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Review

Nitrogen critical loads and management alternatives for N-impacted ecosystems in California

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A B S T R A C T

Empirical critical loads for N deposition effects and maps showing areas projected to be in exceedance of the critical load (CL) are given for seven major vegetation types in California. Thirty-five percent of the land area for these vegetation types (99,639 km^2) is estimated to be in excess of the N CL. Low CL values (3–8 kg N ha^{-1} yr^{-1}) were determined for mixed conifer forests, chaparral and oak woodlands due to highly N-sensitive biota (lichens) and N-poor or low biomass vegetation in the case of coastal sage scrub (CSS), annual grassland, and desert scrub vegetation. At these N deposition critical loads the latter three ecosystem types are at risk of major vegetation type change because N enrichment favors invasion by exotic annual grasses. Fifty-four and forty-four percent of the area for CSS and grasslands are in exceedance of the CL for invasive grasses, while 53 and 41% of the chaparral and oak woodland areas are in exceedance of the CL for impacts on epiphytic lichen communities. Approximately 30% of the desert (based on invasive grasses and increased fire risk) and mixed conifer forest (based on lichen community changes) areas are in exceedance of the CL. These ecosystems are generally located further from emissions sources than many grasslands or CSS areas. By comparison, only 3–15% of the forested and chaparral land areas are estimated to be in exceedance of the NO_3^- leaching CL. The CL for incipient N saturation in mixed conifer forest catchments was 17 kg N ha^{-1} yr^{-1}. In 10% of the CL exceedance areas for all seven vegetation types combined, the CL is exceeded by at least 10 kg N ha^{-1} yr^{-1}, and in 27% of the exceedance areas the CL is exceeded by at least 5 kg N ha^{-1} yr^{-1}. Management strategies for mitigating the effects of excess N are based on reducing N emissions and reducing site N capital through approaches such as biomass removal and prescribed fire or control of invasive grasses by mowing, selective herbicides, weeding or domestic animal grazing. Ultimately, decreases in N deposition are needed for long-term ecosystem protection and sustainability, and this is the only strategy that will protect epiphytic lichen communities.

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1. Introduction

An estimated land area of 52,823 km^2 of California (13% of the state) is exposed to N deposition greater than 10 kg ha^{-1} yr^{-1} (Fig. 1). A significant portion of the Central Valley, and montane sites in the SW Sierra Nevada, and in southern California receive deposition inputs ranging from 15 to 20 kg ha^{-1} yr^{-1} or greater (Fig. 1; Fenn et al., 2008). Forests in the more exposed regions of southern California experience the highest N deposition in North America (30 to over 70 kg ha^{-1} yr^{-1}), while at the opposite end of the deposition spectrum in California large acreages of forests, woodlands, shrublands, grasslands, desert, high elevation ecosystems, and other ecosystem

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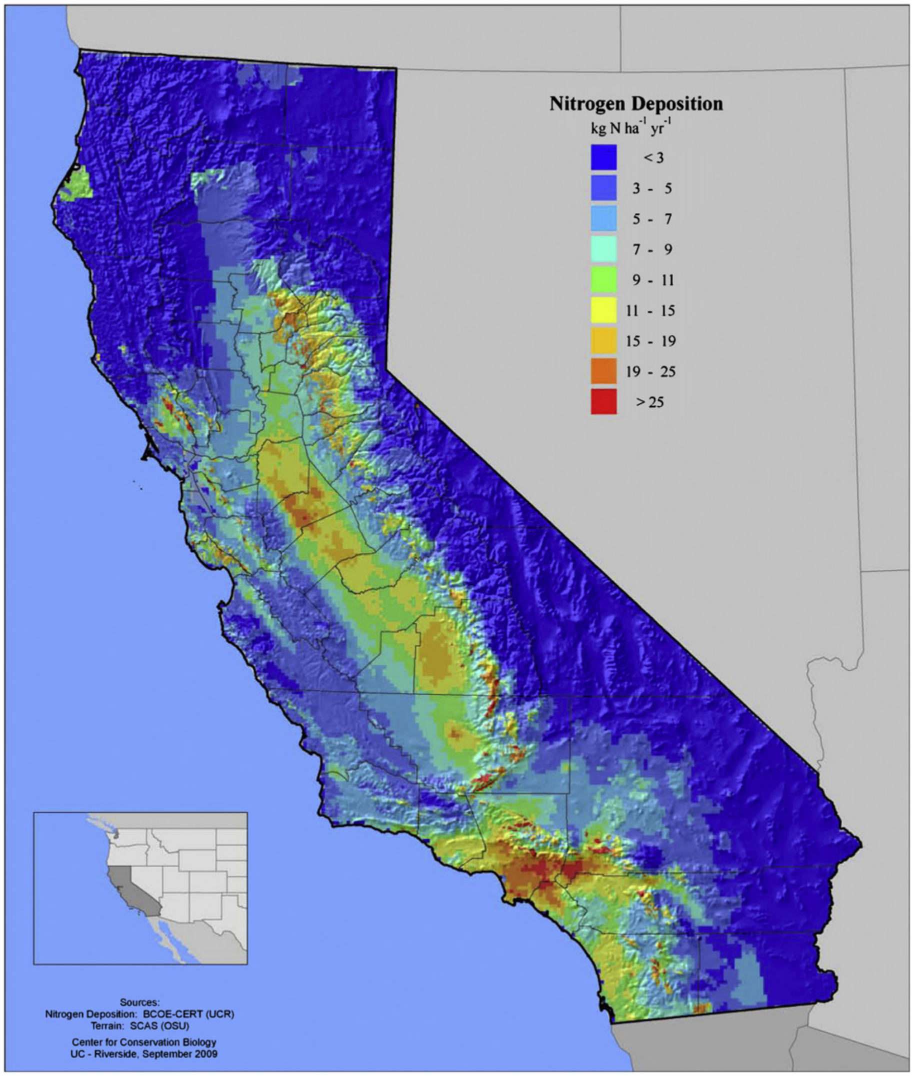

Fig. 1. Map of total annual N deposition in California based on CMAQ simulations. As described in the text, simulated N deposition in forested areas has been adjusted based on the linear relationship with empirical throughfall data.

types are exposed to low deposition (ca. 2–5 kg ha^{-1} yr^{-1}; Fig. 1; Fenn et al., 2003a, 2008).

Nitrogen emissions in California are 3–10 times greater than in the other ten western states (Fenn et al., 2003a). Emission estimates are more uncertain for ammonia (NH_3) than for nitrogen oxides (NO_x), but available data suggest that NH_3 comprises 20–30% of N emissions in California (Cox et al., 2009; Fenn et al., 2003a; USEPA, 2008). A recent study found that 25% of the N emissions from light-duty vehicles in three California cities are in the form of NH_3 and in newer cars this fraction increases (Bishop et al., 2010). Nitrogen deposition studies (Fenn and Poth, 2004; Fenn et al., 2003a, 2008) and monitoring networks of gaseous pollutants (Bytnerowicz et al., 2007; Hunsaker et al., 2007) suggest that NH_3 emissions in California are underestimated. Satellite observations of atmospheric NH_3 also show that concentrations are greater than previous data indicated in several regions of the world, including central and southern California (Clarisse et al., 2009). Emissions of NH_3 appear to be increasing as NO_x emissions decrease (Cox et al., 2009; Fenn et al., 2003a).

Eighty-six percent of NO_x emissions in California are from mobile sources and 11% from stationary sources. The largest source of NH_3 emissions is livestock waste, estimated as approximately 80% of the statewide emissions by the California Air Resources Board (Cox et al., 2009). However, as discussed above, on-road emissions appear to be a more important source of NH_3 emissions than the emissions inventories indicate (Bishop et al., 2010), particularly in urban areas (Battye et al., 2003) or near highways (Fig. 2). In montane and desert regions downwind of greater Los Angeles and in the Central Valley of

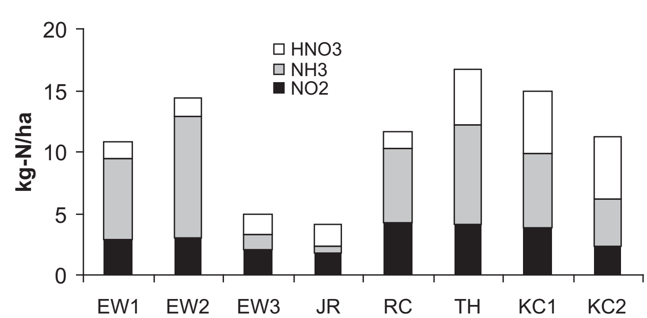

Fig. 2. Passive sampler estimates of dry gaseous deposition at serpentine grassland sites. The Edgewood sites (EW) are from a local gradient adjacent to Highway 280. From these sites the critical load was derived.