Results and Discussion/Milestones:

As described in the materials and methods section, we have sampled a large number of plots to assess ecosystem services over diverse environmental conditions (ranging from Central to Northern California, from coastal to valley to foothill environments), across diverse community types (the dominant exotic forages vs. restored and remnant native habitats vs. invaded by noxious weeds), with diverse management practices. All of this data can assess impacts of drought, and some data can also assess the beginning of drought recovery (from the 2015-16 growing season).

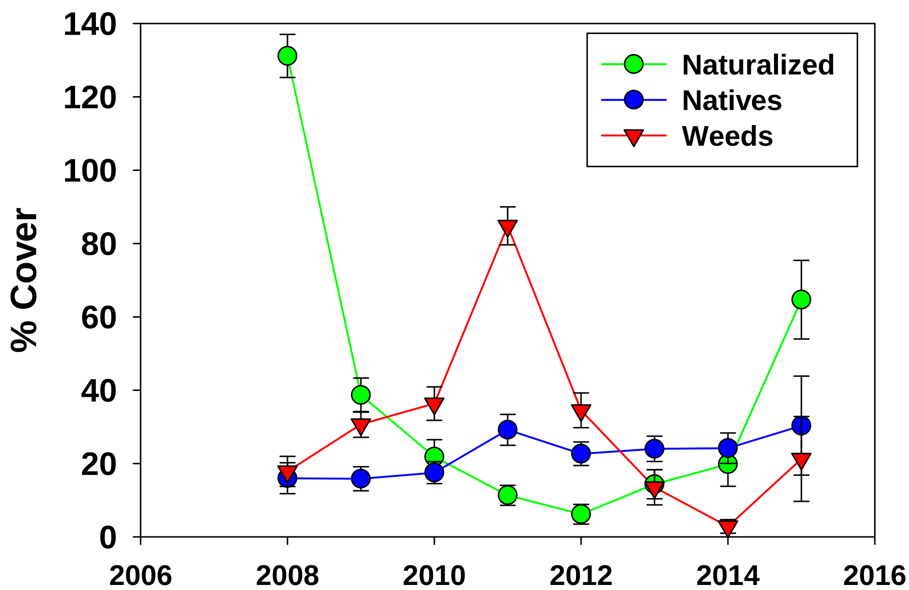
Full environment x management analyses will occur in early 2017, once all data is in the database, and the data is linked with GIS layers to tease apart local environmental variables. Here we highlight the diverse sets of insights that can be derived from the data collected thus far.

1. *Effects of yearly variation in weather conditions and drought*

Vegetation composition

Long-term data from various sites indicates strong effects of yearly weather conditions on vegetation composition. Looking at species composition across 80 rangeland sites spanning from the coast (Mendocino County) to the valley (Yolo and Solano Counties) to the foothills (Yuba County), in general, forb and legume cover increased substantially during drought at most sites. But there were three distinct types of responses of vegetation community composition to drought, largely determined by the 2013-14 drought patterns, where there was a small amount of rain in the fall, and substantial rains didn't occur until February.

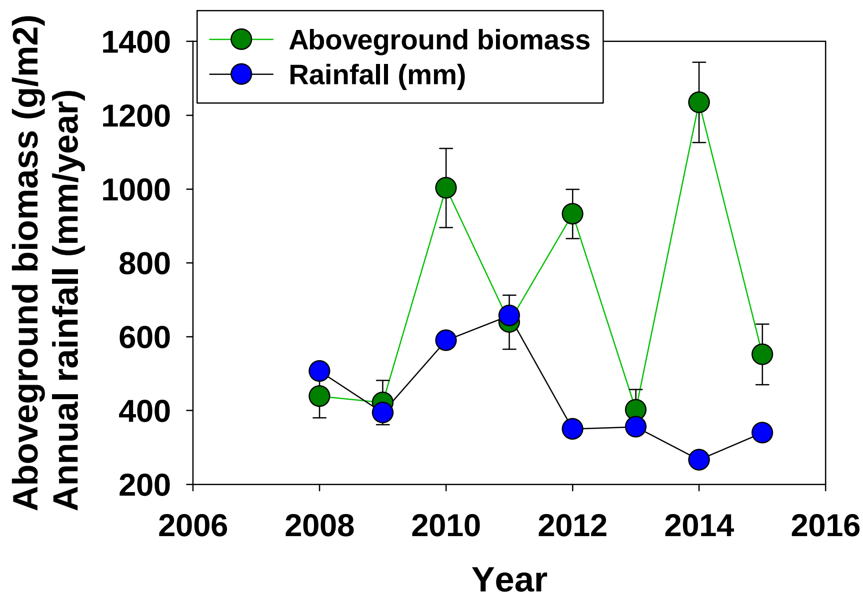
- Site type 1: Early season flush of annual grasses which died off, leaving relatively little live vegetation until the rains in February, when forbs and legumes dominated production. Due to low grass seed production, forb and legume prevalence has been unusually high, only beginning to recover in the post drought 2015-16 growing season.
- Site type 2: Early season flush of annual grasses which survived in stunted form, then grew profusely after February rains. These sites have remained grass dominated throughout the drought. Forb and legume cover was higher during drought, but not during drought-recovery.
- Site type 3: Little germination until February, when annual grasses germinated and dominated. Forb and legume cover was higher during drought, but not during drought-recovery.
- In sites with remnant native grasses and on native grass restoration sites, the prevalence of native perennial grasses increased during the 1st three years of the drought. In the 4th year of drought, native perennials continued to increase in relatively wetter areas (e.g. coastal hills, riparian), but in drier areas (e.g. Central Valley and the lower foothills), previously robust stands of perennial grasses failed to produce viable seed, and appeared to suffer mortality. Most of these areas recovered in the 2015-16 post-drought year.
- Most rangeland noxious weeds (e.g. yellow starthistle, medusahead, goatgrass) are late-season species, relying on moisture in late spring into summer. These noxious weeds greatly increased in the 2010-2011 growing season, with high rainfall, and plummeted in cover during the drought.



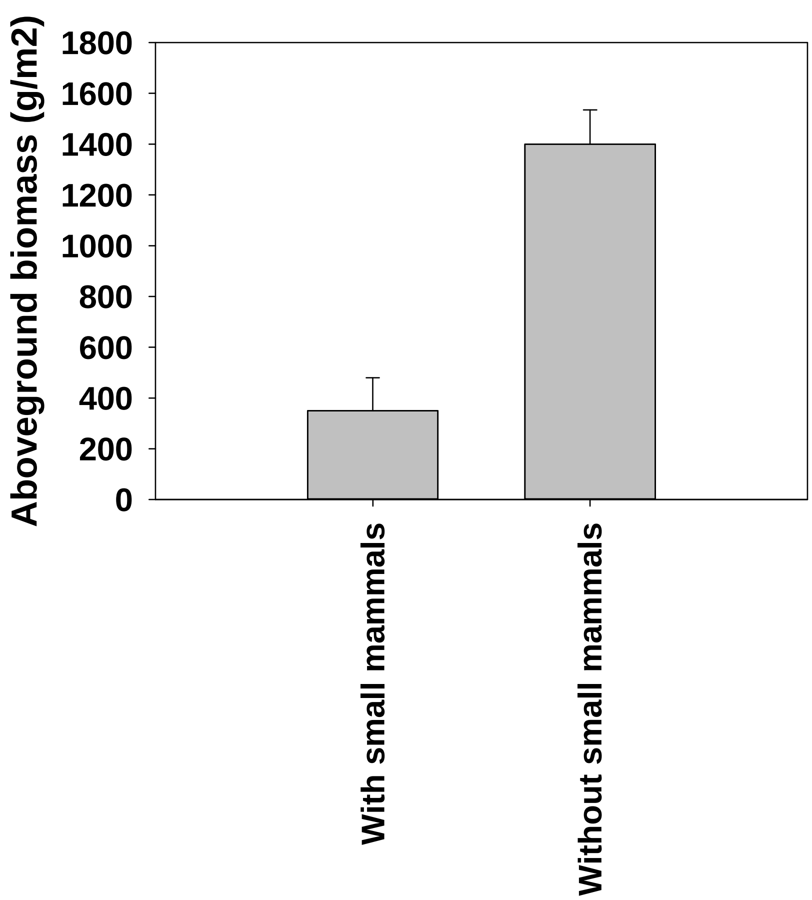
- Together, these results indicate that (1) the forb seedbank is critical for resilient vegetation cover and production during drought, (2) native perennial grasses are also important for resilient vegetation cover and production during short-term droughts, (3) noxious weed prevalence is strongly controlled by rainfall and (4) recovery of annual grass production may be delayed once the drought is over, as it may take a few growing seasons to reestablish grass seed density.

Vegetation production:

Aboveground biomass varied greatly year to year, but this did not mirror precipitation trends. In fact, aboveground biomass tended to boom and bust every other year, with high biomass production regardless of drought conditions. This is partly mediated by small mammal consumption of seeds limiting biomass production. Plots that limited access by small mammals had 2-3 fold higher aboveground production during some years.

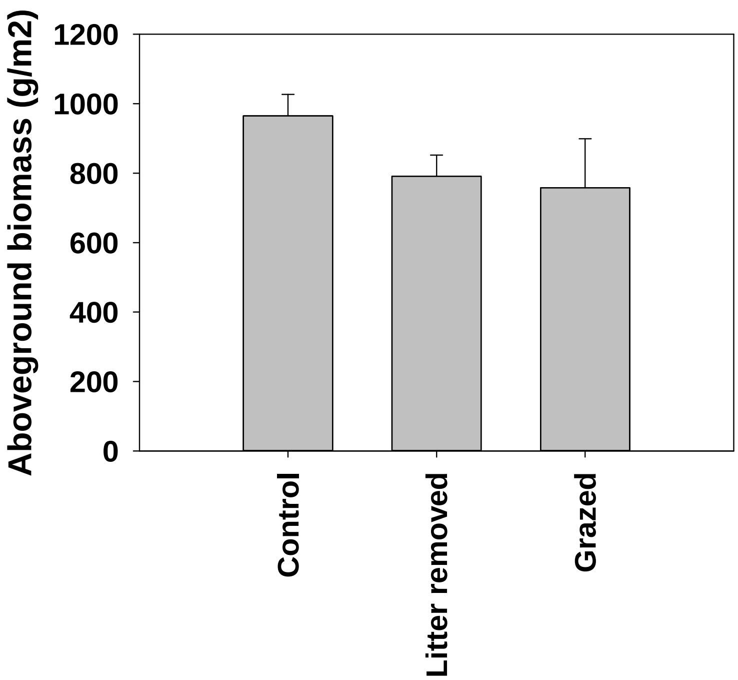


Aboveground biomass
Rainfall (mm)
Aboveground biomass (g/m2)
Annual rainfall (mm/year)
1400
1200
1000
800
600
400
200
2006
2008
2010
2012
2014
2016
Year

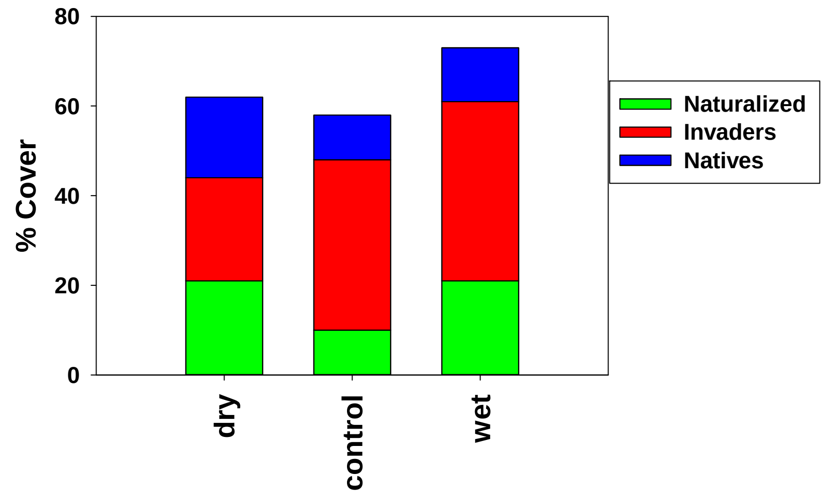


Aboveground biomass (g/m2)
1800
1600
1400
1200
1000
800
600
400
200
0
With small mammals
Without small mammals

One of the largest impacts of drought wasn't consistent effects on vegetation production, but inhibition of litter decomposition, leading to substantial buildup of thatch. We clipped litter from subsets of the plot to assess whether the litter inhibited forage growth. During drought conditions, the presence of thatch increased aboveground biomass production by 22%. Grazing had the same impact as clipping of litter, although the results were more variable. This is likely because the thatch increased soil moisture infiltration and retention (those samples are currently being processed).



2. ***Effects of irrigation/ rainfall manipulation***
   Precipitation manipulations averaged an increase in precipitation by 20%, control (actual rainfall conditions), and decreases by 25-30%. Dry versus wet conditions had large impacts on the relative dominance of naturalized exotics, native perennial grasses, vs. noxious invades (goatgrass, medusahead and yellow starthistle). Drier conditions tend to decrease the noxious invaders. Native grasses tended to increase in cover during both drought and wetter conditions, compared to control plots.



3. Effects of grazing practices.

Forage production

As described above (results, part 1), grazing tended to decrease aboveground biomass production during drought conditions, likely due to the decrease in thatch that buffers soil moisture. Grazing effects during non-drought years was variable depending on site and type of grazing. As the database links the results to site variables (through the GIS tool), we will be able to tease apart the site-specific and year-specific effects.

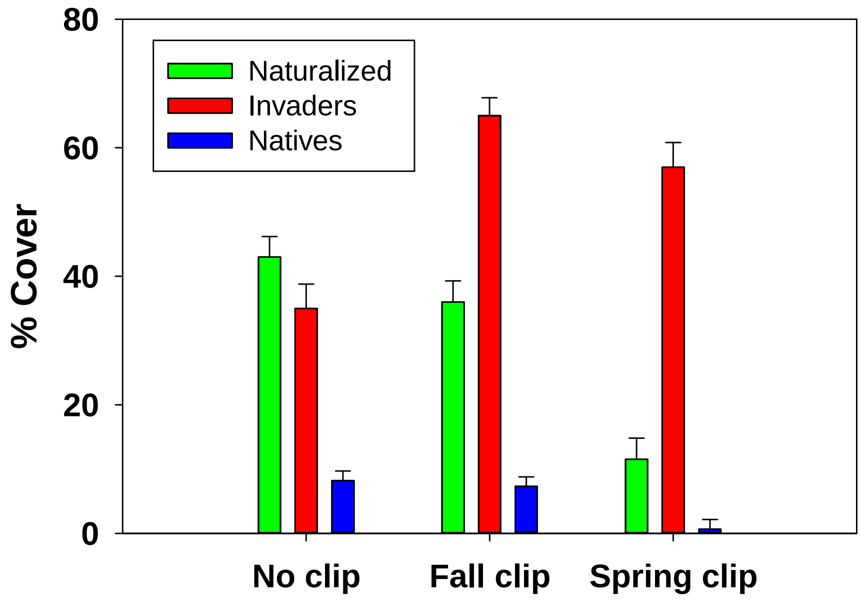
Vegetation composition

Early spring grazing decreases the aboveground biomass of naturalized annuals, such as *Avena sp.* and *Bromus sp.*, thus decreasing their water use, and increasing soil moisture. This increases water availability two-fold to late-season weeds such as medusahead and goatgrass, and leads to their dominance. These results were variable depending on precipitation at the site, and aspect (north vs. south-facing).

Summer grazing of yellow starthistle-infested areas has no impact on invasion in the subsequent year.

4. Effects of mowing/clipping/ RDM

Clipping in both the fall and spring leads to substantial increases in the prevalence of noxious weeds such as medusahead, goatgrass, and yellow starthistle. During dry years, results are different—spring soil moisture is already low, and does not support regrowth of the weeds (or the naturalized forage grasses) after spring grazing. During years with later wet conditions, noxious weed prevalence is high, regardless of grazing.

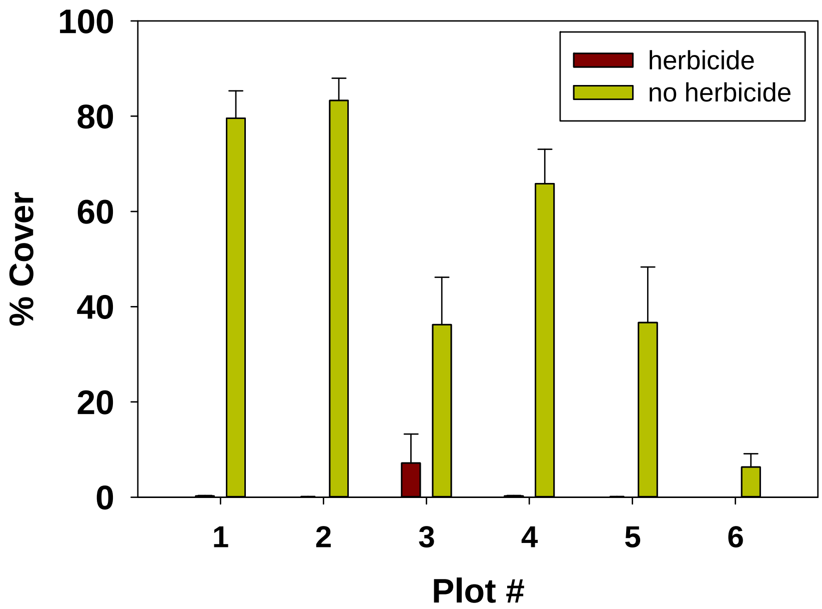


5. ***Effects of fire***

Grassland fires were frequent over the 2014 summer, providing many opportunities to assess vegetation trajectories post-fire. Soil water availability (largely determined by topographical position, aspect, and soil texture) seemed to have the largest impact on vegetation community composition and production in the growing season following fire. Partly due to the drought, weed management (e.g. herbicide, tilling) was extremely effective, and may enhance long-term native establishment.

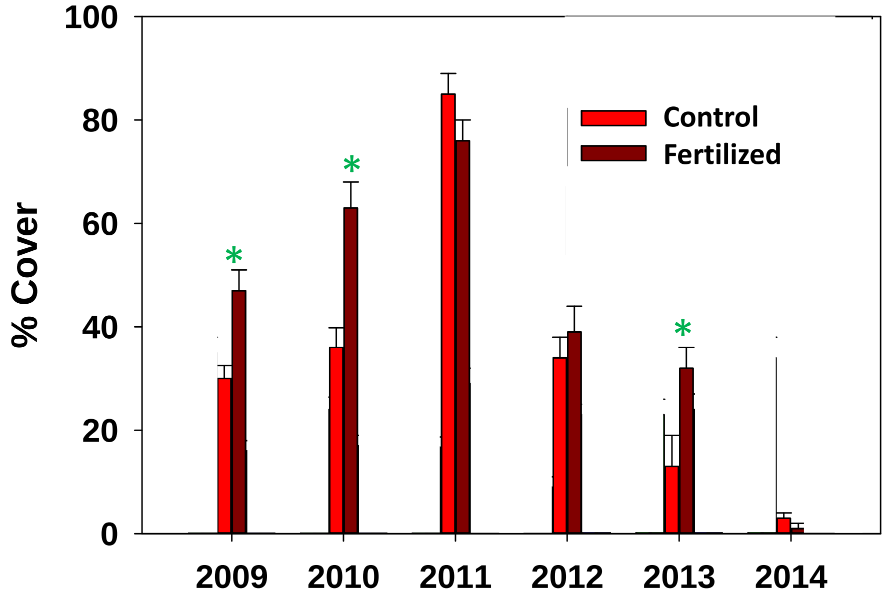
6. ***Effects of invasive species control efforts***

In areas infested with yellow starthistle across Sacramento County, infestation of yellow starthistle tended to be very high the year after fire (from 40-80% cover). Assessing potential management impacts, grazing, burning, and mowing had very little effect on invasion. Only herbicide treatments consistently decreased yellow starthistle cover. This effect lasted into a 2nd growing season after initial control efforts.



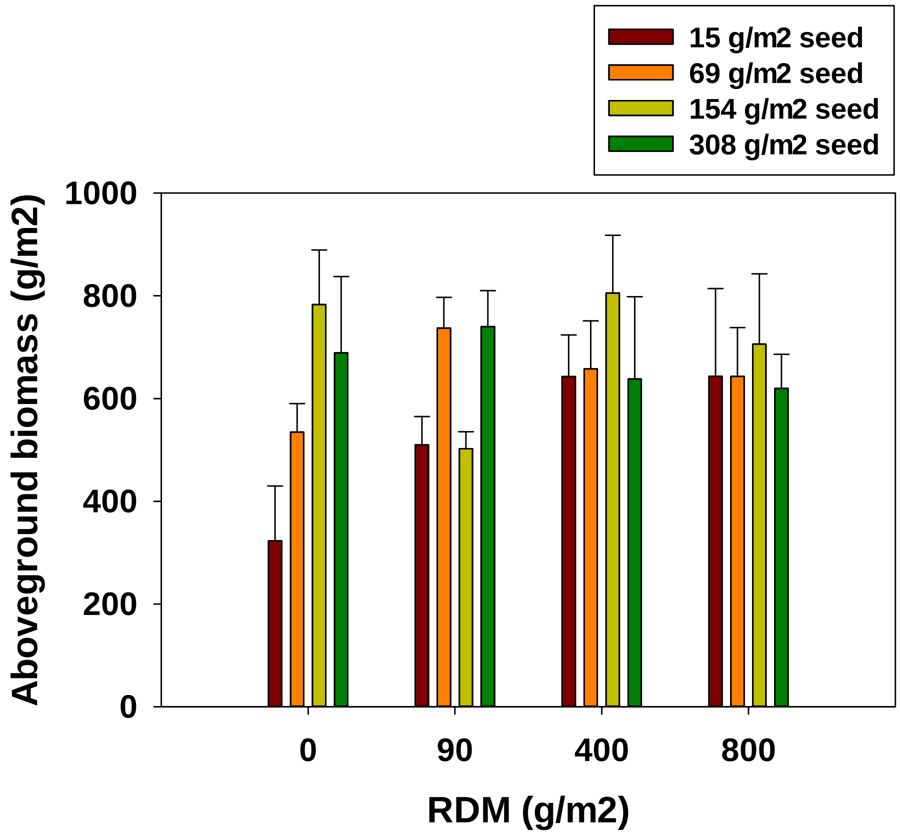
7. Effects of fertilization, compost, ash additions

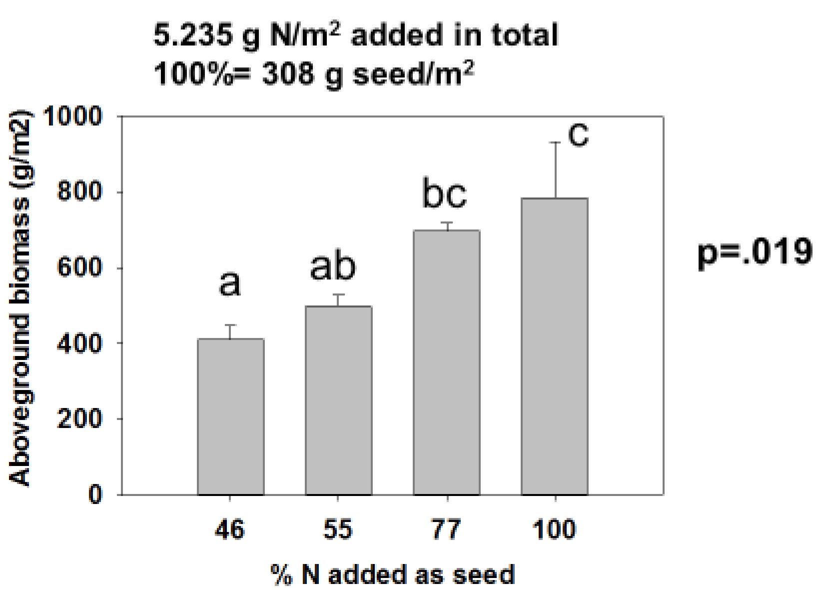
Nitrogen fertilization has variable effects on the abundance of noxious weed species, increasing their prevalence in some years, while having no effect on others. This has no apparent relation to the amount of precipitation in a given year.



8. Effects of rangeland planting practices.

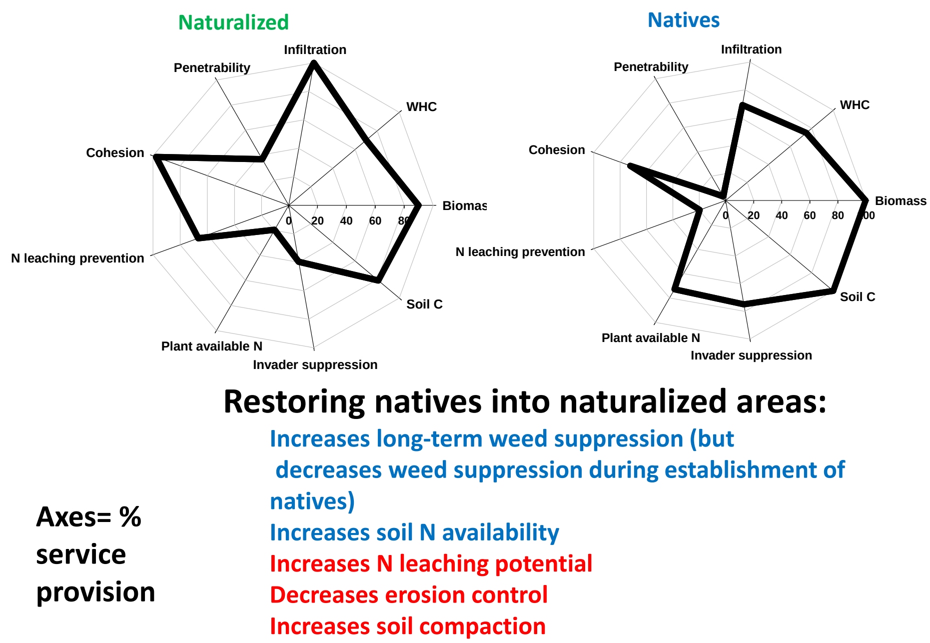
Our previous research had indicated in California's annual dominated grasslands, seed production, and the thinning of seedlings is a major source of plant nutrient availability. Thus, in grassland revegetation efforts (e.g. reclamation of roadsides, development, etc.), the typical low densities of seed inputs may limit grassland production and reestablishment. We planted seed densities at ranges from typically low revegetation densities to natural densities, across a range of RDM levels. At low RDM levels, seed density increased vegetation production, up to doubling forage production. At higher RDM levels, seed density was not important. Revegetation efforts would be less expensive if lower seed densities could be supplemented with slow-release fertilizers, rather than deriving nutrients from seeds. However, high seed density leads to the timing of nutrient release to better match plant needs, leading to substantially higher production, compared to adding the same amount of N with a smaller number of seeds, along with slow-release fertilizer.


15 g/m2 seed
69 g/m2 seed
154 g/m2 seed
308 g/m2 seed
Aboveground biomass (g/m2)
1000
800
600
400
200
0
0
90
400
800
RDM (g/m2)

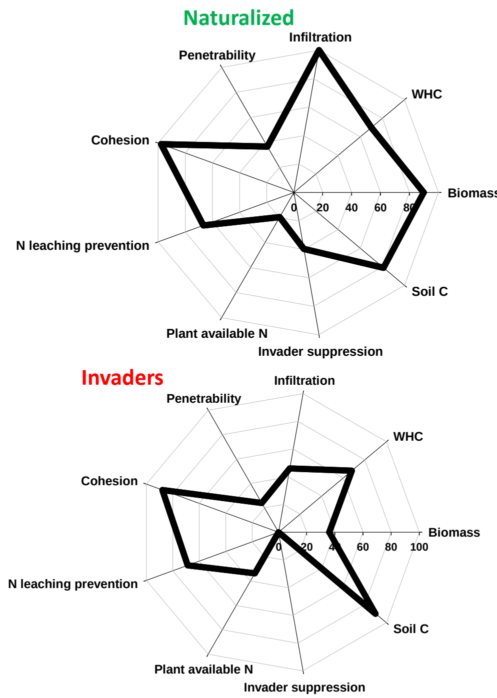

5.235 g N/m2 added in total
100%= 308 g seed/m2
Aboveground biomass (g/m2)
1000
800
600
400
200
0
a
ab
bc
c
46
55
77
100
% N added as seed
p=.019

9. ***What are the effects of vegetation composition on multiple ecosystem services? Comparing naturalized forage annuals, noxious invasive weeds, and restored native grasslands.***

Restoration effects on ecosystem services were highly variable across Northern California grasslands. However, effects of native grass restoration on ecosystem services were relatively consistent within similar ecological sites (e.g. similar climate, soil, aspect). For example, on clay soils in the Central Valley, compared to unrestored sites, native grass restoration sites tended to have higher control of noxious weeds (goatgrass, medusa head), higher deep-soil carbon (40-90 cm), higher mineralizable nitrogen, lower erosion resistance, and lower alleviation of soil compaction.

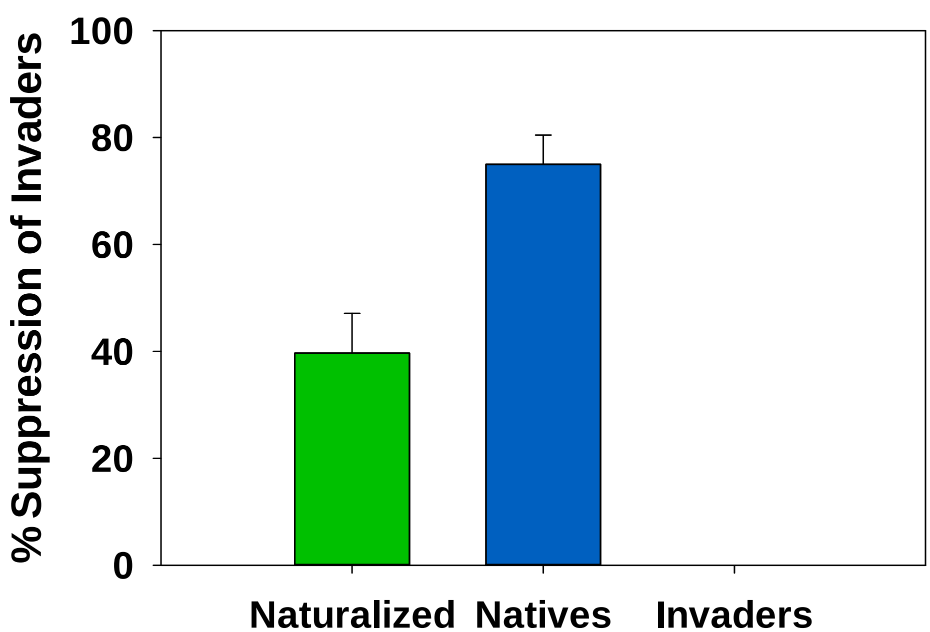


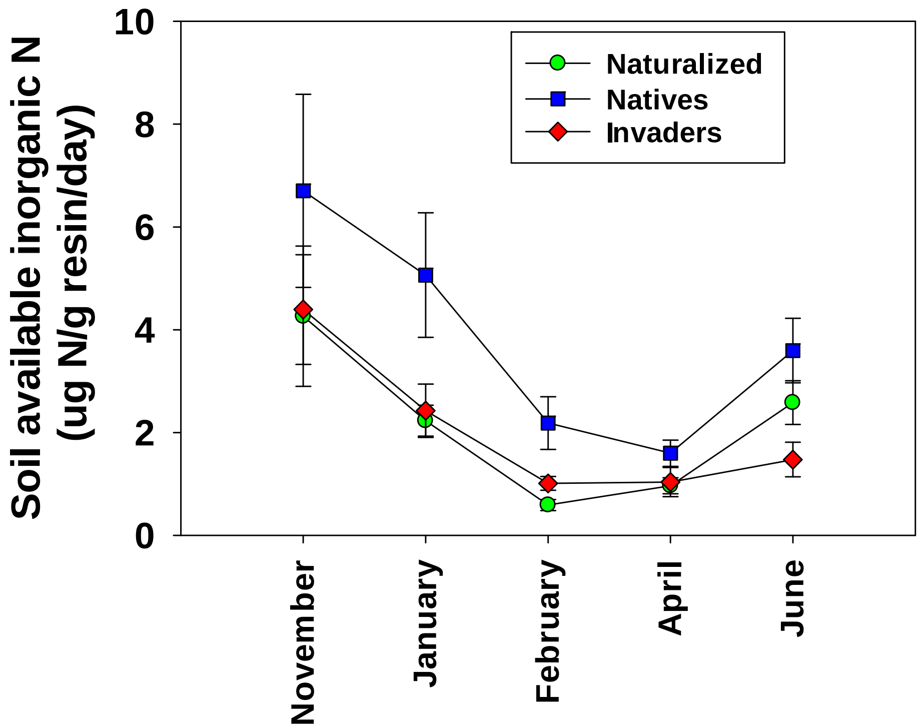
Overall, the ecosystem services provided by noxious weeds, compared to naturalized grasses were similar, with the exception of noxious weeds having lower green biomass in April (peak grazing season on most of these grasslands), lower erosion control, and lower water holding capacity.



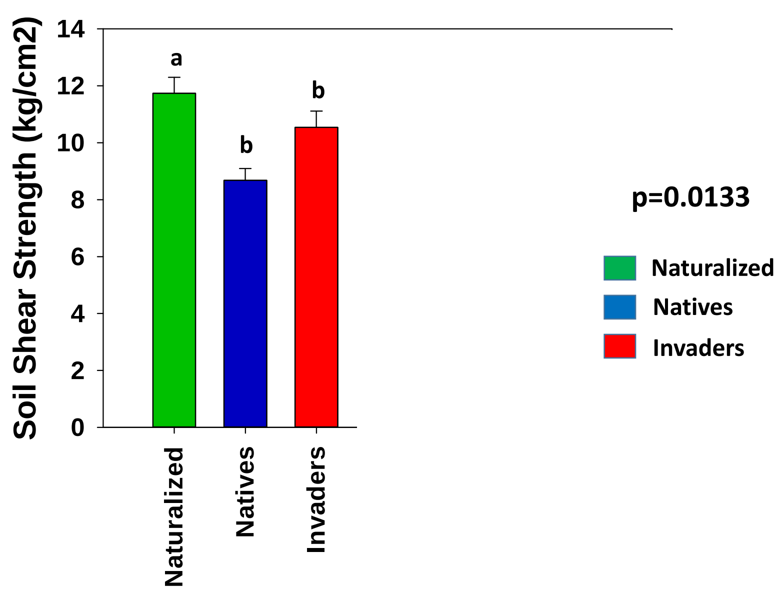
Invasion of noxious weeds into naturalized areas:

- Decreases spring forage availability
- Decrease erosion control
- (Decrease water holding capacity)

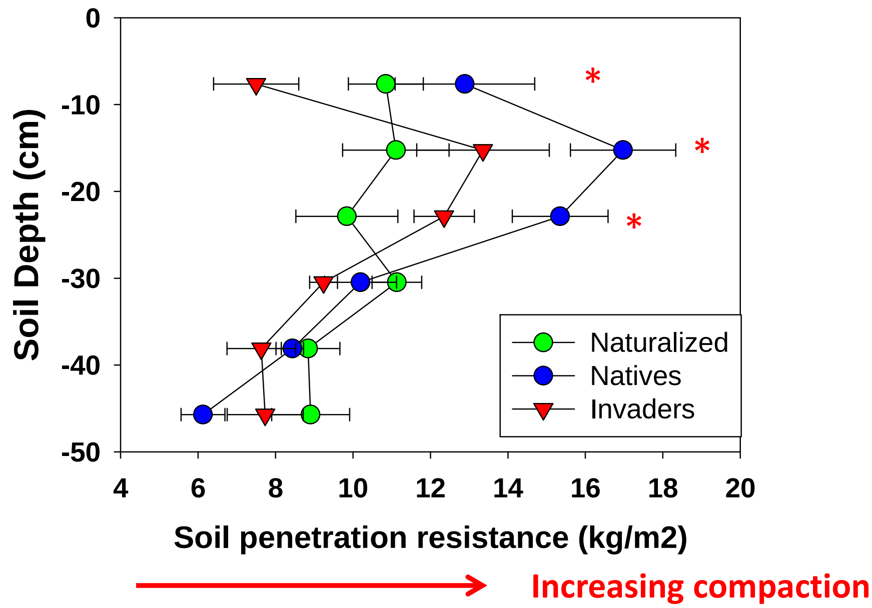




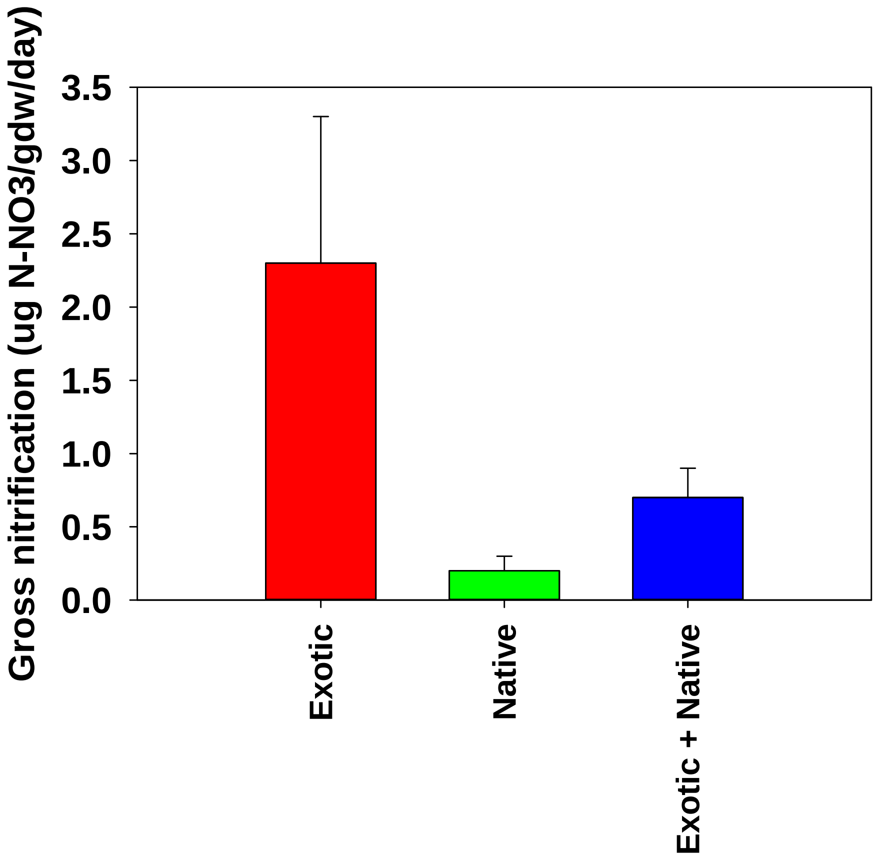
Soil available inorganic N (ug N/g resin/day)
10
8
6
4
2
0
Naturalized
Natives
Invaders
November
January
February
April
June



Soil Shear Strength (kg/cm2)
14
12
10
8
6
4
2
0
a
b
b
Naturalized
Natives
Invaders
p=0.0133
Naturalized
Natives
Invaders

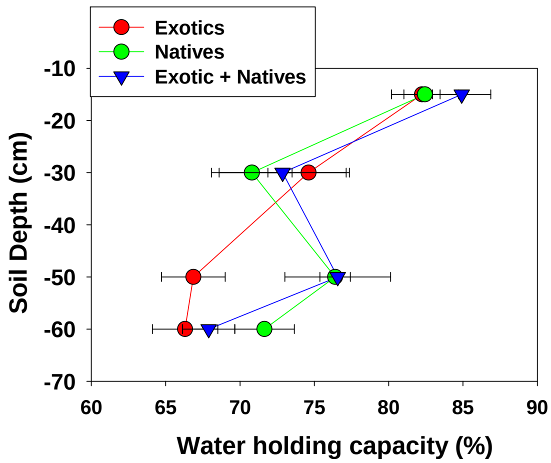


However, in the coastal hills, restoration effects on mineralizable nitrogen were opposite, and in particular, lead to much lower rates of nitrification.

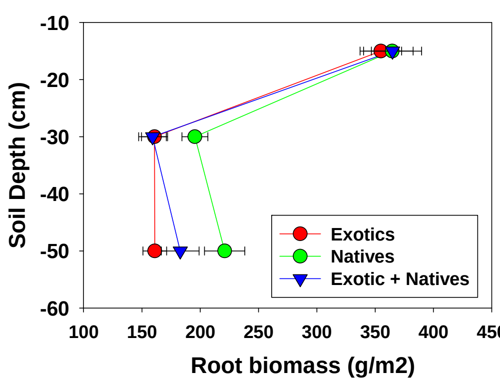


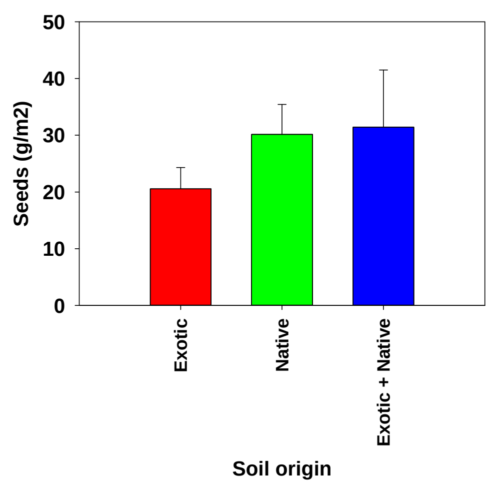
One of the more marked effects of restoration was to increase deep soil organic matter, leading to substantially higher water holding capacity in deeper soil layers, where moisture is provided to support plant growth in the spring, as the system is becoming moisture limited.

Exotics decrease soil water holding capacity below 30 cm depth



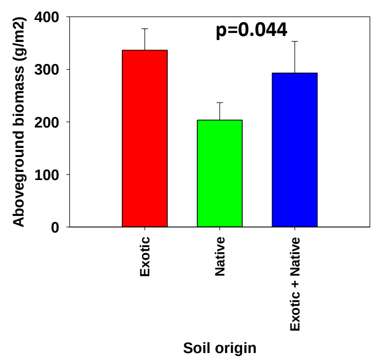
This increase in deep soil water holding capacity leads to only slight increases in aboveground plant production, but significantly higher deep root production, which thus doubles seed production during late-season dry down. This implies that the presence of native grasses can enhance recovery from droughts, by preventing limitation of seed production during dry springs.



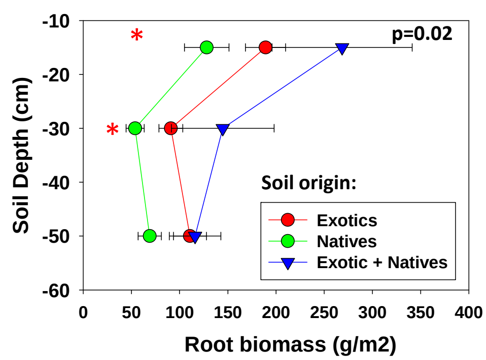


10. Plant effects on soil conditions feedback to alter plant performance.

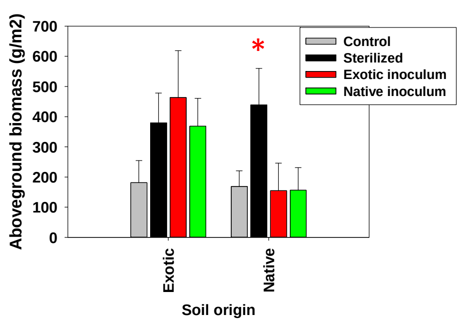
Native grasses change the soil in ways that decrease aboveground growth of native grasses (while having slight increases in growth of exotic grasses, compared to soil that was conditioned by long-term invasion of exotic grasses.) This implies that long-term maintenance of restored native grasslands may require alterations of soil conditions. Testing various soil management techniques (altering nitrogen cycling, altering microbial communities, tilling), sterilization of soil was the only method that increased the growth of natives on their own soil. Further research is determining which aspects of the microbial community are responsible for this result, to help guide more feasible soil management approaches.

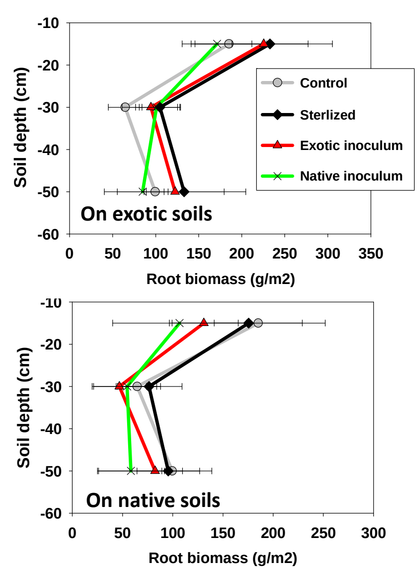


Native plants:
native soils decrease aboveground biomass and root biomass in 0-30 cm deep soil



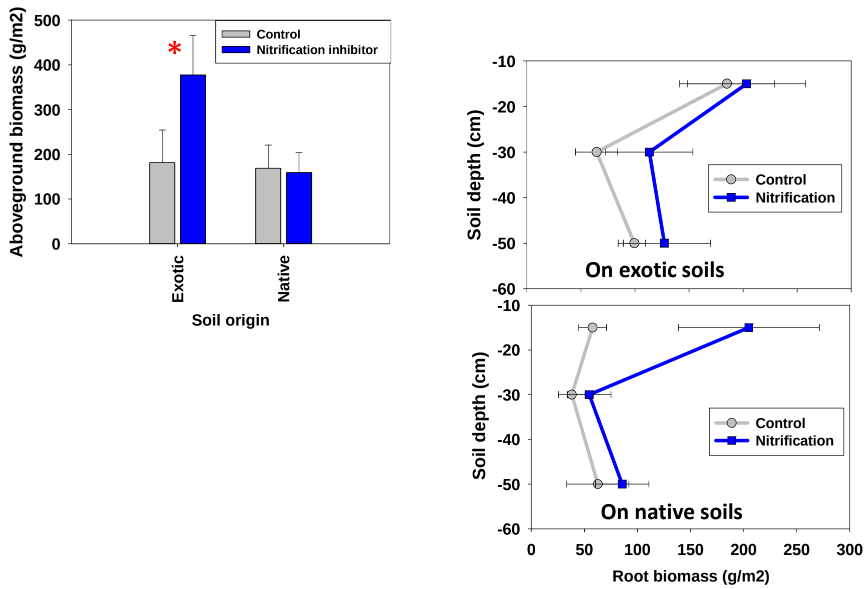
Native soil- soil sterilization enhances native aboveground growth
Exotic soil- no microbial effects



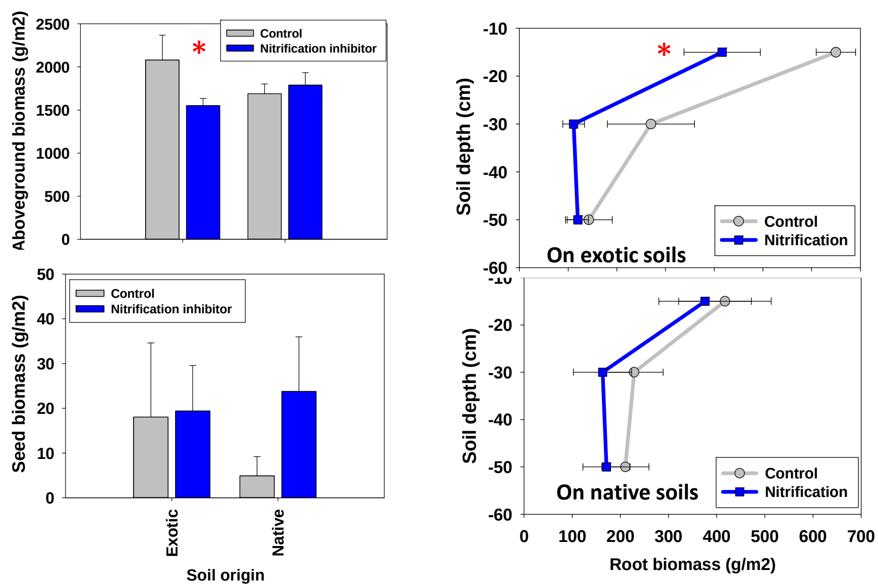


The changes that exotic plants have on soils can also impact the performance of native plant species. Exotic species tend to increase nitrification rates in soils. Adding nitrification inhibitor to offset this change leads to increased native plant biomass, and decreased exotic plant biomass.

Adding nitrification inhibitor to exotic soil increases <u>native</u> aboveground biomass (with no significant effects on roots)

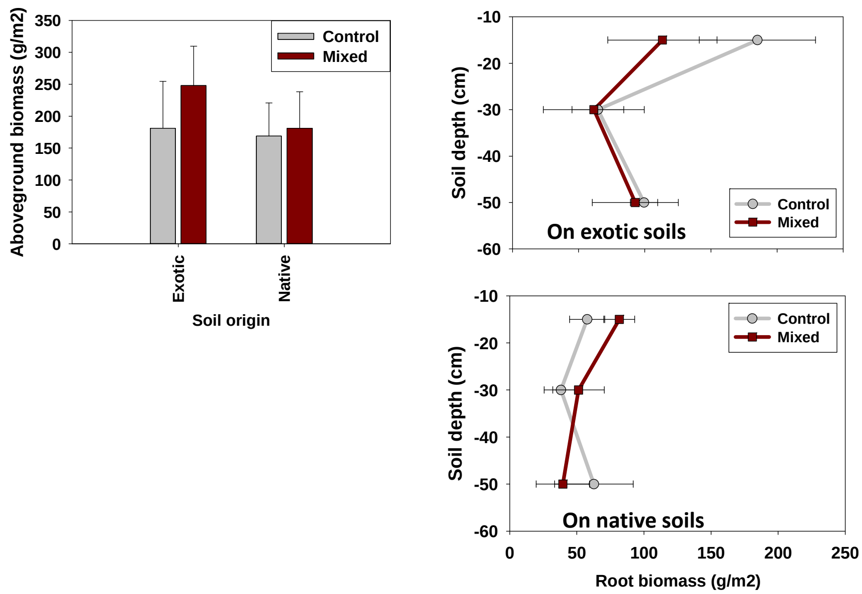


Nitrification inhibitor on exotic soils decreases aboveground <u>exotic</u> biomass, and root biomass 0-15 cm depth. No effect on seeds.



Exotics also decrease deep-soil carbon and water holding capacity. Mixing exotic soil profiles to provide higher deep soil carbon and water holding capacity has no effect on native grasses, but leads to deeper exotic plant roots, and 4-fold increase in seed biomass.

Mixing the soil profile has no impact on native grass



Mixing soil profiles of native soils → no effects
Mixing soil profiles of exotic soils → change exotic root distribution (more deeper roots, fewer surface roots), increases seed biomass 4-fold