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LETTER

Cost of reactive nitrogen release from human activities to the environment in the United States

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Abstract

Leakage of reactive nitrogen (N) from human activities to the environment can cause human health and ecological problems. Often these harmful effects are not reflected in the costs of food, fuel, and fiber that derive from N use. Spatial analyses of damage costs attributable to source at management-relevant scales could inform decisions in areas where anthropogenic N leakage causes harm. We used recently compiled data describing N inputs in the conterminous United States (US) to assess potential damage costs associated with anthropogenic N. We estimated fates of N leaked to the environment (air/deposition, surface freshwater, groundwater, and coastal zones) in the early 2000s by multiplying watershed-level N inputs (8-digit US Geologic Survey Hydrologic Unit Codes; HUC8s) with published coefficients describing nutrient uptake efficiency, leaching losses, and gaseous emissions. We scaled these N leakage estimates with mitigation, remediation, direct damage, and substitution costs associated with human health, agriculture, ecosystems, and climate (per kg of N) to calculate annual damage cost (US dollars in 2008 or as reported) of anthropogenic N per HUC8. Estimates of N leakage by HUC8 ranged from <1 to 125 kg N ha^{-1} yr^{-1}, with most N leaked to freshwater ecosystems. Estimates of potential damages (based on median estimates) ranged from \$1.94 to \$2255 ha^{-1} yr^{-1} across watersheds, with a median of \$252 ha^{-1} yr^{-1}. Eutrophication of freshwater ecosystems and respiratory effects of atmospheric N pollution were important across HUC8s. However, significant data gaps remain in our ability to fully assess N damages, such as damage costs from harmful algal blooms and drinking water contamination. Nationally, potential health and environmental damages of anthropogenic N in the early 2000s totaled \$210 billion yr^{-1} USD (range: \$81–\$441 billion yr^{-1}). While a number of gaps and uncertainties remain in these estimates, overall this work represents a starting point to inform decisions and engage stakeholders on the costs of N pollution.

Introduction

Human modification of biogeochemical cycles is essential to sustain food production and advance technology; but release of chemicals beyond these intended uses can harm human health, ecosystem function, and the global climate system (Bennett *et al* 2001, Galloway *et al* 2003, Davidson *et al* 2012, Leach *et al* 2012). Finding common measures to assess the damages of human-altered biogeochemical cycles has proven complex because of the diversity of effects, multiple spatial and temporal scales on which they are felt, and ambiguity over how alterations are caused by and affect stakeholders (Galloway *et al* 2003, Banerjee *et al* 2013, Ringold *et al* 2013). Additionally, many ecosystem service-related costs are not well