

14 SOUTHERN SEMI-ARID HIGHLANDS

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14.1 Ecoregion description

Most of the Southern Semi-Arid Highlands ecoregion occurs in Mexico, but a portion centered on the Chiricahua Mountains of Arizona and New Mexico lies in the United States. The ecoregion description is adapted from CEC (1997). Rainfall is 300 to 600 mm, with biseasonal distribution (winter and summer). The mountains are volcanic in origin, with valleys and plains of alluvial sediments. The area lies at the intersection of the Sonoran and Chihuahuan Deserts, the Rocky Mountains, and the Sierra Madre (CEC 1997, Fig. 2.1). Consequently, this region is high in plant and animal diversity, having components of all four ecosystem types. Vegetation includes desert grassland interspersed with desert scrub (especially mesquite [*Prosopis* spp.] and acacia [*Acacia* spp.]) at low elevations, oak (*Quercus* spp.) and juniper (*Juniperus* spp.) at intermediate elevations, and coniferous forests at high elevations.

14.2 Ecosystem Responses to N Deposition

Potential nitrogen (N) deposition impacts to the southern highlands are likely to be similar to those described for Mediterranean California and North American Deserts ecoregions (Chapters 13 and 12), where similar vegetation types occur. In the lowlands, ecosystem responses to N deposition might include increases in exotic species, an effect which can lead to the accumulation of fire-sustaining fuel loads and thus increased fire frequency and severity. Other potential effects to lowland ecosystems include alteration of mycorrhizal fungal diversity, abundance, and functioning; shifts in lichen communities; and alteration of biotic crust composition as reported for other desert areas (see Chapter 12).

At intermediate elevations, ecosystem responses to N deposition might include alteration of lichen community composition or functional groups. Further increases in N deposition might affect mycorrhizae and herbaceous plant communities.

In the uplands, ecosystem responses to N at current deposition inputs likely include changes in lichen communities. We hypothesize that if N deposition increased two- to threefold (to approximately 12 to 18 kg ha⁻¹ yr⁻¹), many effects reported for mixed conifer forests (see Chapter 13) would become apparent within a few years as N accumulates in the ecosystem. These expected effects would include elevated nitrate (NO₃⁻) leaching and nitrogenous trace gas emissions from soil, impaired root production, altered mycorrhizal community composition and function, increased susceptibility to pests, and possible effects on understory biodiversity.

14.3 Range of Responses Observed

As we were not able to identify U.S. studies documenting a particular ecosystem response at a given level of N input for this ecoregion, we focus instead on the reported deposition for the U.S. ecoregion and documented ecosystem responses not linked to a specific N level.

The Chiricahua National Monument, a semi-arid site with sparse vegetation cover, is designated a Class I airshed under the Clean Air Act, with management objectives of clear views to 100 miles in any direction (NPS 2006). Threats to air quality include smelting and power plants in Mexico, but especially future plans for power plants within 50 miles of the border. Because both smelting and coal-fired power plants produce sulfur oxides (SO_x), the greater ecological threats in past decades may have come from sulfur (S) rather than N deposition. However, based on temporal trends in the National Atmospheric Deposition Program (NADP) and Clean Air Status and Trends Network (CASTNET) data at the Chiricahua site, N deposition is now greater than S deposition. Sulfur emissions have decreased in this area since around 1999 (US EPA 2008b), when smelters in Playas, New Mexico, and Cananea, Sonora, Mexico, closed. Total S deposition over the past several years as reported by NADP and CASTNET

is approximately $1.2 \text{ kg ha}^{-1} \text{ yr}^{-1}$. Even if the dry deposition of S is underestimated, S deposition levels would still be considered low.

The NADP and CASTNET data report total annual N deposition of 2 to $3 \text{ kg ha}^{-1} \text{ yr}^{-1}$ over the past 15 years at the Chiricahua site (US EPA 2008a). Average annual precipitation at the monitoring site is approximately 400 mm. Reported values of wet N deposition are three times greater than those for dry N deposition, suggesting that the CASTNET modeling approach is underestimating dry deposition and thus total deposition, as has been reported by CASTNET data for other semi-arid sites in the western United States (Fenn et al. 2009). According to NADP data, wet deposition of ammonium (NH_4^+) is similar to wet deposition of NO_3^- . However, dry deposition of ammonia (NH_3) is not measured, and as a result, total N deposition is almost certainly greatly underestimated.

In our judgment, bulk N deposition at the Chiricahua NADP site is likely closer to 4 to $5 \text{ kg ha}^{-1} \text{ yr}^{-1}$. Depending on leaf area index, deposition to canopies in areas with significant vegetation cover would be even higher. Nitrogen deposition in this region was estimated to be 4 to $7 \text{ kg ha}^{-1} \text{ yr}^{-1}$, by the Environmental Protection Agency's Models-3/Community Multiscale Air Quality (CMAQ) model (Byun and Schere 2006) and 2002 emissions data (Fenn et al. 2003b). Based on these estimates, we hypothesize that N deposition in the Chiricahua National Monument occurs at levels that can affect sensitive ecosystem components such as lichen community composition. Other possible effects of incipient N enrichment are community shifts of annual plant species (Fenn et al. 2003a). However, lichen communities likely have also been affected by historical S emissions from copper smelters in the region.

In the San Simon Valley, near Portal, Arizona, and adjacent to the Chiricahua National Monument, the winter annual plant community has undergone marked community change associated with the sustained proliferation of stork's bill (*Erodium cicutarium*), the Eurasian invasive winter annual plant (Schutzenhofer and Valone 2006). As a result, winter annual plant diversity has declined drastically and species composition has shifted. Possible factors contributing to these plant community changes are changes in climate, including decreased winter precipitation and more frequent drought, N deposition from agricultural fields and copper smelters (Bytnerowicz 2009²²), and changes in the rodent community (Ernest et al. 2000). Preliminary atmospheric concentration data for NO_3^- and nitric acid (HNO_3) measured from December 2006 to January 2007 in the San Simon Valley were higher than expected for a remote site.²²

14.4 Future Research Directions and Gaps in Data

Little is known about the effects of N deposition in the Southern Semi-Arid Highlands, as they have not been studied. N deposition needs to be measured within the major ecosystem types. Ecological effects should be investigated by surveying for sites showing N accumulation and enrichment associated with N deposition. Sulfur deposition levels and effects from past and current S deposition should also be evaluated. Where lichen communities occur, they can be surveyed for community shifts and S and N accumulation as early sentinels of ecosystem change and response to air pollution.

²²Bytnerowicz, A. 2009. Personal communication. Ecologist, Pacific Southwest Research Station Forest Fire Laboratory, 4955 Canyon Crest Drive, Riverside, CA 92507.

LITERATURE CITED

- Byun, D.; Schere, K.L. 2006. **Review of the governing equations, computational algorithms, and other components of the Models-3 Community Multiscale Air Quality (CMAQ) modeling system.** Applied Mechanics Reviews. 59: 51-77.
- CEC (Commission for Environmental Cooperation). 1997. **Ecological regions of North America. Toward a common perspective.** Montreal, Canada: Commission for Environmental Cooperation. 71 p. Available at http://www.cec.org/files/pdf/BIODIVERSITY/eco-eng_EN.pdf (May 24, 2010).
- Ernest, S.K.M.; Brown, J.H.; Parmenter, R.R. 2000. **Rodents, plants, and precipitation: spatial and temporal dynamics of consumers and resources.** Oikos. 88: 470-482.
- Fenn, M.E.; Baron, J.S.; Allen, E.B.; Rueth, H.M.; Nydick, K.R.; Geiser, L.; Bowman, W.D.; Sickman, J.O.; Meixner, T.; Johnson, D.W.; and Neitlich, P. 2003a. **Ecological effects of nitrogen deposition in the western United States.** BioScience. 53: 404-420.
- Fenn, M.E.; Haeuber, R.; Tonnesen, G.S.; Baron, J.S.; Grossman-Clarke, S.; Hope, D.; Jaffe, D.A.; Copeland, S.; Geiser, L.; Rueth, H.M.; Sickman, J.O. 2003b. **Nitrogen emissions, deposition, and monitoring in the western United States.** BioScience. 53: 391-403.
- Fenn, M.E.; Sickman, J.O.; Bytnerowicz, A.; Clow, D.W.; Molotch, N.P.; Pleim, J.E.; Tonnesen, G.S.; Weathers, K.C.; Padgett, P.E.; Campbell, D.H. 2009. **Methods for measuring atmospheric nitrogen deposition inputs in arid and montane ecosystems of western North America.** In: Legge, A.H., ed. Developments in environmental science. Relating atmospheric source apportionment to vegetation effects: Establishing cause effect relationships. Vol. 9. Amsterdam: Elsevier: 179-228.
- NPS (National Park Service). 2006. **Chiricahua National Monument—air quality.** Washington, DC: U.S. Department of Interior, National Park Service, Chiricahua National Monument. Available at <http://www.nps.gov/chir/naturescience/airquality.htm> (Accessed May 12, 2010).
- Schutzenhofer, M.R.; Valone, T.J. 2006. **Positive and negative effects of exotic *Erodium cicutarium* on an arid ecosystem.** Biological Conservation. 132: 376-381.
- US EPA (U.S. Environmental Protection Agency). 2008a. **Clean air status and trends network—Chiricahua, total N.** Washington, DC: U.S. Environmental Protection Agency. Available at http://epa.gov/castnet/javaweb/charts/CHA467_totn.png (Accessed March 28, 2011).
- US EPA (U.S. Environmental Protection Agency). 2008b. **Clean air status and trends network—Chiricahua, total S.** Washington, DC: U.S. Environmental Protection Agency. Available at http://epa.gov/castnet/javaweb/charts/CHA467_tots.png (Accessed March 28, 2011).