WILD Equity
INSTITUTE
Building a healthy and sustainable global community for people
and the plants and animals that accompany us on Earth

September 3, 2013

SENT VIA OVERNIGHT MAIL

RECEIVED
2013 SEP -9 AM 8: 24
OFFICE OF THE
EXECUTIVE SECRETARIAT

Gina McCarthy
EPA Administrator
Mail Code 4101M
USEPA Ariel Rios Building (AR)
1200 Pennsylvania Avenue N.W.
Washington, DC 20004

RE: **Petition Requesting EPA Object to the Major Facility Review Permit for Gateway Generating Station, LLC under Title V of the 1990 Clean Air Act Amendments, the Federal Operating Permit Program, and the Bay Area Air Quality Management District's Regulation 2, Rule 6 - Major Facility Review.**

Dear Ms. McCarthy:

Pursuant to 42 U.S.C. § 7661d(b)(2) and 40 C.F.R. § 70.8(d), I submit this petition requesting that you object to Gateway Generating Station, LLC's ("Gateway") Title V Major Facility Review Permit ("Title V Permit" or "Permit"), because, as explained below, the Permit fails to ensure that Gateway satisfies all applicable pollution control requirements.

In particular, the EPA has failed to obtain incidental take authorization for listed species affected by Gateway's ongoing and proposed air pollution. Because Title V requires every major facility review permit to include all "applicable requirements," 42 U.S.C. § 7661d(b)(1), and because CAA, its regulations, and governing agreements between EPA and BAAQMD make such incidental take authorization from the Service an applicable regulation, you must object to this Permit until the incidental take authorization is obtained and incorporated into the Title V Permit.

The Wild Equity Institute raised this objection during the public comment period on Gateway's Permit. But to date no incidental take authorization to pollute listed species and/or their habitats has been obtained by the EPA—despite the Service's express request that EPA reinitiate consultation over Gateway.

Incidental take authorization may be obtained either through an Incidental Take Statement and Biological Opinion issued through consultation with the U.S. Fish and Wildlife Service ("Service"), or through an Endangered Species Act ("ESA") Section 10 Incidental Take Permit.

This petition discusses the areas and species affected by Gateway's operation, the interplay between the ESA's incidental take provisions and the Title V and the PSD program, and the ways Gateway's Permit application falls short of Title V requirements.

The Antioch Dunes National Wildlife Refuge.

During an inter-glacial period approximately 140,000 years ago a network of sand dunes and desert environments stretched from the location of the modern-day Mojave Desert across the Central Valley to the San Joaquin River. As the climate changed, the deserts retreated, but left behind a stretch of sand dunes in Antioch, California, known today as the Antioch Dunes. These dunes were subsequently nourished, at least in part, by sandy soils scrubbed from the Sierra Nevada Mountains by retreating glaciers. These sandy soils were delivered to the Dunes by the Sacramento and San Joaquin River Systems.

The isolation of this area in Antioch from other desert systems allowed species found at the Antioch Dunes to evolve into unique forms of life found nowhere else on Earth. Today the Antioch Dunes National Wildlife Refuge (Antioch Dunes) in Contra Costa County protects the remnants of these habitats, upon which three federally protected species depend: the Contra Costa Wallflower, the Antioch Dunes Evening Primrose, and the Lange's Metalmark Butterfly.

Prior to European settlement, the Antioch Dunes were probably several hundred acres in size. Currently, because of past sand mining, agriculture, and urban development, only about 70 acres of the sand dune habitat remains, all within the Antioch Dunes National Wildlife Refuge.

The Lange's Metalmark Butterfly.

The Lange's Metalmark Butterfly (*Apodemia mormo langei*) is a brightly colored, fragile, and highly endangered butterfly that has been protected by the Federal Endangered Species Act since 1976. 41 Fed. Reg. 22,041 (June 1, 1976). The species is endemic to the Antioch Dunes, which contains the only known extant population of the species.

Between 50 to 100 years ago, the population size of the Lange's Metalmark Butterfly at the Antioch Dunes is estimated to have been approximately 25,000 individuals. However, by 2006, the number had plummeted to a total of 45 adults. For the past seven years, the number of adults observed in the wild has continued to remain at critically low levels.

The sole food plant for the larval (caterpillar) stage of the butterfly is the naked-stemmed buckwheat (*Eriogonum nudum* ssp. *auriculatum*), which grows best in areas with good drainage and nutrient-poor soils. The Lange's metalmark butterfly is entirely dependent on the population of naked-stemmed buckwheat at the Antioch Dunes, and there is a direct positive correlation between the population size of this plant and the population of the butterfly.

However, today the buckwheat is only found in a limited portion of the Antioch Dunes National Wildlife Refuge, and this remaining area is threatened with extirpation due to the prolific overgrowth of non-native, invasive plant species, none of which provide food for the butterfly's caterpillar stage. Although the naked-stemmed buckwheat is not threatened with global extinction, the loss of the plant at the Antioch Dunes National Wildlife Refuge will surely lead to the extinction of the Lange's Metalmark Butterfly.

The Antioch Dunes Evening Primrose and the Contra Costa Wallflower.

The Antioch Dunes Evening Primrose (*Oenothera deltoids* ssp. *howellii*) is a beautiful perennial plant. It has white flower petals with long yellow stamens, and is host to a rare sweat bee species. The Contra Costa Wallflower (*Erysimum capitatum* var. *angustatum*) is a fragrant and highly structured wildflower with yellow petals. Both species have been protected as endangered under the Federal Endangered Species Act since 1978, 43 Fed. Reg. 7,972 (April 26, 1978), and critical habitat has been protected for both species since 1978 as well. 43 Fed. Reg. 39,042 (Aug 31, 1978).

Like the Lange's Metalmark Butterfly, the Contra Costa Wallflower and the Antioch Dunes Evening Primrose are endemic to the Antioch Dunes National Wildlife Refuge. Although the population sizes of these plants fluctuate greatly, the long-term trend indicates both species are in decline. In both cases, the overgrowth of invasive non-native plant species is reducing the available area for colonization and growth of these endangered species.

The Endangered Species Act.

Section 7 of the ESA describes EPA's consultation requirements. Section 7(a)(2) states:

> Each Federal agency shall, in consultation with and with the assistance of the Secretary [of the Interior or Commerce], insure that any action authorized, funded or carried out by such agency . . . is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of [critical] habitat . . . .

16 U.S.C. § 1536(a)(2). "Its very words affirmatively command all federal agencies to insure that actions authorized, funded, or carried out by them do not jeopardize the continued existence of endangered species." *TVA v. Hill*, 437 U.S. 153, 173 (1978). Reinitiation of consultation is required and must be requested by EPA where discretionary federal involvement or control over the action has been retained or is authorized by law, and new information reveals effects of the action that may affect listed species or critical habitat in a manner not previously considered during consultation. 50 C.F.R. § 402.16(b).

Title V.

Title V was enacted to make the CAA permitting process more transparent. *See Com. of VA v. Browner*, 80 F.3d 869, 873 (4th Cir. 1996) ("The permit is crucial to the implementation of the Act: it contains, in a single, comprehensive set of documents, all CAA requirements relevant to the particular polluting source.") (citations removed). It applies to facilities like Gateway. *See* 42 U.S.C. §§ 7602 (defining major stationary source) and 7661a(a) (applying Title V to major sources). The Permit must contain, *inter alia*, "applicable requirements" of the Clean Air Act. 42 U.S.C. § 7661d(b)(1) (requiring the EPA Administrator to object to a permit if it does not contain the requirements of the CAA); BAAQMD regs. 2-6-202 (Defining "Applicable Requirements" as "[a]ir quality requirements with which a facility must comply pursuant to the District's regulations, codes of California statutory law, and the federal Clean Air Act, including all applicable requirements as defined in 40 C.F.R. 70.2.").

The PSD program is one of the "applicable requirements" of the Title V program. 42 U.S.C. §§ 7470-7479 and 7661a(f)(3); 40 C.F.R. § 70.2 (defining applicable requirements to include Subchapter I, Part C – the PSD program); *see also Sierra Club v. Johnson*, 541 F.3d 1257, 1261 (11th Cir. 2008) ("Among the many air quality requirements included in an operating permit, if applicable, are [PSD] limits."); 57 Fed. Reg. 32250, 32250 (July 21, 1992) (Title V permits must contain all pollution control obligations, including those in State Implementation Plans, as well as New Source Performance Standards. such as PSD). As a major stationary source, Gateway is subject to the PSD program. 40 C.F.R. § 52.21(b)(1). Both EPA and BAAQMD recognize that the PSD program applies to Gateway. *See e.g.*, Complaint, *U.S. v. Pacific Gas & Elec.*, 776 F.Supp.2d 1007 (N.D. Cal. 2011) at 9 ("PG&E constructed [Gateway] ... without first obtaining an appropriate PSD permit. . . ."); BAAQMD, Permit to Operate, Gateway Generating Station, Condition No. 18138 (PTO) (listing conditions of operation, noting where PSD limits apply).

While BAAQMD issues PSD permits in the Bay Area, it does so under a delegation agreement, where the EPA Administrator delegates responsibility to a state agency to issue PSD permits while the Federal PSD program is in effect. 40 C.F.R. 52.21(u); Agreement for Partial Delegation of the Federal Prevention of Significant Deterioration (PSD) Program Set Forth In 40 C.F.R. Section 52.21 by the United States Environmental Protection Agency, Region 9 to the Bay Area Air Quality Management District (Delegation Agreement). EPA considers such permits EPA-issued. *See, e.g., In re: Russell Energy Center*, 2010 WL 5573720, 7 (E.P.A.) (Nov. 18, 2010). Per the delegation agreement, BAAQMD must "notify [the Service] and EPA when a submitted PSD permit application has been deemed complete, in order to assist EPA in carrying out its non-delegable responsibilities to consult with FAS under section 7" of the ESA. Delegation Agreement at 7 (Section VI.2.b).

This provision makes it clear that EPA must consult with the Service over potential effects to endangered species during the PSD application process. If, during consultation, the agencies find that the action will likely adversely affect an endangered species – as the the Service believes will occur here –the Service may issue an "Incidental Take Statement" (ITS). 16 U.S.C. § 1536(b)(4); *Arizona Cattle Growers Ass'n v. U.S. Fish and Wildlife, Bureau of Land Management*, 273 F.3d 1229 (9th Cir. 2001). The ITS may, among other things, attach conditions to the activity in an area where endangered species are present and immunizes the actor for any harmful activity incidental to the activity on that land. 16 U.S.C. § 1536(o); *Arizona Cattle Growers*, 273 F.3d at 1239. These statements are permits. *Bennett v. Spear*, 520 U.S. 154, 170 (1997) ("Thus, the Biological Opinion's Incidental Take Statement constitutes a permit authorizing the action agency to "take" the endangered or threatened species so long as it respects the Service's "terms and conditions.").

The ITS is a key part of the PSD program and a possible component of EPA's non-delegable duties under the ESA that must be performed before a Federal agency (or delegated local authority) may issue a PSD permit. Since the PSD program is an "applicable requirement" of the Title V permit, the ITS is also an applicable requirement. 42 U.S.C. 7661d(b)(1).

Previous Consultation Efforts.

In 2001, when this project was known as Contra Costa Power Plant Unit 8, Pacific Gas & Electric's (PG&E) predecessor, Mirant, received a PSD from BAAQMD, issued under a prior delegation agreement. *U.S. v. Pacific Gas & Elec.*, 776 F.Supp.2d 1007, 1013 (N.D. Cal. 2011). Since the PSD permit issuance was a Federal action, EPA engaged in informal consultation with the Service and the U.S. Army Corps of Engineers. SERVICE Letter at 2. However, this consultation concluded that there would be no adverse effects on those species. *See* Letter from Gerardo Rios, Acting Chief, Permits Office, Air Division, EPA Region IX to Jan Knight, Chief, Endangered Species Division, FWS (30 May, 2001) at 2 (" . . . the following species are identified as . . . not likely to be adversely affected by the project: . . . Lange's metalmark butterfly . . . Contra Costa Wallflower . . . Antioch Dunes evening primrose . . . .")

The facility did not become operational until 2009, and in the intervening time the PSD permit expired because of a lapse in construction. *See* Second Amended Consent Decree, *U.S. v. Pacific Gas &Elec.*, 776 F.Supp.2d 1007 (N.D. Cal. 2011) at 1-2. (N.D. Cal. 2011). After receiving approval for the consent decree, PG&E applied for the agreed amendments to the Permit to Operate from BAAQMD, which it granted on September 13, 2011, and subsequently renewed in November 2012. *U.S. v. Pacific Gas & Elec.*, 776 F.Supp.2d 1007 (N.D. Cal. 2011); *see also* BAAQMD, 2012 PTO; BAAQMD, 2011 PTO.

The Service has Requested EPA Consultation Regarding Endangered Species in Antioch Dunes.

Since 2001, the Service has learned of "new scientific information relating to the adverse effects of nitrogen deposition on listed species and natural ecosystems . . . ." *Id.* In a letter to EPA, the Service raised these new concerns, specifically requesting EPA to reinitiate consultation with the Service in order to determine the effects that operation of Gateway will have on the endangered species in Antioch Dunes.

The Gateway Generating Station will have significant nitrogen emissions. Letter from Cay C. Goude, Assistant Field Supervisor of the Fish and Wildlife Service to Jared Blumenfeld, Region 9 Regional Administrator at 2-3 (June 29, 2011) (FWS Letter). As described in The FWS Letter, the long-term chronic adverse biological effects of nitrogen deposition on native ecosystems and associate animals have been described in a number of scientific papers. *See e.g.*, Brooks, Matthew L., "Effects of increased soil nitrogen on the dominance of alien annual plants in the Mojave Desert" 40 J. of Applied Ecology, 344-353 (2003). Sand dunes like the Antioch Dunes are nitrogen deficient, and the changes in plant and microbial communities resulting from increased amounts of the airborne deposition of this chemical has been documented to cause cascading negative effects on ecosystem processes and the species that depend upon the native plant community. One of the primary adverse effects is the enhancement of environmental conditions for the invasion of non-native weeds, which outcompete native plants. *See* Padgett et al., "Differential responses to nitrogen fertilization in native shrubs and exotic annuals common to Mediterranean costal sage scrub of California" 144 Plant Ecology 93-101 (1999); Allen et al., "The Effects of Organic Amendments on the Restoration of a Disturbed Coastal Sage Scrub Habitat" 6 Restoration Ecology, 52-58 (1998).

Currently, the Antioch Dunes Wildlife National Refuge receives nitrogen deposition from the surrounding atmosphere at a rate of 6.51 kilograms per hectare per year. This is above the 5 kg/ha/yr. threshold at which nitrogen deposition effects can result in adverse impacts to native plant communities, and therefore when levels are this high there must be an assessment of the landscape to determine the extent of the impacts on species and ecological communities. California Energy Commission, Revised Staff Assessment of the Marsh Landing Generating Station (08-AFC-03), Sacramento, California (2010); Weiss, S.B. 2006. Impacts of nitrogen deposition on California ecosystems and biodiversity. California Energy Commission, PIER Energy-Related Environmental Research, CEC- 500-2005-165 (May 2006). Gateway is roughly ¾ of a mile from the Antioch Dunes and its operations deposit nitrogen into the Wildlife Refuge. FWS Letter at 1.

The Lange's Metalmark Butterfly, the Antioch Dunes Evening Primrose, and the Contra Costa Wallflower are all highly endangered, and even small changes in the plant distribution at the dunes could take these species, adversely modify critical habitat, impede recovery, and even cause the species to go extinct. In particular, the Lange's Metalmark Butterfly is so critically endangered that a single failure in the productivity of the species host plant could lead to the permanent extinction of the species. The Service believes that "nitrogen deposition is likely to result in adverse affects" to these species. FWS Letter at 3.

The Service's Request for Consultation Shows that All Applicable Requirements Have Not Been Demonstrated in the Title V Permit.

The Service requested consultation over the Antioch Dunes' endangered species based on the settlement agreement and consent decree between EPA and PG&E. Despite the agreement's purpose of bringing Gateway in compliance with what is "thought to represent" PSD requirements, the Service believed it should be consulted on the effects of the allowed emissions on endangered species.[1] FWS Letter at 2.

The FWS Letter shows that the actions clearly meet the ESA's "may affect" threshold requiring consultation. *California ex rel. Lockyer v. U.S. Dept. of Agriculture,* 575 F.3d 999, 1018-19 (9th Cir. 2009) (noting that *"any possible effect"* triggers the "may affect" threshold) (citations and quotation removed); FWS Letter at 3 (". . . nitrogen deposition at [Antioch Dunes] is *likely* to result in adverse effects . . . .") (emphasis added). Without consultation, the Title V permit will be lacking a key part of the PSD permitting program, the ITS for the endangered species at Antioch Dunes.

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[1] Even without the FWS Letter, EPA would still be required to consult with the Service, either because the consent decree is a new federal action, or because Federal Agencies are required to reinitiate when new scientific information becomes available (here, nitrogen deposition) or when an action is modified (here, by the new terms of the PSD permit included in the 2011 Permit to Operate). 50 C.F.R. §§ 401.16 (b),(c). Under the terms of the consent decree, PG&E requested modification of its applications for its permit to operate and Title V operating permit on April 4, 2011, in a letter to Brian Lusher. Since all parties to the consent decree agree that the old permit expired, the amended Permit to Operate necessarily contains a new PSD permit, a Federal action requiring section 7 consultation.

The PSD permit has been issued without consultation and an incidental take statement in violation of the ESA and is invalid.[2] As such, the Title V Permit does not meet all applicable requirements, and you must object to the issuance of the Permit.

Proposals.

To cure the defects specified here and noted in any objection you issue in response to this petition, you should (1) object to Gateway's Title V Permit for failure to include a PSD permit that has been issued in conformity with the consultation requirements of the ESA under BAAQMD Regulation 2 Rule 6, section 313; (2) order EPA to initiate consultation with the Service over the Permit; and (3) order BAAQMD to refrain from issuing the Permit unless and until the PSD provisions reflect the findings from an ESA consultation between EPA and the Service.

Sincerely,

Brent Plater

Brent Plater
Executive Director

cc: Brian Lusher
Senior Air Quality Engineer
Bay Area Air Quality Management District
939 Ellis St.
San Francisco, CA 94109

David Kreskas
PG&E
Law Dept.
PO Box 7442
San Francisco, CA 94120

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[2] Additionally, Gateway operations likely violate section 9 of the ESA, which prohibits the take of any species. 16 U.S.C. § 1538(a)(1)(b). "Take" is defined as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct. *Id.* § 1532(19). The Service "is concerned that the indirect and cumulative effects of the deposition of additional nitrogen at ADNWR resulting from operation of [Gateway and other stations] will result in adverse effects to the Contra Costa wallflower and the Antioch Dunes evening primrose and their critical habitat and in take of the Lange's metalmark butterfly." FWS Letter at 2.

BAY AREA
AIR QUALITY
MANAGEMENT
DISTRICT
SINCE 1955

September 13, 2011

Gateway Generating Station
3225 Wilbur Avenue
Antioch, CA 94509

Attention: Ron Gawer

Application Number: 1000
Plant Number: 18143
Equipment Location: same as above

Dear Applicant:

Enclosed is your Permit to Operate the following:

S-41 Combustion Turbine Generator (CTG) #1
S-42 Heat Recovery Steam Generator (HRSG) #1
S-43 Combustion Turbine Generator (CTG) #2
S-44 Heat Recovery Steam Generator (HRSG) #2
The equipment described above is subject to condition no. 18138.

S-47 Fire Pump Diesel Engine (evaluated under application 21296)
The equipment described above is subject to condition no. 25057.

In accordance with Regulation 2-1-411.2, you must sign your Permit to Operate. All Permits should be posted in a clearly visible and accessible place on or near the equipment to be operated, or kept available for inspection at any time. Operation of this equipment in violation of District Regulations or any permit conditions is subject to penalty action.

In the absence of specific permit conditions to the contrary, the throughputs, fuel and material consumption, capacities, and hours of operation described in your permit application will be considered maximum allowable limits. A new permit will be required before any increase in these parameters, or change in raw material handled may be made.

Please include your permit number with any correspondence with the District. If you have any questions on this matter please call Brian K Lusher, Senior Air Quality Engineer at (415) 749-4623.

Very truly yours,

Jack P. Broadbent
Executive Officer/APCO

by
Engineering Division

Cc: Craig Hoffman, CEC

BKL
Enclosure

939 ELLIS STREET • SAN FRANCISCO CALIFORNIA 94109 • 415.771.6000 • WWW.BAAQMD.GOV

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MANAGEMENT
DISTRICT
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PERMIT TO OPERATE

PLANT No. **18143**

SOURCE No. **41**

Gateway Generating Station

3225 Wilbur Avenue, Antioch, CA 94509

IS HEREBY GRANTED A PERMIT TO OPERATE THE FOLLOWING EQUIPMENT

Combustion Turbine Generator (CTG) #1
General Electric Frame 7FA.03 (Model PG 7231), 1872 MM Btu/hr maximum rated capacity, natural gas fired only

abated by

A-11 Selective Catalytic Reduction System (SCR) *and*
A-12 Oxidation Catalyst

Subject to attached condition no. 18138.[1]

JACK P. BROADBENT
EXECUTIVE OFFICER/APCO

Permit Issue Date	September 13, 2011
Reported Start Up Date	November 1, 2008
Permit Expiration Date	**October 31, 2011**

By

Right of Entry

The Air Pollution Control Officer of the Bay Area Air Quality Management District, the Chairman of the California Air Resources Board, the Regional Administrator of the Environmental Protection Agency, and/or their designees, upon presentation of credentials, shall be granted the right of entry to any premises on which an air pollution source is located for the purposes of : i) the inspection of the source ii) the sampling of materials used at the source iii) the conduction of an emissions source test iv) the inspection of any records required by District rule or permit condition.

Permit Expiration

In accordance with Regulation 3-408, a Permit to Operate is valid for 12 months from the date of issuance or other time period as approved by the APCO. Use of this Permit to Operate is authorized by the District until the later of: the Permit Expiration Date or the Permit Renewal Date. Permit to operate fees will be prorated as described in Regulation 3-402 when the permit is renewed.

This permit does not authorize violation of the rules and regulations of the BAAQMD or the Health and Safety Code of the State of California. District regulations may be viewed on line at www.baaqmd.gov. This permit is not transferable to another person without approval from the District. It is the responsibiliy of the permit holder to have knowledge of and be in compliance with all District Rules and Regulations.

1. Compliance with conditions contained in this permit does not mean that the permit holder is currently in compliance with District Rules and Regulations.

Permit Holder Must Sign Here ____________________

BAY AREA
AIR QUALITY
MANAGEMENT
DISTRICT
SINCE 1955

PERMIT TO OPERATE

PLANT No. **18143**

SOURCE No. **42**

Gateway Generating Station

3225 Wilbur Avenue, Antioch, CA 94509

IS HEREBY GRANTED A PERMIT TO OPERATE THE FOLLOWING EQUIPMENT

Heat Recovery Steam Generator (HRSG) #1,
with Duct Burner Supplemental Firing System, 395 MM Btu/hr maximum rated capacity

abated by

A-11	Selective Catalytic Reduction System (SCR) *and*
A-12	Oxidation Catalyst

Subject to attached condition no. 18138.[1]

JACK P. BROADBENT
EXECUTIVE OFFICER/APCO

Permit Issue Date	September 13, 2011
Reported Start Up Date	January 2, 2009
Permit Expiration Date	**October 31, 2011**

By

Right of Entry
The Air Pollution Control Officer of the Bay Area Air Quality Management District, the Chairman of the California Air Resources Board, the Regional Administrator of the Environmental Protection Agency, and/or their designees, upon presentation of credentials, shall be granted the right of entry to any premises on which an air pollution source is located for the purposes of : i) the inspection of the source ii) the sampling of materials used at the source iii) the conduction of an emissions source test iv) the inspection of any records required by District rule or permit condition.

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Permit Holder Must Sign Here ____________________

BAY AREA
AIR QUALITY
MANAGEMENT
DISTRICT
SINCE 1955

PERMIT TO OPERATE

PLANT No. 18143

SOURCE No. 43

Gateway Generating Station

3225 Wilbur Avenue, Antioch, CA 94509

IS HEREBY GRANTED A PERMIT TO OPERATE THE FOLLOWING EQUIPMENT

Combustion Turbine Generator (CTG) #2
General Electric Frame 7FA.03 (Model PG 7231), 1872 MM Btu/hr maximum rated capacity, natural gas fired only

abated by

A-13	Selective Catalytic Reduction System (SCR) *and*
A-14	Oxidation Catalyst

Subject to attached condition no. 18138.[1]

JACK P. BROADBENT
EXECUTIVE OFFICER/APCO

Permit Issue Date September 13, 2011
Reported Start Up Date November 4, 2008
Permit Expiration Date **October 31, 2011**

By

Right of Entry

The Air Pollution Control Officer of the Bay Area Air Quality Management District, the Chairman of the California Air Resources Board, the Regional Administrator of the Environmental Protection Agency, and/or their designees, upon presentation of credentials, shall be granted the right of entry to any premises on which an air pollution source is located for the purposes of : i) the inspection of the source ii) the sampling of materials used at the source iii) the conduction of an emissions source test iv) the inspection of any records required by District rule or permit condition.

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1. Compliance with conditions contained in this permit does not mean that the permit holder is currently in compliance with District Rules and Regulations.

Permit Holder Must Sign Here ______________________

BAY AREA
AIR QUALITY
MANAGEMENT
DISTRICT
SINCE 1955

PERMIT TO OPERATE

PLANT No. 18143

SOURCE No. 44

Gateway Generating Station

3225 Wilbur Avenue, Antioch, CA 94509

IS HEREBY GRANTED A PERMIT TO OPERATE THE FOLLOWING EQUIPMENT

Heat Recovery Steam Generator (HRSG) #2,
with Duct Burner Supplemental Firing System, 395 MM Btu/hr maximum rated capacity

abated by

A-13	Selective Catalytic Reduction System (SCR) *and*
A-14	Oxidation Catalyst

Subject to attached condition no. 18138.[1]

JACK P. BROADBENT
EXECUTIVE OFFICER/APCO

Permit Issue Date	September 13, 2011
Reported Start Up Date	January 12, 2009
Permit Expiration Date	**October 31, 2011**

By

Right of Entry

The Air Pollution Control Officer of the Bay Area Air Quality Management District, the Chairman of the California Air Resources Board, the Regional Administrator of the Environmental Protection Agency, and/or their designees, upon presentation of credentials, shall be granted the right of entry to any premises on which an air pollution source is located for the purposes of : i) the inspection of the source ii) the sampling of materials used at the source iii) the conduction of an emissions source test iv) the inspection of any records required by District rule or permit condition.

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1. Compliance with conditions contained in this permit does not mean that the permit holder is currently in compliance with District Rules and Regulations.

Permit Holder Must Sign Here ______________________

Gateway Generating Station Permit Conditions

5/7/02 Revised Conditions 6 and 47
9/13/11 Revised Conditions to be consistent with CEC license amendments (August 2009 and Sept. 2011) and to incorporate the approved consent decree requirements (Civil Action No. 09-4503 SI)

Definitions:

1-hour period:
Any continuous 60-minute period beginning on the hour.

Calendar Day:
Any continuous 24-hour period beginning at 12:00 AM or 0000 hours.

Year:
Any consecutive twelve-month period of time.

Heat Input:
All heat inputs refer to the heat input at the higher heating value (HHV) of the fuel, in Btu/scf.

Rolling 3-hour period:
Any three-hour period that begins on the hour and does not include start-up or shutdown periods.

Firing Hours:
Period of time during which fuel is flowing to a unit, measured in fifteen-minute increments.

MM Btu:
million British thermal units.

Gas Turbine Start-up Mode:
The lesser of the first 256 minutes of continuous fuel flow to the Gas Turbine after fuel flow is initiated or the period of time from Gas Turbine fuel flow initiation until the Gas Turbine achieves two consecutive CEM data points in compliance with the emission concentration limits of conditions 20(b) and 20(d).

Gas Turbine Shutdown Mode:
The lesser of the 30 minute period immediately prior to the termination of fuel flow to the Gas Turbine or the period of time from non-compliance with any requirement listed in Conditions 20(b) and 20(d) until termination of fuel flow to the Gas Turbine.

Specified PAHs:
The polycyclic aromatic hydrocarbons listed below shall be

considered to Specified PAHs for these permit conditions. Any emission limits for Specified PAHs refer to the sum of the emissions for all six of the following compounds.

Benzo[a]anthracene
Benzo[b]fluoranthene
Benzo[k]fluoranthene
Benzo[a]pyrene
Dibenzo[a,h]anthracene
Indeno[1,2,3-cd]pyrene

Corrected Concentration:
The concentration of any pollutant (generally NOx, CO, or NH3) corrected to a standard stack gas oxygen concentration. For emission point P-11 (combined exhaust of S-41 Gas Turbine and S-42 HRSG duct burners) and emission point P-12 (combined exhaust of S-43 Gas Turbine and S-44 HRSG duct burners) the standard stack gas oxygen concentration is 15% O2 by volume on a dry basis.

Commissioning Activities:
All testing, adjustment, tuning, and calibration activities recommended by the equipment manufacturers and the GGS construction contractor to insure safe and reliable steady state operation of the gas turbines, heat recovery steam generators, steam turbine, and associated electrical delivery systems.

Commissioning Period:
The Period shall commence when all mechanical, electrical, and control systems are installed and individual system start-up has been completed, or when a gas turbine is first fired, whichever occurs first. The period shall terminate when the plant has completed performance testing, and is available for commercial operation.

Precursor Organic Compounds (POCs):
Any compound of carbon, excluding methane, ethane, carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate.

CEC CPM:
California Energy Commission Compliance Program Manager.

GGS:
Gateway Generating Station.

Conditions for the Commissioning Period

1. The owner/operator of the GGS shall minimize emissions of carbon monoxide and nitrogen oxides from S-41 and S-43 Gas Turbines and S-

42 and S-44 Heat Recovery Steam Generators (HRSGs) to the maximum extent possible during the commissioning period. Conditions 1 through 12 shall only apply during the commissioning period as defined above. Unless otherwise indicated, Conditions 13 through 44 shall apply after the commissioning period has ended.

2. At the earliest feasible opportunity in accordance with the recommendations of the equipment manufacturers and the construction contractor, the S-41 & S-43 Gas Turbine combustors and S-42 & S-44 Heat Recovery Steam Generator duct burners shall be tuned to minimize the emissions of carbon monoxide and nitrogen oxides.

3. At the earliest feasible opportunity, in accordance with the recommendations of the equipment manufacturers and the construction contractor, the A-11 and A-13 SCR Systems and A-12 and A-14 CO Oxidation Catalyst Systems shall be installed, adjusted, and operated to minimize the emissions of carbon monoxide and nitrogen oxides from S-41 & S-43 Gas Turbines and S-42 & S-44 Heat Recovery Steam Generators.

4. Coincident with the as designed operation of A-11 & A-13 SCR Systems, pursuant to conditions 3, 10, 11, and 12, the Gas Turbines (S-41 & S-43) and the HRSGs (S-42 & S-44) shall comply with the NOx and CO emission limitations specified in conditions 20(a) through 20(d).

5. The owner/operator of the GGS shall submit a plan to the District Permit Services Division and the CEC CPM at least four weeks prior to first firing of S-41 or S-43 Gas Turbines describing the procedures to be followed during the commissioning of the gas turbines and HRSGs. The plan shall include a description of each commissioning activity, the anticipated duration of each activity in hours, and the purpose of the activity. The activities described shall include, but not be limited to, the tuning of the Dry-Low-NOx combustors, the installation and operation of the SCR systems and oxidation catalysts, the installation, calibration, and testing of the CO and NOx continuous emission monitors, and

any activities requiring the firing of the Gas Turbines (S-41 & S-43) and HRSGs (S-42 & S-44) without abatement by their respective SCR and CO Catalyst Systems.

6. During the commissioning period, the owner/operator of the GGS shall demonstrate compliance with conditions 8 through 11 through the use of properly operated and maintained continuous emission monitors and data recorders for the following parameters:
   - firing hours for each gas turbine and each HRSG
   - fuel flow rates to each train
   - stack gas nitrogen oxide emission concentrations at P-11 and P-12
   - stack gas carbon monoxide emission concentrations P-11 and P-12
   - stack gas carbon dioxide or oxygen concentrations P-11 and P-12

   The monitored parameters shall be recorded at least once every 15 minutes (excluding normal calibration periods or when the monitored source is not in operation) for the Gas Turbines (S-41 & S-43) and HRSGs (S-42 & S-44). The owner/operator shall use District-approved methods to calculate heat input rates, NOx mass emission rates, carbon monoxide mass emission rates, and NOx and CO emission concentrations, summarized for each clock hour and each calendar day. All records shall be retained on site for at least 5 years from the date of entry and made available to District personnel upon request.

7. The District-approved continuous emission monitors specified in condition 6 shall be installed, calibrated, and operational prior to first firing of the Gas Turbines (S-41 & S-43) and Heat Recovery Steam Generators (S-42 & S-44). After first firing of the turbines, the detection range of these continuous emission monitors shall be adjusted as necessary to accurately measure the resulting range of CO and NOx emission concentrations. The type, specifications, and location of these monitors shall be subject to District review and approval.

8. The total number of firing hours of S-41 Gas Turbine and S-42 Heat Recovery Steam Generator

without abatement of nitrogen oxide emissions by A-11 SCR System and/or A-12 Oxidation Catalyst System shall not exceed 500 hours during the commissioning period. Such operation of S-41 Gas Turbine and S-42 HRSG without abatement shall be limited to discrete commissioning activities that can only be properly executed without the SCR or Oxidation Catalyst Systems fully operational. Upon completion of these activities, the owner/operator shall provide written notice to the District Permit Services and Enforcement Divisions and the unused balance of the 500 firing hours without abatement shall expire.

9. The total number of firing hours of S-43 Gas Turbine and S-44 Heat Recovery Steam Generator without abatement of nitrogen oxide emissions by A-13 SCR System and/or A-14 Oxidation Catalyst System shall not exceed 500 hours during the commissioning period. Such operation of S-43 Gas Turbine and S-44 HRSG without abatement shall be limited to discrete commissioning activities that can only be properly executed without the SCR or Oxidation Catalyst Systems fully operational. Upon completion of these activities, the owner/operator shall provide written notice to the District Permit Services and Enforcement Divisions and the unused balance of the 500 firing hours without abatement shall expire.

10. The total mass emissions of nitrogen oxides, carbon monoxide, precursor organic compounds, PM10, and sulfur dioxide that are emitted by the Gas Turbines (S-41 & S-43) and Heat Recovery Steam Generators (S-42 & S-44) during the commissioning period shall accrue towards the consecutive twelve-month emission limitations specified in condition 24.

11. Combined pollutant mass emissions from the Gas Turbines (S-41 & S-43) and Heat Recovery Steam Generators (S-42 & S-44) shall not exceed the following limits during the commissioning period. These emission limits shall include emissions resulting from the start-up and shutdown of the Gas Turbines (S-41 & S-43).

Pollutant	Daily Mass Limit (lb/calendar day)	Maximum Hourly (lb/hour)
NOx(as NO2)	8,400	400
CO	13,000	584
POC(as CH4)	535	
PM10	624	
SO2	297	

12. Prior to the end of the Commissioning Period, the Owner/Operator shall conduct a District and CEC approved source test using external continuous emission monitors to determine compliance with condition 21. The source test shall determine NOx, CO, and POC emissions during start-up and shutdown of the gas turbines. The POC emissions shall be analyzed for methane and ethane to account for the presence of unburned natural gas. The source test shall include a minimum of three start-up and three shutdown periods. No later than twenty working days before the execution of the source tests, the Owner/Operator shall submit to the District and the CEC Compliance Program Manager (CPM) a detailed source test plan designed to satisfy the requirements of this condition. The District and the CEC CPM will notify the Owner/Operator of any necessary modifications to the plan within 20 working days of receipt of the plan; otherwise, the plan shall be deemed approved. The Owner/Operator shall incorporate the District and CEC CPM comments into the test plan. The Owner/Operator shall notify the District and the CEC CPM within seven (7) working days prior to the planned source testing date. Source test results shall be submitted to the District and the CEC CPM within 30 days of the source testing date.

Conditions for the Gas Turbines (S-41 & S-43) and the Heat Recovery Steam Generators (HRSGs; S-42 & S-44)

13. The Gas Turbines (S-41 and S-43) and HRSG Duct Burners (S-42 and S-44) shall be fired exclusively on natural gas. (BACT for SO2 and PM10)

14. The combined heat input rate to each power train consisting of a Gas Turbine and

its associated HRSG (S-41 & S-42 and S-43 & S-44) shall not exceed 2,227 MM Btu per hour, averaged over any rolling 3-hour period. (PSD for NOx)

15. The combined heat input rate to each power train consisting of a Gas Turbine and its associated HRSG (S-41 & S-42 and S-43 & S-44) shall not exceed 49,950 MM Btu per calendar day. (PSD for PM10)

16. The combined cumulative heat input rate for the Gas Turbines (S-41 & S-43) and the HRSGs (S-42 & S-44) shall not exceed 34,900,000 MM Btu per year. (Offsets)

17. The HRSG duct burners (S-42 and S-44) shall not be fired unless its associated Gas Turbine (S-41 and S-43, respectively) is in operation. (BACT for NOx)

18. Except as provided in Condition No. 8, S-41 Gas Turbine and S-42 HRSG shall be abated by the properly operated and properly maintained A-11 Selective Catalytic Reduction (SCR) System whenever fuel is combusted at those sources and the A-11 catalyst bed has reached minimum operating temperature. (BACT for NOx)

19. Except as provided in Condition No. 9, S-43 Gas Turbine and S-44 HRSG shall be abated by the properly operated and properly maintained A-13 Selective Catalytic Reduction (SCR) System whenever fuel is combusted at those sources and the A-13 catalyst bed has reached minimum operating temperature. (BACT for NOx)

20. The Gas Turbines (S-41 & S-43) and HRSGs (S-42 & S-44) shall comply with requirements (a) through (h) under all operating scenarios, including duct burner firing mode. Requirements (a) through (h) do not apply during a gas turbine start-up or shutdown. (BACT, PSD, and Toxic Risk Management Policy)

    a. Nitrogen oxide mass emissions (calculated in accordance with District approved methods as NO2) at P-11 (the combined exhaust point for the S-41 Gas Turbine and the S-42 HRSG after abatement by A-11

SCR System) shall not exceed 20 pounds per hour or 0.0090 lb./MM Btu (HHV) of natural gas fired. Nitrogen oxide mass emissions (calculated in accordance with District approved methods as NO2) at P-12 (the combined exhaust point for the S-43 Gas Turbine and the S-44 HRSG after abatement by A-13 SCR System) shall not exceed 20 pounds per hour or 0.0090 lb./MM Btu (HHV) of natural gas fired. (PSD for NOx)

b.The nitrogen oxide emission concentration at emission points P-11 and P-12 each shall not exceed 2.5 ppmv, on a dry basis, corrected to 15% O2, averaged over any 1-hour period. (BACT for NOx)

c.Carbon monoxide mass emissions at P-11 and P-12 each shall not exceed 0.013 lb./MM Btu (HHV) of natural gas fired or 29.22 pounds per hour, averaged over any rolling 3-hour period. (PSD for CO)

d.The carbon monoxide emission concentration at P-11 and P-12 each shall not exceed 6 ppmv, on a dry basis, corrected to 15% O2, averaged over any rolling 3-hour period. (BACT for CO)

e.Ammonia (NH3) emission concentrations at P-11 and P-12 each shall not exceed 5 ppmv, on a dry basis, corrected to 15% O2, averaged over any rolling 3-hour period. This ammonia emission concentration shall be verified by the continuous recording of the ammonia injection rate to A-11 and A-13 SCR Systems. The correlation between the gas turbine and HRSG heat input rates, A-11 and A-13 SCR System ammonia injection rates, and corresponding ammonia emission concentration at emission points P-11 and P-12 shall be determined in accordance with permit condition #29. (TRMP for NH3)

f.Precursor organic compound (POC) mass emissions (as CH4) at P-11 and P-12 each shall not exceed 5.6 pounds per hour or 0.0025 lb./MM Btu of natural gas fired. (BACT)

g. Sulfur dioxide (SO2) mass emissions at P-11 and P-12 each shall not exceed 6.18 pounds per hour or 0.0028 lb./MM Btu of natural gas fired. (BACT)

h. Particulate matter (PM10) mass emissions at P-11 and P-12 each shall not exceed 11 pounds per hour or 0.00588 lb./MM Btu of natural gas fired when the HRSG duct burners are not in operation. Particulate matter (PM10) mass emissions at P-11 and P-12 each shall not exceed 13 pounds per hour or 0.00584 lb./MM Btu of natural gas fired when the HRSG duct burners are in operation. (BACT)

21. The regulated air pollutant mass emission rates from each of the Gas Turbines (S-41 and S-43) during a start-up or a shutdown shall not exceed the limits established below. (PSD)

Pollutant	Cold Start-Up (lb/start-up)	Hot Start-Up (lb/start-up)	Shutdown (lb/shutdown)
Oxides of Nitrogen (as NO2)	452	189	59
Carbon Monoxide (CO)	990	291	73
Precursor Organic Compounds (as CH4)	109	26	6

22. The Gas Turbines (S-41 and S-43) shall not be in start-up mode simultaneously. (PSD)

23. Total combined emissions from the Gas Turbines and HRSGs (S-41, S-42, S-43, and S-44), including emissions generated during Gas Turbine start-ups and shutdowns shall not exceed the following limits during any calendar day:

a. 1,994 pounds of NOx (as NO2) per day (CEQA)

b. 3,602 pounds of CO per day (PSD)

c. 468 pounds of POC (as CH4) per day (CEQA) d.624 pounds of PM10 per day (PSD)

e.297 pounds of SO2 per day (BACT)

24.Cumulative combined emissions from the Gas Turbines and HRSGs (S-41, S-42, S-43, and S-44) and the Diesel Fire Pump Engine (S-47), including emissions generated during gas turbine start-ups and shutdowns shall not exceed the following limits during any consecutive twelve-month period:

a.174.3 tons of NOx (as NO2) per year (Offsets, PSD)

b.259.1 tons of CO per year (Cumulative Increase)

c.46.6 tons of POC (as CH4) per year (Offsets)

d.105 tons of PM10 per year (Offsets, PSD)

e.48.5 tons of SO2 per year (Cumulative Increase)

25.Toxic and HAP Emission Limits

25.1 The maximum projected annual toxic air contaminant emissions (per condition 28) from the Gas Turbines and HRSGs combined (S-41, S-42, S-43, and S-44) shall not exceed the following limits:

4,102 pounds of formaldehyde per year
506 pounds of benzene per year
38 pounds of specified polycyclic aromatic hydrocarbons (PAHs) per year

unless the following requirement is satisfied:

The owner/operator shall perform a health risk assessment using the emission rates determined by source test and the most current Bay Area Air Quality Management District approved procedures and unit risk factors in effect at the time of the analysis. This risk analysis shall be submitted to the District and the CEC CPM within 60 days of the source test date. The owner/operator may request that the District and the CEC CPM revise the carcinogenic compound emission limits specified above. If the owner/operator demonstrates to the satisfaction of the APCO that these revised emission limits will result in a cancer risk of not more than 1.0 in one million, the District and the CEC CPM may, at their discretion, adjust the carcinogenic compound emission limits listed above. (TRMP)

25.2 The maximum projected annual Hazardous Air Pollutant (HAP) emissions from the Gas Turbines And HRSGs combined (S-41, S-42, S-43, and S-44) shall not exceed the following limit:

20,000 pounds of hexane per year (US-CAA, Section 112(g))

Conformance with this limit shall be verified by the source testing in condition 32.

26. The owner/operator shall demonstrate compliance with conditions 14 through 17, 20(a) through 20(d), 21, 23(a), 23(b), 24(a), and 24(b) by using properly operated and maintained continuous monitors (during all hours of operation including equipment Start-up and Shutdown periods) for all of the following parameters:

a. Firing Hours and Fuel Flow Rates for each of the following sources: S-41 & S-42 combined and S-43 & S-44 combined.

b. Carbon Dioxide (CO2) or Oxygen (O2) concentrations, Nitrogen Oxides (NOx) concentrations, and Carbon Monoxide (CO) concentrations at each of the following exhaust points: P-11 and P-12.

c. Ammonia injection rate at A-11 and A-13 SCR Systems

d. Deleted

The owner/operator shall record all of the above parameters every 15 minutes (excluding normal calibration periods) and shall summarize all of the above parameters for each clock hour. For each calendar day, the owner/operator shall calculate and record the total firing hours, the average hourly fuel flow rates, and average hourly pollutant emission concentrations.

The owner/operator shall use the parameters measured above and District-approved calculation methods to calculate the following parameters:

e. Heat Input Rate for each of the following sources: S-41 & S-42 combined and S-43 & S-44 combined.

f. Corrected NOx concentrations, NOx mass emissions (as NO2), corrected CO concentrations, and CO mass emissions at each of the following exhaust points: P-11 and P-12.

Applicable to emission points P-11 and P-12, the owner/operator shall record the parameters specified in conditions 26(e) and 26(f) at least once every 15 minutes (excluding normal calibration periods). As specified below, the owner/operator shall calculate and record the following data:

g. total Heat Input Rate for every clock hour and the average hourly Heat Input Rate for every rolling 3-hour period.

h. on an hourly basis, the cumulative total Heat Input Rate for each calendar day for the following: each Gas Turbine and associated HRSG combined and all four sources (S-41, S-42, S-43, and S-44) combined.

i. the average NOx mass emissions (as NO2), CO mass emissions, and corrected NOx and CO emission concentrations for every clock hour and for every rolling 3-hour period.

j. on an hourly basis, the cumulative total NOx mass emissions (as NO2) and the cumulative total CO mass emissions, for each calendar day for the following: each Gas Turbine and associated HRSG combined, and all four sources (S-41, S-42, S-43, and S-44) combined.

k. For each calendar day, the average hourly Heat Input Rates, Corrected NOx emission concentrations, NOx mass emissions (as

NO2), corrected CO emission concentrations, and CO mass emissions for each Gas Turbine and associated HRSG combined.

l. on a daily basis, the cumulative total NOx mass emissions (as NO2) and cumulative total CO mass emissions, for the previous consecutive twelve month period for all four sources (S-41, S-42, S-43, and S-44) combined.

(1-520.1, 9-9-501, BACT, Offsets, NSPS, PSD,
Cumulative Increase)

27. To demonstrate compliance with conditions 20(f), 20(g), 20(h), 23(c) through 23(e), and 24(c) through 24(e), the owner/operator shall calculate and record on a daily basis, the Precursor Organic Compound (POC) mass emissions, Fine Particulate Matter (PM10) mass emissions (including condensable particulate matter), and Sulfur Dioxide (SO2) mass emissions from each power train. The owner/operator shall use the actual Heat Input Rates calculated pursuant to condition 26, actual Gas Turbine Start-up Times, actual Gas Turbine Shutdown Times, and CEC and District-approved emission factors to calculate these emissions. The calculated emissions shall be presented as follows:

a. For each calendar day, POC, PM10, and SO2 emissions shall be summarized for: each power train (Gas Turbine and its respective HRSG combined) and all four sources (S-41, S-42, S-43, and S-44) combined.

b. on a daily basis, the 365 day rolling average cumulative total POC, PM10, and SO2 mass emissions, for all four sources (S-41, S-42, S-43, and S-44) combined.

(Offsets, PSD, Cumulative Increase)

28. To demonstrate compliance with Condition 25, the owner/operator shall calculate and record on an annual basis the maximum projected annual emissions of Formaldehyde, Benzene, and Specified PAHs. Maximum

projected annual emissions shall be calculated using the maximum Heat Input Rate of 34,900,000 MM Btu/year and the highest emission factor (pounds of pollutant per MM Btu of Heat Input) determined by any source test of the S-41 & S-43 Gas Turbines and/or S-42 & S-44 Heat Recovery Steam Generators. If this calculation method results in an unrealistic mass emission rate (the highest emission factor occurs at a low firing rate) the applicant may use an alternate calculation, subject to District approval. (TRMP)

29. Within 60 days of start-up of the GGS, the owner/operator shall conduct a District-approved source test on exhaust point P-11 or P-12 to determine the corrected ammonia (NH3) emission concentration to determine compliance with condition 20(e). The source test shall determine the correlation between the heat input rates of the gas turbine and associated HRSG, A-11 or A-13 SCR System ammonia injection rate, and the corresponding NH3 emission concentration at emission point P-11 or P-12. The source test shall be conducted over the expected operating range of the turbine and HRSG (including, but not limited to minimum, 70%, 85%, and 100% load) to establish the range of ammonia injection rates necessary to achieve NOx emission reductions while maintaining ammonia slip levels. Continuing compliance with condition 20(e) shall be demonstrated through calculations of corrected ammonia concentrations based upon the source test correlation and continuous records of ammonia injection rate. (TRMP)

30. Within 60 days of start-up of the GGS and on an annual basis thereafter, the owner/operator shall conduct a District-approved source test on exhaust points P-11 and P-12 while each Gas Turbine and associated Heat Recovery Steam Generator are operating at maximum load to determine compliance with Conditions 20(a), (b), (c), (d), (f), (g), and (h), while each Gas Turbine and associated Heat Recovery Steam Generator are operating at minimum load to determine compliance with Conditions 20(c) and (d), and to verify the accuracy of the continuous emission monitors required in condition 26. The owner/operator

shall test for (as a minimum): water content, stack gas flow rate, oxygen concentration, precursor organic compound concentration and mass emissions, nitrogen oxide concentration and mass emissions (as NO2), carbon monoxide concentration and mass emissions, sulfur dioxide concentration and mass emissions, methane, ethane, and particulate matter (PM10) emissions including condensable particulate matter.(BACT, offsets)

31. The owner/operator shall obtain approval for all source test procedures from the District's Source Test Section and the CEC CPM prior to conducting any tests. The owner/operator shall comply with all applicable testing requirements for continuous emission monitors as specified in Volume V of the District's Manual of Procedures. The owner/operator shall notify the District's Source Test Section and the CEC CPM in writing of the source test protocols and projected test dates at least 7 days prior to the testing date(s). As indicated above, the Owner/Operator shall measure the contribution of condensable PM (back half) to the total PM10 emissions. However, the Owner/Operator may propose alternative measuring techniques to measure condensable PM such as the use of a dilution tunnel or other appropriate method used to capture semi-volatile organic compounds. Source test results shall be submitted to the District and the CEC CPM within 60 days of conducting the tests. (BACT)

32. Within 60 days of start-up of the GGS and on a biennial basis (once every two years) thereafter, the owner/operator shall conduct a District-approved source test on exhaust point P-11 or P-12 while the Gas Turbine and associated Heat Recovery Steam Generator are operating at maximum allowable operating rates to demonstrate compliance with Condition 25. If three consecutive biennial source tests demonstrate that the annual emission rates calculated pursuant to condition 28 for any of the compounds listed below are less than the BAAQMD Toxic Risk Management Policy trigger levels shown, then the owner/operator may discontinue future testing for that pollutant:

Benzene	less than or equal	26.8 pounds/year
Formaldehyde	less than or equal	132 pounds/year
Specified PAHs	less than or equal	0.18 pounds/year

(TRMP)

33. The owner/operator of the GGS shall submit all reports (including, but not limited to monthly CEM reports, monitor breakdown reports, emission excess reports, equipment breakdown reports, etc.) as required by District Rules or Regulations and in accordance with all procedures and time limits specified in the Rule, Regulation, Manual of Procedures, or Enforcement Division Policies & Procedures Manual. (Regulation 2-6-502)

34. The owner/operator of the GGS shall maintain all records and reports on site for a minimum of 5 years. These records shall include but are not limited to: continuous monitoring records (firing hours, fuel flows, emission rates, monitor excesses, breakdowns, etc.), source test and analytical records, natural gas sulfur content analysis results, emission calculation records, records of plant upsets and related incidents. The owner/operator shall make all records and reports available to District and the CEC CPM staff upon request. (Regulation 2-6-501)

35. The owner/operator of the GGS shall notify the District and the CEC CPM of any violations of these permit conditions. Notification shall be submitted in a timely manner, in accordance with all applicable District Rules, Regulations, and the Manual of Procedures. Notwithstanding the notification and reporting requirements given in any District Rule, Regulation, or the Manual of Procedures, the owner/operator shall submit written notification (facsimile is acceptable) to the Enforcement Division within 96 hours of the violation of any permit condition. (Regulation 2-1-403)

36. The stack height of emission points P-11 and P-12 shall each be at least 195 feet above grade level at the stack base. (PSD, TRMP)

37. The Owner/Operator of GGS shall provide adequate stack sampling ports and platforms to enable the performance of source testing. The

location and configuration of the stack sampling ports shall be subject to BAAQMD review and approval.(Regulation 1-501)

38. Within 180 days of the issuance of the Authority to Construct for the GGS, the Owner/Operator shall contact the BAAQMD Technical Services Division regarding requirements for the continuous monitors, sampling ports, platforms, and source tests required by conditions 26, 29, 30 and 32. All source testing and monitoring shall be conducted in accordance with the BAAQMD Manual of Procedures. (Regulation 1-501)

39. Prior to the issuance of the BAAQMD Authority to Construct for the GGS, the Owner/Operator shall demonstrate that valid emission reduction credits in the amount of 200.5 tons/year of Nitrogen Oxides, 53.6 tons/year of Precursor Organic Compounds or equivalent (as defined by District Regulations 2-2-302.1 and 2-2-302.2), and 315 tons of Sulfur Oxides are under their control through enforceable contracts, option to purchase agreements, or equivalent binding legal documents. (Offsets)

40. Prior to the start of construction of the GGS, the Owner/Operator shall provide to the District valid emission reduction credit banking certificates in the amount of 200.5 tons/year of Nitrogen Oxides, 53.6 tons/year of Precursor Organic Compounds or equivalent as defined by District Regulations 2-2-302.1 and 2-2-302.2 and 315 tons of Sulfur Oxides. (Offsets)

41. Pursuant to BAAQMD Regulation 2, Rule 6, section 404.3, the owner/operator of the GGS shall submit an application to the BAAQMD for a significant revision to the Major Facility Review Permit prior to commencing operation. (Regulation 2-6-404.3)

42. Pursuant to 40 CFR Part 72.30(b)(2)(ii) of the Federal Acid Rain Program, the owner/operator of the GGS shall not operate either of the gas turbines until either:

   a. a Title IV Operating Permit has been issued;

b. 24 months after a Title IV Operating Permit Application has been submitted, whichever is earlier.

(Regulation 2, Rule 7)

43. The GGS shall comply with the continuous emission monitoring requirements of 40 CFR Part 75. (Regulation 2, Rule 7)

44. The owner/operator shall take monthly samples of the natural gas combusted at the GGS. The samples shall be analyzed for sulfur content using District-approved laboratory methods or the owner/operator shall obtain certified analytical results from the gas supplier. The sulfur content test results shall be retained on site for a minimum of five years from the test date and shall be utilized to satisfy the requirements of 40 CFR Part 60, subpart GG. Sulfur content shall be no more than 1.0 grains/100scf. (cumulative increase)

Additional Conditions from Approved Federal Consent Decree (Civil Action No. 09-4503 SI) Included by PG&E's Request

CD-1 The Gas Turbines (S-41 & S-43) and HRSGs (S-42 & S-44) shall comply with requirements (a) and (b) under all operating scenarios, including duct burner firing mode, except as specified in Condition CD-2.

a. The nitrogen oxide emission concentration at emission points P-11 and P-12 each shall not exceed 2.0 ppmv, on a dry basis, corrected to 15% O2, averaged over any 1-hour period.

b. Particulate matter (PM10) mass emissions at P-11 and P-12 each shall not exceed 7.50 pounds per hour when the HRSG duct burners are not in operation. Particulate matter (PM10) mass emissions at P-11 and P-12 each shall not exceed 9.0 pounds per hour when the HRSG duct burners are in operation. Particulate matter (PM10) mass emissions at P-11 and P-12 each shall not exceed 0.004 lb/MMBtu of natural gas fired.

(Basis: Voluntary-Consent Decree)

CD-2 NOx emissions during Natural-Gas Combustion Turbine Start-up Mode and during

Natural-Gas Combustion Turbine Shutdown Mode shall not be included in calculating compliance with the one-hour 2.0 ppmv NOx concentration emission limit set forth in Condition CD-1. Natural-Gas Combustion Turbine Start-up Mode is the lesser of the first 256 minutes of continuous fuel flow to the natural gas-fired combustion turbine after fuel flow is initiated or the period of time from natural gas-fired combustion turbine fuel flow initiation until the natural gas-fired combustion turbine achieves two consecutive continuous emission monitor data points in compliance with the 2.0 ppmv NOx emission concentration limit. Natural-Gas Combustion Turbine Shutdown Mode is the lesser of the 30 minute period immediately prior to the termination of fuel flow to the natural gas-fired combustion turbine or the period of time from noncompliance with the 2.0 ppmv NOx emission concentration limit until termination of fuel flow to the natural gas fired combustion turbine.
(Basis: Voluntary-Consent Decree)

CD-3 Cumulative combined emissions from the Gas Turbines and HRSGs (S-41, S-42, S-43, and S-44), including emissions generated during gas turbine start-ups and shutdowns, shall not exceed the following limits during any consecutive twelvemonth period:
a. 139.2 tons of NOx (as NO2) per year
b. 18.5 tons of SO2 per year
(Basis: Voluntary-Consent Decree)

CD-4 The Gas Turbines (S-41 and S-43) and HRSG Duct Burners (S-42 and S-44) shall be fired exclusively on natural gas with a maximum sulfur content no greater than 1 grain per 100 standard cubic feet.
(Basis: Voluntary-Consent Decree)

End of Conditions

BAY AREA
AIR QUALITY
MANAGEMENT
DISTRICT
SINCE 1955

PERMIT TO OPERATE

PLANT No. 18143

SOURCE No. 47

Gateway Generating Station

3225 Wilbur Avenue, Antioch, CA 94509

IS HEREBY GRANTED A PERMIT TO OPERATE THE FOLLOWING EQUIPMENT

Diesel Fire Pump Engine
Emergency standby, IC Engine, Deere Power Systems, model JW6H-UFADF0, 311 bhp

Subject to attached condition no. 25057.[1]

JACK P. BROADBENT
EXECUTIVE OFFICER/APCO

Permit Issue Date	September 13, 2011
Reported Start Up Date	August 6, 2010
Permit Expiration Date	**October 31, 2011**

By

Right of Entry

The Air Pollution Control Officer of the Bay Area Air Quality Management District, the Chairman of the California Air Resources Board, the Regional Administrator of the Environmental Protection Agency, and/or their designees, upon presentation of credentials, shall be granted the right of entry to any premises on which an air pollution source is located for the purposes of : i) the inspection of the source ii) the sampling of materials used at the source iii) the conduction of an emissions source test iv) the inspection of any records required by District rule or permit condition.

Permit Expiration

In accordance with Regulation 3-408, a Permit to Operate is valid for 12 months from the date of issuance or other time period as approved by the APCO. Use of this Permit to Operate is authorized by the District until the later of: the Permit Expiration Date or the Permit Renewal Date. Permit to operate fees will be prorated as described in Regulation 3-402 when the permit is renewed.

This permit does not authorize violation of the rules and regulations of the BAAQMD or the Health and Safety Code of the State of California. District regulations may be viewed on line at www.baaqmd.gov. This permit is not transferable to another person without approval from the District. It is the responsibiliy of the permit holder to have knowledge of and be in compliance with all District Rules and Regulations.

[1] ***Compliance with conditions contained in this permit does not mean that the permit holder is currently in compliance with District Rules and Regulations.***

Permit Holder Must Sign Here ____________________

Plant Name: Gateway Generating Station
Source No. 47 Diesel Fire Pump Engine
Condition No. 25057 Plant No. 18143 Application No. 21296

1. The owner/operator shall not exceed 50 hours per year per engine for reliability-related testing.
[Basis: "Stationary Diesel Engine ATCM" section 93115, title 17, CA Code of Regulations, subsection (e)(2)(A)(3) or (e)(2)(B)(3)]

2. The owner/operator shall operate each emergency standby engine only for the following purposes: to mitigate emergency conditions, for emission testing to demonstrate compliance with a District, State or Federal emission limit, or for reliability-related activities (maintenance and other testing, but excluding emission testing). Operating while mitigating emergency conditions or while emission testing to show compliance with District, State or Federal emission limits is not limited.
[Basis: "Stationary Diesel Engine ATCM" section 93115, title 17, CA Code of Regulations, subsection (e)(2)(A)(3) or (e)(2)(B)(3)]

3. The owner/operator shall operate each emergency standby engine only when a non-resettable totalizing meter (with a minimum display capability of 9,999 hours) that measures the hours of operation for the engine is installed, operated and properly maintained.
[Basis: "Stationary Diesel Engine ATCM" section 93115, title 17, CA Code of Regulations, subsection(e)(4)(G)(1)]

4. Records: The owner/operator shall maintain the following monthly records in a District-approved log for at least 36 months from the date of entry (60 months if the facility has been issued a Title V Major Facility Review Permit or a Synthetic Minor Operating Permit). Log entries shall be retained on-site, either at a central location or at the engine's location, and made immediately available to the District staff upon request.
    a. Hours of operation for reliability-related activities (maintenance and testing).
    b. Hours of operation for emission testing to show compliance with emission limits.
    c. Hours of operation (emergency).
    d. For each emergency, the nature of the emergency condition.
    e. Fuel usage for each engine(s).

    [Basis: "Stationary Diesel Engine ATCM" section 93115, title 17, CA Code of Regulations, subsection (e)(4)(I), (or, Regulation 2-6-501)]

5. At School and Near-School Operation:
If the emergency standby engine is located on school grounds or within 500 feet of any school grounds, the following requirements shall apply:

    The owner/operator shall not operate each stationary emergency standby diesel-fueled engine for non-emergency use, including maintenance and testing, during the following periods:
    a. Whenever there is a school sponsored activity (if the engine is located on school grounds)
    b. Between 7:30 a.m. and 3:30 p.m. on days when school is in session.

    "School" or "School Grounds" means any public or private school used for the purposes of the education of more than 12 children in kindergarten or any of grades 1 to 12, inclusive, but does not include any private school in which education is primarily conducted in a private home(s). "School" or "School Grounds" includes any building or structure, playground, athletic field, or other areas of school property but does not include unimproved school property.
    [Basis: "Stationary Diesel Engine ATCM" section 93115, title 17, CA Code of Regulations, subsection (e)(2)(A)(1)] or (e)(2)(B)(2)]

6. The owner/operator shall use the latest EPA Tier level engine available at the time of permit issuance for the diesel fire pump. (BACT)

End of Conditions

Agreement for Partial Delegation of the Federal Prevention of Significant Deterioration (PSD) Program Set Forth In 40 C.F.R. Section 52.21 by the United States Environmental Protection Agency, Region 9 to the Bay Area Air Quality Management District

The undersigned, on behalf of the Bay Area Air Quality Management District (District) and the United States Environmental Protection Agency (EPA), hereby agree to partial delegation of authority to issue Prevention of Significant Deterioration (PSD) initial permits, to modify existing PSD permits, and to extend existing PSD permits, subject to the terms and conditions of this Agreement. This partial delegation is executed pursuant to 40 C.F.R. Section 52.21(u), Delegation of Authority.

I. Background Recitals

1. In accordance with Sections 165 *et seq.* of the Clean Air Act, EPA has adopted regulations that implement the Clean Air Act's Prevention of Significant Deterioration (PSD) program. These regulations are set forth in 40 C.F.R. Section 52.21. These regulations have been incorporated as part of the applicable California State plan for implementation of the New Source Review program under the Clean Air Act pursuant to 40 C.F.R. Section 52.270(a)(3), and they govern the implementation of the Clean Air Act's PSD requirements in the San Francisco Bay Area.
2. EPA's PSD regulations require that certain stationary sources of air pollutant emissions must undergo a PSD source review and obtain a PSD permit before they may be constructed and operated, as set forth in 40 C.F.R. Section 52.21.
3. Under Subsection (u) of EPA's PSD Regulations, 40 C.F.R. § 52.21(u), EPA may delegate its authority to conduct its PSD source review under 40 C.F.R. Section 52.21 to the District for sources within the District's geographical jurisdiction. Pursuant to such delegation, the District "stands in the shoes" of EPA for purposes of conducting the PSD source review and issuing the PSD permit, and in doing so must follow and implement

the same substantive and procedural requirements as EPA would if it were conducting the PSD source review and issuing the PSD permit itself.

4. EPA and the District have entered into several PSD delegation agreements in the past under 40 C.F.R. Section 52.21(u), the most recent of which became effective February 6, 2008. These prior delegation agreements were based on a finding that the PSD portion of District Regulation 2, Rule 2, generally meets the requirements of 40 C.F.R. Section 52.21 for issuing PSD permits, and that District permits issued in accordance with the provisions of District Regulation 2, Rule 2 would therefore be deemed to meet the federal PSD permit requirements in 40 C.F.R. Section 52.21. (These prior delegation agreements did not, however, delegate authority to issue PSD permits using new additional calculation methodologies for determining if a proposed project will result in a major modification and the application of a Plantwide Applicability Limit (PAL), which were promulgated by EPA effective March 3, 2003, (*see* 67 Fed. Reg. 80,186), and were upheld by the United States Court of Appeals for the District of Columbia Circuit on June 24, 2005.)
5. It has now become clear that although the PSD portion of District Regulation 2, Rule 2 may be generally consistent with the Federal PSD requirements in 40 C.F.R. Section 52.21, the District's regulations are not completely consistent with the Federal PSD requirements in every respect. Accordingly, if the District issues PSD permits under its Regulation 2, Rule 2, such permits may not in certain circumstances satisfy all federal PSD requirements in 40 C.F.R. Section 52.21, or all federal procedural requirements for PSD permit issuance in 40 C.F.R. Part 124. EPA and the District are therefore revising their delegation agreement under 40 C.F.R. Section 52.21(u) to clarify that the District must issue PSD permits pursuant to the federal PSD requirements of 40 C.F.R. Section 52.21, and under the provisions of District Regulation 2, Rule 2 only to the extent that that such provisions are consistent with the requirements of 40 C.F.R. Section 52.21.

II. Scope of Partial Delegation

1. This partial delegation of authority to issue, modify and extend PSD permits does not delegate authority to the District to issue new or modified PSD permits based on PALs.
2. For all applications for new, modified, or extended PSD permits other than those described in Paragraph II.1. above, District-issued permits with federal PSD provisions that:
   a. satisfy all of the substantive requirements of the PSD program in 40 C.F.R. Section 52.21, including (without limitation) the federal BACT requirement pursuant to 40 C.F.R. Section 52.21(j) and 40 C.F.R. Section 52.21(b)(12), and the impact analysis requirements pursuant to 40 C.F.R. Section 52.21(k)-(o); and
   b. have been issued in compliance with all of the procedural requirements of the PSD program in 40 C.F.R. Section 52.21 and 40 C.F.R. Part 124;

   shall be deemed to meet federal PSD permit requirements pursuant to the provisions of this delegation agreement.

III. Applicability

1. EPA and the District have agreed to this partial delegation of PSD authority to allow the District to issue initial and modified PSD permits and extensions of PSD permits, except for modified permits based on an applicability determination using the methods adopted on December 31, 2002 (*see* 67 Fed. Reg. 80,186). EPA shall make the PSD applicability determination and issue any necessary PSD permits if a source seeks a PSD applicability determination using the methods adopted on December 31, 2002; or seeks a new or modified PSD permits with a PAL. (Modifications include Administrative Amendments, Major Modifications, and non-Major Modifications.)
2. Pursuant to this partial delegation agreement, the District shall have primary responsibility for issuing all new and modified PSD permits and extensions of PSD permits.

3. The authority to issue a PSD permit containing a PAL is not delegated to the District as part of this delegation agreement. If any facility subject to this agreement requests a new permit or permit modification to incorporate conditions for a PAL, as provided in 40 C.F.R. Section 52.21(aa), EPA shall process the application and issue the final PAL permit for the modification.

4. EPA is responsible for the issuance of PSD permits on Indian Lands under Sections 110 and 301 of the Clean Air Act. This agreement does not grant or delegate any authority under the Clean Air Act on Indian Lands to the District.

5. This partial delegation of PSD authority becomes effective upon the date of signature by both parties to this agreement.

IV. General Delegation Conditions

1. The District shall issue PSD permits under this partial delegation agreement in accordance with the requirements of 40 C.F.R. Section 52.21 in effect as of the date the District issues the final permit, except as provided in Subsection III; and, to the extent that the PSD requirements of the District's Regulation 2, Rule 2 are consistent with the requirements of 40 C.F.R. Section 52.21, in accordance with those requirements as well.

2. The District may (but shall not be required to) issue Federal PSD permits in an integrated permit proceeding along with permits required under California law and District regulations, and may include both Federal PSD requirements and California and/or District requirements in a single, integrated permit document. All Federal PSD permit conditions shall be clearly identified in any integrated permit document issued. Nothing in this partial delegation agreement shall be construed to direct or to authorize the District to issue PSD permits in an integrated permit proceeding that are inconsistent with Federal PSD requirements, however. Any provisions that are included in an integrated permit document under California law or District regulations that are not consistent with or authorized by the Federal PSD requirements shall not be considered part of the Federal PSD permit.

3. This partial delegation agreement may be amended at any time by the formal written agreement of both the District and the EPA, including amendments to add, change, or remove terms and conditions of this agreement.
4. EPA may review the PSD permit(s) issued by the District to ensure that the District's implementation of this delegation agreement is consistent with federal PSD regulations for major sources, major modifications, and permit extensions as set forth in 40 C.F.R. Section 52.21 and 40 C.F.R. Part 124.
5. If EPA determines that the District is not implementing or enforcing the PSD program in accordance with the terms and conditions of this partial delegation agreement, 40 C.F.R. Section 52.21, 40 C.F.R. Part 124, or the Clean Air Act, EPA may after consultation with the District revoke this partial delegation agreement in whole or in part. Any such revocation shall be effective as of the date specified in a Notice of Revocation to the District.
6. Revocation of this partial delegation agreement as specified in Paragraph IV.5. above shall be the sole remedy available for any failure by the District to implement or enforce the PSD program in accordance with the terms and conditions of this partial delegation agreement, 40 C.F.R. Section 52.21, 40 C.F.R. Part 124, or the Clean Air Act. The District's agreement to implement the Federal PSD program on EPA's behalf, and EPA's agreement to delegate its authority for the Federal PSD program to the District under 40 C.F.R. Section 52.21(u), is not intended and shall not be construed to alter or expand the statutory limits on the imposition of sanctions against the District under the Clean Air Act for failure to administer and enforce federal regulatory requirements as described in *Brown v. EPA*, 521 F.2d 827 (9th Cir. 1975), *vacated as moot*, 431 U.S. 99 (1977), and *Brown v. EPA*, 566 F.2d 665 (9th Cir. 1977).
7. If the District determines that issuing a PSD permit or permits in accordance with the terms and conditions of this partial delegation agreement, 40 C.F.R. Section 52.21, 40 C.F.R. Part 124, and the Clean Air Act conflicts with State or local law, or exceeds the

District's authority or resources to fully and satisfactorily carry out such responsibilities, the District after consultation with EPA may remand administration of such permits, or of Federal PSD delegation in its entirety, to EPA. Any such remand shall be effective as of the date specified in a Notice of Remand to EPA.

8. The permit appeal provisions of 40 C.F.R. Part 124, including subpart C thereof, pertaining to the Environmental Appeals Board (EAB), shall apply to all federal PSD permitting action appeals to the EAB for PSD permits issued by the District under this partial delegation agreement. For purposes of implementing the federal permit appeal provisions under this partial delegation, the District shall notify the applicant and each person who submitted written comments or requested notice of final permit decision of the final permit decision in accordance with 40 C.F.R. Section 124.15. The notice of final permit decision shall include (i) reference to the procedures for appealing the final permit decision under 40 C.F.R. Section 124.19; and (ii) a statement of the effective date of the final permit decision established pursuant to 40 C.F.R Section 124.15(b) and that the effective date shall be suspended if the final permit decision is appealed pursuant to 40 C.F.R. Section 124.19 until such appeal is resolved by the EAB.

V. Communication Between EPA and the District

The District and EPA will use the following communication procedures:

1. The District will forward to EPA copies of (1) all draft PSD permits prepared by the District pursuant to 40 C.F.R. Section 124.6; (2) all "Statements of Basis" prepared by the District pursuant to 40 C.F.R. Section 124.7 and/or "Fact Sheets" prepared by the District pursuant to 40 C.F.R. Section 124.8; and (3) all public notices the District issues pursuant to the requirements of 40 C.F.R. Section 124.10. Such copies shall be provided to EPA at or prior to the beginning of the public comment period for each PSD preliminary determination.
2. Upon any final PSD permit issuance, the District will forward to EPA copies of the notice of final permit issuance required by 40 C.F.R Section 124.15(a) and the responses to

public comments required by 124.17(a) (if any); and, if requested by EPA, copies of all substantive comments (if any).

3. The District shall forward to EPA copies of all PSD non-applicability determinations that utilize netting. All such determinations must be accompanied by a written justification.

VI. EPA Policies Applicable to PSD Review

1. All PSD BACT determinations are required to perform a "top-down" BACT analysis. EPA will consider as deficient any BACT determination that does not begin with the most stringent control options available for the source under review.
2. The District shall notify and/or consult with the appropriate Federal, State and local agencies as required by 40 C.F.R. Section 52.21 and 40 C.F.R. Part 124. The District shall (among other requirements as applicable):
   a. Notify the appropriate Class I area Federal Land Manager(s) within 30 days of receipt of a PSD permit application and at least 60 days prior to any public hearing if the emissions from a proposed facility may affect any Class I area(s), as required by 40 C.F.R. Section 52.21(p);
   b. Notify the Fish and Wildlife Service (FWS) and EPA when a submitted PSD permit application has been deemed complete, in order to assist EPA in carrying out its non-delegable responsibilities to consult with FWS under Section 7 of the Endangered Species Act;
   c. Notify the applicant of the potential need for consultation between EPA and FWS if an endangered species may be affected by the project; and
   d. Refrain from issuing a final PSD permit unless FWS has determined that the proposed project will not adversely affect any endangered species.

VII. Permits

1. The District shall follow EPA guidance on any matter involving the interpretation of sections 160-169 of the Clean Air Act or 40 C.F.R. Section 52.21 relating to applicability determinations, PSD permit issuance and enforcement. EPA shall provide guidance to

the District as appropriate in response to any request by the District for guidance on such federal PSD issues.

2. The District shall at no time grant any waiver of the PSD permit requirements.
3. Federal PSD permits issued by the District must include appropriate provisions to ensure permit enforceability. PSD permit conditions shall, at a minimum, contain reporting requirements on initiation of construction, initial commencement of operation, and source testing (where applicable).
4. When any conditions of a PSD permit are incorporated into a Title V permit, the District shall clearly identify PSD as the basis for those conditions.
5. The primary responsibility for the administration and enforcement of the following EPA-issued permits is delegated to the District:

Facility	EPA File Number	Permit Issuance Date
Calpine Gilroy Cogen	SFB 84-04	August 1, 1985
Cardinal Cogen	SFB 82-04	June 27, 1983
IBM Corporation	SFB 82-01	June 9, 1982
Martinez Cogen Limited Partnership	SFB 83-01	December 13, 1983
Tosco Corporation	SFB 78-07	December 18, 1978
Tosco SF Area Refinery at Rodeo	SFB 85-03	March 3, 1986

District-issued modifications to these permits which meet the requirements of 40 C.F.R. Section 52.21 will be considered valid by EPA. The District shall issue any permit modifications to the above listed facilities pursuant to this agreement.

VIII. Permit Enforcement

1. The primary responsibility for enforcement of the PSD regulations rests with the District. The District will enforce the provisions of the PSD program, consistent with the enforcement provisions of the Clean Air Act and Paragraph VIII.3. of this agreement, except in those cases where District rules, policies, or permit conditions are as stringent

or more stringent than the PSD requirements. In that case, the District may elect to enforce the as stringent or more stringent District requirements.

2. Nothing in this partial delegation agreement shall prohibit EPA from enforcing the PSD provisions of the Clean Air Act, 40 C.F.R. Section 52.21, or any PSD permit issued by the District pursuant to this agreement.
3. In the event that the District is unwilling or unable to enforce a provision of this partial delegation agreement with respect to a source subject to the PSD regulations, the District will immediately notify the Air Division Director. Failure to notify the Air Division Director does not preclude EPA from exercising its enforcement authority.

3-8-11
Date

Jack P. Broadbent
Executive Officer/APCO
Bay Area Air Quality Management District

2-7-2011
Date

Deborah Jordan
Director, Air Division
U.S. EPA, Region IX

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Sacramento Fish and Wildlife Office
2800 Cottage Way, Room W-2605
Sacramento, California 95825-1846

In Reply Refer To:
81420-2011-TA-0173

JUN 29 2011

Mr. Jared Blumenfeld
Regional Administrator, Region 9
U. S. Environmental Protection Agency
75 Hawthorne Street
San Francisco, California 94105-3901

Subject: Effects of Nitrogen Deposition at Antioch Dunes National Wildlife Refuge Resulting from Existing and Proposed Power Generating Stations in Contra Costa County, California

Dear Mr. Blumenfeld:

This letter conveys the U.S. Fish and Wildlife Service's (Service) concerns regarding the effects of nitrogen deposition from existing and proposed power generating stations located in Contra Costa County, California, on federally listed species at the Antioch Dunes National Wildlife Refuge (ADNWR). At issue are the potential adverse effects of the operational Gateway Generating Station (GGS), the proposed Marsh Landing Generating Station (MLGS), and the proposed Oakley Generating Station (OGS) on the endangered Lange's metalmark butterfly (*Apodemia mormo langei*), endangered Contra Costa wallflower (*Erysimum capitatum* var. *angustatum*), endangered Antioch Dunes evening primrose (*Oenothera deltoides* ssp. *howellii*), and designated critical habitat for these two listed plants. This letter is issued under the authority of the Endangered Species Act of 1973, as amended (16 U.S.C. § 1531 *et seq.*)(Act).

The Lange's metalmark butterfly, the Contra Costa wallflower, and the Antioch Dunes evening primrose occur almost exclusively on the ADNWR. The primary threat to these species is the overgrowth of non-native plant species that displace the wallflower, primrose, and host plants and nectar sources for the Lange's metalmark butterfly. The GGS and the proposed MLGS and OGS are all located less than two miles from the ADNWR and operation of these power generating stations will result in the deposition of nitrogen at ADNWR. Nitrogen deposition is known to exacerbate the growth of non-native weeds; these effects are particularly problematic in nitrogen deficient habitats, such as the sand dunes at ADNWR, where changes in plant and microbial communities resulting from increased nitrogen deposition can result in cascading negative effects on the ecosystem processes and the species that depend upon the native plant community.

The Service is concerned that the indirect and cumulative effects of the deposition of additional nitrogen at ADNWR resulting from operation of these power generating stations will result in adverse effects to the Contra Costa wallflower and the Antioch Dunes evening primrose and their critical habitat and in take of the Lange's metalmark butterfly. Adverse effects to the Lange's metalmark butterfly are of particular concern. The status of this species has declined dramatically in the last few years and because the ADNWR supports the only existing population of Lange's metalmark butterfly, any adverse effects to habitat at ADNWR may place the butterfly in danger of extinction in the foreseeable future.

Gateway Generating Station

On May 30, 2001, the U.S. Environmental Protection Agency (EPA) requested informal consultation with the Service on the addition of a 30 megawatt natural gas fired combination combustion turbine, that is now referred to as the GGS, to the existing Contra Costa Power Plant. On June 29, 2001, the Service concurred that aside from the potential adverse effects of the existing cooling water intake system on the threatened delta smelt (*Hypomesus transpacificus*) and the formerly threatened Sacramento splittail (*Pogonichthys macrolepidotus*), both of which were addressed in a section 7 consultation with the U.S. Army Corps of Engineers, the installation of the new turbine was not likely to adversely affect listed species.

However, although the consultation process for the GGS was concluded in 2001, this facility apparently did not become operational until 2009. It is our understanding that, because of the lapse in time between the EPA's issuance of a Prevention of Significant Deterioration permit to Pacific Gas and Electric (PG&E) for GGS and the construction and operation of the GGS facility, your agency and PG&E recently entered into a settlement agreement to impose emission limits on GGS consistent with current standards. Although this agreement will impose emission limits on nitrogen oxides (NOx), carbon monoxide (CO), sulfur dioxide (SO_2) and particulate matter that are thought to represent what the result of a new permitting process with the EPA would be, the Service was not consulted regarding the effects of these emissions on listed species.

New scientific information relating to the adverse effects of nitrogen deposition on listed species and natural ecosystems has become available since 2001 when the original permits were issued, and consultation with the Service was concluded. Based on current scientific literature, a baseline nitrogen deposition value of 5 kilograms per hectare (kg/ha/yr) recently has been recognized as the level above which effects of nitrogen deposition should be analyzed (Weiss 2006, California Energy Commission 2010). According to the best available estimates for the ADNWR area, that are based on 2002 data, the baseline nitrogen deposition is thought to be approximately 6.39 kg/ha/yr (Tonneson *et al.* 2007). This already exceeds the 5 kg/ha/yr threshold above which nitrogen deposition can result in adverse impacts to native plant communities. Although the amount of nitrogen deposition at ADNWR resulting from operation of GGS has not been modeled, it is reasonable to assume that based on the location, type of generating station, and amount of power to be generated by GGS, the amount of nitrogen deposition at ADNWR is similar to the amount estimated for MLGS and OGS and described below. Based on the current scientific literature available, it is the Service's opinion that the deposition of this amount of nitrogen deposition at ADNWR is likely to result in adverse effects to the Contra Costa wallflower, the Antioch Dunes evening primrose, and in take of the Lange's metalmark butterfly.

Marsh Landing Generating Station

The California Energy Commission (CEC) is the primary state and local permitting authority for new power plants in California. Based on the CEC's final staff assessment for MLGS, the facility is predicted to result in an estimated 0.04 kg/ha/yr of additional nitrogen deposition to current baseline levels at ADNWR. On August 17, 2010, the Service submitted a letter to the CEC, conveying our concerns that the deposition of this amount of nitrogen at ADNWR would result in adverse effects to federally listed species and recommending that the applicant seek authorization for incidental take of the Lange's metalmark butterfly pursuant to either section 7 or 10(a) of the Act. We stated that should a Federal agency be involved with the permitting, funding, or carrying out of the project, that agency should initiate formal consultation with the Service pursuant to section 7 of the Act. If a Federal agency was not involved, we recommended an incidental take permit pursuant to section 10(a)(1)(B) of the Act be obtained. On August 25, 2010, the CEC issued Mirant Energy a Certificate to Construct and Operate the proposed MLGS. Although the CEC's conditions for certification for MLGS included a nominal annual payment to ADNWR for weed removal in order to mitigate for the effects of nitrogen deposition at ADNWR, the CEC did not recommend consultation with the Service and noted that section 7 of the Act would not apply because section 7 does not apply "to activities simply approved by state agencies, as we approve MLGS here". However, it is the Service's understanding that the EPA has delegated regional implementation of the Federal Clean Air Act to the Bay Area Air Quality Management District (BAAQMD) and that based on the CEC's environmental analysis, the BAAQMD issued an Authority to Construct permit for MLGS on August 31, 2010. Irrespective of the need for authorization of incidental take, we are concerned the payment of minimal funding will not, by itself, adequately compensate for the adverse effects of the project to listed species.

Oakley Generating Station

Based on the CEC's final staff assessment for OGS, the facility is predicted to result in an estimated 0.083 kg/ha/yr of additional nitrogen deposition to current baseline levels at ADNWR. The Service submitted comment letters to the CEC on October 13, 2010, February 14, 2011, and April 28, 2011, conveying our concerns that the deposition of nitrogen at ADNWR would result in adverse effects to federally listed species, recommending the applicant assist with the captive propagation and release of Lange's metalmark butterfly, and recommending the applicant seek authorization for incidental take pursuant to either section 7 or 10(a) of the Act. Again the CEC required the annual payment of nominal fees to ADNWR for weed eradication but did not recommend consultation with the Service.

Recommendations

The Service is concerned that the current operation of GGS, and the proposed operation of MLGS and OGS, will not be in compliance with the Endangered Species Act of 1973, as amended, because take of the Lange's metalmark butterfly, and adverse effects to the Antioch Dunes evening primrose, the Contra Costa wallflower, and critical habitat for these two plants are likely to occur as result of these projects. Therefore, we recommend that:

1. Based on the availability of new scientific information that reveals adverse effects to listed species not previously considered and based on changes to the GGS project resulting from entering into the recent settlement agreement with PG&E, the EPA should reinitiate section 7 consultation with the Service for the GGS pursuant to 50 CFR § 402.14 of the Act.

2. The EPA should contact the Service in order to clarify their role in the permitting and review of OGS and MLGS. If the EPA's permitting authority has been delegated to a state or local agency, the EPA should either retain their permitting authority over these projects and initiate section 7 consultation with the Service or delegate their authority for consultation with the Service to the responsible State or local permitting agency.

We are interested in assisting the EPA in determining how to proceed with the consultation process for these power generating stations. Please contact Stephanie Jentsch, Ryan Olah, or Chris Nagano at the letterhead address, electronic mail (Stephanie_Jentsch@fws.gov; Ryan_Olah@fws.gov; Chris_Nagano@fws.gov), or at telephone (916) 414-6600 if you have any questions regarding this letter.

Sincerely,

Cay C. Goude

Cay C. Goude
Assistant Field Supervisor

cc:
Gerardo Rios, U.S. Environmental Protection Agency, San Francisco, California
Jack Broadbent, Brian Lusher, and Kathleen Truesdell, Bay Area Air Quality Management District, San Francisco, California
Randi Adair, California Department of Fish and Game, Yountville, California
Rick York, California Energy Commission, Sacramento, California
Louie Terrazas, Mendel Stewart, Don Brubaker, San Francisco Bay National Wildlife Refuge, Newark, California

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California Energy Commission. 2010. Revised staff assessment of the Marsh Landing Generating Station (08-AFC-03). Sacramento, California.

Tonnesan. G., Z. Wang, M. Omary, and C. J. Chien. 2007. Assessment of nitrogen deposition: modeling and habitat assessment. California Energy Commission. PIER Energy-Related Environmental Research. CEC-500-2005-032.

Weiss, S.B. 2006. Impacts of nitrogen deposition on California ecosystems and biodiversity. California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2005-165.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, California 94105-3901

30 May 2001

Ms. Jan Knight
Chief, Endangered Species Division
U.S. Fish and Wildlife Service
2800 Cottage Way, Suite W2605
Sacramento, California 95825-3901

Re: Request for Concurrence with EPA Finding of No Likely Adverse Effect under Section 7 of the ESA for Modification to Contra Costa Power Plant, Antioch, California

Dear Ms. Knight:

By this letter, the U.S. Environmental Protection Agency, Region 9 ("EPA") seeks to conclude informal consultation under Section 7 of the Endangered Species Act ("ESA") between EPA and the U.S. Fish and Wildlife Service ("FWS" or "Service") concerning the Contra Costa Power Plant Project (the "Project"). The Project involves a modification at an existing power plant to add a 530 MW natural gas-fired combined cycle combustion turbine (the "Turbine") at the existing Contra Costa Power Plant. Mirant Delta, LLC ("Mirant") has applied to the Bay Area Air Quality Management District ("BAAQMD") for a federal Prevention of Significant Deterioration ("PSD") permit for the Project, as required by Part C of the Clean Air Act and regulations at 40 C.F.R. § 52.21. Background information on the PSD program and more detailed information regarding the Project and this consultation are included below.

Background on PSD Program

Region 9 is responsible for complying with ESA Section 7 requirements with respect to federal PSD permitting. In some instances, EPA has delegated its PSD permitting authority to a state agency or air district pursuant to the PSD regulation at 40 C.F.R. § 52.21(u). In such instances, issuance of a federal PSD permit by a state agency or air district in EPA's stead is considered a federal action that may be subject to ESA requirements. (A "Delegation Agreement" establishes the roles and responsibilities for EPA and the State delegated to administer the PSD program and issue federal PSD permits in EPA's stead.)

A PSD permit for the Project is required for the modification to the existing power plant (i.e., installation of the Turbine). EPA has determined that issuance of the federal PSD permit for the Project is a federal action that may affect listed species or habitat through its construction or operation, thereby triggering ESA Section 7. Final action on this PSD permit may not occur until EPA has determined that permit issuance will be consistent with the substantive and procedural requirements of the ESA.

Informal Consultation and Request for Concurrence under Section 7 of the ESA

EPA has been engaged in informal consultation with your office regarding the Project. We understand that you have been forwarded a copy of the California Energy Commission's Final Staff Assessment for the Project, which evaluates the environmental effects of the Project, including effects on listed species and habitat. In addition, as you are aware, Mirant previously submitted to the Service an application for an ESA Section 10 permit concerning the existing Contra Costa Power Plant. In this context, Mirant has prepared documents providing an analysis of the effects of the Contra Costa Power Plant on listed species and critical habitat, which were compiled as part of the ESA Section 10 permit application. Since EPA understands that your office already has copies of these documents, we are not forwarding them to you with this letter.

Mirant has discussed with the Service the potential impacts to species/habitat related to the Contra Costa Power Plant. The Service has identified the existing cooling water intake system at the facility as a concern, due to the potential for impingement and entrainment of the following listed threatened species: Delta smelt (*Hypomesus transpacificus)* and the Sacramento splittail (*Pogonichthys macrolepidotus*). The following listed threatened species under the National Marine Fisheries Service ("NMFS") jurisdiction also may be affected by the existing cooling water intake system: Central Valley ESU spring-run and winter-run chinook salmon (*Oncorhynchus tshawytscha*) and the Central Valley ESU Steelhead (*Oncorhynchus mykiss)*. In addition, the following species are identified as occurring near the Project area but not likely to be adversely affected by the Project: San Joaquin harvest mouse (*Reithrodontomys raviventris*), California least tern (*Sterna antillarum browni*), Sort bird's-beak (*Cordylanthus mollis ssp. mollis*), Lange's metalmark butterfly (*Apdemia mormo langei*), Contra Costa Wallflower (*Erysimum capitatum angustatum*), Antioch Dunes evening Primrose (*Oenothera deltoids howellii*), all of which are listed endangered species.

Mirant has agreed to take measures that would avoid or minimize the effects associated with the power plant, namely the installation of an Aquatic Filter Barrier to address potential impacts from the cooling water intake at the existing facility. Mirant has applied for a permit from the United States Army Corps of Engineers ("COE") for installation of the Aquatic Filter Barrier on the cooling water intake system at the Contra Costa Power Plant. By letter dated April 19, 2001, the COE requested consultation under ESA Section 7 concerning its permit action for the Aquatic Filter Barrier. Since the COE has requested consultation on a matter that specifically addresses the cooling water intake system, the FWS and NMFS will have the opportunity to address any impacts of this intake system to species or habitat through COE's ESA Section 7 consultation.

EPA has discussed with the FWS potential effects associated with PSD permit issuance for the Project. Per a discussion between Pamela Schultz (Office of Regional Counsel, EPA, Region 9), Roger Kohn (Air Division, EPA, Region 9) and Michael Thabault (FWS) on March 30, 2001, the FWS noted that its only concern with respect to the Contra Costa Power Plant was related to impacts on listed and threatened species due to the cooling water intake system.

Apart from potential impacts associated with the existing cooling water intake system, EPA believes that there are no likely adverse effects to species or habitat resulting from the addition of the new Turbine to the Contra Costa Power Plant. As noted above, the COE has requested consultation with respect to its federal permit for installation of the Aquatic Filter Barrier at the cooling water intake system. EPA believes that COE's federal action is more directly related to the area of concern (i.e., effects of cooling water intake) than EPA's air permitting action and defers to COE and the outcome of COE's Section 7 consultation to address any potential impacts associated with the cooling water intake. With respect to EPA's air permitting matter, EPA finds that, in all other regards, the Project is not likely to adversely affect listed species or critical habitat, in accordance with 50 C.F.R. §§ 402.13 and 402.14(b). I am writing to request written concurrence from the Service with this finding.

If you have any questions regarding this request, please contact Roger Kohn at (415) 744-1238.

Sincerely,

Gerardo Rios
Acting Chief, Permits Office
Air Division

cc: Mike Thabault, USFWS
Steve Hill, BAAQMD

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Effects of increased soil nitrogen on the dominance of alien annual plants in the Mojave Desert

MATTHEW L. BROOKS

United States Geological Survey, Western Ecological Research Center, Las Vegas Field Station, 160 N. Stephanie St., Henderson, NV 89074, USA

Summary

1. Deserts are one of the least invaded ecosystems by plants, possibly due to naturally low levels of soil nitrogen. Increased levels of soil nitrogen caused by atmospheric nitrogen deposition may increase the dominance of invasive alien plants and decrease the diversity of plant communities in desert regions, as it has in other ecosystems. Deserts should be particularly susceptible to even small increases in soil nitrogen levels because the ratio of increased nitrogen to plant biomass is higher compared with most other ecosystems.

2. The hypothesis that increased soil nitrogen will lead to increased dominance by alien plants and decreased plant species diversity was tested in field experiments using nitrogen additions at three sites in the in the Mojave Desert of western North America.

3. Responses of alien and native annual plants to soil nitrogen additions were measured in terms of density, biomass and species richness. Effects of nitrogen additions were evaluated during 2 years of contrasting rainfall and annual plant productivity. The rate of nitrogen addition was similar to published rates of atmospheric nitrogen deposition in urban areas adjacent to the Mojave Desert (3·2 g N m^{-2} $year^{-1}$). The dominant alien species included the grasses *Bromus madritensis* ssp. *rubens* and *Schismus* spp. (*S. arabicus* and *S. barbatus*) and the forb *Erodium cicutarium*.

4. Soil nitrogen addition increased the density and biomass of alien annual plants during both years, but decreased density, biomass and species richness of native species only during the year of highest annual plant productivity. The negative response of natives may have been due to increased competitive stress for soil water and other nutrients caused by the increased productivity of aliens.

5. The effects of nitrogen additions were significant at both ends of a natural nutrient gradient, beneath creosote bush *Larrea tridentata* canopies and in the interspaces between them, although responses varied among individual alien species. The positive effects of nitrogen addition were highest in the beneath-canopy for *B. rubens* and in interspaces for *Schismus* spp. and *E. cicutarium*.

6. The results indicated that increased levels of soil nitrogen from atmospheric nitrogen deposition or from other sources could increase the dominance of alien annual plants and possibly promote the invasion of new species in desert regions. Increased dominance by alien annuals may decrease the diversity of native annual plants, and increased biomass of alien annual grasses may also increase the frequency of fire.

7. Although nitrogen deposition cannot be controlled by local land managers, the managers need to understand its potential effects on plant communities and ecosystem properties, in particular how these effects may interact with land-use activities that can be managed at the local scale. These interactions are currently unknown, and hinder the ability of managers to make appropriate land-use decisions related to nitrogen deposition in desert ecosystems.

8. *Synthesis and applications.* The effects of nitrogen deposition on invasive alien plants should be considered when deciding where to locate new conservation areas, and in evaluating the full scope of ecological effects of new projects that would increase nitrogen deposition rates.

Key-words: biomass, density, fertilization, invasive species, nitrogen deposition, plant communities, soil nutrients, species richness.

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Introduction

Soil nitrogen is an important determinant of plant community productivity, diversity and invasibility (Chapin, Vitousek & Van Cleve 1986; Wedin & Tilman 1996). Increased levels of soil nitrogen caused by atmospheric nitrogen deposition can increase the dominance of invasive alien plants and decrease the diversity of plant communities world-wide (Vitousek *et al.* 1997). Where nitrogen levels are naturally low, such as in deserts, relatively small increases in nitrogen may cause large changes in plant communities, because the ratio of increased nitrogen to plant biomass is higher compared with ecosystems with higher plant productivity (Aber *et al.* 1989).

Human population levels are increasing rapidly in the Mojave Desert of North America, making it one of fastest growing regions in the USA (United States Census Bureau 2000). Along with increased human populations will come increased levels of atmospheric pollution and nitrogen deposition. Increased nitrogen deposition has led to increased levels of soil nitrogen in semi-arid coastal sage scrub adjacent to the Mojave Desert (Padgett *et al.* 1999). Levels of soil nitrate and ammonium were also shown to increase 700% (1–8 p.p.m.) and 500% (2–12 p.p.m.), respectively, during summer and through to mid-winter near an urban desert area where air pollution and atmospheric nitrogen levels were high (M. Allen, unpublished data). In comparison, soil nitrate and ammonium levels did not increase during the same time interval at an otherwise similar desert site where air pollution and atmospheric nitrogen levels were low. It is suggested, therefore, that increased atmospheric nitrogen from air pollution can increase soil nitrogen levels. If this happens in the Mojave Desert, then it may cause plant community changes.

The abundance of soil nitrogen varies naturally between microhabitats in desert shrublands. Soils beneath the canopy of desert shrubs represent islands of greater soil nutrients compared with the surrounding interspaces (Garcia-Moya & McKell 1970; Halvorson & Patten 1975; Parker *et al.* 1982; Schlesinger *et al.* 1996). In the Mojave Desert, levels of nitrogen and phosphorous can be 50% higher beneath the north side of *Larrea tridentata* (DC.) Cov. (creosote bush) canopies than in interspaces (Brooks 1998). Nitrogen limitations in deserts may be lower where soil nitrogen is relatively high beneath woody shrubs compared with the interspaces between them (Romney, Wallace & Hunter 1978) and during years of low productivity when water may be more limiting to plant growth (Gutierrez & Whitford 1987). Accordingly, nitrogen additions may have different effects beneath shrubs than in interspaces and during years of high compared with low plant productivity.

Increased soil nitrogen may have different effects on native and alien annual plants in desert regions. Native plants of low fertility ecosystems such as deserts generally have lower maximal growth rates and respond less to increased soil nutrients than plants that have evolved in more fertile ecosystems (Grime 1977; Chapin, Vitousek & Van Cleve 1986). Many of the common alien annual plant taxa in the Mojave Desert (e.g. *Bromus* spp. and *Erodium cicutarium*) evolved in more fertile Mediterranean regions (Brooks 2000a; Jackson 1985) and may therefore benefit more than native desert annuals from increased levels of soil nitrogen. Effects of increased nitrogen may also differ among these alien plant species because of differing life-history characteristics (Lodge 1993; Brooks 1999a). In addition, increased density and biomass of alien annuals created in response to increased soil nitrogen may heighten competition for soil moisture, potentially decreasing density, biomass and diversity of native annual plants.

The purpose of this study was to evaluate how increased levels of soil nitrogen affect annual plant communities in the Mojave Desert. It was predicted that alien plants would increase in density, biomass and species richness in response to increased nitrogen, and that the net effect on natives would be negative. It was also predicted that the effects of increased nitrogen would be greater where soil nitrogen is naturally low in interspaces compared with where it is naturally high beneath creosote bush canopies, and that the effects would be greater during a year of high annual plant productivity than a year of low productivity.

Materials and methods

STUDY SITES

Three 1-ha sites were established within the central (35°07′30″N, 117°07′45″W), southern (34°41′30″N, 116°57′30″W) and western (35°14′30″N, 117°51′15″W) Mojave Desert. Distances between the sites ranged from 51 to 102 km. To choose the site within each region, a 1-mile^2 (259-ha) township section was selected randomly from among those owned by the United States Department of the Interior, Bureau of

Correspondence: Matthew L. Brooks, United States Geological Survey, Western Ecological Research Center, Las Vegas Field Station, 160 N. Stephanie St., Henderson, NV 89074, USA (fax 702 914 2045; e-mail matt_brooks@usgs.gov).

Land Management, and the study site was located where it was accessible via an unpaved road. All sites contained a creosote bush-dominated plant community with an understorey of winter annual plants growing on granitic, sandy loam soils. More details of the study sites are reported in Brooks (2000b).

Three alien annual plant taxa dominated each site, including the forb *Erodium cicutarium* (L.) L'Hér and the grasses *Bromus madritensis* ssp. *rubens* (L.) Husnot (hereafter called *B. rubens*) and *Schismus* spp., comprising *Schismus arabicus* Ness. and *Schismus barbatus* (L.) Thell. The latter two species are closely related (Faruqi & Quraish 1979; Faruqi 1981) and difficult to distinguish reliably (Brooks 2000c) so they were combined for analysis in this study. Overall, the composition of *Schismus* spp. was estimated to be 75% *S. barbatus* and 25% *S. arabicus*.

Long-term rainfall patterns at each site were estimated by averaging the linear distance-weighted monthly precipitation averages from the three closest National Oceanic and Atmospheric Administration weather stations (National Oceanic and Atmospheric Administration 1996). Rainfall patterns during the study were determined by recording rainfall every 2 weeks from November to April during each year of the study using a single rainfall gauge located at the centre of each site. The amount and temporal distribution of rainfall was similar at the three study sites but differed between 1996 and 1997 (Brooks 2000b). Winter rainfall (October–April) was 94% of the average prior to spring 1996, and 77% of the average prior to spring 1997. However, 46 mm, of the total 67 mm of winter rainfall during 1997, occurred during December, 307% of the monthly average. This pulse of December rainfall resulted in mass germination and higher productivity and diversity of the seedling cohort during 1997, even though total rainfall was higher in 1996.

EXPERIMENTAL TREATMENTS

Three treatments consisted of nitrogen added as ammonium nitrate (NH_4NO_3), nitrogen added as 15-15-15 (NPK) fertilizer, and an unfertilized control. The NPK fertilizer treatment was included because availability of phosphorous can limit plant growth in some desert soils (Lajtha & Schlesinger 1988; DeLucia, Schlesinger & Billings 1989). Fertilizers were added in dry, water-soluble form to minimize the chance of burning foliage and leaching downward through the soil profile. The 2–4-mm diameter pellets remained in place at the soil surface even when subjected to high winds (M. Brooks, personal observation).

The rate of nitrogen application ($3{\cdot}2$ g N m^{-2} $year^{-1}$) was similar to maximum rates of atmospheric nitrogen deposition adjacent to the Mojave Desert in chaparral shrublands of the Los Angeles basin ($3{\cdot}0$ g N m^{-2} $year^{-1}$) (Bytnerowitcz *et al.* 1987). Ammonium nitrate and NPK treatments were added in two equal amounts ($1{\cdot}6$ g N m^{-2} each) on 27–29 December 1995 and 6 March 1996 during the first year, and 20 December 1996 and 13 February 1997 during the second year.

EXPERIMENTAL DESIGN

Three experimental treatments (NH_4NO_3, NPK, control) were replicated in 25 blocks at each of the three study sites in a randomized complete block design with no replication within blocks (Steel & Torrie 1980). The blocks were arranged in a 5 × 5 grid with an average of 25 m between each block (1 ha total area for each site). Each block was centred on a creosote bush with ≥ 150 cm canopy diameter and contained two microhabitats, the area beneath the canopy on the north side of the creosote bush (beneath-canopy) and the adjacent open space ≥ 1 m from the canopy edge (interspace). Three 40 × 50-cm contiguous plots were established in each microhabitat, each randomly receiving a different treatment. Treatments were repeated in the same plots during the second year. The 150-cm minimum creosote bush canopy diameter allowed enough room to fit the treatment plots completely within the beneath-canopy microhabitat.

The response of native annuals to fertilization was evaluated by sampling annual plants when winter annuals reached peak biomass and most species were flowering and setting seed. This occurred from 10 to 18 April 1996 and 9 to 17 March 1997. In each 40 × 50-cm treatment plot, live annual plants were clipped at ground level within a 10 × 20-cm (200 cm^2) sampling frame, sorted and counted by species, dried to a constant mass at 60 °C, and weighed to determine aboveground live dry biomass. Species were identified using Hickman (1993). Species richness was calculated as the number of species within each biomass sample. Samples collected during the second year were located 20 cm from the first-year samples, within each treatment plot.

DATA ANALYSES

Repeated-measures analysis of variance (rmANOVA) was used to evaluate main and interactive effects of fertilization on annual plants during 1996 and 1997 (SAS 1988). ANOVA models included all main and interactive effects of treatment, microhabitat and year. Data were pooled from the three sites in all analyses because interactions of site-by-treatment, site-by-microhabitat, site-by-treatment-by-microhabitat and site-by-treatment-by-microhabitat-by-year were not significant (rmANOVA, $P < 0{\cdot}300$; Underwood 1997).

The data were analysed in three steps, all using the full model plus additional factors and their interactions with treatment. First, to evaluate differential responses of alien and native plant density, biomass and species richness, a group factor was added (native, alien). Secondly, to evaluate the differential responses among the most abundant alien species, the group factor was replaced with a species factor (*B. rubens*,

Table 1. Annual plant species sampled at the three study sites

Species*		No. of sites	Species		No. of sites
Amsinckia tessellata	NF	3	*Gilia minor*	NF	3
Astragalus didymocarpus	NF	3	*Guillenia lasiophylla*	NF	3
Bromus rubens	AG	3	*Lasthenia californica*	NF	3
Bromus tectorum	AG	3	*Layia glandulosa*	NF	2
Bromus trinii	AG	2	*Linanthus dichotomus*	NF	3
Camissonia campestris	NF	3	*Lotus humistratus*	NF	3
Camissonia claviformis	NF	2	*Lupinus odoratus*	NF	2
Chenactis fremontii	NF	3	*Malacothrix coulteri*	NF	3
Chenactis stevioides	NF	3	*Malacothrix glabrata*	NF	3
Chorizanthe brevicornu	NF	3	*Monoptilon belliforme*	NF	3
Chorizanthe watsonii	NF	3	*Oxytheca perfoliata*	NF	3
Coreopsis bigelovii	NF	3	*Pectocarya* spp.	NF	3
Cryptantha circumscissa	NF	3	*Phacelia distans*	NF	1
Cryptantha dumetorum	NF	3	*Phacelia fremontii*	NF	3
Crypthantha nevadensis	NF	3	*Phacelia tanacetifolia*	NF	3
Crypthantha pterocarya	NF	3	*Salvia columbariae*	NF	2
Descurainia pinnata	NF	3	*Schismus arabicus*	AG	3
Eremalche exilis	NF	1	*Schismus barbatus*	AG	3
Eriophyllum wallacei	NF	3	*Stephanomeria parryi*	NF	3
Erodium cicutarium	AF	3	*Vulpia microstachys*	NG	3
Eschscholzia minutiflora	NF	3	*Vulpia octoflora*	NG	3
Filago californica	NF	3			

*AF, alien forb; AG, alien grass; NF, native forb; NG, native grass.

Schismus spp., *E. cicutarium*. Thirdly, to evaluate the individual responses of these alien species, density and biomass of each were analysed separately.

When overall effects were significant levels within each factor were compared using Fisher's protected least significant difference (Day & Quinn 1989). Because all effects except block were fixed, the significance of each was tested using the block × factor interaction as the error term. Data were transformed prior to analysis for species richness and density using square root ($x + 0.5$), for biomass using log ($x + 1$), and for proportions using arcsin (square root x) (Sokal & Rohlf 1995). Data were reported as untransformed values, and effects were considered significant at $P < 0.050$. Bonferonni-corrected P-values were used when comparing the individual effects of alien species.

Results

Forty-three annual plant species were sampled, ranging from 38 to 41 species per site (Table 1). Of these species, 35 were native forbs, two were native grasses, one was an alien forb and five were alien grasses. It should be noted that *S. arabicus* and *S. barbatus* were pooled into *Schismus* spp. prior to analysis, resulting in four alien grass taxa (five total alien taxa) used to calculate alien species richness.

Bromus rubens, *Schismus* spp. and *E. cicutarium* were the most abundant alien species, comprising 95% of the total alien plant density and 98% of the total alien plant biomass combined across all sites and treatment plots. *Amsinckia tesselata* A. Gray, *Descurania pinnata* (Walter) Britton, *Guillenia lasiophylla* (Hook. & Arn.)

Table 2. Density, biomass and species richness of annual plants in 0·02-m² plots. This repeated-measures analysis of variance table shows treatment effects (control, ammonium nitrate, NPK) and interactions with microhabitat (*Larrea*-north, *Larrea*-south, interspace), group (aliens, natives) and the repeated factor year (1996, 1997). *F*-ratios were calculated with the block-by-effect interaction as the error term. Significant *P*-values are in italic (< 0·05)

Source	$F_{2,36}$	P
Density		
Treatment	1·88	0·157
Treatment × microhabitat	2·79	0·062
Treatment × group	6·14	*0·007*
Treatment × microhabitat × group	2·30	0·104
Year × treatment	1·16	0·316
Year × treatment × microhabitat	0·17	0·842
Year × treatment × group	1·07	0·347
Year × treatment × microhabitat × group	0·46	0·634
Biomass		
Treatment	75·61	*< 0·001*
Treatment × microhabitat	2·71	0·076
Treatment × group	80·50	*< 0·001*
Treatment × microhabitat × group	4·31	*0·014*
Year × treatment	26·04	*< 0·001*
Year × treatment × microhabitat	10·39	*< 0·001*
Year × treatment × group	31·81	*< 0·001*
Year × treatment × microhabitat × group	8·87	*< 0·001*
Species richness		
Treatment	15·62	*< 0·001*
Treatment × microhabitat	0·97	0·383
Treatment × group	16·15	*< 0·001*
Treatment × microhabitat × group	1·16	0·339
Year × treatment	17·77	*< 0·001*
Year × treatment × microhabitat	2·85	0·061
Year × treatment × group	12·04	*< 0·001*
Year × treatment × microhabitat × group	0·73	0·483

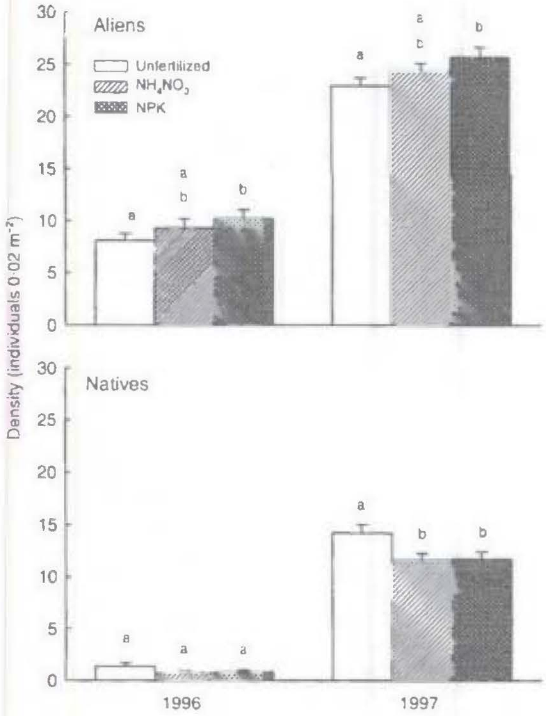

Fig. 1. Density of annual plants after experimental treatments in April 1996 and March 1997. Values are averages (n = 150, + 1 SE) and dissimilar letters within years and groups indicate significant differences within each year using Fisher's protected LSD ($P < 0·05$).

E. Greene, *Malacothrix coulteri* A. Gray and *Phacelia tanacetifolia* Benth. were the most abundant native annuals in the beneath-canopy microhabitat. *Amsinckia tessellata*, *Filago californica* Nutt. *Lasthenia californica* Lindley and *Pectocarya* spp. were the most abundant natives in the interspace microhabitat.

EFFECTS OF TREATMENTS ON ALIENS AND NATIVES

The total density of annual plants was not significantly affected by nutrient treatments (treatment-by-group interaction; Table 2), due to the contrasting responses of aliens and natives (Fig. 1). Alien plant density increased whereas native density decreased in response to nutrient additions, and effects were similar for ammonium nitrate and NPK fertilizer. Treatment effects did not differ significantly between microhabitats or years (Table 2).

Total biomass of annuals was significantly affected by nutrient treatments, and effects varied between aliens and natives (Table 2). The effects of fertilizer treatments were similar, and their average effects resulted in 56% and 52% increases in alien biomass, and 37% and 42% decreases in native biomass, during 1996 and 1997, respectively (Fig. 2). Treatment effects did not differ significantly between microhabitats but did differ between years (Table 2).

Species richness of annual plants was significantly affected by nutrient treatments, and the effects differed between aliens and natives (Table 2). Alien species richness was unaffected by treatments during both years, possibly because there were only three alien species present, and control plots averaged 1–2 alien species even without nutrient additions. In contrast, native species richness was significantly reduced by nutrient treatments but only in 1997 when the seedling cohorts comprised a wide range of species (Fig. 3). Effects were similar for the two fertilizer treatments. Treatments did not differ significantly among microhabitats but did vary between years (Table 2).

EFFECTS OF TREATMENTS ON INDIVIDUAL ALIEN SPECIES

Among these three most abundant alien species, *B. rubens*, *Schismus* spp. and *E. cicutarium*, nitrogen treatment effects were not significantly different for density (treatment-by-species interaction, $F_{2,148} = 0·60$, $P = 0·668$) but were significantly different for biomass (treatment-by-species, $F_{2,148} = 18·16$, $P < 0·001$). Biomass effects among alien species also varied between microhabitats (treatment-by-species-by-microhabitat, $F_{2,148} = 52·34$, $P < 0·001$) and between years (treatment-by-species-by-year, $F_{2,148} = 12·25$, $P < 0·001$). Thus, nutrient treatments had a stronger effect on alien biomass than density, and effects on alien biomass differed between microhabitats and years.

Responses of each alien species to nitrogen treatments differed between microhabitats and between years.

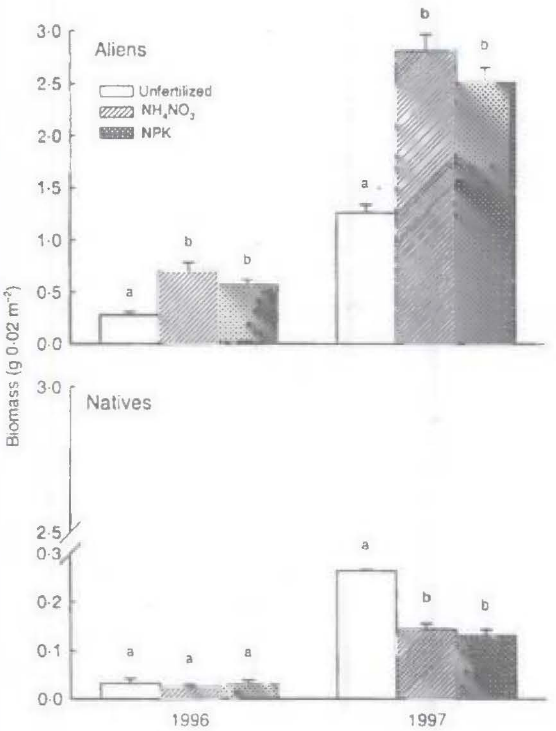

Fig. 2. Biomass of annual plants after experimental treatments in April 1996 and March 1997. Values are averages (n = 150, + 1 SE) and dissimilar letters indicate significant differences within each year using Fisher's protected LSD ($P < 0·05$).

Bromus rubens biomass was higher, and its response to nutrient treatments was stronger, where soil nutrient levels were naturally high in the beneath-canopy microhabitat compared with the interspace microhabitat (Table 3 and Fig. 4). Effects on *B. rubens* were similar for ammonium nitrate and the NPK fertilizers. In contrast, *Schismus* spp. and *Erodium cicutarium* biomasses were higher, and their response to nutrient treatments were stronger where soil nutrient levels were naturally low in the interspace microhabitat. Although effects of the two nutrient treatments were similar, biomass of *Schismus* spp. was highest with NPK fertilizer and biomass of *E. cicutarium* was highest with ammonium nitrate (Fig. 4). Nutrient treatments significantly increased biomass of aliens during both years (Fig. 4). However, effects were generally stronger during 1997 than 1996, especially for *B. rubens* biomass (Table 3 and Fig. 4).

Discussion

Alien plants comprise a relatively small proportion of desert floras world-wide (Lonsdale 1999), possibly because many invasive species cannot survive the low soil moisture and nitrogen levels found in desert regions. This study demonstrated that soil nitrogen addition can increase the dominance of alien annual plants in the Mojave Desert. The increased biomass of alien plants and decreased biomass of natives also suggests that aliens may have higher seed production than natives in response to increased nitrogen, because plant biomass and fecundity are positively correlated (Cousens & Mortimer 1995). These results indicate that moderate increases in soil nitrogen (3·2 g N m^{-2} year^{-1}) that are comparable to observed rates of atmospheric nitrogen deposition in adjacent semi-arid shrublands near more urbanized areas (3·0 g N m^{-2} year^{-1}) (Bytnerowicz

Table 3. Absolute biomass (grams) of individual alien annual plant species in 0·02-m^2 plots. This repeated-measures analysis of variance table shows treatment effects (control, ammonium nitrate, NPK) and interactions with microhabitat (Larrea-north, Larrea-south, interspace) and the repeated factor year (1996, 1997). F-ratios were calculated using the block-by-effect interaction as the error term. Significant P-values are in italic (< 0·05)

Source	$F_{2,144}$	P
Bromus rubens		
Treatment	36·84	*< 0·001*
Treatment × microhabitat	32·22	*< 0·001*
Year × treatment	21·45	*< 0·001*
Year × treatment × microhabitat	18·93	*< 0·001*
Schismus spp.		
Treatment	18·45	*< 0·001*
Treatment × microhabitat	15·59	*< 0·001*
Year × treatment	3·71	*0·027*
Year × treatment × microhabitat	3·47	*0·034*
Erodium cicutarium		
Treatment	56·52	*< 0·001*
Treatment × microhabitat	56·26	*< 0·001*
Year × treatment	4·23	*0·016*
Year × treatment × microhabitat	3·26	*0·041*

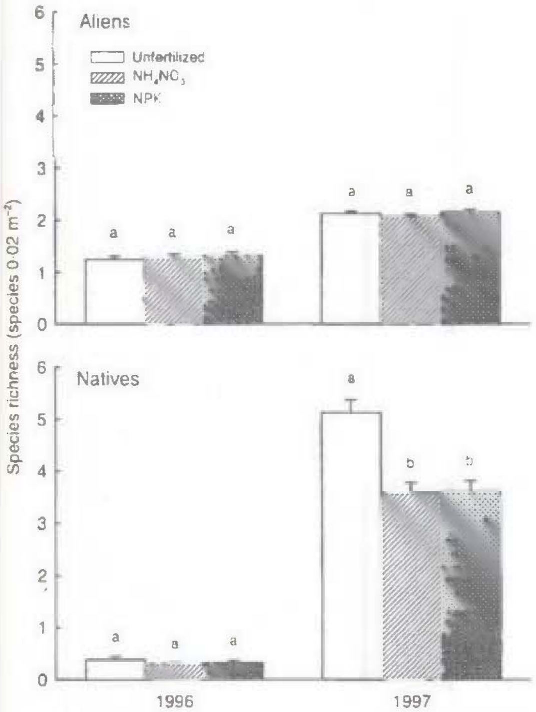

Fig. 3. Species richness of annual plants after experimental treatments in April 1996 and March 1997. Values are averages ($n = 150$, +1 SE) and dissimilar letters indicate significant differences within each year using Fisher's protected LSD ($P < 0{\cdot}05$).

et al. 1987) can significantly affect annual plant communities in the Mojave Desert.

Biomass of the alien annual grass *S. arabicus* also increased relative to native species after addition of nitrogen at a desert site in Chile (Gutierrez, Aguillera & Armesto 1992). Similar experiments were conducted in the northern Mojave Desert from 1967 to 1975, but aliens were uncommon at that time and significant densities of *B. rubens* and *S. arabicus* did not appear until 1975, when their densities were still < 5% of those observed in the current study (Romney, Wallace & Hunter 1978). Fertilization with nitrogen (10 g N m^{-2} $year^{-1}$) increased biomass of native annuals from 130% for *Chaenactis fremontii* A. Gray to 716% for *Amsinckia tessellata* (Romney, Wallace & Hunter 1978). These same two species were present in the current study, and *Amsinckia tessellata* was one of the most abundant, but increased soil nitrogen did not significantly increase either their density or biomass (M. Brooks unpublished data). These results suggest that native desert annuals may benefit from increased nitrogen when aliens are scarce, but may not benefit when aliens are abundant.

Decreased native annual plant density, biomass and species richness caused by increased soil nitrogen levels may have been due to increased competition with alien species for soil water and other nutrients. Native seedlings senesced approximately 1–2 weeks earlier than alien seedlings on fertilized compared with unfertilized plots in the current study (M. Brooks, personal observation). Natives also senesced 2 weeks sooner than alien species where the net competitive effect of aliens was stronger on unthinned plots, compared with plots that were thinned of aliens at the same sites and during the same years as the current study (Brooks 2000b). Wilson, Harris & Gates (1966) found that nitrogen additions increased *Bromus* yields and led to competitive suppression of the native bunchgrass *Agropyron spicatum*. Melgoza & Nowak (1991) showed that *B. tectorum* extracts soil water at a faster rate than native shrub seedlings, resulting in its competitive superiority in post-fire landscapes. Increased biomass of alien annual plants caused by elevated soil nutrient levels may increase their competitive effects on natives, thereby decreasing their abundance and leading to a decrease in species richness of native annual plants.

The competitive effects of aliens on native desert plants should be most apparent during years when native plants germinate in large numbers (Brooks 2000b). Native annuals typically remain dormant for many years until sufficient rainfall stimulates germination (Beatley 1974). The large differences in density and biomass of natives between 1996 and 1997 in the current study was a result of sufficient rainfall for mass germination only occurring prior to spring 1997 (Brooks 2000b). However, increases in native plant density and biomass between the first and second years were significantly lower in nitrogen-addition plots, where alien abundance was highest, compared with control plots. The ability of native annual plants to respond to ephemeral rainfall events with the increased growth and reproduction necessary to maintain their

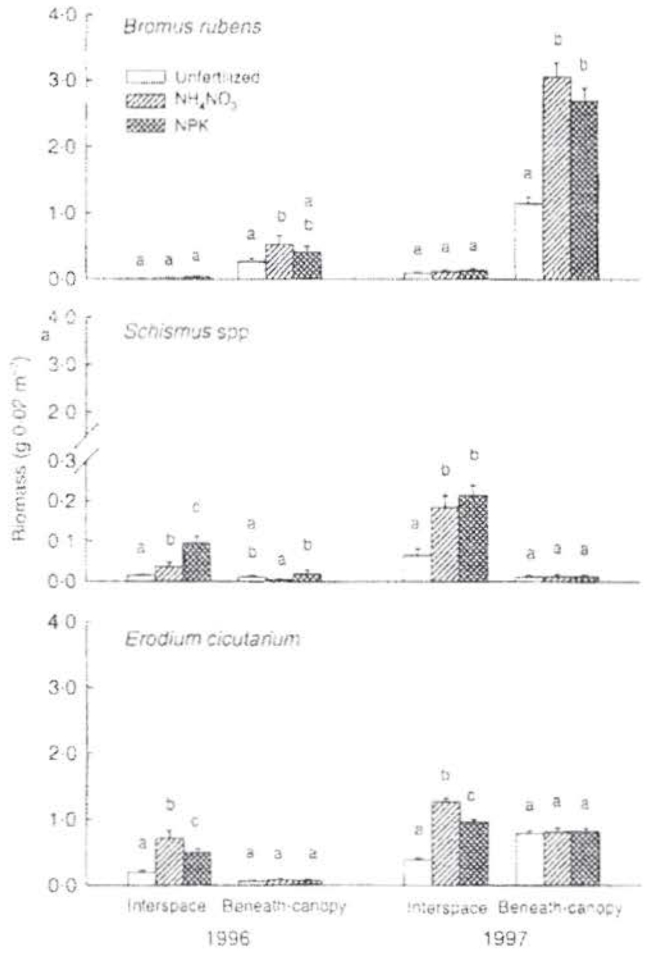

Fig. 4. Biomass of three alien annual plant species after experimental treatments in April 1996 and March 1997. Values are averages ($n = 75$, +1 SE) and dissimilar letters indicate significant differences within each microhabitat within each year using Fisher's protected LSD ($P < 0.05$).

populations may be hindered by increased alien plant growth stimulated by soil nitrogen additions.

Annual plants that are alien to desert regions typically do not have strict germination requirements and germinate in response to much less rainfall than native species (Beatley 1966; Vidiella & Armesto 1989; Gutierrez 1992). As a result differences in density and biomass of aliens between 1996 and 1997 were not nearly as dramatic as those observed for native annuals. The ability of alien species to germinate during years of low rainfall allows them to utilize soil nitrogen at a time when most native annuals remain dormant as seeds. The danger in germinating after small rainfall events is that there may not be enough residual soil moisture to support plant growth, and seedlings may die before reproducing. This vulnerability may be more acute for *B. rubens*, which evolved in mesic and semi-arid Mediterranean regions, than for *Schismus* spp. or *E. cicutarium*, which evolved in more arid regions (Brooks 1999a).

Increased soil nitrogen levels are thought to affect annual plants only during years of moderate or high rainfall in desert regions (Romney, Wallace & Hunter 1978; Gutierrez 1992). The current study suggests that this is true for native desert annuals but that increased nitrogen levels may affect alien annuals during all but the driest years. In addition, this study provides evidence that patterns of rainfall within years may be more important than annual rainfall totals in predicting germination events and effects of nitrogen on desert annual plant communities. Despite lower rainfall in 1997, annual plant productivity was higher and the responses of annual plants to nitrogen addition were stronger compared with 1996, due to very high rainfall events during December that triggered germination of annual plants. Thus, extreme rainfall events rather than seasonal averages should be considered when evaluating the potential magnitude of annual plant responses to increased levels of soil nitrogen.

Nitrogen limitations for plant growth in desert regions are also thought to be greater where soil nitrogen levels are naturally low in the interspaces between shrubs, than where they are naturally high beneath shrub canopies (Romney *et al.* 1974). Nitrogen additions should therefore have the greatest effects on annual plants in interspaces, where they would cause the highest percentage increase in soil nitrogen. Results of the current study indicate that this is not always true, and that increased nitrogen can increase annual plant biomass in both microhabitats although individual species may respond differently. For example, effects of nitrogen treatments were highest in the beneath-canopy for *B. rubens* and in interspaces for *Schismus* spp. and *E. cicutarium*.

MANAGEMENT IMPLICATIONS OF INCREASED SOIL NITROGEN

As human populations and air pollution levels increase in the Mojave Desert and other desert regions, nitrogen deposition from atmospheric pollutants will probably increase soil nitrogen levels, causing potentially dramatic changes in annual plant communities. Productivity and reproduction rates of alien annual plants could increase at the expense of native annuals that may be at a competitive disadvantage. Years of nitrogen deposition may cause directional shifts in desert annual plant communities towards increased dominance by alien species and decreased diversity of native species.

Nitrogen deposition may have synergistic effects with other forms of disturbance. For example, surface disturbances caused by grazing, off-highway vehicle use or construction of linear corridors for roads or pipelines could facilitate the invasions and establishment of alien plants that may in turn respond to increased levels of soil nitrogen. Increased productivity of alien annual grasses caused by atmospheric nitrogen deposition, especially during years of high rainfall, may also affect desert fire regimes. Alien annual grasses produce large amounts of continuous fine fuels that facilitate the spread of fire where fires were historically infrequent (Rogers & Vint 1987; D'Antonio & Vitousek 1992; Brooks 1999b). Post-fire desert landscapes are often dominated by alien annual grasses, creating conditions that promote recurrent fire (Brooks & Pyke 2001). Thus, nitrogen deposition could facilitate changes in desert fire regimes by increasing productivity of alien annual grasses.

Management of atmospheric nitrogen deposition requires a regional approach that is often beyond the control of local land managers. However, these managers need to understand the potential effects of nitrogen deposition on desert ecosystems, and in particular how these effects may interact with land-use activities that they can manage. Additional studies are needed to determine these relationships, and to evaluate the relative ecological impact of nitrogen deposition compared with other forms of disturbance in desert ecosystems.

New conservation areas should be located where current and projected future rates of nitrogen deposition are low, whenever possible. Examples of such sites would be far removed, or at least downwind, from major sources of atmospheric nitrogen pollutants. The evaluation of environmental threats posed by new projects that would increase the production of nitrogen pollutants should consider their potential to increase the dominance of invasive alien plants and to facilitate the invasion of new alien species.

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Differential responses to nitrogen fertilization in native shrubs and exotic annuals common to mediterranean coastal sage scrub of California

Pamela E. Padgett & Edith B. Allen
Department of Botany and Plant Sciences, University of California, Riverside, CA 92521-0124, USA
(E-mail: ppadgett@mail.ucr.edu)

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Abstract

This study examined the growth responses of exotic annuals and native shrubs to elevated N levels to test the hypothesis that increased N availability favors nitrophilous annuals over the slower-growing shrubs. The vegetation structure of the coastal sage scrub ecosystems in southern California is shifting from shrubland to annual grasslands. Over the last 30 years large tracts of wildlands, particularly those adjacent to urban centers, have lost significant native shrub cover, which has been replaced by exotic annuals native to the Mediterranean Basin. During this same time, air pollution has led to increased terrestrial eutrophication by atmospheric deposition. Changes in vegetation are often the result of changes in resource availability. The results of our experiments showed the three native shrubs tested to be more nitrophilous than the three annuals tested, which contrasts with most models of perennial species' adaptation to stressful environments. Under greenhouse conditions the annual grasses exhibited yield depression at the highest N treatments of 80 μg g^{-1} in soil. The three shrub species evaluated continued to increase shoot biomass at 80 μg g^{-1} N in soil. The grasses also exhibited increased tissue N concentrations with increased soil N in contrast with the shrubs where there was little difference in tissue N concentrations with increasing availability. Although the differential yield responses to elevated N do not explain the success of the annual vegetation in replacing shrubs, the inability of the shrubs to regulate growth under elevated N levels may explain the poor survival of mature individuals.

Introduction

Changes in vegetation structure are often related to changes in resource availability (McLendon & Redente 1991; Tilman & Olff 1991; Tilman 1993; Keeley & Swift 1995). It is widely believed that shifts in vegetation composition in response to shifts in nutrient resources are the result of differential growth or plasticity among the plant species present (Westman 1981b; Tilman 1987; McLendon & Redente 1991). Species that are best able to grow under the new conditions tend to replace the less adapted species. The coastal sage scrub (CSS) plant community of southern California appears to be undergoing a shift from native shrubby vegetation to exotic annual grassland. The encroachment of exotic annuals in CSS corresponds to serious losses in native shrub densities and impoverishment of species diversity, particularly in areas adjacent to urban development (Freudenberger et al. 1987; Minnich & Dezzani 1998). At the same time, N deposition from atmospheric pollution has increased terrestrial, inorganic N loads. Soil NO_3^- concentrations under high deposition conditions has been measured as high as 90 μg N g^{-1} soil during the summer dormant period, as compared with 1 to 2 μg N g^{-1} (as NO_3^-) in soils collected from cleaner locations at the same time of the year (Allen et al. 1997; Padgett et al. 1999).

Other studies suggest that the species best able to increase biomass in response to increased N sources (i.e., nitrophilous) will become dominant under higher N conditions. Because the N response of the species native to CSS is unknown, this study was undertaken to determine whether differential N responses could explain the shift in vegetation structure by impacting early establishment of seedlings.

The physiological basis for plant responses to changes in soil nutrient status is poorly understood. In general, increasing the availability of a limiting soil nutrient or other resource results in an increase in biomass. But the specific growth responses vary broadly across the plant kingdom (Chapin 1980; Chapin et al. 1986). Some species, particularly the ruderal and annual species, exhibit nitrophilous behavior when exposed to increasing N availability. In these species biomass may more than double at the higher treatment levels (Garnier et al. 1989; Muller & Garnier 1990). Among the perennial species, the individual growth responses tend to correspond to the native fertility (Grime 1979; Chapin 1980). Species adapted to low-fertility ecosystems tend to be slow growing and exhibit limited responses to increased N supply. These species generally absorb and store the nutrients rather than synthesize new tissues in response to increased availability.

The magnitude of nitrophilly exhibited by individual plant species correlates well with survival in specific ecosystems (Grime & Hunt 1975; Tilman 1987). Where N availability is abundant, the rapidly growing species tend to out compete the slower-growing species for light, water and nutrients. Where N availability is low, the slower-growing species are better able to take advantage of flushes in availability by regulating growth and storing reserves for periods of scarcity. Thus, the slower-growing plants are better able to persist under impoverished conditions but do not survive under nutrient-rich conditions. And the rapidly growing species do not grow well under deficient conditions but flourish where resources are high. A natural or anthropogenic shift in the inherent fertility of an ecosystem is often accompanied by a shift in plant community structure (Westman, 1981a, b; D'Antonio & Vitousek 1992; Keeley & Swift 1995).

Several studies have linked N deposition to changes in the composition of shrub and grassland plant community (Heil & Bobbink 1993; Pearson & Stewart 1993; Dueck & Elderson 1992). Research conducted in the nutrient-poor heathlands and chalk grasslands of the Netherlands have shown that increased N availability correlates with significant changes in species composition (Bobbink & Willems 1987; Bobbink 1991). The most common interpretation is that the additional N resources have enabled the nitrophilous grass species to out-compete the low-nutrient-adapted shrubs and forbs for other soil resources. In the CSS ecosystems of southern California a similar process seems to be occurring.

Coastal sage scrub is a low-productivity ecosystem native to the coastal foothills and inland valleys of southern California (Westman 1981b). Southern California's Mediterranean climate limits the rainfall to the winter months of October through March. To cope with the 6-month annual drought, most of the shrub species have adopted a drought deciduous, summer-dormant habit. Although some work on the water relations of these species has been conducted (da Silva & Bartolome 1984; Davis & Mooney 1985; D'Antonio & Mahall 1991; Eliason & Allen, 1997), little is known about the nutrient requirements or N responses of the CSS native species. This study was undertaken to evaluate the early growth responses of three native shrubs compared to three exotic annual seedlings to test the hypothesis that the success of the invasive annuals can be explained by N-enhanced growth.

Materials and methods

Seed source

Seeds for the native shrubs *Artemisia californica* Less., *Eriogonum fasciculatum* Benth. and *Encelia farinosa* Torrey & Gray were collected from stable stands of mature shrubs. Seeds were stored without cleaning at 5 °C but were separated from chaff just prior to planting. All seeds were no older than one growing season. Seeds of the exotic annuals *Bromus rubens* L. and *Brassica geniculata* L. were harvested from a highly weedy site. The fruit structures were left intact for storage at 5 °C. Seeds for the annual *Avena fatua* L. were purchased from S & S seed (Carpinteria, CA, USA). Genera and species names are as identified in Munz & Keck (1959).

Potting media and protocols

An artificial potting mix 'UC mix #3' (75% fine quartz sand, 25% ground peat moss), was used. Earlier attempts to use native soils collected for field sites were abandoned because of difficulties in regulating nitrogen concentrations. Seven hundred grams of steam-sterilized UC mix were used for each pot. Six replicate pots (6.4 × 25 cm 'Deepots', Stuewe & Sons, Corvallis, OR, USA) were established for each treatment. Pots were filled with potting mix and leached with approximately 1 l of distilled, deionized

Table 1. Mineral nutrient composition of coast sage scrub soil solution evaluated during the spring growing season and composition of nutrient solution used for pot studies. Soil solution concentration was determined by saturated paste extract. Data shown are the Means of 5 replications. The nutrient solutions were added to the potting medium before and during the growth period depending on seedling growth rate. No erogenous Mo. Ni or was added. Final solution pH was 6.5.

Element	Soil solution (mM)	Nutrient solution (mM)	Specific compound
Ca	0.63	1.2	$CaCO_3$
Mg	0.32	0.6	MgO
Na	0.53	1	NaOH
K	0.07	0.14	KCl
Cl	0.15	3	HCl
S	0.06	1.2	$MgSO_4$
P	0.0008	0.16	KH_2PO_4
Mn	n/a	0.0001	$MnSO_4$
Zn	n/a	0.001	$ZnCl_2$
Cu	n/a	0.0001	$CuSO_4$
B	n/a	0.003	H_3BO_3
Fe	n/a	5 mg l^{-1}	Fe EDTA

(DDI) water prior to planting. Field capacity was measured, established at 30% (240 g water pot^{-1}) and used to calculate soil solution volume for application of nutrient solutions.

To duplicate the chemical and nutrient conditions of CSS, the mineral nutrient content of native soils was analyzed by saturated paste extractions (Soon & Warren 1993). A multiple-nutrient solution (excluding N) was developed to mimic natural spring growing-season soil solutions (Table 1). Pots were fertilized with 125 ml pot^{-1} double-strength multiple-nutrient solutions (which represented half the volume of water held in the pots at field capacity) just prior to planting and at 1- to 4-week intervals depending upon seedling size and growth rate. Soluble phosphorus was periodically monitored to maintain 2 $\mu g\ g^{-1}$ KCl extractable phosphorus as determined by continuous flow analysis (O'Halloran 1993).

N treatments

Nitrogen was applied as solutions of NH_4Cl (5.4 g l^{-1}) or KNO_3 (10 g l^{-1}) to achieve final soil N concentrations of 2, 20, 40 and 80 $\mu g\ g^{-1}$. Following N applications, pots were watered with approximately 100 ml DDI water to distribute solubilized N. Soil concentrations were chosen on the basis of preliminary studies that indicated only small differences in yield responses of the annuals at concentrations above 80 $\mu g\ g^{-1}$. These concentrations also reflected the range of soil inorganic N measured under polluted conditions in the field.

Background N in the potting medium was approximately 2 $\mu g\ g^{-1}$ N as NH_4^+. No NO_3^- was detected after the first leaching. The NH_4^+ was assumed to be derived from mineralization of the peat moss and appeared to be firmly bound and largely inaccessible to the seedlings. In preliminary experiments where seedlings were treated with the nutrient solution only, without additional N, seedlings did not survive for more than 2 or 3 weeks. Therefore, the lowest N treatment was maintained at 2 $\mu g\ g^{-1}$ by exogenous application. This concentration provided just enough N for seedlings to survive the 3-month experiments.

Soils were sampled every 1 to 2 weeks depending on the size of the seedlings. One or two 5 × 100 mm cores were removed from each pot and analyzed for NO_3^- and NH_4^+. When soil concentrations fell below 10 $\mu g\ g^{-1}$ of the targeted concentrations, N solutions were added to re-establish soil concentrations.

Planting and harvesting

Pots were planted with 10 seeds each. Final germination was recorded at 10 to 14 days after seeding. Pots were thinned to one seedling per pot, and one pot per treatment was maintained with no seedlings for evaluation of soil- versus plant-mediated changes in N characteristics. Seedlings of all species were harvested 3 months after initiation. The experimental duration was based on time to flower for the annuals and avoidance of pot-bound conditions for the shrubs. These conditions were determined in preliminary experiments.

At the conclusion of the experiments the intact soil mass was separated from roots by soaking in water. Even with care, species with fragile roots, especially *A. californica* lost fine root mass, so root weight data were not complete for all species but can be compared across treatments within a species. Intact plants were oven dried at 60 °C for 48 h, separated into roots and shoots and weighed.

Tissue and soil analysis

Dried leaves were separated from stems and ground in a ball mill to a fine powder. Approximately 10 mg of ground tissue was weighed into tin capsules, and %C and %N was determined by flash combustion chromatography (Carlo-Erba Instruments, Fisons, Dearborn, MI, USA).

Soil NO_3^- and NH_4^+ content was determined by 1-g extraction in 1 M KCl by standard technique (Maynard & Kalra 1993). Soil samples were weighed into plastic centrifuge tubes, and 10 ml KCl was added. The soil slurries were either shaken on a wrist shaker for 30 min or overnight on a reciprocal shaker. Soil was separated from the extractant by centrifugation at 2000 × *g* for 10 min, and 2 to 3 ml of the extractant was transferred into autosampler cups and stored at −20 °C until analyzed by continuous flow analyzer. Solutions were simultaneously analyzed for NH_4^+ by the indophenol blue procedure and NO_3^- by the cadmium reduction procedure (Maynard and Kalra 1993)

Statistical analysis

Yield and tissue N content were analyzed separately for each species by one-way ANOVA and t-tests using SigmaStat, version 2.0 by Jandel Scientific Software (San Rafael, CA USA).

Results

Biomass

After 3 months of growth, a trend toward larger plants under NH_4^+ fertilization as compared to NO_3^- fertilization was noted for *A. fatua*, *A. californica* and *E. fasciculatum*; the opposite trend of smaller plants under NH_4^+ as compared with NO_3^- fertilization was observed for *B. rubens*, *B. geniculata* and *E. farinosa* (Table 2). Since the yield response to the individual N sources was significant only for *A. fatua* ($P < 0.05$) and there was no consistency between native shrub and exotic annual species, it does not appear that pot cultures revealed a clear species-specific preference for one N source over another, nor can any generalizations be drawn regarding N source and the origin of these six plant species.

Changes in root:shoot ratio (R:S) often accompany changes in N availability (Levin et al. 1989). This predisposition was demonstrated by the R:S responses of *A. fatua* (Table 2). Changes in R:S were not so clear for the other species, however. Ammonium fertilization resulted in a trend of decreased R:S in *B. rubens* but not in the NO_3^- treatments. The R:S in *B. geniculata* was highly variable and also indicated no specific trends. Results of the 2-μg g^{-1} treatments compared directly with those of the 80-μg g^{-1} treatments showed that fertilization with NO_3^- resulted in significantly ($P < 0.05$) increased R:S for *A. californica*, but NH_4^+ fertilization caused a significant decrease. The R:S for both *E. farinosa* and *E. fasciculatum* was highly variable and yielded no discernible trends.

Relative yield responses

The difference in relative yield response to NO_3^- compared with NH_4^+ fertilization was not significant for either exotic annuals (Figure 1A, 1C) or native shrubs (Figure 1B, 1D). However, the pattern of response to increasing N availability was distinctly different between the grasses and the shrubs, with *B. geniculata* responding more like the shrubs (Figure 1). With both of the N source treatments *A. fatua* and *B. rubens* reached maximum biomass at 40 μg g^{-1} N. Yield was depressed with the 80-μg g^{-1} treatment (Figure 1A, 1C) for these two species but not for the shrubs or *B. geniculata* (Figure 1B, 1D). For all three shrubs, the 40-μg g^{-1} treatment resulted in approximately 70 to 80% of the maximum yield.

Shoot N content

The predisposition of these species to accumulate N in leaf tissue differed between life forms (Figure 2). All of the annuals had increased tissue N with increasing application rate (Figure 2A, 2C). As with the yield rate, there was no difference in tissue N between the NO_3^- and NH_4^+ treatments. For the shrubs, the pattern of tissue accumulation differed from that observed in the annuals. *Artemisia californica* contained significantly ($P < 0.01$) more N than any of the other shrubs and accumulated relatively large quantities of N in the N-starved seedlings (Figure 2B, 2D). *Encelia farinosa* tended to have the lowest percent leaf N, but the differences between *E. farinosa* and *E. fasciculatum* were not significant. All of the shrub species indicated little propensity to accumulate large quantities of tissue N under high fertility conditions, especially as compared with the annuals. A small increase in tissue N concentration was noted for *E. fasciculatum* at the highest NO_3^- and NH_4^+ concentrations and for *E. farinosa* at 80 μg g^{-1} N as NO_3^-.

Table 2. Biomass after 3 months of growth. Seedlings were harvested and oven dried. Data shown are the means with SE indicated by parentheses ($n = 5$). All species demonstrated significant ($P < 0.01$) biomass differences with increasing nitrogen application. Differences between NH_4^+ and NO_3^- treatments were significant ($P < 0.05$) only for *Avena fatua*.

	NO_3^-				NH_4^+			
	2 μg g^{-1}	20 μg g^{-1}	40 μg g^{-1}	80 μg g^{-1}	2 μg g^{-1}	20 μg g^{-1}	40 μg g^{-1}	80 μg g^{-1}
Avena fatua								
Shoots	0.17	0.91	1.35	0.99	0.03	0.85	1.57	1.37
	(0.05)	(0.16)	(0.26)	(0.21)	(0.02)	(0.15)	(0.37)	(0.34)
Root:Shoot	13.30	5.28	8.58	4.99	13.30	4.80	4.85	3.45
	(2.74)	(0.98)	(1.40)	(1.09)	(3.55)	(0.50)	(1.05)	(0.73)
Bromus rubens								
Shoots	0.25	0.64	1.68	1.37	0.19	0.56	1.39	1.15
	(0.03)	(0.06)	(0.34)	(0.26)	(0.03)	(0.11)	(0.25)	(0.07)
Root:Shoot	1.78	1.53	1.42	1.59	1.07	1.12	0.99	0.83
	(0.39)	(0.34)	(0.48)	(0.34)	(0.20)	(0.18)	(0.19)	(0.19)
Brassica geniculata								
Shoots	0.01	0.39	0.89	1.32	0.01	0.23	0.42	0.81
	(0.00)	(0.06)	(0.07)	(0.10)	(0.00)	(0.06)	(0.26)	(0.21)
Root:Shoot	0.78	1.81	1.29	1.21	0.54	1.58	1.12	1.16
	(0.45)	(0.17)	(0.15)	(0.23)	(0.15)	(0.21)	(0.40)	(0.90)
Artemisia californica								
Shoots	0.07	0.67	0.96	1.18	0.08	0.85	1.25	1.73
	(0.01)	(0.12)	(0.06)	(0.21)	(0.02)	(0.16)	(0.14)	(0.18)
Root:Shoot	0.12	0.41	0.37	0.36	0.48	0.24	0.19	0.16
	(0.02)	(0.04)	(0.03)	(0.07)	(0.14)	(0.03)	(0.05)	(0.04)
Encelia fatinosa								
Shoots	0.05	0.20	0.40	0.45	0.05	0.17	0.17	0.39
	(0.01)	(0.03)	(0.02)	(0.06)	(0.01)	(0.06)	(0.02)	(0.07)
Root:Shoot	1.58	1.85	2.16	2.82	1.18	1.90	1.64	1.94
	(0.27)	(0.27)	(0.26)	(0.49)	(0.16)	(0.51)	(0.20)	(0.08)
Eriogonum fasiculatum								
Shoots	0.05	1.28	1.45	1.86	0.55	0.93	1.75	2.43
	(0.03)	(0.38)	(0.26)	(0.28)	nd	(0.18)	(0.39)	(0.29)
Root:Shoot	3.66	6.17	2.05	0.99	0.26	2.09	1.15	2.09
	(3.29)	(4.28)	(0.36)	(0.17)	nd	(0.50)	(0.20)	(3.34)

Discussion

The results of these experiments indicate that as seedlings, the three CSS shrub species showed a greater relative yield response to increased N availability than the three exotic annuals. This contrasted with predictions for N response based on native fertility, productivity and species life form, in which it was expected that the shrubs would engage in uptake and storage of N rather than increased tissue synthesis. All of the six species tested demonstrated 1.5- to 2.5-fold increases in biomass between the 20-μg g^{-1} treatment and the treatment resulting in the highest biomass accumulation. However, the grasses attained their highest yields at 40 μg g^{-1} N, whereas the shrubs and *B. geniculata* grew significantly larger with the 80-μg g^{-1} treatment.

No difference in the relative yield response patterns between N as NO_3^- or NH_4^+ was detected. And in only one case was the absolute biomass significantly different between the two sources. Determination of N preference was important to understanding plant

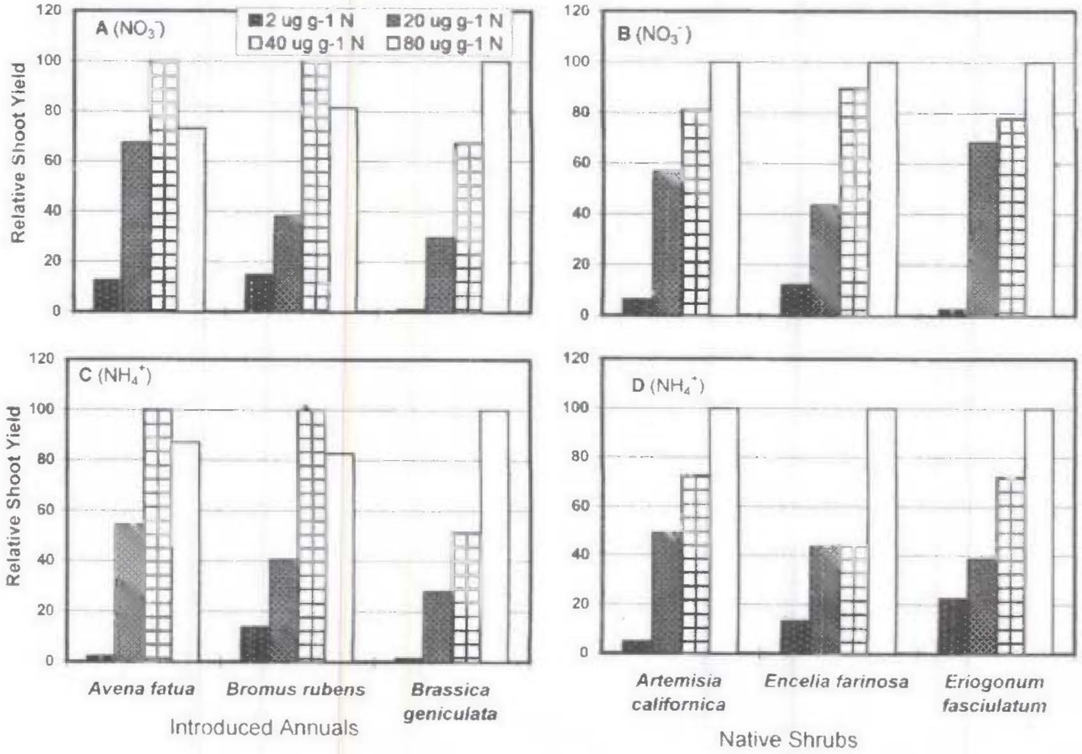

Figure 1. Relative shoot yield in response to two N sources, NO_3^- and NH_4^-. Relative yield was calculated as a percentage of the biomass from the highest yielding treatment. The responses were significantly different ($P < 0.01$) within but not between treatments.

response to deposition loads because in southern California more than 70% of the N deposited from pollution is as NO_3^- (Bytnerowicz & Fenn 1996; Allen et al. 1997; Padgett et al. 1999). This is in contrast to many of the European studies where most of the deposited N is derived from agricultural NH_4^+ (Bobbink 1991). For these six species, however, the N source in a pot study was of little importance.

Changes in R:S that frequently accompany changes in N availability are often used to explain the outcome of interspecific competition (Garnier et al. 1989; Gutschick 1993; Van der Werf et al. 1993). The results of this study did not indicate any clear trends regarding root responses. For example, the decrease in R:S with increased N by *A. fatua* suggest that at higher N rates, this species would be less competitive below-ground because of reduced root surface in relationship to shoot biomass. However, *A. fatua* also demonstrated the highest R:S among the 6 species under all N treatments. Comparisons between the annuals and perennial shrubs is probably not appropriate in this study because of the noted difference in biomass allocation patterns to roots or shoots between monocots and dicots (Lambers & Poorter 1992).

The significantly higher N content of *A. californica* leaves is probably related to leaf morphology and anatomy. The leaves are thread-like, and microscopic investigation suggests that they consist of one layer of epidermal cells, a row of palisade parenchyma and a vascular bundle (Padgett unpubl. obser.). There is very little schlerophilous tissue, spongy parenchyma or fibers. Although it might be tempting to conclude that this species is particularly N inefficient because of the high tissue content (*sensu* Killingbeck & Whitford 1996), the N content is probably more related to the lack of cells and tissues devoted to structural maintenance such as fibers. Thus, a greater proportion of the dry weight is involved in physiological processes that would require nitrogenous compounds.

The apparent nitrophilous nature of *A. californica*, *E. farinosa* and *E. fasciculatum* observed in this study concur with observations by Gray & Schlesinger

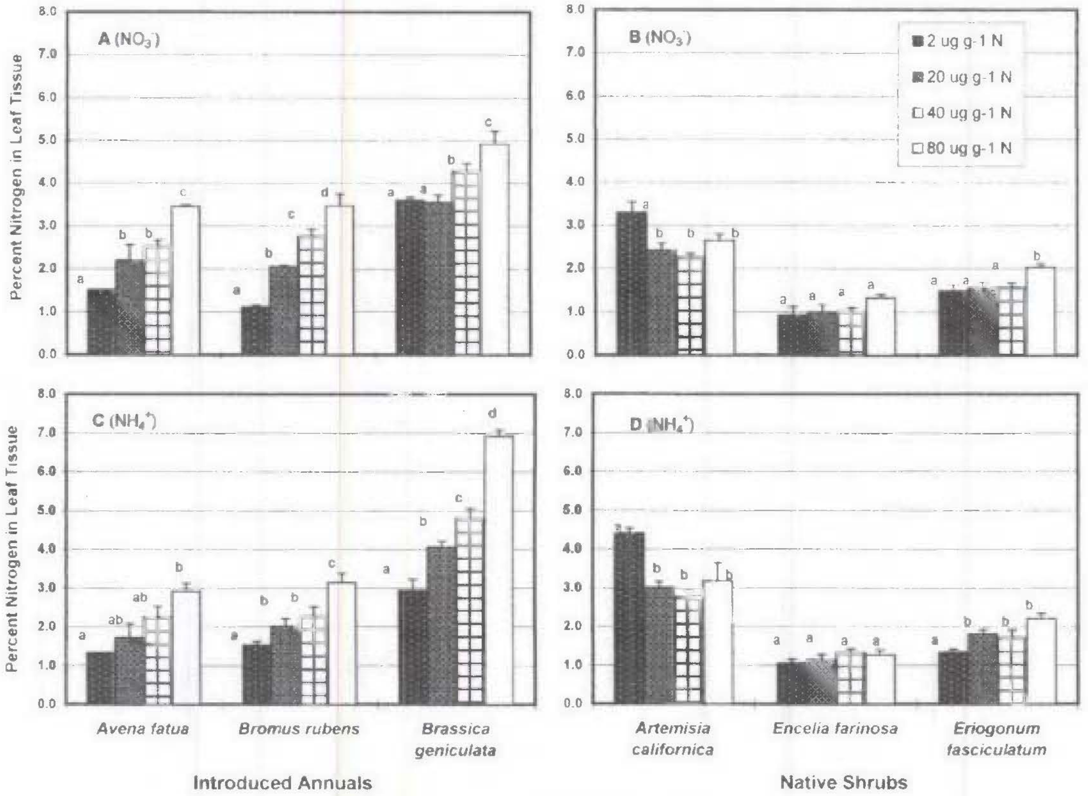

Figure 2. Mean N content ($n = 5$) in leaf tissue of six CSS species treated with four levels of NO_3^- and NH_4^-. Bars = SE.

(1983) of the N response of *Salvia leucophylla*, another semideciduous shrub native to CSS. Like *A. californica*, *E. farinosa* and *E. fasciculatum*, *S. leucophylla* demonstrated a linear growth response with increased N availability up to the highest treatment level, of 168 $\mu g\ g^{-1}$ N. The N response of *S. leucophylla* differed substantially from that of a comparison sclerophyllous evergreen shrub, *Ceanothus megacarpus*. This shrub is an evergreen nonleguminous N fixer native to the physiographically similar chaparral ecosystems. Maximum yield for *C. megacarpus* was achieved at 84 $\mu g\ g^{-1}$ N, which was half the N concentration required for maximum yield of *S. leucophylla*. Although the Gray & Schlesinger study was conducted in sand culture using flowing nutrient solutions, the targeted concentrations of 21 to 168 $\mu g\ g^{-1}$ in solution were similar to the 2 to 80 $\mu g\ g^{-1}$ in soil used in this study. The results of Gray & Schlesinger (1983) suggest that higher biomass would have been obtained in our work had we used N concentrations above 80 $\mu g\ g^{-1}$.

The response of the CSS shrubs to increasing N is contrary to observations of other perennial species as compared to ruderal annuals (e.g., Chapin et al. 1986; Chapin & Moilanen 1991). All plants do have some ability to respond to changes in resource levels either by regulating growth or by regulating nutrient absorption (Glass et al. 1985; Aslam et al. 1993). In these experiments analysis of the potting mix during the growth experiments indicated little difference in uptake rate among the six species suggesting that the differential yield response was not due to differences in uptake rates among these species (data not shown).

The apparent nitrophilous nature of the CSS shrubs might be expected to give them a competitive advantage under fertile conditions such as those occurring in areas of high N deposition. However, the field observations indicate that the native shrubs fare poorly under high N deposition, particularly once grasses are well established (Schultz 1996; Eliason & Allen 1997; Minnich & Dezanni 1998). The exotic grasses are well adapted to the semi-arid, Mediterranean ecosystems of California, and once established their populations are self-sustaining, making eradication very difficult (da Silva & Bartolome 1984; Welker et al. 1991). Although differential yield responses between the life forms were clearly evident, at first glance they do not seem to explain the success of the invasive grasses and forbs and the loss of native shrubs during early seedling establishment.

Other hypotheses for the success of exotic grasses have been tested, including greater seedling size and growth rate resulting in shading of adjacent shrubs, below-ground competition for other nutrients or water (Eliason & Allen 1997), poor shrub seedling emergence under dense grass litter (Schultz 1996) and general depletion of shrub seed bank reserves following disturbances. If N were the only variable in the competition between invasive annuals and native shrubs, the results of this study indicate that neither group has a particular advantage in the face of increasing N availability due to N deposition.

One other explanation yet to be extensively explored is that poor regulation of growth results in shortened life spans. Poor long-term survival of arid-adapted plants grown under horticultural conditions is common (Keator 1994). Because these shrubs apparently lack the ability to restrict growth in the presence of exogenous N, under high deposition conditions, they may not receive or respond to environmental cues that should initiate preparation for dormancy. Absorption of N pollutants is thought to occur through foliar means in addition to the normal root pathway (Vose & Swank 1990; Hanson & Garten 1992; Nussbaum et al. 1993). If this were to occur in CSS species, foliar deposition and subsequent absorption could cause a bypass in the normal environmental cues resulting in continued growth when these species should be preparing for summer dormancy. This hypothesis is consistent with the observed pattern of loss of mature shrubs in the field. Work is ongoing to test this and other hypotheses to develop a generally applicable understanding of arid and semi-arid ecosystem responses to N deposition.

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The Effects of Organic Amendments on the Restoration of a Disturbed Coastal Sage Scrub Habitat

Thomas A. Zink
Michael F. Allen

Abstract

The effectiveness of organic mulch as a simple means of enhancing the restoration of disturbed lands by providing a competitive edge to native perennials, such as *Artemisia californica* (California sagebrush), over exotic annuals, such as *Avena fatua* (wild oat), was studied by investigating the effect of organic amendments on microbial activity and nitrogen immobilization through both soil analysis and aboveground plant growth. The addition of organic amendment resulted in an increase in microbial activity, a parallel increase in nitrogen immobilization, and no significant differences in total soil nitrogen. It is likely that nitrogen was gradually being removed from its more available form of nitrate and being immobilized in the tissues of the increasing microbial biomass. The survival rate of planted native perennial seedlings of *A. californica* in organic amended plots was almost double that of control-plot seedlings, and plant volume was significantly higher. When the availability of nitrogen was reduced through increased immobilization, amended plots established an environment more conducive to native perennial shrubs, allowing them to outcompete exotic annuals for water and nutrients. This simple procedure could have major implications for enhancing the restoration of disturbed lands.

Department of Biology, College of Sciences, San Diego State University, San Diego, CA 92182–4614, U.S.A.

Introduction

Ecological restoration is the return of an ecosystem to a self-sustaining entity in which natural ecological processes operate without the continued intervention of resource managers or reliance on engineered structures (Berger 1993). The aim of restoration is not merely the establishment of aboveground vegetation but the return to a native-dominated community. One often-neglected aspect of such a return is the reestablishment of the belowground components of the ecosystem (Allen 1988). The availability of soil nutrients is in large part controlled by belowground biota, which regulate mineralization and immobilization. These processes determine nitrogen availability for uptake, volatilization, and leaching, which are crucial for successful restoration (Whitford et al. 1988).

Lands severely disturbed by either natural or anthropogenic causes tend to have dysfunctional nitrogen cycles associated with the removal of plants and increased mineralization because of physical soil disturbance (Marrs et al. 1983; Carpenter & Allen 1988; George et al. 1993). Nitrogen-rich systems often are conducive to the establishment and maintenance of exotic annual species rather than native perennials (Chapin 1980; Jackson et al. 1988; Hart et al. 1993; Davidson et al. 1990). To reestablish a perennial native-dominated community on such lands, it may be necessary to shift the cycling to a slow, steady-release, nitrogen-poor system favored by native perennials. This might be accomplished by the sequestering of nitrogen from the soil to reduce the competitive abilities of nitrophilous exotic annuals while increasing the competitive abilities of native perennials. This may be especially critical in relatively nutrient-rich soils such as those that predominate in coastal sage vegetation in California (Allen et al. 1996).

This study was designed to test the effectiveness of organic mulch as a simple means of enhancing the restoration of disturbed lands. Research was conducted on an ecological reserve that had experienced large-scale disturbance 10 years before through the construction of a pipeline corridor. The corridor is presently dominated by exotic annual species on a relatively nitrogen-rich soil (Zink et al. 1995). The addition of organic amendments to increase microbial activity and the subsequent increase in nitrogen immobilization were tested through both belowground chemical and biological analysis and aboveground analysis of plant growth.

Methods

Study Site

We studied a disturbed area on the Santa Margarita Ecological Reserve. The reserve has approximately 1200 ha of native grassland, coastal sage, oak woodland, chaparral, and riparian habitat. Though surrounded by both agricultural development (avocado and citrus groves) and urbanization, the reserve remains relatively undisturbed. The area has a history of intermittent grazing from the mid-nineteenth century through the 1950s (Burcham 1957) and has been protected as a reserve since 1965.

The Santa Margarita Ecological Reserve is located near the city of Temecula, California, (33°32′10″N, 117°10′25″W) at an elevation of 338 m. It has a Mediterranean climate with over 300 frost-free days per year and a mean temperature range of 15–19°C. Precipitation ranges from 228 to 460 mm per year, with a mean of 280 mm. Soil is a Lithic Haploxerol with moderately slow to slow permeability (Cooper et al. 1973).

The disturbance was caused by the installation of two underground water pipelines along a corridor ranging in width from 45 to 120 m. The corridor is relatively homogeneous along its entire length, and the vegetation bears little resemblance to the native habitats through which it passes. It has been 10 years since the disturbance occurred and there has been little reestablishment of native species within the disturbance corridor (Zink et al. 1995).

Experimental Design

We established 27 plots (1 m × 0.5 m) in January 1993 on the disturbed site using a random block design of three blocks each with nine plots. Annual vegetation was mowed to ground level prior to plot establishment. Treatments were randomly placed within each block to provide three control plots where no amendment was applied; three plots with a highly recalcitrant amendment (pine bark), approximately 3 cm thick; and three plots with a less recalcitrant amendment (oat straw), also 3 cm thick. The amendments were applied on the surface without disking to eliminate the "green manure" effect of increased mineralization by not incorporating the organic matter into the soil (Holland & Coleman 1987; Paustian et al. 1992). Weedy invasives were not subsequently controlled.

The experimental design consisted of a complete randomized block design with three blocks. Within each block, nine plots were randomly assigned with the following treatments: *Artemisia californica* (California sagebrush) plus bark mulch, *A. californica* plus straw mulch, *A. californica* and no mulch, *Stipa pulchra* (purple stipa) plus bark mulch, *S. pulchra* plus straw mulch, *S. pulchra* and no mulch, no seedlings and bark mulch, no seedlings and straw mulch, no seedlings and no mulch. Each planted plot consisted of 12 seedlings per plot.

Soil Sampling and Plant Growth Measurements

Soil samples were taken regularly at three-month intervals. Three 10-cm-deep cores per plot were taken with a 2-cm stainless steel corer sterilized with 50% ethanol and were placed in separate sterile soil sample bags that were transported back to the laboratory in a cooled ice chest. All soil samples were kept refrigerated at 5°C and analyzed within 24 hours of collection. The following parameters were measured: active fungal hyphal length and bacteria counts, ammonium, nitrate, total nitrogen, and organic matter.

Plant growth comparison was conducted by measuring plant volume for all seedlings. *S. pulchra* seedlings suffered from extensive herbivory by rabbits, and all aboveground growth was consistently removed during each growing season. We therefore could not measure *S. pulchra* seedlings, so growth comparisons were conducted only for *A. californica* seedlings.

Plant volume was determined by the formula $V = 4/3\pi r_1 r_2 r_3$, where the first radius was a vertical measurement and the other two radii were measured on a horizontal plane, perpendicular to each other, at the plant's widest point.

Microbial Measurements

Europium staining procedures outlined by Anderson and Slinger (1975) and modified by Trent (1993) and Conners and Zink (1994) were used to determine active fungal hyphal lengths and bacteria counts. In this procedure, Europium(III) thenoyltrifluoroacetonate ($Eu(TTA)_3$) is mixed with a fluorescent brightener (FB) in 50% ethanol and water to create a differential fluorescent stain (DFS). The stain is absorbed by living soil organisms and other organic material but not inorganic particles. The DFS emits light between 615 and 630 nm and is observed as red due to the europium. This identifies living tissue. Europium staining minimizes the interference from nonmicrobial particles often found in association with living cells (Scaff et al. 1969; Anderson & Westmoreland 1971; Anderson & Slinger 1975).

A Lietz Laborlux 12 microscope using ultraviolet light from a band pass excitation filter with a wavelength of 340–380 nm and a Pulnix TM-845 video camera were used for stain evaluation. The Imageviewer computer program (W. Morris, San Diego State University) was used to store and analyze the images following imaging procedures outlined in Morgan et al. (1991). Fungi were observed with a 40× phase-contrast lens. Bacteria were observed under an oil-immersion 100× lens. A 1:1 dilution was used unless the bacteria were so numerous as to require use of a 1:4 dilution for image definition. Each stained image was recorded and the imaged area totalled and used to calculate either hyphal length per gram of soil or number of bacteria per gram of soil. These were then converted to biomass numbers. For fungi the formula $\pi r^2 1$ was used, with $r = 3\ \mu m$ and $1\ cm^3 = 1\ g$. For bacteria the formula $\pi r^3(n)$

was used, with $r = 0.3$ µm and n = number of bacteria imaged.

Soil Physicochemical Properties

Ammonium and nitrate were determined by potassium chloride extraction (Keeney & Nelson 1982). Total nitrogen was determined by the Kjedahl digestion method (Bremner & Mulvaney 1982), and organic matter was determined by the loss-on-ignition method (Nelson & Sommers 1982).

Analysis

All parameters were analyzed by two-factor (treatment and block) analysis of variance. Fisher's protected least significant difference test was used to check for significant difference, with $p \leq 0.05$ used to denote significance (Zar 1984). Values of $p \leq 0.10$ were noted as indicative of possible trends. All parameters at the test site were analyzed for the effects of seedling presence, with no significant differences noted for any parameter.

Results

Plant Growth and Microbial Measurements

All *A. californica* seedlings were approximately 5 cm high at the time of planting in February 1993. During the first three months after planting, seedlings in all three treatment plots experienced die-off, probably from transplant shock. Survival rate was highest (84%) in bark-amended plots and lowest (44%) in control plots. After three months the survival rate for all three treatments leveled out and remained fairly steady for the remaining two years of the experiment (Fig. 1).

Significant differences in plant volume between amended plots and control plots began to appear in October 1993 and continued throughout the experimental period (Fig. 2). From October 1993 through February 1995 seedlings in both bark- and straw-amended plots showed significantly more growth ($p \leq 0.05$) than control plot seedlings. By the end of the experiment bark-amended plots still maintained this increased seedling growth compared to control plots.

Measurements of active fungal hyphae, taken in February 1993 just prior to the establishment of the plots, indicated no initial significant difference among treatments. Beginning in January 1994, amended plots began to show higher amounts of active fungal biomass than control plots (Fig. 3). In January 1994 bark-amended plots contained more active fungal hyphae than control plots ($p \leq 0.10$). This increase in active fungal hyphae continued over the next two growing seasons, with significant differences seen between control and amended plots in July 1994 ($p \leq 0.05$), February 1995 ($p \leq 0.01$), and May 1995 ($p \leq 0.01$).

Bacteria levels did not differ between treatments throughout the entire testing period, with only two exceptions (Fig. 4). Straw-amended plots showed a significant increase in bacteria over control plots in July 1994 ($p \leq 0.05$) and in February 1995 ($p \leq 0.01$).

Soil Nitrogen and Organic Matter

No initial significant differences among all three treatments were detected for nitrate, ammonium, and total nitrogen content in the soil. Beginning in July 1993, soil

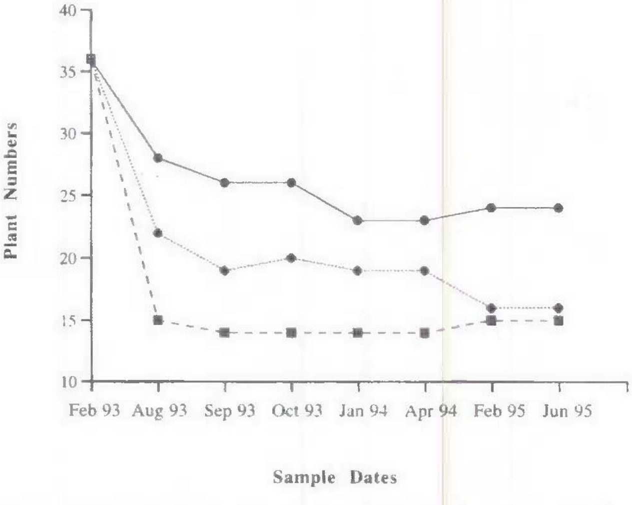

Figure 1. Survival rates for seedlings planted under control (dashed line), straw-amended (dotted line), and bark-amended (solid line) treatments.

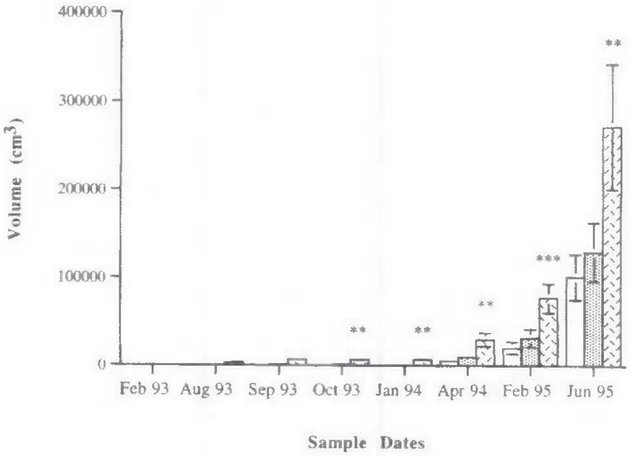

Figure 2. Plant volume under control (plain), straw-amended (stipuled), and bark-amended (cross-hatched) treatments. Significant difference at $p \leq 0.05$ represented by two asterisks; significant difference at $p \leq 0.01$ represented by three asterisks.

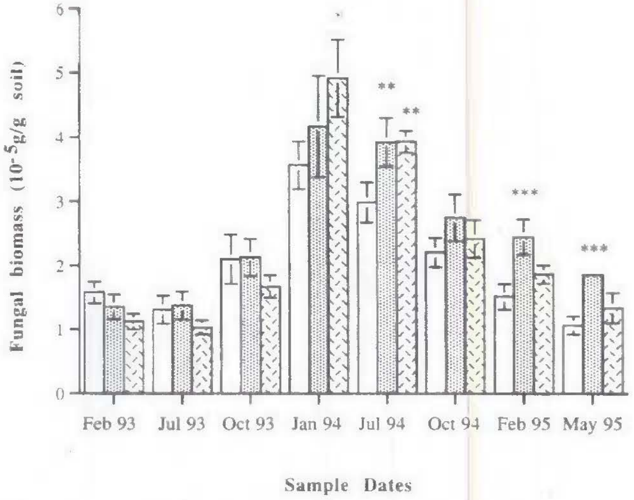

Figure 3. Active fungal biomass under control (plain), straw-amended (stipuled), and bark-amended (cross-hatched) treatments. Significant difference at $p \leq 0.10$ represented by one asterisk; significant difference at $p \leq 0.05$ represented by two asterisks; significant difference at $p \leq 0.01$ represented by three asterisks.

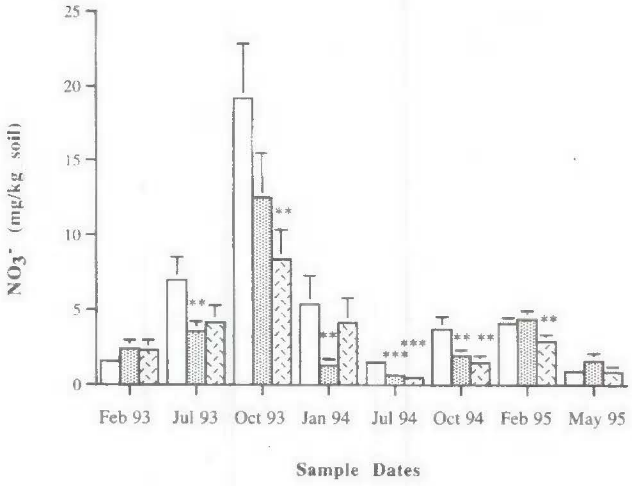

Figure 5. Available soil nitrogen in the form of nitrate under control (plain), straw-amended (stipuled), and bark-amended (cross-hatched) treatments. Significant difference at $p \leq 0.05$ represented by two asterisks; significant difference at $p \leq 0.01$ represented by three asterisks.

nitrate content was significantly lower in amended plots than in control plots (Fig. 5). Straw-amended plots showed significantly lower values in July 1993 ($p \leq 0.05$), January 1994 ($p \leq 0.05$), July 1994 ($p \leq 0.01$), and October 1994 ($p \leq 0.05$). Nitrate under bark-amended plots was significantly lower than in control plots in October 1993 ($p \leq 0.01$), July 1994 ($p \leq 0.01$), October 1994 ($p \leq 0.05$), and February 1995 ($p \leq 0.05$). Significant difference was detected in the amount of ammonium on three sampling dates. Ammonium under straw-amended plots was significantly lower than in control plots in July 1993 ($p \leq 0.05$) and in January 1994 ($p \leq 0.01$). Bark-amended plots showed significantly lower ammonium than control plots in January 1994 ($p \leq 0.01$). In May 1995, reverse results were seen, with bark-amended plots having significantly higher ammonium than both straw-amended and control-plots ($p \leq 0.10$) (Fig. 6). Total nitrogen for all three treatments remained fairly consistent throughout the experiment, with no significant differences except for the last sampling data taken in May 1995 (Fig. 7). At this time both bark- and straw-amended plots had significantly more soil nitrogen ($p \leq 0.01$) than control plots.

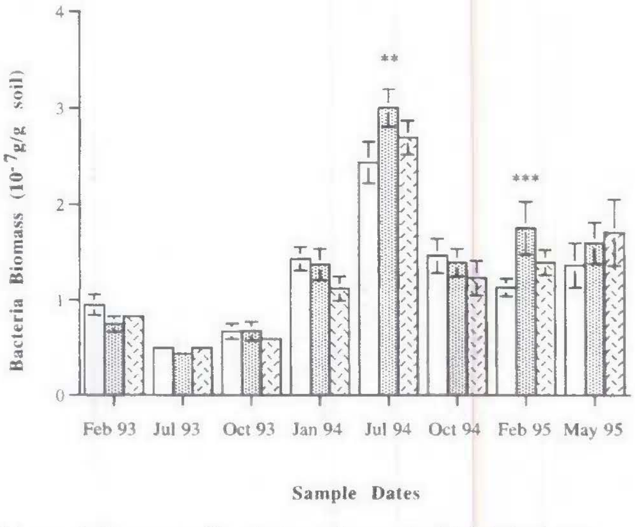

Figure 4. Biomass of bacteria under control (plain), straw-amended (stipuled), and bark-amended (cross-hatched) treatments. Significant difference at $p \leq 0.05$ represented by two asterisks; significant difference at $p \leq 0.01$ represented by three asterisks.

Soil organic matter content did not differ among the three treatments for the first six months of the experiment. But first in July 1993 and then from January 1994 through the end of the research in May 1995, organic matter content increased significantly under the bark-amended plots compared to control plots (Fig. 8). No change in soil organic matter was detected under the straw-amended treatment.

Discussion

Results from this study demonstrated that the addition of recalcitrant amendment is beneficial for the restoration of native shrubs on disturbed lands by increasing microbial activity and subsequently increasing nitrogen

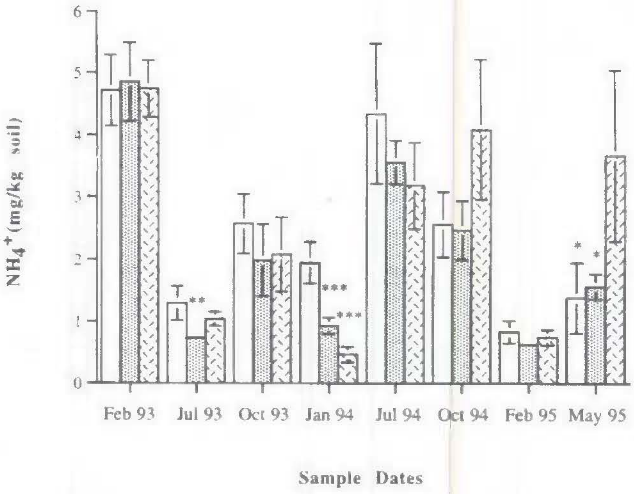

Figure 6. Available soil nitrogen in the form of ammonium for control (plain), straw-amended (stipuled), and bark-amended (cross-hatched) treatments. Significant difference at $p \leq 0.10$ represented by one asterisk; significant difference at $p \leq 0.05$ represented by two asterisks; significant difference at $p \leq 0.01$ represented by three asterisks.

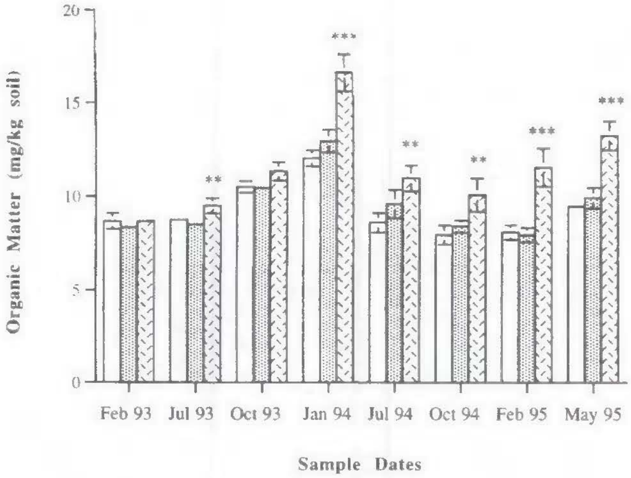

Figure 8. Total soil organic matter under control (plain), straw-amended (stipuled), and bark-amended (cross-hatched) treatments. Significant difference at $p \leq 0.05$ represented by two asterisks significant difference at $p \leq 0.01$ represented by three asterisks.

immobilization. Microbial activity was increased in bark-amended plots, especially fungal biomass. This increase in microbial activity was paralleled by a significant decrease in available nitrogen, in the form of nitrate, and a significant increase in soil organic matter. Soil ammonium results were inconclusive. Because total nitrogen did not differ in the recalcitrant amended plots, it is likely that nitrogen was gradually removed from its more available form of nitrate and immobilized in the tissues of the increasing fungal biomass and organic matter.

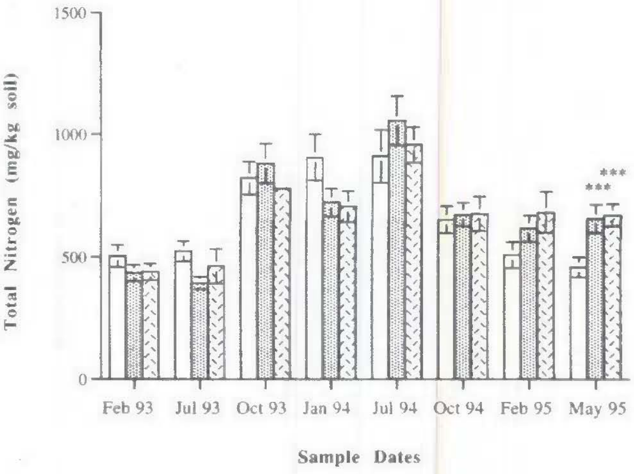

Figure 7. Total soil nitrogen under control (plain), straw-amended (stipuled), and bark-amended (cross-hatched) treatments. Significant difference at $p \leq 0.01$ represented by three asterisks.

Increased microbial activity resulting in lower available nitrogen has been shown previously. Using crop residue, Schomberg et al. (1994) found that additional nitrogen was immobilized in soil containing litter with high lignin. Holland and Coleman (1987) also reported that higher steady-state levels of soil organic matter were present when surface-applied, fungal-decomposed litter was added to the soil.

Fungi are more tolerant of low water potentials and may have an advantage over bacteria in decomposing surface litter. The ability of fungi to form hyphal networks and bridge the gap between soil and surface organic matter also provides a more favorable environment for fungi than for bacteria (Doran 1980). This was demonstrated by Holland and Coleman (1987), who found an increase in fungal biomass with surface-applied litter and a subsequent increase in net nitrogen immobilization and slower microbial biomass turnover. Their results are similar to those of Kassim et al. (1981), who showed fungal biomass to be more recalcitrant than bacteria. Fungal biomass, with a higher proportion of cell wall material than that of bacteria, mineralizes slower and therefore retains nitrogen in an organic form longer than bacteria. Increased fungal biomass appears to increase nitrogen immobilization and decrease the rate of mineralization.

Planted native perennial seedlings benefited from the addition of recalcitrant organic amendment. The survival rate of seedlings in bark amended plots was almost double that of control plot seedlings. Such a dramatic difference in seedling survival might be the result in part of an improved microclimate, because increased water retention and temperature moderation were observed. We suggest that the improved plant growth in bark-amended plots over control plots was likely a result of the increase in microbial activity and nitrogen immobilization causing a reduction in competition with exotic weeds. Exotic annuals are highly plastic and, in nitrogen fertilization experiments in coastal sage, responded to high nitrogen inputs. Native shrubs, on the other hand, did not respond as well to elevated concentrations of nutrients (Allen et al. 1996). By reducing the availability of nitrogen through immobilization, bark amendments establish an environment more conducive to native perennial shrubs, allowing them to outcompete the exotic annuals for water and nutrients. Such a connection between increased plant growth and the chemical and biological changes occurring in amended soils concurs with several previous studies (Schuman & Sedbrook 1984; Smith et al. 1985, 1986).

Whitford et al. (1988) described the value of bark as an organic amendment to restore stable decomposition and mineralization and to provide the desired slow release of energy for microflora. He emphasized that organic matter is the key to stable microbial activity in arid and semiarid ecosystems. Several other studies have also confirmed that the addition of recalcitrant organic matter to disturbed soil results in higher rates of decomposition and mineralization through the development of soil microorganisms comparable to those of undisturbed systems (Elkins et al. 1984; Ingham et al. 1985; Smith et al. 1986; Schuman & Belden 1991). Though there have been studies of the nitrogen cycle of several California ecosystems (Bartolome 1979; Jackson & Roy 1986; Jackson et al. 1988; Davidson et al. 1990; Hart et al. 1993), little research on the effects of organic matter amendments has been performed in southern California, and no literature could be found on the effect of recalcitrant organic matter on soil fungi in this area. Southern California's coastal sage habitat consists mainly of perennial shrubs that steadily produce litter with a relatively high lignin content throughout most of the year (Woodmansee & Duncan 1980). Such recalcitrant litter is slow to decompose and leads to immobilization of nitrogen, which is subsequently released slowly over time. Thus, native habitats in arid and semiarid regions are usually poor in available nitrogen (Whitford 1986).

It appears that the addition of organic amendments, such as bark or straw, affects the nitrogen cycle on disturbed lands by increasing the immobilization of nitrogen through increasing microbial activity. This would effectively slow the release of available nitrogen necessary to support the quick nutrient turnaround required by exotic annuals and could be a significant factor in providing a competitive edge to native perennials. This simple procedure could have major implications for enhancing the restoration of disturbed lands.

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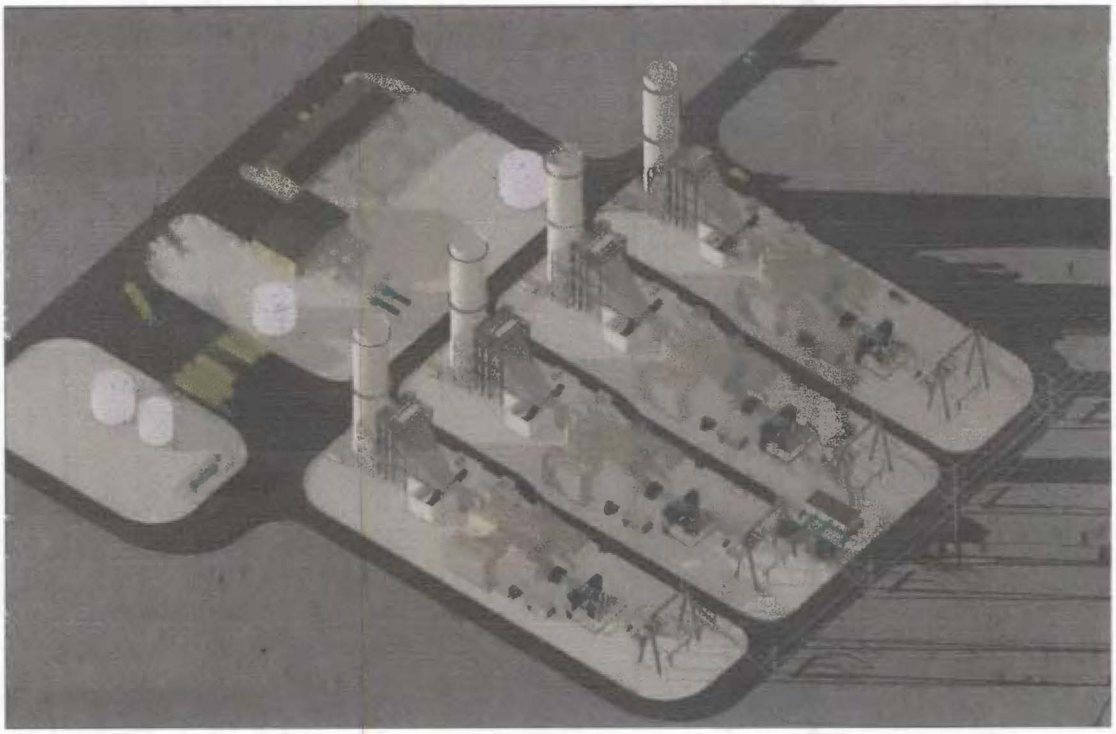
MARSH LANDING GENERATING STATION

Revised Staff Assessment



CALIFORNIA
ENERGY COMMISSION
Arnold Schwarzenegger, Governor

JUNE 2010
CEC-700-2010-010 REV

DOCKET NUMBER 08-AFC-03

surfaces; therefore the amount of stormwater discharge is expected to be the same or less than under existing conditions (URS 2008a). Impacts to the San Joaquin River would not occur. For a complete analysis of water quality impacts, refer to the **Soil and Water Resources** section of this Revised Staff Assessment.

Air Emissions – Nitrogen Deposition

Nitrogen deposition is the input of nitrogen oxide (NO_x) and ammonia (NH_3) derived pollutants from the atmosphere to the biosphere. Mechanisms by which nitrogen deposition can lead to impacts on sensitive species include direct toxicity, changes in species composition among native plants, and enhancement of invasive species (Fenn et al 2003; Weiss 2006a). The increased dominance and growth of invasive annual grasses is especially prevalent in low-biomass vegetation communities that are naturally nitrogen-limited, such as coastal sage scrub, serpentine grassland, desert scrub, and sand dunes (Weiss 2006a).

The Antioch Dunes National Wildlife Refuge (NWR), which is approximately 0.75-mile west of the MLGS site, was once part of an expansive aeolian (wind-blown) dune system along the shoreline of the San Joaquin River. Established in 1980, the Antioch Dunes NWR comprise 67 acres in two disjunct units (Sardis Unit and Stamms Unit) and supports the last known natural populations of the federally endangered Lange's metalmark butterfly, federally and state endangered Antioch Dunes evening primrose, and federally and state endangered Contra Costa wallflower (USFWS 2001b). Antioch Dunes evening primrose, Contra Costa wallflower, and naked-stemmed buckwheat, the larval host plant of Lange's metalmark butterfly, require open sandy substrate for survival. Annual survey data collected from 1984 to 2009 shows that the populations of these endangered species are generally in decline and largely sustained by artificial propagation and transplantation (USFWS 2009a; USFWS 2009b; Euing 2010).

Noxious weeds (e.g., yellow starthistle, winter vetch, and ripgut brome) are the greatest threat to the endangered species at the Antioch Dunes NWR (USFWS 2001b; USFWS 2009a; USFWS 2009b). Invasive, non-native vegetation affects Antioch Dunes evening primrose, Contra Costa wallflower, and naked-stemmed buckwheat by out-competing them for space, sunlight, moisture, and nutrients as well as increasing fuel loads (Pavlick and Manning 1993). A soil evaluation conducted for the Antioch Dunes NWR found that Antioch Dunes evening primrose, Contra Costa wallflower, and naked-stemmed buckwheat are more competitive growing in or better adapted to less-fertile soils or areas of low-percent vegetative cover (Jones and Stokes 2000). Despite significant efforts in 2006, 2007, 2008, and 2009 to manage invasive weeds, populations continue to thrive throughout the refuge (USFWS 2009a; USFWS 2009b).

Excessive nitrogen deposition is strongly correlated with the growth of non-native vegetation (Huenneke et al 1990; Inouye and Tilman 1995; Weiss 1999; Bowman and Steltzer 1998; Brooks 2003) and field studies have found that nitrogen fertilization in sites with elevated nitrogen deposition will enhance grass invasion (Rillig et al 1998; Brooks 2003). Several recent studies have attempted to quantify the critical load or rate at which nitrogen deposition begins to result in adverse effects to nitrogen-sensitive ecosystems. Studies in the United Kingdom suggest that the critical load ranges from 10 to 20 kilograms of nitrogen per hectare per year (kg/ha/yr) for mobile and fixed sand dune ecosystems (Jones et. al. 2004; Plassmann, et. al. 2009). Fenn et. al. (2003) counter that estimated nitrogen deposition thresholds for ecological effects for other geographic regions are frequently not applicable to the western United States. Research conducted in the South San Francisco Bay area on grasslands in nutrient-poor serpentinic soils indicates that intensified annual grass invasions can occur in areas with nitrogen deposition levels of 11 to 20 kg/ha/yr, with relatively limited invasions at levels of 4 to 5 kg/ha/yr (Weiss 2006b). In previous northern California power plant cases licensed by the Energy Commission (e.g., CEC 2007) as well as a California-wide study of nitrogen deposition (Weiss 2006a), 5 kg/ha/yr was used as a benchmark for analyzing nitrogen deposition impacts to plant communities (CEC 2007); this benchmark was also used as the significance threshold in the applicant's nitrogen deposition impact analysis (URS 2010, Data Response #99).

An Energy Commission Public Interest Energy Research study modeled total nitrogen deposition throughout California (Tonneson et. al. 2007); results showed that most of California experiences elevated rates of annual nitrogen deposition, especially near urban areas. In the area encompassing the Antioch Dunes NWR, the baseline nitrogen deposition rate is estimated to be approximately 6.39 kg/ha/yr (Tonneson et. al. 2007). Although this estimate was produced using 2002 data, it is believed to be the most comprehensive and accurate data set available. Advances in emission control technology and offsets for stationary sources have resulted in a decrease of NOx emissions (BAAQMD 2010a). However, given the increase in vehicle transportation activity, emissions controls that cause NH3, and use of synthetic fertilizers, NH3 emissions in the region could be increasing over time, although there is no formal inventory or prediction of long-term trends (BAAQMD 2009; BAAQMD 2010b). Therefore, without updated modeling at a similar scale (4 km^2 grid), it is difficult to determine whether this baseline level of nitrogen deposition has changed substantially since 2002.[1]

According to the applicant's response to data request #99 (URS 2010a) and as recently updated by the applicant (URS 2010b), modeled nitrogen deposition rates from MLGS at the Antioch Dunes NWR would be between 0.0307 and 0.0447 kg/ha/yr. In combination with background levels, the maximum direct nitrogen deposition rate at Antioch Dunes NWR would be approximately 6.4347 kg/ha/yr. Threats to the endangered species at the Antioch dunes from noxious weeds are likely exacerbated by nitrogen fertilization; therefore, additional nitrogen deposition at this already stressed ecosystem would be a significant impact.

Staff's proposed mitigation approach requires the applicant to remit annual payment towards the operation and maintenance cost of the Antioch Dunes NWR. The annual operating cost is approximately $385,000 and includes money for non-native plant removal/fire prevention, sand acquisition, grazing management, butterfly propagation, and rare plant propagation (Picco 2009). Contributing payment would partially fund the management activities required to address impacts to the Antioch Dunes NWR from the effects of noxious weed proliferation resulting from nitrogen deposition.

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[1] In data response #60 (URS 2009d), the applicant estimated the baseline nitrogen deposition rate to be 1.63 kg/ha/yr. These data were collected from a monitoring station in Davis, California, approximately 40 miles north of the proposed project area. This baseline estimate included inorganic wet deposition from nitrate and ammonium. It did not estimate **total** nitrogen, which also includes **dry deposition** (a significant proportion of total nitrogen (see Weiss 1999, Tonneson 2007, and Fenn et. al. 2003) and **all the nitrogen species** (i.e., HNO_3, NH_3, NO, NO_2, N_2O_5, PAN, and aerosol ammonium nitrate [NH_4NO_3]).

It is understood that emissions from the proposed MLGS project would not be the only source of nitrogen deposition at Antioch Dunes NWR. There are existing industrial stationary sources as well as mobile sources (i.e., transportation) in the San Francisco Bay area that have collectively elevated local and regional nitrogen deposition. Accordingly, staff proposes that the applicant's payment toward the operating cost of Antioch Dunes NRW be proportional to the proposed project's contribution toward total nitrogen deposition at Antioch Dunes NWR. The following equation was developed by staff to calculate the amount of mitigation that would be proportional to the project's contribution to ongoing impacts. Refer also to Condition of Certification **BIO-8** (Antioch Dunes National Wildlife Refuge Funding).

(MLGS N-dep at ADNWR / baseline N-dep at ADNWR) x annual operating cost of ADNWR = mitigation $/year

(0.0447 kg/ha/yr/6.3947 kg/ha/yr) x $385,000 = $2,693.00/year

It is staff's determination that annual payment toward the operating cost of Antioch Dunes NWR that is proportional to the MLGS project's contribution to cumulative total nitrogen deposition (as calculated using the above equation and described in **BIO-8**) would mitigate adverse impacts to Antioch Dunes NWR and the Antioch Dunes evening primrose, Contra Costa wallflower, and Lange's metalmark butterfly from noxious weed proliferation exacerbated by MLGS nitrogen deposition.

It should be noted that the Applicant retains sufficient certificates to offset the MLGS project's NO_x emissions (BAAQMD 2010b; refer also to the **Air Quality** section of this Revised Staff Assessment for additional information). However, for the following reasons, these offsets would not sufficiently mitigate indirect impacts from nitrogen deposition at the Antioch Dunes NWR:

- Precursor organic compounds (POC) offsets may be used to offset emission increases of NO_x (BAAQMD 2010b, Regulation 2-2-302.2). POCs do not pertain to nitrogen deposition.
- Available offsets are temporally and spatially variable and therefore would not directly ameliorate the current nitrogen deposition at the Antioch Dunes NWR in particular.
- The NO_x offsets do not address NH_3, which is a substantial contributor to total nitrogen deposition.

CUMULATIVE IMPACTS

"Cumulative" impacts refer to a proposed project's incremental effect viewed over time together with other closely related past and present projects and projects in the reasonably foreseeable future whose impacts may compound or increase the incremental effect of the proposed project (Public Resources Code Section 21083; California Code of Regulations., Title 14, Sections 15064[h], 15065[c], 15130, and 15355).

The cumulative scenario for biological resources includes past, present and reasonably foreseeable future projects with emissions that contribute to nitrogen deposition at

Antioch Dunes NWR. These projects include the Willow Pass Generating Station (proposed), Oakley Generating Station (proposed), Contra Costa Power Plant (existing), Gateway Generating Station (existing), Pittsburg Power Plant (existing), as well as several other existing and proposed industrial stationary sources (e.g., manufacturing facilities).

The Antioch Dunes NWR is the first and only refuge in the United States established to protect endangered plants and insects (USFWS 2001b). The 67-acre NWR is an isolated patch of a formerly expansive and biologically diverse dune system. The federally endangered Lange's metalmark butterfly, federally and state endangered Antioch Dunes evening primrose, and federally and state endangered Contra Costa wallflower are only known from this location and their numbers are in decline. Given the low population numbers and isolated geographic area, the endangered species at the Antioch Dunes NWR are extremely vulnerable to environmental change and stochastic events. The largest threat to these species is noxious weed invasion and the resultant cascading effects (e.g., competition, wildfires). As described above, noxious weed invasion is facilitated by nitrogen deposition, which is a result of the emissions of many mobile and stationary sources within the region.

The proposed MLGS project when considered with the aforementioned past, present, and reasonably foreseeable future projects would contribute to nitrogen deposition at Antioch Dunes NWR, thereby exacerbating cumulative impacts to the federally endangered Lange's metalmark butterfly, federally and state endangered Antioch Dunes evening primrose, and federally and state endangered Contra Costa wallflower. However, adequate payment toward the operating cost of Antioch Dunes NWR to partially fund management activities (as described in **BIO-8**) would mitigate impacts resulting from MLGS nitrogen deposition at the NWR, thereby eliminating the proposed project's contribution to cumulatively considerable effects.

COMPLIANCE WITH LORS

The proposed project must comply with state and federal LORS that address state and federally listed species, as well as other sensitive species and their habitats. Applicable LORS are presented in **BIOLOGICAL RESOURCES Table 1**. Direct impacts to biological resources are largely avoided, and accordingly most applicable LORS complied with, because the proposed project is sited in a highly industrialized, disturbed location within the existing CCPP. LORS compliance issues for indirect effects of the proposed project are discussed below.

ENDANGERED SPECIES ACT (ESA; 16 USC SECTION 1531 ET SEQ.)

Potential take of federally-listed species (i.e., federally endangered Lange's metalmark butterfly, federally endangered Antioch Dunes evening primrose, and federally endangered Contra Costa wallflower) at the Antioch Dunes NWR, which is federal land, requires compliance with the federal Endangered Species Act (ESA). The definition of "take" under ESA section 3(19) includes "harm". Harm is further defined by USFWS to include "significant habitat modification or degradation that results in death or injury to listed species by significantly impairing behavioral patters such as breeding, feeding, or sheltering" (50 CFR section 17.3). It is staff's opinion that the proposed project's relatively small incremental contribution to cumulative nitrogen deposition and the resultant habitat degradation at Antioch Dunes NWR would not result in harm, as described above. Therefore, it is staff's determination that the proposed project would comply with the federal ESA.

CALIFORNIA ENDANGERED SPECIES ACT (FISH AND GAME CODE SECTION 2050 ET SEQ.)

The California Endangered Species Act (CESA) prohibits the "take" (defined as "to hunt, pursue, catch, capture, or kill") of state-listed species (i.e., state-endangered Antioch Dunes evening primrose, and state-endangered Contra Costa wallflower). It is staff's opinion that the proposed project's relatively small incremental contribution to cumulative nitrogen deposition and the resultant habitat degradation at Antioch Dunes NWR would not result in take, as defined above. Therefore, it is staff's determination that the proposed project would comply with CESA.

NOTEWORTHY PUBLIC BENEFITS

The proposed MLGS would facilitate the replacement of the existing CCPP, which consists of the remaining operating Units 6 and 7. Mirant Delta, LLC, the owner of the CCPP, has agreed (subject to regulatory approval) to shut down and retire the CCPP as of midnight on April 30, 2013, which is just before MLGS is scheduled to commence commercial operation. Retirement of CCPP would eliminate its use of once-through cooling, which draws cooling water from the San Joaquin River and then discharges it back into the river after use. The resulting elimination of impingement and entrainment of aquatic organisms as well as the reduction in thermal pollution from discharge water into the San Joaquin River is a noteworthy environmental public benefit.

RESPONSES TO COMMENTS

Staff received comments on the Biological Resources section of the Staff Assessment for the proposed MLGS Project from CDFG. CDFG's comment and staff's response are provided below.

California Department of Fish and Game
May 27, 2010 (CDFG 2010b)

Comment: "We agree that the applicant should contribute funds to the Antioch Dunes National Wildlife Refuge to offset the effects of nitrogen deposition resulting from the project. However, we believe that the calculation used to determine the annual fee was incorrect. The fee was based on the existing management costs rather than future management costs. As nitrogen deposition occurs, management costs at the Refuge associated with invasive species control will increase substantially over time. Moreover, the fee assumed by the CEC does not account for annual inflation. Thus, the proposed fee does not meet DFG's definition of full mitigation for impacts on sensitive and listed species. Please consult with Refuge staff and DFG, and adjust the fee accordingly."

> **Response:** The Antioch Dunes NWR annual management cost that was used to calculate the payment required to offset the MLGS project's effects of nitrogen

deposition was provided to staff by USFWS in consultation with NWR staff. Based on recent discussions with CDFG, staff's understands that CDFG is working further with USFWS to identify a management cost (and assumptions) that accounts for future increases in management costs, but would not require annual recalculation of the amount of payment required per Condition of Certification **BIO-8**. This information was unavailable at the time of RSA publication, but may be provided by CDFG; staff will consider adjusting its analysis accordingly and provide supplemental testimony prior to the evidentiary hearings, if necessary.

Condition of Certification **BIO-8** requires each annual payment to be adjusted for inflation in accordance with the Employment Cost Index – West or its successor, as reported by the U.S. Department of Labor's Bureau of Labor Statistics.

CONCLUSIONS

Impacts to biological resources would be largely avoided because the proposed power plant site, construction laydown areas, and routes of proposed linear facilities (i.e., transmission, water, and natural gas) are highly disturbed or developed and surrounded by heavy industrial uses including the Contra Costa Power Plant and the Gateway Generating Station. The potential for the project area to support sensitive biological resources is low; the immediate vicinity supports wildlife that are likely habituated to frequent disturbance. With implementation of applicant-proposed avoidance and minimization measures and staff's proposed conditions of certification, direct impacts to biological resources would be less than significant.

Indirect impacts to the Antioch Dunes National Wildlife Refuge (NWR) would result from nitrogen deposition caused by MLGS emissions. The Antioch Dunes NWR, comprises 67 acres of remnant sand dunes, which contain the last known populations of the federally endangered Lange's metalmark butterfly, federally and state endangered Antioch Dunes evening primrose, and federally and state endangered Contra Costa wallflower. The greatest threat to these listed species is noxious weed invasion and the resultant cascading effects (e.g., competition, wildfire). Noxious weed proliferation is exacerbated by nitrogen deposition. Emissions from the proposed project would deposit a maximum of approximately 0.04 kilograms per hectare per year (kg/ha/yr) of nitrogen at the Antioch Dunes NWR. Additional nitrogen deposition at this already stressed ecosystem would be a significant impact.

It is staff's determination that annual payment toward the operating cost of Antioch Dunes NWR that is proportional to the MLGS project's contribution to cumulative total nitrogen deposition (as described in **BIO-8**) would mitigate adverse impacts to Antioch Dunes NWR and the Antioch Dunes evening primrose, Contra Costa wallflower, and Lange's metalmark butterfly from noxious weed proliferation exacerbated by MLGS nitrogen deposition to less than significant.

In summary, staff concludes that the proposed project would be consistent with the applicable laws, ordinances, regulations, and standards (LORS) pertaining protection of biological resources and with implementation of staff's proposed conditions of

Arnold Schwarzenegger
Governor

IMPACTS OF NITROGEN DEPOSITION ON CALIFORNIA ECOSYSTEMS AND BIODIVERSITY

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
Bren School of Environmental Science and Policy, University of California, Santa Barbara
Creekside Center for Earth Observations

May 2006
CEC-500-2005-165

PUBLIC INTEREST ENERGY RESEARCH
"Research Powers the Future"

Prepared By:
Stuart B. Weiss

Bren School of Environmental Science and Policy
University of California, Santa Barbara
Santa Barbara, California

Creekside Center for Earth Observations
27 Bishop Lane
Menlo Park, California 94025

Contract No. 500-99-013
Work Authorization 61

Prepared For:
California Energy Commission
Public Interest Energy Research (PIER) Program

Linda Spiegel,
Contract Manager

Kelly Birkinshaw,
Program Area Team Lead

Martha Krebs, Ph.D.
Acting Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

B. B. Blevins
Executive Director

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Please cite this report as follows:

Weiss, S. B. 2006. *Impacts of Nitrogen Deposition on California Ecosystems and Biodiversity.* California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2005-165.

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.
PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

What follows is the final report for the contract Assessment of Nitrogen Deposition: Modeling and Habitat Assessment, contract number 500-99-013, Work Authorization 61, conducted by the Bren School of Environmental Science and Policy at the University of California Santa Barbara, and the Creekside Center for the Earth Observations. The report is entitled *Impacts of Nitrogen Deposition on California Ecosystems and Biodiversity*. This project contributes to the Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

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Abstract

Recognized as a "biodiversity hotspot," California supports numerous endemic taxa with narrow ranges, and that diversity may be threatened by atmospheric nitrogen deposition. This California-wide risk screening included: (1) a 36 x 36 kilometer (km) map of total Nitrogen (N)-deposition for 2002, developed from the Community Multiscale Air Quality Model (CMAQ); (2) identification of sensitive habitats; (3) an overlay of the Forest Resource and Protection (FRAP) vegetation map; (4) an overlay of animal and plant species occurrence data from the California Natural Diversity Data Base (CNDDB); (5) an initial analysis of species life history and habitat; and (6) a discussion of relevance and guidance for assessments of power plant impacts. An area of 55,000 square kilometers (km^2) of California is exposed to more than 5 kilograms of N per hectare per year (kg-N ha^{-1} $year^{-1}$), and 10,000 km^2 are exposed to more than 10 kg-N ha^{-1} $year^{-1}$. Deposition hotspots include: Los Angeles-San Diego, the San Francisco Bay Area, the Central Valley, and the Sierra Nevada foothills. The major documented impact of N-deposition on California terrestrial biodiversity is to increase invasive annual grasses in low biomass ecosystems, resulting in species loss. Of 225 "threatened" and "endangered" plant taxa, 99 are exposed to an average > 5 kg-N ha^{-1} $year^{-1}$. Of 1022 "rare" plant taxa, 290 are exposed to > 5 kg-N ha^{-1} $year^{-1}$. Listed animal species follow similar patterns. This initial screening outlines potential impacts on California's biodiversity and provides targeted guidance for assessing the impacts of power plant and other sources of atmospheric N-deposition.

Keywords: nitrogen deposition, biodiversity, California, annual grasses, invasive species, deserts, grasslands, threatened and endangered species, eutrophication

Executive Summary

Introduction

Atmospheric nitrogen deposition alters the structure and function of terrestrial ecosystems, because nitrogen is often a primary limiting nutrient on overall productivity. These alterations can drive losses of biodiversity, as nitrophilous species increase in abundance and outcompete species adapted to more oligotrophic conditions. California is recognized as a "biodiversity hotspot," with a high fraction of endemic taxa with narrow ranges, and many of those taxa may be at risk from atmospheric nitrogen deposition.

Project Objectives

The California Energy Commission's Public Interest Energy Research (PIER) program funded a project to investigate the potential scope of nitrogen deposition (N-deposition) risks to biodiversity in California. This statewide risk screening includes the following elements: (1) identification of sensitive habitat types, as documented by literature and local expertise; (2) a 36 x 36 kilometer (km) map of total N-deposition for 2002, developed from the Community Multiscale Air Quality Model (CMAQ); (3) an overlay of a statewide Forest Resource and Protection (FRAP) vegetation map; (4) an overlay of animal and plant species occurrence data from the California Natural Diversity Data Base (CNDDB); (5) a compilation of life history and habitat requirements for each species; and (6) a discussion of relevance and guidance for assessments of power plant impacts over which the Energy Commission has regulatory authority.

Project Outcomes

The major documented impact of N-deposition on California terrestrial biodiversity is to increase growth and dominance of invasive annual grasses in low biomass ecosystems such as coastal sage scrub, serpentine grassland, and desert scrub. Lichen communities may be altered. Vernal pools and sand dunes are vulnerable to annual grass invasions that are likely enhanced by N-deposition. Oligotrophic mountain lakes are also vulnerable.

Conclusions

The CMAQ model indicates that an area of 55,000 square kilometers (km^2) (out of California's total area of 405,205 km^2) are exposed to more than 5 kilograms of N per hectare per year (kg-N ha^{-1} year $^{-1}$),[1] and 10,000 km^2 are exposed to more than 10 kg-N ha^{-1} year^{-1}. Deposition hotspots include the major urban areas (Los Angeles-San Diego, and the San Francisco Bay Area), agricultural areas of the Central Valley, and portions of the Sierra Nevada foothills. Exposure of 48 different FRAP vegetation types were calculated. For example, 800 km^2 out of a total 6300 km^2 of coastal sage scrub are exposed to more than 10 kg-N ha^{-1} year^{-1}, primarily in Southern California.

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[1] Throughout the discussion of N-deposition exposure, a benchmark of 5 kg-N ha^{-1} yr^{-1} is used. This benchmark does not imply that 5 kg-N ha^{-1} yr^{-1} is the critical load for negative impacts for all ecosystems—some may be more sensitive and some may be less sensitive. Data are presented so that any benchmark can be used.

In contrast, many high elevation (> 1500-meter) montane vegetation types are minimally exposed, because they are far from pollution sources, except for localized occurrences in mountains surrounding the Los Angeles Basin. Of 225 federal and state listed "threatened" and "endangered" plant taxa, 101 are exposed to an average greater than 5 kg-N ha^{-1} $year^{-1}$. Of an additional 1022 plant taxa listed as "rare," 288 are exposed to greater than 5 kg-N ha^{-1} $year^{-1}$. Many of these highly exposed taxa are associated with sensitive habitat types and are vulnerable to annual grass invasions. The CNDDB was not of sufficient resolution or completeness to support finer-scale regional analyses. This initial, broad-scale screening indicates that N-deposition poses large potential impacts on California's unique biodiversity.

Recommendations

1. Based on the review and broad-scale screening in this report, nitrogen deposition impacts on ecosystems and species are extensive in California, and should be considered in local environmental assessments.
2. The impacts of N-deposition on California ecosystems are generally cumulative. Establishing critical cumulative loads for particular ecosystems is a research priority.
3. Local environmental assessments should initially focus on low biomass, nutrient poor habitats and the rare species they support, but also consider more general impacts. The state-wide information in this report provides a start, but is not sufficient for local use.
4. Increased invasions by introduced annual grasses and other weeds are the major threat to consider in mitigation. Finding a balance between habitat acquisition, habitat management, and weed management that effectively mitigates the incremental impacts of new power plant sources is a key goal.
5. Establishing reliable bioindicators along N-deposition gradients, such as changes in lichen communities, plant nutrient balances, and degree of weed invasions, will provide better spatial resolution of ecosystem effects.
6. The complexity of N-deposition forces a transdisciplinary approach to any research program.

Benefits to California

Nitrogen deposition is a growing threat to the biodiversity of California. This report is the first statewide analysis of exposure of ecosystems and special-status species to N-deposition, and provides the basis for systematic assessment of threats to specific ecosystems, and development of mitigation and management techniques. Along with an accompanying report on modeling by Tonnesen and Wang, this report provides regulatory guidance for impact assessments of new power plants. The report will provide an impetus for additional research for better understanding this complex phenomenon.

1.0 Introduction

Atmospheric nitrogen deposition has been demonstrated to alter terrestrial and aquatic ecosystem function, structure, and composition in many parts of the world, including Europe, Eastern North America, and Western North America (Galloway, Aber et al. 2003). Emissions, deposition, and N-cycling are highly complex processes and pose many scientific and policy challenges. The major purpose of this report is to examine the known and potential impacts of N-deposition on the varied ecosystems and species in California, using biogeographic data and modeled N-deposition.

Nitrogenous air pollutants have many sources, including transportation, agriculture, industry, electricity generation, wildfire, and emissions from natural and semi-natural ecosystems. Electric power plants in California, primarily fired by natural gas, are major point sources of nitrogen oxides (NO_x) from combustion, and ammonia (NH_3) from selective catalytic reduction (SCR) units used to control NO_x emissions. The California Energy Commission (Energy Commission), in conjunction with other regulatory agencies, is responsible for assessment of environmental impacts from energy-related developments and activities, including siting of new power plants.

Biology staff at the Energy Commission analyzed potential impacts from nitrogen deposition on several power plant licensing cases (Table 1, California Energy Commission 2003, 2001a, 2001b, 1997a, 1997b). These power plants were located in areas where nitrogen deposition impacts to nitrogen-poor, sensitive plant communities are an issue. Such communities are often rare and support many of California's rare and endangered plant and animal species. It is expected that future siting cases may need to review the impact of a power plant emissions on nitrogen-saturated or nitrogen-limited ecosystems. Nitrogen saturation has several detrimental effects, including decreased plant function as a result of leached nutrients (e.g., calcium) from the soil; loss of fine root biomass; decreases in symbiotic mycorrhizal fungi; promotion of exotic invasive species; and, leaching losses of base cations and nitrate into surface waters and ground waters, which increases soil and surface water acidification.

Table 1. California power plant licensing cases

Name	County
Metcalf Energy Center	Santa Clara
Los Esteros Critical Energy Facility	Santa Clara
Gilroy Peaker Plant	Santa Clara
Pico (Donald Von Raesfeld)	Santa Clara
Otay Mesa	San Diego
Sutter	Sutter

The PIER program funded a project to address these issues. The scope of work specifies four broad tasks: (1) a critical review of various air quality models used to determine power plant emissions of nitrogen (nitrogen oxide (NO), nitrogen dioxide (NO_2), and NH_3) concentration, release rate, dispersion, and deposition at ground level; (2) a chemical analysis of power plant plume characteristics including reaction rate from gas to particulate; (3) an assessment of nitrogen-limited habitats that could be at higher risk from further nitrogen deposition, and (4) location of nitrogen-saturated soils/ecosystems in California. Generally, the Energy Commission is interested in assessing impacts to terrestrial ecosystems from nitrogen deposition during power plant commissioning and operation and understanding the validity, strengths and weaknesses of models used to determine this impact. Specifically, the interest is in the short-distance and long-distance nitrogen deposition impacts to nitrogen-limited habitats and species dependent upon those habitats.

The project was awarded to the University of California, Santa Barbara (UCSB) (Dr. Frank Davis P.I.) and the University of California, Riverside (UCR) (CE-CERT, Dr. Gail Tonnesen P.I). This report presents investigations by UCSB into the biotic impacts of N-deposition (topics 3 and 4). Modeling reviews and assessments (topics 1 and 2) are the subject of an accompanying report by the UCR group (Tonnesen and Wang forthcoming).

Apart from this introduction, this biotic impacts report consists of four sections. Section 2 contains a review of existing information and research on N-cycling and the effects of N-deposition on ecosystems in general and California ecosystems in particular. Section 3 describes the spatial distribution of total N-deposition in California at 36 x 36 kilometer (km) scale, using the Community Multiscale Air Quality model (CMAQ) , and the exposure of vegetation types from the Fire and Resource Assessment Program (FRAP) map. Section 4 describes the N-deposition exposure of plant and animal species from the California Natural Diversity Data Base (CNDDB), along with relevant habitat and life history information of those species with higher exposure. Section 5 provides a synthesis and recommendations for further research.

2.0 Review

This review of existing information and research on the effects of nitrogen deposition on sensitive habitats in California draws heavily from a number of edited volumes and review papers regarding multiple aspects of N-deposition (and air pollution in general) in ecosystems (Langran 1999; Bell and Treshow 2002; Bytnerowicz, Arbaugh, et al. 2003), and especially from recent review work of N-deposition and ecological effects in Western North America (Fenn, Baron et al. 2003; Fenn; Haeuber et al. 2003). Interested readers should consult those works for extensive bibliographies of primary research, as there are hundreds of scientific papers dealing with various aspects of N-deposition.

This review will describe key processes in the nitrogen cycle, N-limitations in California terrestrial and aquatic ecosystems, effects of chronic deposition on N-cycling, and mechanisms by which N-deposition can lead to impacts on sensitive species, including direct toxicity, changes in species composition, and enhancement of invasive species. Ecosystems and habitats that are known to be and suspected to be sensitive to N-deposition are listed and specific mechanisms are briefly discussed as background for the biogeographic screening of habitats and species.

2.1. The Nitrogen Cycle

A basic understanding of the nitrogen cycle is essential background for assessing N-deposition impacts on ecosystems. The intricacies of the N-cycle involve diverse plants, animals, fungi, and bacteria interacting in complex aboveground and belowground environments (Schlesinger 1997), and a full discussion is well beyond the scope of this review. Figure 1 outlines key elements of the N-cycle that are relevant to this review.

Nitrogen (N_2) is the most abundant gas in the atmosphere (78%), but the strong triple bond is difficult to break and the gas is relatively inert. Reactive N (N_r) that can be directly used by organisms includes oxidized and reduced inorganic N and numerous forms of organic N. Inputs of N_r to ecosystems include biological N-fixation and atmospheric deposition. Atmospheric N_2 is directly available only to plants with N-fixing symbiotic bacteria. N-fixing plants in California include the Fabaceae (legumes), several genera in the Rosaceae, the genus *Ceanothus* (Rhamnaceae), and alders (Betulaceae). N-fixing cyanolichens are prominent in many ecosystems. Free-living cyanobacteria such as *Nostoc* are present in most ecosystems, and can be abundant in cryptobiotic crusts in deserts. N-fixation can vary from < 1 kg-N ha^{-1} yr^{-1} in habitats that are poor in N-fixers to > 100 kg-N ha^{-1} yr^{-1} in stands of alders, and other N-fixing trees and shrubs.

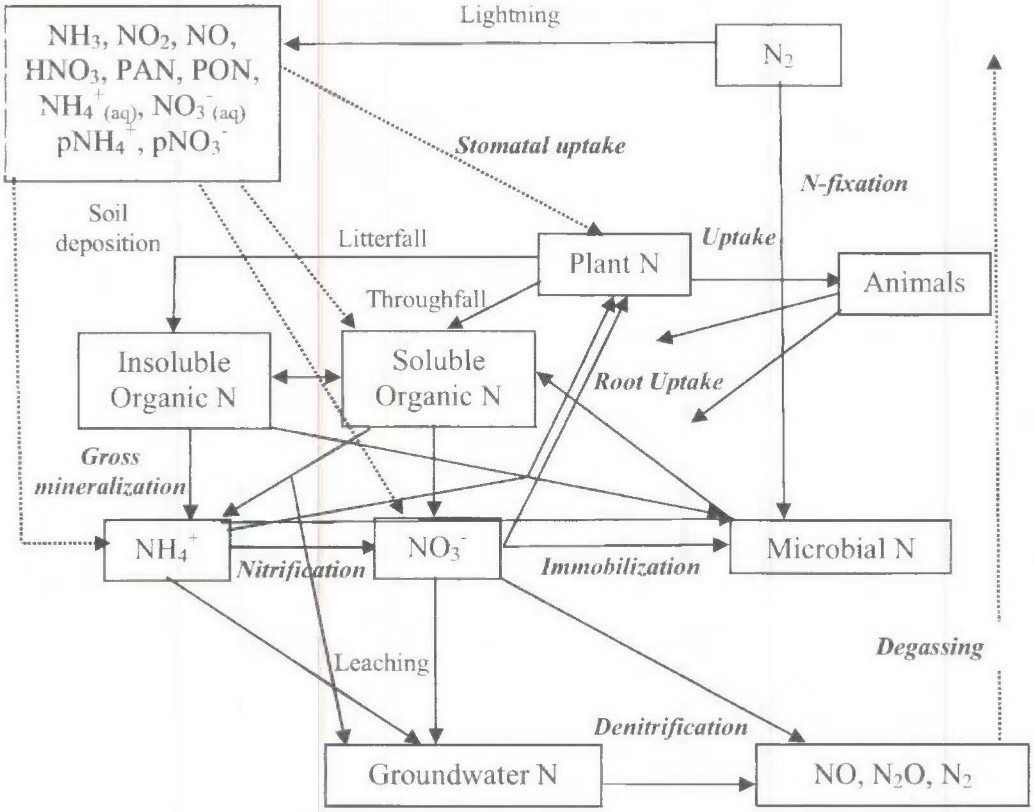


Figure 1. The N-cycle simplified. Biological processes are labeled in bold italics, and the lighter arrows show deposition pathways.

Natural background wet and dry atmospheric deposition originates from NO_x fixed by lightning, marine aerosols, N volatilized by fire, and N_r gases emitted from ecosystems. Large-scale combustion of fossil fuels, fertilizer applications, emissions from livestock, and other sources have greatly increased atmospheric deposition rates. Preindustrial atmospheric deposition in the western United States is estimated at 0.25 kg-N ha^{-1} yr^{-1}; elsewhere, approximate preindustrial background is ~1 kg-N ha^{-1} yr^{-1} (Fenn, Haeuber et al. 2003; Galloway, Aber et al. 2003). Very localized deposition originating from seabird colonies or other animal aggregations may be much higher, but those are exceptional situations. Atmospheric deposition enters ecosystems directly as wet deposition in precipitation and cloudwater, and as dry deposition to surfaces and through plant stomata. The significance of deposition pathways will be discussed below when considering the impacts of elevated deposition.

Most available N in terrestrial ecosystems is provided by decomposition of organic matter, known as *N-mineralization.* Most N is in the soil organic matter pool. Surface litter and larger woody debris decompose in a complex series of steps driven by a diverse array of detritovores (e.g., arthropods, nematodes, and other soil fauna), and ultimately by bacteria and fungi that mineralize organic nitrogen to ammonium (NH_4^+). While microbial biomass may be a small component of soil organic matter, microbial biomass is the key component through which a large portion of N is processed. The depolymerization of proteins into amino acids is a key step in N-availability, and amino acids may be taken up directly by microbes and plants—organic N in soils is difficult to study and relatively poorly understood (J. Schimel, pers. comm.). Turnover of fine roots also contributes to organic matter. Decomposition and mineralization rates generally increase with temperature, and show a hump-shaped relationship with moisture—slow in dry soils, faster up to an optimal moisture level, and slower in waterlogged soils. Either temperature or moisture may be seasonally limiting. The rate of litter decomposition, even under ideal temperature and moisture conditions, is affected by the litter carbon-to-nitrogen (C:N) ratio—high C:N litter generally decomposes more slowly than low C:N litter, although excess N in litter can slow decomposition as well. The coniferous and sclerophyllous evergreen species characteristic of many California ecosystems tend to produce high C:N litter, deciduous trees generally produce lower C:N litter. Many annual grasses produce lower C:N litter. Litter quality provides a major biogeochemical feedback and control over N-cycling, and mediates ecosystem response to increased atmospheric deposition.

The total amount of NH_4^+ released in decomposition is termed *gross mineralization.* Much of the gross mineralization is quickly immobilized as it is incorporated into microbial biomass. The remainder of potentially plant available NH_4^+ is referred to as *net mineralization.* Additions of readily available carbon (sugars, for example) can greatly increase immobilization rates and reduce net mineralization. NH_4^+ is readily adsorbed onto soil cation exchange sites, hence, it is relatively immobile and not prone to leaching. In high pH soils under dry conditions, NH_4^+ can be volatilized into NH_3 gas and lost to the atmosphere.

NH_4^+ is oxidized to nitrate (NO_3^-) by microbes in the process of nitrification. In coarse-textured soils in California, nitrification rates are relatively high and systems tend to be dominated by NO_3^- as opposed to NH_4^+. Nitrification rates are generally reduced by low pH, low O_2, very dry soils or very wet soils, and high litter C:N ratios, but exceptions are known especially under high N-deposition (de Boer and Kowalchuk 2001). NO_3^- is highly soluble in water, and subject to leaching below the root zone. Nitrification also leads to emissions of NO gas, which can be a significant pathway for N-loss back to the atmosphere. Small amounts of N_2O are also produced by nitrification. In most unfertilized ecosystems, N-leaching and NO emissions are minimal, indicating a relatively closed N-cycle. Nitrification provides another critical biogeochemical feedback and control over N-cycling.

Low instantaneous levels of soil NH_4^+ or NO_3^- do not necessarily indicate low N availability over the course of the growing season. Fluxes into and out of these mineral pools integrated over time are a much better indicator of soil N availability. In fact, extended high levels of mineral nitrogen, and leaching of NO_3^- in native ecosystems are symptoms of N-saturation. Similarly, low standing microbial biomass may mask rapid turnover. Measurement of mineralization, nitrification, and microbial dynamics in the field is a complex problem.

Plant roots take up both NO_3^- and NH_4^+ from soil solutions, some species prefer one to the other, but in general, even plants with a nitrogen form preference do better when both are available. Soils adjacent to roots are generally depleted of mineral N and other critical nutrients, indicating high uptake efficiency. NO_3^- is carried by mass flow of soil water to the near-root zone, which increases plant availability; conversely, plants may increase production of fine roots to seek out soil-bound NH_4^+. Cation and anion exchange processes at the root surface during N-uptake affect local soil chemistry.

Mycorrhizal fungi are symbiotic fungi that associate with plant roots and exchange mineral nutrients for plant-derived carbon. Although standing biomass of mycorrhizae may be low compared with plant biomass, the length of fungal filaments can be far greater than plant roots and contribute to N-uptake. Mycorrhizae are known to improve the nutrition of a majority of the macro- and micronutrients required for plant growth, including NH_4, NO_3, and organic N. Mycorrhizae can be sensitive indicators of N status (Egerton-Warburton and Allen 2000), and mutual feedbacks between fungus and plants can mediate ecosystem responses to N-deposition.

Increased N-availability in the soil (during the growing season) leads to either greater plant biomass production or higher tissue N-concentrations, depending on availability of water and other nutrients and the biochemical capabilities of the plants. Increased production and/or N-content leads to an acceleration of parts of the N-cycle (discussed below).

Live plants can emit NH_3 gas back to the atmosphere, especially under high soil N availability in fertilized pastures. Emissions of NH_3 in fertilized systems lead to complications in modeling NH_3 deposition. Plant tissue N (as well as litter) can be volatized through fire as NO_x, NH_3, and particulate-N. Herbivory may also have profound effects on rates of N-cycling. Animals feeding on plants can export N from the system, and redistribute it in relatively concentrated and labile forms. Herbivores are very sensitive to plant-N and selective herbivory can change plant species composition.

NO_3^- is denitrified into N_2O and N_2 under anaerobic conditions (wet soils or oxygen poor microsites). Denitrification is an important pathway for N loss in wetlands, surface water, and in groundwater. Denitrification in coarse, well-drained soils is relatively slow, but anaerobic microsites in soil particles provide some opportunities for denitrification. N_2O emissions are of concern as a greenhouse gas (GHG) and as a destroyer of stratospheric ozone. Denitrification and long-term geologic burial are the only pathways that remove N_r from the biosphere as a whole. Conditions that favor complete denitrification to N_2, with minimal production of N_2O, are the ideal objective of management aimed at removing N_r from ecosystems.

The N-cycle is under strong biotic control, and because of the multiple pathways, processes, and feedbacks that occur in site-specific combinations, it is difficult to generalize about it. Scientific understanding of the N-cycle at many scales is growing, but field measurement of many aspects of the N-cycle and the organisms that drive it continue to challenge ecosystem scientists.

2.2. N-limitations in California Terrestrial Ecosystems

California is recognized worldwide as a biodiversity hotspot, reflecting geographic isolation, strong regional and local climatic gradients, and geologic complexity (Bakker 1984). The mediterranean-type climate of cool wet winters and warm dry summers varies from the wet north to the dry south, from warm lowlands to frigid mountains, and from the maritime coastal zone to more continental inland regions—often over scales of a few kilometers. The complex and often violent geologic history of the state creates diverse edaphic conditions, ranging from shallow infertile serpentine soils and leached sands to deep fertile alluvial soils. California ecosystems span a broad range of physiognomic types, including the world's tallest high biomass evergreen forests, evergreen and deciduous forests, woodlands and shrublands, annual and perennial grasslands, deserts, and localized ecosystems specific to unique edaphic situations. Dramatically different vegetation types are often juxtaposed across abrupt topoclimatic and edaphic gradients, and fires create successional patchiness, creating rich local and regional vegetation mosaics. Aquatic ecosystems are diverse as well, ranging from oligotrophic mountain lakes, eutrophic lakes, seasonal lakes, freshwater and alkaline wetlands, mountain streams, large lowland rivers, and coastal marshes.

According to the Jepson Manual (Hickman 1993), California supports more than 5800 native plant species, of which 1169 are endemic to the California Floristic Province (the strongly mediterranean climate region of the West Coast). There are numerous localized endemic species, subspecies, and varieties that have minuscule ranges corresponding to special edaphic or climatic conditions. Geographic and botanical diversity also have produced a highly diverse fauna, again with many local endemic taxa. Many of these local endemics are listed as rare, threatened, and endangered by the U.S. Fish and Wildlife Service (USFWS) and California Department of Fish and Game (CDF&G) under their respective Endangered Species Acts. The California Native Plant Society (CNPS) maintains a list of rare, threatened, and endangered plants as well (CNPS 2003).

Urban and agricultural development pressures directly threaten habitats—few native species survive paving over and plowing under. Biological invasions, both plant and animal, pose one of the greatest threats to California's biodiversity. California ecosystems have been, and continue to be, heavily invaded by non-native plants—more than 1000 alien species have naturalized, and many have extensively and irrevocably altered millions of acres of California. Native grasslands, in particular, have been heavily altered by annual grasses and forbs from Eurasia, but few ecosystems have completely avoided invasions. Changes in plant composition affect animal communities, especially host-specific herbivores.

Water, temperature, and nutrients all can limit ecosystem productivity in California. The overall physiognomy and productivity of mature vegetation is largely determined by long-term site water balance and the effective length of the growing season. The length of the dry season is particularly important. However, given local water and temperature limitations, additions of nitrogen often produce immediate growth responses, indicating some degree of N-limitation. Phosphorous and other mineral nutrients are generally not limiting in the relatively young soils that dominate California, except in special soil types such as serpentine.

Under the mediterranean climate, seasonal patterns of N-availability, driven by decomposition, N-mineralization, and nitrification, are alternately limited by water and temperature. Most N-cycling occurs in shallow soil layers that contain the majority of organic matter. Soils are dry during the summer, wet with moderate temperatures following the first autumn/winter rainfall, wet but cool in the winter, and warm and wet only in the spring. Decomposition is slow for most of the year, and litter, especially coarse woody debris, tends to accumulate in the absence of fires. Fire is a key process in California ecosystems, and plays a critical role in driving N-deposition impacts (see below, Section 2.6).

Plant uptake and soil-N availability are often out of phase, and California ecosystems may be naturally "leaky," with some seasonal leaching of NO_3. N-mineralization and nitrification spike in autumn after the first soil wetting, but root uptake may lag behind until perennials develop new fine roots and annuals establish root systems. A pulse of NO_3^- can be flushed below the root zone or run off into surface water if early rains are sufficient to cause deep infiltration and runoff. Low plant uptake during the cool winter months can lead to NO_3^- leaching if sufficient rainfall occurs. In cold areas, deposited N accumulates in snowpack, with a large flush during melt. Flushes of NO_3^- following fires and other disturbances are important transient responses.

Specific evidence for N-limitations in a range of California terrestrial ecosystems are discussed in Section 2.4.

2.3. N-limitations in California Aquatic Ecosystems

Aquatic systems range from oligotrophic (i.e., nutrient-poor clear waters, such as Lake Tahoe) to mesotrophic to eutrophic (i.e., nutrient-rich waters with limited visibility, such as Clear Lake). Productivity in aquatic systems can be limited either by N or P, and phytoplankton communities are indicative of limiting nutrients. If N is limiting and P is relatively abundant, N-fixing phytoplankton (cyanobacteria) become more dominant. If P is limiting and N is abundant, then other phytoplankton taxa will dominate. If both N and P are abundant, some other nutrient (silica, for example, in the case of diatoms) may limit productivity. Both N and P enrichment can lead to algal blooms that can decrease water quality, and in extreme cases, decomposition of high algal biomass can deplete oxygen.

Many of the thousands of oligotrophic mountain lakes in the Western United States, including those in the Sierra Nevada, are naturally N-limited. NO_3^- is the major N species in montane lakes, and most N arrives as surface and subsurface flow into lakes and N-inputs depend strongly on the surrounding vegetation and soils. Lake Tahoe, an ultimate example of a naturally oligotrophic system, has changed from N-limitation to P limitation in recent decades (Jassby, Reuter et al. 1994).

Flowing waters are less susceptible to N-eutrophication, but can contain high levels of NO_3^-. NO_3^- is a criteria water quality pollutant. Intermittent streams often exhibit a flush of NO_3^- in high pollution areas, and long-term accumulation of N in watersheds can lead to high NO_3^- in baseflow originating from groundwater. Much N runoff in larger rivers in agricultural regions is associated with agricultural fertilization and livestock emissions, but elevated atmospheric deposition can also play a role.

Wetlands are susceptible to changes in structure and function under elevated N, and atmospheric deposition can encourage the spread of nitrophilous species (Morris 1991). Wetlands can act as filters, both capturing N in high productivity vegetation and in sediments, and perhaps more important, by denitrification in saturated soils (Morris 1991). The loss of riverine wetlands and floodplains greatly reduces basin-wide denitrification (Galloway, Aber et al. 2003).

Coastal bays and nearshore waters may also be N-limited—hypoxia and other water quality problems have been attributed to N-runoff on the East Coast and Gulf of Mexico. Extreme water quality problems in coastal California waters have generally been associated with large point sources, such as sewage outfalls and the mouths of urban creeks. However, recent work has indicated that seepage of polluted groundwater can contribute substantial nutrients to coastal waters (Boehm, Shellenbarger et al. 2004).

2.4. Effects of Chronic Deposition on N-cycling

The fate and impact of deposited N into ecosystems is driven by the response of plants and microbes to increased N-availability, and a series of biogeochemical feedbacks (Langran 1999). This section discusses general ecosystem responses to elevated N-deposition. Dry and wet deposition dynamics are complex and will only be briefly mentioned here, and models and algorithms are reviewed by Tonnesen et al. in an accompanying report (Tonnesen and Wang, forthcoming).

Dry deposition is modeled using atmospheric concentrations and deposition velocities. Deposition velocity is determined by aerodynamic, boundary-layer, and surface resistances (Metcalfe, Fowler et al. 1998). Aerodynamic resistance is driven by atmospheric turbulence, which is a function of surface roughness and wind velocity. There is greater turbulent transport over rougher surfaces, such as forests, than over smooth surfaces, such as grassland. Boundary layer resistance accounts for gaseous diffusion through the thin still layer of air surrounding all surfaces. Surface resistance accounts for the affinity of each particular gas species to different surfaces and moisture regimes. Of the major atmospheric N_r species, HNO_3, and NH_3 have the highest deposition velocities, because they are highly soluble in water, including thin films that remain on apparently dry surfaces. NO_2 is relatively insoluble in water and typically has deposition velocities an order of magnitude lower than HNO_3 and NH_3, and NO hardly dry deposits at all. Extensive reviews of atmospheric chemistry and deposition processes/modeling can be found in Metcalfe, Fowler et al. (1998) and Fowler (2002).

Atmospheric N-deposition enters ecosystems via deposition to plant and soil surfaces and via stomatal uptake into leaf interiors (Metcalfe, Fowler et al. 1998; Fowler 2002). Precipitation contains N_r in various oxidized and reduced forms. *Throughfall* (below canopy wet deposition) includes dry deposition on the surfaces of plant canopies that is washed into soils by precipitation and by fog drip (Collet, Daube, et al. 1990; Fenn, Poth, et al. 2000). Throughfall can also include inorganic and organic N leached from leaves. In California, dry deposition (especially of HNO_3) accumulates over the long summer droughts, and large pulses of accumulated N may be washed into soils with the first rains. Depending on the timing of winter rainfall, similar but smaller spikes of throughfall inputs may occur through the winter. Summer storms can also drive significant throughfall events. The combination of immediate deposition inputs with the initial pulse of mineralization and nitrification as soils are wetted produces a seasonal spike of high mineral N in the autumn. In coarse-textured California upland soils, NH_4^+ inputs—both as NH_3 gas and NH_4^+ particulates—are usually rapidly nitrified. However, the effective differences between reduced and oxidized N species in California are not well known. As mentioned above, NO_3^- leaching may occur following the substantial rainfall events—either summer thunderstorms or winter storms.

Stomatal uptake delivers N directly to the leaf interiors, and stomatal dynamics are essential to deposition models (Fowler 2002). The major deposition pathway for NO_2 is through stomata, as NO_2 is relatively insoluble in water and does not readily deposit to soils and foliage. Nitrogen dioxide is reduced to NH_4^+ in the leaves via nitrite reductase, and NH_4^+ is incorporated into amino acids. Ammonia is also rapidly deposited through stomata, although a high fraction may deposit on wet surfaces and on residual water films. Ammonia input into stomata is directly incorporated as NH_4^+ into amino acids. HNO_3 is also absorbed through stomata, and can also be transported through cuticles into leaf interiors (Marshall and Cadle 1989). Stomatal uptake can provide a substantial fraction of the N requirement of plants, but some plants may have difficulties assimilating NO_2—the ability of plants to tolerate NO_2 depends on antioxidants, nitrite reductase regulation, and other biochemical processes within leaves. Stomatal uptake of NO may not provide a large source of mineral N, but can affect metabolic processes—direct NO effects are an area of uncertainty (Mansfield 2002). NO levels generally decrease with distance from primary source, as it is rapidly oxidized to NO_2.

Once atmospheric N_r is deposited into ecosystems, it has cascading effects as it is assimilated, transformed, and recycled by organisms. The literature of N-fertilization in natural and agricultural systems is large. An extensive review of nitrogen addition experiments in arid, semiarid, and subhumid ecosystems indicates that aboveground net primary production (ANPP) is co-limited by N and water (Hooper and Johnson 1999). Nitrogen and water availability are tightly linked through biogeochemical feedbacks, including changes in litter quality and decomposition rates, microbial community dynamics, allocation patterns within plants, species composition, and other processes. The immediate effects of N and water additions are often additive in arid and semi-arid ecosystems.

Plant productivity typically exhibits a parabolic response to nutrient additions—at low levels, additions of nutrients increases growth, peaking at some intermediate level, and declining at higher levels. The typical immediate response to N-fertilization is a growth increase of existing plants, and such growth responses are taken as evidence of N-limitations. The direct uptake of atmospheric N_r also leads to growth increases in some species. Not all species are capable of large growth increases because of co-limitations from other nutrients or plant life history, architecture, and biochemistry. Plant tissue-N also increases, especially when other nutrients become more limiting; many plants take up available N in excess of demand. Nutrient imbalances can lead to changes in plant allocation, decomposition, herbivory, and other ecosystem processes.

Over longer time scales, increased productivity at the stand level is driven by changes in species composition, as nitrophilous species (adapted to high N conditions) outcompete other species by shading, root competition, selective herbivory, and other mechanisms. Species composition, through differences in foliage quality and phenology, affects N-cycling rates, which further affect species composition and feeds back into N-cycling. Changes in species composition have been extensively documented in Europe and elsewhere under long-term fertilization and N-deposition, and will be discussed below. Species composition changes also involve non-native invasive species, many of which respond strongly to N-fertilization. At ever higher levels of N-availability, productivity may decline as nutrient imbalances disrupt ecosystem processes

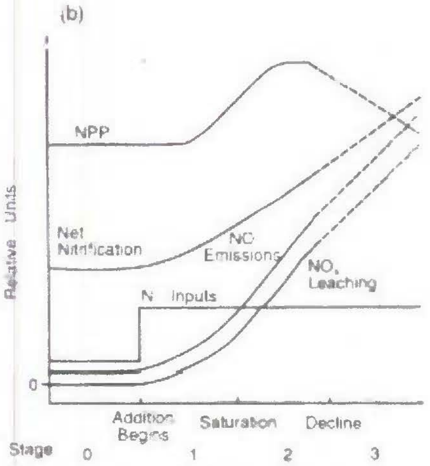
N-deposition can also lead to soil acidification and loss of base cations (e.g., calcium, magnesium, and potassium). Nitric acid (HNO_3) is a strong acid and directly contributes H^+ when it dissociates. Ammonia and NH_4^+ contribute 4 H^+ ions during nitrification, and acidification under high NH_3 deposition is well documented in Europe. Most California soils have high base cation saturation, and appear relatively resilient to acidification, but long-term deposition can reduce base cation saturation and increase acidity.

2.4.1. Nitrogen saturation

N-deposition is a cumulative process, eventually leading to N-saturation. Increased N inputs accelerate N-cycling, as greater litter fall with lower C:N ratios and increase decomposition and mineralization rates, which then stimulate nitrification and production of NO_3^-. Eventually, biotic demand for N (plant uptake and microbial immobilization) is exceeded by supply and N-saturation commences, representing a breakdown of biotic controls over N-cycling and exports.

Nitrogen saturation occurs in several stages in xeric western forests (Figure 2). Stage 0 is the original condition of low deposition, with low NO emissions and NO_3^- leaching—a high fraction of net nitrification is taken up by plants and microbes, and effectively recycled within the system. In Stage 1, incremental N-deposition leads to higher N-availability via increased nitrification and stomatal uptake by plants, leading to increases in net primary productivity (NPP). At saturation (Stage 2), NO emissions and NO_3^- leaching increase as plant uptake and microbial immobilization fall behind nitrification. Decline (Stage 3) is usually the result of multiple stress interactions, including ozone stress, susceptibility to bark beetles, and reduced fine-root biomass (Fenn, Baron, et al. 2003). Nutrient imbalances lead to stress and mortality, decreasing biotic N demand, but also increasing dead biomass inputs. N-saturated watersheds in Southern California have some of the highest levels of NO production and NO_3^- leaching recorded worldwide from non-agricultural ecosystems.

Excess nitrate leaching into surface and groundwater is a major symptom of N-saturation, and poses risks to water quality. A full discussion of water quality impacts is beyond the scope of this report



Source: (Fenn, Poth et al. 1998)

Figure 2. Stages of N-saturation in western xeric forests

The cumulative nature of N-deposition has lead to the concept of *critical loads,* defined as "a quantitative estimate of an exposure to N as NH_x and NO_y below which empirical detectable changes in ecosystem structure and function do not occur according to present knowledge." (Bull 1992; Bull and Sutton 1998) Applicability of critical loads to California ecosystems will be discussed below, but the rigorous identification of critical loads for specific ecosystems is beyond the scope of this report. Critical loads to sensitive European grasslands range as low as 5 kg-N ha^{-1} yr^{-1}, and critical loads for oligotrophic lakes may be even lower (Fenn, Baron et al. 2003). Throughout the comparative discussion of N-deposition exposure, a standard benchmark of 5 kg-N ha^{-1} yr^{-1} is used. This benchmark does not imply that 5 kg-N ha^{-1} yr^{-1} is the critical load for negative impacts for all ecosystems—some may be more sensitive and some may be less sensitive. As better information becomes available, this benchmark number may be modified for particular ecosystems; for this reason, data are graphically presented so that any benchmark can be used.

It is important to realize that the widespread increased atmospheric deposition of oxidized and reduced nitrogen is an unprecedented development—background levels across much of the world are estimated at 0.25-1 kg-N ha^{-1} yr^{-1}. The cumulative and insidious nature of N-deposition effects on ecosystems may be realized only after decades of elevated N inputs, and critical cumulative loads are poorly understood for most California ecosystems.

2.5. Mechanisms by Which N-deposition Can Lead to Impacts on Sensitive Species

2.5.1. Direct toxicity

Potential cases of direct toxicity óf N compounds have been reported specifically in California. High ambient levels of HNO_3 in the Los Angeles Basin can approach levels that directly damage conifer foliage, and perhaps other species. High soil N may also be directly toxic—100% of *Artemisia californica* (sagebrush) seedlings died when grown in soils with NO_3^- concentrations similar to field concentrations of high-deposition areas near Riverside. However, these experiment are based on high exposure under artificial conditions. There is some evidence that NO may have direct inhibitory effects on plants at high concentrations (Mansfield 2002). Peroxyacetyl nitrate (PAN) may be toxic as well (Grosjeans and Bytnerowicz 1993).

2.5.2. Changes in species composition among native plants

In Europe, a large body of work has linked N-deposition to changes and losses of biodiversity in bogs, grasslands, heathlands, and forest understory (Bobbink, Hornung et al. 1998; Bobbink and Larners 2002; Stevens, Dise et al. 2004). Increases in nitrophilous grasses, primarily perennials but also some annuals, are a common response in species-rich grasslands on acid soils and calcareous soils, and in heathlands. Acidification from large amounts of NH_3 deposition also contributes to floral changes, but species losses in acid grasslands in the UK are proportional to N-deposition levels and only weakly associated with acidity. Heathlands convert to grasslands when *Calluna vulgaris* (heather) canopies open from herbivory, stress, and disturbance, and nitrophilous grasses quickly establish and dominate. Comprehensive reviews of N-deposition impacts on European ecosystems can be found in several edited compilations (Langran 1999; Bell and Treshow 2002).

Changes in native species composition in California habitats directly attributable to N-deposition have not been explicitly identified, except in the case of invasive species as described below. Air pollution can affect species composition in native dominated habitats—ozone induced mortality in ponderosa and Jeffery pines has led to increases in ozone-resistant species such as incense cedar and white fir in Southern California forests, but the interactions with N-deposition remain an active research arena (Fenn, Poth et al. 2003).

2.5.3. Enhancement of invasive species

Invasive plant species have severely altered numerous California ecosystems. The major documented mechanism of N-deposition impacts on sensitive species is the enhancement of invasions by nonnative species, especially annual grasses. Historical annual grass invasions into richer soils, prior to widespread N-deposition, have restricted many native grassland species to patches of thin soil, or onto naturally nutrient-poor soils such as serpentine. Many, if not most, non-native annual grass species respond strongly to N additions by increasing growth and seed production (e.g. Jones and Evans 1960; Jones 1963; Huenneke, Hamburg, et al. 1990; Yoshida and Allen

2004). Invasive grasses, both annual and perennial, have been documented to alter biodiversity and ecosystem function across the world (D'Antonio and Vitousek 1992). They are highly effective in depleting shallow soil moisture, and provide continuous fine fuels that accelerate fire cycles. Dense buildup of thatch smothers short-statured native plants and suppresses seedling recruitment. Once annual grasses replace shrubs, N-cycling rates increase and continue to favor grasses over shrubs.

Increased fire frequency, driven by annual grass invasions, is hypothesized to drive type conversions in many ecosystems along a biomass gradient. Low biomass shrublands are most sensitive, but chaparral and forests may be vulnerable over longer time-scales (Fenn, Baron et al. 2003). There is some current controversy over the exact role of N-deposition in type conversions of some California shrublands (Keeley, Keeley, and Frothingham 2005), and like any complex ecological problem there may be multiple forcing factors. But, the strong positive response of annual grasses to N-fertilization clearly implicates N-deposition in many of the cases discussed below.

Invasions of many other nonnative weeds are likely enhanced by N-deposition. These plants have high relative growth rates, are effective competitors for water, nutrients, and light, have few herbivores, and respond strongly to N-availability.

2.6. Specific California Ecosystems Known to Be Sensitive

The following accounts are brief summations of documented effects of N-deposition on specific California ecosystems. For a fuller review and extensive literature citations, see (Fenn, Baron et al. 2003).

2.6.1. Conifer forests

Mixed conifer forests of many different sub-types occur across large swaths of California. N-deposition in conifer forests in Southern California leads to high nitrification rates, leaching of NO_3^- into ground and surface waters, and emissions of NO. Impacts of ozone on mixed conifer forests have been extensively documented, and include reductions in photosynthesis and productivity. The combination of high ozone and high N-deposition reduces needle retention, disrupts root growth, increases foliage N, weakens trees, and can leave forests vulnerable to insects. Biomass and litter accumulation increases fuel loads and eventual fire intensity.

2.6.2. Evergreen chaparral

Chaparral ecosystems in the San Gabriel Mountains and Southern Sierra Nevada have experienced N-saturation, as evidenced by high NO_3^- leaching, accumulation of soil NO_3, and high emissions of NO.

In comparison to coastal sage scrub or even Mohave shrublands, chaparral ecosystems are nitrogen-rich. Many of the dominant species are nitrogen fixers, so increases in N-availability is not likely to change the ecosystem function or processes.

Changes in species composition in evergreen chaparral have not been documented. The closed canopy of chaparral can effectively keep out annual grasses in the absence of fires. Following fires, a fire-following herbaceous flora can dominate for several years, until resprouting shrubs and seedling recruitment close the canopy. Post-fire seeding with *Lolium multiflorum* (Italian ryegrass, an annual) and *Lolium perenne* (Perennial ryegrass) for erosion control can suppress the herbaceous phase. *Lolium* responds strongly to N-deposition (see Section 2.6.5). Increased fire frequency can reduce shrub diversity, and eventually eliminate shrubs.

2.6.3. Coastal sage scrub

Coastal sage scrub (CSS) is a primarily deciduous shrubland that occupies relatively dry sites along the coast and further inland. Typical species include *Artemisia californica, Eriogonum* sp., and *Salvia* sp. The relative dominance of species and degree of canopy closure changes along geographic gradients, and these changes are reflected in sub-types of sage scrub—Diegan, Riversidian, Venturan, Central (Lucian), and Northern (Franciscan). Coastal sage scrub in southern California supports a wealth of sensitive species that are at risk from habitat destruction by urban development.

Mature coastal sage has few nitrogen fixers in the mature vegetation stands, thus the ecological processes and functions tend to be more sensitive to changes in nitrogen cycling. Furthermore, in CSS during most years, evapotranspiration exceeds rainfall and no runoff occurs—so any nitrogen that deposits in the ecosystem stays in the ecosystem. Leaching losses may occur only under exceptionally high rainfall events, so soil nitrate tends to accumulate through time.

In high N-deposition areas near Riverside (20–35 kg-N ha^{-1} yr^{-1}), CSS provides a well-studied case of large-scale annual grass invasion converting shrublands to grasslands. N-deposition has been implicated as a major (but not the only) driver of these invasions. (Fenn, Baron et al. 2003). Major invasive grasses include *Bromus madritensis rubens, Avena* sp., and other *Bromus* sp. Dense annual grass can eliminate small native forbs, suppress shrub recruitment, and provide fine continuous fuels that lead to stand-replacing fires. Two successive burns can effectively eliminate shrubs. Mycorrhizal fungal diversity drops with increasing N-deposition (Egerton-Warburton and Allen 2000). Qualitative observations of annual grass invasions in CSS east of San Diego (B. Toone, San Diego Zoological Society, pers. comm. July 2004) indicate that N deposition may be having similar effects there.

The change from shrublands to annual grassland increases the rate of N-cycling in the ecosystem. In annual grasslands, biomass turnover is faster and litter C:N ratio is lower. Shrubs accumulate woody biomass that decomposes slowly, and resorption of leaf N (and other nutrients) reduces litter quality.

Management of annual grasses in CSS poses many difficulties. Restoration to shrublands may be difficult and expensive. Changes in the mycorrhizal community may favor grasses over reestablishment of shrubs. Grazing by cattle, effective for controlling annual grasses in serpentine grassland and vernal pools (see below), may threaten the uninvaded lenses of clay soils that still support cryptobiotic crusts and native forbs. Occasional leaching/flushing events may provide opportunities for shrub re-establishment.

2.6.4. Desert scrub

California desert scrubs vary greatly across elevation climatic gradients, and are characterized by widely spaced shrubs and showy displays of annual wildflowers in wet years. In the Mojave Desert, N-deposition can lead to invasions by annual grasses, including *Bromus madritensis rubens* (red brome), and *Schismus barbatus* (Mediterranean annual split grass) (Brooks 2003). Wet years greatly intensify the grass invasions, and fine continuous fuel loads encourage extensive stand-replacing fires that were not possible prior to the grass invasions. In cooler deserts, *Bromus tectorum* (cheatgrass) has invaded large tracts with similar results, although invasions have occurred in the absence of significant N-additions (D'Antonio and Vitousek 1992).

2.6.5. Bay Area serpentine grassland

In the San Francisco Bay area, serpentine soils support native grasslands with high diversity of annual and perennial wildflowers, and perennial bunchgrasses (right side of fence in Figure 3). Under N-deposition, ungrazed serpentine grasslands (left side of fence in the Figure 3) are invaded by annual grasses primarily *Lolium multiflorum* (Italian ryegrass), *Hordeum murinum leporinum* (wild barley), *Bromus hordaceous* (soft chess), *Bromus madritensis* (red brome), and *Avena* sp. (wild oats) (Weiss 1999). *Lolium* growth strongly responds to N-fertilization and additional water, and rapidly absorbs and assimilates atmospheric NH_3 through stomata (Sommer and Jensen 1991). Nitrogen dioxide may also produce similar responses (Fowler 2002; Mansfield 2002). Concentrations of HNO_3 in south San Jose approach those in polluted parts of the Los Angeles Basin (S.B. Weiss unpublished data). N-deposition effects have been observed along regional pollution gradients and local gradients adjacent to a heavily traveled freeway.

Figure 3. San Francisco Bay Area grasslands in serpentine soils. The area on the left is ungrazed and dominated by non-native grasses. The area on the right is grazed and dominated by native species

Losses of plant diversity are accelerated by accumulation of grass thatch, which smothers small annual forbs. Moderate cattle grazing maintains high plant diversity in these grasslands, because cattle selectively graze N-rich *Lolium*, remove N and biomass from the system, prevent thatch buildup, and provide bare mineral soil for annual forb germination. Cattle also redistribute N and accelerate local N-cycling rates.

Bay Area serpentine grasslands are a biodiversity hotspot, supporting numerous threatened and endangered species, including the Bay Checkerspot butterfly, *Euphydryas editha bayensis* (USFWS 1998). Population extinctions of the butterfly follow grass invasions, because the larval host plant, *Plantago erecta* (dwarf plantain, a short annual forb) is crowded out by grass invasions.

The N-deposition threat to protected species in serpentine grasslands prompted precedent-setting mitigation for power plant emissions from the Metcalf Energy Center in San Jose (and other power plant projects, see Table 1), stimulated specific mitigation for highway projects and industrial developments, and drove the initiation of a Habitat Conservation Plan/Natural Communities Conservation Plan (HCP/NCCP) for Santa Clara County.

2.6.6. Mountain lakes

Primary productivity in Lake Tahoe has increased greatly over the last decades, and has changed from N-limitation to P-limitation (Jassby, Reuter et al. 1994). Atmospheric deposition is a primary source of elevated N in Lake Tahoe, contributing more than half of the N-loading, but the overall N-budget of the Tahoe Basin is still uncertain. Similar changes in phytoplankton communities—a shift from oligotrophic to more mesotrophic species—have been documented in the Southern Sierra Nevada (Fenn, Poth et al. 2003).

2.6.7. Lichen communities

Lichens are common and diverse in many ecosystems, and are sensitive indicators of various air pollutants. Nitrogen-sensitive lichen species have disappeared from high N-deposition areas—more than 50% of the native lichens in parts of the Los Angeles Basin have disappeared. Evidence of affected lichen communities extends across much of the state (Fenn, Baron et al. 2003).

2.7. Other California Ecosystems that May Be Sensitive

2.7.1. Vernal pools

Vernal pools are seasonal wetlands that contain water in the winter rainy season and dry over the summer drought. An impervious subsoil layer (hardpan or claypan) prevents rapid drainage. Vernal pools are characterized by a pronounced mound to pool bottom gradient, where mounds support upland grassland, with progressively longer flooding periods as one descends to the pool bottom. Pool bottoms and intermediate zones are characterized by a unique flora and fauna adapted to seasonal flooding. Many rare, threatened, and endangered species—both plants and animals—are found in vernal pools.

Annual grass invasions in vernal pools have been documented in the Sacramento Valley (Barry 1998; Gerhardt and Collinge 2003). Recent work in the Consumnes Reserve (Marty 2005) has identified annual grasses as a major threat to ungrazed vernal pools (Figure 4). When annual grasses are allowed to grow ungrazed, they evaporate more water from the mound areas, reducing inundation periods in the pools and allowing grasses to further invade deeper portions of the pools. These grass invasions, which occur over 2–3 years, lead to a direct loss of biodiversity of native vernal pool plants through competition and thatch buildup, and the shorter inundation periods lead to losses of invertebrates such as endangered fairy shrimp, and tiger salamander and red-legged frogs. Annual grass invasions, especially by *Lolium multiflorum*, have been noted in vernal pool systems in Sonoma County, with substantial losses of native biodiversity including listed plant species (D. Glusenkamp, Audubon Canyon Ranch, pers. comm.).

Given the well-documented responses of annual grasses to N-additions, and impacts in other California ecosystems, the intensity of annual grass invasions in vernal pools is likely increased by N-deposition and vernal pools can be considered a sensitive ecosystem.

Figure 4. Grassland invasion at a vernal pool

2.7.2. Sand dunes

Annual grass invasions in the Antioch Dunes threaten the endemic flora and fauna of this inland dune system (Steve Edwards, East Bay Regional Park District, pers. comm.). Coastal dune systems are in relatively clean coastal air, but inland sand dune systems may be at risk. Annual grass invasions have been noted in eolian sands in the Arena Plains San Joaquin Valley, where cattle grazing has been a key management practice (Silviera 2000).

2.7.3. California "annual" grassland

Although many California grasslands are dominated by invasive annual grasses and forbs, they can still support local concentrations of native wildflowers and bunchgrasses. Increased annual grass growth stimulated by N-deposition may further restrict native forbs to nutrient-poor thin soils around rock outcrops and on steep slopes.

Coastal grasslands are susceptible to invasion by the native shrub *Baccharis pilularis* (coyote brush) in the absence of fire or grazing. Such invasions occur in clean coastal areas, so N-deposition is likely not the primary driving factor, but the potential contribution of N-deposition to this process is not known.

2.7.4. Oak woodlands

Oak woodlands and savannahs have understory grasslands—formerly dominated by native perennial grasses and annual and perennial forbs, but now dominated by introduced annual grasses—that may be affected by increased annual grass growth as described above. Annual grasses are effective competitors for soil moisture in spring, and have been implicated in suppressing oak seedling recruitment. Grazing removal from oak woodlands in the East Bay regional Park District has led to intensified invasions of annual grasses (S. Edwards. EBRP, pers. comm.), but grazing can also directly affect oak recruitment, and remains a contentious issue in resource management.

2.7.5. Alpine communities

In alpine areas in Colorado, N-deposition has been linked to changes in species composition, with an increase in nitrophilous species and changes in N-cycling. N-inputs may be particularly high and effects substantial in wet meadows where windblown snow accumulates and water limitations are few. Water limitations in rocky fell field communities may restrict growth responses to increased N-deposition. No comparable changes have been explicitly documented in California.

2.7.6. Serpentine soils (other than Bay Area grasslands)

Serpentine soils provide numerous limitations to plant growth, including low calcium, phosphorus, molybdenum, and nitrogen, and high magnesium, nickel, chromium, and other heavy metals. Soils tend to be thin and rocky. The unique and harsh growing conditions on serpentine soils, combined with their island-like distribution have led to the evolution of many serpentine endemic plants. Serpentine soils also provide a refuge for many species crowded off richer soils by invasive species. Serpentine communities range from stunted conifer forests, chaparral, grasslands, and near total barrens.

N-deposition may promote annual grass invasions in serpentine soils. Reports of non-native grasses invading serpentine habitats have been accumulating (Harrison, Inouye et al. 2003). In some cases it appears that some grass species are becoming better adapted to serpentine, but links to N-deposition have not been made explicit. Other serpentine sites where grass invasions have been noted include the Red Hills in Tuolumne County (J.B. Norton, UC Cooperative Extension, pers. comm.).

2.7.7. Alkali sinks

Low-lying areas in deserts and semi deserts accumulate salts and provide habitat for a variety of halophytes. Drier upland soils may be dominated by annual grassland. Dense grass growth and thatch are present in places such as the Springtown Sink near Livermore, covering all but the most saline soils (Figure 5). The potential for N-deposition effects in these habitats has not been explicitly addressed, but alterations similar to those in vernal pools may be expected.

Figure 5. Dense grass growth and thatch in alkali sink near Livermore, California

2.7.8. Salt marshes

Salt marsh productivity is limited by N (Morris 1991). Salt marshes export organic N to adjacent coastal waters, but are also major sites for denitrification. Many salt marshes are locally subjected to elevated N in sewage effluent. The direct impacts of atmospheric N-deposition on California salt marshes have not been assessed. The potential for atmospheric N-deposition to enhance invasion rates by non-native *Spartina* (salt grass) around San Francisco Bay is unknown.

2.7.9. Freshwater marshes

Nitrogen can be limiting to productivity in freshwater marshes (Morris 1991), but the role of atmospheric N-deposition in California freshwater marshes is not known at present.

2.7.10. Other edaphic oddities

California has pockets of unusual soils that support unique ecosystems because of harsh growing conditions. Ione clay is a unique ancient lateritic soil in the foothills of the central Sierra Nevada, supporting several local endemic taxa. Ione clays are heavily leached and very acidic. Impacts of N-deposition are unknown, but annual grasses are present among the endemic shrubs (see Figure 6). Limestone outcrops in the San Bernardino Mountains support a cluster of rare species, as do shallow infertile "pebble-plains" at higher elevations. Gabbro soils in the Sierra foothills also support a cluster of rare species, but no documentation of annual grass invasion or N-deposition impacts has been reported.

Figure 6. Grasses among endemic shrubs (*Arctostaphylos myrtifolia*) in the Ione formation

2.7.11. Surface waters

The leaching of nitrate from N-saturated ecosystems contributes to water quality problems downstream. While nitrate pollution of groundwater and release to surface waters is widely recognized in agricultural areas, there may be atmospheric deposition inputs in other areas, especially in mountain watersheds in the Los Angeles Basin and other high pollution zones. The effects of large nitrate pulses into coastal waters may contribute to near-shore pollution episodes.

3.0 Distribution of N-deposition in California and Ecosystem Exposure

3.1. Distribution of N-deposition at 36 km

The 36 x 36 km CMAQ map of total annual N-deposition identifies levels of exposure across California (Figure 7). Hill-shaded topography and county boundaries are shown to facilitate geographic location. The map is repeated without the topography in following sections. It is extremely important to note that the 36 km scale precludes highly site-specific assessment, and provides a screening tool appropriate to regional-scale analyses. Sharp coastal gradients, in particular, are only approximated at best, and local hotspots within grid squares cannot be resolved. Individual circumstances where greater resolution is needed for assessment accuracy will be identified, but fine-scale analysis will require the completed 4 x 4 km map currently being produced by the UCR group (forthcoming).

Figure 8 presents the overall distribution of N-deposition across California as a cumulative distribution function (CDF). In this presentation format, the proportion of total area below (or above) any selected N-deposition level can be read directly from the graph, and converted to absolute area (in hectares) by multiplying by the total area. For example, approximately 75% of the state (~30,000,000 ha) receives < 5 kg-N ha^{-1} yr^{-1}, or conversely, 25% (or ~10,000,000 ha) receives more. Similarly, approximately 4% (or ~1,600,000 ha) receives > 10 kg-N ha^{-1} yr^{-1}. This graph format will be consistently used for assessing exposure of specific vegetation types from the FRAP map, because it allows the determination for any chosen threshold.

Throughout the discussion of N-deposition exposure, a benchmark of 5 kg-N ha^{-1} yr^{-1} will be used for comparative purposes. If an ecosystem is exposed to substantial areas >10 kg-N ha^{-1} yr^{-1}, that is also noted. Once again, this benchmark does not imply that 5 kg-N ha^{-1} yr^{-1} is the critical load for negative impacts for all ecosystems—the CDF graphs are designed to allow for consideration of all potential thresholds for impacts as they are identified.

The obvious hotspot for N-deposition is the South Coast Air Basin (SoCAB), with a maximum deposition of 21 kg-N ha^{-1} yr^{-1} in the Central Los Angeles Basin, and surrounding cells of 13–16 kg-N ha^{-1} yr^{-1}, dropping off to 8–10 kg-N ha^{-1} yr^{-1} further east and north. Deposition in the Mojave Desert ranges from 6–9 kg-N ha^{-1} yr^{-1} in the west, and decreases to 3–4 kg-N ha^{-1} yr^{-1} in the east.

In the San Diego Air Basin (SDAB), maximum values are 8–9 kg-N ha^{-1} yr^{-1}, just east of San Diego. The coastal areas receive 1–2 kg-N ha^{-1} yr^{-1}. The lightly developed Camp Pendleton gap in Northern San Diego County (5 kg-N ha^{-1} yr^{-1}) is barely resolved at this scale. Deserts in eastern San Diego County receive 6 kg-N ha^{-1} yr^{-1}.

In the San Francisco Bay Area, the maximum deposition is 8–9 kg-N ha^{-1} yr^{-1}. The coastal grid squares such as the San Mateo County Coast have low deposition (1 kg-N ha^{-1} yr^{-1}), and inland areas in the East and South Bay receive 6 kg-N ha^{-1} yr^{-1}.

The deposition hotspot in the San Joaquin Valley is near Modesto (13–14 kg-N ha^{-1} yr^{-1}). The east side of the San Joaquin Valley and lower Sierra foothills receive from 5–9 kg-N ha^{-1} yr^{-1}. The west side of the Valley and adjacent slopes of the Inner Coast Ranges receive 3–4 kg-N ha^{-1} yr^{-1}.

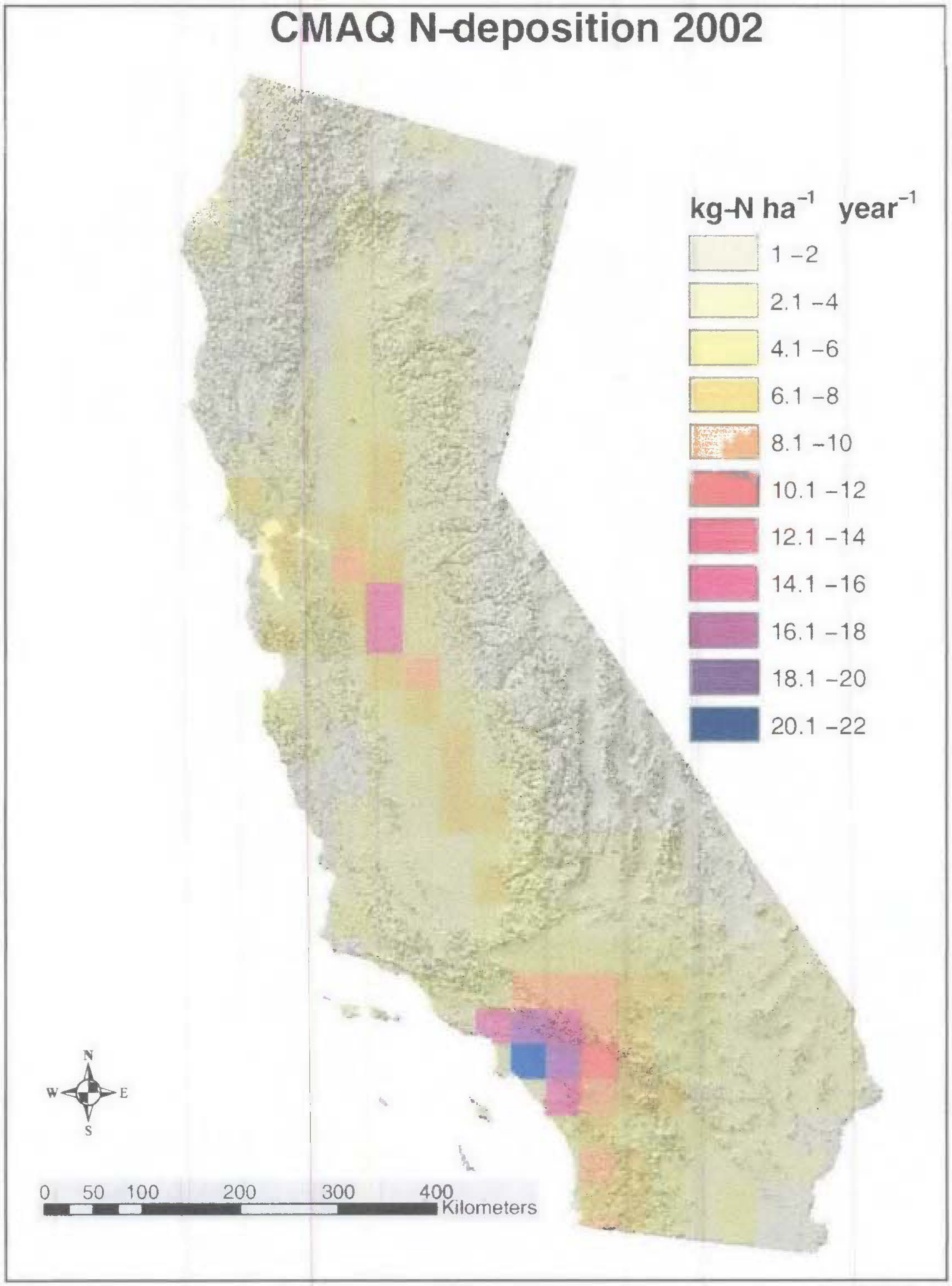


Figure 7. CMAQ 36 km N-deposition

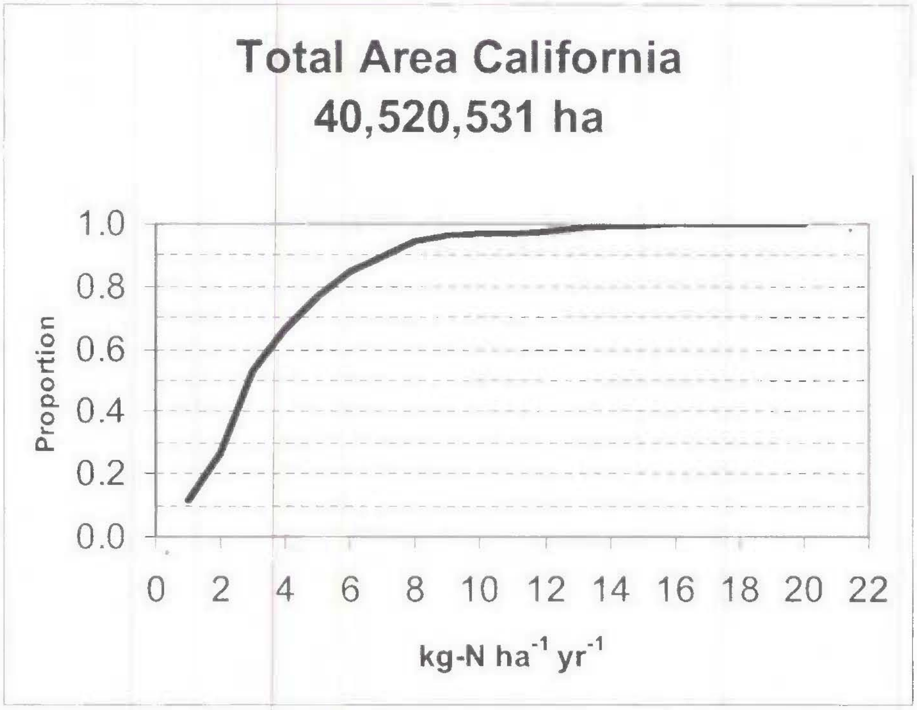


Figure 8. Statewide N-deposition proportion (CDF format)

Maximum values in the Sacramento Valley are 6–8 kg-N ha^{-1} yr^{-1} at the southern end and near Sacramento itself. The Northern Sacramento Valley receives 5–6 kg-N ha^{-1} yr^{-1} along the eastern side, and 3 kg-N ha^{-1} yr^{-1} on the western side.

Coastal areas are generally quite clean. The North Coast has a small area of 4 kg-N ha^{-1} yr^{-1} near Eureka. The Central Coast has two hotspots of 5 kg-N ha^{-1} yr^{-1} near Santa Maria and Monterey, and Ventura County receives 6 kg-N ha^{-1} yr^{-1}.

The Sierra Nevada exhibits a strong gradient away from the Central Valley, with deposition ranging from 4–5 kg-N ha^{-1} yr^{-1} at the lower elevations to 1–2 kg-N ha^{-1} yr^{-1} at the crest. The Eastside has low deposition, similar to the crest. The highest deposition in the Sierra Nevada is in the southern Sierra.

3.2. Ecosystem (Vegetation Type) Exposure

The overlay of the 36 x 36 km CMAQ model with the FRAP map (Figure 9) allows the broad-scale exposure of each vegetation type to N-deposition to be assessed. The complex map does not lend itself to detailed examination at such a small map scale, but is presented to illustrate the complexity of vegetation types in the state. Figure 10 presents the exposure levels to 48 FRAP vegetation types as cumulative distribution functions, as in Figure 8. The CDF graphs are grouped (approximately) by vegetation structure. Appendix A presents maps of the 48 FRAP vegetation types overlaid with the CMAQ 36 km deposition, in the same order as in Figure 10.

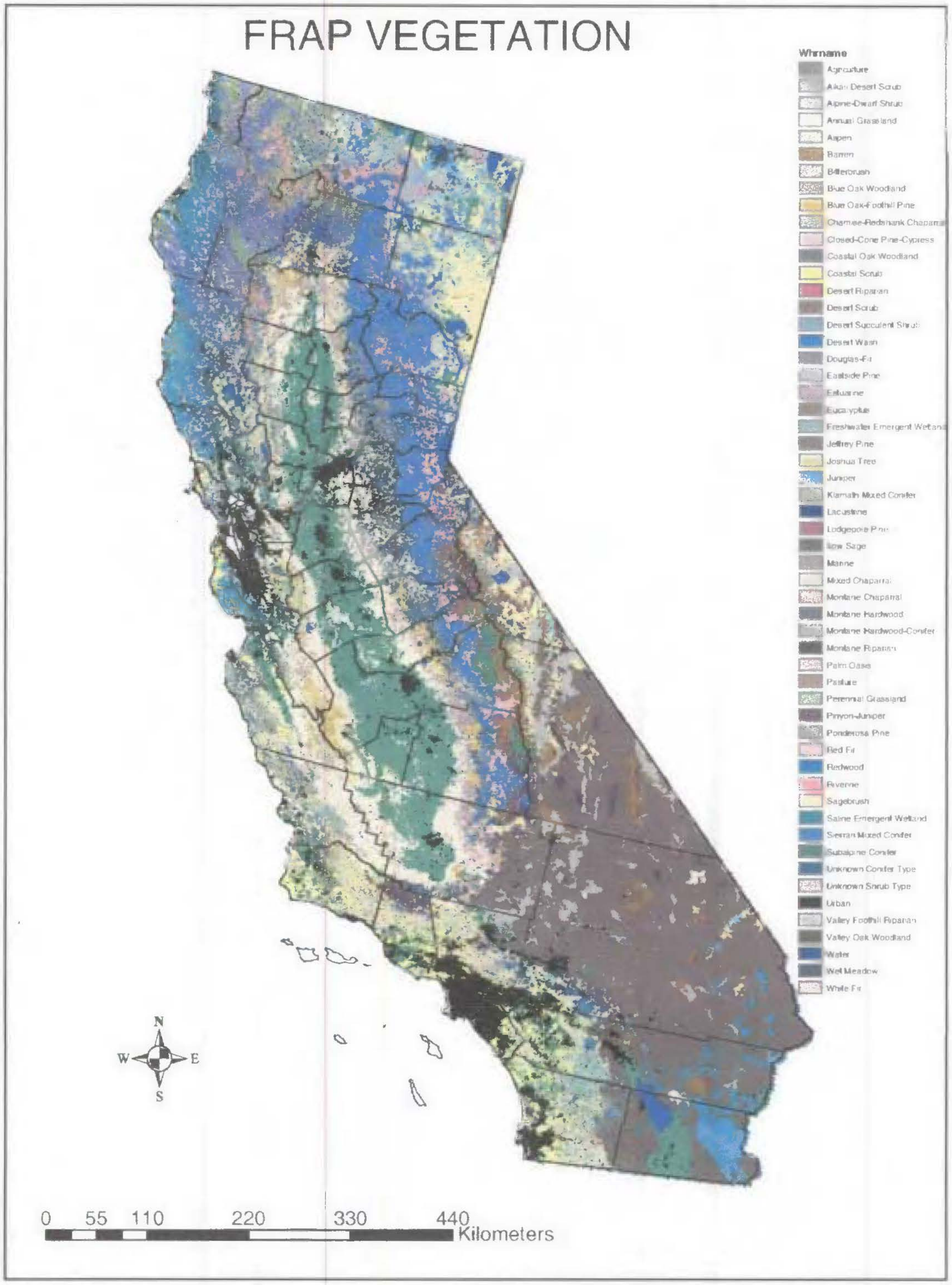


Figure 9. FRAP vegetation

3.2.1. Coastal sage scrub

Approximately 50% of CSS (350,000 ha) is exposed to > 5 kg-N ha^{-1} yr^{-1}. CSS is highly exposed to N-deposition in Southern California—the majority of the ~140,000 ha exposed to > 8 kg-N ha^{-1} yr^{-1} are near Riverside and San Diego. CSS on the central and north coasts is generally exposed to relatively low levels, but there are some hotspots around Santa Maria, Monterey, and the San Francisco Bay Area.

3.2.2. Annual grassland

Annual grassland covers more than 4,300,000 ha of lowland California. About 30% of the annual grassland receives > 5 kg-N ha^{-1} yr^{-1}. The majority of this grassland is on the east side of the Central Valley. These grasslands also support many vernal pools.

3.2.3. Wet meadows

Wet meadows are scattered across the state, and < 5% (~5000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}. These limited hotspots are in the Central Valley and Peninsular Ranges. Meadows in the High Sierra receive low N-deposition.

3.2.4. Perennial grasslands

Perennial grasslands are mapped mostly in San Diego County (especially the Camp Pendleton area), which may reflect a bias in the FRAP map. 90% (~23,000 ha) of mapped perennial grasslands are exposed to > 5 kg-N ha^{-1} yr^{-1}.

3.2.5. Agriculture

Agriculture covers > 4,500,000 ha of land, and is a major source of reactive N, especially NH_3, in the atmosphere. 50% of agricultural land receives > 5 kg-N ha^{-1} yr^{-1}, and 5% (225,000 ha) receives a "fertilizer subsidy" of > 10 kg-N ha^{-1} yr^{-1}.

3.2.6. Urban

Urban areas are the other major source of reactive N, producing NO_x from combustion and vehicles, and NH_3 from catalytic converters on vehicles. Deposition is naturally quite high within and near to urban sources, and 25% of the urban surface area receives > 10 kg-N ha^{-1} yr^{-1}.

3.2.7. Saline emergent wetland (salt and brackish marsh)

The largest remaining areas of salt marsh in California surround the San Francisco Estuary. 30% (~8500 ha) receive > 5 kg-N ha^{-1} yr^{-1}.

3.2.8. Freshwater emergent wetlands

Freshwater emergent wetlands include tule marshes, cattail marshes (both natural and managed) and are most abundant in the Central Valley. 50% (~40,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, and 5% (~4000 ha) are exposed to > 10 kg-N ha^{-1} yr^{-1}, primarily in the northern San Joaquin Valley (Modesto area).

3.2.9. Valley oak woodland

Valley oak woodland has been reduced to scattered remnants across the state, primarily on deep valley floor soils. 20% (11,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}. The grassland understory is likely the most sensitive component in all oak woodlands in the short-term.

3.2.10. Blue oak woodland

Extensive stands of Blue Oak Woodlands surround the Central Valley at elevations just above the annual grassland and extend into the Inner Coast Ranges. 20% (~225,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, primarily in the Sierra Nevada foothills.

3.2.11. Coastal oak woodland

Coastal Oak Woodlands are dominated by evergreen oak species. 30% (~130,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, much of which in the San Francisco Bay Area. 4% (~17,500 ha) are exposed to > 10 kg-N ha^{-1} yr^{-1}, all in the Los Angeles Basin.

3.2.12. Blue oak-foothill pine woodland

Blue Oak-Foothill Pine Woodland occupies elevations just above the Blue Oak Woodland. 15% (~59,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, primarily in the Mt. Hamilton Range (southeast of San Jose) and in the Tehachipis.

3.2.13. Montane hardwood-conifer

Montane hardwood-conifer is a closed canopy forest type. 10% (~65,000 ha) is exposed to > 5 kg-N ha^{-1} yr^{-1}, primarily east of San Diego and the eastern San Bernardino Mountains. 4% is exposed to > 10 kg-N ha^{-1} yr^{-1}, adjacent to the Los Angeles Basin.

3.2.14. Montane hardwood

10% (~180,000 ha) of montane hardwood forest is exposed to > 5 kg-N ha^{-1} yr^{-1}, including parts of the San Francisco Bay Area, San Diego, and the eastern San Bernardino Mountains. Only 1% is exposed to > 10 kg-N ha^{-1} yr^{-1}, adjacent to the Los Angeles Basin.

3.2.15. Valley foothill riparian

Valley-Foothill Riparian forests have been reduced to scattered remnants across the Central Valley and other inland valleys. 59% (~30,000 ha) is exposed to > 5 kg-N ha^{-1} yr^{-1}, and 10% is exposed to > 10 kg-N ha^{-1} yr^{-1}, primarily in the northern San Joaquin Valley near Modesto, with small remnants in the Los Angeles Basin.

3.2.16. Montane riparian

Montane riparian forests occur as narrow strips in canyon bottoms in most mountain ranges in California. 10% (~8500 ha) is exposed to > 5 kg-N ha^{-1} yr^{-1}, primarily in the Transverse ranges near Ventura.

3.2.17. Mixed chaparral

Mixed chaparral occurs in numerous mountain ranges across California, and consists of diverse shrub species in various combinations that depend on local factors. 40% (760,000 ha) is exposed to > 5 kg-N ha^{-1} yr^{-1}, and 10% (190,000 ha) is exposed to > 10 kg-N ha^{-1} yr^{-1}, with the highest exposure in extensive stands in the mountains around the Los Angeles basin.

3.2.18. Chamise redshank chaparral

Chamise redshank chaparral is dominated by *Adenostoma* sp. and is particularly abundant near the San Diego-Riverside County border. 50% (228,000 ha) is exposed to > 5 kg-N ha^{-1} yr^{-1}, and only 2%–3% is exposed to > 10 kg-N ha^{-1} yr^{-1}.

3.2.19. Unknown shrub type

Various stands of difficult-to-characterize shrub stands in the Coast Ranges and Sierra Nevada foothills fall in this category. Twenty percent (41,000 ha) is exposed to > 5 kg-N ha^{-1} yr^{-1}, and very little (< 1%) is exposed to > 10 kg-N ha^{-1} yr^{-1}.

3.2.20. Bitterbrush

Stands of bitterbrush are distributed on the Modoc Plateau and around the Owens Valley, and are in relatively clean air areas. < 1% (1000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}.

3.2.21. Alpine-dwarf shrub

Alpine-dwarf shrub is distributed along the crest of the High Sierra and is minimally exposed to N-deposition.

3.2.22. Sagebrush

Sagebrush is mainly distributed east of the Sierra Nevada and Cascade ranges, with outlying patches in Mojave Desert mountains, Tehachipis, and Transverse Ranges. Less than 2% is exposed to > 5 kg-N ha^{-1} yr^{-1}.

3.2.23. Montane chaparral

Montane chaparral is distributed at high elevations in the Sierra Nevada, Cascades, and Klamath Mountains. Small patches are found in the high mountains outside Los Angeles. About 5% (30,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, primarily around the Los Angeles Basin.

3.2.24. Low sage

Low sage is distributed on the Modoc Plateau, and around the Owens Valley. None is exposed to > 5 kg-N ha^{-1} yr^{-1}.

3.2.25. Ponderosa pine

Ponderosa Pine forests are distributed in the Sierra Nevada, Cascades, and Klamath Mountains. About 5% (15,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, primarily in the southern Sierra Nevada.

3.2.26. Jeffrey pine

Jeffrey Pine forests are distributed in the central, southern and Eastern Sierra Nevada, with outlying stands in the Transverse ranges and Peninsular Ranges. 7% (20,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, and 6,000 ha are exposed to > 10 kg-N ha^{-1} yr^{-1} in the Los Angeles Basin.

3.2.27. Sierran mixed conifer

Sierran mixed conifer forests are distributed along the whole length of the Sierra Nevada and Cascades, with outliers in the Transverse and Peninsular Ranges. 4% (80,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, and 17,000 ha are exposed to > 10 kg-N ha^{-1} yr^{-1} around the Los Angeles Basin.

3.2.28. White fir

White Fir forests are distributed in the Northern Sierra Nevada, Cascades, and Klamath Mountains. Less than 1% are exposed to > 5 kg-N ha^{-1} yr^{-1}.

3.2.29. Lodgepole pine

Lodgepole Pine forests are distributed in the Sierra Nevada and Cascade Ranges. 0.5% (1,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}.

3.2.30. Red fir

Red-fir forests are distributed in the Sierra Nevada and Cascades. 0.5% (2,500 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}.

3.2.31. Subalpine conifer

Subalpine conifer forests are distributed across the High Sierra, Cascades, and Klamath Mountains, with outliers at the highest elevations of the San Gabriel, San Bernardino, and San Jacinto Mountains. 2% (5,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1} around the Los Angeles Basin.

3.2.32. Eastside pine

Eastside pine forests are distributed primarily east of the Cascades, with outliers on the east flanks of the San Gabriel and San Bernardino Mountains. 3% (15,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1} around the Los Angeles Basin.

3.2.33. Redwood

Redwood forests are distributed along the coast from Big Sur north. About 10% (50,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, in the San Francisco Bay Area. This may be an overestimate, because the 36 km CMAQ map does not capture steep coastal deposition gradients in Santa Cruz and Sonoma Counties.

3.2.34. Klamath mixed conifer

Klamath mixed conifer forests are distributed in far northern California, distant from major pollution sources. None are exposed to > 5 kg-N ha^{-1} yr^{-1}, with the highest exposure (4–5 kg-N ha^{-1} yr^{-1}) northeast of the Sacramento Valley.

3.2.35. Unknown conifer type

Coniferous forests of unclassified composition(s) are distributed in the Santa Cruz Mountains and Diablo Range, along with small patches along the west slope of the Sierra Nevada and the Tehachipis. 60% (26,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, primarily in the southern San Francisco Bay Area.

3.2.36. Juniper

Juniper forests are distributed on the eastern slopes of most major mountain range, including the Peninsular and Transverse Ranges. 15% (60,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1} in Southern California.

3.2.37. Aspen

Aspen forests are distributed in the Central Sierra Nevada, and none are exposed to > 5 kg-N ha^{-1} yr^{-1}. Aspens themselves are present in many mid-high elevation coniferous forest types, including those of the Los Angeles Basin.

3.2.38. Closed-cone pine-cypress

Closed-cone pine-cypress forests are distributed in scattered pockets from the Mexican border to the North Coast Ranges. These forests contain some narrowly distributed conifers such as the Tecate Cypress in San Diego County. 10% (6,200 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}.

3.2.39. Pinyon juniper forests

Pinyon-juniper forests are distributed on the east flanks of most mountain ranges. 13% (60,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, primarily on the east flanks of the Peninsular ranges.

3.2.40. Eucalyptus

Non-native eucalyptus forests were planted in many parts of California, relatively close to urban areas. 50% (2800 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}. Eucalyptus can invade adjacent native habitats, and groves on the immediate coast often support overwintering monarch butterflies.

3.2.41. Desert riparian

Small patches of desert riparian habitats are distributed across the Mojave and Colorado Deserts. 15% (2800 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1} in the western Mojave Desert. Desert riparian zones are susceptible to invasions by non-native tamarisk.

3.2.42. Palm oasis

Small areas of *Washingtonia* palms (total 1250 ha) exist around springs in the SW California deserts. 2.5% (35 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}.

3.2.43. Desert scrub

Desert scrub is distributed across southeastern California. 27% (2,000,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, primarily from the western Mojave Desert south to Eastern San Diego County.

3.2.44. Alkali desert scrub

Alkali desert scrub occupies saline valley bottoms across the Mojave Desert, with outliers in the Southern Inner Coast Range. 15% (270,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, primarily in the western Mojave Desert.

3.2.45. Barren

Barren land is distributed as high alpine (Sierra Crest and other high mountains) and low desert (Death Valley). 3% (50,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}, primarily in the Mojave Desert.

3.2.46. Joshua tree

Joshua tree woodlands are concentrated in the little San Bernardino Mountains. 50% (16,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}. Joshua trees themselves are much more widely distributed at middle elevations in the Mojave Desert than they are in the map of this vegetation type in Appendix A.

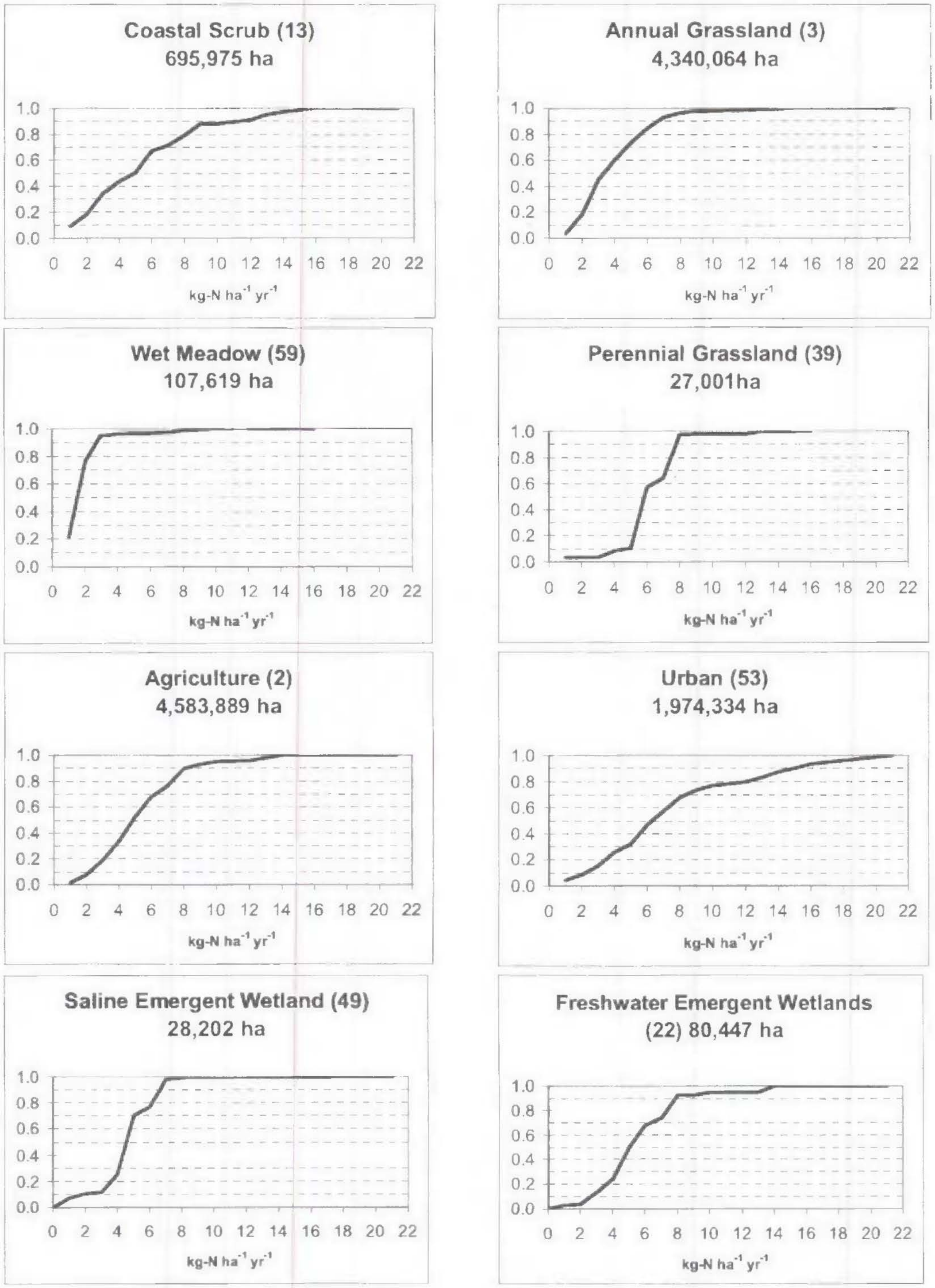
3.2.47. Desert succulent scrub

Desert succulent scrub, with a high proportion of cacti and other fleshy plants, is distributed in low-elevation deserts in San Diego and Imperial Counties. 17% (45,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}.

3.2.48. Desert wash

Desert washes are distributed in far southeastern California (Colorado Desert). 2.5% (26,000 ha) are exposed to > 5 kg-N ha^{-1} yr^{-1}.

Figure 10. Cumulative distribution functions of N-deposition exposure of FRAP vegetation types. The FRAP code numbers for each vegetation type are in parentheses, followed by total area in hectares so that proportions (Y axis) may be converted to area affected. Maps of each vegetation type are presented in Appendix A, in the same order.



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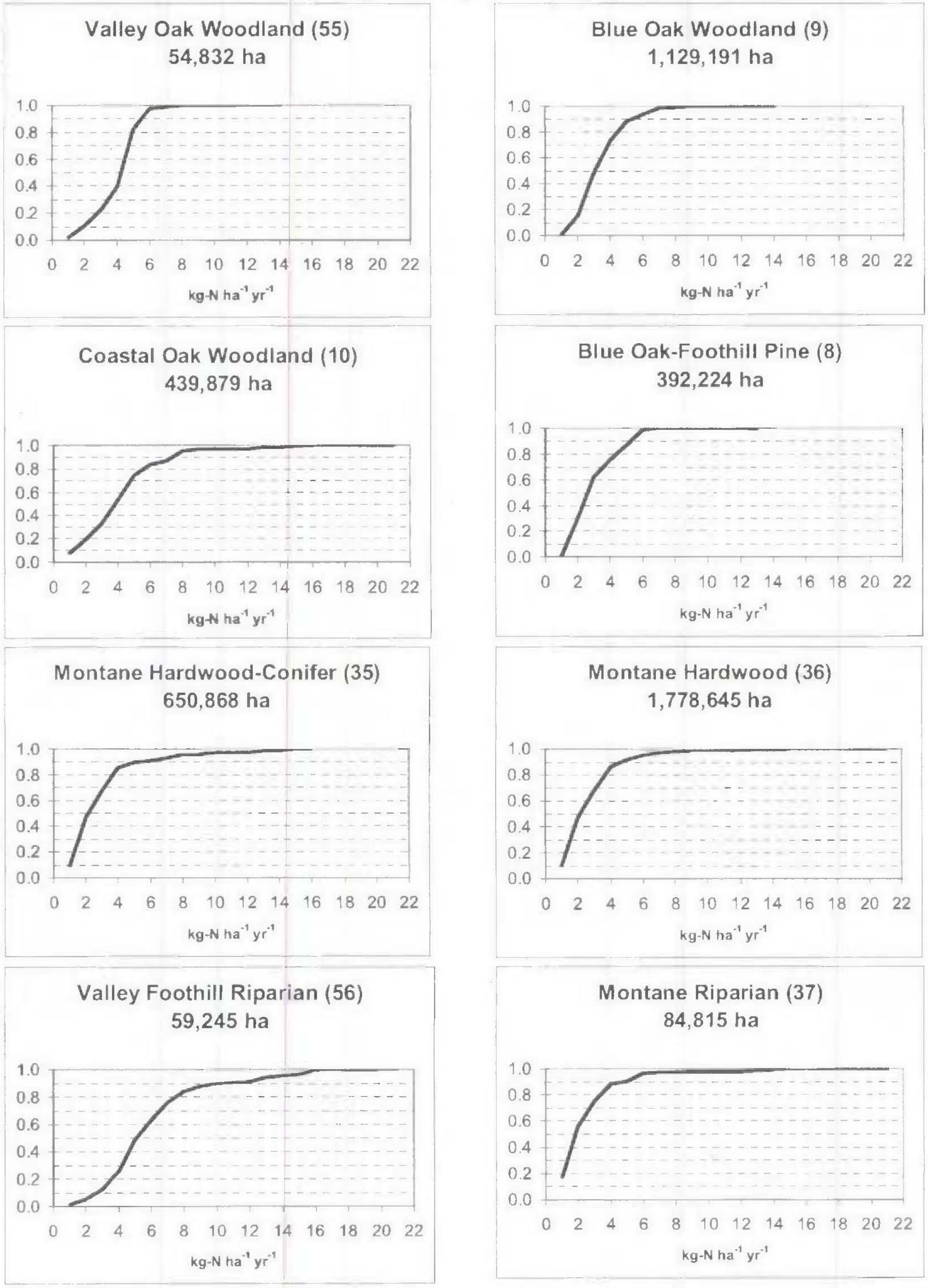

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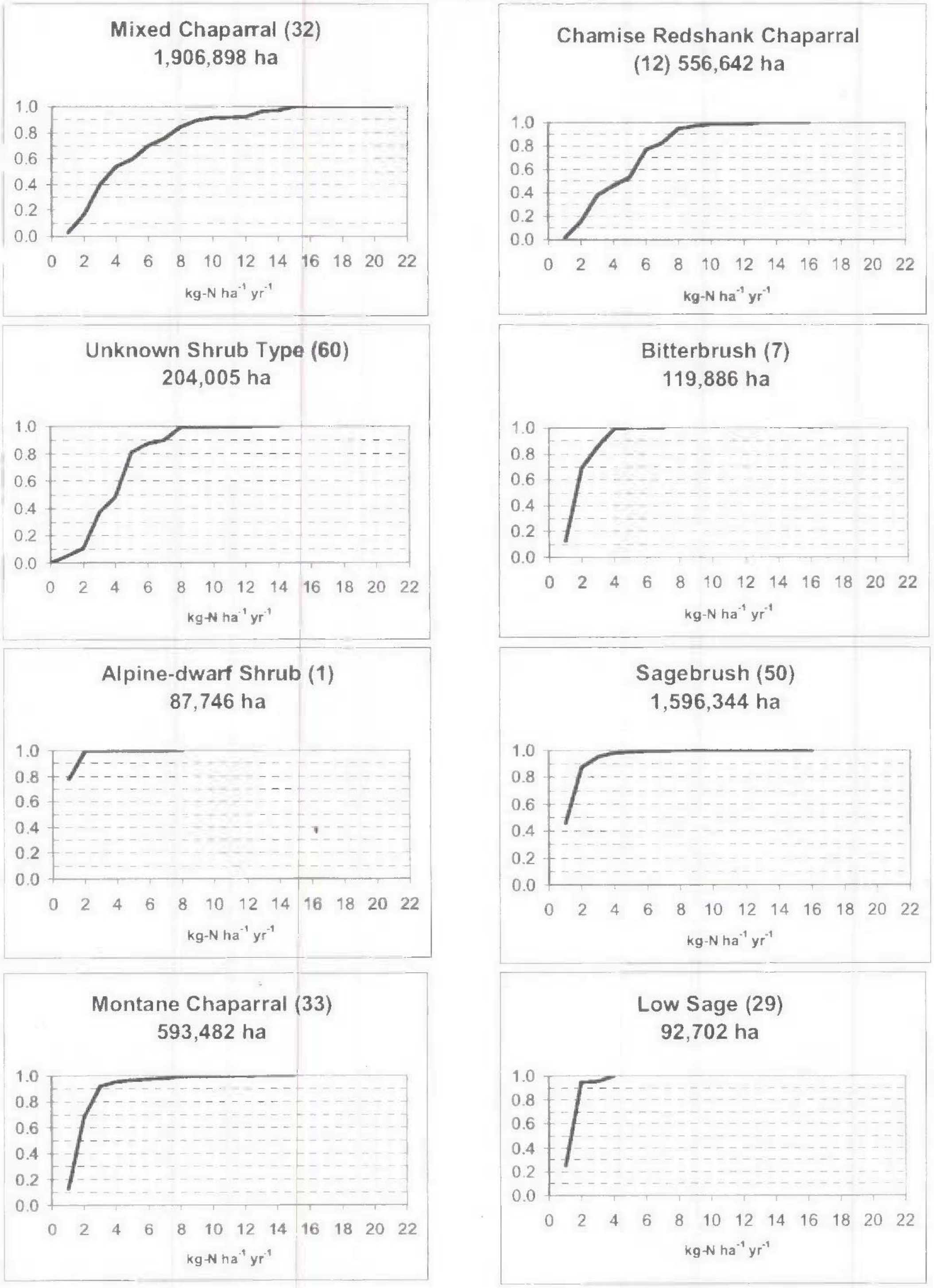


Mixed Chaparral (32)
1,906,898 ha

Chamise Redshank Chaparral
(12) 556,642 ha

Unknown Shrub Type (60)
204,005 ha

Bitterbrush (7)
119,886 ha

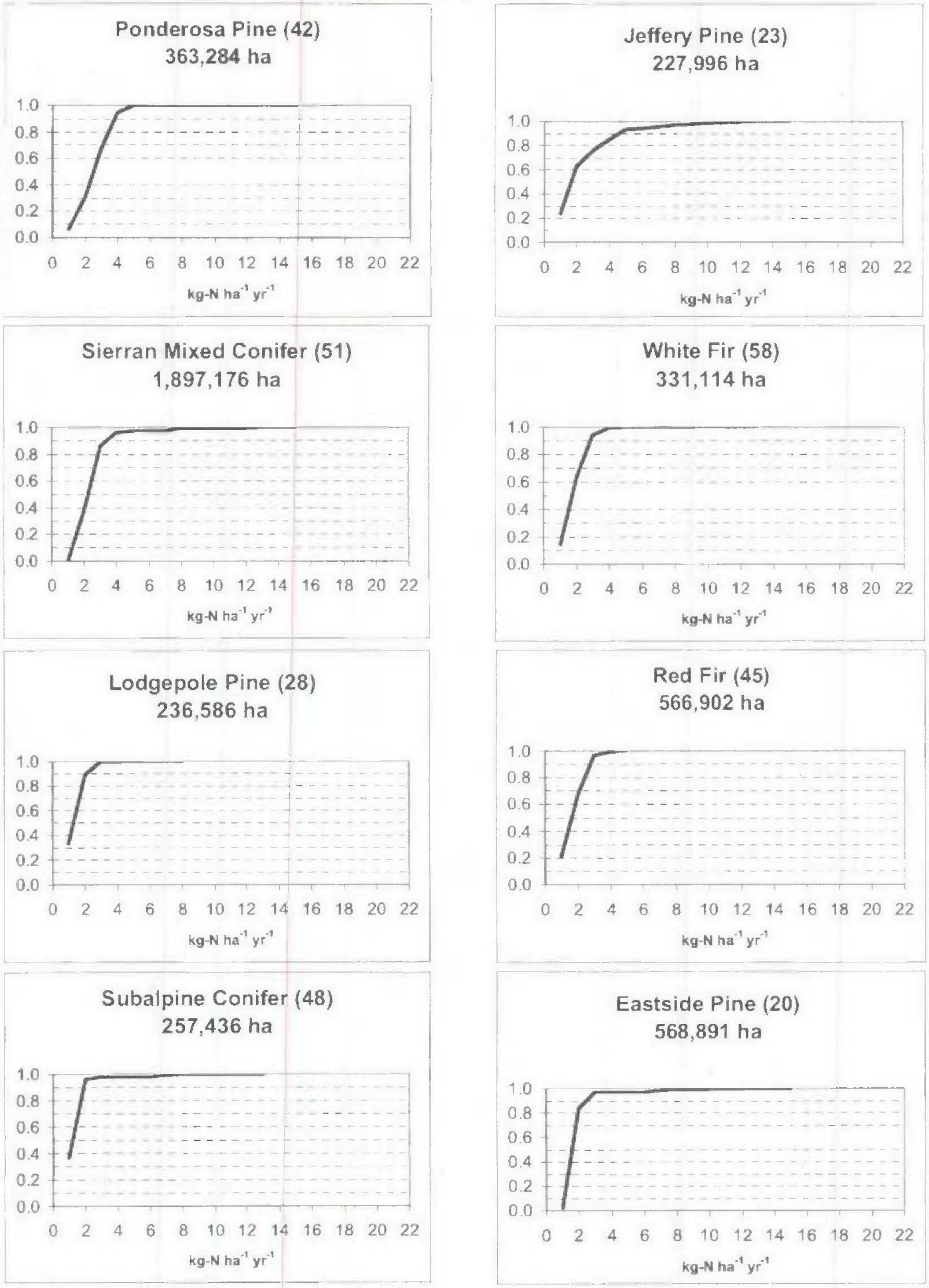
Alpine-dwarf Shrub (1)
87,746 ha

Sagebrush (50)
1,596,344 ha

Montane Chaparral (33)
593,482 ha

Low Sage (29)
92,702 ha

Figure 10. (continued)



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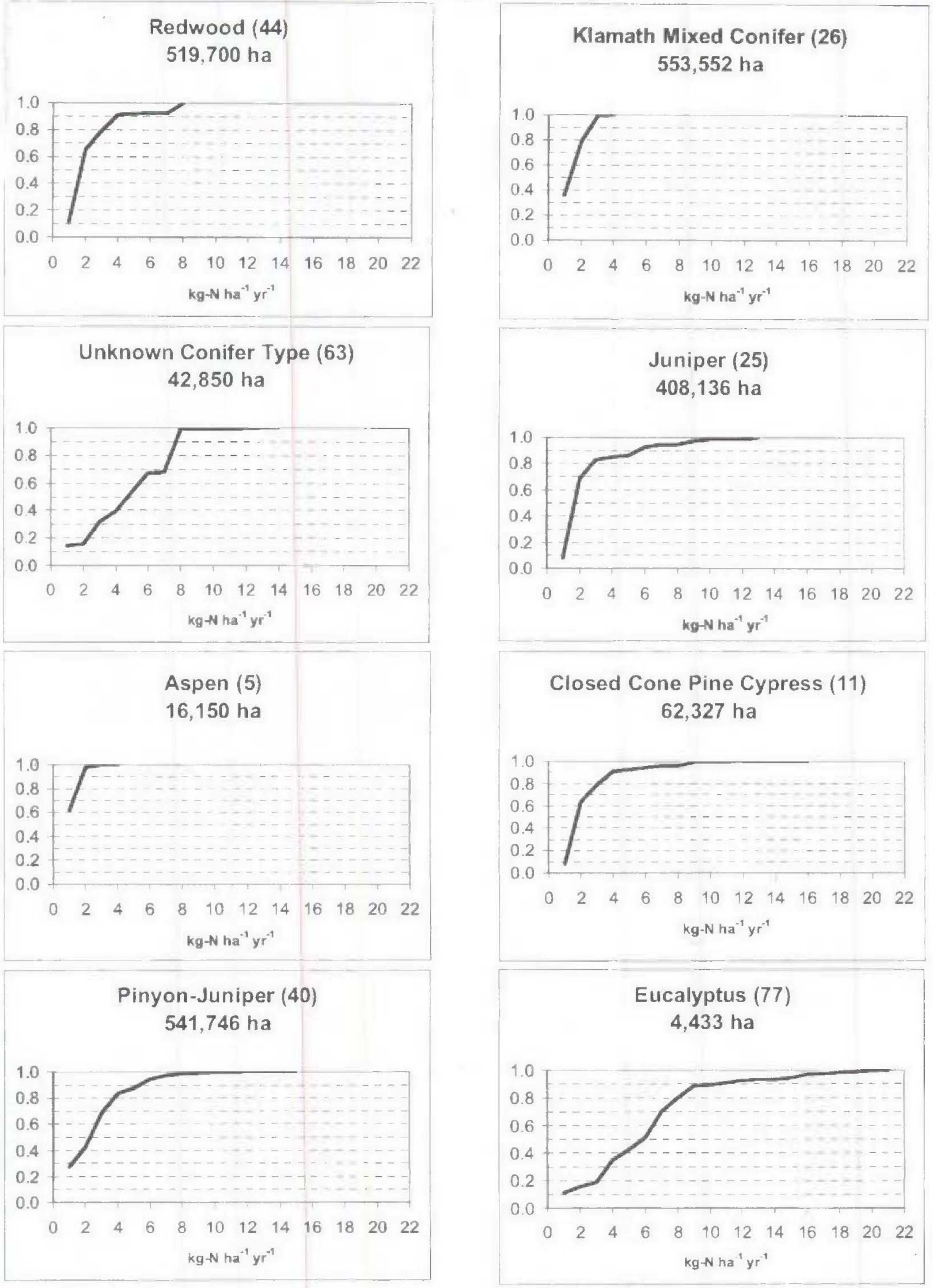

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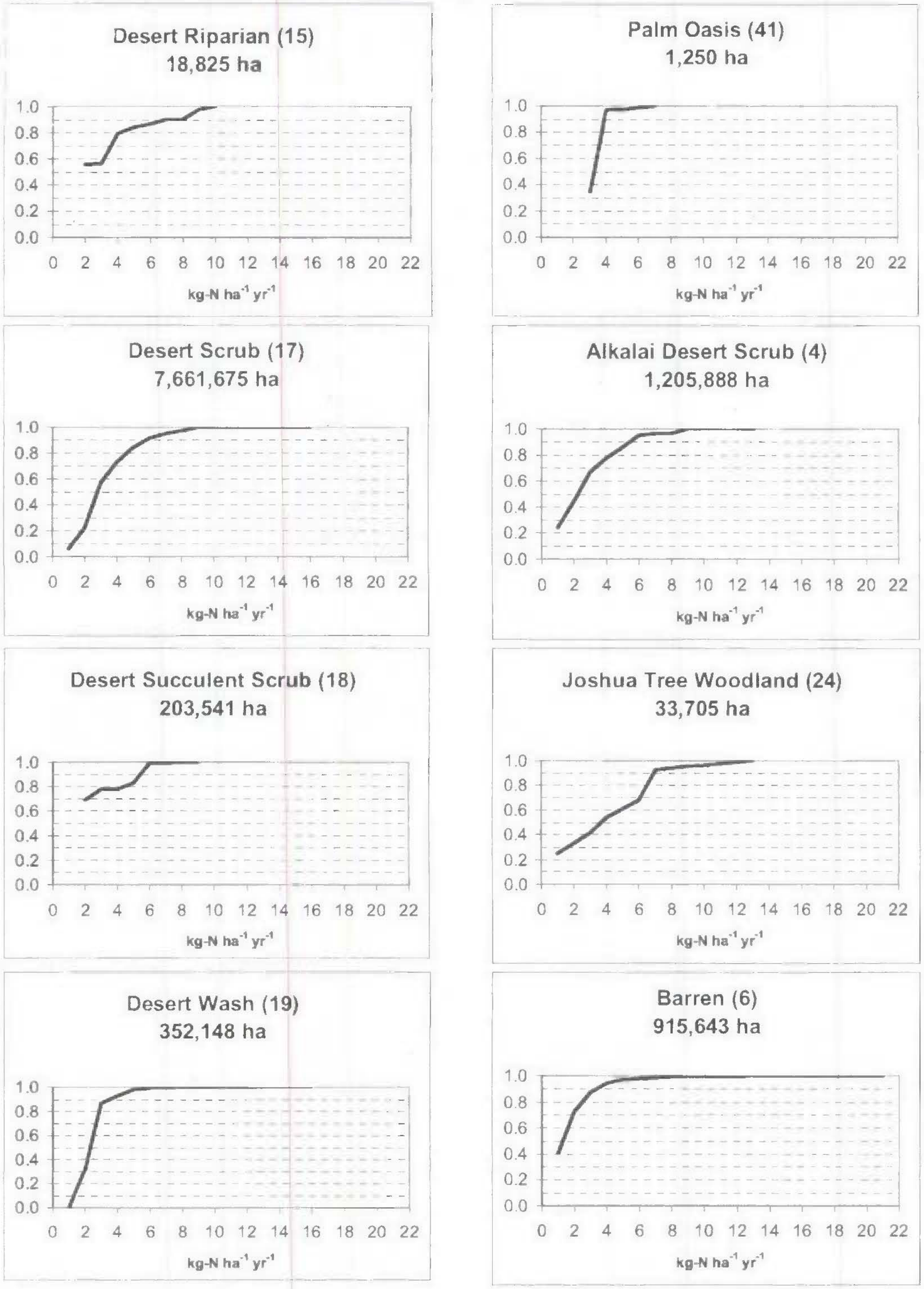

4.0 Exposure and Risks to Endangered, Threatened, and Rare Species

4.1. Methods

This section presents the results of an overlay of the CNDDB and the CMAQ 36 x 36 km map for total N-deposition in 2002. This analysis considers 1242 plant taxa in the CNDDB, including 225 taxa (species, subspecies, and varieties) that are federal- or state-listed as "threatened or endangered." The remaining 1017 taxa are regarded as rare, and include CNPS listed species (CNPS 2003). Mean exposure was calculated using all CNDDB occurrences, so that if a taxon has multiple occurrences in a single CMAQ grid square, all of those occurrences are used to derive the mean exposure. Maximum and minimum exposure across the full range of each taxa were also reported.

The same analysis is also done for the 447 animal taxa in the CNDDB, including 108 taxa (species, subspecies, and varieties) that are federal- or state-listed as "threatened or endangered," and an additional 339 taxa considered rare.

The full results are presented in Appendix B, which is in a spreadsheet format that can be filtered and searched for specific taxa.

Data are presented as CDF graphs of mean exposure and maximum exposure, so that (similar to the vegetation-type analysis) the total number of taxa above and below any given threshold can be obtained readily. The absolute numbers have been used instead of percentages. Note that the orderings of taxa for mean and maximum N-deposition exposure are different.

Note that this analysis is not appropriate for assessing site or region-specific impacts, nor is it sufficient for detailed species-specific assessment. CNDDB-type data are admittedly incomplete and have various degrees of bias, but the overall range of most taxa is at least coarsely accurate. The mean exposure is the prime risk criteria for the present analysis. The maximum exposure analysis can suggest that some part of the species range may be highly exposed, but the 36 km resolution of the CMAQ map makes definitive statements about taxon- and site-specific exposure difficult, until the 4 km CMAQ map becomes available in 2006. The problem is especially acute in near-coastal areas with steep pollution gradients, but local hotspots will undoubtedly be found in nearly many regions of the state.

Information on life history and habitat was compiled for 389 plant taxa with exposure >5 kg-N ha^{-1} yr^{-1}. This threshold represents the lowest critical loads established for European grasslands (Bobbink and Roelofs 1995), and *serves only as benchmark for coarse screening at present*, and identifies relatively high pollution areas in California according to the 36 km CMAQ map. To reemphasize, this report's authors do not yet know the critical loads for California ecosystems, let alone loads that threaten any individual plant taxa. The data can be reanalyzed for any chosen threshold. Life history and habitat were obtained from Calflora and the online *Jepson Manual;* habitat was identified as best as possible from these descriptions. Identification of special soil types—serpentines, limestones, pebble plains, gabbros, and Ione clays—is included in habitat when noted, so that soil endemics (see Section 2.7.10.) can be mapped out. Habitat and life history factors are presented in tables for selected groups of plants.

4.2. Results

4.2.1. Plant taxa

A substantial fraction of the 225 threatened and endangered (T&E) plant taxa are exposed to elevated N-deposition (Figure 11). There are 126 taxa below the 5 kg-N ha^{-1} yr^{-1} mean benchmark, and 99 above. There are 6 T&E plant taxa above the 10 kg-N ha^{-1} yr^{-1} mean benchmark.

For maximum exposure, 93 taxa are below and 132 taxa are above 5 kg-N ha^{-1} yr^{-1}, and 31 are above 10 kg-N ha^{-1} yr^{-1} (Figure 12). Note again that any benchmark may be chosen on these graphs.

Similar proportions apply to the 1017 listed rare taxa. There are 727 taxa below 5 kg-N ha^{-1} yr^{-1} and 290 are above (Figure 13). There are 24 taxa above 10 kg-N ha^{-1} yr^{-1}. For maximum exposure, 597 taxa are below and 420 taxa are above 5 kg-N ha^{-1} yr^{-1} (Figure 14), and 72 are above 10 kg-N ha^{-1} yr^{-1}.

The map of occurrences of T&E taxa with mean exposure > 5 kg-N ha^{-1} yr^{-1} clearly show concentrations in the high N-deposition regions: Southern California, the floor and east side of the Central Valley, and the San Francisco Bay Area (Figure 15).

It is beyond the scope of this report to discuss individual plant taxa, given the high numbers in the analysis. All CNDDB plant taxa are listed in Appendix B, along with mean, maximum, and minimum N-deposition, initial habitat assignment for the higher exposure plants, federal status, state status, and global and state ranks according to The Nature Conservancy. Note that this list provides only a starting point for regional and local assessments, especially assignments to specific vegetation types.

A breakdown of life form of listed taxa exposed to > 5 kg-N ha^{-1} yr^{-1} (Table 2) shows that most listed taxa are perennial and annual forbs (including several hemiparasitic taxa), followed by shrubs, and then a variety of other life-forms. Annual forbs may be the most immediately vulnerable to annual grass invasions, but in the long run, perennial forbs and shrubs may be at risk from habitat conversion via fire. Assignment of quantitative risk factors based on life history will eventually require a taxon-by-taxon analysis.

A breakdown by habitat (Table 3) shows that 23 T&E plant taxa and 22 rare taxa are vernal pool dependent. Vernal pool taxa are concentrated on the east side of the Central Valley, the Southern California Coast, and the North Bay Area (Figure 16). Assignment of taxa to specific vegetation types will require a regional scale assessment by local experts; available data (CalFlora and Jepson Herbarium) were insufficiently precise for systematic use in this report.

Many other taxa are in low-biomass habitats that are at risk from annual grass invasions, including sandy soils, clay, grasslands, open areas, and meadows, among others. There are sets of taxa that are specialized on particular soils; these soil endemics with mean exposure > 5 kg-N ha^{-1} yr^{-1} include: serpentines in the Bay Area, gabbro; Ione clays, and serpentine in the Sierra Foothills; limestone in the San Bernardino Mountains; and metavolcanics east of San Diego (Figure 17).

As mentioned above, these analyses are constrained by the coarse resolution of the 36 km CMAQ map, especially in coastal areas. Subregional patterns will be resolved with finer resolution N-deposition modeling from the 4 km map. Note also that some highly exposed plant taxa have outliers in low N-deposition regions.

Once again, the results indicate a need for regional and subregional analyses, and Appendix B provides a starting point. Specific treatment of more than a few taxa is beyond the scope of this report.

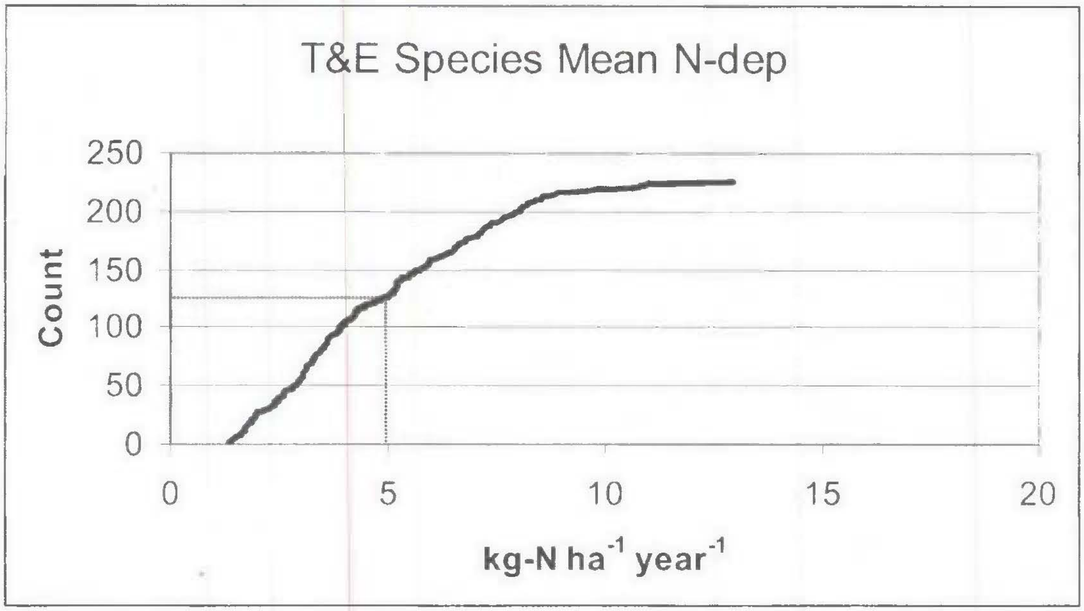

Figure 11. Average N-deposition exposure, state- and federal-listed T&E plant taxa (n = 225)

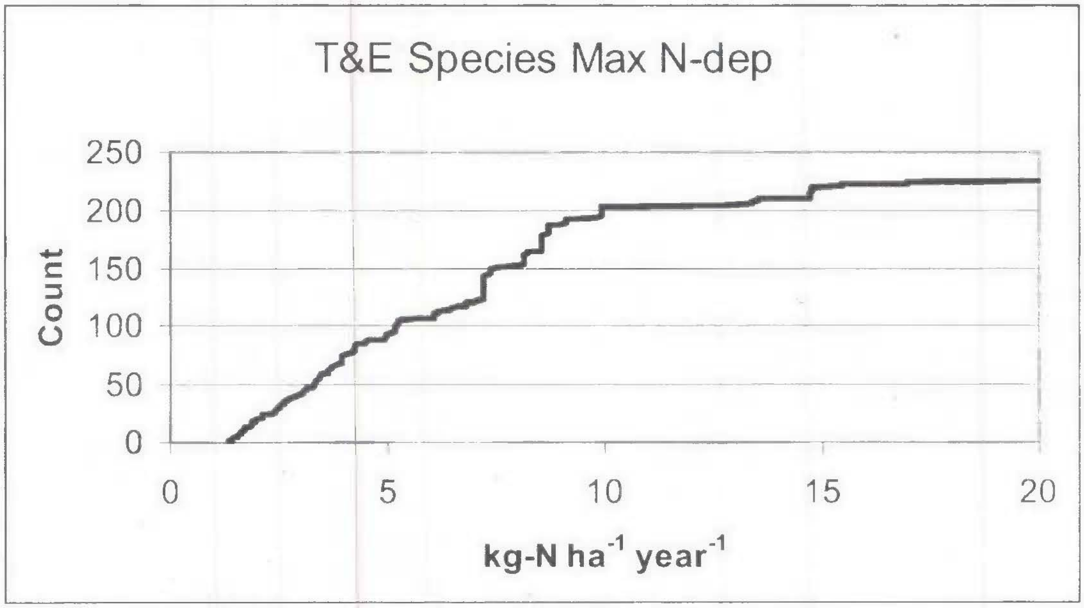

Figure 12. Maximum N-deposition exposure, state- and federal-listed T&E plant taxa (n = 225)

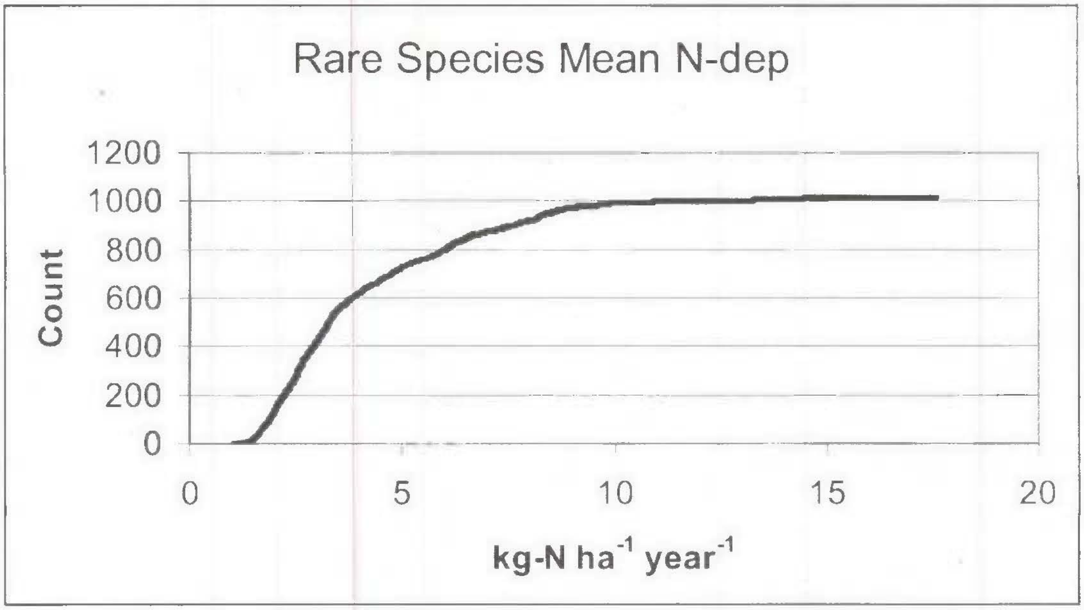

Figure 13. Mean N-deposition exposure, listed rare plant taxa (n = 1017)

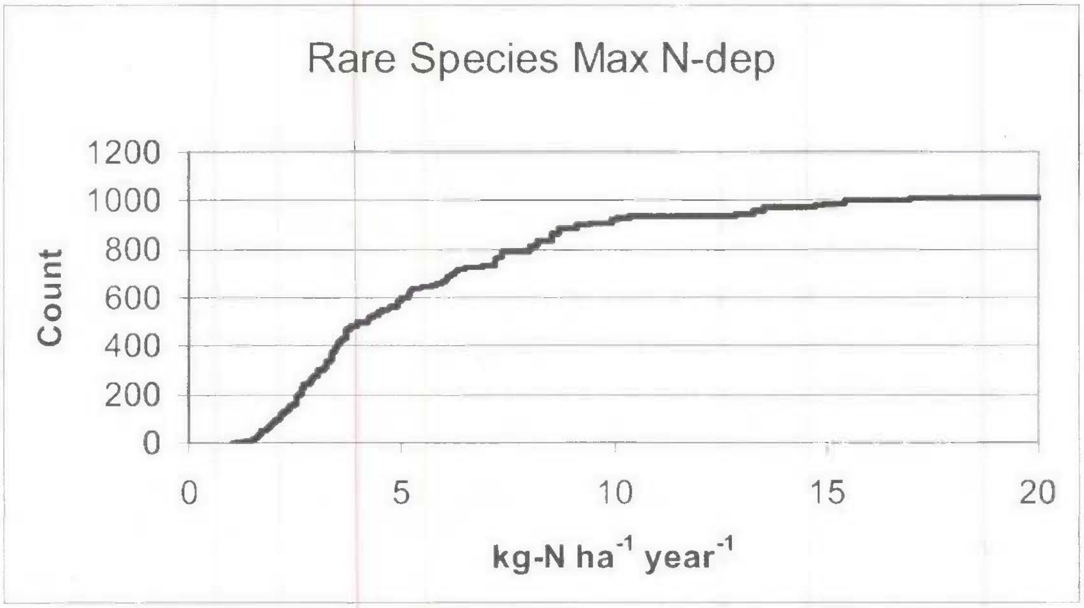

Figure 14. Maximum N-deposition exposure, listed rare plant taxa (n = 1017)

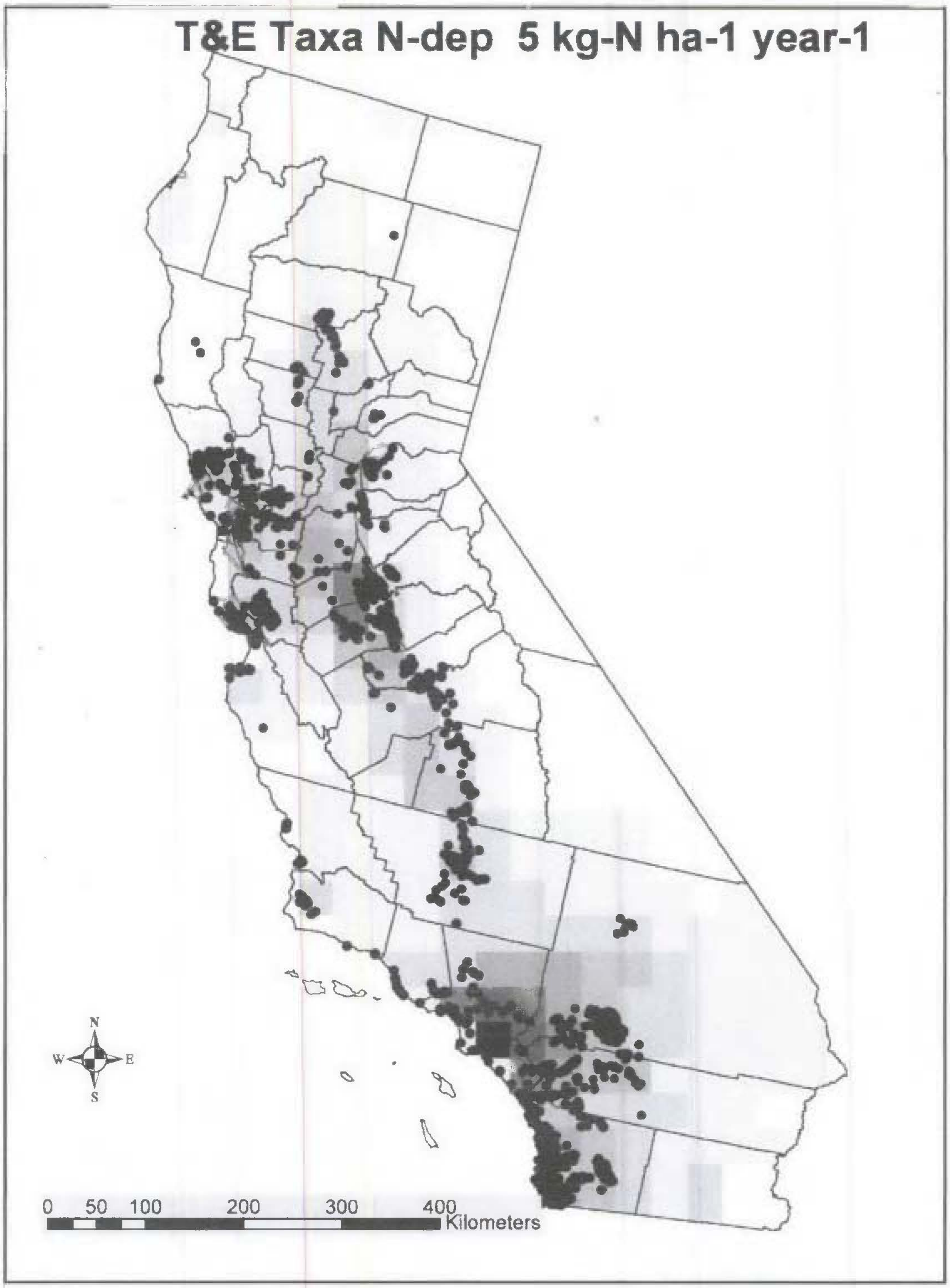

Figure 15. Distribution of federal- and state-listed T&E species exposed to > 5 kg-N ha^{-1} year $^{-1}$

Table 2. Life history exposure > 5 kg-N ha-1 yr^{-1}

Life Form	T&E	Rare	Total
Perennial forb	38	122	160
Annual forb	35	93	128
Shrub	10	41	51
Annual grass	7	2	9
Annual forb, hemiparasitic	4	4	8
Annual-Perennial forb	3	5	8
Tree	1	6	7
Perennial cactus	1	4	5
Perennial sedge		4	4
Perennial fern		3	3
Perennial Forb parasitic		2	2
Annual rush		1	1
Duckweed		1	1
Perennial grass		1	1
Perennial rush		1	1
Total	**99**	**290**	**389**

Table 3. Habitats of plant taxa exposed to > 5 kg-N ha^{-1} yr^{-1}

Habitat	T&E	Rare	Total
(blank)	17	58	72
Rocky	6	41	47
Vernal pools	23	22	45
Sandy		25	25
Open areas	1	18	19
Serpentine	8	11	19
Meadows	5	13	18
Alkali	1	13	14
Dry soils	1	12	13
Clay	5	7	12
Pebble-plain	2	8	10
Riparian	1	9	10
Dunes	4	4	8
Freshwater-marsh	3	5	8
Washes		8	8
Limestone	3	3	6
Disturbed	1	4	5
Gabbro	3	2	5
Salt marsh	3	2	5
Understory		5	5
Granite soils		4	4
Grassland	2	2	4
Ione clays*	3	1	4
Playas		3	3
Alluvial fans	2		2
Lake-margins	1	1	2
Sandstone	1	1	2
Scrub	2		2
Bogs, seeps	1	3	4
Bluffs		1	1
Exposed sites		1	1
Metavolcanic		1	1
Non-native**		1	1
Ponds		1	1
Grand Total	**99**	**290**	**389**

* See Section 2.7.10

** There is some doubt as to whether this one rare species is native or non-native.

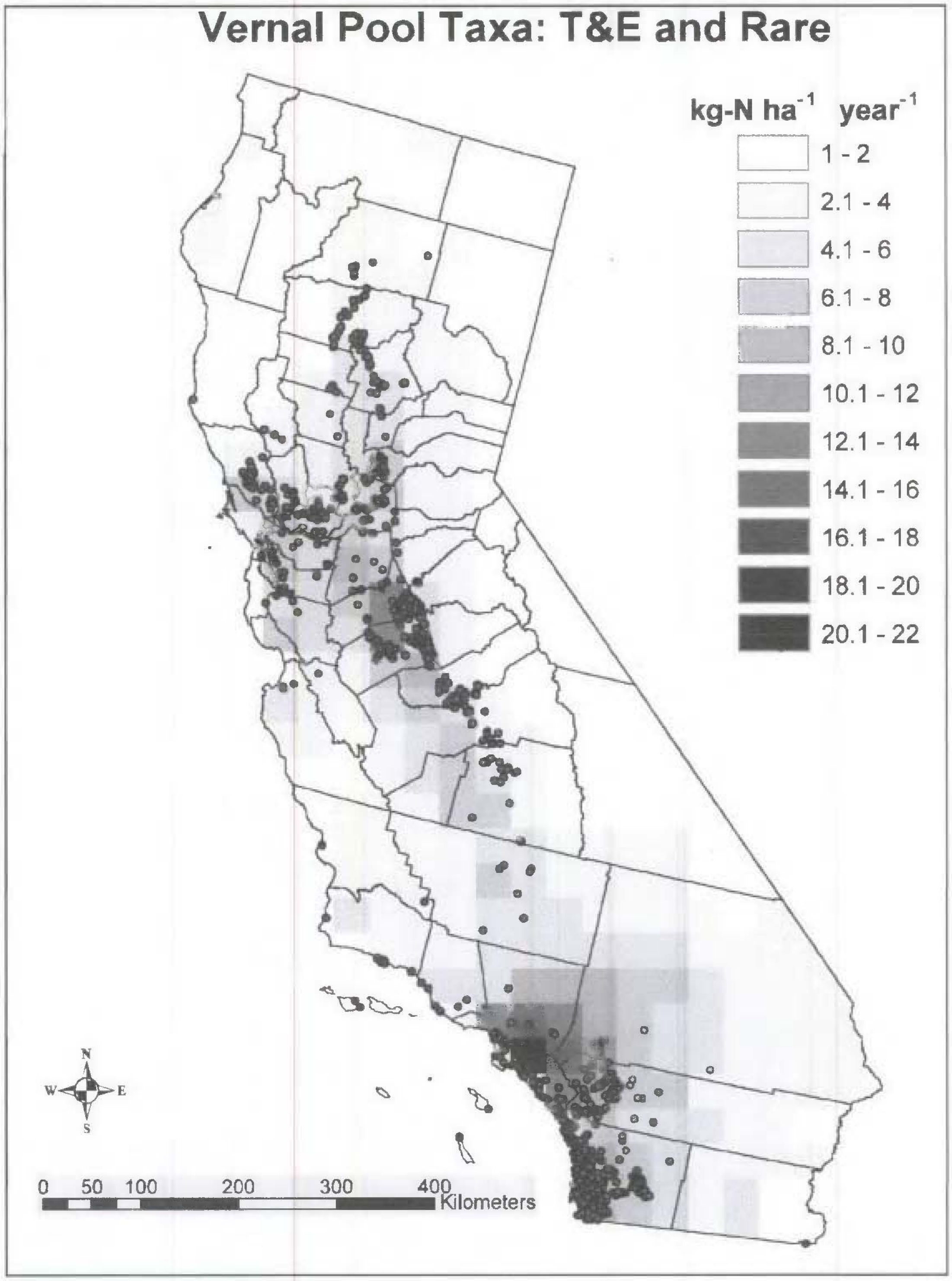

Figure 16. Location of vernal pool taxa exposed to mean > 5 kg-N ha^{-1} yr^{-1}

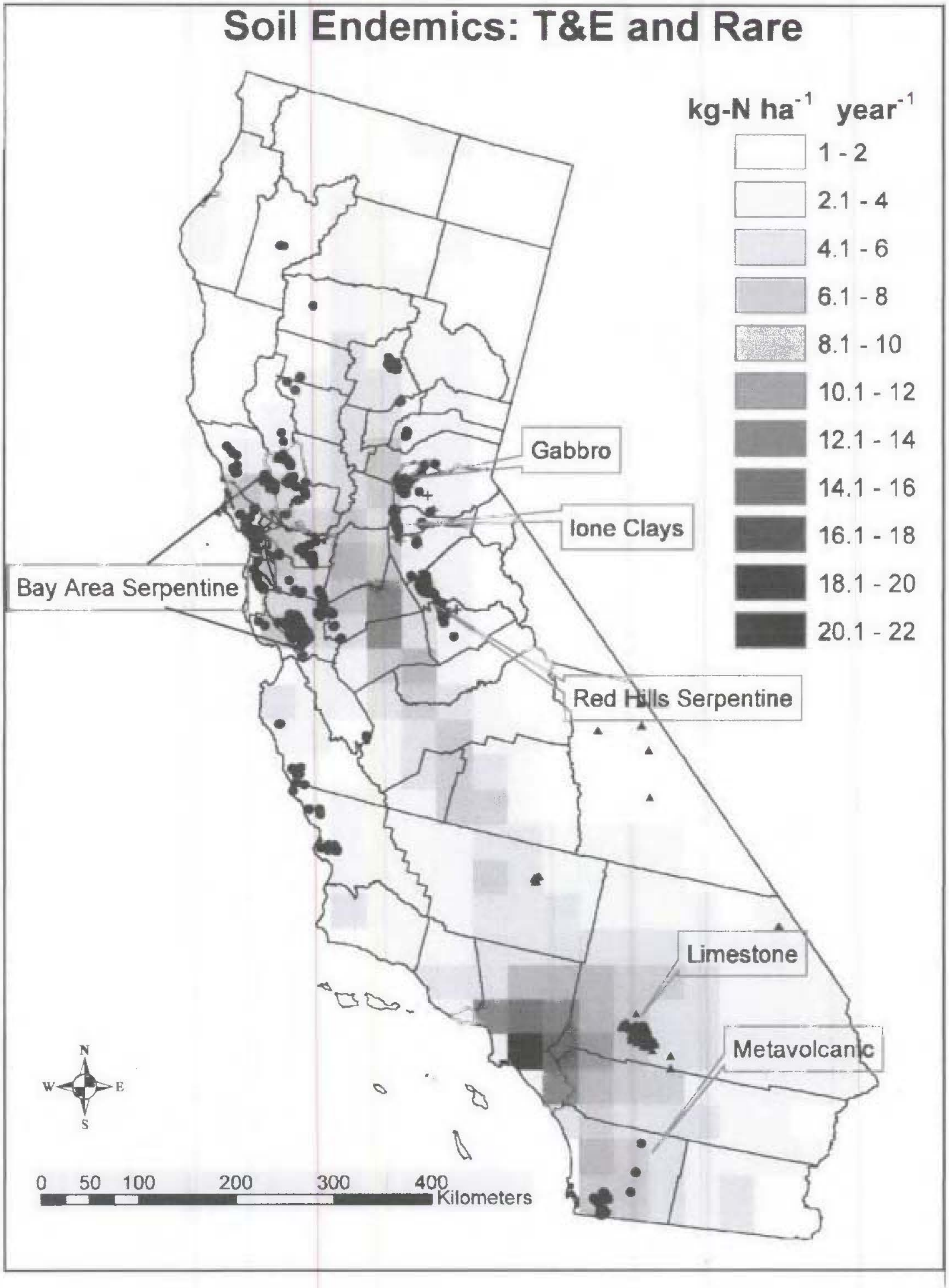

Figure 17. Locations of soil endemic plant taxa exposed to mean > 5 kg-N ha^{-1} yr^{-1}

4.2.2. Animal taxa

The exposure of 108 T&E animal taxa is roughly parallel to that of plants. There are 62 animal taxa below the 5 kg-N ha^{-1} yr^{-1} mean threshold, and 46 above (Figure 18). There are 4 T&E animal taxa above the 10 kg-N ha^{-1} yr^{-1} mean threshold. For maximum exposure, 40 taxa are below and 68 taxa are above 5 kg-N ha^{-1} yr^{-1}, and 28 are above 10 kg-N ha^{-1} yr^{-1} (Figure 19).

The exposure of 339 rare animal taxa is similar (Figure 20). There are 217 rare animal taxa below the 5 kg-N ha^{-1} yr^{-1} mean threshold, and 122 above. There are 5 rare animal taxa above the 10 kg-N ha^{-1} yr^{-1} mean threshold. For maximum exposure, 163 taxa are below and 176 taxa are above 5 kg-N ha^{-1} yr^{-1}, and 61 are above 10 kg-N ha^{-1} yr^{-1} (Figure 21). The geographic distribution of exposed animal taxa is virtually the same as that of the plants, so no map has been prepared.

The CNDDB listed animal species have broad taxonomic representation (Table 4), as do those exposed to > 5 kg-N ha^{-1} yr^{-1}. Species-by-species accounts are beyond the scope of this report.

Vulnerability to N-deposition via grass invasions is most likely in several circumstances. Butterflies and other herbivorous insects are vulnerable to displacement of larval hostplants and nectar sources by annual grasses. These butterflies include: the Bay Checkerspot (*Euphydryas editha bayensis*), in serpentine grassland with mean N-deposition exposure of 5.1 kg-N ha^{-1} yr^{-1}; the Quino Checkerspot (*E. editha quino*), in coastal sage scrub and grassland with mean N-deposition exposure of 6.9 kg-N ha^{-1} yr^{-1}; and Lange's metalmark (*Apodemia mormo langei)* in the Antioch Dunes with mean exposure of 5.2 kg-N ha^{-1} yr^{-1}. The Delhi Sands flower-loving fly (*Rhaphiomidas terminatus abdominalis*) is the most highly exposed animal with mean exposure of 13.7 kg-N ha^{-1} yr^{-1}.

Highly exposed vernal pool invertebrates include various taxa of fairy shrimp; Riverside fairy shrimp (*Streptocephalus woottoni*, mean 9 kg-N ha^{-1} yr^{-1}), San Diego fairy shrimp (*Branchinecta sandiegonensis*, mean 8.2 kg-N ha^{-1} yr^{-1}), Conservancy fairy shrimp (*Branchinecta conservatio*, mean 7.7 kg-N ha^{-1} yr^{-1}), vernal pool tadpole shrimp (*Lepidurus packardi*, mean 7 kg-N ha^{-1} yr^{-1}), Longhorn fairy shrimp (*Branchinecta longiantenna*, mean 6.5 kg-N ha^{-1} yr^{-1}), and vernal pool fairy shrimp (*Branchinecta lynchi*, mean 6.0 kg-N ha^{-1} yr^{-1}) are all vulnerable to grass invasions that shorten the inundation periods of pools (Marty 2005). California red-legged frogs *(Rana aurora draytonii*, mean 5 kg-N ha^{-1} yr^{-1}) and Tiger salamanders (*Ambystoma californiense*, mean 6.1 kg-N ha^{-1} yr^{-1}) often breed in vernal pools and are also highly susceptible to shortened inundation periods.

Animal species dependent on coastal sage scrub, such as the coastal California gnatcatcher (*Polioptila californica californica*, mean 8.7 kg-N ha^{-1} yr^{-1}) are vulnerable to habitat conversion to annual grassland. Animal species dependent on desert scrub may also be vulnerable to habitat conversion.

Threatened and endangered animal taxa and mean, maximum, and minimum N-deposition exposure are listed in Appendix B.

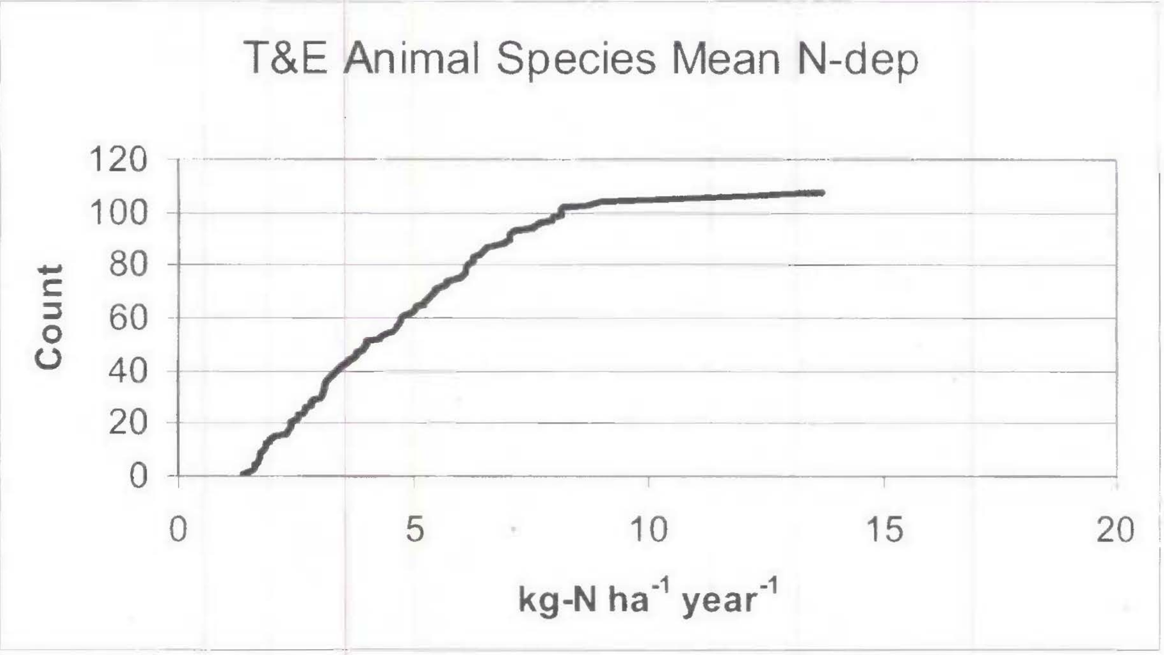

Figure 18. Average N-deposition exposure, state- and federal-listed T&E animal taxa (n = 108)

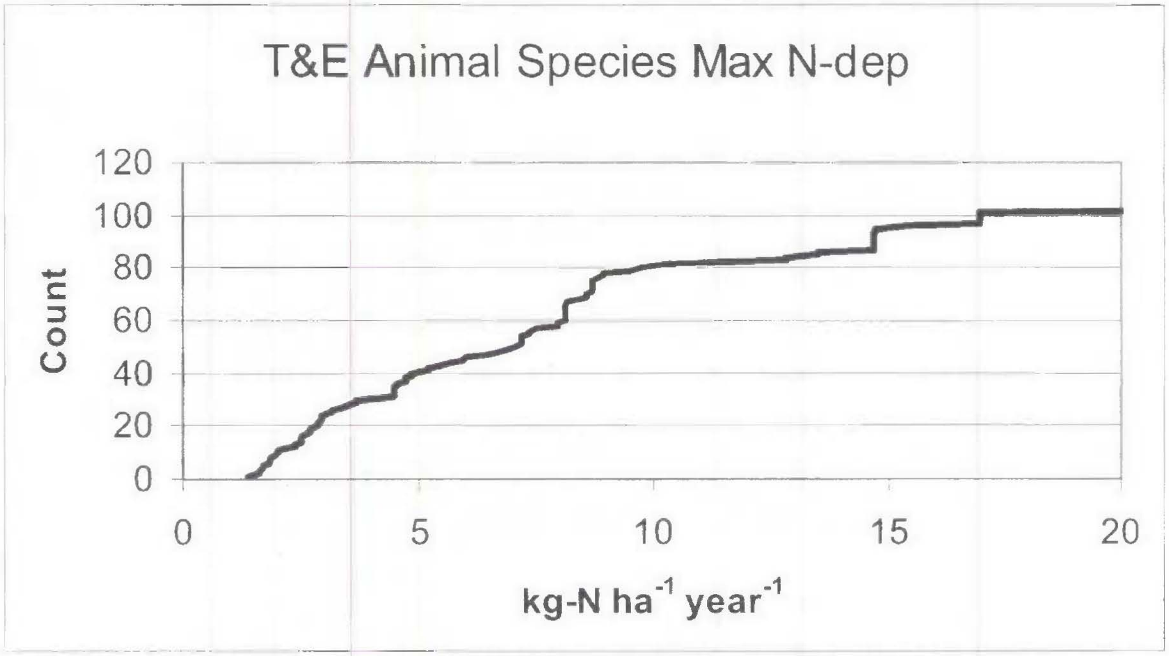

Figure 19. Maximum N-deposition exposure, state- and federal-listed T&E animal taxa (n = 108)

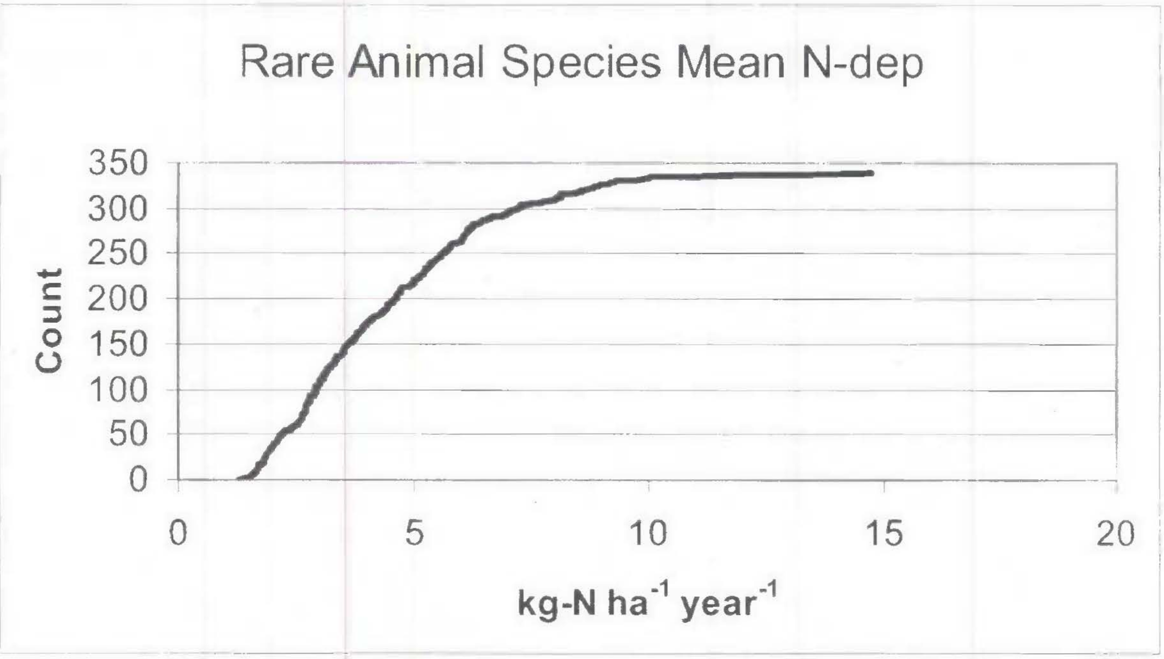

Figure 20. Mean N-deposition exposure, state- and federal-listed rare animal taxa (n = 339)

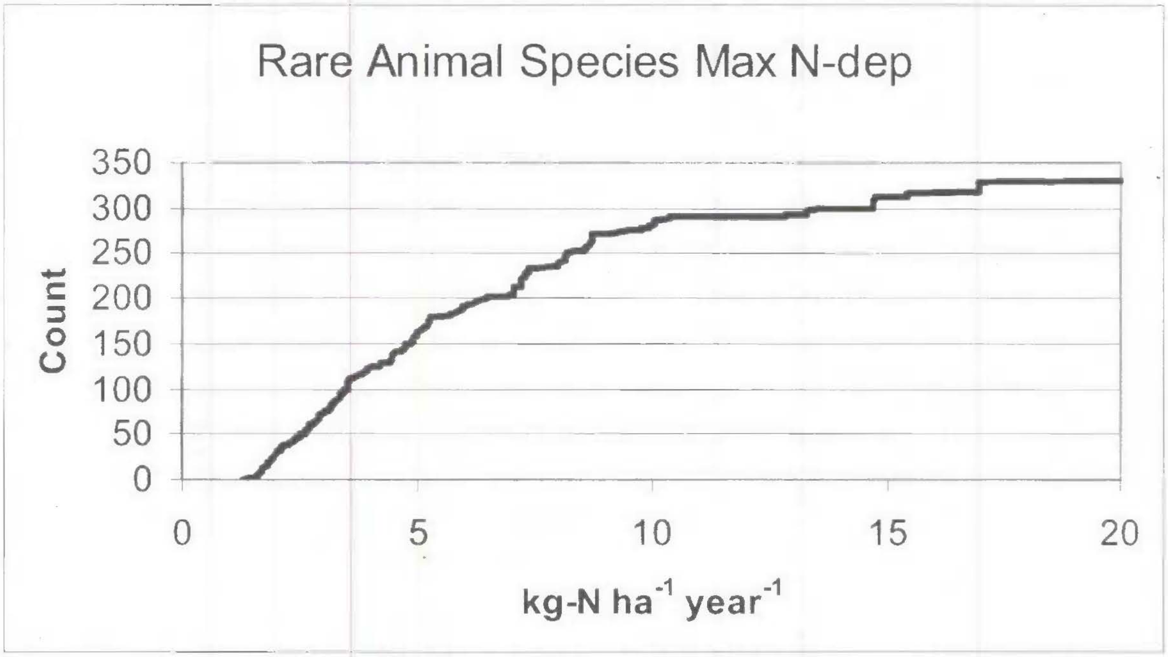

Figure 21. Maximum N-deposition exposure, state- and federal-listed rare animal taxa (n = 339)

Table 4. Taxonomic composition of T&E and rare animals

Life Form	T&E All	Rare All	T&E > 5 kg-N	Rare > 5 kg-N
Fish	26	35	6	6
Bird	25	65	8	28
Insect	19	59	9	22
Mammal	17	62	9	27
Invertebrate	9	60	7	10
Reptile	7	25	3	19
Amphibian	5	32	4	10
Grand Total	**108**	**339**	46	122

5.0 Policy Implications

There is broad scientific consensus that atmospheric nitrogen deposition profoundly changes functioning of ecosystems, which can lead to losses of biological diversity in both terrestrial and aquatic ecosystems (Vitousek 1994; Vitousek, Aber et al. 1997; Fenn, Poth et al. 1998; Galloway, Cowling et al. 2002; Matson, Lohse et al. 2002; Galloway, Aber et al. 2003). A recent synthesis of N-deposition effects in the Western United States (Fenn, Baron et al. 2003; Fenn, Haeuber et al. 2003) documents impacts on numerous California ecosystems. Large areas of California are exposed to highly elevated N-deposition, and the 36 km CMAQ map captures the geographic distribution at a regional level. In this report, the broad-scale overlays of 36 km CMAQ N-deposition with vegetation-types and special status species illustrate the broad threat that N-deposition poses to biodiversity across much of California.

The best documented mechanism for biodiversity impacts is the enhanced invasion of introduced annual grasses, which directly crowd out native species, shorten the fire cycle, and alter hydrology, microclimate, and nutrient cycling (D'Antonio and Vitousek 1992). These effects have been documented and explicitly linked to N-deposition in coastal sage scrub, serpentine grassland, and desert scrub (Fenn, Baron et al. 2003). Annual grass invasions also threaten vernal pools (Marty 2005), and are likely enhanced by N-deposition. Species that may be at risk include many narrowly distributed endemic plants that inhabit nutrient-poor soil types or microsites. Animals that depend on specific plants, hydrologic regimes, or vegetation structure are at risk in the sensitive habitat types. While annual grass invasions are well-documented, N-deposition may be enhancing the spread of numerous other weeds.

There are two routes toward minimizing and mitigating N-deposition impacts on California biodiversity: (1) decreasing N_r emissions into the atmosphere, and (2) preserving and managing sensitive habitats.

5.1. Minimizing N-deposition Impacts Via Emissions Controls

Despite the complexities of N-deposition as a process extending from initial emissions through atmospheric transport and chemical transformations; dry-and wet-deposition; changes in ecosystem function, structure, and biodiversity; and cascading "downstream" effects, the ultimate solution is to greatly decrease emissions. Some of the nitrogenous pollutants of concern are primary pollutants (NH_3, NO_x, and N_2O). Others are secondary pollutants (HNO_3, NO_3- particulates, and NH_{4+} particulates). Policy and regulatory strategies can differ depending on the source and mechanisms of synthesis.

Ongoing efforts to control NO_x emissions from vehicles and industrial sources have somewhat decreased atmospheric concentrations of NO_x in many regions of California, even in the face of population growth (Alexis, Delao et al. 2001). However, emissions of NH_3 are unregulated, although increasing attention is being paid to NH_3 because of its importance as a particulate matter ($PM_{2.5}$) precursor. On a statewide basis, power plants are a relatively minor component of emissions (Alexis, Delao et al. 2001), but nonetheless add both NO_x and NH_3 that will eventually deposit somewhere downwind.

Specific to mitigating power plant sources, the application of Best Available Control Technology (BACT) and purchase of pollution credits have been implemented to meet local air quality regulations (CARB 2000). Pollution credits are primarily aimed at ozone precursors (NO_x and ROG), and direct emissions of PM_{10}. The effectiveness of BACT and emissions credits in minimizing N-deposition is complicated by two factors. First, both NO_x and ROG credits may be purchased to offset ozone precursors, so that the total NO_x emissions may not be covered by emission offsets. Second, selective catalytic reduction (SCR) is recognized as the BACT, but SCR units emit NH_3 (known as *ammonia slip*), especially as catalysts age. There are no emissions credits for NH_3, nor is the additional N-deposition taken into account for NO_x credits. Ammonia emissions from the Metcalf Energy Center (MEC) project (see Table 1) were regulated to a maximum of 10 ppm, which was used in the assessment of N-deposition impacts on adjacent and downwind serpentine grassland habitats. The actual NH_3 emissions from SCR units may be substantially less than the regulated cap.

Determining the best modeling approach for site-specific deposition estimates from new power plants is the subject of the accompanying report by Tonnesen and Wang (forthcoming).

5.2. Mitigating N-deposition Impacts: Habitat Acquisition

Given current levels of N-deposition and the premise that source controls will at best lead to gradual decreases in deposition, the only feasible immediate actions for mitigation are habitat preservation, management, and research.

Identification of sensitive habitats and plant/animal taxa at risk can begin with the analyses presented in this report. The listing of taxa in the tabular data in Appendix B provides an initial start for assessment purposes. An independent search of the CNDDB should provide a relevant list of local special-status taxa. Local knowledge of habitat requirements can place each taxon into a habitat-type, and sensitivity to grass and other weed invasions and other impacts may be assessed. The increased N-deposition exposure of specific habitats can be estimated from modeling.

Preserving habitats through acquisition of fee title or easements is a standard mitigation practice. However, given that even a large power plant will only incrementally increase deposition in the polluted areas where species are at risk, the actual area of habitat protected in such a manner may be small relative to the extent of the target ecosystem. For example, mitigation for the MEC project included 47 ha (131 acres) of serpentine grassland habitat, in a 116 acre parcel adjacent to the power plant; and 6 ha (15 acres) several kilometers away, out of several thousand hectares of serpentine grassland. While transfer of any amount of land into protected status is a positive step, it was the *qualitative* impact of this mitigation—establishing a precedent that could be applied to highway construction, commercial/residential developments, and other power plants—that has provided the impetus for ongoing purchases of hundreds of hectares and the development of a Habitat Conservation Plan/Natural Communities Conservation Plan (HCP/NCCP) for Santa Clara County.

5.3. Monitoring, Adaptive Management, and Treatments

Monitoring and adaptive management of protected land is absolutely necessary, and can extend beyond land directly protected by purchase or easements. Numerous management treatments, including hand labor, targeted herbicides, soil/landscape disturbance, and fire are all worth exploring in one or more of the threatened ecosystems. The key is monitoring and using the monitoring data to inform the next round of treatment options—adaptive management is explicitly experimental and empirical.

For example, in serpentine grassland and vernal pools, moderate well-managed cattle grazing is effective in curbing annual grass invasions and maintaining native biodiversity and T&E/rare species. Grazing management was an explicit component of the MEC mitigation, along with adaptive management of grazing levels based on detailed monitoring of grassland composition.

Many conservation organizations, including The Nature Conservancy, California State Parks, East Bay Regional Park District, and the CNPS, are rethinking attitudes toward grazing management, because of empirical experience with negative impacts of *removing* grazing—primarily enhanced annual grass invasions that reduce native forb and grass cover. Management options may be limited, though. Grazing may be problematic in other ecosystems, such as coastal sage scrub, where the remnants of native forb cover may be on cryptobiotic crusts on clayey soils that are easily disturbed by cattle. Or, the invading grasses may be relatively unpalatable (red brome in deserts, for example).

There are relatively few options for managing annual grasses, besides livestock grazing. Fire may be useful in grasslands, but proper seasonal timing is essential and institutional barriers (air quality concerns, safety, and availability of trained personnel) can limit opportunities. Fire in grass-invaded shrublands is likely to exacerbate the problem and lead to habitat conversion unless restoration measures can be developed. Mowing can be effective if timed correctly, but may have a high cost/acre. Targeted, grass-specific herbicides can be used on fine scales, but broad applications are problematic because of cost, effectiveness, and regulatory concerns. Broadleaf weeds can be controlled by any number of approaches, as well.

Weed management is a regional-scale issue and contributions to Weed Management Areas and other organizations for long-term management of weed invasions may be effective mitigation for the dispersed impacts of N-deposition. Such contributions, in the form of a long-term endowment, may be preferable to buying small, expensive, and difficult to manage mitigation parcels, but these decisions need to be made on a case-by-case basis.

5.4. Research

Research can provide a basis for understanding the complexities of N-deposition impacts, and can guide management decisions. *Adaptive management* views management decisions as experiments that require ongoing evaluation. Monitoring the results of management activities is essential and drastic changes in management need careful consideration and perhaps should be implemented as small-scale experiments.

The complexities of the N-cycle at global, regional, and local scales are widely recognized in the scientific community. Examples include the First, Second, and Third International Nitrogen conferences, multiple sessions at major conferences (e.g., the American Geophysical Union, Ecological Society of America, and others), and specific symposia (e.g., Atmospheric Ammonia Workshop, N-eutrophication Symposium). Many efforts are underway to define long-term research goals for N-science, and the complete research agenda is well beyond the ability of any one agency to fully fund.—Research needs are similar in scale to the carbon-cycle science that has developed over the last decade. The research recommendations below are a small subset of the potential questions and topics that are of interest to California and the Energy Commission in particular.

5.4.1. Estimates of N-deposition

Research all along the pathway of emissions/transport/chemical transformations/deposition is necessary to better quantify the flux of various N-species to ecosystems.

Emissions: Emission inventories are the most uncertain input into models such as CMAQ, and need continual improvement and adaptation to new circumstances. Emissions from power plants are monitored under AQ regulations, but the progression of NH_3 slip over several years under actual operating conditions is an uncertainty that could be reduced by compilation and analysis of emission records from existing SCR units in California and elsewhere, or by collecting new data. A 1-year pilot study could assess existing data and recommend if a multi-year monitoring program (3 years, at a series of power plants) would be necessary.

Modeling: The modeling research needs are dealt with in the accompanying report by Tonnesen and Wang (forthcoming). Ready availability of the 4 km model results—in monthly time steps and by N-species—for regional assessments and validation studies will greatly enhance the capacity to study N-deposition in California.

Measurements: Atmospheric concentrations of N_r species are first-order drivers of N-deposition, and can be measured at various time-intervals. Passive sampling systems economically measure time-averaged concentrations (days to weeks/months) of NO_2, NO, HNO_3, NH_3, and O_3, and can supplement existing AQ networks (Bytnerowicz, Arbaugh et al. 2003). Standardized measurement of NH_3 and HNO_3 concentrations are lacking in current AQ networks. A 1-year scoping study and pilot project on the design and implementation of regional and local passive monitoring networks in California would establish costs and protocols for an optimized network that could answer key N-deposition questions and be used to calibrate AQ models. The 4 km CMAQ output provides a first hypothesis on regional gradients to test with passive samplers.

Throughfall measurements, using ion exchange resins, is a passive method of estimating N-deposition to forests and shrublands but may not capture stomatal uptake and direct deposition to soil surfaces (Fenn and Poth 2004).

Passive flux monitors are a relatively new development (Fritz and Pisano 2002) that allows for directional sampling of total flux (wind speed x concentration) of the same gaseous species as passive samplers. Deployment of a network around a power plant, and relative to other local sources, would deconvolute sources and allow for estimation of the power plant contribution to local concentrations and deposition.

Direct measurement of atmospheric deposition of multiple N-species to various surfaces is one of the most technically challenging fields of science. Eddy-flux systems can be adapted for NH_3 and NO_y, and in conjunction with measurements of CO_2 and H_2O fluxes can establish key deposition parameters such as surface resistances and stomatal conductance under varying conditions and calibrate deposition models to specific ecosystems.

Recent advances in analyses of stable isotopes and radiocarbon provide opportunities to trace emissions sources, deposition rates, and biogeochemical processing (e.g. Kendall and McDonnell 1998). Nitrogen, oxygen, and carbon isotopes provide multivariate information to constrain and deconvolute N-budgets along the N-cascade.

The development of cost-effective biomonitors will be critical for realistic integrated measurements of N-deposition. Field deployable lysimeters—small pots with standardized species composition, soil, and isotopic composition—can potentially measure N-accumulation, isotopic composition, and effects on growth among growing seasons and across local and regional deposition gradients. It may be a challenge to separate out the effects of co-occurring pollutants, especially ozone, but careful consideration of initial lysimeter conditions, local pollution sources, and deployment patterns may overcome these limitations.

5.4.2. Ecosystem impacts

Further studies of all aspects of N-cycling and budgets in California ecosystems are critical. Such research will necessarily be complex, and include field surveys along local and regional gradients, site-specific experiments, modeling, and development of N-deposition indicators in an array of local ecosystems. These studies are more process oriented, and complement targeted surveys of annual grass and other weed impacts in high deposition areas.

Among the key questions to be addressed in an integrated manner are the following:

- How much N_r in various forms is deposited in particular ecosystems, and what are the effective differences between oxidized and reduced N forms? How does direct stomatal uptake effect plant performance compared with throughfall and root uptake?

- How is N-deposition accumulated, stored, cycled, and lost from various ecosystem components through time, especially in low-biomass systems? Key loss processes include: leaching, volatilization, trace gas emissions, denitrification, and fire. Key accumulation processes are plant uptake and storage, litter, and soil organic matter accumulation. The focus on semi-arid California ecosystems would include field measurements and applications of appropriate ecosystem models.

- What is the N-saturation status of California ecosystems? Assessment will require development of ecosystem indicators—N-content of vegetation and soils, readily measured processes that indicate enhanced N-cycling rates, repeatable changes in species composition—and application to known and suspected sensitive ecosystems.

- What are critical loads for particular ecosystems and habitats, and how do we account for the cumulative nature of N-deposition impacts? What are the broad implications for water quality as more ecosystems begin to export nitrate in surface and groundwater?

- How does N-deposition drive weed invasions? Which weed species are particularly advantaged under N-deposition, and how do weeds affect biogeochemical processes, and reduce native biodiversity? Mechanistic studies of differences in response between native species and introduced species could untangle the roles of herbivory, mycorrhizal status, and other ecological interactions in determining the likelihood of N-deposition impacts.

- What are the management and restoration options for mitigating N-deposition impacts? Local studies using good experimental designs should be part of any adaptive management program mandated by mitigation requirements. Other activities include: surveys of existing management activities—grazing and prescribed fire, especially—in a variety of ecosystems and establishment of exclosures.

5.4.3. Education and public awareness

The disruption of the N-cycle is a profound change that is relatively unknown among land managers, regulators, conservation groups, elected officials, and the public at large. A concerted effort to develop appropriate educational materials, both printed and web-based, to raise awareness of the magnitude and severity of the problem among the various groups is a key step in moving toward solutions

5.5. Benefits to California

This research provides a systematic study of known and potential threats of N-deposition to California's biodiversity. The benefits to the state include the following:

- Recognition that N-deposition is a serious threat to biodiversity across much of the state is the first step in dealing with the problem. This report provides technical background material and an entry to the large worldwide N-deposition literature.

- The geographic analyses provide a basis for regional and local studies to further understand the problem. Understanding N-deposition as a driving force behind intensified annual grass invasions and potential intensification of other weed invasions, provides land managers with key information that can inform site-specific management to protect sensitive species and habitats.

- An outline of regulatory guidance (Section 5.6 below) provides a basis for more efficiently establishing mitigation requirements and options to meet those requirements.

- The research recommendations highlight promising and necessary steps to greater understanding of the N-deposition phenomenon and impacts, and can help make California a pioneer in addressing the issues.

5.6. Regulatory Guidance Outline

Based on the procedure followed for the Metcalf Energy Center (Section 5) and other power plant projects (Table 1) the following outline presents a synthesis of key questions to ask and possible avenues for effective mitigation measures. Many of the steps are already routine in an environmental assessment and can be applied to developing impact analysis and mitigation for N deposition.

I. Estimate additional N-deposition generated by a power plant
    A. Use maximum allowable emissions under AQ regulations for the specific plant
        1. May overestimate the actual emissions (especially SCR ammonia slip), but parallels AQ analysis
    B. Estimate spatial distribution of deposition
        1. Model choice and implementation are covered in Tonnesen and Wang (forthcoming)
        2. Background levels for 2002 will soon be available in 4 x 4 km map from Tonnesen et al.
        3. The 36 km map is not suitable for local analysis, except to identify high deposition regions
II. Assess potential impacts on local ecosystems and species
    A. Develop local list of habitat types, rank into qualitative sensitivity classes according to available data
        1. The discussion in this report provides the preliminary list, but local knowledge and expertise are essential.
        2. Consider weed threats to these habitats, especially from annual grass, but also from annual and perennial forbs and shrubs.
    B. Develop a local list of Endangered, Threatened, and Listed Species, along with habitat associations, and rank into potential sensitivity classes according to available data
        1. CNDDB inquiry for local listed species is standard in environmental review. The list of species from the CNDDB in Appendix B of this report

provides an initial screening for species-specific range-wide N-deposition exposure.

2. Finer-scale local data sources and experts should be consulted when available for habitat associations of listed species.
3. Sensitivity of particular species needs to be considered on a local scale. The criteria outlined here—overall exposure statewide from Appendix A, habitat type, life form, and rarity—can be used to rank risks in a local context.
4. Conduct initial surveys to identify potential weed threats to habitats and species.

C. Assess exposure of sensitive elements

1. Choose the most appropriate local/regional habitat maps with explicit connections between sensitive species and habitat types and set target areas.
2. Overlay local map of sensitive habitats with N-deposition exposure from model.
3. If detailed species distributions data are available, also calculate species-specific exposure.
4. Calculate a histogram of annual increment of deposition increase on habitat within areas receiving an increment greater than 0.005 kg-N ha^{-1} $year^{-1}$, the Deposition Analysis Threshold value for Class 1 areas (NPS 2001, www2.nature.nps.gov/air/permits/flag/NSDATGuidance.htm).
5. Calculate the impact as a proportional increase over background levels multiplied by the habitat area affected. However, proportional impacts will be lower in high pollution zones where impacts may already be acute, and higher in low pollution areas. This point needs careful consideration, perhaps in the framework of Prevention of Significant Deterioration (PSD).
6. Apply a mitigation ratio (U.S. Fish & Wildlife Service has used 3:1) to the impact. Mitigation ratios are commonly used for off-site mitigation—if for example, the impact is estimated to be 1 hectare, then 3 hectares of mitigation land need to be secured.

III. Evaluate mitigation options

A. Land purchases

1. If suitable examples of impacted habitat-types of sensitive species are available, then attempt to buy sufficient habitat to meet mitigation ratio.
    a) Areas close to the power plant site that are predicted to have higher deposition increments are preferable to those farther away.
    b) The uncertainties of the real estate market, availability of appropriate habitat, and potentially small size of mitigation parcels are complicating factors, and alternatives to purchase (section III-B) could be considered.

B. Contribution to monitoring, management , restoration, and weed control in local reserves

1. Many established local reserves are in need of targeted management money for short- and long-term weed control. The provision of endowment money specifically for this purpose so that weed control can

be implemented over areas equal to or greater than the mitigation requirement.

    2. Funding for restoration of habitats sufficient to cover the mitigation requirements may be considered.

  C. Contribute to research on N-deposition effects and mitigation options in the region.

    1. N-deposition is a complex process, and funding for targeted research (see research priorities, Section 5.4) may be lacking. Developing methods for monitoring N-deposition, effects on ecosystems, changes in biodiversity, and restoration of degraded habitats can add to capacity for mitigating impacts.

IV. Fund and institutionalize implementation

  A. Develop a Property Analysis Report (PAR) for purchased land, establish an Inventory and Capital Phase, and set aside an endowment sufficient to implement long-term monitoring and adaptive management of target species and habitat.

    1. Monitoring should adhere to high scientific standards, and adaptive management should include experimental scale evaluation of options.

  B. If management monies are used for weed control and management on existing reserve lands, implement monitoring and documentation of the efforts that adhere to high scientific standards.

  C. Require an annual report and meeting of stakeholders.

    1. Field tours during the appropriate season are important to firsthand understanding of issues.

    2. When possible, coordination with other local and regional conservation entities, and adjacent landowners should be pursued.

6.0 References

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Personal Communications

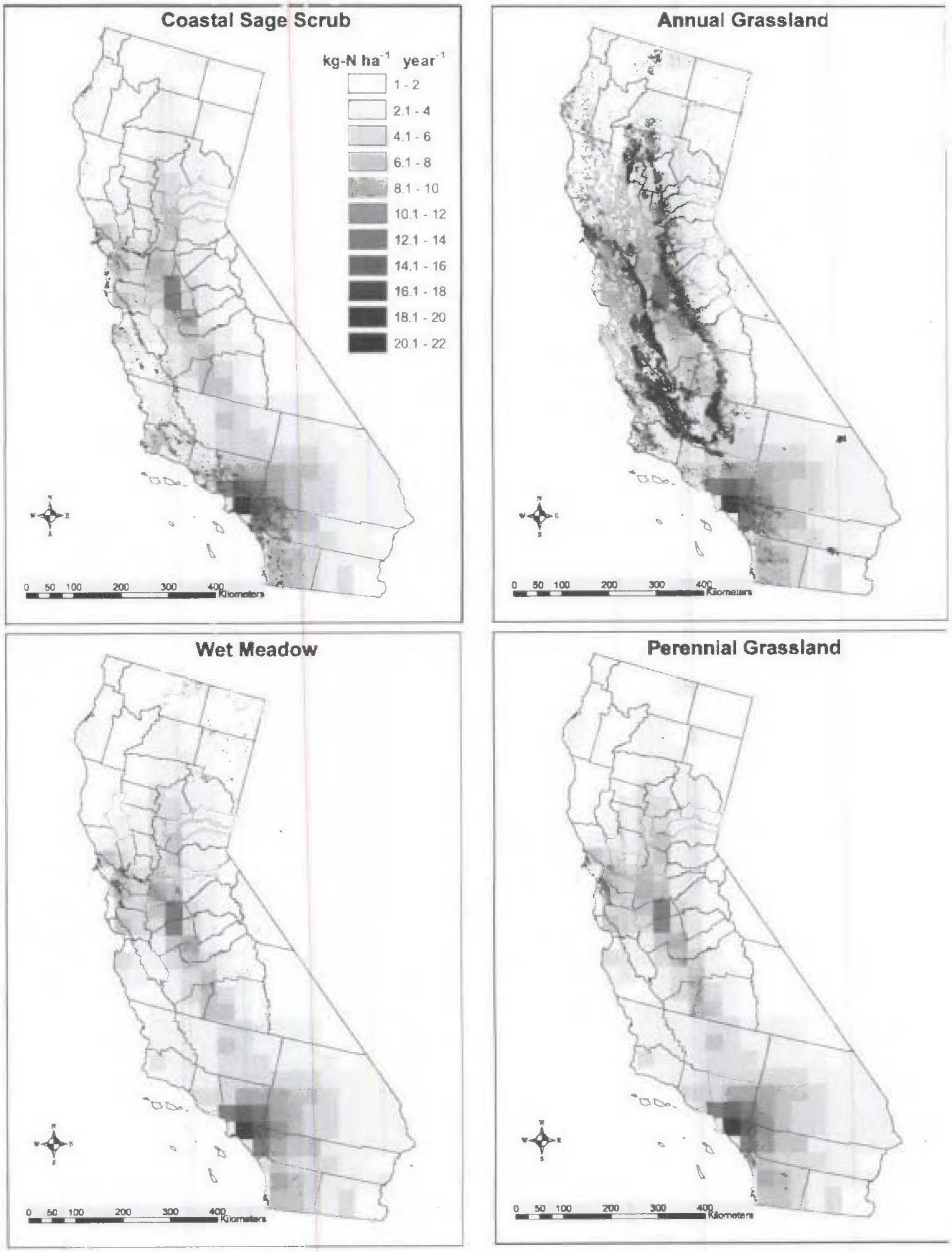
Steve Edwards, East Bay Regional Park District, April 2004
J. B. Norton, UC Cooperative Extension, December 2004
Joshua Schimel, UC Santa Barbara, May 2004
Bill Toone, San Diego Zoological Society, July 2004

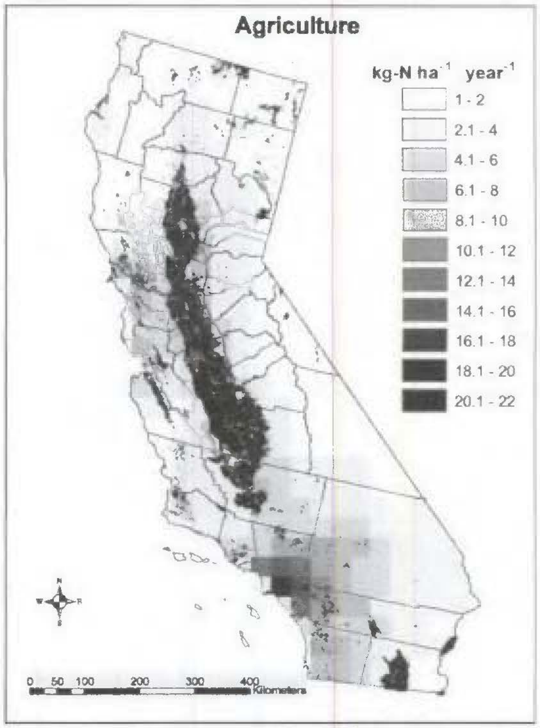
Glossary

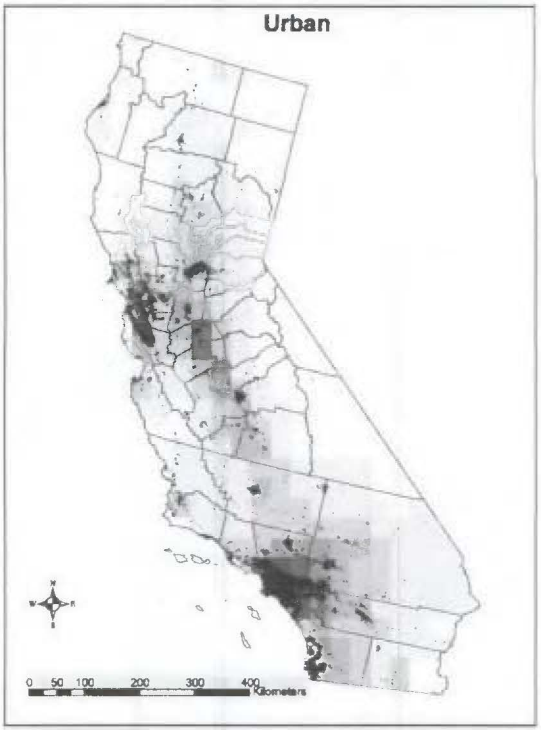
BACT	best available control technology
CDF	cumulative distribution function
cryptobiotic	soil containing microbes that hold together the soil and reduce erosion
depolymerization	the breakdown of proteins into amino acids
edaphic	affected by the soil
eutrophic	nutrient-rich water bodies
forb	a non-woody, broadleaved wild plant, such as many wildflowers
gabbro	coarse-grained igneous rock
halophytes	plants that can live in a saline environment
HCP	Habitat Conservation Plan
herbivory	the process of animals eating plants
HNO_3	nitric acid
hypoxia	a low oxygen supply
lateritic	leached, clay rich soils
mycorrhizal fungi	symbiotic fungi attached to plant roots
N_2	Nitrogen
NCCP	Natural Communities Conservation Plan
net mineralization	the amount of NH_4^+ released from breakdown of organic matter
NH_3	ammonia
NH_4^+	ammonium
nitrophilous	rich in nitrogen
nitrogen-fixing	the ability of a plant to fix atmospheric nitrogen into itself
NO	nitrogen oxide
NO_2	nitrogen dioxide
NO_3^-	nitrate
N_2O	nitrous oxide
oligotrophic	water bodies that have low nutrient levels
PAN	peroxyacetyl nitrate
$PM_{2.5}$	particulate matter ≤ than 2.5 microns
PM_{10}	particulate matter ≤ than 10 microns
pNH_4^+	particulate ammonium
pNO_3^-	particulate nitrate
PON	particulate organic nitrogen
ppm	parts per million
reductase	an enzyme that reduces the substrate
sclerophyllous	tough evergreen leaves
SCR	selective catalytic reduction
SoCAB	South Coast Air Basin
stomata	pores on the underside of leaves
taxa	groups of organisms under comparison
T&E	threatened and endangered
xeric	characterized by a dry habitat

Appendix A

Maps of the 48 FRAP Vegetation Types Overlaid with the CMAQ 36 km Deposition Maps

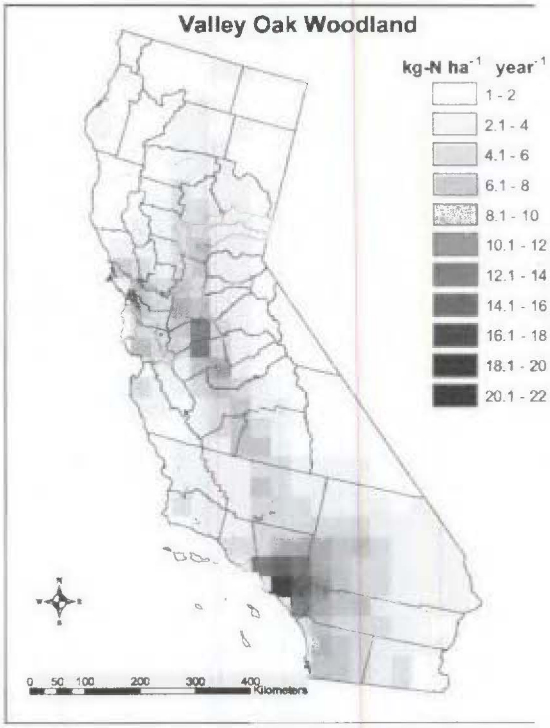

Coastal Sage Scrub
kg-N ha^{-1} year^{-1}
1 - 2
2.1 - 4
4.1 - 6
6.1 - 8
8.1 - 10
10.1 - 12
12.1 - 14
14.1 - 16
16.1 - 18
18.1 - 20
20.1 - 22
0 50 100 200 300 400 Kilometers
Annual Grassland
0 50 100 200 300 400 Kilometers
Wet Meadow
0 50 100 200 300 400 Kilometers
Perennial Grassland
0 50 100 200 300 400 Kilometers

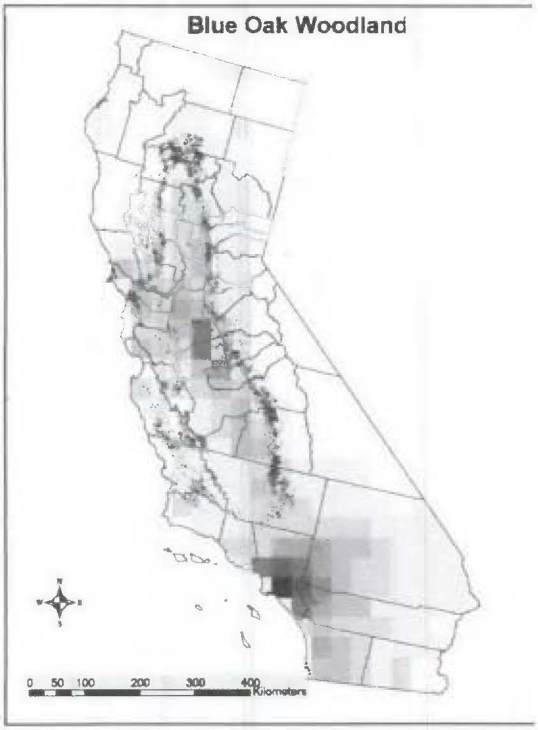

Agriculture

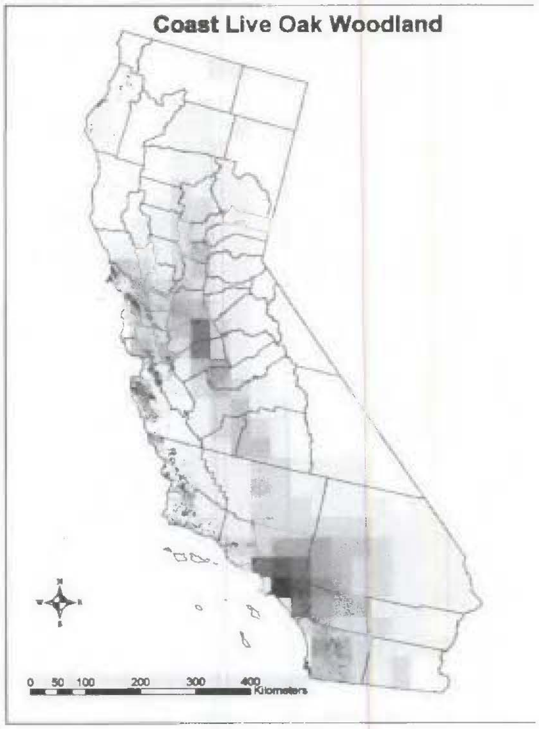

Urban


Urban

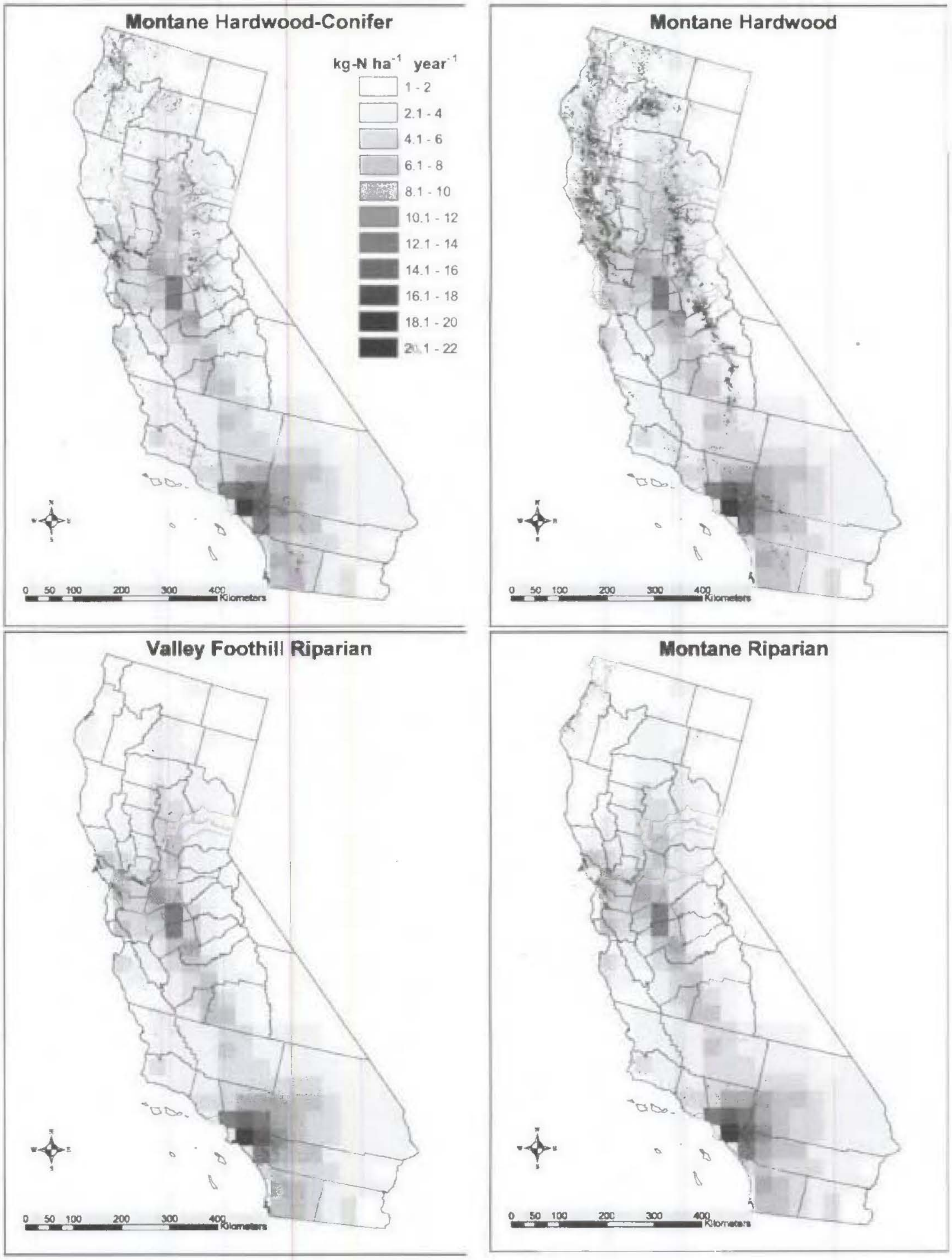

Saline Emergent Wetland

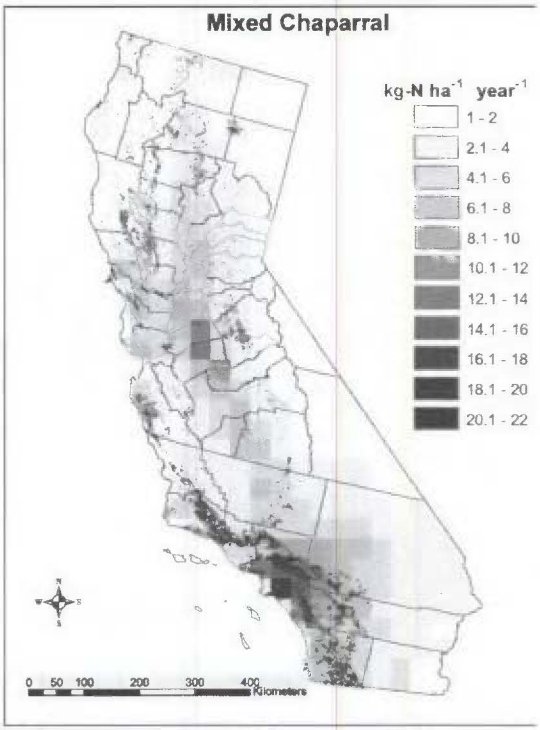

Valley Oak Woodland


Blue Oak Woodland


Coast Live Oak Woodland


Blue Oak-Foothill Pine


Montane Hardwood-Conifer
Montane Hardwood
Valley Foothill Riparian
Montane Riparian
kg-N ha⁻¹ year⁻¹
1 - 2
2.1 - 4
4.1 - 6
6.1 - 8
8.1 - 10
10.1 - 12
12.1 - 14
14.1 - 16
16.1 - 18
18.1 - 20
20.1 - 22
N
W
E
S
0 50 100 200 300 400
Kilometers

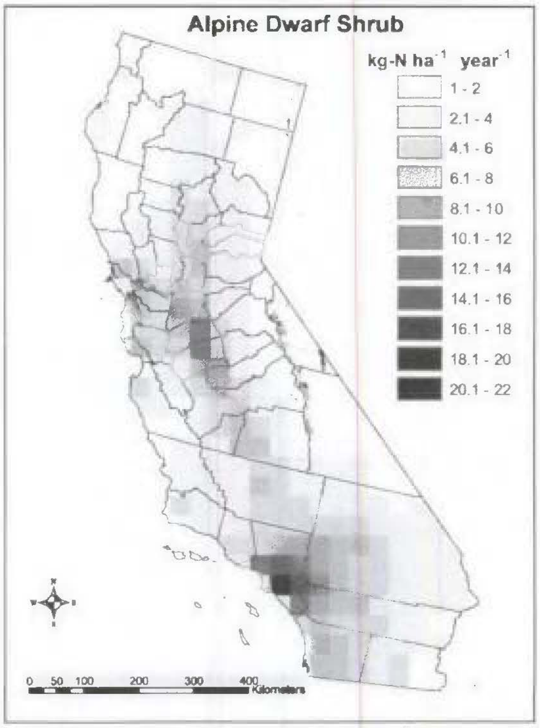


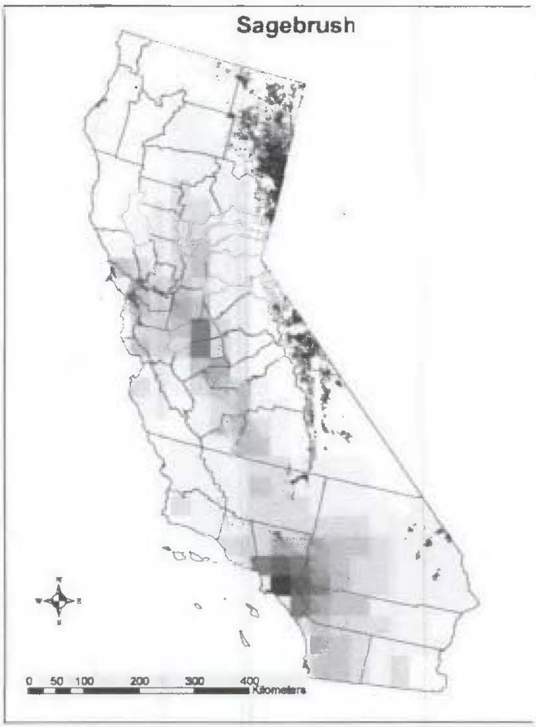
Mixed Chaparral

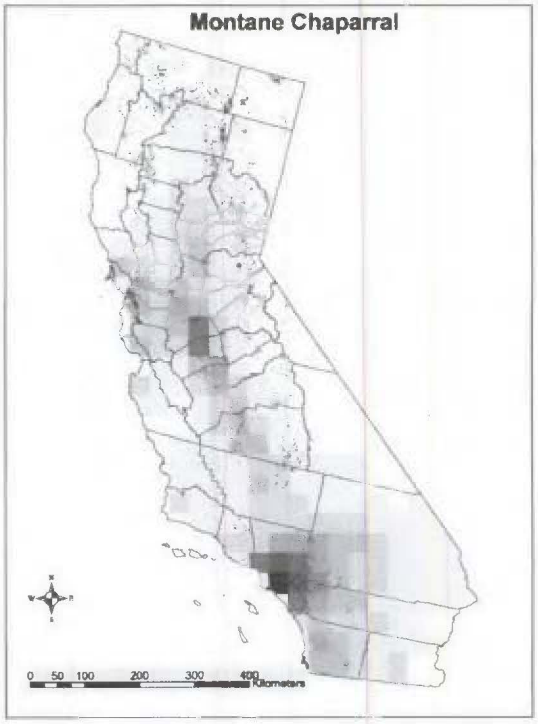
Chamise-Redshank Chaparral

Unknown Shrub Type

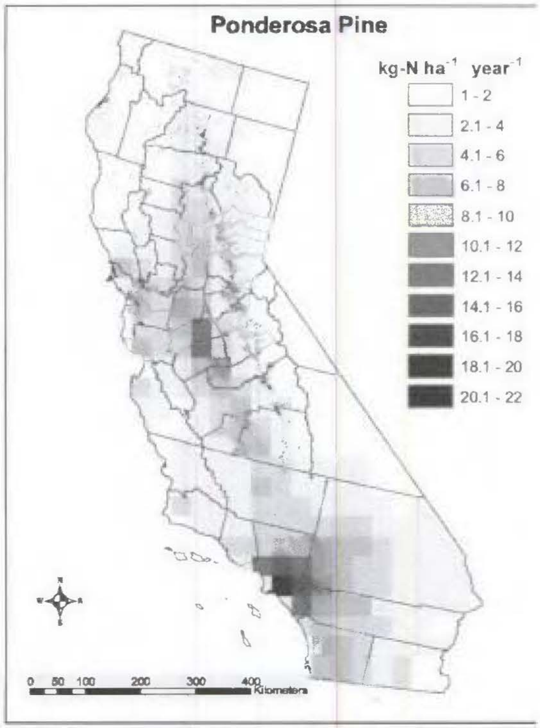
Bitterbrush


Alpine Dwarf Shrub
kg-N ha-1 year-1
1 - 2
2.1 - 4
4.1 - 6
6.1 - 8
8.1 - 10
10.1 - 12
12.1 - 14
14.1 - 16
16.1 - 18
18.1 - 20
20.1 - 22
0 50 100 200 300 400
Kilometers

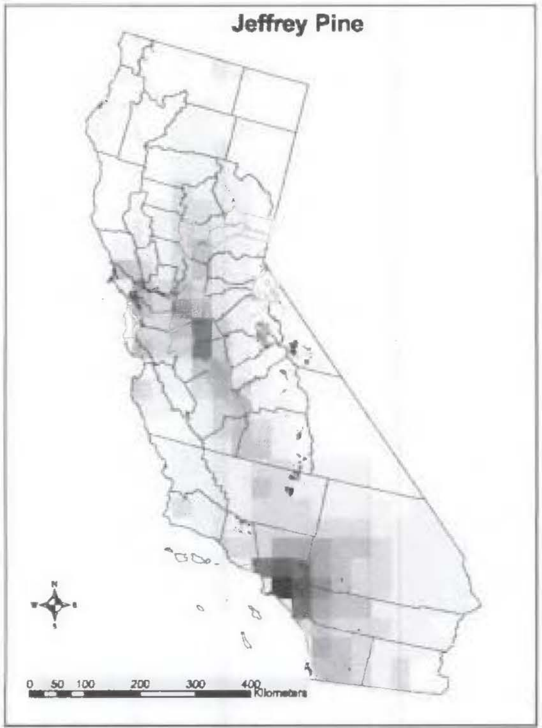

Sagebrush
0 50 100 200 300 400
Kilometers


Montane Chaparral
0 50 100 200 300 400
Kilometers

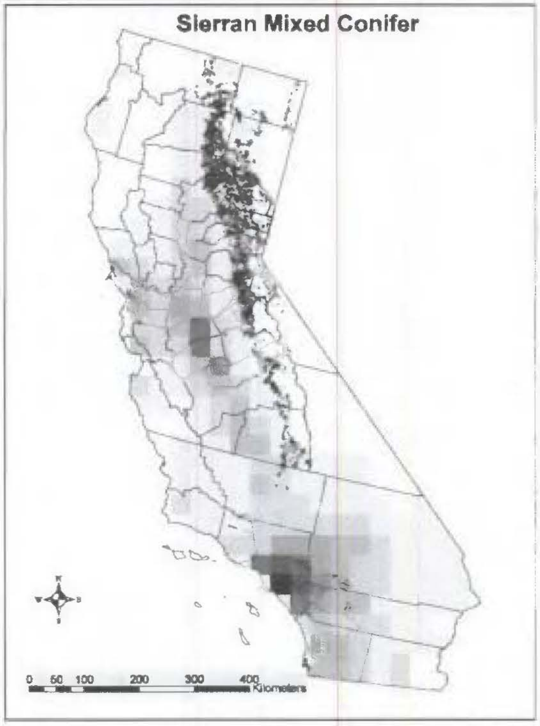

Low Sage
0 50 100 200 300 400
Kilometers



Ponderosa Pine

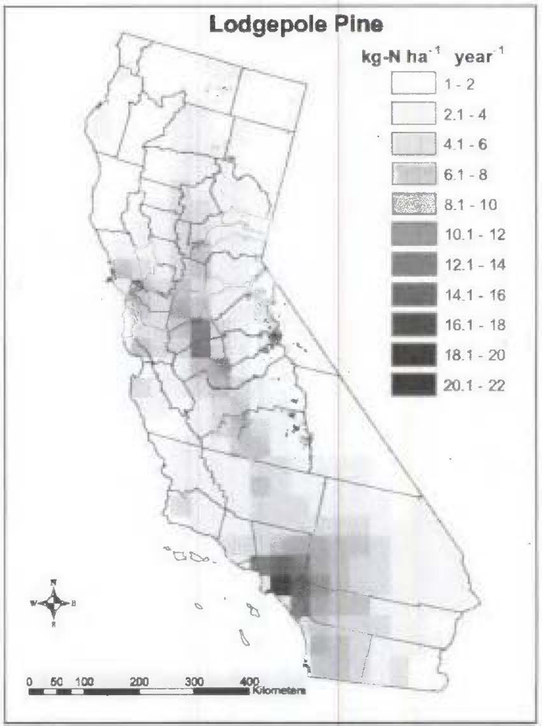


Jeffrey Pine

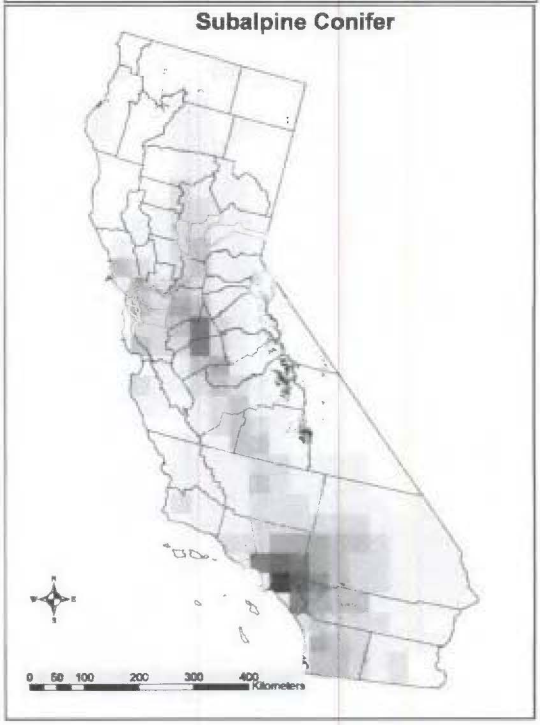


Sierran Mixed Conifer

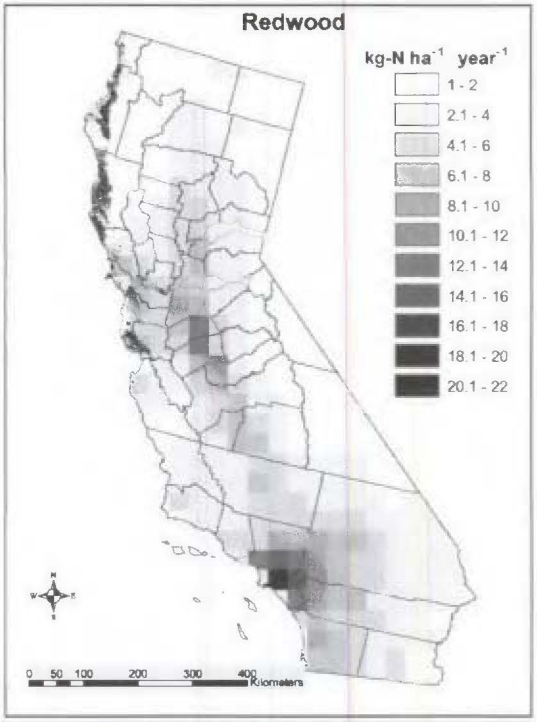
White Fir


Lodgepole Pine


Red Fir

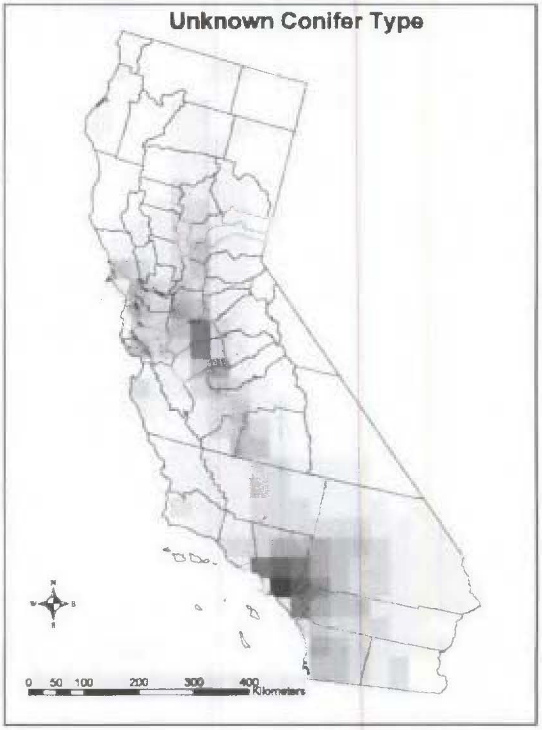

Subalpine Conifer


Eastside Pine

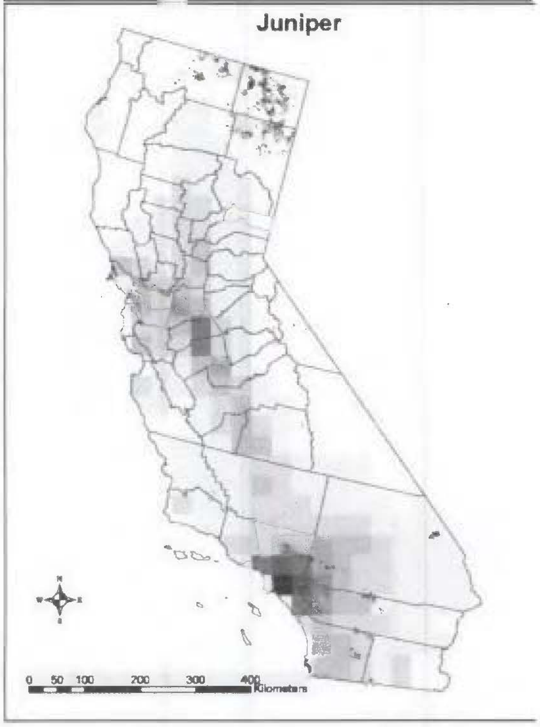


Redwood

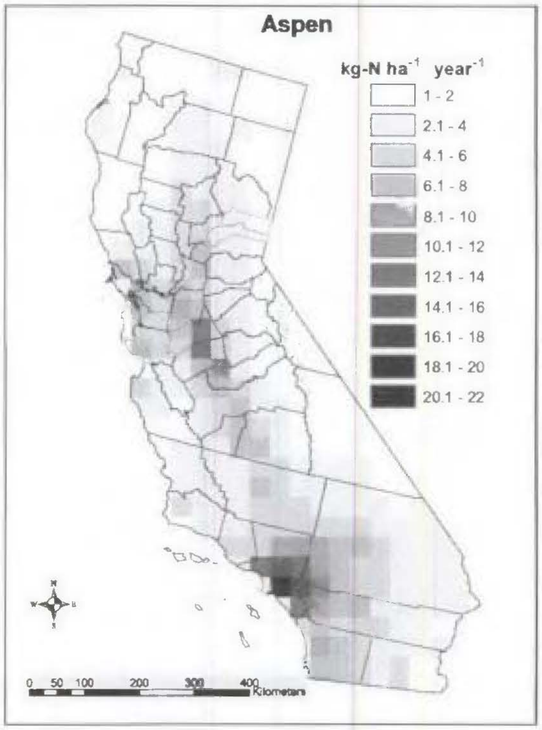
Klamath Mixed Conifer



Unknown Conifer Type



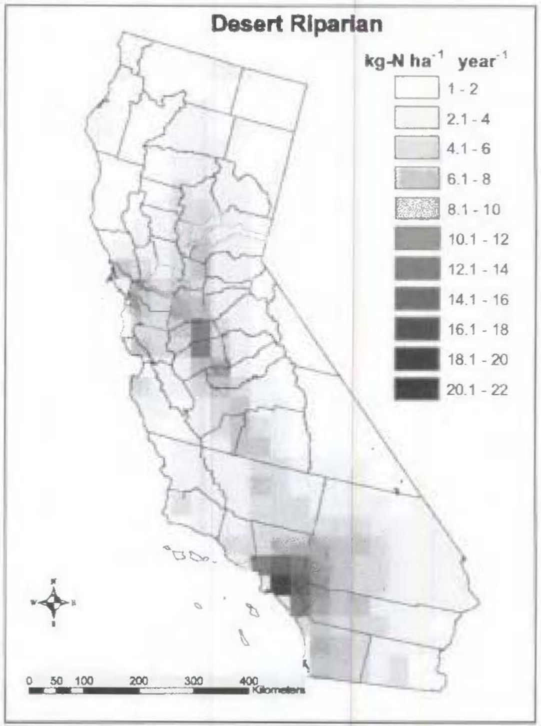
Juniper


Aspen


Closed-Cone Pine-Cypress

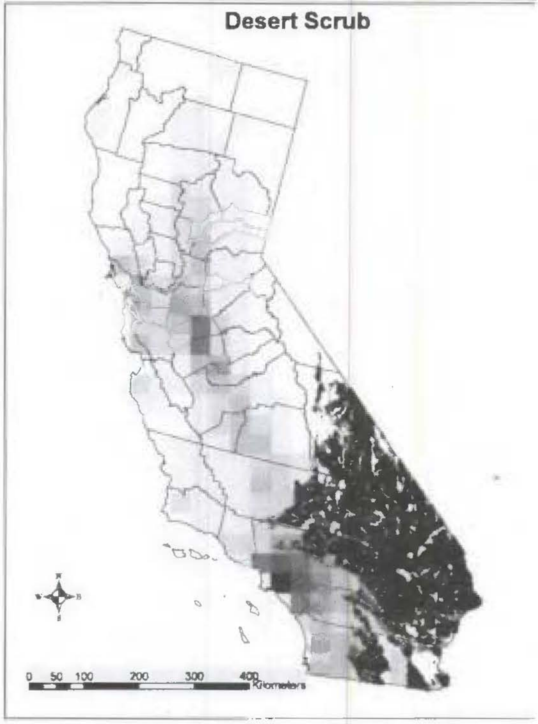

Pinyon-Juniper


Eucalyptus

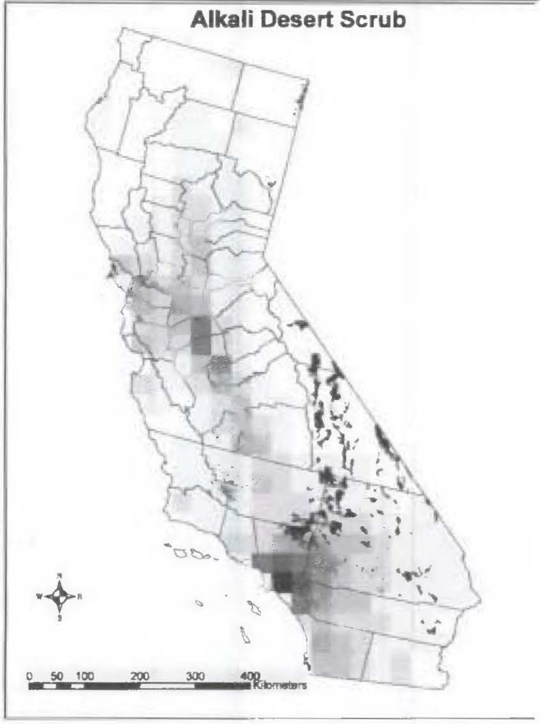


Desert Riparian

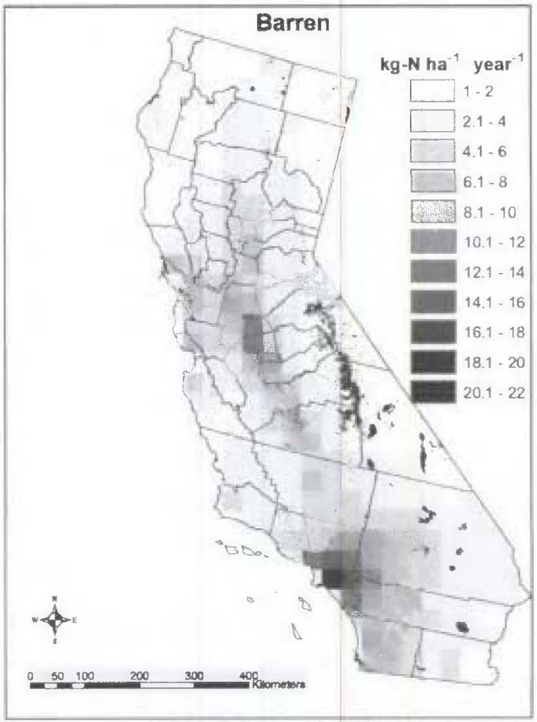
Palm Oasis



Desert Scrub



Alkali Desert Scrub



Barren

Joshua Tree

Desert Succulent Scrub

Desert Wash

Appendix B

California Natural Diversity Data Base (CNDDB) Plant and Animal Taxa List with N-deposition exposure

This Excel spreadsheet contains information from the California Natural Diversity Data Base (CNDDB) and the 36 km CMAQ map. The codes for Fedlist and Statelist (columns G and H) are 1 = Endangered, 2 = Threatened, and 3 or more = Rare. Global and State rankings (columns N and O) are The Nature Conservancy classifications of status, and definitions can be found at the CNDDB site. Nitrogen deposition exposure is in kg-N ha^{-1} yr^{-1} (columns I [Mean], J [Max], and K [Min]). Threatened and Endangered status (column V) is inclusive of both state and federal lists.

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Phone

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