an iconic species in the northeast, when interacting with the environment.

This chain, when expanded fully, highlights one of the challenges mentioned of having the chain branch out into multiple processes before narrowing back towards the same effect/FEGS (Figure 20).

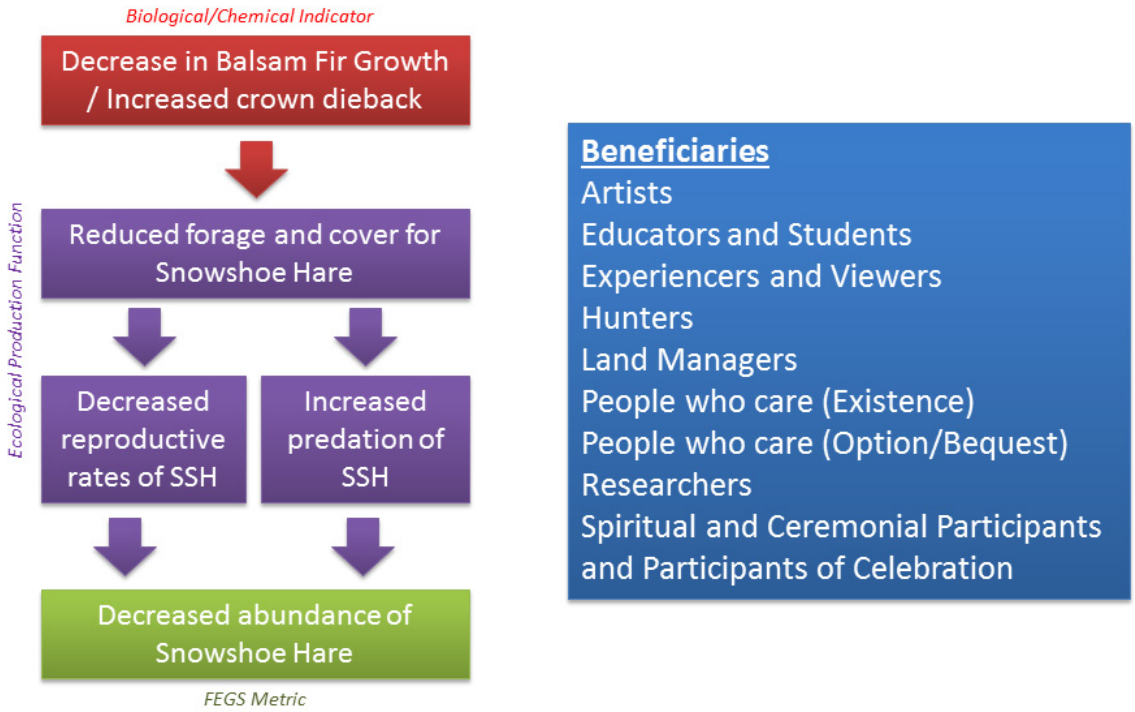

Figure 21. As the balsam fir canopy dies back due to terrestrial acidification, habitat for snowshoe hares declines.

White Ash/Baseball Bats

White ash provides habitat and forage for a variety of birds and mammals. However, we focused on the products that are made from white ash such as baseball bats, guitars, fine tools, and cabinets. We felt the strongest tie was to baseball, as approximate half of the bats used in Major League Baseball are made of this wood. As growth rates and wood quality decline due to acidification, the integrity of the bats will decline as well. This would directly impact the beneficiary timber harvesters, but has cascading effects to the millions of people who follow baseball.

Additional research needs to be conducted on the relationship between decreased tree health due to aluminum toxicity and infestation by the emerald ash borer. This pest is a growing problem within the range of the white ash, but it is currently a less preferred food source than green ash and black ash.

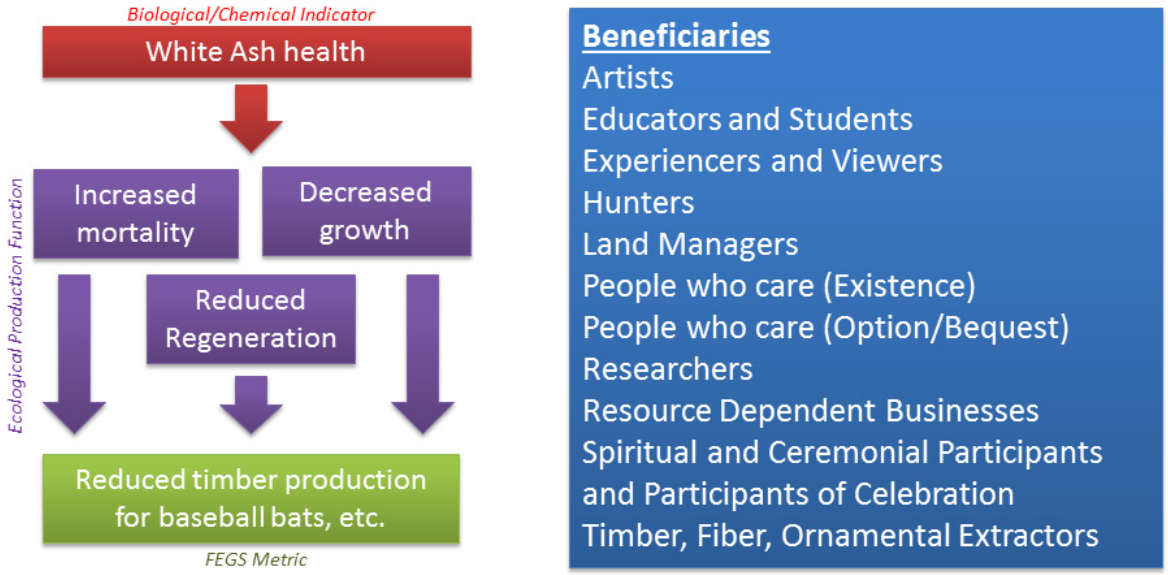

Figure 22. Terrestrial acidification reaches far outside of natural systems by impacting beneficiaries who use products produced from resources.

Full Chain Diagram

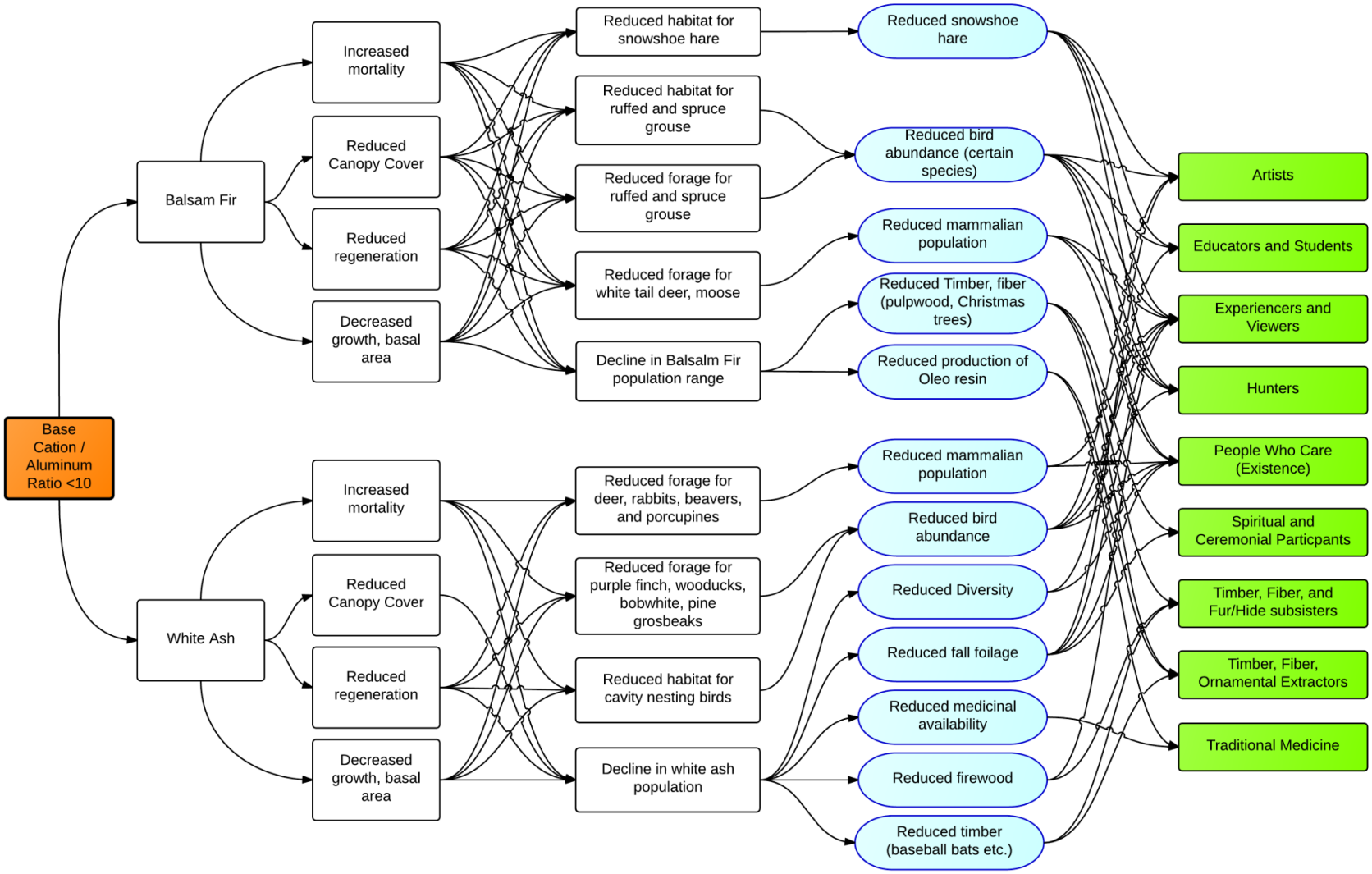

Figure 23. All links between FEGS and their beneficiaries for ecosystem process impacted by terrestrial acidification. Ecosystem production functions are based on the change in growth of balsam fir and white ash.

Workgroup #3: Aquatic Eutrophication

Randy Waite (Facilitator), Charles Rhodes (Rapporteur), Andi Heard, Julie Hewett, Jason Lynch, Drew Bingham.

Process

The Aquatic Acidification group began our discussion by focusing on three major biotic groups impacted by eutrophication: diatoms/algae, macroinvertebrates, and fish. Nitrogen (N) loading to water bodies comes from various sources (air deposition, storm water runoff, agriculture, industrial and municipal discharges, atmospheric deposition, and septic tank seepage). It can be difficult to determine the contribution of atmospheric deposition relative to these other sources and indirect water bodies without complex waterbody-specific modeling. In addition to the complexities due to multiple sources of N, it is challenging to quantify the amount of atmospheric deposition that reaches a given waterbody. A known example is the Chesapeake Bay where a sophisticated model was developed to tie all inputs of nitrogen to biotic responses in the bay. Because the Chesapeake Bay model is very specific to its watershed and waterbody, the model cannot easily be transferred to other waterbodies. However, for freshwater systems, models do exist to project water column concentrations of nitrogen based on various inputs. Because we were not able to directly link the dissolved N level to deposition, we instead chose to use water column N concentration as our initial measureable indicator and set a critical load of 1 mg/l NO_3^- for species shifts, because this threshold has been used in the literature as an early indicator of aquatic eutrophication associated with shifts in diatom species and abundance.

We had focused our analysis on two initial ecosystem responses: change in diatom/algal communities and change in macrophyte and wetland vegetation. The majority of our interactions stemmed from the diatom/algae changes as they are the base of the aquatic food chain and the most responsive to N additions. The two main paths of diatom/algae impacts stem from a change in algal abundance leading first to altered food chains, with changes in zooplankton composition which can directly affect food sources of small fish and invertebrates, and second to potential decreased oxygen levels, which causes cascading effects within the ecosystem and can lead to the loss of fish dependent wildlife. We then proceeded to evaluate effects of algal blooms on direct human uses, e.g., swimming, drinking water, and aesthetics.

After establishing a few basic chains of ecosystem responses, we then took the approach of grouping by trophic levels as FEGS instead of splitting groups out into individual species. As many of the baseline responses of diatoms are going to be similar across water bodies, this allows the framework to be applied to any region, with each specific area replacing the trophic level with their local species. Within the spreadsheet we created a copy of each chain for rivers and streams, lakes, estuaries, near-coastal marine systems, and wetlands.

Challenges

The main challenge in identifying critical loads for aquatic eutrophication is that there is often a nonlinear response of diatoms and vegetation to dissolved N in a waterbody, i.e., the response is very waterbody specific. This creates more tenuous relationships within the ecological production function. While these remain grounded in science, they make it difficult to select a single critical load

because local N deposition does not always directly correspond to dissolved N levels. Identifying the critical load requires a thorough understanding of the inputs and local N-cycling processes within the watershed.

There was also the confounding effect that the response to nitrogen is dependent on whether the waterbody is nitrogen or phosphorus limited. The ratios of N:P are fairly well understood, so if the phosphorus level of the waterbody is known, then this can be taken into account,

The last challenge was that while creating the chains, we came to realize that some segments of the chain could be both intermediate and final, depending on the FEGS. We linked these to the FEGS from all places we felt appropriate, and accepted that further partitioning will have to take place to avoid double-counting these processes.

Chains

We identified 637 chains linked to nine FEGS that affect 19 beneficiary groups. Breaking out trophic groups into individual species based on region would significantly increase the number of FEGS and chains. Each FEGS interacted with a minimum of six beneficiary groups with a maximum of 15. Based on these interactions, each beneficiary group interacted with multiple FEGS, giving them multiple reasons to care about nutrient loading to water bodies.

We inferred overlap between the final link of our ecosystem production function and FEGS. The greatest overlap occurred with the FEGS "Change in water fauna species." This makes sense, because as you deconstruct the food chain from the bottom, the higher levels will dissipate. As most people are not interested in the loss of diatoms from the system, the two main stories we focused on were the loss of water clarity and algal blooms leading to fish kills.

<u>Decreased Water Clarity</u>

Increased N inputs to a waterbody can have a eutrophication effect and lead to increased primary productivity (i.e. increased algal and bacteria abundance). This increased growth results in an overall change in total organic matter in the water column and decreases water clarity (Figure 23). Loss of water clarity reduces enjoyment of the waterbody and larger viewshed for direct users including swimmers, anglers, boaters, hikers, and property owners. Water clarity changes in a lake ecosystem may also lead to changes in the thermal structure and spatial photosynthesis patterns, which can have cascading ecological effects.

This is an issue of concern on the national level that speaks to 13 unique beneficiaries although expectations vary by waterbody and beneficiary. For example, a hiker viewing a remote alpine lake in Rocky Mountain National Park will have a higher expectation of water clarity than a homeowner that lives on a lake in an urban area. However, both of these beneficiaries have interest in protecting the clarity of these waterbodies. The contribution from atmospheric N deposition is of national concern, but will also vary by waterbody and location. In remote mountain lakes atmospheric deposition is the primary N input of concern. In more developed areas it must be considered along with N inputs from storm water, agricultural, industry, municipal, and septic sources.

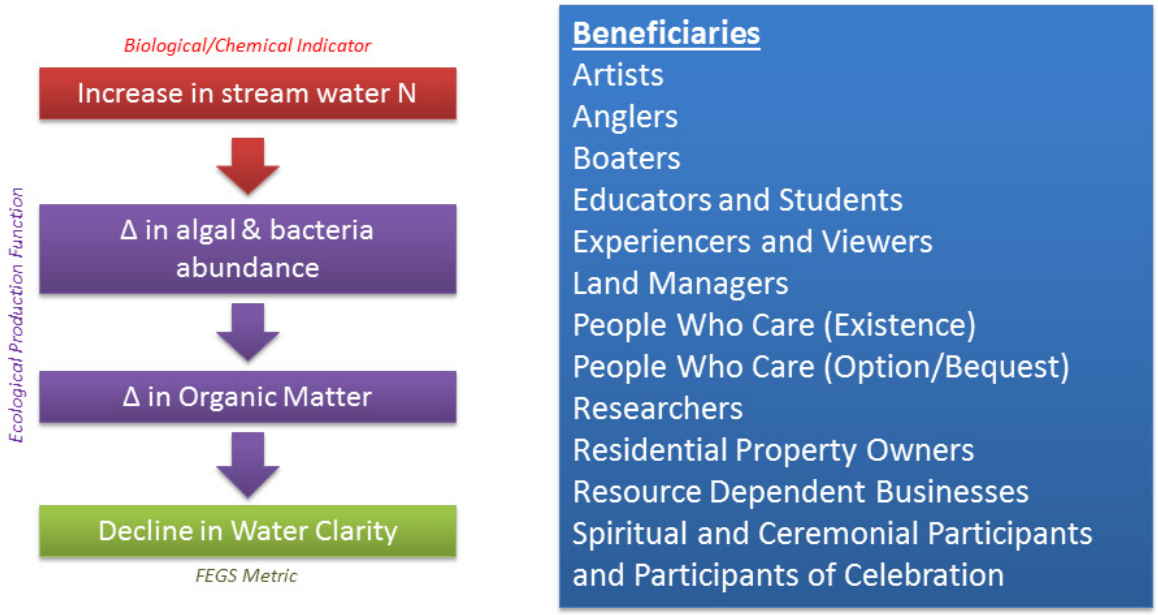

Figure 24. An increase in stream water N leads to a decline in water clarity due to the accumulation of organic matter.

Dissolved O_2/Fish Kills

As N is added to the system, algal blooms begin to develop, leading to a change in the richness and biodiversity of diatoms and algae within the water body. The increase in algae leads to a decrease in dissolved O_2 in the water due to high amounts of respiration occurring at night and algal decomposition. The loss of O_2 from the aquatic ecosystem then has a cascading effect, killing off other fauna in the water (Figure 24). This has sweeping impacts, as it not only removes species people are interested in seeing but also makes the water unusable for recreation. Algal blooms also impact other aquatic flora as light penetration is diminished. There is lastly an impact on water quality, as carbon and nitrogen storage and cycling capacity are diminished.

One of the limiting factors of this chain is that while there is good science connecting deposition/nitrogen loading to algal increases, food chain modifications, and eventual decreases in O_2; dose-response curves are difficult to develop without complex waterbody-specific modeling. This makes the existing science more difficult to implement as a management tool.

Tying this chain to more widely-known animals provides a better vehicle for expanding the critical loads message. There are studies that show the effect of species composition change to a change in zooplankton, but very few of these are predictive across waterbodies. This research gap needs to be explored, to empirically identify characteristics of water bodies and keystone diatom assemblages that result in large species shifts.

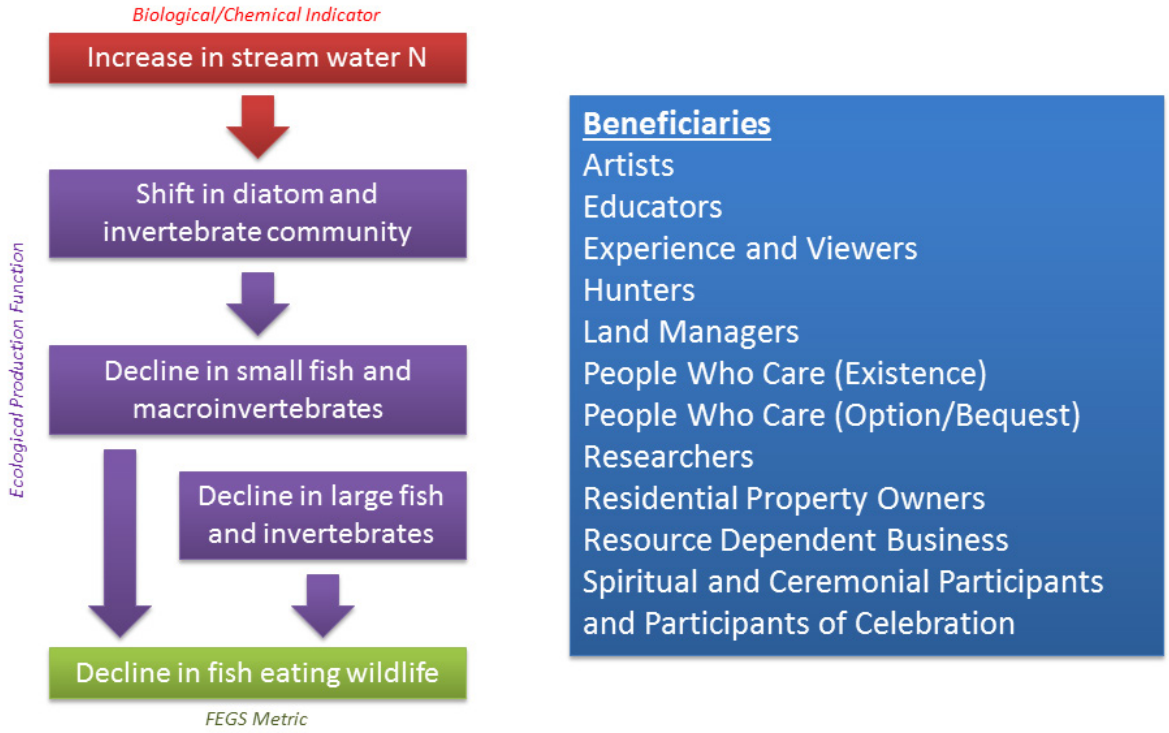

Figure 25. Changes in water chemistry due to air pollution can cross over to terrestrial systems through the food chain.

Full Chain Diagram

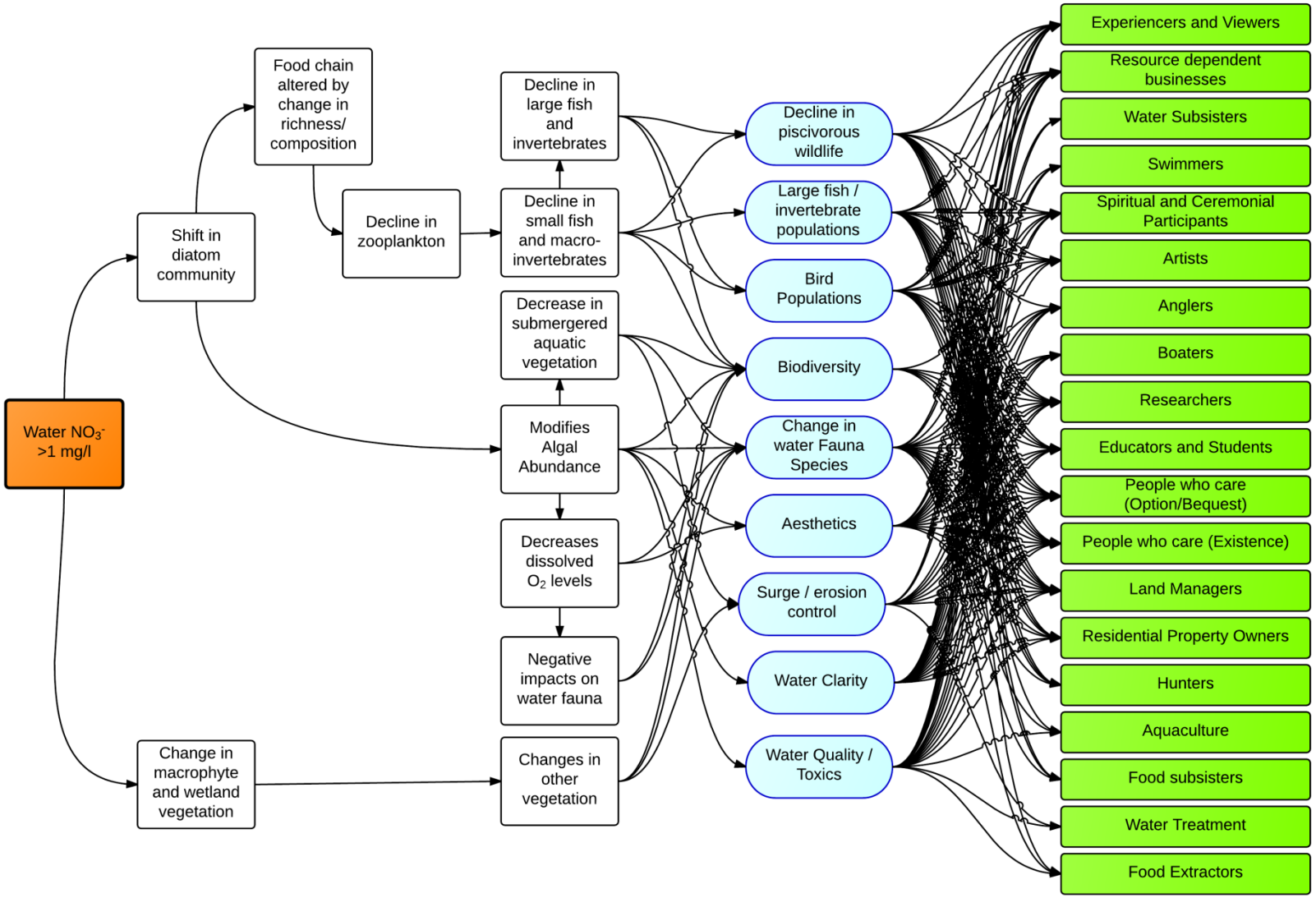

Figure 26. All links between FEGS and their beneficiaries for ecosystem process impacted by aquatic eutrophication. Ecosystem production functions are based off of changes in diatom and macrophyte communities.

Workgroup #4: Aquatic Acidification

Dixon Landers (Facilitator), Sarah Anderson (Rapporteur), Tim Sullivan, Claire O'Dea, Frank Casey.

Process

The Aquatic Acidification group began with a general discussion of critical loads for aquatic acidification: how they have been determined and where different research efforts have taken place. We identified that acid neutralizing capacity (ANC) serves as the most accurate chemical criterion to determine the critical load for aquatic acidification. Base cation surplus and pH are other variables that could be measured and used, but relationships with ANC are well documented and defined. We identified an ANC of 50 as a standard chemical criterion for freshwater ecosystem responses to acidification. Most other chemical indicators are correlated with ANC, making it a relatively all-encompassing value.

Restoration of acidified streams and lakes can take considerable time and effort. Oftentimes, lowering local deposition alone will not return water ANC to levels above 50 because cations are not available in the soil, and extensive weathering must occur to replace them. Lowering atmospheric deposition does improve the likelihood of successful restoration and will allow managers to reach target levels sooner. Stream restoration timelines are often on the order of 50-100 years. We did not get into the quite voluminous topic of application of lime to raise the pH/ANC.

After identifying our chemical criterion, we decided to work backwards and identify all of the beneficiaries who would be impacted by acidification. This allowed us to create FEGS that each beneficiary used from aquatic systems and gave us targets to work towards when building our ecological production functions.

Even though we had identified ANC as the main chemical criterion, we realized that biological responses were often based on alternative chemical interactions that could be sourced back to ANC. Therefore, we built chains off of three main building blocks: ANC<50, decreased pH, and loss of Ca^{++}. We used a combination of specific and general FEGS to highlight high impact species as well as keep some chains adaptable to multiple regions.

Challenges

We identified challenges around how and when to measure ANC to identify when a system is in exceedance of the critical load. The first is to know how often and at what time to measure ANC. Annual measurements may be sporadic based on the timing of precipitation during the season. Storm flow pulses often have lower ANC due to leaching, so it may take multiple measurements to understand the system. In addition, some freshwater systems are naturally acidic and have never had an ANC greater than 50, which makes using this value as the chemical criterion imperfect. It can often be difficult to identify these streams after the fact, but local knowledge of watershed and stream characteristics can be used to screen out naturally acidic waters.

The other challenge was separating the impacts of the different chemical criteria. As noted, the changes in each chemical indicator are correlated with one another, but the addition or subtraction of specific ions is usually what initiates the biological response.

Chains

We identified 66 chains linked to eight FEGS that affect 16 beneficiary groups. The number of FEGS and chains would be significantly increased by breaking out trophic groups into individual species based on region.

The most common beneficiary groups (Artists, Educators, and People Who Care) highlighted the intrinsic value of aquatic biodiversity and how it impacts many users. Direct human consumption from aquatic systems was mainly identified as Anglers and Resource Dependent Businesses. We chose to highlight one chain based on the presence of brook trout, and the other on the presence of loons. Brook trout are well researched because they are a common, charismatic species in eastern lakes, streams and rivers. Loons were chosen because people tend to enjoy the presence of loons on a lake, are a hunted species, reside higher on the aquatic food chain, and are easy to monitor.

Additional beneficiaries were identified through the loss of shellfish as an ornamental export from water bodies.

All of our ecological production functions have a strength of science score of "High".

<u>Brook Trout</u>

Brook trout are important to beneficiaries of streams and lakes both as a top-level predator in the food chain as well as the leading resource extracted by humans. Acidification tends to affect cohorts of brook trout through episodic acidification and can extirpate the species from a stream when acidification becomes chronic. Younger individuals are more susceptible to the effects of acidification, so if ANC drops too low during a storm event or snow melt episode, an entire age class could be lost. The most direct cause of brook trout decline is the increase in aluminum within the water due to a decrease of pH in the water, which has a negative effect on gill function. Secondary effects include loss of food sources through a change in phytoplankton/zooplankton communities and loss of macrophyte diversity (Figure 26). None of the impacts to brook trout are species specific, so this chain could be used as a placeholder for other large fish species.

The loss of brook trout from streams directly affects Anglers, which use the trout as a recreational and consumptive resource, and Aquaculture and Resource Dependent Businesses which utilize the trout as an economic resource. Indirect effects impact Experiencers and Viewers, Land Mangers, Artists, and Researchers, as removing trout from the system detracts from both its aesthetics as well as its natural function.

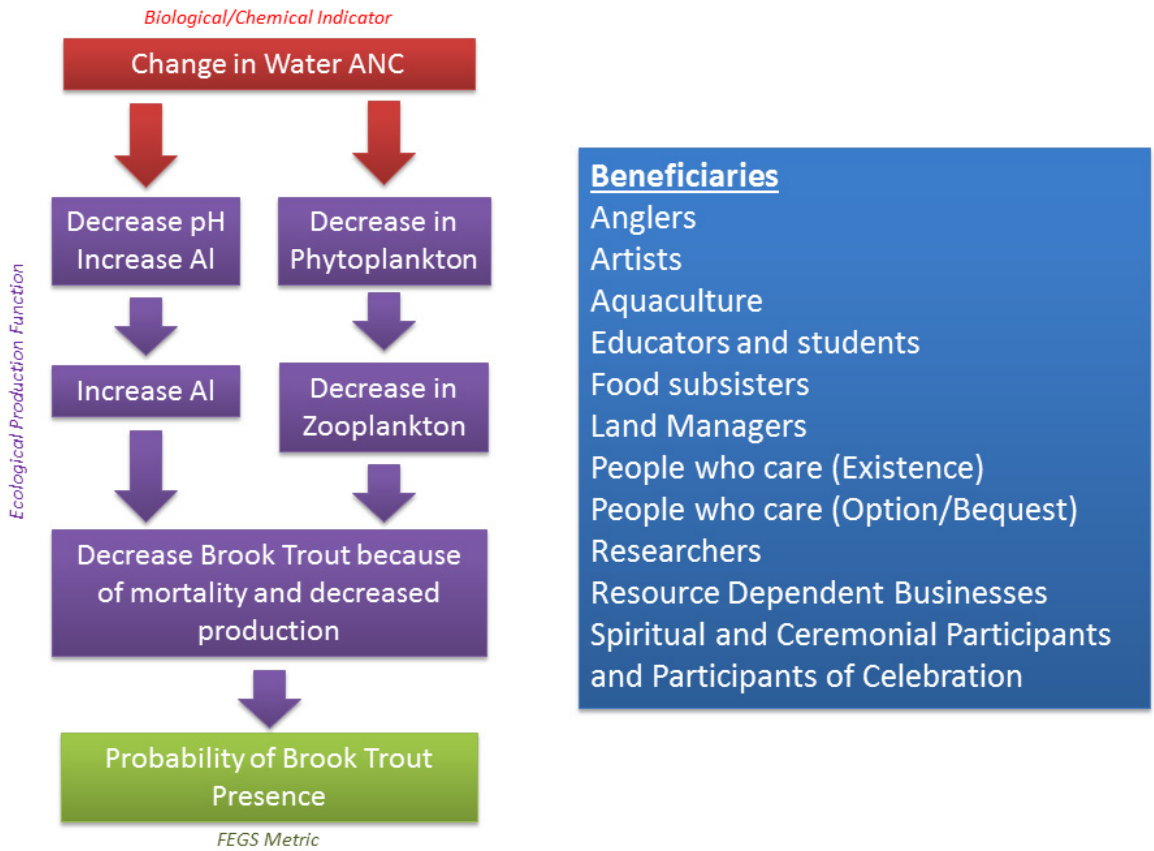

Figure 27. A decline in water ANC below 50 decreases food sources for brook trout and is correlated with an increase in acidity leading to the decline of brook trout within the stream.

Aquatic birds (loons)

Loons are piscivorous birds that survive through consumption of small fish. They are territorial birds so presence/absence is the best indicator since abundance is a function of lake size. This chain builds off of the previous one, but within a lake setting. As loons are more likely to feed off smaller fish in lakes, and smaller fish are often more susceptible to ANC changes, loons (and other piscivorous birds and mammals) serve as indicators of lower level changes (Figure 27). The FEGS Metric associated with this chain could be changed for regional specificity or for the management goal.

The direct take and consumption of loons impacts Hunters, Resource Dependent Businesses, and Timber, Fiber, and Ornamental Extractors that all use the loons for their feathers. The presence of loons indicates a stable ecosystem that is used by Experiencers and Viewers and Artists. Residential Property Owners are also linked to loons as the presence of a healthy community can increase enjoyment and property value.

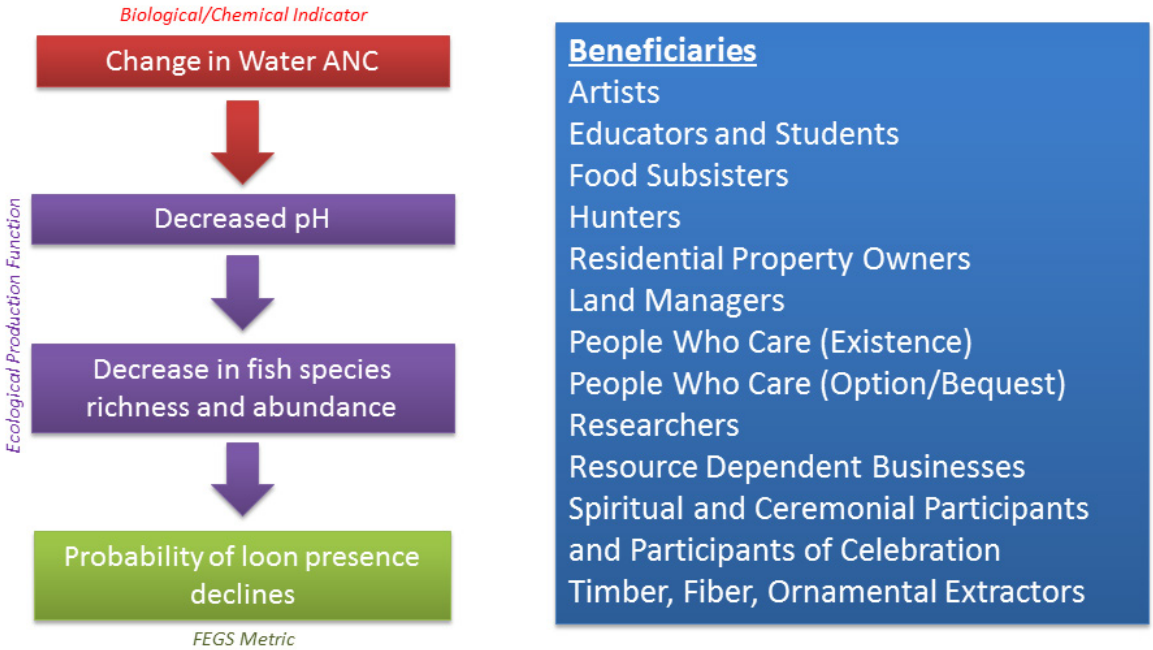

Figure 28. Fish eating birds are a good mechanism to monitor the health of aquatic systems as they live above the water and are easy to count.

Full Chain Diagram

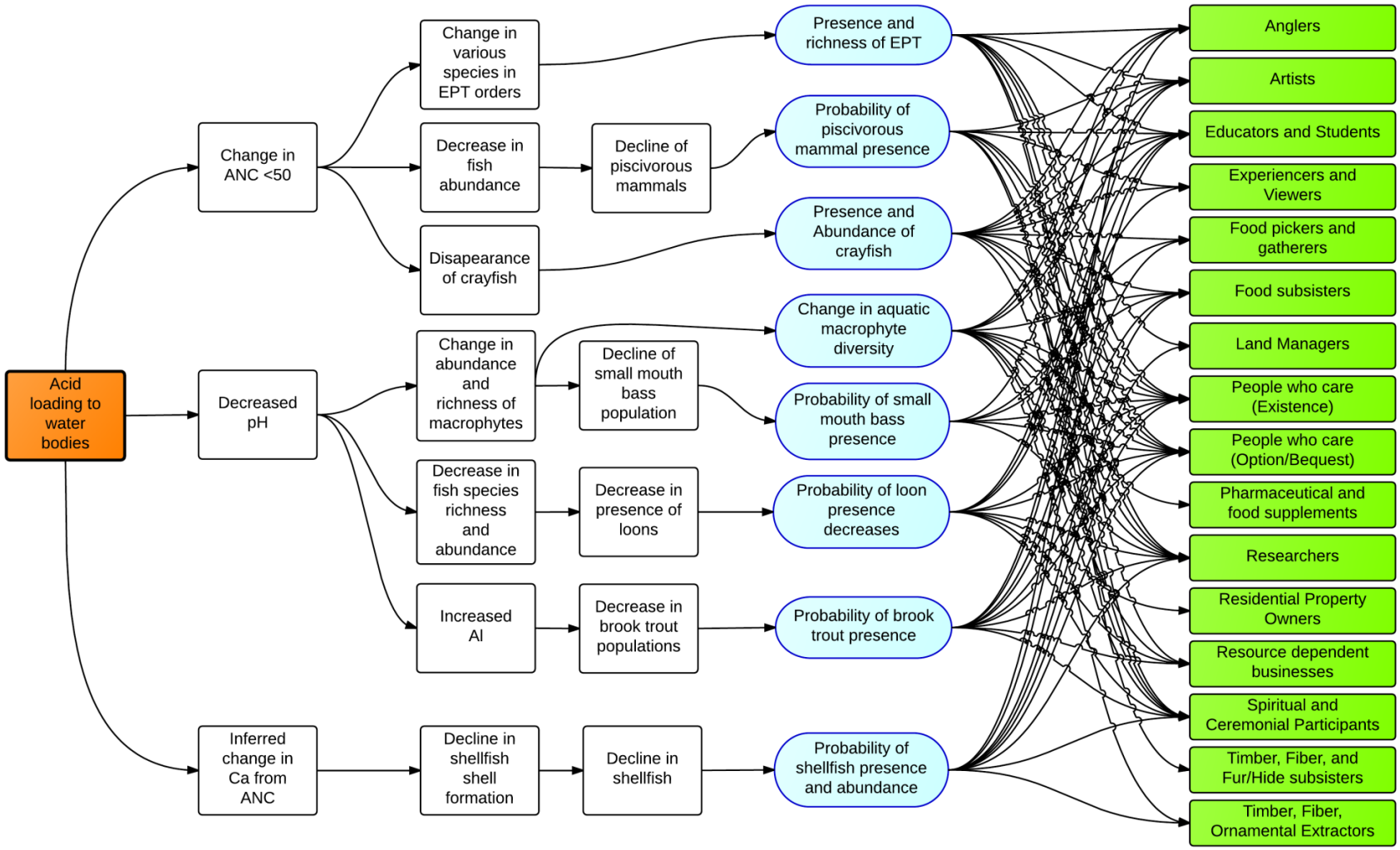

Figure 29. All links between FEGS and their beneficiaries for ecosystem process impacted by aquatic acidification. Ecosystem production functions are based off the decrease in ANC and pH.

Beneficiary Focused Analysis

The benefit of the structure of the spreadsheet is that it allows for users to sort by any of the columns to retrieve the appropriate data. Scientists are more likely to want to focus on the direct ecosystem response to air pollution, but managers may be more interested in how air pollution is impacting certain users of their land. Sorting based on the beneficiary of interest can provide a list of critical loads to enhance that beneficiary's experience and provide a list of management objectives to realize that goal. This could be productive if the land manager is creating a plan for recreational impacts (e.g. Experiencers and Users; Figure 29) or extractive-use impacts (e.g., Timber harvest; Figure 30).

As mentioned previously, the most common beneficiary group was Experiencers and Users (120 chains). This category encompasses all visitors who are interacting with a natural resource being affected by air pollution, as well as non-consumptive users, such as recreational visitors. With an extraordinarily large number of beneficiaries interested in existence value or the naturalness of a system, they may represent a visible and vocal set of beneficiaries. Figure 29 shows a graphical representation of all chains that end in Experiencers and Users. Within the spreadsheet this can be simplified down to ecosystem impacts to quickly provide local impacts to the user experience.

Timber production on the other hand is limited first to terrestrial systems and then to only a subset of the ecosystems identified by each group creating only 23 chains (Figure 30). This is then very easy for a manager to identify if air pollution impacts are potentially affecting the future productivity of the forest.

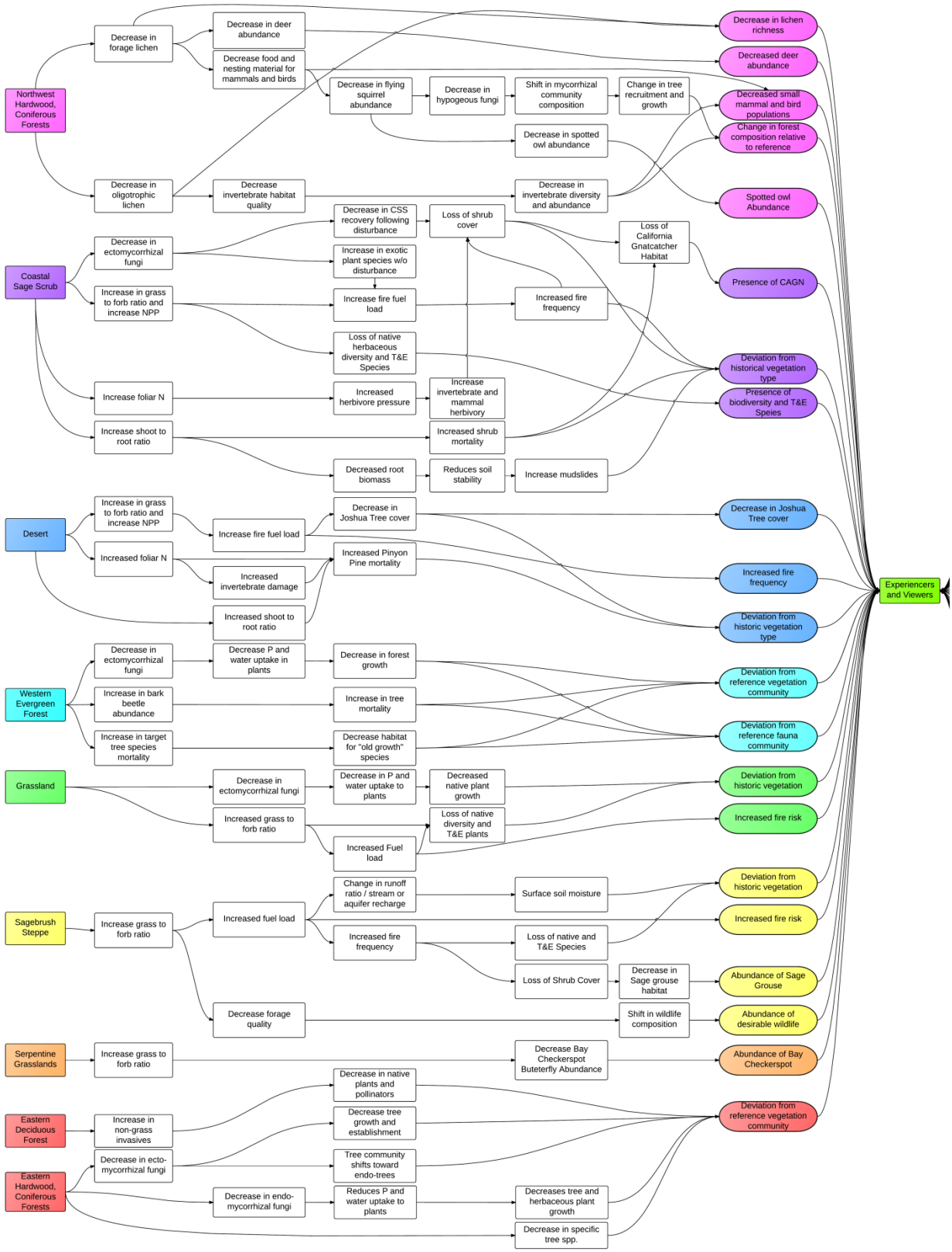

Figure 30. All chains linked to Experiencers and Users

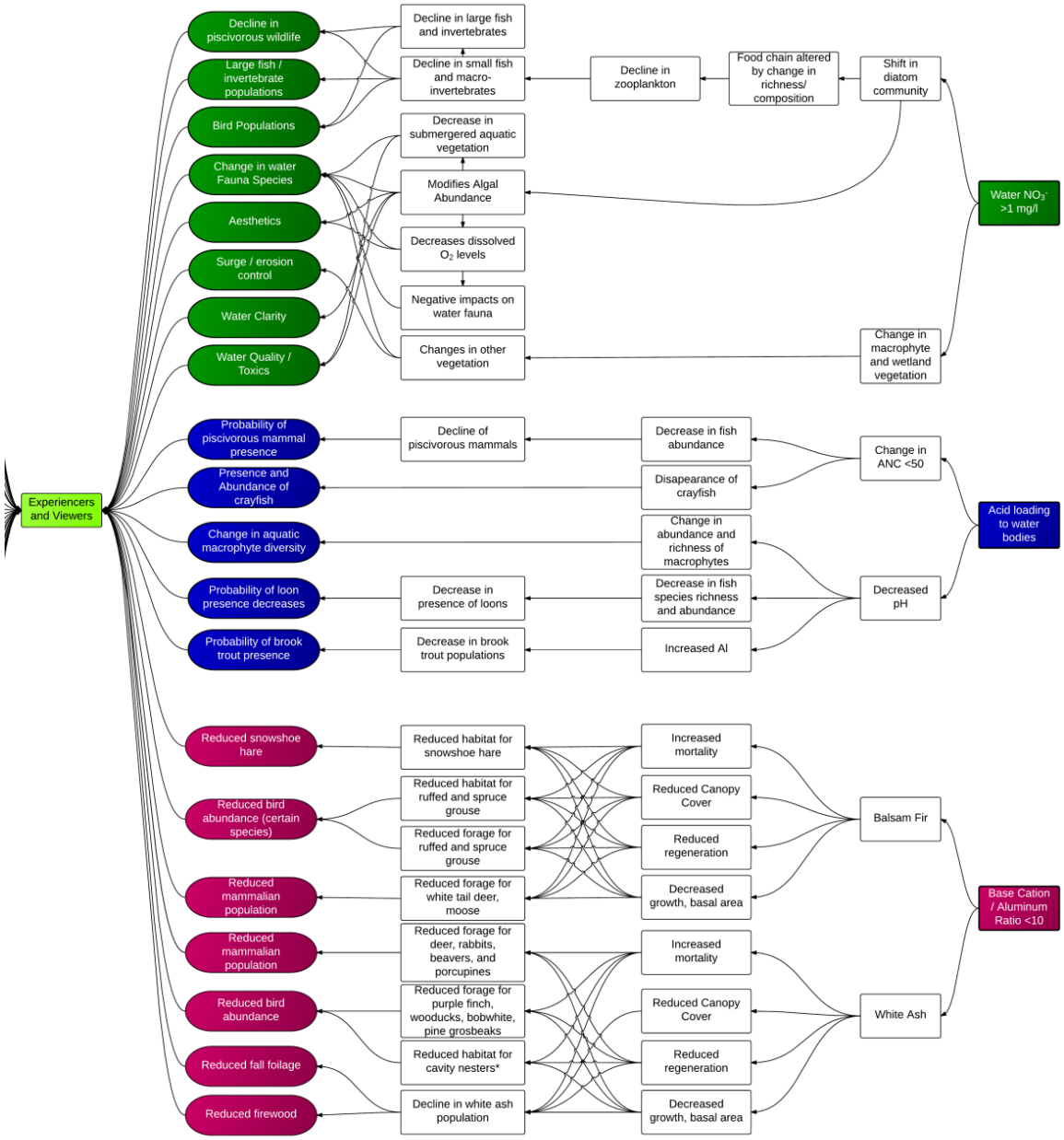

Figure 31. All chains linked to Experiencers and Users

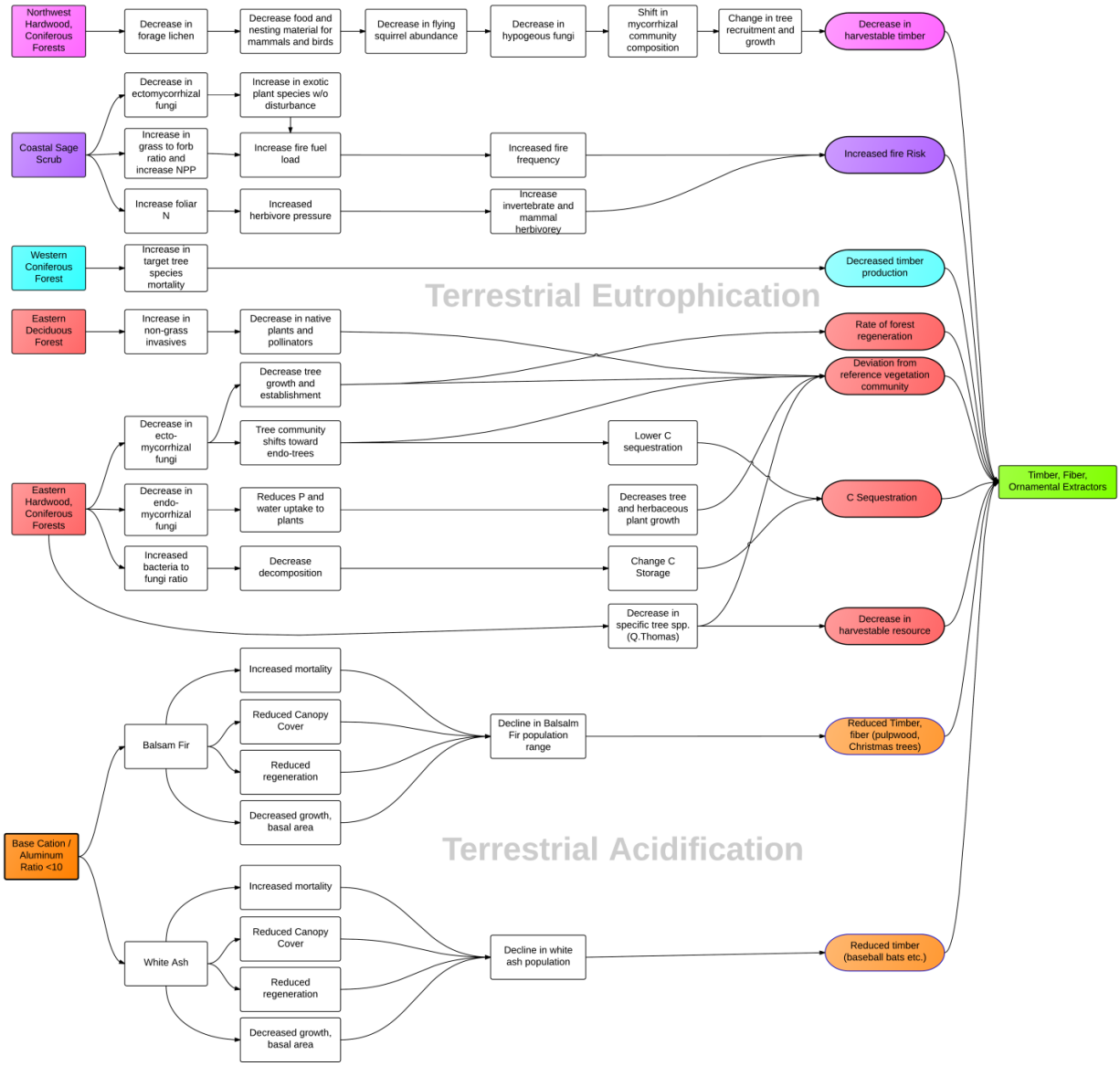

Figure 32. All chains linked to timber production

CONCLUSIONS

Workshop participants from the natural and social science communities were able to communicate across disciplines and develop collaborative output products linking multiple biological indicators affected by air pollution with a large number of final ecosystem goods and services. The process succeeded because: (1) the purpose and objectives of the workshop were clearly articulated; (2) pre-work was assigned to participants to encourage familiarity with the materials; (3) a process was established in advance which would help participants describe details of the ecological production functions, providing group members with a format used to develop the chains; (4) both FEGS and CL had previously been developed conceptually and were vetted in the peer-reviewed literature; (5) presentations at the beginning of the workshop gave overviews of topic areas and discussion time allowed participants to ask questions and clarify issues before work began; (6) small interdisciplinary working groups were tasked with specific products to develop and provided time and resources to do so; and (7) the "right" expertise was represented in that participants were subject matter experts, comprising air quality, ecological, and ecosystem services expertise, and each participant functioned well in a team setting.

Box 1: How acidification ruined Christmas (trees) and Easter (bunnies)

Balsam fir are an important tree species in cold high elevation areas of the eastern US. They represent a $17,000,000 business in Christmas trees and aromatic oils in the U.S. They also serve as valuable habitat for small mammals and birds. However balsam fir trees are vulnerable to acid rain, because chemical changes in the soils deplete essential nutrients which many types of tree species need to thrive. Acidification of soils in the eastern US has decreased the growth of balsam fir and made them susceptible to damage by ice storms, insects and disease. In the Southern Appalachians only small relic populations of these tree species remain. Snowshoe hare population declines (through decreased reproduction and increased predation) in the Appalachians have been associated with decreases in balsam fir tree health because hares require dense forests which they use for both food and shelter. Acidification of forest soils in the eastern US has consequences throughout these ecosystems, impacting both the economic benefits of forest products, such as Christmas trees, and the societal desire to protect locally endangered species, such as the snowshoe hare.

This workshop linked balsam fir to nine beneficiary groups who care a lot about balsam fir trees… they just may not know it yet.

The work products produced by the small groups had two very different audiences: complex diagrams to provide details of interest to scientists and subject matter experts, and simple stories for management and public audiences. This dual approach was important to reach broader audiences. Subject matter experts need to see the detail behind the associations, citation of peer-reviewed work, and characterizations of uncertainty. This same information must also be translated into a format that is easily understood by non-experts and one way to accomplish this is through developing "stories." Stories can be very useful for connecting ecosystem endpoints to users, because they provide emotional connection and resonance (Boxes 1-4). Participants felt that case studies, to demonstrate specific impacts and connections, were especially compelling when presented within a larger context (a description of the number of chains which were identified) to better illustrate the magnitude of potential consequences to beneficiaries. However, because some chains may have connections to beneficiaries which are indirect or currently difficuly to quantify, the ultimate impact to beneficiaries may not always be easy to assess.

The workshop provided an excellent opportunity to test how well the FEGS-CS worked in providing a framework for secondary beneficiaries for a specific policy and management question. In this case the question was: who (which types of beneficiaries) would benefit from (or otherwise value) reductions in air pollution that result in less acidic precipitation and less reactive N deposition on the landscape? The rationale and approach to developing the FEGS-CS was explained in some detail ahead of the workshop and then again at the workshop with ample time for discussion and questions. This process was deemed crucial to the workshop success since the FEGS concept and the FEGS-CS are relatively new ideas and it was desirable to get all workshop participants on the same page with regard to terminology, definitions, boundaries and the workshop purpose.

Although FEGS and FEGS-CS were new to many of the attendees, the workshop participants grasped the information and goals and proceeded very directly to the tasks at hand. They did have, expectedly, the need for additional information about their tasks and the FEGS and FEGS-CS approaches, but this did not appear to affect the group's performance in any negative way.

The tangible accomplishments of each four groups greatly exceeded the expectations of the organizers. All four work groups succeeded in producing comprehensive products describing effects of deposition, summarizing all the associated science-based pathways, and linking them to final ecosystem goods and services. While each group derived their own detailed way of making progress, they were all highly successful in achieving their general goals and in communicating their specific approaches, decisions and results.

All in all, this work could not have been achieved without the use of FEGS and the FEGS-CS (or some similar classification system) as an organizational tool which identified a complete set of specific types of environments (i.e. lake, stream, wetland, forest, etc.) and the hypothesized beneficiaries or human users of the environmental components that are provided. This classification system that coupled "environment" with "beneficiaries" quite directly facilitated approaching and achieving the workshop goal of having four different groups of experts working independently on the workshop objectives.

A question that arose during the workshop was whether "Land Managers" should be considered an

Box 2: How acidification struck out baseball and silenced rock and roll

White ash trees do not tolerate acid rain well, it causes them to grow more slowly, decreases the ability of their seedlings to survive, and kills off trees when they are stressed for other reasons (like very cold winters, or insect outbreaks). The wood from white ash trees makes the most desirable baseball bats, since ash contains air pockets that make bats flex when the ball is hit. Ash is also a highly valued wood for electric guitars, as it creates a unique sound. White ash trees are vulnerable to acid rain, because chemical changes in the soils deplete essential nutrients which many types of trees need to thrive. Acidification of soils in the eastern US has decreased the growth of white ash.

Acid rain has damaged populations of many species of trees in the eastern US. Just white ash alone was linked to nine different beneficiary groups, many of whom may also be baseball fans or music aficionados.

additional type of beneficiary (this group is not currently included in the FEGS classification system list). Some workshop participants representing Federal land management agencies felt strongly that "Land Managers" should be considered a separate beneficiary group because while this group takes actions on behalf of the public, competing or conflicting desires of the public mean that land managers must instead sometimes make decisions based on the missions of each Agency rather than the desire of one or more direct beneficiary**.** Participants theorized that "Land Managers" could be similar to other FEGS designated beneficiaries such as "Farmers," or "Water treatment operators," who manage resources for a larger purpose. However, the ecosystems services subject matter experts at the workshop concluded that professional land managers are not the FEGS beneficiaries because they are professionals who are getting paid for their work. They do not benefit directly from the activities they direct on Federal Lands, they get a pay check for conceiving of, managing and implementing a range of activities (selling lumber, protecting native flora and fauna, installing toilets at campsites to preserve surface water quality, etc.). The bulk of these activities relate to other beneficiaries, the park visitors or non-consumptive users/beneficiaries of the Federal lands**.** Farmers, on the other hand, do benefit from the place, soil quantity and quality, climate etc. for the production of crops (loosely defined) from which they derive well-being (i.e., get paid for producing after entering into a large and complex series of economic production functions). The farmer interacts directly with the land for his/her well-being, while the Land Manager interacts with the land in response to others' interests. Therefore, while Land Manager was retained as a type of beneficiary in the group products described in this report, its future utility as a beneficiary type is arguable.

One of the stated purposes of the workshop was to develop products EPA might consider useful in illustrating the potential benefits and value to the public of emission reductions of nitrogen and sulfur pollutants which contribute to acidification and eutrophication of ecosystems. EPA will have many factors to consider in weighing their potential approaches to the secondary standards review for NOx and SOx, and therefore it is unknown whether products developed during the course of this workshop will be explicitly presented or referenced in the science, risk or policy assessments for the review of these standards. However, participants uniformly praised the workshop products as demonstrating significant progress in making connections between air pollution induced acidification and eutrophication, and ecosystem services, and felt that the chains had great potential in setting the foundation for future work which could provide information the EPA needed to continue to make progress in this area.

Box 3: How a rain of fertilizer caused a reign of fire

Nitrogen deposition is like fertilizer raining down out of the sky. Just as the fertilizer that people put on their lawns causes them to be lush and grow quickly, atmospheric deposition of excess nitrogen can cause invasive grasses biomass to increase exponentially in natural areas, where they don't belong. In Joshua Tree National Park, a desert area in southern California, nitrogen deposition has caused non-native grasses to increase so much that they can now carry fire across some parts of the landscape. Park managers are now preparing for increased fire in the park, and it is unknown what will happen next, as large, intense fires have never been observed there since the establishment of Joshua Tree National Monument in 1936.

This workshop linked nitrogen induced invasive grass species to 12 different potential beneficiary groups.

Next steps

At the conclusion of the workshop, participants brainstormed the next steps necessary to make the information developed more accessible and functional for users. The key steps were:

- Identify research which would be needed to fill gaps within the chains, perhaps focusing on those chains containing many beneficiaries, or strong chains with one weak scientific link, or chains where a beneficiary group is particularly important (e.g. where strong advocacy from that group exists, or where many people are affected over a broad geographic area).
- Review and standardize the SOS scoring system to develop consistency in approach between groups including how to produce final scores for whole ecological production functions (based on the number of steps and scores of each step). A metric needs to be created to quantify the strength of the relationships in the entire chain so that chains can be better compared to one another based on their scientific integrity.
- Determine how the "FEGS metrics" might be used to characterize (quantitatively where possible) the relationship between changes in air quality and changes in FEGS.
- Use the National Ecosystem Services Classification System (NESCS) or similar tool to facilitate quantification and valuation (the "demand side") of the natural systems that provide ecosystem services now that this workshop has achieved preliminary progress on the "supply side" using the FEGS-CS tool. To do this the group recommended the following:
    1. Select chains for further analysis which contain services that benefit all humanity: clean air, clean water, sustainable soils (overarching ecosystem services that benefit all people).
    2. Select a few key chains with strong "strength of science" scores for benefit-relevant indicators ("monetary" and "non-monetary" valuation), using metrics which encompass societal benefits (e.g., # of people affected, % of area impacted).
    3. Consider the extent to which valuation of identified FEGS are "substitutable" within and between geographic areas.
    4. Evaluate the extent to which beneficiaries care about or understand the chains (strength of relationship between the FEGS and the beneficiaries) to identify where to focus efforts for the valuation step. Some resources are more readily identified by beneficiaries than others (education may increase the perceived value of the service).

5. Investigate the potential use of benefit-transfer methods to value various identified ecosystem services.

- Workshop participants can immediately begin to use products developed in this workshop as educational tools (e.g., land managers can use them to explain the importance of national park, national forest, and wilderness resources). Four examples with high confidence in the chains have been expanded upon in this report (see inset boxes). Other examples of high confidence chains suitable for educational tools can be found in the workshop spreadsheet. Highlights include:
    - Reduction of fall foliage viewing opportunities due to increased quaking aspen mortality from terrestrial eutrophication.
    - Loss of recreational opportunities such as fishing, boating or scenic enjoyment due to algae blooms resulting from aquatic eutrophication.
- Devote future efforts to more fully developing an understanding of the response curve following CL exceedance. In other words, what does the ecological response surface look like after the deposition loads are exceeded?
- Continue work begun at this workshop to elaborate upon the complexities of ecosystems. Some participants felt that we did not scratch the surface of the ecosystem services that could be lost, and that we need to focus future efforts on chains where services/components of system will be difficult to regain once lost.
- Explore the role of biological substitution in future economic valuations. We do not yet have a good understanding of the degree to which loss or damage of resources from air pollution would be compensated by increase or substitution of other resources.

Box 4: Whoooooooo cares about lichen?

Some types of lichens are very sensitive to air pollution, and have disappeared from forests in the Pacific NW in areas where air pollution has increased just a small amount. Many of these same lichen species serve as critical food and nesting material for mammals and birds. For example, the northern flying squirrel relies exclusively on forage lichens as a winter time food source. In turn, the flying squirrel is almost the exclusive food source of spotted owl. The spotted owl is an endangered species and its recovery plan has been controversial, because of the associated estimated $3.6 billion in economic losses from logging and related industries that must be reduced for better habitat protection. Despite that investment, -owl populations are continuing to decline because of many factors. Air pollution may be one of these factors, as decreases in sensitive lichen species and flying squirrels have also been documented. So when excess air pollution causes declines in sensitive lichen species, the whole food chain may be impacted, all the way up to the endangered spotted owl!

This workshop linked lichen to 11 different beneficiary groups.

APPENDIX A: WORKSHOP PARTICIPANTS

Name	Affiliation	Expertise/Role
Sarah Anderson	Washington State Univ.	NSPIRE fellow: N issues (policy to science)
Mike Bell	UC Irvine	N effects/ critical loads on arid land systems
Drew Bingham	NPS (ARD)	NPS - author of ES journal articles
Tamara Blett	NPS (ARD)	NPS critical loads lead
Jim Boyd	Resources for the Future	Economist w/ expertise in ES
Frank Casey	USGS	Economist w/ expertise in ES
Chris Clark	EPA (ORD)	Critical loads & biodiversity
Jana Compton	EPA (ORD)	EPA ecosystem services and nitrogen (research)
Christine Davis	EPA (OAQPS/HEID)	EPA ecosystem services and air quality (policy)
Eric Davidson	Univ of MD Cent for Environ Sci	Biogeochemist; PI administering the NSF grant that is supporting the workshop
Mark Fenn	FS	N and S deposition effects on western terrestrial ecosystems, esp. CA
Linda Geiser	FS	Lichen and critical loads
Tara Greaver	EPA (ORD/NCEA)	Broad-based knowledge and experience assessing effects of N and S effects, acidification index
Andi Heard	NPS	Aquatic resources, biogeochemistry
Julie Hewitt	EPA (OW)	Economist with experience in ES
Cindy Huber	NADP	NADP - FOCUS critical loads project manager
Irina Irvine	NPS	N deposition effects on S. Cal ecosystems
Laurence Jones	UK-Env Ctr Wales	Critical loads (N,S,O_3) and links to ES in the UK
Dixon Landers	EPA (ORD)	EPA ecosystem services supply-side approach - FEGS
Jason Lynch	EPA (OAR)	CLAD -critical loads database and surface water data expert
Claire O'Dea	FS	Forest Service use of critical loads
Jen Phelan	RTI	Critical loads and forest soils cycling
Charles Rhodes	ORISE Post-doctoral Fellow	Economist with specialization in ecosystem services classification
Robert Sabo	Univ. of MD, Appalachian Lab	N effects to forests in Mid-Atlantic region
Tim Sullivan	E&S	Published on critical loads links to ES, soil and water chemistry and CL expertise
George van Houtven	RTI	ES demand-side approach- NESCS
Randy Waite	EPA (OAR)	NOx/SOx secondary standards

APPENDIX B: WORKSHOP AGENDA

Tuesday, February 24, 2015

Complementary continental breakfast at hotel

7:30am: Meet in hotel lobby for transport to meeting venue

8am -12pm: Workshop Kick-Off and Orientation

- Welcome – Tamara Blett/Eric Davidson
- Logistics – Irina Irvine
- Purpose of the workshop, roles of the participants, agenda and expected products. – Tamara Blett
- Introductions
- Presentations to help create a common understanding of critical loads, ecosystem services and what EPA needs in terms of ecosystem response functions to make these links useful.
    - History and Background: Ecosystem Services - *Jim Boyd*
    - Applying Final Ecosystem Goods and Services - *Dixon Landers*
    - Critical Loads Overview: definitions, available data, and how CLs can be used – *Tamara Blett*
    - Setting the stage for regulatory action: What does EPA need? – *Randy Waite/Tara Greaver*

Noon – 1pm: Lunch on-site

1pm – 5pm: Conceptual Framework for Creating the Links

- Share a list of consistent terminology and definitions to be used.
- Share and discuss the process that will be used to create the links, or Chains, between existing biological indicators and specific ecosystem services.
- Work through an example of the process with the entire group.
- Break into four small groups (aquatic acidification, aquatic eutrophication, terrestrial acidification and terrestrial eutrophication) to begin creating the links.

6:30pm: Evening: *Group dinner has been arranged at Brendan's Irish Pub:* Located at 495 N. Ventu Park Road, in the Palm Garden Hotel, about a 7 minute walk from our hotel. Dinner is

provided by the Reactive Nitrogen Research Coordination Network. However, you must pay for your own alcoholic beverages.

Wednesday, February 25, 2015

Complementary continental breakfast at hotel

7:30am: Meet in hotel lobby for transport to meeting venue

We will break into our smaller groups and work through the Critical Load-Ecological Chain-Ecosystem Service Matrix process for each biological indicator. This process will allow us to link specific CL biological indicators with specific ecosystem services. In the afternoon we will have a field trip.

8am – 12pm: Creating the Links

- Continue to create "CL to ecosystem services" chains
  - Subgroups produce Chains and associated Strength of Relationship (SOR) scores for each biological indicator.
  - Chain and SOR scores will be assigned, and posted, to the appropriate cell of a central ecosystem services matrix.

Noon: Box lunches will be provided at the office or field site.

Afternoon: Field Trip with Irina Irvine to learn about Nitrogen deposition and effects research in the Park

Dinner: On your own or join in with one of several small groups going to nearby restaurants.

Thursday, February 26, 2015

Complementary continental breakfast at hotel

7:30am: Meet in hotel lobby for transport to meeting venue

8am – 12pm: Using CLs to measure FEGS

- Small groups present their work.

- Explore how to translate CL exceedance into a change in ecosystem services.
  - Consider how CL exceedances affect the ecological conditions and ecosystem services, and especially the challenges of associating threshold responses (CL) to incremental or continuous changes in ecosystems.
  - Brainstorm on metrics that could be used to characterize the change in ecosystem services associated with critical load exceedances.
  - Realize that this discussion may have to be continued after the workshop.

Noon – 1 pm: *Lunch on-site*

1pm – 5pm: Follow Up – Telling the Story

- Review workshop findings.
- Brainstorm next steps, products that could be developed and how we could use those products.
- Discuss the workshop report (and journal article). Make assignments and set due dates.

Friday, February 27, 2015

Complementary continental breakfast at hotel

8-10am: Steering Team wrap up (Location To Be Determined)

APPENDIX C: DEFINITIONS

Term	Definition
acidification	
Acid neutralizing capacity	*ability of a solution to neutralize inputs of strong acid to a preselected equivalence.*
assessment criterion (chemical or biological criterion)	*parameter used to assess the biological response; could be chemical (e.g. stream ANC, soil base cation/aluminum ratio) or diversity based.*
beneficiaries	*the interests of an individual (i.e., person, group, and/or firm) that drive active or passive consumption and/or appreciation of ecosystem services resulting in an impact (positive or negative) on their welfare.*
beneficiary approach	*the classification of ecosystem services by Beneficiary [Sub-]Categories.*
benefits	*an impact, positive or negative, on human welfare.*
biological indicator	*selected organism(s) or populations sensitive to the effects resulting from changing loading of deposition.*
classification system	*an organized structure for identifying and organizing ecosystem services into a coherent scheme.*
Critical Load (CL)	*the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment are not expected to occur according to present knowledge.* *The threshold of air pollution deposition that causes harm to sensitive resources in an ecosystem.*
critical threshold	*the value of the assessment criterion parameter, or combination of parameters, that does not cause a significant harmful response in the biological indicator.*
ecosystem attributes	*a biological, physical, or chemical characteristic or feature inherent to an ecosystem/environment.*
ecosystem services	*a general term used to refer to "the benefits people obtain from ecosystems[20]". A variation of this general term is "ecosystem goods and services" (EGS). Ecosystem services, used in this general way, is all-inclusive, and may include along with final services, ecological processes and functions (sometimes referred to as intermediate services), among anything within the environment.*

[20] Millennial Ecosystem Assessment (MA). 2005. Ecosystems and Human Well-Being. Island Press, Washington. 155pp

Term	Definition
ecological effects (of N and S deposition)	*acidification or eutrophication*
eutrophication	*the process by which an ecosystem (aquatic or terrestrial) becomes enriched in nutrients that stimulate the growth of specific species.*
Final Ecosystem Goods and Services (FEGS)	*"components of nature, directly enjoyed, consumed, or used to yield human well-being" (Boyd and Banzhaf, 2007). The final ecosystem service is a biophysical quality or feature and needs minimal translation for relevance to human well-being. Furthermore, a final ecosystem service is the last step in an ecological production function before the user interacts with the ecosystem, either by enjoying, consuming, or appreciating the good or service, or using it as an input in the human economy.*
Final Ecosystem Goods and Services Classification System (FEGS-CS)	*a tool designed to be used by environmental and land management policy makers to develop the supply-side information on the natural systems that provide ecosystem services. It has been developed to identify ecosystem classes and subclasses and the beneficiary class and sub classes that interact with an ecosystem component.*
FEGS Matrices	*a collection of 15 tables that represents the FEGS-CS, in which, for a specific Environmental Sub-Class, beneficiaries and sets of FEGS are identified and described.*
intermediate ecosystem goods and services	*ecological processes, functions, structures, characteristics, and interactions that are essential to the environment and the production of Final Ecosystem Goods and Services, but that are not directly enjoyed, consumed, or appreciated by beneficiaries.*
Metrics and indicators	*a direct or indirect measurement of a FEGS that can be consistently and reliably related to a FEGS. There can be multiple metrics and indicators for a single FEGS, possibly necessitating the aggregation and weighting of metrics and indicators into an index.*
Non-use	*appreciates the its consuming or even interacting with the existence of an ecosystem, resource, or species without the expectation of ever using or experiencing the ecosystem, resource, or species – including any desire to reserve the option for future use or bequest*
production function	*models of the relationship between inputs and factors of production to production outputs. In the case of ecosystem services, there can be both ecological production functions, relating to natural structure and function (Daily and Matson 2008), and economic production functions, relating to human capital and economic products.*
nitrogen saturation	*the availability of mineral nitrogen in excess of biotic demand.*
subsister	*a beneficiary that relies on the environment's abundance [for water, food, timber, fiber, and fur, and/or building materials) as a major supplement to their livelihood.*
viewscape	*a scene in its entirety within a range of sight, which may include components such as ridgelines, peaks, open meadows, or a "patchwork" of (human-tended, or agricultural) fields.*

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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