Biogeochemical Cycles and Soil Biology Following Fire and Invasive Species in the Desert

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Objectives

- Present new results and review literature on impacts of fire in invaded and native deserts
- Discuss changes in soil biology, chemistry, and physical properties
- Discuss implications for biogeocycling
- Present research needs

Point 1: Invasives have a more persistent effect on soil ecology than fire

- Ecosystems can recover from fire through successional processes
- Invasive species are persistent and cause permanent changes, except in some cases where they can be removed/restored
- There are interactions between invasive species and fire--the main concern of this symposium!

Number of studies showing changes in soil parameters following invasive or exotic species

Parameter	increase	decrease	no change
Plant biomass	**16**	4	0
NPP	**10**	0	2
Growth rate	**10**	0	0
Litter mass	7	5	2
R/S	1	**5**	1
Soil C	6	6	1
C mineralization	**4**	2	2
Decomposition	**10**	2	0
microbial C	**3**	1	2
Total soil N	**9**	6	6
Extr. soil N	**9**	4	4
N mineralization	**13**	3	2
N fixation	**8**	2	0
Biomass N	**11**	1	2
Soil C/N	2	1	1

From Ehrenfeld, J. G. 2003 Ecosystems 6:503

Sometimes the same species can have different effects in different ecosystems: cheatgrass

- Cheatgrass invading C_4 grassland on the Colorado Plateau caused <u>decreased</u> N supply, <u>decreased</u> N mineralization, increased litter C:N (Evans et al 1995 Ecol Appl)
- Cheatgrass invading Great Basin sagebrush-steppe always had <u>increased</u> soil N and other nutrients (Blank 2004 IPSM)
- Cheatgrass-dominated soils had higher N_2O emissions (Norton et al 2008 SBB)

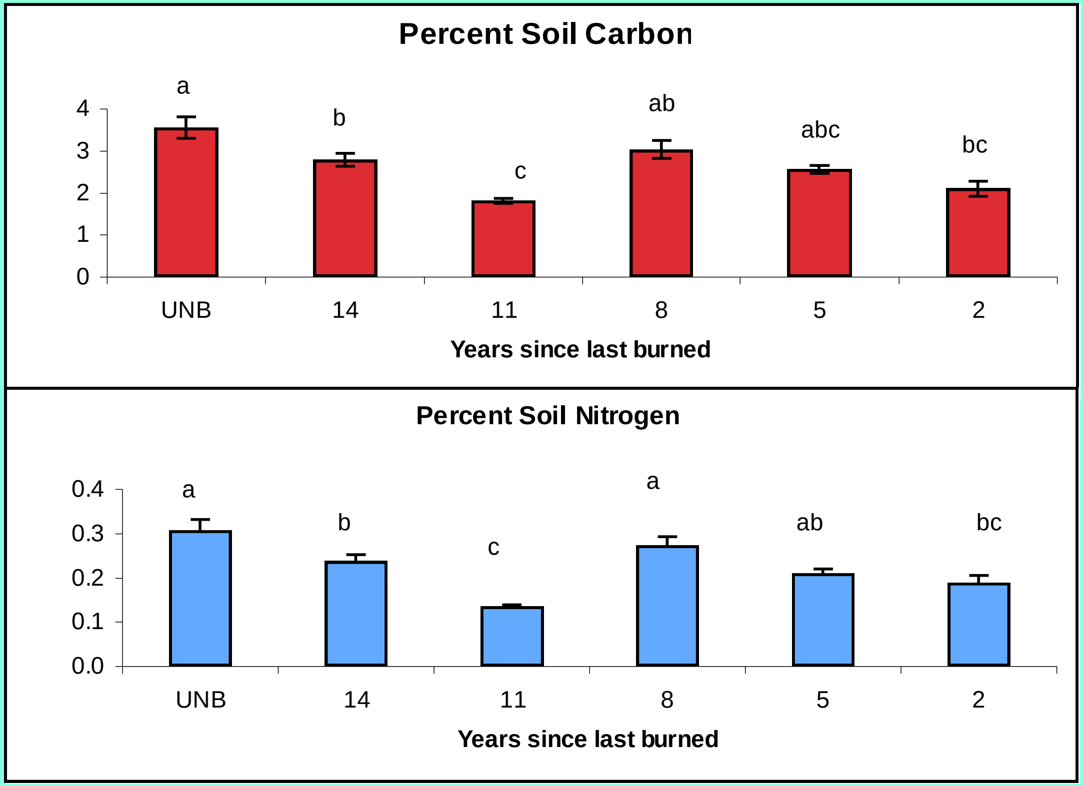
Fire effects: Changes in arid/semiarid soil physical and chemical properties following fire, most with native vegetation (summary of 26 studies)

PROPERTY	INCREASE	DECREASE	NO CHANGE
soil total N	1	**11**	5
soil O.M., C	3	**11**	4
soil extr. N	**11**	4	3
soil extr. P	**6**	3	3
other ions	**8**	6	4
soil pH	**10**	0	2
bulk density	**4**	0	1

Point 2: Desert fires fueled by either invasive or native plants decrease soil total N and C

- Ignition of organic matter on surface soil will cause loss of N (200^{o}C) and C (180^{o})
- As much as 50% of litter and plant tissue N can be lost in a hot fire (500^{o})
- Aboveground N is a small fraction of total N in deserts with high root/shoot ratio
- Recovery of N depends on rate of plant growth and new N inputs following burn

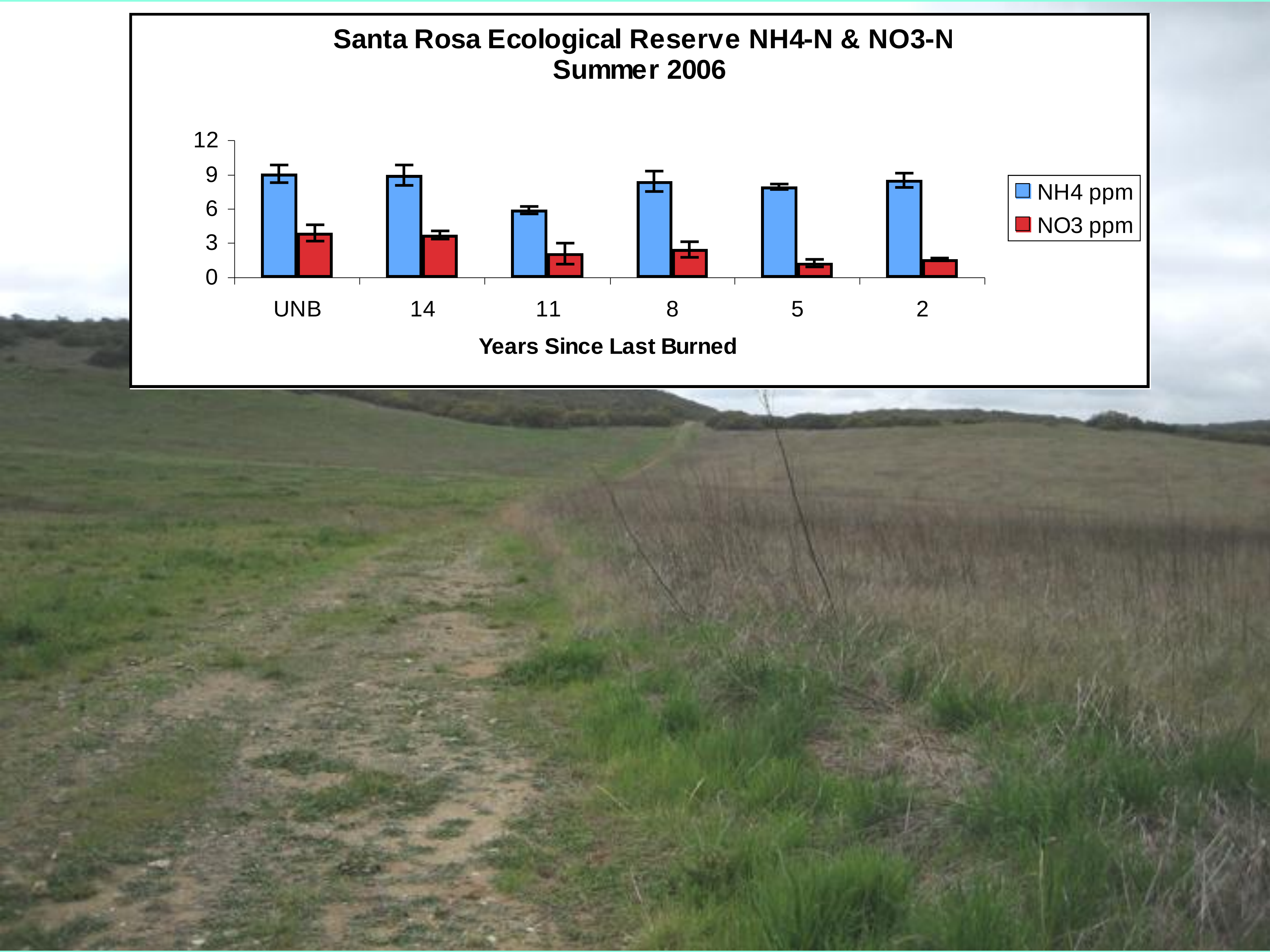
% Soil C and N in semiarid grassland in S. CA, burned 2 to 14 years ago, and unburned



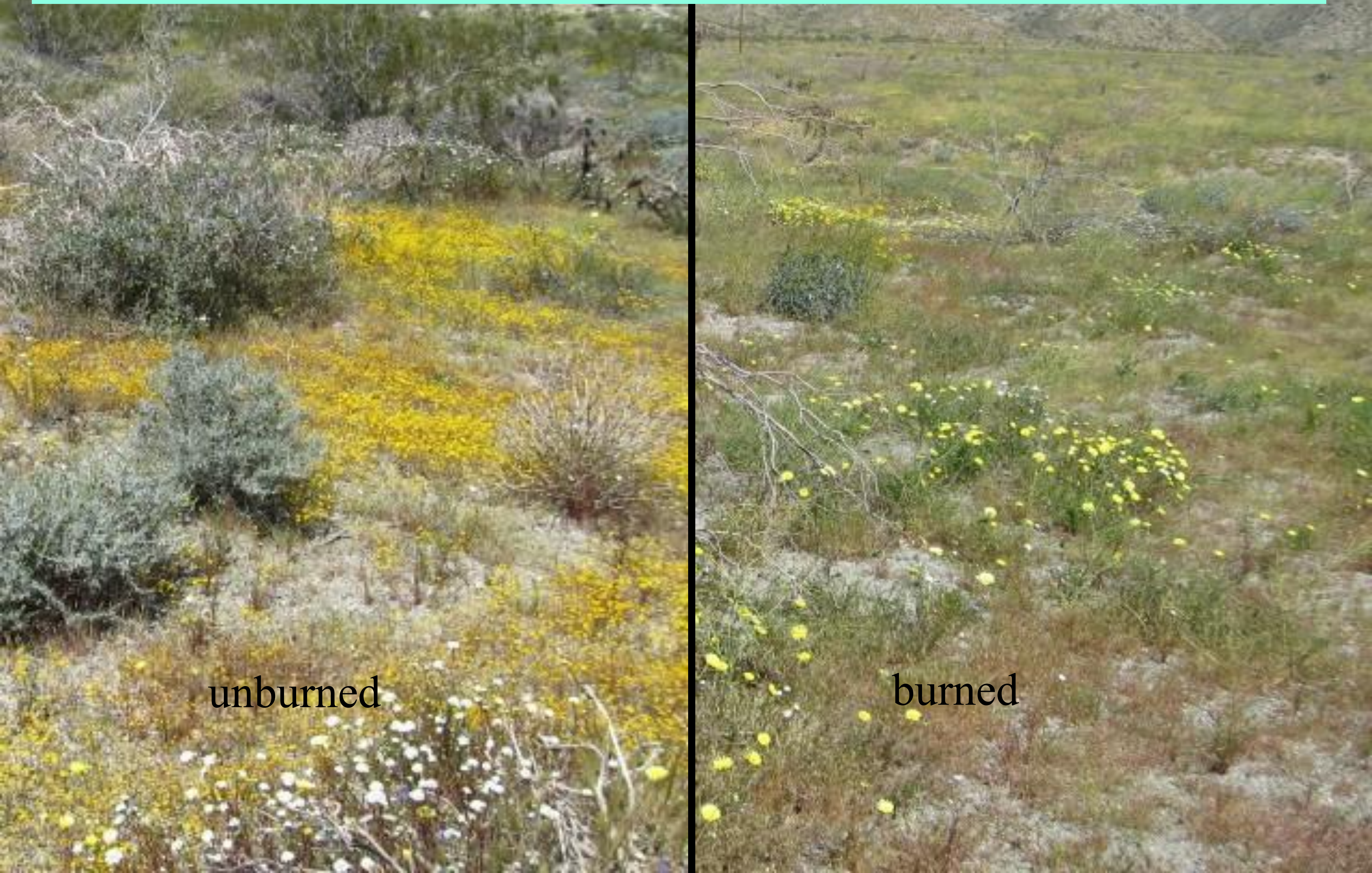
All sites have been burned 2-3 times in the past except 11 year (one time) and UNB (at least 20 years since fire)

Point 3: Desert fires fueled by either invasive or native plants <u>initially increase soil extractable N</u>

- Most studies show an initial increase in mineral N (NO_3^- and NH_4^+) and other nutrient ions following fire
- High plant production and tissue N immediately following fire is the result of N mineralized by fire
- Mineral N may return to pre-fire levels after only 1-2 growing seasons

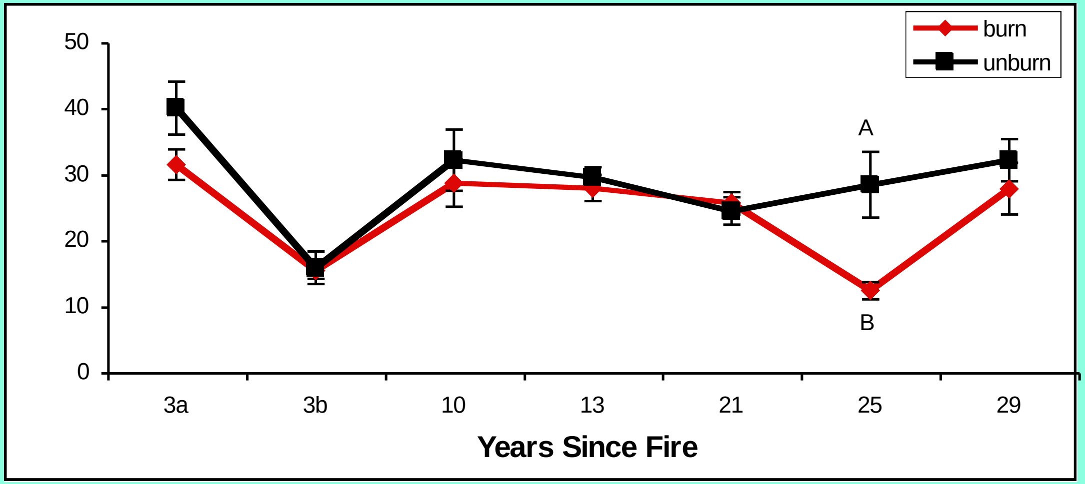

Santa Rosa Ecological Reserve NH4-N & NO3-N
Summer 2006
12
9
6
3
0
UNB
14
11
8
5
2
Years Since Last Burned
NH4 ppm
NO3 ppm

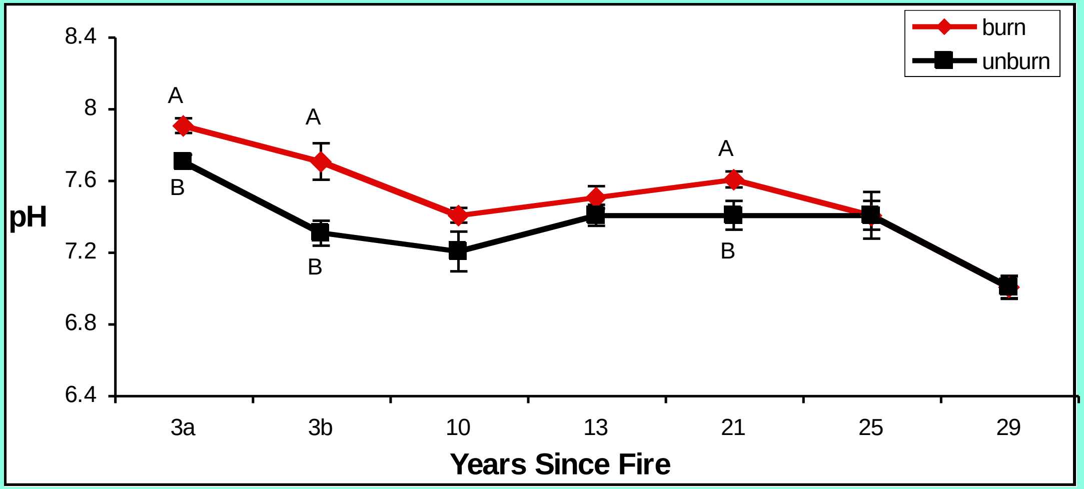
Succession study in creosote bush scrub, Coachella Valley, CA, paired sites burned 3 to 29 years ago



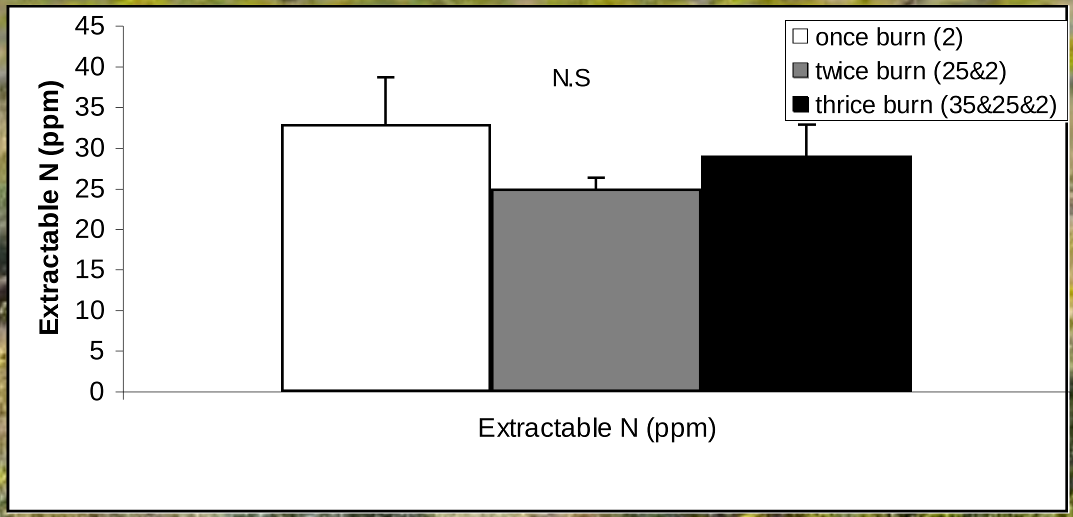
Extractable N and pH in burned creosote bush scrub, 3 to 29 years

No differences in total N, C, or P in these sites with burn age





Point 4: Do multiple fires following invasions reduce soil N? No significant changes in three Coachella Valley sites



Snow Creek, burned 1983, now dominated by brittlebush

Point 5: Desert fires may destroy shrub "islands of fertility"

- Multiple fires in juniper woodland and mesquite <u>reduced</u> island fertility (White et al 2006 REM, Wilson & Thompson 2005 Geoderma)
- Increased hydrophobicity of soils under burned shrubs (Ravi et al 2007 J Geophy Res)
- Creosote bush was replaced by brittlebush in Coachella Valley (Steers 2008)
- In contrast, extractable N was higher under burned juniper than interspace (Stubbs & Pyke 2005 Pl&So)

Soil nutrients under creosote bush and interspace

	Total N %	NH4 ppm	S.E.	NO3 ppm	S.E.	Total P ppm	S.E.	Olsen P ppm	S.E.
interspace	<0.05	0.40	0	1.4	0.1	530	4	1.77	0.4
under shrub	**0.064**	**0.37**	0.11	**11.7**	1.4	**650**	2	**12.3**	0.1

From the standpoint of ecosystem functioning, loss of shrub islands may be the most damaging effect of invasions following fire. Brittlebush, which colonizes after fire, does not form fertile islands

Unburned creosote bush

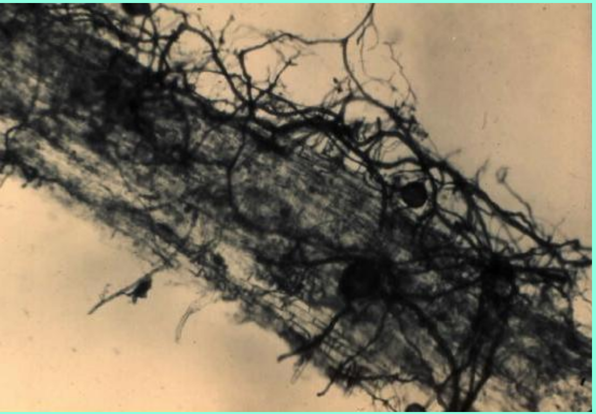
Burned site with brittlebush

Point 6: Desert fires have no long-lasting effect on mycorrhizae or other microorganisms beneath the surface

- Soil is a good insulator, and microorganisms a few cm deep are protected from all but the most extreme burns, e.g., slash piles
- Surface microorganisms that are burned may recover within a few years
- Alternatively, microbial species composition may be altered by invasive species. Fire following invasions may have a positive feedback on microorganisms as well as plants

Mycorrhizal response following fire

Source	vegetation	location	AM/ EM	root infection	other
Stendell 1999	pine forest	California	EM	high infection	reduced fungal species, biomass
Baar 1999	pine forest	California	EM	high infection	reduced fungal species
Miller 1998	pine forest	Yellowstone	EM	50 % of seedlings died, survivors were EM	
Launonen 1999	eucalyptus	Australia	EM	NC or reduced	dependent on soil type
Rashid 1997	shrubland	Pakistan	AM	NC	inoculum in resprouts
Anderson 1997	pine/grass	Florida	AM	NC	
Korb 2003	pine forest	Arizona	AM	NC	
Korb 2004	pine forest	Arizona	AM	reduced	intense fire, slash piles
Haskins 2004	pinyon-juniper	Arizona	AM	Recovered in 5 years	Intense fire, slash piles



AM = arbuscular mycorrhizal,
EM = ectomycorrhizal

Initial (1-2 yr) effects of fire on other microbial processes

- Bacterial density + or - (Acea 1996)
- Soil respiration + or - (Badia 2003, Bauhus 1993)
- Nitrification + (Bauhus 1993)
- N mineralization + or - (Ojima et al 1993)

Point 7: Cryptogamic crusts may recover from fire event, but were obliterated following cheatgrass colonization

- Recovery of biotic crust after fire occurred only on sites with native bunchgrass, not cheatgrass (Ponzetti et al 2007)
- Crust had reduced N fixation after fire in shortgrass steppe, but effect was short-lived (Ford et al. 2006 J Arid Env)
- Fire caused no net change in lichen N fixation in Mongolian grassland (Wu et al. 2008)
- Colonization of cheatgrass in formerly pristine bunchgrass greatly reduced biotic crust (Belnap et al.)

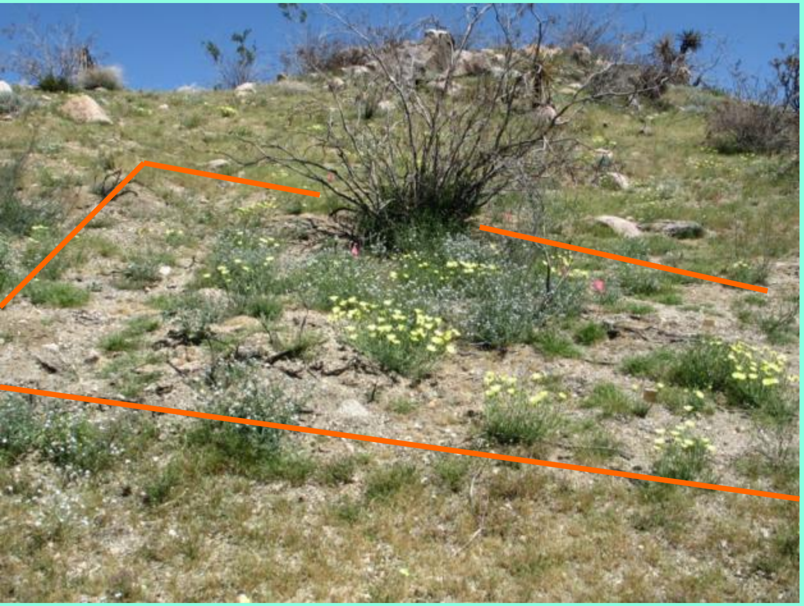
Point 8: Desert fires reduce seed banks of native and invasive species

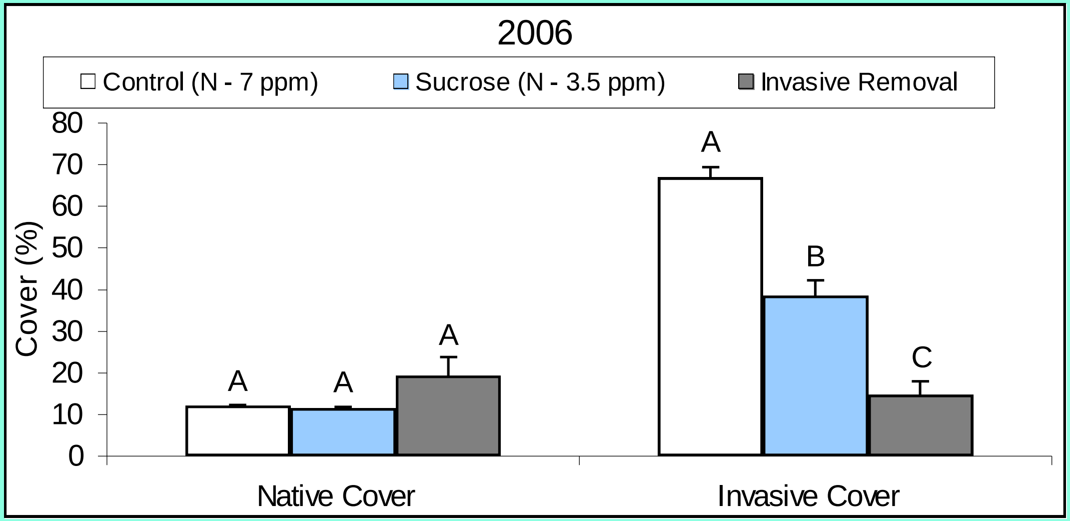
- Decline in invasive seed after fire may be a window of opportunity for natural establishment or reseeding natives (Cox and Allen 2008)
- Native and invasive seed bank declines especially under desert shrubs, not in interspaces (Brooks 2002)
- Seedling recruitment from burned soil under pinyon was high, but seed under sagebrush were burned (Allen, EA et al 2008)
- Fire caused shifts in species composition of emerging seedlings (Snyman 2005)

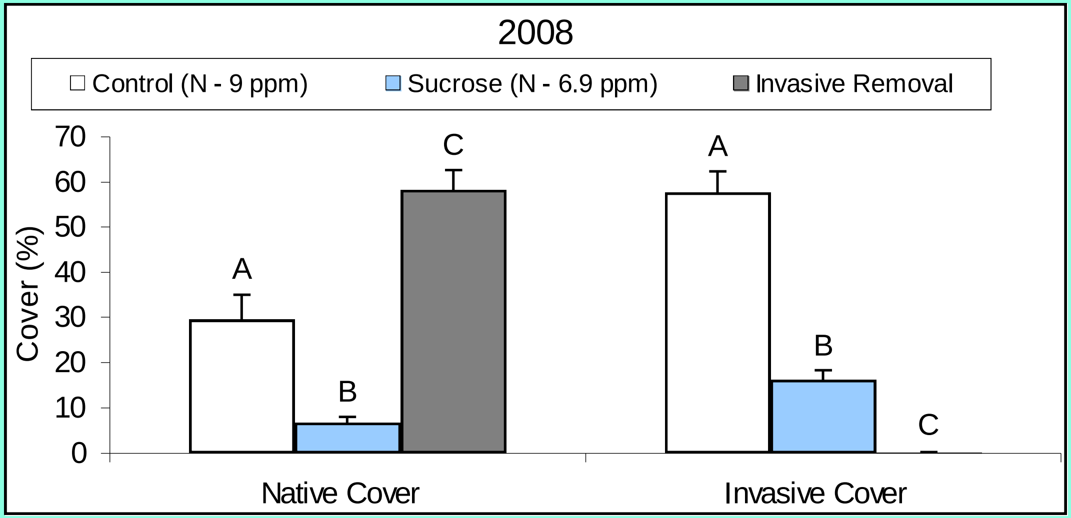
Point 9: Restoration--Reducing elevated soil N in invaded stands has variable effects on native vegetation establishment

- Sucrose used to immobilize N had a temporary effect on cheatgrass reduction and did not improve perennial grass establishment (Mazzola et al 2008 REM)
- Low soil N reduced invasive as well as native plant RGR (James 2008 PlSo)

Sucrose to immobilize N reduced exotic grass but either reduced or did not improve native forb cover







Research Issues

- Fires in deserts are relatively recent, and much of our knowledge about soil impacts is from more mesic environments.
- Invasive species have a more permanent effect on biogeocycling than does fire. Interactions?
- Because soil is a good insulator, soil microbes a few cm deep are little affected by fire. Recovery rate?
- Shrub islands may be destroyed by multiple fires with invasive species. What are changes in biogeocycling?
- The reduction of vegetation cover subjects the site to erosional losses that may cause more severe degradation than immediate fire effects (next talk).

Effects of fire on plants

Source	location	vegetation	duration yr	plant growth	tissue N	other	notes
Anderson 1997	Florida	sandhill pine	> 1		+	+	fire effect reduced over time
Bennett 2003	Australia	semi-arid grassland	> 1	- (drought)	+ then NC	+	do not rec. prescr burn
Carreira 1992	Spain	Medit. shrub	> 1	+	+	+	
Franco 1997	Baja, CA	CSS, chap.	1		+, then NC		
Blank 2003	Nevada	riparian	3		+	+,-	
Launonen 1999	Australia	Eucalyptus	2		+,-	+	dependent on soil type
Seastedt 1990	Kansas	grassland	10 yr,				
			annual burn	+			no erosion observed
Ojima 1990	Kansas	grassland	10 yr,				
		model	annual burn	+			assume erosion