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Effects of Nitrogen Deposition on Sensitive Species and Habitats Resulting from the Southern California Association of Governments Regional Transportation Plan

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The Southern California Association of Governments (SCAG) prepared a long-range Regional Transportation Plan (RTP) and associated Program Environmental Impact Report (PEIR). The plan is known as Connect SoCal and includes over \$650 billion in future transportation infrastructure. The Center for Biological Diversity has retained us to evaluate the potential impacts of nitrogen deposition from transportation sources on sensitive habitats and species within the project region.

Deposition of nitrogen on natural lands represents a significant threat to sensitive resources (Bytnerowicz and Fenn 1996, Allen et al. 1998, Weiss 1999). Nitrogen is, quite literally, fertilizer and its presence encourages growth of plants that are nutrient limited. For southern California scrublands and grasslands, the addition of excess nitrogen promotes the growth of nonnative, invasive grass species. The PEIR does not assess the impacts of this adverse impact on sensitive natural resources, including endangered species, as we present in detail below.

Expanding the Transportation System May Increase Deposition of Nitrogen

Vehicles powered by internal combustion engines emit nitrogen oxides (NO_x) produced by high temperature combustion. Vehicular NO_x emissions are closely regulated by the California Air Resources Board and are controlled effectively by catalytic converters. An unfortunate side-effect of the catalytic converters is the production of ammonia gas (NH_3); there is a fundamental tradeoff between NO_x and NH_3 production from vehicles equipped with catalytic converters (Heeb et al. 2006). Even as NO_x emissions decline in response to regulation, NH_3 emissions from roadways will increase (Kean et al. 2009, Leip et al. 2011, Fenn et al. 2018). For example, on-road NH_3 emissions increased 91% between 1990 and 2010 in the United States (Leip et al. 2011, Xing et al. 2013) and nitrogen deposition in this form has increased throughout many regions even as NO_x emissions have decreased (Du et al. 2014, Li et al. 2016, Hůnová et al. 2017).

Ammonia is not a regulated element of tailpipe emissions, but its deposition causes environmental impacts. The PEIR does not consider NH_3 emissions and the analysis of impacts cannot rely on CARB regulations to reduce them over the life of the RTP. All sources of nitrogen emissions should be considered together, and the amount of emissions with the RTP compared to a no project scenario that still takes into account CARB regulations already in place. It is highly likely that the RTP will result in increased nitrogen emissions over that period and in specific locations when compared with a scenario with existing regulations in place but without the road construction associated with the RTP.

Southern California Is Already a Nitrogen Deposition Hotspot

Southern California has some the highest nitrogen deposition in the United States (Fenn et al. 2003, Fenn et al. 2010, Fenn et al. 2018). The maps below are from TDEP (Total Deposition), produced by the US Environmental Protection Agency (**Figure 1**). TDEP synthesizes measurements and atmospheric models and represent the state of the art in deposition estimates at regional scales, presented on a 4 km grid (Schwede and Lear 2014). Dry deposition, a complex process whereby gases adsorb onto surfaces or are absorbed directly by plants in the absence of precipitation, dominates in coastal California. Total deposition in the region (at the 4 km scale) can exceed $25 \text{ kg-N ha}^{-1} \text{ year}^{-1}$, and local hotspots can exceed $50 \text{ kg-N ha}^{-1} \text{ year}^{-1}$ (Fenn et al. 2003). Pre-industrial background is estimated at $< 1 \text{ kg-N ha}^{-1} \text{ year}^{-1}$. Oxidized-N results from emissions of nitrogen oxides (NO_x) and reduced-N results from emissions of ammonia (NH_3). Both forms are important, but have different magnitudes and local patterns (**Figure 1**).

Nitrogen Exceeding Critical Loads Degrades Sensitive Natural Communities

Deposition of atmospheric nitrogen favors non-native annual plants; and native annual forbs are declining due to competition from those non-native annuals (Padgett and Allen 1999, Padgett et al. 1999, Weiss 1999, Cione et al. 2002, Fenn et al. 2010).

Fenn et al. (2010) identified the “critical loads” of nitrogen deposition beyond which vegetation communities are disrupted. In native grasslands, nonnative grass invasion is facilitated at $6 \text{ kg N ha}^{-1} \text{ y}^{-1}$ of deposition (Weiss 1999, Fenn et al. 2010). For coastal sage scrub, a decrease in native plant richness is seen at $7.8\text{--}10 \text{ kg N ha}^{-1} \text{ y}^{-1}$ (Fenn et al. 2011). At $10 \text{ kg N ha}^{-1} \text{ y}^{-1}$, a significant decrease in arbuscular mycorrhizal spore density is observed (Fenn et al. 2011), which has potentially significant impacts on the ability of native plants to form symbiotic relationships with these fungi and exclude nonnative plants (St. John 1993, Corkidi et al. 2002). In chaparral and oak woodlands, the epiphytic lichen community is transformed into nutrient-tolerant species at $5.5 \text{ kg N ha}^{-1} \text{ y}^{-1}$.

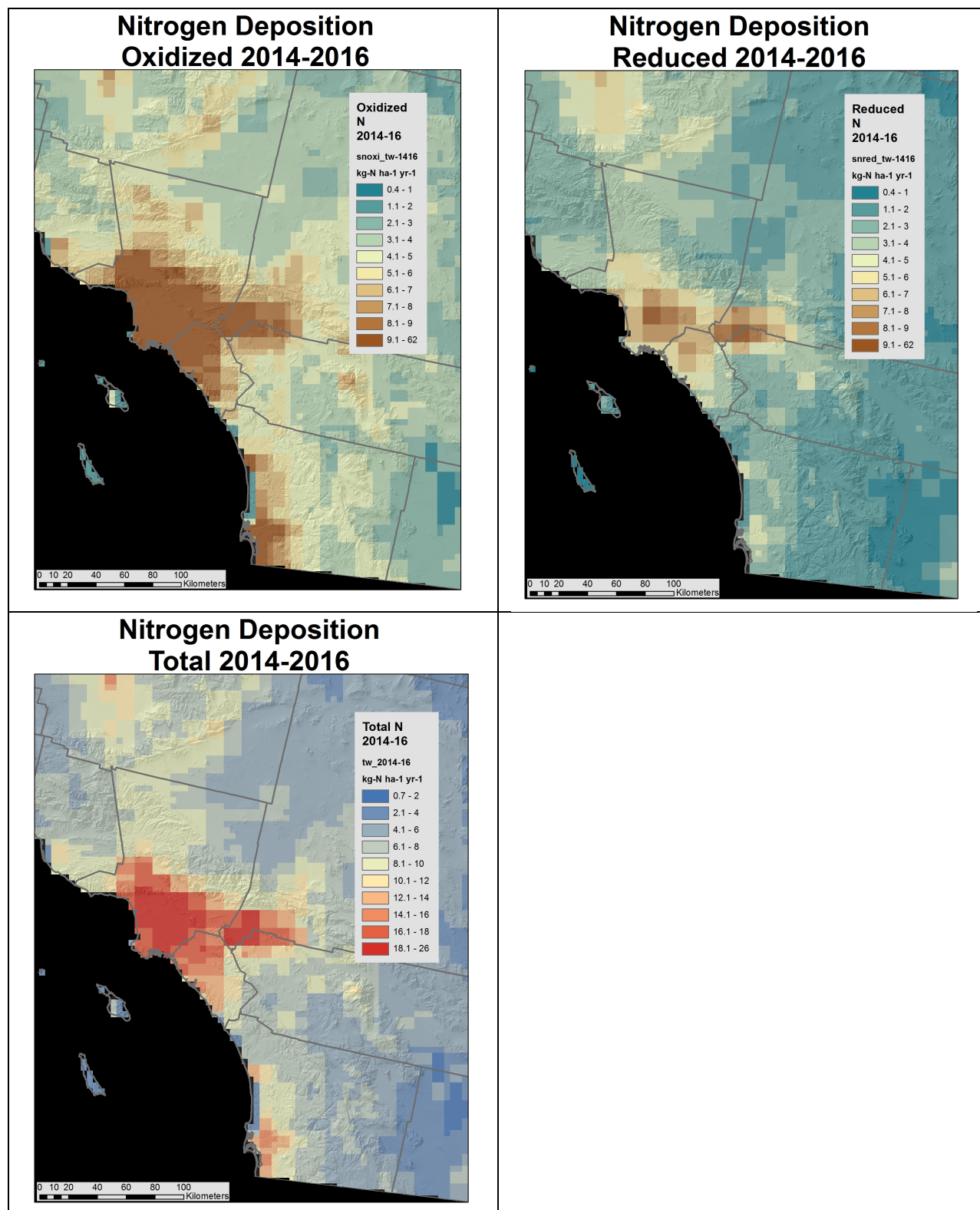


Figure 1. TDEP estimates of oxidized, reduced, and total nitrogen deposition (Schwede and Lear 2014).

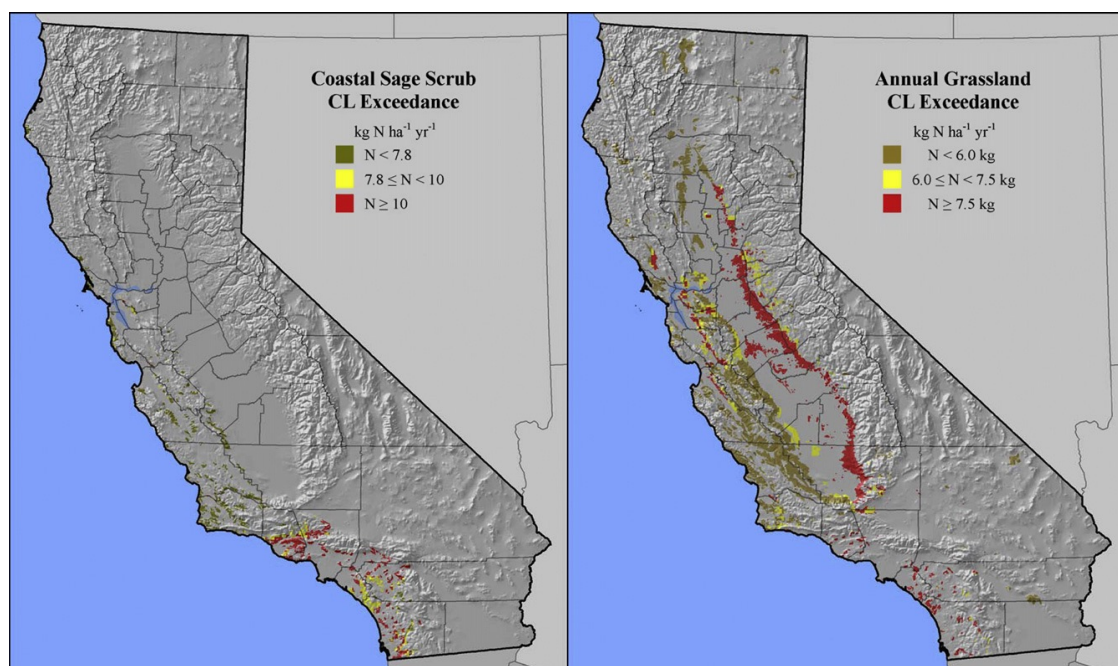


Figure 2. Critical load exceedances for coastal sage scrub and grassland in California (Fenn et al. 2010). The critical load for CSS is $7.8 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ and $6.0 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ for grassland.

Much of the region subject to additional development of transportation infrastructure under the SoCal Connect RTP is approaching or has exceeded the critical loads for coastal sage scrub and grasslands. Those areas already exceeding critical levels have been mapped (**Figure 2**).

Because the scrublands and grasslands of the project area are already subject to nitrogen deposition at or near established critical loads, any additional deposition would constitute a significant impact. Although the PEIR claims that NO_x will decline over the life of the project, total nitrogen deposition is not considered, and the control measures that reduce NO_x from internal combustion engines will result in an increase in NH_3 emissions.

Emissions from Roads Impacts Endangered Species Habitat

The NO_x and NH_3 emissions from a road have local and regional impacts, both of which can impact endangered species in the project area. The plume from the road line source elevates pollutant concentrations for several hundred yards downwind, falling off in an exponential decay with distance, because of dispersion upward and deposition downward (Seinfeld and Pandis 2016). For example, along Highway 280 in San Mateo County, ammonia deposition at the fenceline (~50 yards from the road centerline) was about $10 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$, and was reduced to $1 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ 500 yards to the east (Fenn et al. 2010, Fenn et al. 2018). The situation with NO_x is more complicated, because of the rapid (scale of seconds) conversion of the primary emissions of NO (little deposition) to NO_2 (higher deposition) as the plume moves downwind, which mutes the distance effect so that NO_2 deposition decreases by only 50% over the same gradient.

Once the local plume disperses upward, emissions contribute to, but become difficult to detect relative to, background, especially in polluted regions like Southern California. The emissions merge with the regional plume and undergo further chemical transformations, such as the

oxidation of NO₂ into HNO₃ and formation of particulate of NH₄NO₃ (a major component of PM_{2.5}). These compounds can travel and deposit long distances downwind.

The PEIR sets a standard for assessing local impacts of individual projects that is too conservative. The PEIR limits consideration of impacts on sensitive species to only 500 feet surrounding projects. Elevated local deposition of nitrogen occurs at least to 1,500 feet away from a roadway or point source (Fenn et al. 2010, Fenn et al. 2018), and other edge effects such as light pollution have impacts more than 500 feet away.

Nitrogen deposition originating both locally and as part of the regional plume impacts habitat for threatened, rare, and endangered species in the project area. We focus on two examples, the Quino checkerspot butterfly and the array of endangered and threatened plant species that are found in Southern California.

Quino Checkerspot Butterfly

Quino checkerspot (*Euphydryas editha quino*) was once an unimaginably common spring butterfly of the open forblands, grasslands, and sparse shrublands of Southern California where it typically laid its eggs on the small native forb, *Plantago erecta* (Mattoni et al. 1997). As these landscapes were lost to urban development throughout Los Angeles and Orange county, the remaining populations in Riverside and San Diego counties have been threatened by the invasion of nonnative grasses spread through the ranching era and accelerated by deposition of nitrogen. The grasses thrive in the presence of additional nitrogen and choke out the diminutive native forbs that once carpeted the understory of sparse scrublands in the spring (Minnich and Dezzani 1998, Minnich 2008), a pattern that has been repeated across the state (Huenneke et al. 1990, Weiss 1999). The decline in grasslands has been underway for 200 years, associated with widespread grazing, then urbanization. The degradation of open scrublands and their forb understory has only accelerated in the past 40–50 years (Allen et al. 1998, Minnich and Dezzani 1998, Talluto and Suding 2008).

Nitrogen deposition is currently high across the recovery units of Quino checkerspot butterfly, and artificially elevated soil nitrogen is identified as a key threat that must be remediated in the recovery plan (U.S. Fish and Wildlife Service 2003). Within the project area, Recovery Units in Riverside County are vulnerable to impacts from the RTP (**Figure 3**). The species Recovery Plan is clear, that “Conversion from native vegetation to nonnative annual grassland will be the greatest threat to Quino checkerspot butterfly reserves,” and ties this conversion to nitrogen pollution, along with fire, grazing, and off-road vehicle activity (U.S. Fish and Wildlife Service 2003). This concern is well-founded, since additional nitrogen decreases the size and density of the larval host plant *P. erecta* (Koide et al. 1988).

Highway expansion projects included in the Plan’s project list may have local nitrogen deposition impacts on listed species like Quino checkerspot. At a minimum, these include (1) the widening of highway 79 (RTP ID 3A04SH12), which is within 1.5 miles of critical habitat for Quino checkerspot at Skinner Reservoir and (2) the widening of I-15, which is adjacent to the Northwest Riverside recovery unit outlined in the recovery plan. In addition to these local impacts, the regional plume of nitrogen pollution threatens the remaining range of the species.

Both types of impacts should be recognized and a framework for mitigation established in the PEIR.

Nitrogen deposition poses a direct threat to the viability of Quino checkerspot butterfly in areas that have been set aside and are being managed for the species, because nitrogen deposition critical levels are being exceeded. To be clear, nitrogen deposition is a threat to habitats that have already been protected for conservation and are being held in perpetuity for that purpose. Without a strategy to offset impacts of nitrogen deposition, those investments will be in vain.

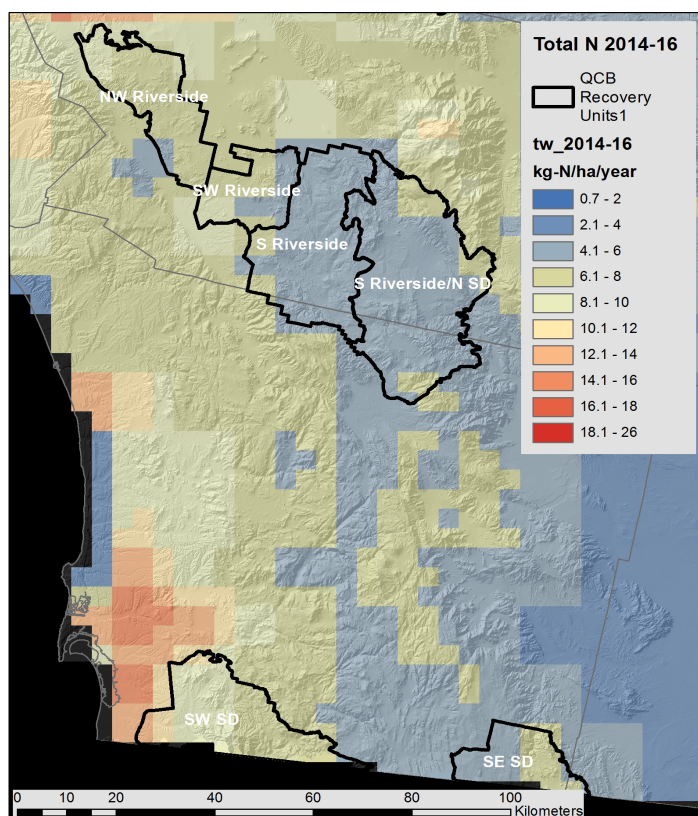


Figure 3. 2014–2016 total nitrogen deposition in relation to Recovery Units for Quino checkerspot butterfly (U.S. Fish and Wildlife Service 2003).

Endangered Plant Species

The RTP area includes many plant species that are threatened, rare, or endangered. All of these species are adversely impacted by nitrogen deposition through direct and indirect mechanisms (Fenn et al. 2010). Directly, additional nitrogen favors nonnative invasive species that out-compete native species, as documented above. Indirectly, the additional nonnative annual grasses and weeds on the landscape fundamentally transforms fire return intervals. Areas subject to annual grass invasion facilitated by nitrogen deposition burn more often than native habitats and the repeated fire then excludes species that must grow for years before they set seed (e.g., some coastal sage scrub and chaparral species) or are not adapted to fire (e.g., desert species).

To illustrate that listed plant species are already found within the RTP area and are threatened by nitrogen deposition, we collated the total nitrogen deposition for listed plant taxa located in

Riverside and Orange Counties that have been subject to Habitat Conservation Plans (HCPs) and Natural Community Conservation Plans (NCCPs). The exposure of the locations of these listed plant taxa near or exceed the defined critical thresholds defined for the vegetation communities where they are found (**Figure 4**).

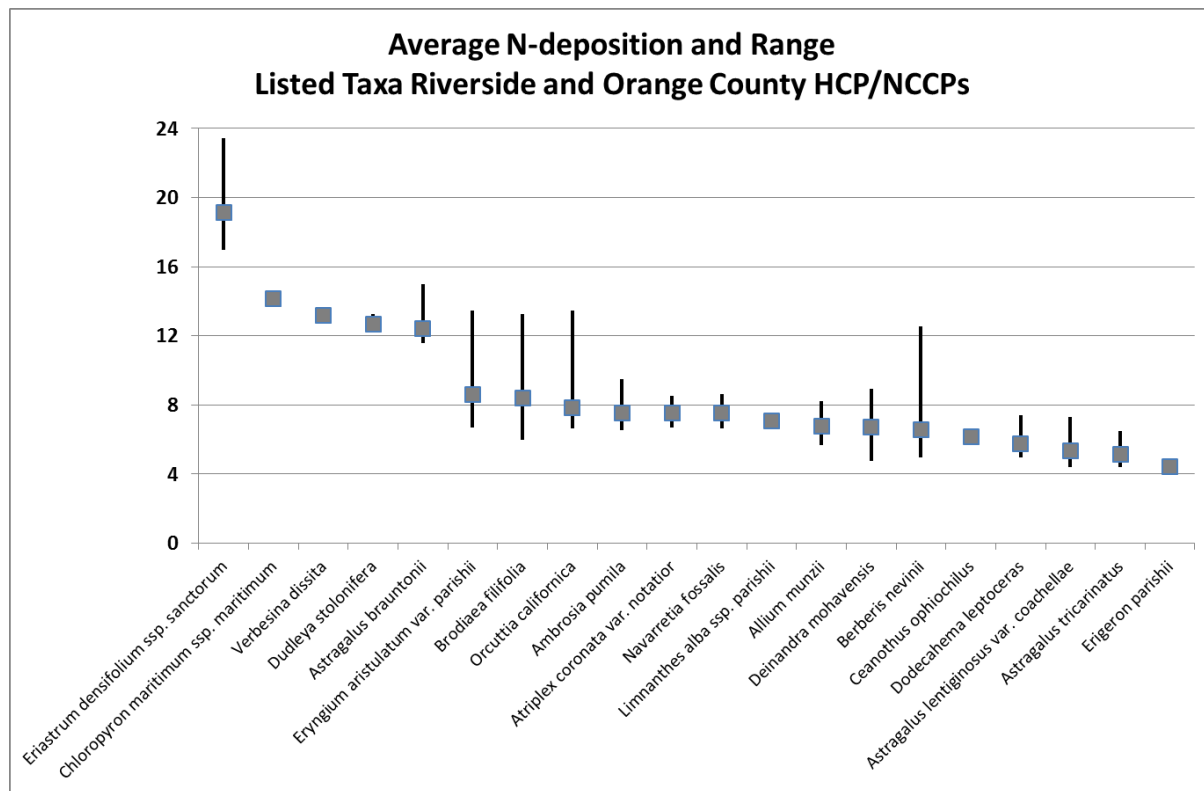


Figure 4. Average and range of annual total nitrogen deposition (N-kg ha⁻¹ yr⁻¹) for 2014-2016 period for habitat occupied by listed plant species covered by HCPs and NCCPs in Los Angeles County and Orange County.

A Regional Strategy Is Necessary to Mitigate Nitrogen Deposition

Mitigation of nitrogen deposition associated with continued expansion of the transportation system will not be effective if put off to project-level environmental review and mitigation planning. A program-level approach is necessary because of the difficulty of reversing impacts and the need to act regionally to protect sensitive habitats and imperiled species.

It is difficult to restore habitats that have been degraded by nitrogen deposition. Invasive grasses end up dominating the seedbank, the point of completely excluding native plant species (Cione et al. 2002). Although fire has been suggested to reduce exotic seed banks, use of fire to restore degraded grasslands is generally not feasible because of air quality regulations and risk. Effective restoration of scrublands can be achieved through the use of mechanical or chemical weed control over a sustained period, followed by seeding of native species (Brooks et al. 2019). Such an approach is labor intensive, requires large amounts of seed, and also relies on use of mycorrhizal inoculum that forms a network with the planted species and helps exclude nonnative species (St. John 1993).

The transportation network has contributed substantially to the existing conditions of nitrogen pollution that degrade private and protected lands on an ongoing basis. Mitigating these impacts requires a regional plan and mitigation scheme so that mitigation offsets from individual projects can be used to protect, manage, and restore habitats for endangered species that may not occur at a transportation project location but are nevertheless incrementally harmed by that project. Only a program-level approach can analyze these impacts and establish an equitable process through which each project can pay its fair share of the consequences of nitrogen pollution.

Precedents for Mitigation for Nitrogen Deposition Impacts on Sensitive Species in California

Mitigation for increased nitrogen deposition impacts on sensitive species emissions has been implemented in California since 2001. The link between N-deposition and adverse modification of Bay checkerspot butterfly habitat through increased annual grass growth was established by Weiss (1999). Since that time, prime examples of off-site mitigation for nitrogen emissions resulting from infrastructure projects include:

Metcalf Energy Center, Los Esteros Critical Energy Facility, Donald von Raesfeld Generating Plant: These three natural gas-fired powerplants in Santa Clara County independently provided mitigation for cumulative impacts of increased NO_x and NH₃ emissions, starting in 2001. Mitigation actions included acquisition of sensitive serpentine grassland habitat (211 acres of habitat), ongoing funding for monitoring and management (>\$100,000 per year), and establishment of endowments (~\$2,000,000) for funding after the power plants are retired.

Highway projects in Santa Clara County: Widening Highway 101 and construction of interchanges in Coyote Valley by the Santa Clara Valley Transportation Authority (VTA) triggered a Section 7 consultation that resulted in 540 acres of serpentine being acquired along with ongoing monitoring and management funding, and a \$700,000 management endowment. The project was also the trigger for the development of the Santa Clara Valley Habitat Plan.

Santa Clara Valley Habitat Conservation Plan/Natural Communities Conservation Plan (Valley Habitat Plan): This comprehensive plan covers 19 taxa, including 10 taxa dependent on nitrogen sensitive serpentine grassland. The 50-year, \$665,000,000 (2013 dollars) plan will result in a reserve system of ~42,000 acres, provide monitoring and management funds for the duration of the plan, and a >\$100,000,000 endowment for management in perpetuity. One funding source for the Valley Habitat Plan is a small *one-time* nitrogen deposition fee based on vehicle trips generated by a project (\$45.80 per single residence, or \$4.70 per new daily vehicle trip for commercial projects).

Otay Power Generating Station: This natural gas-fired powerplant at the western base of Otay Mountain (San Diego County) provided \$400,000 for habitat management to mitigate impacts on the Quino checkerspot butterfly.

Lange's Metalmark butterfly at Antioch Dunes National Wildlife Refuge: The Refuge is a remnant sand dune system supporting the endangered butterfly and two endangered plants. Nitrogen deposition has contributed to the nutrient poor dunes becoming overrun with annual grass growth. Five gas-fired powerplants surrounding the Antioch Dunes NWR were approved

by the California Energy Commission in the 2000s. As part of a lawsuit settlement, the Marsh Landing Generating Station committed to ~\$2,000,000 in funding for dune management and community pollution response.

About the Authors

Stuart B. Weiss (Ph.D. Stanford University) is founder and Chief Scientist of the Creekside Center for Earth Observation, which provides scientific support for conservation and restoration. Dr. Weiss has expertise in population biology, climate change, statistical analysis, GIS, and most aspects of conservation biology. He is a recognized expert in nitrogen deposition and biodiversity, not only publishing scientific papers but also consulting on mitigation strategies and implementation, as well as organizing scientific sessions on nitrogen deposition at major conferences.

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Literature Cited

- Allen, E. B., P. E. Padgett, A. Bytnerowicz, and R. Minnich. 1998. Nitrogen deposition effects on coastal sage vegetation of southern California. Pages 131–139 in *Proceedings of the international symposium on air pollution and climate change effects on forest ecosystems*. Gen. Tech. Rep. PSW-GTR-166. . US Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.
- Brooks, T., M. Griswold, T. Longcore, and M. Riedel-Lehrke. 2019. Habitat Restoration and Enhancement Plan Update: County of Orange Central and Coastal Subregion, Natural Community Conservation Plan/Habitat Conservation Plan. Natural Communities Coalition, Los Angeles.
- Bytnerowicz, A., and M. E. Fenn. 1996. Nitrogen deposition in California forests: a review. *Environmental Pollution* **92**:127–146.
- Cione, N. K., P. E. Padgett, and E. B. Allen. 2002. Restoration of a native shrubland impacted by exotic grasses, frequent fire, and nitrogen deposition in southern California. *Restoration Ecology* **10**:376–384.
- Corkidi, L., D. L. Rowland, N. C. Johnson, and E. B. Allen. 2002. Nitrogen fertilization alters the functioning of arbuscular mycorrhizas at two semiarid grasslands. *Plant and Soil* **240**:299–310.

- Du, E., W. de Vries, J. N. Galloway, X. Hu, and J. Fang. 2014. Changes in wet nitrogen deposition in the United States between 1985 and 2012. *Environmental Research Letters* **9**:095004.
- Fenn, M. E., E. B. Allen, and L. H. Geiser. 2011. Mediterranean California. Pages 143–170 in L. H. Pardo, M. J. Robbin-Abbott, and C. T. Driscoll, editors. *Assessment of N deposition effects and empirical critical loads of N for ecoregions of the United States*. General Technical Report NRS-80. U.S. Forest Service, Northeastern Research Station, Newtown Square, Pennsylvania.
- Fenn, M. E., E. B. Allen, S. B. Weiss, S. Jovan, L. H. Geiser, G. S. Tonnesen, R. F. Johnson, L. E. Rao, B. S. Gimeno, and F. Yuan. 2010. Nitrogen critical loads and management alternatives for N-impacted ecosystems in California. *Journal of Environmental Management* **91**:2404–2423.
- Fenn, M. E., A. Bytnerowicz, S. L. Schilling, D. M. Vallano, E. S. Zavaleta, S. B. Weiss, C. Morozumi, L. H. Geiser, and K. Hanks. 2018. On-road emissions of ammonia: an underappreciated source of atmospheric nitrogen deposition. *Science of the Total Environment* **625**:909–919.
- Fenn, M. E., R. Haeuber, G. S. Tonnesen, J. S. Baron, S. Grossman-Clarke, D. Hope, D. A. Jaffe, S. Copeland, L. Geiser, and H. M. Rueth. 2003. Nitrogen emissions, deposition, and monitoring in the western United States. *Bioscience* **53**:391–403.
- Heeb, N. V., A.-M. Forss, S. Brühlmann, R. Lüscher, C. J. Saxer, and P. Hug. 2006. Three-way catalyst-induced formation of ammonia—velocity-and acceleration-dependent emission factors. *Atmospheric Environment* **40**:5986–5997.
- Huenneke, L. F., S. P. Hamburg, R. Koide, H. A. Mooney, and P. M. Vitousek. 1990. Effects of soil resources on plant invasion and community structure in Californian [USA] serpentine grassland. *Ecology* **71**:478–491.
- Hůnová, I., P. Kurfürst, V. Stráník, and M. Modlík. 2017. Nitrogen deposition to forest ecosystems with focus on its different forms. *Science of the Total Environment* **575**:791–798.
- Kean, A. J., D. Littlejohn, G. A. Ban-Weiss, R. A. Harley, T. W. Kirchstetter, and M. M. Lunden. 2009. Trends in on-road vehicle emissions of ammonia. *Atmospheric Environment* **43**:1565–1570.
- Koide, R. T., L. F. Huenneke, S. P. Hamburg, and H. A. Mooney. 1988. Effects of applications of fungicide, phosphorus and nitrogen on the structure and productivity of an annual serpentine plant community. *Functional Ecology* **2**:335–344.
- Leip, A., B. Achermann, G. Billen, A. Bleeker, A. Bouwman, W. de Vries, U. Dragosits, U. Doring, D. Fernall, M. Geupel, J. Herolstab, P. Johnes, A. C. Le Gall, S. Monni, R. Neveceral, L. Orlandini, M. Prud'homme, H. Reuter, D. Simpson, G. Seufert, T. Spranger, M. Sutton, J. van Aardenne, M. Voss, and W. Winiwarter. 2011. Integrating nitrogen fluxes at the European scale. Pages 345–376 in M. Sutton, C. Howard, J. W. Erisman, G. Billen, A. Bleeker, P. Greenfelt, H. van Grinsven, and B. Grizzette, editors. *The European Nitrogen Assessment*. Cambridge University Press, Cambridge.
- Li, Y., B. A. Schichtel, J. T. Walker, D. B. Schwede, X. Chen, C. M. B. Lehmann, M. A. Puchalski, D. A. Gay, and J. L. Collett. 2016. Increasing importance of deposition of reduced nitrogen in the United States. *Proceedings of the National Academy of Sciences* **113**:5874–5879.

- Mattoni, R. H. T., G. F. Pratt, T. R. Longcore, J. F. Emmel, and J. N. George. 1997. The endangered Quino Checkerspot butterfly, *Euphydryas editha quino* (Lepidoptera: Nymphalidae). *Journal of Research on the Lepidoptera* **34**:99–118.
- Minnich, R. A. 2008. California's fading wildflowers: lost legacy and biological invasions. University of California Press, Berkeley.
- Minnich, R. A., and R. J. Dezzani. 1998. Historical decline of coastal sage scrub in the Riverside-Perris Plain, California. *Western Birds* **29**:366–391.
- Padgett, P. E., and E. B. Allen. 1999. Differential responses to nitrogen fertilization in native shrubs and exotic annuals common to Mediterranean coastal sage scrub of California. *Plant Ecology* **144**:93–101.
- Padgett, P. E., E. B. Allen, A. Bytnerowicz, and R. A. Minnich. 1999. Changes in soil inorganic nitrogen as related to atmospheric nitrogenous pollutants in southern California. *Atmospheric Environment* **33**:769–781.
- Schwede, D. B., and G. G. Lear. 2014. A novel hybrid approach for estimating total deposition in the United States. *Atmospheric Environment* **92**:207–220.
- Seinfeld, J. H., and S. N. Pandis. 2016. Atmospheric chemistry and physics: from air pollution to climate change. John Wiley & Sons, Hoboken, New Jersey.
- St. John, T. V. 1993. Benefits of mycorrhizae in revegetation and restoration. Pages 269–272 in J. E. Keeley, editor. *Interface Between Ecology and Land Development in California*. Southern California Academy of Sciences, Los Angeles.
- Talluto, M. V., and K. N. Suding. 2008. Historical change in coastal sage scrub in southern California, USA in relation to fire frequency and air pollution. *Landscape Ecology* **23**:803–815.
- U.S. Fish and Wildlife Service. 2003. Final recovery plan for the Quino Checkerspot butterfly (*Euphydryas editha quino*). U.S. Fish and Wildlife Service, Portland, Oregon.
- Weiss, S. B. 1999. Cars, cows, and checkerspot butterflies: nitrogen deposition and management of nutrient-poor grasslands for a threatened species. *Conservation Biology* **13**:1476–1486.
- Xing, J., J. Pleim, R. Mathur, G. Pouliot, C. Hogrefe, C. M. Gan, and C. Wei. 2013. Historical gaseous and primary aerosol emissions in the United States from 1990 to 2010. *Atmospheric Chemistry and Physics* **13**:7531–7549.