Connecting Nitrogen Deposition and Final Ecosystem GOODS and SERVICES for Air Quality Standards Review
The U.S. Environmental Protection Agency (EPA) is currently reviewing the secondary National Ambient Air Quality Standards (NAAQS) for oxides of nitrogen and sulfur (NOx and SOx). In addition to the primary NAAQS based on human health effects, the Clean Air Act calls for setting secondary standards based on the adverse effects on public welfare, defined as effects on “soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation” (section 302h, Clean Air Act 1970 [CAA]). These standards are reviewed every five years for their adequacy based on the current state of the science. While the statute has been in existence for 40+ years, scientists are continually improving our understanding of air quality effects. This article discusses new research to create a framework that allows for a fuller quantification of air pollutant impacts on many aspects of public welfare.

Nitrogen (N) emission to air and subsequent deposition to land and water can affect terrestrial and aquatic ecosystems directly by changing their chemistry and indirectly by changing their structure and function through chains of events that affect plant or microbial community composition, fire susceptibility, and soil properties. Key changes in ecosystem structure and function can result in impacts that are important to the public, including negative effects on recreation, drinking water, timber production, wildlife viewing, hunting, climate stability, fire risk and human “non-use” values associated with the existence of intact, natural ecosystems. Figure 1 illustrates how these adverse effects occur along the N cascade and then connect to ecosystem services and human beneficiaries. Daily (1997) defined ecosystem services as the “conditions and processes through which natural ecosystems and species therein sustain and fulfill human life or have the potential to do so in the future.” While this definition is a useful starting point for discussion, recent work is expanding our ability to quantify ecosystem services in a way that can be used for policy and regulatory endpoints that benefit people.

The prior secondary NAAQS review process began to explore the potential for incorporating the concept of ecosystem services to represent public welfare impacts (U.S. EPA 2008). The science connecting ecological research, in terms of the ecosystem service supply, to human demands for and impacts on ecosystem services is relatively new. While the concept of ecosystem services includes many of the public welfare issues described in the CAA statute, some authors have pointed out that there are few examples of scientifically defensible accounting frameworks that have linked ecosystem services to decision-making (Daily et al. 2009; Jordan et al. 2010). Emerging work is beginning to develop more precise and useful concepts and definitions regarding ecosystem services. Boyd and Banzaf (2007) defined Final Ecosystem Goods and Services (FEGS) as those components of nature, directly enjoyed, consumed or used to yield human well-being. There has been an effort to identify the mechanistic links between N and ecosystem services (Compton et al. 2011; Rea et al. 2013; Jones et al. 2013), and to develop approaches to economically value the impacts of N on ecosystem services (van Grinsven et al. 2013; Sobota et al. 2015). Developing a framework that makes the connections between N deposition and FEGS explicit can inform our regulators by clearly illustrating the impacts of N deposition on important issues for public welfare. Here we describe the FEGS concept and how it can be applied to the air quality standards review process, and provide some examples of some of the currently quantifiable damages to ecosystem services from N deposition in the U.S.
Application of the FEGS framework to policy and decision-making

During the initiation of EPA’s Ecosystem Service Research Program in 2008, research and policy staff began to explore the use of the ecosystem services concept for cost/benefit analysis and other regulatory needs. This required a system for defining and classifying ecosystem services that was: 1) relatively complete; 2) minimally duplicative; 3) linked to beneficiaries; and which 4) facilitated metric identification. At the time, commonly cited definitions and uses for ecosystem services stemming from the Millennium Assessment (MA 2005) were found to be inadequate for many of the applications that EPA envisioned for ecosystem services. One of the major issues was that identifying what to measure as an ecosystem service was a difficult problem (Nahlik et al. 2012). Additionally, for useful accounting, the overlap or double-counting among various ecosystem services needed to be eliminated or minimized. Double-counting occurs when ecosystem processes, structure and function are combined in some ecosystem service and there is no way to efficiently and accurately separate them. To value ecosystem services (and perform cost-benefit and cost-effectiveness analyses), inform policy and management decisions that are relevant to human wellbeing, and effectively communicate, it is imperative to identify ecosystem services that are connected directly to what people value. Therefore, determining the connection between ecosystem services and value is as equally important as identifying their relationship with nature.

EPA staff proceeded to develop a new classification scheme based on the Final Ecosystem Goods and Services (FEGS) through the Nitrogen cascade (modified from Galloway et al. 2003 and Compton et al. 2011).
and Services perspective championed by Boyd and Banzaf (2007). This approach was published as a report and sets of FEGS tables that may be manipulated online based on the needs of a user (Landers and Nahlik, 2013). Each FEGS is identified in the EPA classification system (FEGS-CS) by a unique six digit number that represents the environment from which it was derived (e.g. lake, forest, grassland, created greenspace) and to whom it is a service. By defining who the specific beneficiary of this specific FEGS from nature may be, FEGS function as the hand-off from the natural to social sciences.

The FEGS concept can be used to distinguish the production function that is mainly ecological in nature from the other inputs that are mainly economic (Figure 2). The ability to define and identify FEGS and the specific biophysical components of goods and services that are derived principally from nature across the landscape is a considerable advancement in the understanding of ecosystem services. The Final Ecosystem Goods and Services Classification System (FEGS-CS; Landers and Nahlik, 2013) provides the detailed rationale for such a system and the principles on which the FEGS-CS was based. This new classification system is a critical foundation for measuring, quantifying, mapping, modeling, and valuing ecosystem services, as well as for other ecosystem service-centric activities that are dependent on a defined and rigorous framework.

As Figure 2 illustrates, there are myriad intermediate ecosystem services (often processes and functions) represented in the ecological production function that are vital to the production of FEGS. A large component of common benefits derived by people, such as agricultural products or even drinking water, are typically not attained until there is some significant input of labor and/or capital goods (for example human capital to plant and harvest crops, or to treat and deliver drinking water). These benefits are not predominantly ecological in nature, since they result from the addition of human capital. However, since we can identify the beneficiaries for specific FEGS, we can determine those ecosystem attribute(s) associated with the specific FEGS that the beneficiary values, and these can directly lead to identifying appropriate metrics and indicators for FEGS. The FEGS, therefore, represent those goods and services that are largely environmentally derived without major inputs of human capital.

The FEGS-CS is a good way to link potential beneficiaries of air quality to human well-being directly through human health impacts relevant to the primary NAAQS, or indirectly through the N cascade, where air-mediated impacts such as deposition of acids and N cause changes in the environment that people care about. The FEGS-CS can be used to directly identify specific beneficiaries and to hypothesize what it is that they appreciate or value in the environment that is altered by acidic deposition and/or nutrient deposition. Many of these impacts have links to timber production, recreation, water quality and climate stability that benefit foresters, recreationists, residential land owners and all humans (Figure 1). Making these connections quantitatively requires interdisciplinary thinking and systems research described in the next section.

Figure 2. Connections between the environment, beneficiaries and ecological production functions, and economic production functions that lead to human well-being and economic values.
Measuring damages to ecosystem services from N deposition

There are a number of pathways for effects of N deposition on ecosystem services and beneficiaries (Figure 1). These impacts can be broadly categorized into effects on air quality, climate and UV regulation, and effects on terrestrial, freshwater, groundwater and coastal systems. Nitrogen deposition intersects with climate regulation in a number of ways, directly by increasing the production of the important greenhouse gas nitrous oxide ($N_2O$), and indirectly through impacts on net carbon storage in plants and soils (Liu and Greaver 2010). $NO_x$ also causes ozone formation, which impact production in crop and natural ecosystems; however in a regulatory sense this effect is covered through the ozone NAAQS, and is thus excluded from this discussion.

In terms of the impacts on ecosystem services, it is important to focus on the internal components of Figure 1. Nitrogen deposition can alter the structure and function of terrestrial ecosystems through eutrophication and acidification. Eutrophication can alter the internal N cycle of terrestrial ecosystems, which in turn can result in changes in species composition, altered organic matter storage, increased herbivory, increased N leaching, increased fire risk and changes in net carbon storage (Fenn at al. 2003; Rao et al. 2010; Jones et al. 2014). Acidification in terrestrial ecosystems can alter soil pH, organic matter dynamics, metal dynamics, forest growth and species composition. These impacts can change climate stability and water quality, and can feed into changes in aquatic ecosystems via effects on pH and cycling of metals (Greaver et al. 2012).

Impacts on the terrestrial landscape could connect to multiple beneficiaries. For example, foresters could be affected where species composition or forest production is altered by acidification or nutrient enrichment; recreational users could be affected by reductions in visibility or changes in the habitat that alters wildlife viewing or hiking aesthetic qualities (Banzhaf et al. 2006). Recent work in Europe revealed significant economic benefits of N reductions on recreation (Jones et al. 2014). Nitrogen deposition can alter plant species composition to annual exotic grasses and, in turn, wildfire risk in some areas like these coastal sage scrub and chaparral ecosystems in the Santa Monica Mountains National Recreation Area in California.
Impacts on freshwater and coastal ecosystems can be difficult to directly connect to N deposition because often N inputs to these systems come from various sources other than deposition. Also, in many cases a complete set of potential beneficiaries is undefined and therefore unknown. Based on previous work mapping of N inputs to watershed units (HUC8), we estimated the contribution of N deposition to total N inputs to these watershed units in the U.S. (Figure 3a). Across most of the U.S., at least

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20% of the anthropogenic N inputs to the U.S. landscape derived from deposition; the exception is the midwestern and western U.S. where agricultural activities dominate N inputs (Figure 3b). In forested areas, at least 20% and sometimes more than 40% of the N comes from deposition, representing an important input of N to the landscape. In streams and lakes where atmospheric N is a dominant source of N loading to the landscape, N deposition altered stream species composition, N concentrations, organic matter dynamics and denitrification (Baron et al. 2006; Elser et al. 2009). Given that N deposition is an important component of total loading to watersheds across the U.S. (Figure 3), approaches that link impairment of waters to N loading by source is a key research need.

In order to inform the use of the ecosystem services concepts in the current NOₓSOₓ secondary NAAQS review process and to develop greater connectivity between clean air and nature's benefits, EPA and the National Park Service (NPS) convened a workshop on Air Quality and Ecosystem Services (AQES) in February 2015. The AQES workshop convened a diverse group of 27 scientists and environmental policy makers from EPA, NPS, USGS, USFS and university and private entities in order to identify linkages between existing critical loads for atmospheric deposition and FEGS. Critical loads represent the point at which ecosystem processes and characteristics begin to be impaired (http://nadp.sws.uiuc.edu/lib/brochures/criticalloads.pdf). When critical loads are exceeded by current atmospheric deposition, human welfare benefits may be altered, and in some cases impairment of ecosystem services may occur. A critical load does not, however, provide a measure of impairment of ecosystem services or of economic value to the people concerned by the impairment (beneficiaries). The workshop explored a process to link biological indicators to the ecological conditions that support or lead to FEGS. This group adopted the Final Ecosystem Goods and Services Classification System/FEGS-CS as their starting point for connecting thresholds of N and sulfur loading. Subsequently, we identified metrics and beneficiaries to characterize change in specific final ecosystem goods and services that occur when critical loads are exceeded. Final products of the workshop will include a report and journal articles.
Summary
There has been an increased effort to document changes in ecosystem structure and function in response to changing N deposition, and a picture is beginning to develop that connects the specific effects to beneficiaries of these changes in the ecosystem (Chesnut and Mills 2005; Banzhaf et al. 2006; Evans et al. 2008; Compton et al. 2011). In spite of this renewed interest, the 2011 NAPAP assessment concluded that current information about response of ecosystem services related to changes in N and sulfur deposition was insufficient to examine in a comparable way to human health and cost information (Burns et al. 2011). Making these linkages will require more ecological and economic research that allows adequate assessment of economic benefits to ecosystem services of changes in N and sulfur deposition. Using a FEGS framework in addressing these questions will allow researchers to make these connections to the beneficiaries and ultimately to economic valuation. More study is needed at local and regional scales to identify the specific damages and benefits associated with N and S emissions and deposition. And as more studies are completed, they can be placed into the FEGS-CS systems-level framework for identifying beneficiaries in order to economically value the effects of N deposition on ecosystem services.

References

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