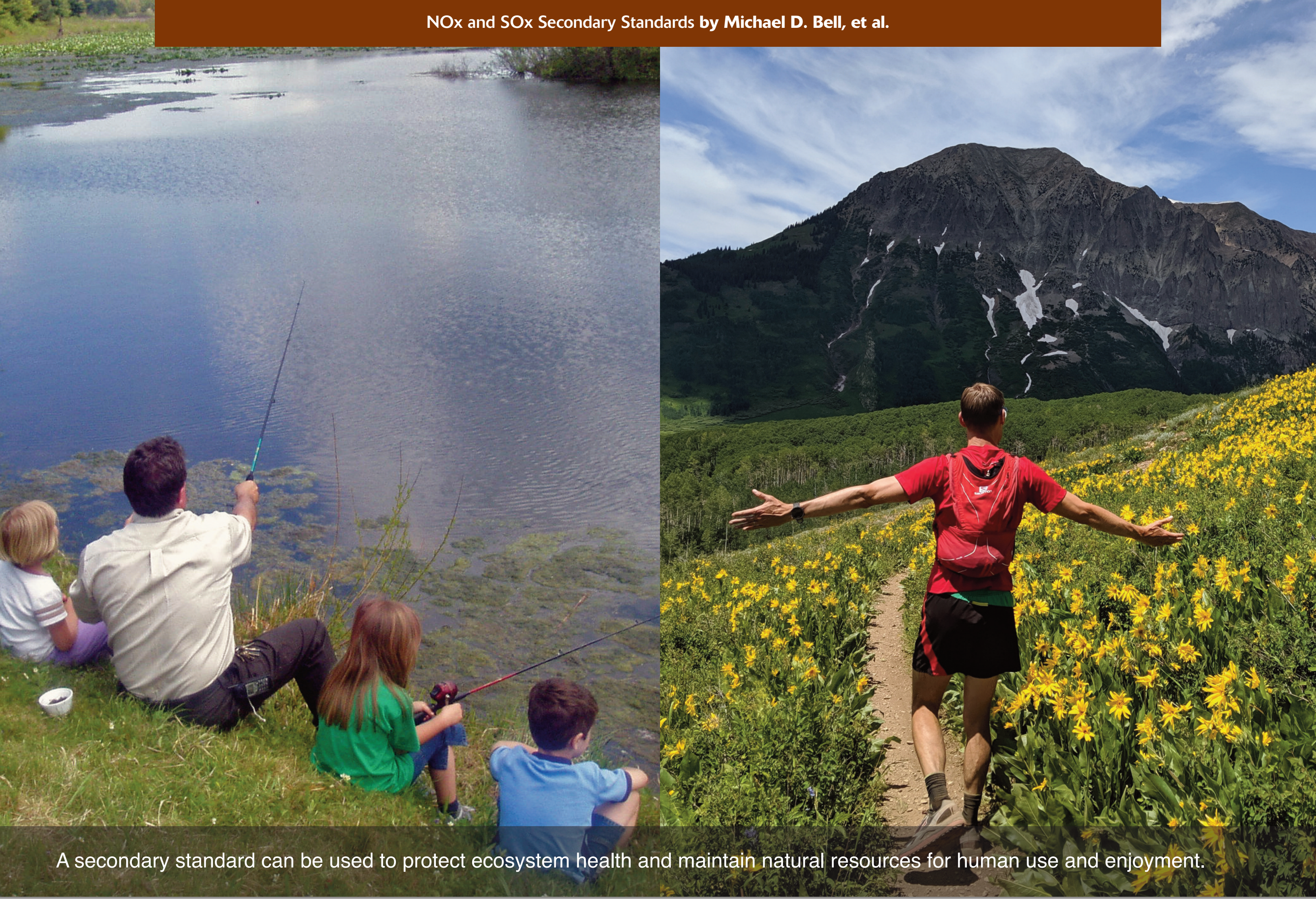

A secondary standard can be used to protect ecosystem health and maintain natural resources for human use and enjoyment.

Secondary Standards for NOx and SOx

Can Help Protect Natural Resources on Federal Lands

by Michael D. Bell, Emmi Felker-Quinn, Linda H. Pardo, Bret A. Schichtel, John C. Vimont, and Jennifer L. Wilkening

This article considers the urgency of additional NOx and SOx emissions reductions through the implementation of secondary standard regulations to protect sensitive ecosystems

The U.S. Clean Air Act requires the U.S. Environmental Protection Agency to set secondary National Ambient Air Quality Standards (NAAQS) to protect the public welfare from known or anticipated adverse effects associated with the presence of various air pollutants, including the oxides of nitrogen (NOx) and sulfur (SOx). The NOx and SOx secondary NAAQS levels were originally set in 1971 and were retained after a review in 2012. These secondary standards are intended to protect vegetation against high ambient concentrations that can cause leaf damage, decrease plant growth, and make plants more susceptible to drought and pests; all of which can reduce crop yield.[1-3] However, the secondary standards do not address or prevent the widespread and well-characterized effects of deposition of NOx and SOx to terrestrial and aquatic ecosystems.

When deposited onto sensitive ecosystems via wet (rain, snow) or dry deposition (gaseous, dust), NOx and SOx alter the chemistry of soil and water, leading to acidification and eutrophication that impair the growth and survival of individual plant and animal species and alter competitive dynamics within communities.[4,5] Preventing air pollution impacts is particularly urgent in the face of other threats to conservation, including climate change and resulting biodiversity decline.[6] Recent research shows that reductions in nitrogen pollution could prevent predicted biodiversity declines associated with rising temperatures in terrestrial and aquatic communities.[7,8] NOx and SOx deposition also diminishes the benefits that healthy ecosystems provide to humans, including, but not limited to, improved water quality, outdoor recreation, artistic inspiration, and timber harvest.[9,10] Therefore, an ecologically relevant secondary standard that can be directly related to deposition would more closely align with public well-being as well as with the legal responsibilities and policies of other federal agencies.

The National Park Service (NPS), U.S. Forest Service, and U.S. Fish and Wildlife service are mandated to protect natural resources for the enjoyment, education, and inspiration of current and future generations through legislation, including the NPS Organic Act and the Wilderness Act. These federal land managers (FLM) use critical loads (CLs) to assess and mitigate risks to ecosystems from NOx and SOx deposition.[11] A CL is the threshold of air pollution deposition below which harm to an ecosystem component does not occur.[12] Critical loads are currently calculated for nitrogen (N) and/or sulfur (S) for a diverse set of ecological components.[13]

Recent research on North American CLs has advanced the science and generated national and regional datasets that provide spatially explicit data on how sensitive resources—herbaceous communities,[14] epiphytic macrolichen communities,[15] individual tree species,[16] and individual herbaceous species[17]—respond to N and/or S deposition. Important commonalities across these CL datasets are that each considers environmental variation, such as temperature and precipitation, which may serve to extend their application beyond air pollution into models examining ecological effects of climate change. Also, each CL dataset derives a threshold for optimal growth/survival/richness from extensive field surveys collected over a range of ambient deposition values.

Comparing Deposition Rates to Critical Load Values

To understand if an ecosystem is at risk of harm from air pollution, researchers and FLMs compare the current rates of N and S deposition at a location to the CL values associated with that site. When deposition exceeds a particular CL there is increased risk of harm to the target ecological component. Importantly, as the magnitude and duration of an exceedance increases, the relative harm to the ecosystem component increases following modeled responses. Once a CL is exceeded, the ecosystem begins to change; so lowering pollution levels may not immediately lead to recovery, due to a shift in the biological community toward pollution tolerant individuals, loss of pollution sensitive individuals, or changes in soil or water chemistry.[18,19] Thus, it is beneficial to keep deposition levels below these threshold values where they are not yet exceeded. However, even in places where many CLs are exceeded, a reduction in deposition would be expected to improve growth, survival, or abundance of sensitive species, even if future deposition remains above their defined CLs.

Figure 1 shows the variation of CLs of N for the ecological components identified above and the level of exceedance of each critical load based on the 2018–2020 average total N deposition from the National Atmospheric Deposition Program (NADP) Total Deposition Model.[20] For example, the CL of N for a N-sensitive epiphytic lichen species richness is a uniform 3.1 kg-N ha^{-1} yr^{-1} across forested ecosystems and prevents a decline of more than 20% in richness; which is the level of loss determined to harm animals that use lichens to forage or for nests (Figure 1A).[15] The modeled response to N also includes the level of deposition that correlate to 0%, 10%, 50%, and 80% declines in lichen species richness, so the exceedance map helps identify where increased loss is expected to occur.

Similar to the lichen CLs, the CL of N for a decline in herbaceous community richness is applied to appropriate landcover types; yet in this instance the CLs fluctuate with local soil and climate conditions (Figure 1B).[14] The resulting CLs range from 6 to 23 kg-N ha^{-1} yr^{-1} and represent the level of deposition that correlates to a shift in community composition due to the local environmental conditions. The increasing exceedance of the CL creates a competitive advantage for species capable of using additional nutrients leading to additional loss of species richness.

The maps for herbaceous species (Figure 1C) and tree species (Figure 1D) present the minimum CL value of all species present at a location, thus protecting all species at a site known to respond to N for the corresponding vegetation class. As the exceedance of the minimum CL increases, the

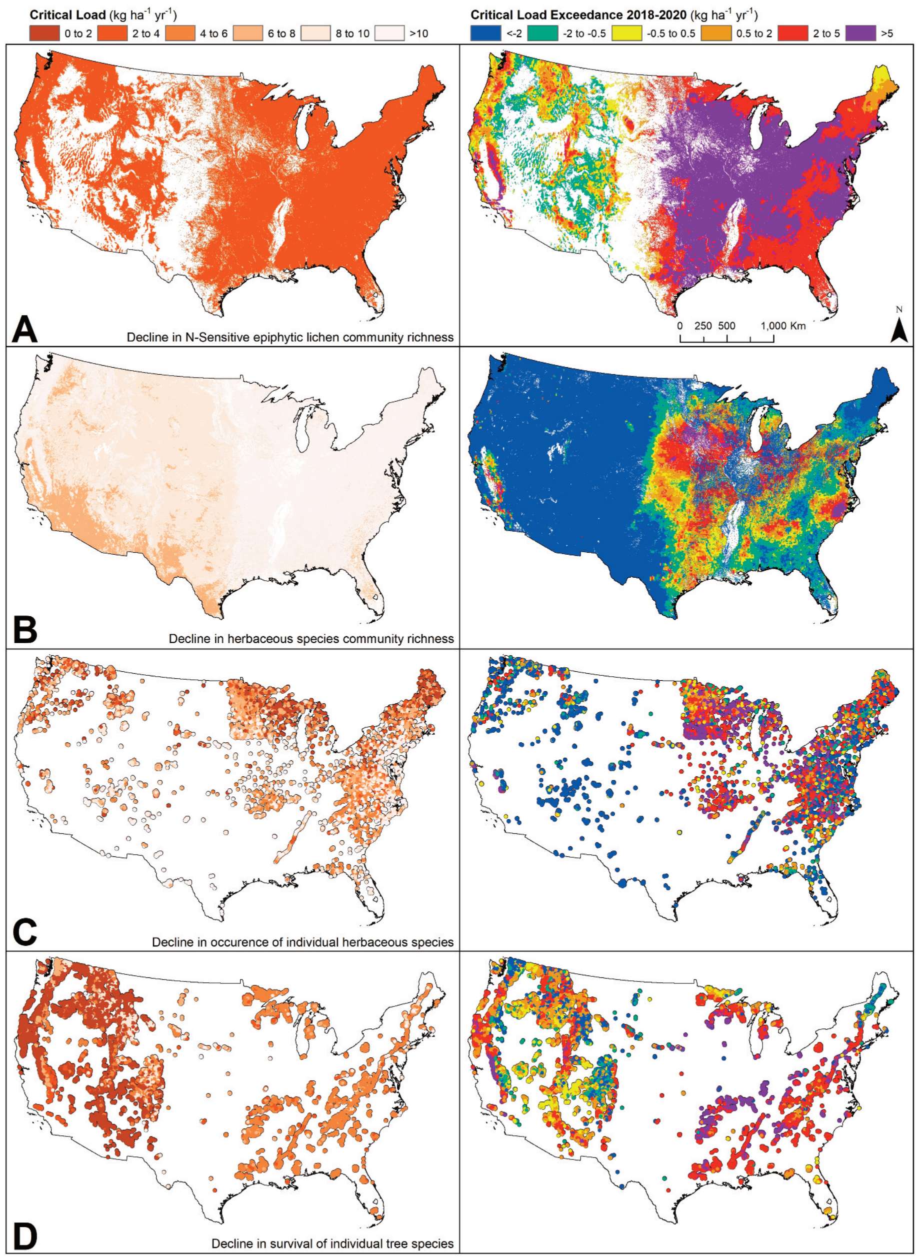

Figure 1. The left column shows the variation of CLs of N for A) N-sensitive epiphytic microlichen species richness, B) a decline in herbaceous species richness, C) tree species survival, and D) decline in herbaceous species presence. The right column shows the level of exceedance of each of the CLs based on the 2018–2020 average total N deposition from the NADP Total Deposition Model (NADP 2022[10]).

level of harm and the number of species impacted also increase. Local environmental conditions can change the level of N that leads to a response in an individual species, so managers can use this data to evaluate the health of the community and the health of a species across its range.

When CL exceedances occur on federally managed lands, the FLM is often unable to request emission reductions from pollution sources that are causing the problem. Instead, they must rely upon the U.S. Environmental Protection Agency and states who have the regulatory authority to implement control strategies. The secondary NAAQS could provide a mechanism that the FLM can use to work with these regulators to implement emission controls needed to mitigate the problems.

Further Emissions Reductions Needed

Over the past 30 years, emissions of NOx and SOx have decreased by a factor of 2.5 and 8, respectively,[21] due in part to the effective implementation of the Clean Air Act. Many ecosystems across the United States have responded positively to the resultant reductions in NOx and SOx deposition, allowing tree health to improve and fish to return to previously acidified waters.[22,23] However, current deposition levels still cause declines in growth and survival of individual species and shifts in community richness. The diversity of ecosystems across the United States presents a challenge to identifying a single level at which to set a secondary NAAQS standard, but CLs and their current exceedances can be used as a tool to guide this decision. Using local, component-specific CLs is a superior option to regional-scale standards, similar to those established by Pardo et al.[4] because the increase in spatial resolution and species-specific responses identify areas and species that will need active management or pollution reduction to prevent harm. Protecting the most sensitive or ecologically relevant species and processes will provide broad protection to all wildland areas that have yet to be impacted by deposition and reduce the extent of impairment in ecosystems that are already in exceedance. **em**

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