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Editorial

Responses of Forest Ecosystems to Nitrogen Deposition

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Environmental legislation in countries around the world has led to notable recent declines in the atmospheric deposition of nitrogen (N), although most decreases relate to oxidized N, with reduced N increasing in many areas [1]. Still, deposition of N remains high in many regions globally. For areas where chronic atmospheric deposition of N has led to N saturation, excess N chronically threatens the structure and function of ecosystems. Indeed, critical loads for N remain widely exceeded for many forests, leading to a variety of deleterious effects, including loss of biodiversity and altered biogeochemical cycles, all of which threaten the sustainability of impacted forests [2]. It is likely that the recovery of N-impacted sites might require extended periods of time, especially in locations where base cations, such as Ca^{++}, have been depleted by accelerated NO_3^- leaching. Thus, understanding the potential responses of forest ecosystems to N deposition remains essential.

This Special Issue of *Forests* explores the multifaceted responses of forest ecosystems to both increases and decreases in N deposition on a global scale. This includes effects on plants and plant assemblages, as well as effects of N on forest biogeochemistry, and comprises studies from Asia, Europe, and North America.

Certainly, the fundamental paradigms of N cycling in terrestrial ecosystems have shifted greatly over the past several decades [3], and N has been the focus of extensive research as both basic and applied science. More recently and more specifically this has been carried out by biogeochemists, extending from the discovery of N as an element in 1772, to its central place in von Liebig's Law of Minimum for plant growth articulated in 1827, to the discovery of symbiotic N fixation in 1888, to the development of the Haber-Bosch process in 1913 (initiating of its use as fertilizer in crop production), and finally to the present awareness that excess N in the environment can alter the structure and function of ecosystems [4].

Chronic N deposition has been an environmental threat throughout most of Asia. In Japan, research has demonstrated that effects of excess N can include trophic interactions involving tree foliar tissue and defoliating insects, which can be particularly notable in N_2-fixing trees [5]. Excess N also influences the biogeochemical cycles of tropical Asian forests. Experimental additions of N significantly inhibited mineralization of soil carbon (C) in tropical forest soils of southern China (the Dinghushan Biosphere Reserve—DHSBR), increasing concentrations of dissolved organic carbon [6]. Deposition of N can interact with that of other nutrients, e.g., phosphorus (P), to alter plant tissue nutrient stoichiometry, especially in humid tropical forests that are typically N-rich, but limited by P. Another factorial field experiment at DHSBR demonstrated that additions of P, rather than N, greatly altered foliar N and P concentrations in understory plants [7].

Europe has long experienced excess N deposition from increased emissions of gaseous N from industrial, domestic, and agricultural sources. Long-term (~30 yr) data from the Australian Alps has shown that, although N deposition approximated or exceeded critical loads, >80% of this was retained in the ecosystem, maintaining lower hydrologic N loss; tree growth was identified as the main sink for N [8]. Indeed, forest dynamics often mitigate effects of high N deposition, including the response of soil nutrient cations, i.e., Ca^{++}, Mg^{++}, and K^+. Work in hardwood and conifer stands of central Germany found

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significant differences between these stand types regarding the effects of excess N on the biogeochemical cycling of these essential plant nutrients [9].

Most research on effects of excess N on forest ecosystems has been carried out via plot-based field designs which have the advantage of being fully factorial and involving replications, but the disadvantage of lacking realistic simulations of increased deposition of N from the atmosphere. Accordingly, whole-watershed manipulations, wherein N is applied from rotary or fixed-wing aircraft, are rare. Research at the Fernow Experimental Forest (FEF), Tucker County, West Virginia, comprises both plot-based and whole-watershed approaches, with aerial additions of $(NH_4)_2SO_4$ at 35 kg N ha^{-1} yr^{-1} to the treatment watershed beginning in 1989. Although this site is an eastern deciduous forest, results from over a quarter century have relevant implications for other forest types, as well [10,11].

Past and ongoing work at FEF is highly varied with respect to forest response variables. An unexpected outcome has been the discovery that excess N can make some hardwood species more susceptible to damage from storm-related winds, which has implications for climate change and the future of impacted forests [12]. Excess N can also greatly alter the species composition and diversity of forest herbaceous communities, which is where up to 90% of plant diversity is found in forest ecosystems [10,13,14]. Recent efforts have demonstrated that this response can vary greatly with stand age and dominant tree species [15]. Not surprisingly, the response of forest trees to excess N can be highly species specific, and work at FEF has shown that several hardwood species, such as sweet birch (*Betula lenta* L.), black cherry (*Prunus serotina* Ehrh.), and red maple (*Acer rubrum* L.) responded positively to N additions, whereas yellow poplar (*Liriodendron tulipifera* L.) responded negatively [16]. These species-specific responses have implications for ecosystem-level effects of N on forests, as some hardwood species, especially sugar maple (*Acer saccharum* L.), can facilitate greater loss of N, via leaching of NO_3^-, by enhancing rates of net nitrification [17].

Recent studies have speculated about the future of N-impacted forest ecosystems under conditions of decreased N deposition [1,18–20]. In 2019, aerial applications of NS ceased after 30 yr of treatment at FEF. This new phase of research at FEF now allows researchers the opportunity to test these predictions empirically [21], further advancing our knowledge and understanding of the complexity of N biogeochemistry in forest ecosystems.

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