Soil Biology and Rangeland Restoration

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Do No Harm Workshop: Considerations of pathogens, pests, and plant disease in restoration activities

UC Palm Desert Campus

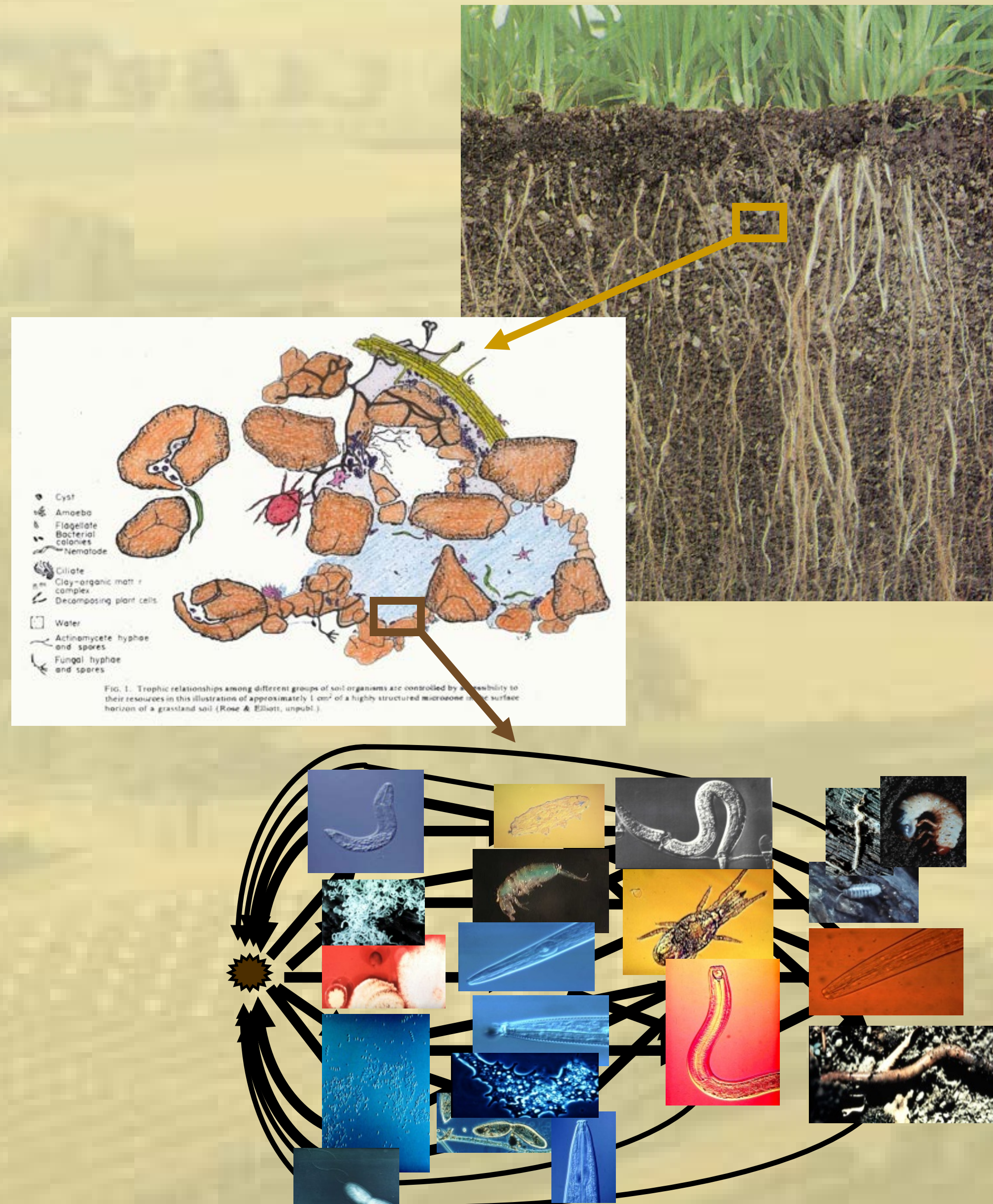
November 5, 2015

This talk

- Introduction to soil biology and soil food webs
- Research projects on soil biodiversity and ecosystem functions
  1) Soil microbial communities along a land-use gradient on similar granitic soil types
  2) Landscape inventory of biodiversity along agricultural and rangeland waterways
  3) Soil food webs in California riparian oak woodlands at a nature reserve
- Implications of soil biology for ecosystem restoration activities

Introduction to soil biology and soil food webs

- Many different species and functional groups present in soil
  - Many unknowns
- The nature of a community is more than the sum of its constituent species; it includes their interactions
- Restoration requires an understanding of:
  - Soil biotic interactions
  - Impacts of different management practices



Soil microbes and function

- Counting
  - Gives numbers
  - Distinguishes major groups, *e.g*., plate counts, microscopy
- Cellular constituents
  - DNA gives community fingerprint and can distinguish individual species, *e.g*., pathogens, survival of innoculants
  - Phospholipids give community fingerprint and distinguish different groups

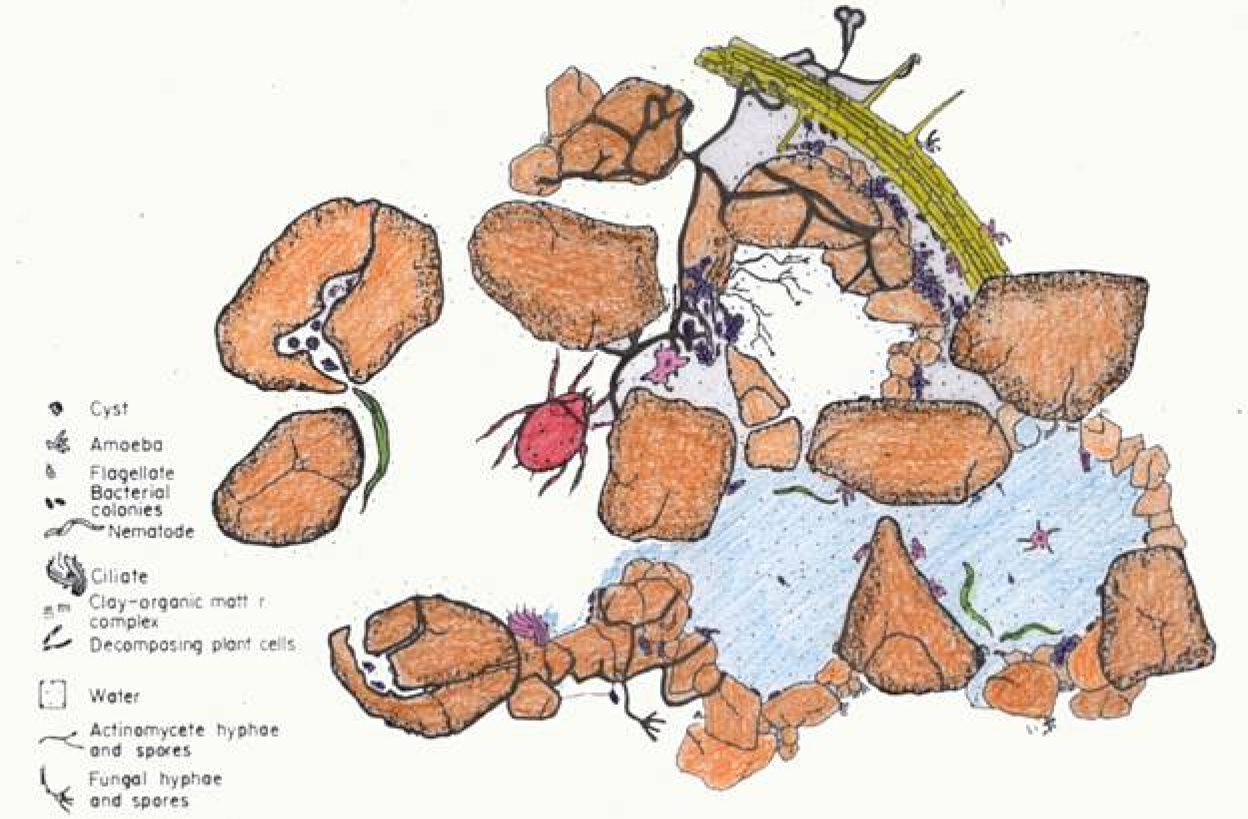
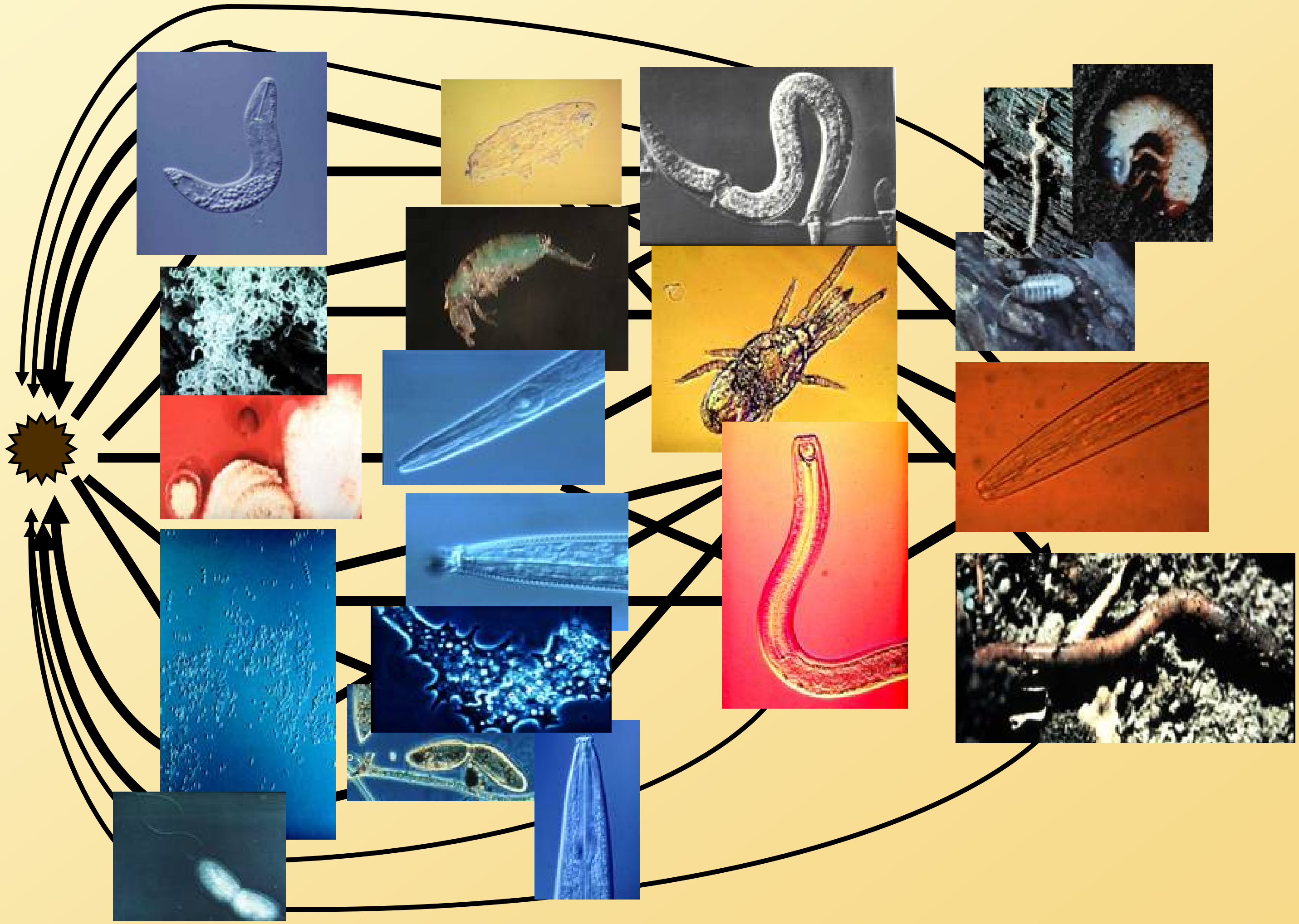


FIG. 1. Trophic relationships among different groups of soil organisms are controlled by accessibility to their resources in this illustration of approximately 1 cm^2 of a highly structured microzone in the surface horizon of a grassland soil (Rose & Elliott, unpubl.).

- Activity
  - Reflects the “work’ that the community can do
  - Actual or potential, *e.g*., respiration, N mineralization

Soil food web & biodiversity

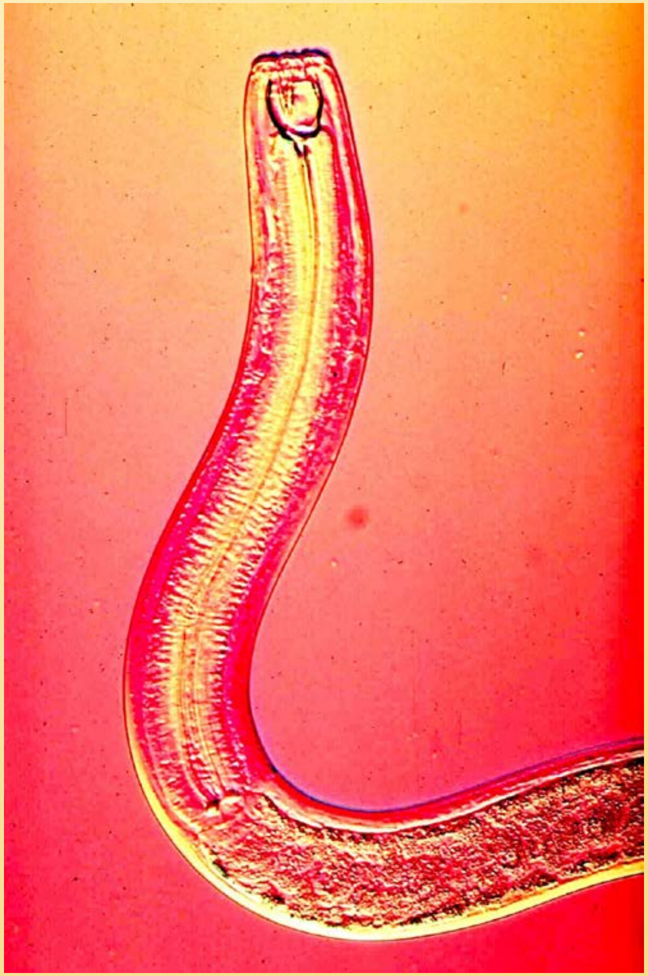
Soil organisms: their functions, interactions and distributions are typically associated with resource availability

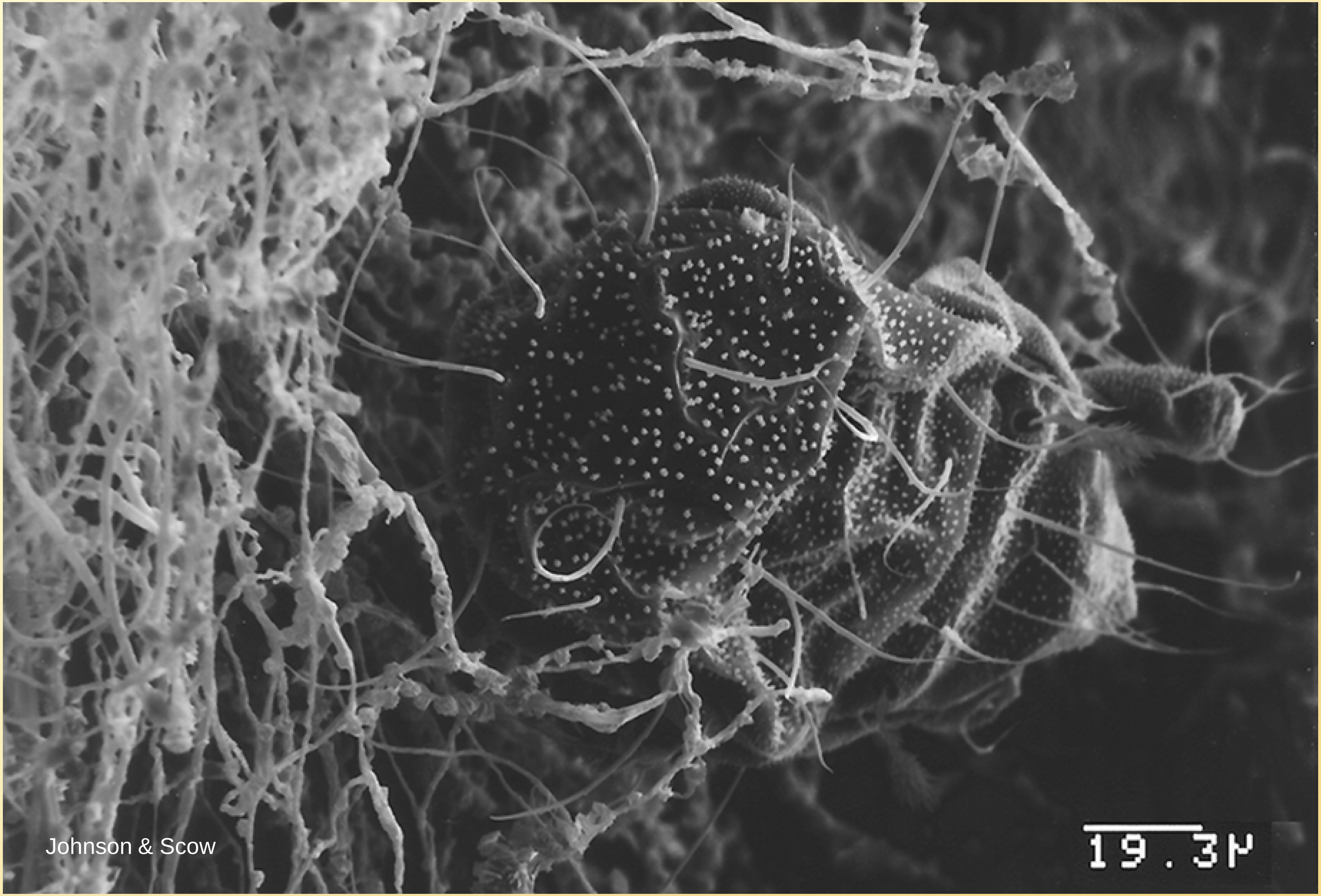


SAFS slide

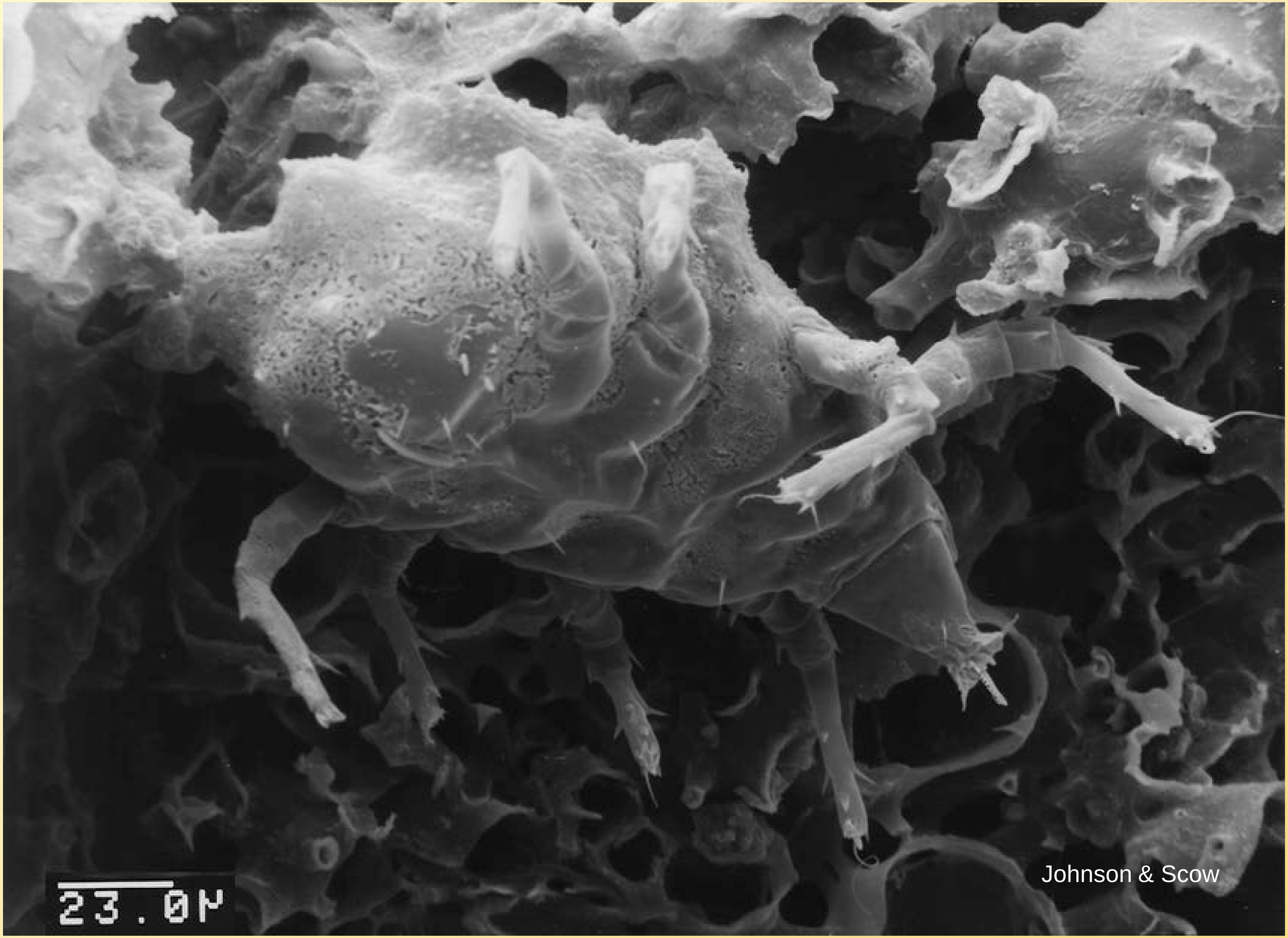
Nematodes as bio-indicators

- Nematodes have key positions in soil food webs
- Clear relationship between structure and function
- Abundant and ubiquitous
- Each soil sample has high intrinsic information value

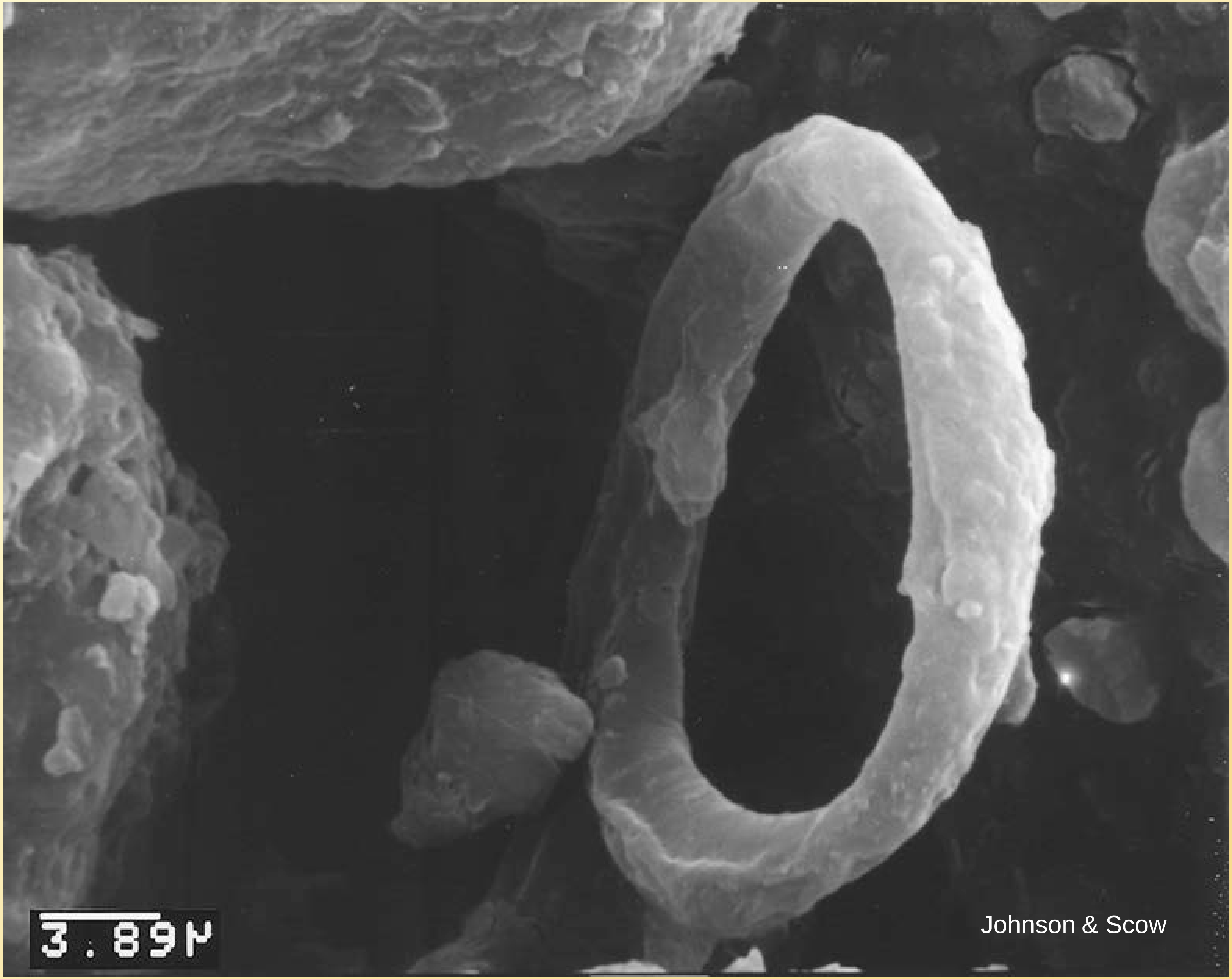




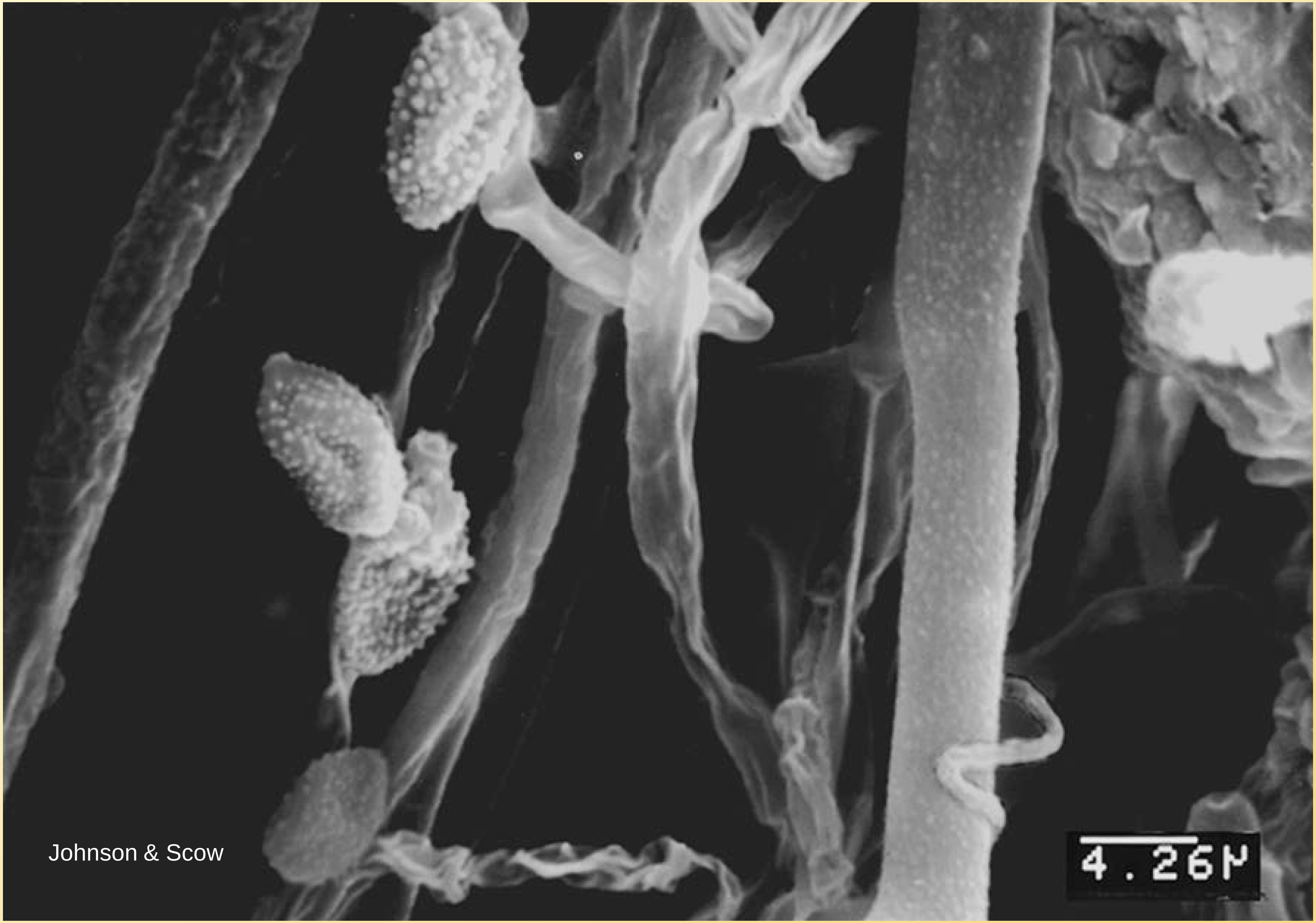
Mite (deceased) entangled in fungal hyphae



Mite caught foraging in decomposing corn cob

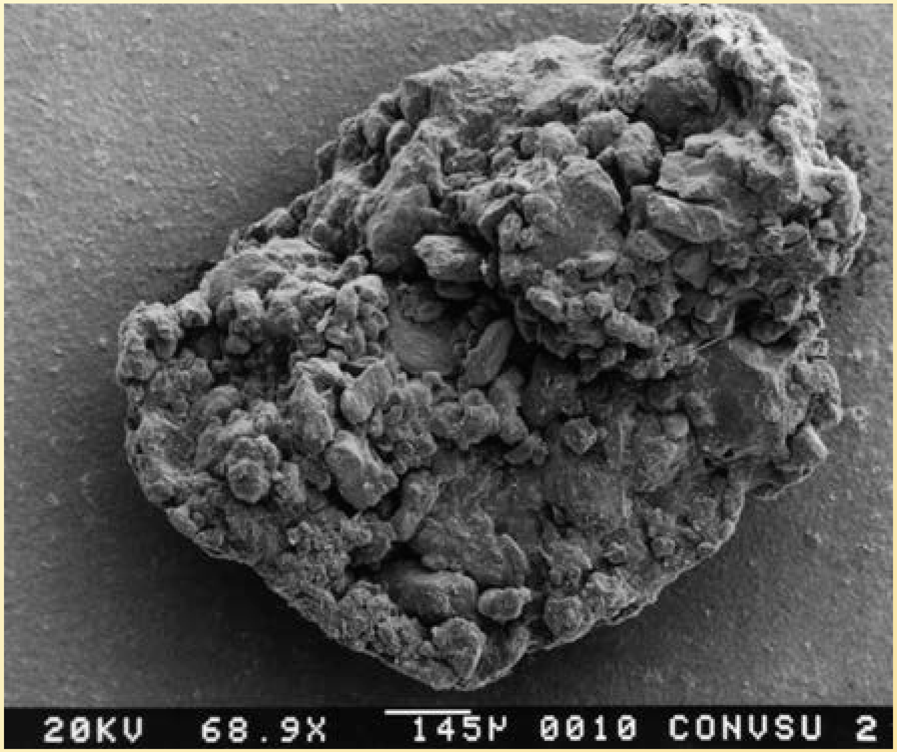


The “noose” of a nematode-trapping fungus

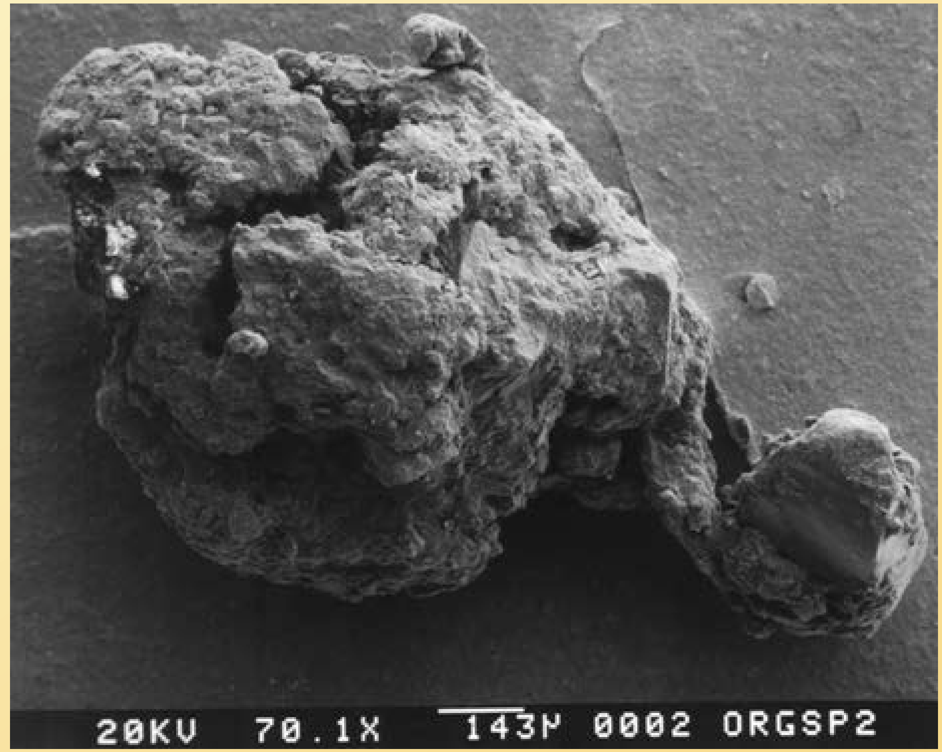


Relative sizes of bacteria and fungi in soil

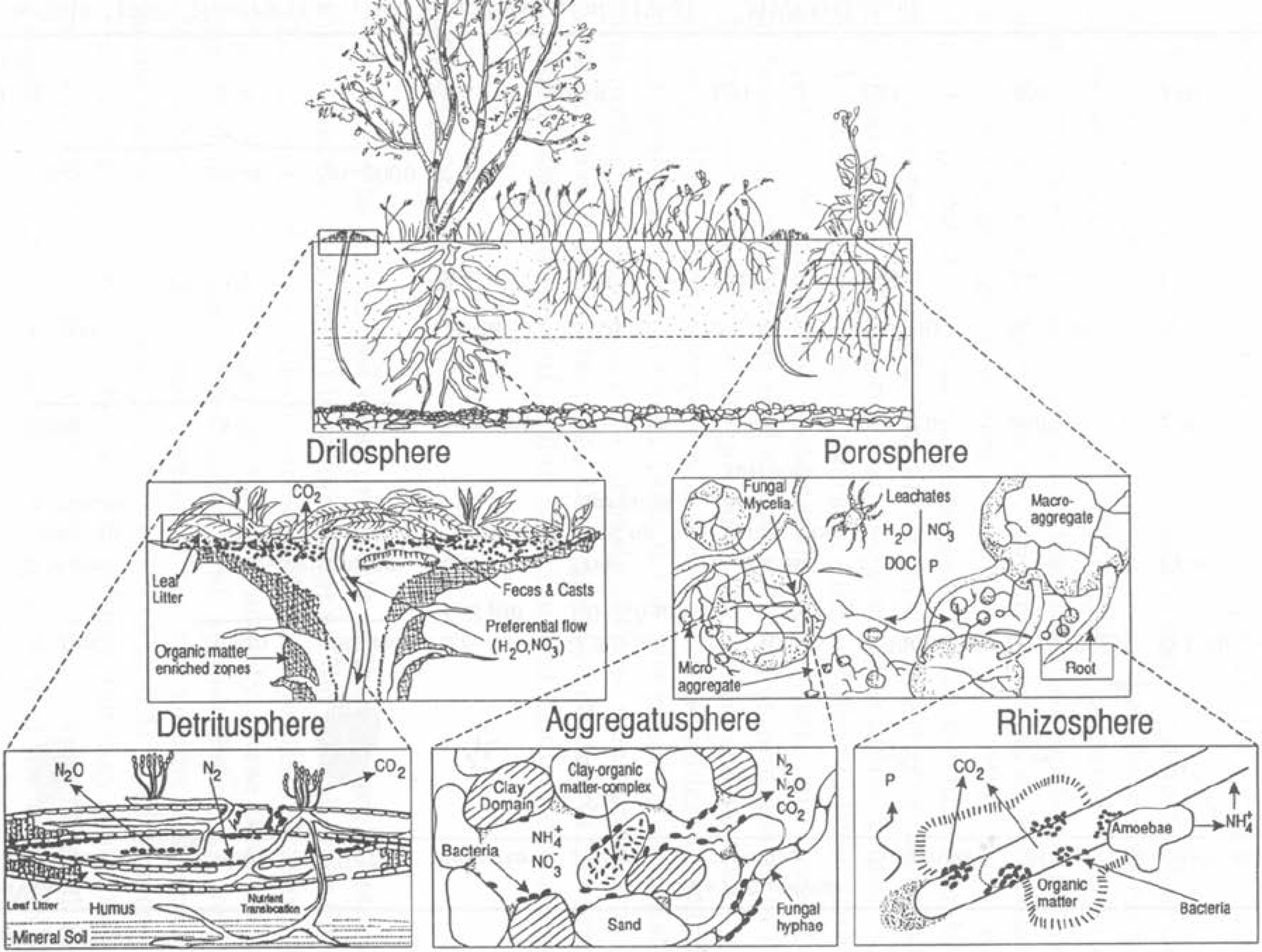
Aggregates from Sustainable Agriculture Farming (SAFS) plots at UC Davis



Conventional
Management Regime



Organic
Management Regime



Wardle et al. 2004

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- Introduction to soil biology and soil food webs
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    1) Soil microbial communities along a land-use gradient on similar granitic soil types
    2) Landscape inventory of biodiversity along agricultural and rangeland waterways
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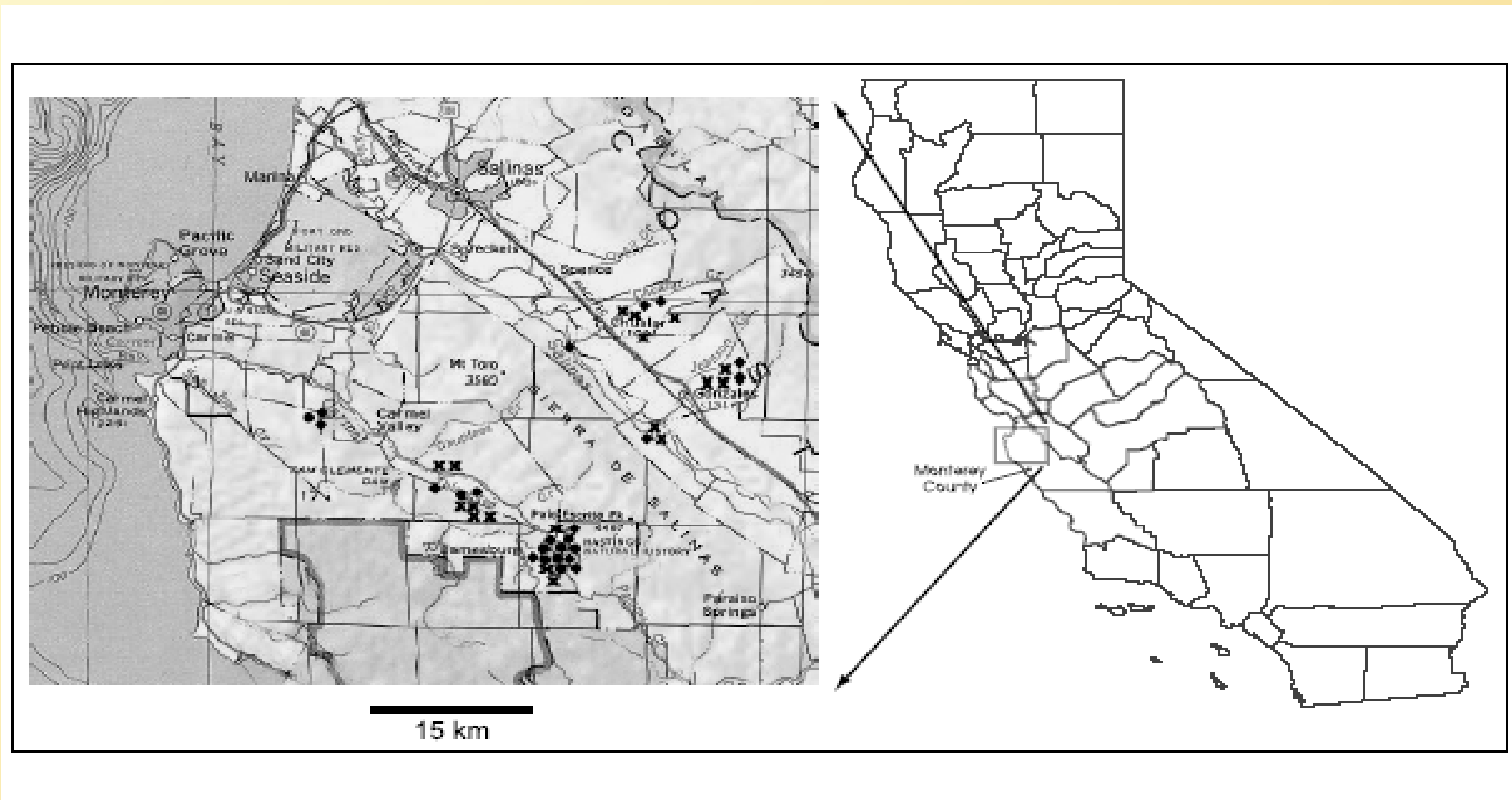
- Implications of soil biology for grassland restoration

1) Soil microbial communities along a land-use gradient on similar granitic soil types

- Comparison of several agricultural and grassland land use types for total soil C, N, and phospholipid fatty acids (PLFA)
- Short-term response to tillage of grassland and vegetable soils
- Typical changes with transition from grassland→agriculture (Smith & Young 1975; Woods 1989; de Luca & Keeney 1994)
  - Rapid decline in soil microbial biomass and soil organic matter
  - Decreased respiration and potential N mineralization
  - Higher soil NO_3^- and NO_3^-:NH_4^+ ratios

Transect of land use types on similar granitic soils in Monterey County, CA



Soil microbial communities

- Most soil microbes have not been identified and have not been cultured
- Phospholipid fatty acid (PLFA) analysis gives ‘community fingerprint’
- Phospholipid fatty acids are:
  - In membranes of all living cells
  - Rapidly turned over on cell death
  - Excellent signature molecules

- Microbes:
  - Produce diverse range of PLFAs => community composition
  - Total PLFA concentration is a measure of total microbial biomass
  - Specific PLFAs are associated with some particular subsets of the microbial community. *e.g.* prokaryotes, fungi, gram-positive bacteria, cyanobacteria, actinomycetes

Land-use types along a disturbance gradient

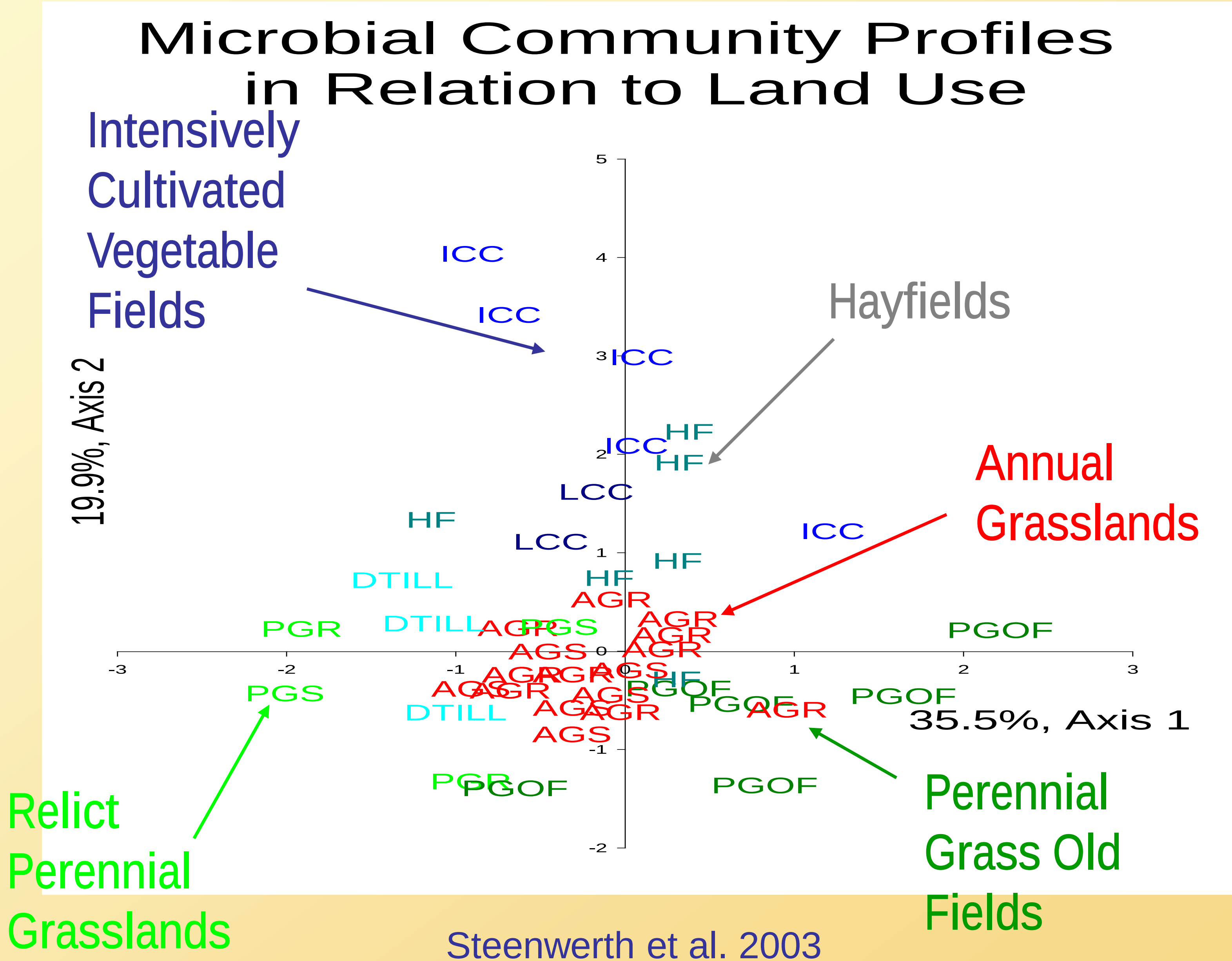
- Irrigated agriculture compared to annual grassland:
  - 60% less total soil C
  - 40% less total soil N
  - 65% less total PLFA (with large differences in composition)
- Annual and perennial grasslands do not show large differences

	CULTIVATED	
	Irrigated	Non-irrigated
pH	6.1-7.7	5.2-7.1
Total Carbon	1.007% -1.244%	1.336% -2.273%
Total Nitrogen	0.093% - 0.286%	0.133% - 0.208%
Total PLFA	3.3 - 19.8 *u*g/g	9.7 - 23.3 *u*g/g
	GRASSLAND	
	Annual	Perennial
pH	5.2 - 6.3	4.8 - 6.5
Total Carbon	1.297% - 5.262%	1.261% - 3.228%
Total Nitrogen	0.113% - 0.466%	0.156% - 0.314%
Total PLFA	15.7 - 48.0 *u*g/g	27.4 - 82.6 *u*g/g

Survey of 42 sites on granitic soils of similar texture and moisture in the Salinas and Carmel Valleys; 0-6 cm depth

Steenwerth et al. 2003

Land use types have distinctive PLFA profiles



Steenwerth et al. 2003

Simulated tillage of an annual grassland and a vegetable production soil

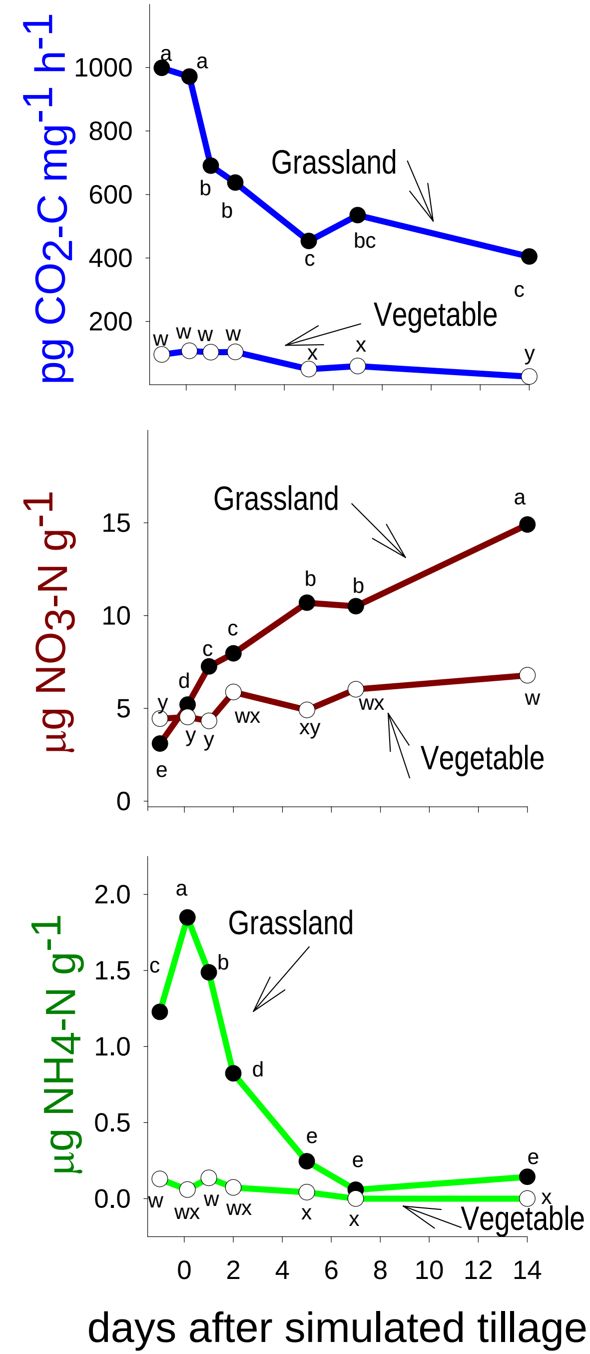
- Intact cores with identical soil texture and moisture
- Greenhouse expt. with no irrigation
- Soil sieved and replaced in cores, then 0-15 cm layer measured for 2 wks

Respiration declined after simulated tillage, and the decrease was earlier and more pronounced in the grassland soil.

Nitrate accumulated after simulated tillage in both soils, but more rapidly in the grassland soil.

Ammonium was low in both soils. Although it was initially higher in the grassland soil, it declined rapidly, and never returned to pre-disturbance levels.

Calderón et al. 2000



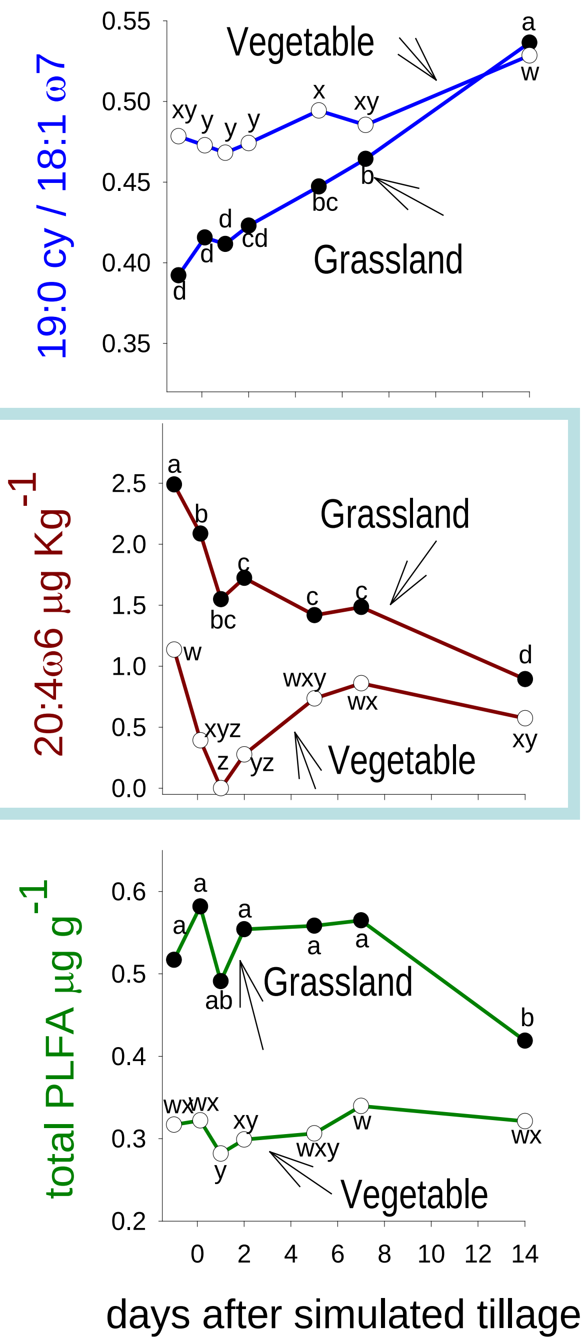
PLFA after simulated tillage, cont'd…

- Individual PLFA markers showed greater resistance and resilience to disturbance in the vegetable soil
- PLFA profiles of the entire microbial community were more variable through time in the grassland soil (not shown)

The ratio of a cyclopropyl fatty acid to its precursor, an indicator of microbial stress, showed increased stress after simulated tillage, especially in the grassland soil.

An indicator of microeukaryotes decreased rapidly in both soils after disturbance. Later recovery in the vegetable soil indicates greater resilience to disturbance than in the grassland soil.

Total PLFA, a measure of total microbial biomass, remained relatively constant in the vegetable soil, but decreased after one week in the grassland soil.



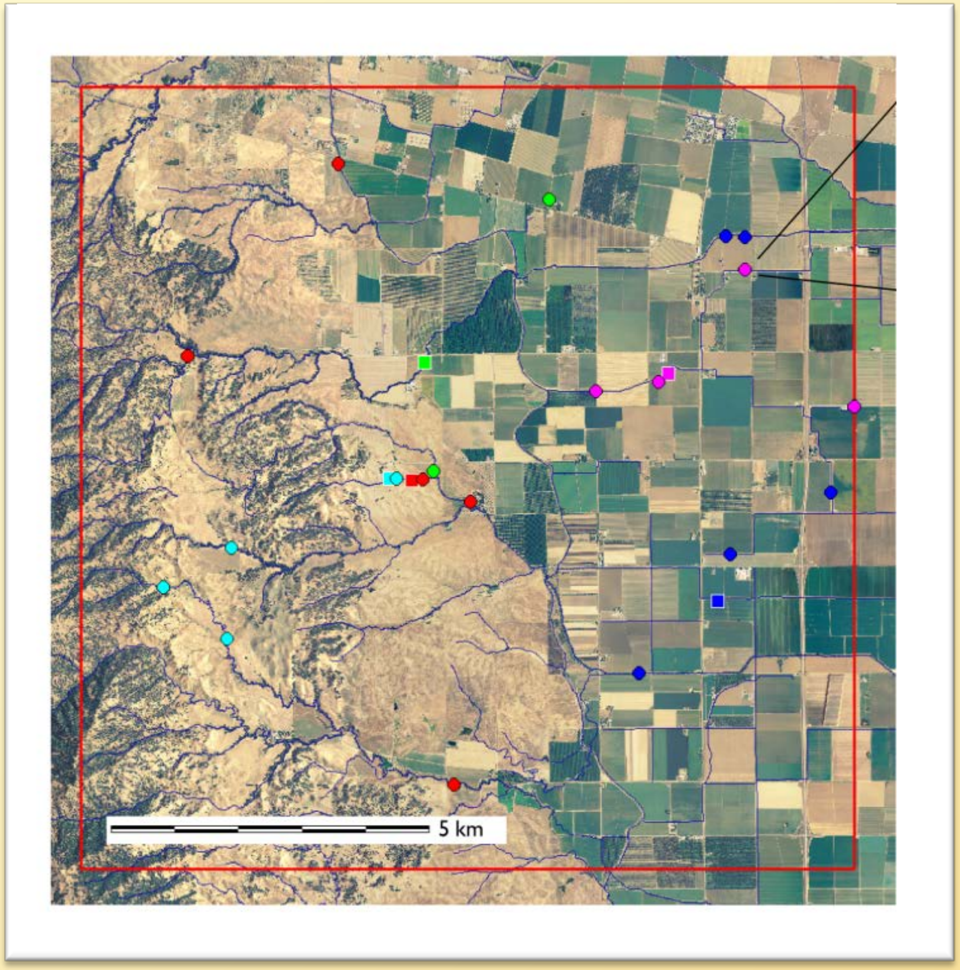
Calderón et al. 2000

1) Summary: Land use change on similar granitic soil types

- Grassland vs. tilled agricultural soils
  - Higher soil C and total PLFA (microbial biomass) in grasslands
  - Large differences in microbial communities
- Low resilience and resistance to disturbance in microbial communities from annual grassland than intensive agriculture
- Annual grasslands have similar PLFA profiles regardless of tillage history
- Relict perennial grasslands tend to have different microbial communities than annual or restored perennial old field grasslands

Once soils are disturbed, e.g., by tillage, it may be very difficult to restore the soil microbial community to that of native relict grasslands.

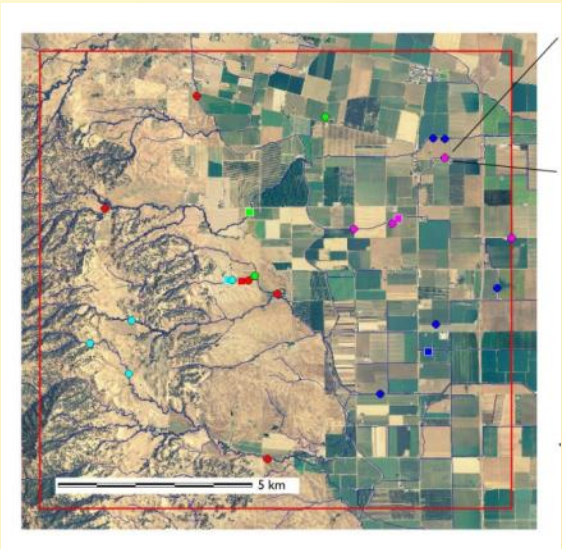
2) Landscape inventory of biodiversity along agricultural and rangeland waterways



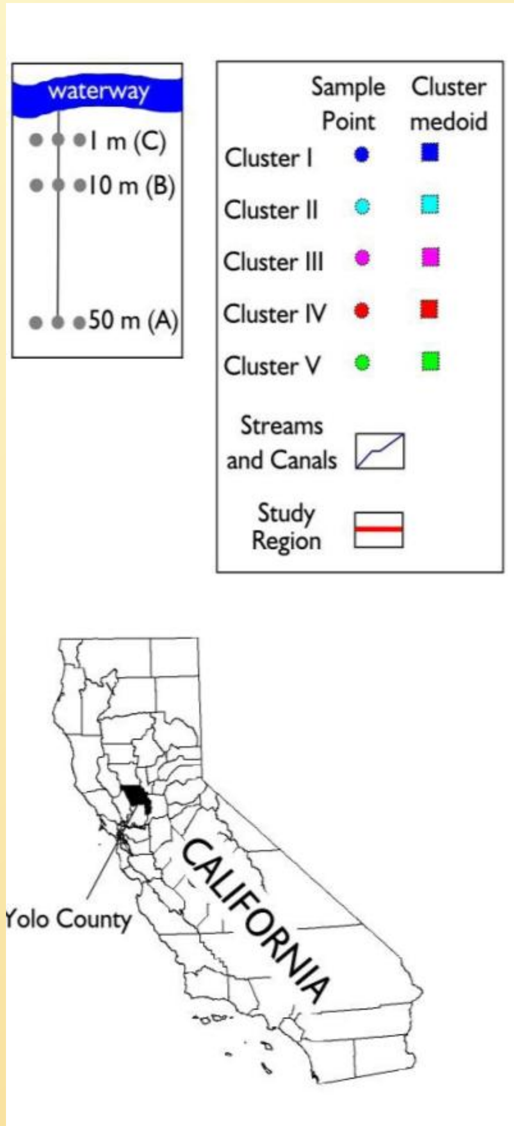
Culman et al. 2010 Landscape Ecol
Young-Mathews et al. 2010 Agroforestry Systems
Sánchez-Moreno et al. 2012 Soil Biol Biogeochem

- Intensive agriculture: grazed dryland savanna to irrigated row crops
- Waterways in a I50 km^2 landscape (Yolo County)
- Disturbed riparian corridors are only remaining natural vegetation
- GIS analysis to obtain representative data across landscape
- Ecological assessments & farmer interviews (sites shown)
- Agricultural intensification index: non-renewable inputs + landscape complexity at each sampled point

Representative sampling of waterways in the landscape



- GIS layers
  - Soil properties
  - Drainage
  - Vegetation
  - Wetlands
  - Land use
- 2050 random sites along waterways
- PAM multivariate analysis to cluster sites
- Sampling points chosen from each of 5 clusters

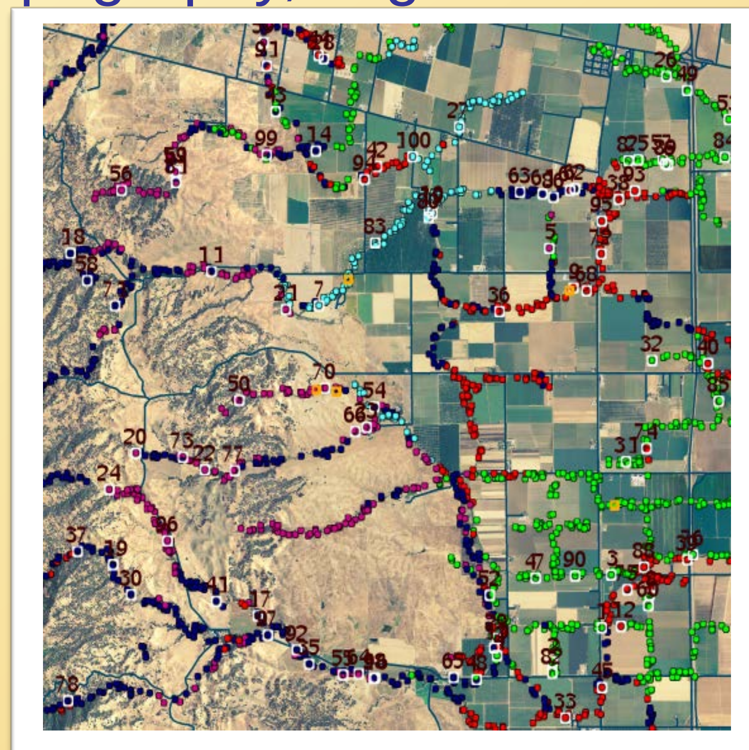


Agricultural intensification index for each sampled point:

- Field level
  - Land use type
  - Tilled in last 30 days
  - Tilled in last 2 years
  - Irrigated in last 30 days
  - Planted in last 30 days
  - Organic vs. conventional
  - Riparian restoration
  - Channel disturbance
  - Riparian health rating
- Landscape level
  - % managed land within 100 m, 500 m or 1000 m radius
  - Number of land use types within 100 m, 500 m or 1000 m

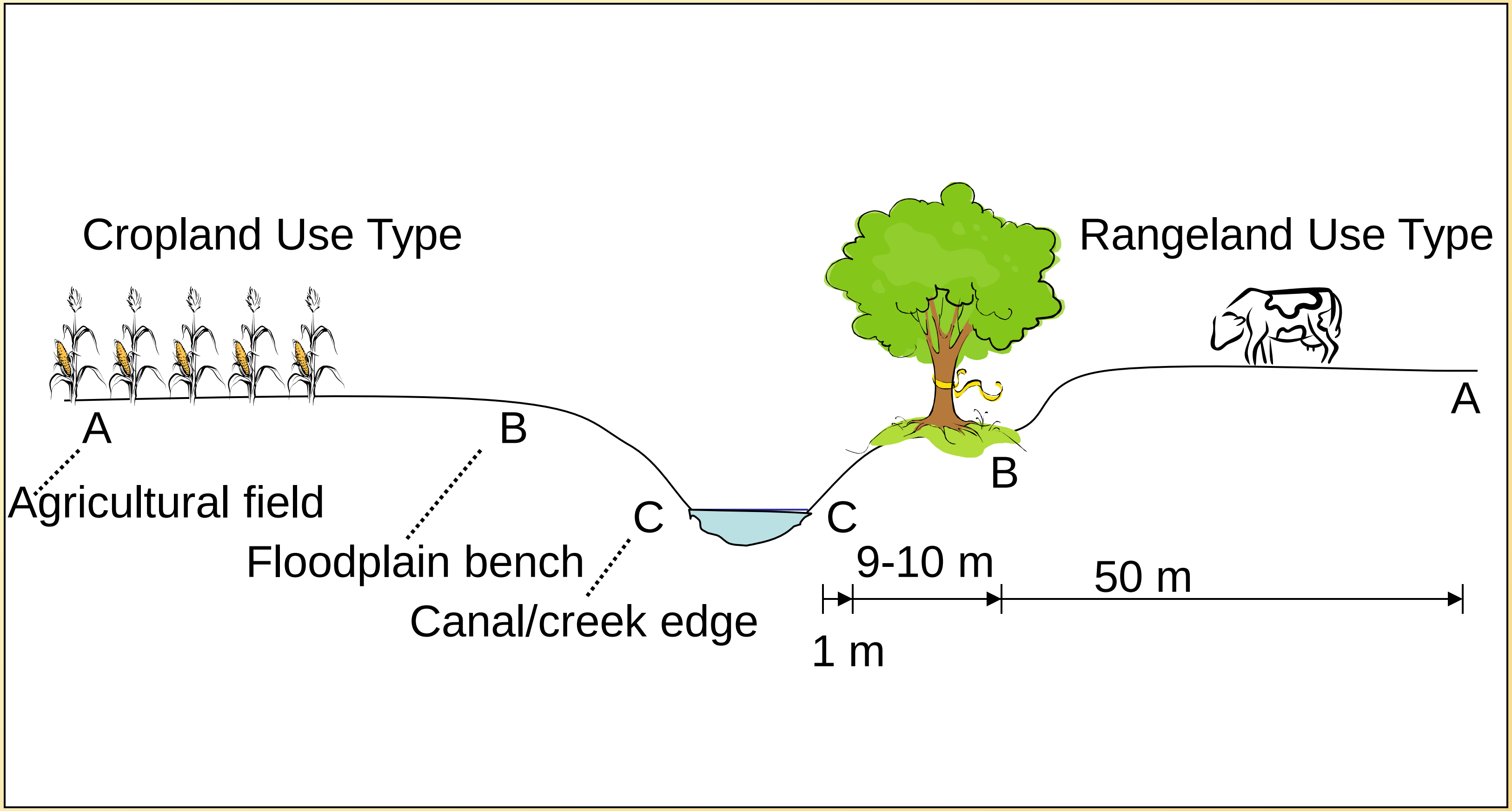
GIS of random sites along waterways

2050 sites (each 50 m from a waterway)
classified into 1 of 5 clusters using multivariate analysis of
publically available data on soil, topography, vegetation etc.



4 to 6 sites chosen per cluster for sampling
20 sites represent the variation among and within 5 clusters

Sampling scheme for each of the 20 sites



Examples of rangeland sites

Biodiversity & functional groups

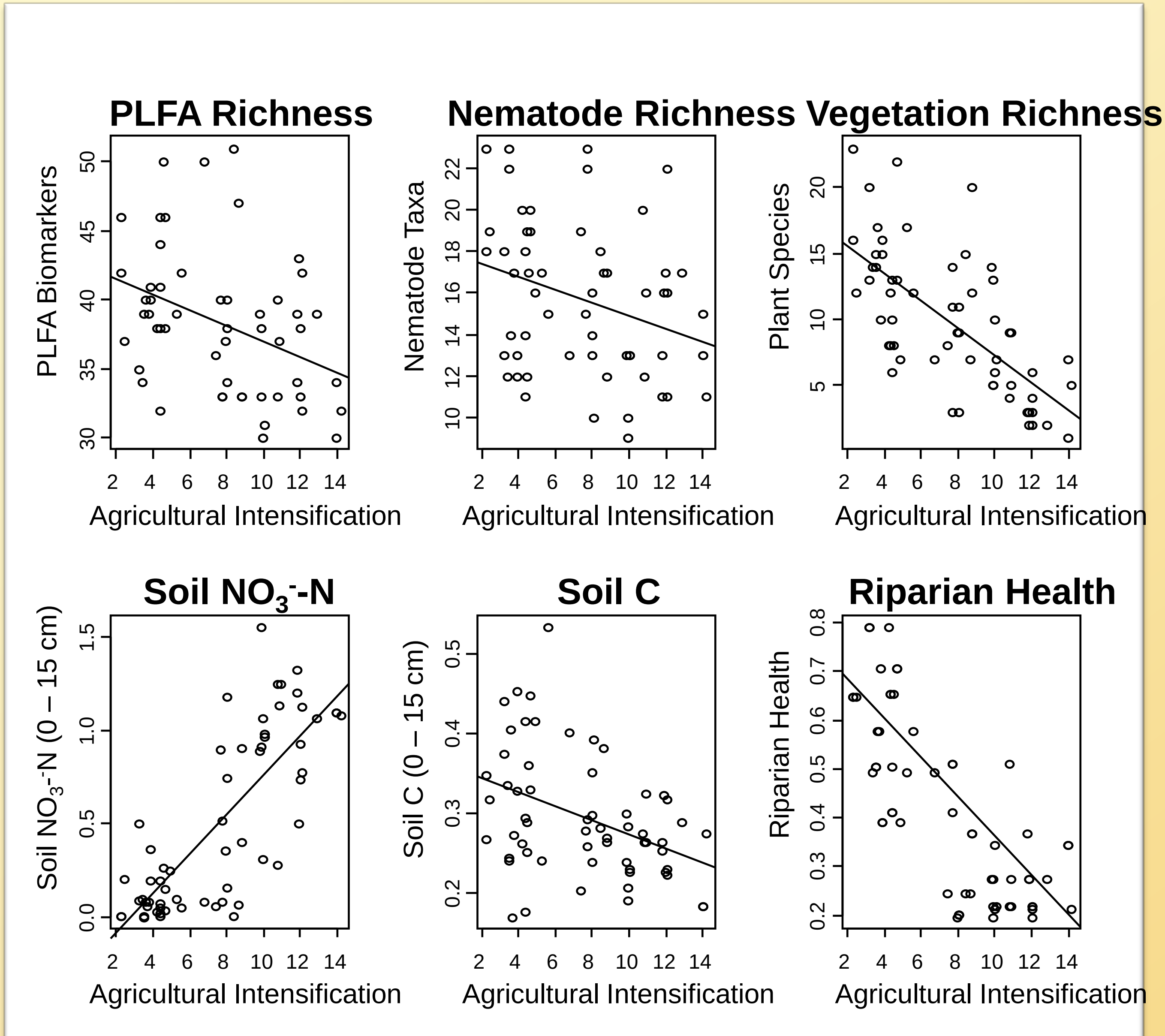
Means and ranges for 60 sampled points in the Yolo County landscape

Biota	mean	range
Vegetation		
No. spp.	10	1-35
Annual grass (cover)	28	0-95
Annual forb (cover)	10	0-40
Per. grass (cover)	5	0-53
Per. woody (cover)	12	0-111
PLFA		
No. biomarkers	38	30-57
Fungal (nmol g^{-1})	5	1-13
Gram + (nmol g^{-1})	8	2-18
Gram - (nmol g^{-1})	5	1-15
Total PLFA (nmol g^{-1})	38	11-90

Biota	mean	range
Nematodes		
No. taxa	16	7-30
Bacterivore (100 g^{-1})	116	2-426
Fungivore (100 g^{-1})	181	1-786
Plant feeder (100 g^{-1})	121	1-552
Omnivore (100 g^{-1})	26	0-117
Predator (100 g^{-1})	<1	0-10

Low mean number of taxa, especially predator nematodes and native perennial plants

Effects of agricultural intensification



A higher agricultural intensification index was significantly correlated with lower:

- No. of taxa of plants & nematodes
- No. of PLFA biomarkers
- Soil quality indicators
- Riparian health scores
- …but note low number of taxa overall

Culman et al. 2010 Landscape Ecol

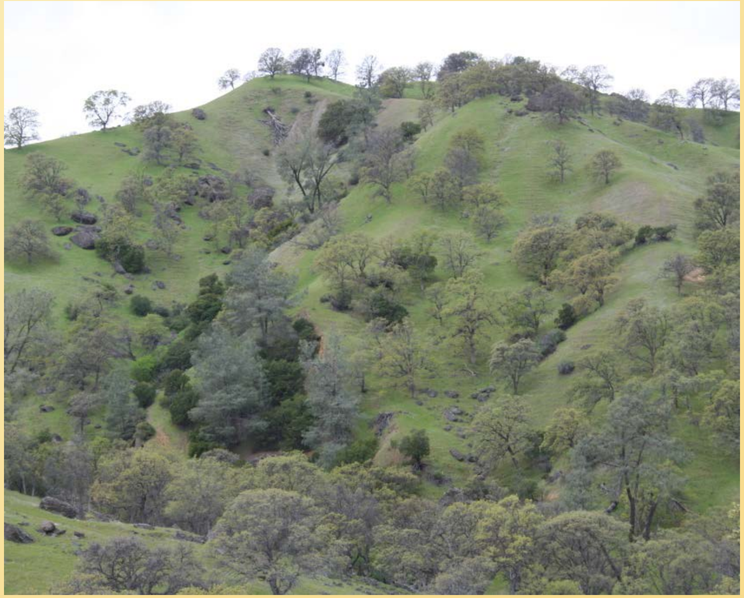
2) Summary: Landscape inventory of biodiversity

- Minor differences in nematodes and PLFA along creek vs. in agricultural fields
- Soil food webs have few omnivore or predator nematodes
- Very weak relationships between plant & soil communities (Mantel tests; data not shown)
- Lack of soil biodiversity is problematic for truly restoring a native ecosystem
- Homogenization of the landscape?
- Low biodiversity due to Mediterranean type climate?

Culman et al. 2010 Landscape Ecol
Young-Mathews et al. 2010 Agroforestry Systems
Sánchez-Moreno et al. 2012 Soil Biol Biogeochem

3) Soil food webs in California riparian oak woodlands at a nature reserve

- Examine how soil nematodes and food webs differ along relatively undisturbed streams
- Conduct fine-scale sampling to see if there are specific habitats preferred by nematode taxa
- 3 km away from landscape biodiversity study
- Two sites with almost no cattle grazing
  - South-facing slopes
  - Dominant tree and shrub species: *Arctostaphylos glandulosa, Heteromeles arbutifolia, Quercus douglasii*
  - Average soil C, C:N, texture (sand, silt and clay) is similar between sites



Two riparian corridor sites at the Bobcat Ranch nature reserve near Winters, CA

- Drier creek bed
- Some animal disturbance
- Higher variance in soil properties

Site 1

- Flowing water
- Little disturbance
- Lower variance in soil properties

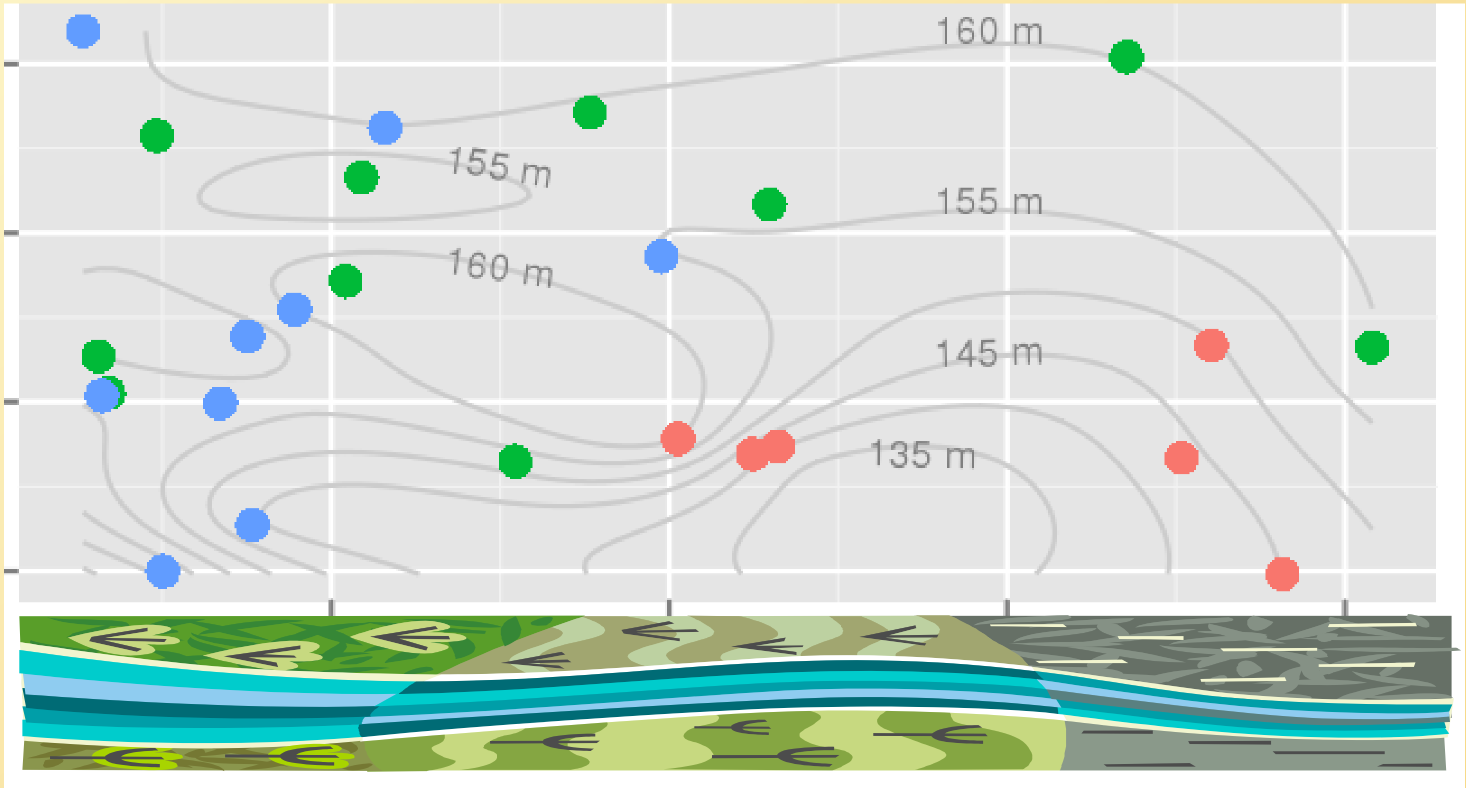
Site 2

Mapping trees along the two stream corridors

- Tree species change with distance with distance from the stream edge

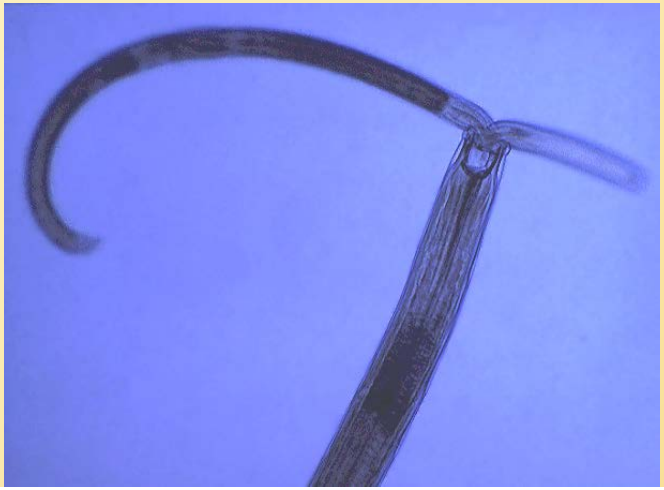
- Evergreen sclerophyllous
- Evergreen leathery
- Deciduous

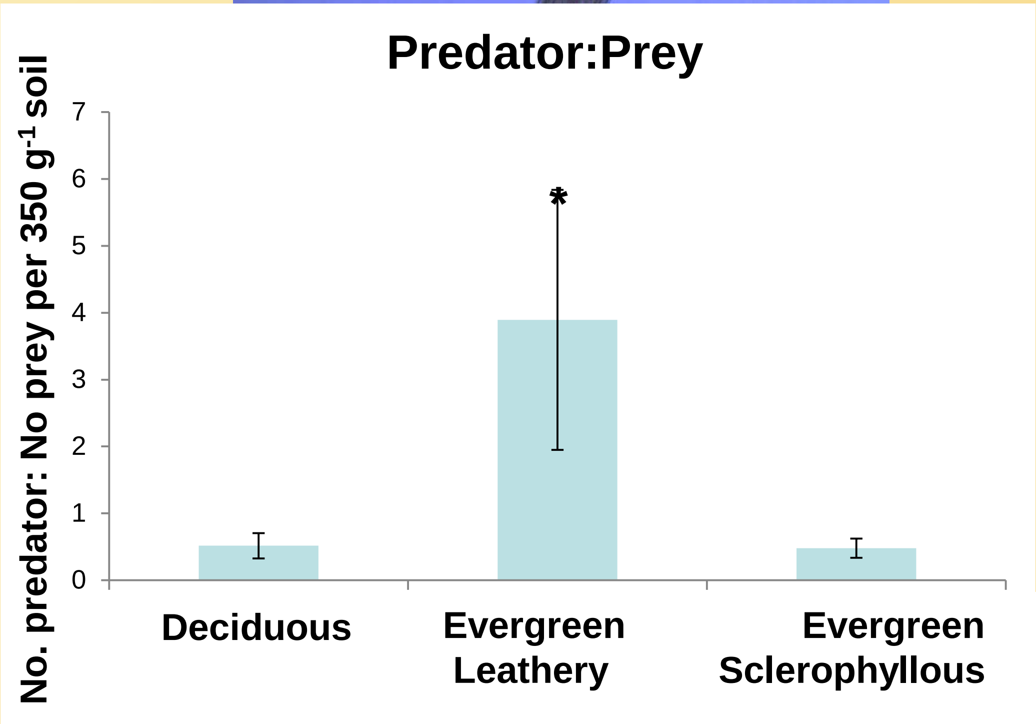
Leaf toughness



Site 2: Ratios of predator:prey

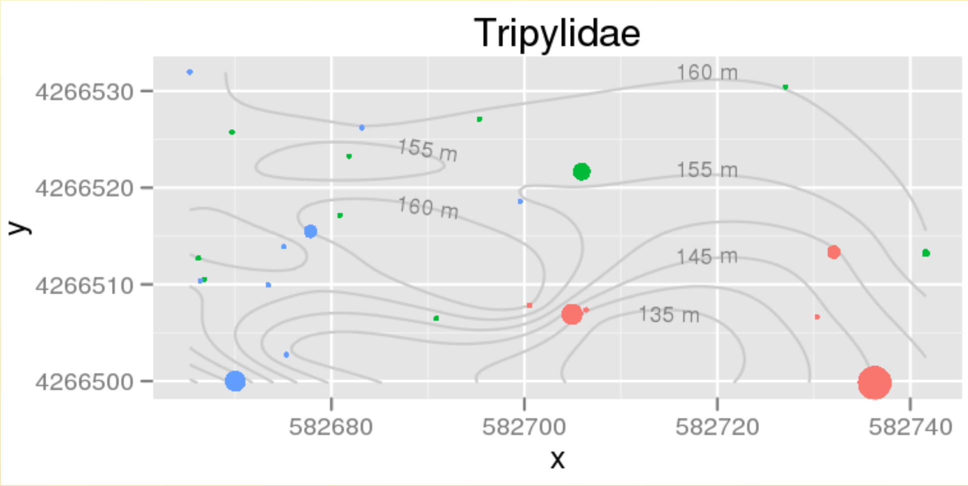
- Food web snapshot
- Can indicate resource and pest regulation
- What causes a high ratio?
- Is litter chemical complexity allowing more dynamic cycling of food web?

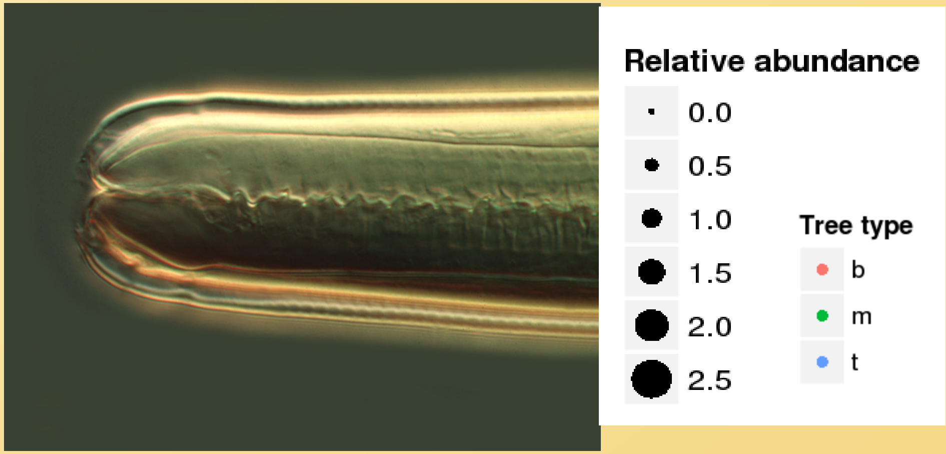




Site study in native riparian woodland

- Abundant and diverse omnivore and predator nematodes
  - 25 nematode groups/site vs. 16 in intensive agriculture landscape
- Spatial heterogeneity within sites (*e.g.* predator *Triplyidae*)
  - Higher abundance near the creek and under blue oak (*Q. douglasii*)
- High soil C and low inorganic N

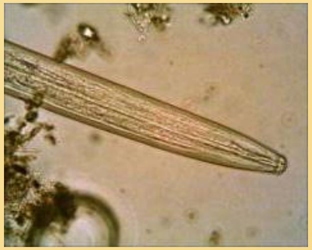




Hodson et al. 2014 Geoderma

3) Summary: Soil food web in native riparian woodland

- Upland ungrazed native riparian woodland soils (~ 3 km from ag landscape) have diverse nematode communities and food webs
- Heterogeneity within sites related to trees/shrubs that differ in leaf functional traits and litter quality (deciduous, evergreen, or evergreen/sclerophyllous) and distance from stream
- The California Floristic Province is a ‘global biodiversity hotspot’. Areas now in agriculture likely had much higher soil biodiversity before European settlement



Hodson et al., 2014 Geoderma

This talk

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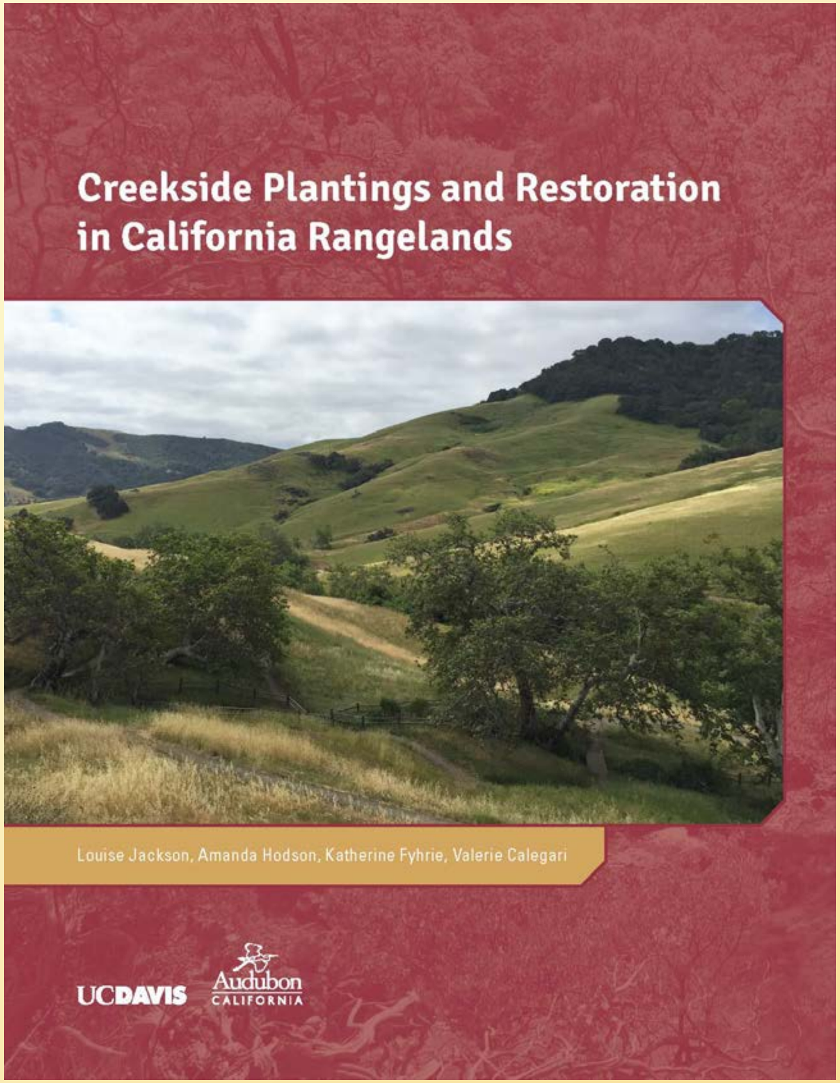
Implications of soil biology for ecosystem restoration activities

- Introduction to soil biology and soil food webs
  - Find out the history of your site and treat the soil with awareness for the complexity of soil biota and their beneficial functions
- Soil biodiversity and ecosystem functions

1) Avoid tillage, disking and grading of grasslands and woodlands which disturb the soil community and its functions (e.g. soil C sequestration, nutrient retention etc.)
2) Design restoration activities to avoid erosion and loss of the surface soil that is rich in soil biota and organic matter
3) Realize that soil biodiversity along intensive agricultural and grazed rangeland waterways can be low in California, but increasing soil organic matter and litter will improve functioning of the existing biota
4) Protect remnant 'relict' ecosystems by avoiding disturbance and inputs that change habitats for native soil biota and food webs
5) Don't gather soil from remnant ecosystems for nurseries due to damage to native biota *in situ* and the food web will likely not survive when transferred and mixed in potting soil.

Restoration booklet, August 2015



- 90-page booklet funded by USDA-CIG grant
- Literature review: '*Habitat Restoration Practices for California Rangeland Riparian Corridors*'
  - planning strategies
  - technical aspects
  - evaluation of success and failure of riparian restoration
- Case studies: Practices described for three California ranches
- Worksheet: '*Riparian Habitat Restoration Planning Worksheet for California Rangelands*'

http://ucanr.edu/sites/Jackson_Lab/Project_1/Riparian_Restoration_in_California_Rangelands/

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- **Post-docs and students:**
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  - Annie Young-Mathews
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  - Mark Stromberg
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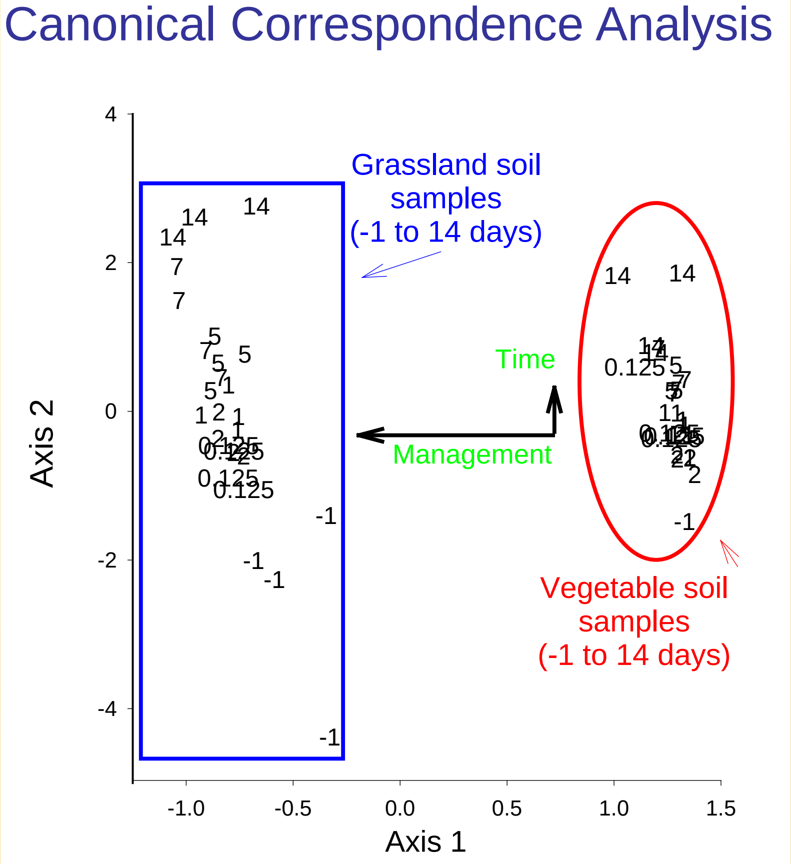
  - USDA-NRI Soils and Soil Biology Program
  - USDA-CIG Program

PLFA profiles after simulated tillage of grassland and vegetable production soils

- Large differences between grassland vs. vegetable production time courses
  - 26 shared PLFA between grassland and vegetable soils
- Simulated tillage did not increase the similarity between the two soils
- Land use history had greater effects on PLFA profiles than short-term disturbance



Calderon et al. 2000

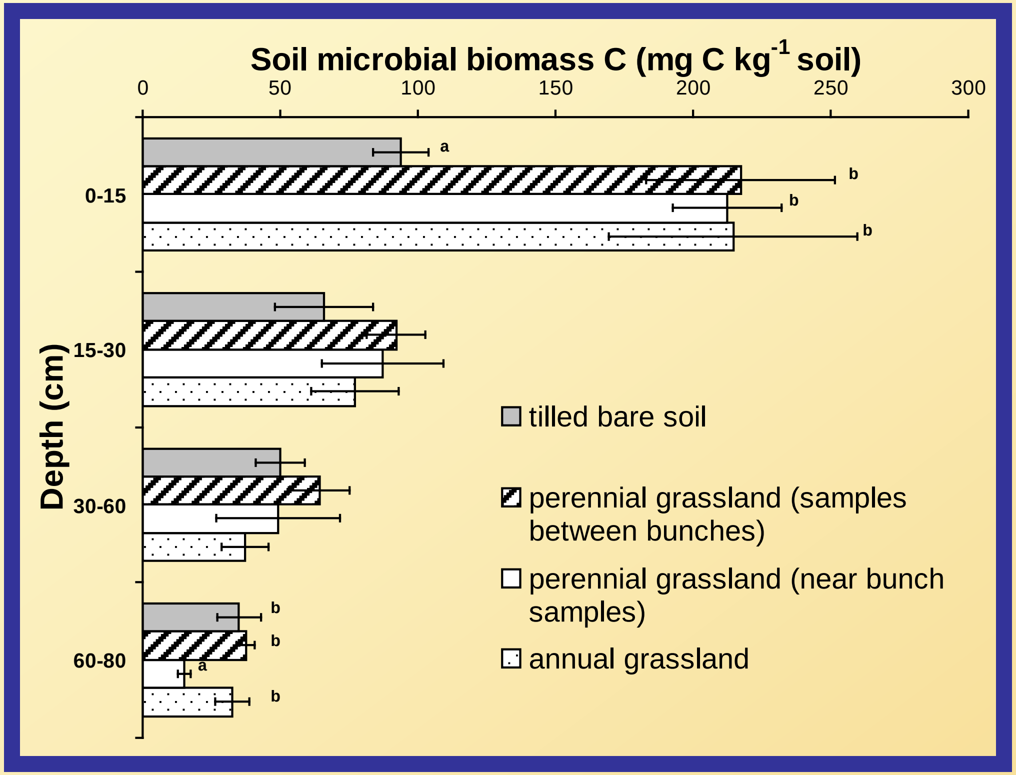
5 years after restoration of native perennial grassland began: Plant species composition

- Aboveground biomass is highest near *Nassella pulchra* bunches in the restored perennial grassland
  - Total biomass is fairly similar across the restored perennial and annual grasslands
- Restoration increased the cover of native species compared to its prior state as annual grassland
  - Other restored sites also show a weak trend toward greater cover and number of native species

	Restored perennial grassland (near bunches)	Restored perennial grassland (between bunches)	Annual grassland
Aboveground biomass (g m^{-2})	153	49	81
Cover of native species	82%	32%	14%
No. native species	5	4	6
	7 total		
No. of exotic species	7	7	6
	7 total		

Potthoff et al. 2005

5 years after restoration of native perennial grassland began: Soil microbial biomass



- Soil microbial biomass was similar in both grassland types
- Continuous tillage causes soil microbial biomass and total C to decrease
  - Lower fungal PLFA markers than in grassland plots
- PLFA of the restored perennial grassland resembled PLFA of annual grassland, even after two years of tillage

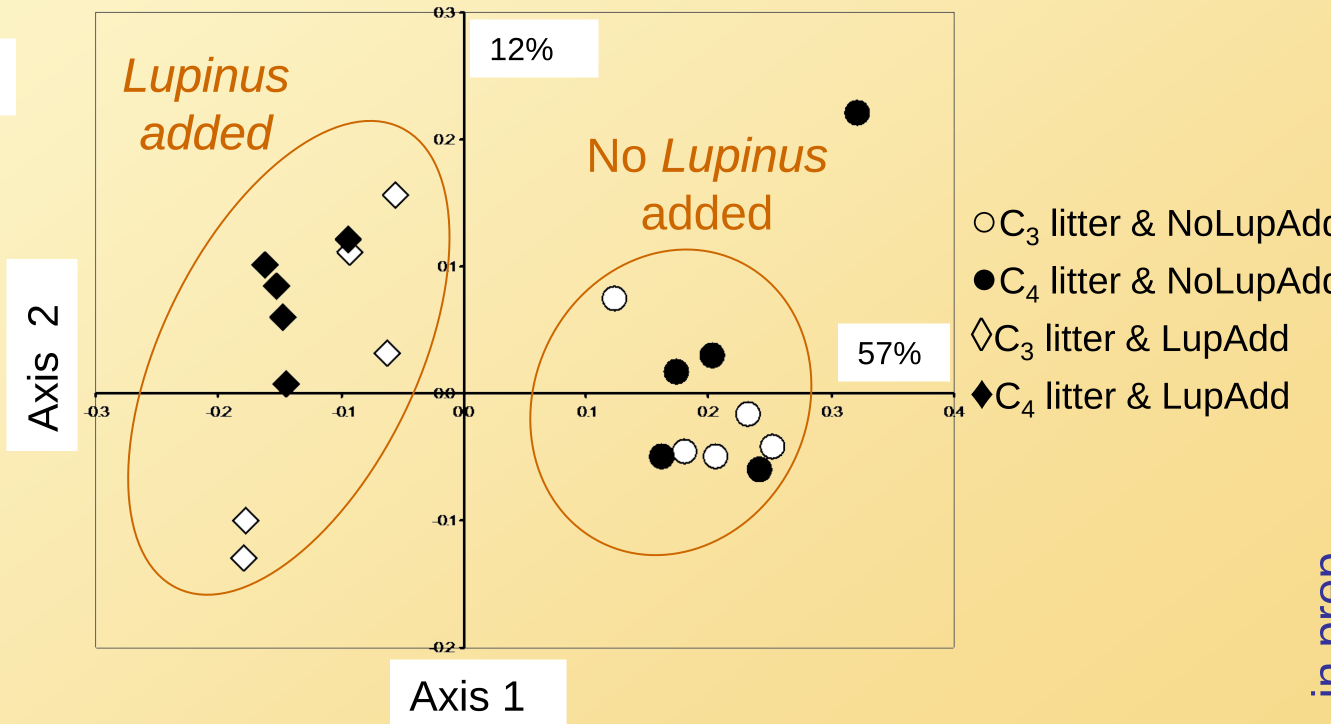
Potthoff et al. 2005

Effects of adding *Lupinus bicolor* and high C:N litter to restored *Nassella* grassland

with perennial grass litter

with *Lupinus bicolor*

CA of PLFA two years after seeding *Lupinus*



- PLFA fungal markers increased with added *Lupinus*
- Biomass, and %P of annual litter increased, and $\delta^{15}N$ decreased with added *Lupinus*
- *Nassella* little affected by adding *Lupinus*
- Little effect of adding high C:N litter

Potthoff et al. in prep

Nassella pulchra along a gradient of land use intensification

- Do native bunchgrasses cultivate the same microbial community across a gradient of land use intensification?
  - No
- Experimental approach:
  - Three *Nassella* ecosystems on similar soil types
    - Relict perennial grassland
    - Restored perennial grassland
    - Agricultural grassland
  - ± annual plants (removal) around the bunchgrasses
  - Sampled PLFA and microbial activity in fall, winter, and spring

- PLFA profiles of *Nassella* soil differed
  - Seasonally
  - Between *Nassella* surrounded by bare soil vs. annual plants
  - Between ecosystems

…but not consistently

- There is high variability in *Nassella*'s impact on its soil microbial communities, and on their activity
- Planting *Nassella* does not 'restore' a microbial community that resembles that of the relict perennial grassland

Steenwerth et al. 2006

Land use change, soil C, and soil microbial communities

Literature review (largely outside of California):

- Grasslands have a high capacity to store soil C
  - High primary productivity
  - Accumulation of litter and rhizodeposits
  - Stability of by-products produced during decomposition
- Soil C is lost when grasslands are tilled
  - Previously protected C becomes available to microbes
  - Temperature/moisture regime favors microbial activity
- Soil C increases after cropland abandonment
  - Affected by plant species composition, primary production, and management (fertilization and irrigation)
- Soil microbial and faunal communities are important for the stabilization of soil C from plant and microbial residues
  - Direct relationships among taxa are difficult to assess
  - Seek associations with ecosystem functions

Burke et al., 1989, Guggenberger et al. 1999, Wardle et al. 2004, Sparling et al., 2006