SOIL ORGANISMS, BACTERIA, FUNGI, PROTOZOA, NEMATODES AND ROTIFERS

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INTERIOR COLUMBIA BASIN
ECOSYSTEM MANAGEMENT PROJECT

SOIL ORGANISMS: BACTERIA; FUNGI, PROTOZOA, NEMATODES, AND ROTIFERS

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This report consists of:

- a brief introduction,.
- a table which summarize critical soil foodweb organisms in majo ecosystem-types found in the Columbia River Basin (Table 1),
- a table which summarizes critical genera or species of each soi foodweb group in each ecosystem-type (Table 2),
- an overview of critical soil foodweb components responses to majo disturbances, (watershed document) and
- summary reports, in the requested format, for each soil foodweb group
  - a. Beneficial Bacteria: N-fixers - Rhizobium
  - missing — b. Beneficial bacteria: Cyanobacteria and crust-forming communitie
  - c. Competitive bacteria: Bacillus
  - d. Competitive bacteria: Pseudomonas
  - e. Bacteria: N-immobilizers
  - f. Bacterial pathogens
  - g. VAM fungi
  - h. Ectoycorrhizal mat-forming fungi
  - i. Saprophytic fungi
  - j. Fungal pathogens
  - k. Protozoa: bacterial predators
  - 1. Bacterial-feeding nematodes
  - m. Fungal-feeding nematodes
  - n. Plant-feeding nematodes
  - o. Rotifers

INTRODUCTION

The study of the community structure of soil organisms, their functiona roles in controlling ecosystem productivity and structure are only now bein investigated. Soil ecology has just begun to identify the importance o understanding soil foodweb structure and how it can control plant vegetation and how, in turn, plant community structure affects soil organic matte quality, root exudates and therefore, alters soil foodweb structure. Sinc this field is relatively new, not all the relationships have been explored nor is the fine-tuning within ecosystems well understood.

Regardless, some relationships between ecosystem productivity, soi organisms, soil foodweb structure and plant community structure and dynamic are known, and are extremely important determinants of ecosystem processe (Ingham and Thies, submitted). In fact, alteration of soil foodweb structur can result in sites which cannot be regenerated to conifers, even with 2 years of regeneration efforts (Perry, 1988; Colinas yet al, 1993). Work i intensely disturbed forested ecosystems suggests that alteration of soil foodweb structure can alter the direction of succession. By managing foodwet structure appropriately, early stages of succession can be prolonged, or deleted (Allen and Allen, 1993). Initial data indicates that replacement of grassland with forest in normal successional sequences requires alteration of soil foodweb structure from a bacterial-dominated foodweb in grasslands to a fungal-dominated foodweb in forests (Ingham et al, 1986 a, b; Ingham 1991; Ingham and Thies, submitted).

In addition to responses to disturbance, it is clear that species diversity, community diversity and foodweb complexity increases with increasinc successional stage (Moore et al., 1992; Ingham 1991). Indeed, examination of foodweb interactions and ecosystem diversity, instead of community diversity, may result in new ecosystem measures which reflect this increased community diversity and increased connectivity in later successional stages.

Some knowledge about soil foodweb structure (Table 1), and specie: composition or important species present in each of the vegetation-basec ecosystems (Table 2) for the Greater Columbia River Basin have been at leas: initially assessed, or extrapolated from similar ecosystem-types in relatec areas of the U.S.

Two measures of ecosystem processes are discussed in the appropriate section! in this report: the ratio of fungal to bacterial biomass (Ingham and Horton 1987) and the Maturity Index for nematodes (Bongers, 1985). Both appear tc be useful predictors of ecosystem health, although they must be properly interpreted given the successional stage being -addressed. For example recently disturbed systems have nematode community structures skewed toward: opportunistic species and genera, while the less-opportunistic, more K- selected species of nematodes return as time-since-disturbance increases Thus, healthier soils tend to have more mature nematode community structures However, as systems mature, nutrients tend to be more sequestered in soi biomass and organic matter, and thus the maturity index reflects an optimal intermediate-disturbance period in which greatest ecosystem productivity i: likely to occur.

Ratios of fungal to bacterial biomass also predict this type of response Highly productive agricultural soils tends to have ratios near one, but as a system undergoes succession into a grassland, this ratio dips downwards indicating that for a healthy grassland system, the ratio should be less tha. one. In other words, bacterial-biomass dominates in healthy grassland soils However, as succession proceeds yet further, fungal biomass begins t dominate and healthy forest systems have fungal to bacterial biomass ratio of greater than one, usually greater than 10.

Riparian or deciduous forests appear to be intermediate within this range o values. Alder forest soils are dominated by bacterial biomass, while popula forest soils are fungal-dominated. Clearly, further investigation i required.

The predators of bacteria and fungi tend to follow the dominance of th decomposer groups. Thus, bacterial-dominated soils have a majority o bacterial-predators (protozoa and bacterial-feeding nematodes), while fungal dominated soils have a majority of fungal-predators (fungal-feeding nematode and fungal-feeding microarthropods).

Much work is still required at the bacterial and fungal species level. Whi the species of protozoa and nematodes have been researched in soils of th area of the west, publication of much of this information has yet to occu Up-dates will be required as this information becomes available.

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Table 1. Dominant functional groups in each vegetative type in the Columbia/Klamath/Great Basin areas.

Veaetative types	Dominant functional groups of organisms in each vegetative type
Agricultural	Bacteria, VAM, protozoa, bacteria;-feeding nematodes, plant-feeding nematodes, microarthropod: (especially root-feeders)
Range grass	Bacteria, VAM, protozoa, bacterial-feeding nematodes
Mixed grass	Bacteria, VAM, protozoa, bacterial-feeding nematodes earthworms, rotifers
Shrubs	
Berry	Bacteria/fungi, ericoidmycorrhizae, protozoa, bacterial feeding nematodes, fungal-feeding nematodes
Chaparral	Bacteria, fungi, nematodes, insects
Sage	Bacteria, fungi, nematodes
Forest	
Fir, pine, cedar	Fungi, ectomycorrhizal fungi, ectomycorrhizal mats fungal-feeding nematodes, fungal-feedin microarthropods
Mesquite	Fungi, ectomycorrhizal fungi, fungal- feeding nematodes fungal-feeding microarthropods
Aspen, alder, willow	Bacteria, fungi, protozoa, nematodes, rotifers microarthropods
Oak, madrone	Fungi, ectomycorrhizal fungi, ectomycorrhizal mats fungal-feeding nematodes, fungal-feedin microarthropods
Sub-alpine herbacious	Bacteria, VAM, protozoa, bacterial-feeding nematodes
Alpine tundra	Fungi, bacteria, protozoa, nematodes, rotifers
Glacial tundra	Bacteria, protozoa, nematodes

Table 2. Functional groups and species of concern in different ecosystem-types of th
Columbia River Basin (species composition information based mostly on work recentl
performed by Ingham et al., in prep).

Agricultural	
Bacteria	
Beneficial bacteria in the rhizosphere	
N-fixers:	Rhizobium
Competitive bacteria:	Pseudomonas, Bacillus
N-immobilizers	
Pathogens:	
Bacterial	Erwinia, Zymomonas, Agrobacterium
Fungi	
VAM:	Glomus
Pathogens:	Sclerotium
Protozoa:	Bodo, Amoebae, Colpoda
Bacterial-feeding nematodes:	Acrobeloides, Acrobeles
Plant-feeding nematodes:	Paratylenchus, Meloidogyne
Ratio of fungi to bacteria = 1	
Maturity index of nematode functional groups	
Ranse grass	
Bacteria	
Beneficial bacteria in the rhizosphere:	
Cyanobacteria/cryptobiotic crust communities	
N-fixers:	Azotobacterium
Competitors with pathogens:	Pseudomonas, Arthrobacter
N-immobilizers	
Pathogens	
Fungi	
VAM:	Glomus, Gigaspora
Pathogens:	Rhizoctonia
Protozoa:	Bodo, Amoebae, Colpoda
Bacterial-feeding nematodes:	Actobeloides, Acrobeles, Panagrolaimus
Ratio of fungi to bacteria < 1	
Maturity index of nematode functional groups	
Mixed grass	
Bacteria	
Beneficial bacteria in the rhizosphere:	
N-fixers:	Rhizobium, Azotobacterium
Cyanobacteria/cryptobiotic crusts	
Rhizosphere competitors:	Pseudomonas, Bacillus, Arthrobacter
N-immobilizers	
Pathogens	
Fungi	
VAM:	Glomus, Gigaspora
Pathogens:	Rhizoctonia
Protozoa:	Bodo, Amoebae, Colpoda
Bacterial-feeding nematodes:	Acrobeloides, Acrobeles, Panagrolaimus
Earthworms:	Lumbricus, Eosenia
Rotifers	
Ratio of fungi to bacteria < 1	
Maturity index of nematode functional groups	
Shrubs - Berries	
Bacteria	
Beneficial bacteria in the rhizosphere	
N-fixers:	Ftankia, Azotobacterium.
Competitive bacteria:	Pseudomonas, Bacillus
Litter decomposers:	Arthrobacter
Fungi	
Ectomycorrhizal fungi	
Ericoid fungi	

Saprophytes: Penicillium
Pathogens: Rhizoctonia
Protozoa: Bodo, Amoebae, Colpoda
Bacterial-feeding nematodes: Acrobeloides, Acrobeles, Panagrolaimus
Fungal-feeding nematodes: Aphelenchus, Tylenchus
Ratio of fungi to bacteria = 1 to 10
Maturity index of nematode functional groups

Shrubs Chaparral
Bacteria
Beneficial bacteria in the rhizosphere
N-fixers: Frankia, Azotobacterium
Competitive bacteria: Pseudomonas, Aeromonas
Litter decomposers: Arthrobacter
Fungi
Ericoid mycorrhizal fungi
Litter decomposing fungi
VAM: Glomus
Pathogens: Rhizoctonia
Bacterial-feeding nematodes: Wilsonema, Acrobeles, Elaphonema
Fungal-feeding nematodes: Ditylenchus, Aphelenchus
Ratio of fungi to bacteria = 1 or greater
Maturity index of nematode functional groups

Shrub - Sage
Bacteria
Beneficial bacteria in the rhizosphere
N-fixers: Frankia, Azotobacterium
Competitive bacteria: Pseudomonas, Aeromonas
Litter decomposers: Arthrobacter
Cyanobacteria/Cryptobiotic crust
Fungi
VAM: Glomus
Litter decomposing fungi
Pathogens: Rhizoctonia
Bacterial-feeding nematodes: Wilsonema, Acrobeles, Panagrolaimus
Fungal-feeding nematodes: Aphelenchus, **Aphelenchoides**,
Ratio of fungi to bacteria = 1
Maturity index of nematode functional groups

FOREST
Fir, pine, cedar
Bacteria
Fungi
Ectomycorrhizal mat-forming fungi: Hysterangium, Gautieria
Ectomycorrhizal fungi: Lacaria, numerous others
Saprophytes
Wood decomposing fungi: **White-** and brown-rot fungi
Pathogens: Ceratocystis, blister rust laminated root-rot
Protozoa: Bodo
Testate Amoebae: **Arcella, Difflugia**
Colpoda
Bacterial-feeding nematodes: Cephalobus, Cervidellus, Eucephalobus
Fungal-feeding nematodes: Aphelenchus, Tylencholaimus, Filenchus
Ratio of fungi to bacteria = 10 or greater
Maturity index of nematode functional groups

Mesquite (unstudied)
Bacteria
Fungi
Ectomycorrhizal fungi
Saprophytes

Wood decomposing fungi
Pathogens
Protozoa
Bacterial-feeding nematodes
Fungal-feeding nematodes
Ratio of fungi to'bacteria = ?
Maturity index of nematode functional groups

<u>Aspen, alder, willow</u>

Bacteria	
N-fixers:	Rhizobium, Frankia
Anaerobic, saturated soil bacteria:	Methanogens, Hydrogen-sulfide producers Clostridium
Fungi	
VAM	
Saprophytes	
Decomposer fungi:	White-rot fungi
Root pathogens	
Protozoa:	Cercomonas, Chaos, Testate Amoebae Mastigophora, Glossglockneria
Bacterial-feeding nematodes:	Acrobeles, Cephalobus
Fungal-feeding nematodes:	Aphelenchoides, Tylenchus
Rotifers	
Ratio of fungi to bacteria < 1	
Maturity index of nematode functional groups	

<u>Oak. madrone</u>

Bacteria	
N-fixers:	Azotobacteria, Frankia
Fungi	
Ectomycorrhizal mat-forming fungi:	Hysterangium, Gautieria
Ectomycorrhizal fungi	
Saprophytes	
Wood decomposing fungi:	White-rot fungi
Pathogens	
Protozoa	
Bacterial-feeding nematodes	
Fungal-feeding nematodes	
Rotifers	
Ratio of fungi to bacteria = 10 or greater	
Maturity index of nematode functional groups	

<u>Sub-alpine herbacious</u>

Bacteria
VAM fungi
Protozoa
Bacterial-feeding nematodes

<u>Alpine tundra</u>

Litter-decomposing fungi
Bacteria
Protozoa
Nematodes
Rotifers

<u>Glacial tundra</u>

Bacteria	
Protozoa:	Flagellates, Amoebae, Ciliates
Bacterial-feeding nematodes:	Scottnema

COLUMBIA RIVER BASIN - WATERSHED INFORMATION

Date: December 29, 1994 Panelist Name: Elaine R. Ingham

Species or Species Group: Relative Fungi / Bacteria

Geographic Area and/or Habitat Type:

1. RANGELAND WATERSHED INCLUDES:
   A. NORTH SLOPES:
      i. JUNIPER UPLAND - OPEN CANOPY TREE'LAYER, PATCHES OF BUNCHGRASS, CRYPTOBIOTIC CRUST DEVELOPMENT BETWEEN JUNIPER, GRASS PATCHES. SEASONAL WILDFLOWERS, HERBS. SAND-LOAM SOILS, LOW OM WITH PATCHY DISTRIBUTION OF HIGHER OM AREAS.
      ii. MID-SLOPE GRASSLAND - CLOSED CANOPY UNIFORM BUNCHGRASS, CRYPTOBIOTIC CRUST BETWEEN PLANTS. SANDY-LOAM SOILS, LOW OM
   B. SOUTH SLOPES:
      i. UPLAND GRASSLAND - OPEN CANOPY PATCHES OF WHEATGRASS, BUNCHGRASS, CHEATGRASS, HERBACEOUS PLANTS, WEEDS, CRYPTOBIOTIC CRUST BETWEEN PLANTS. ROCKY SAND-LOAM SOILS, LOW OM.
      ii. MID-SLOPE GRASSLAND - CLOSED CANOPY UNIFORM BUNCHGRASS, CRYPTOBIOTIC CRUST BETWEEN PLANTS, SANDY-LOAM SOILS, SOIL PROFILE WITH MINIMAL DEVELOPMENT
   C. SWALE:
      i. MULTI-STRATA RIPARIAN - QUACK GRASS, TALL BUNCH GRASS, SOME SHRUBS, ALDER, WILLOW, COTTONWOOD
      ii. WETLAND/STREAM

2. FORESTED WATERSHED INCLUDES:
   A. MATURE LARCH, PONDEROSA PINE, DOUG-FIR, GRAND-FIR MIXED FOREST - UNDERSTORY HERBS, GRASSES, SHRUBS, LOGS BOTH THINNED (BROKEN CANOPY) AND UNTHINNED (CLOSED CANOPY) STANDS. MAZAMA ASH, POORL DEVELOPED HORIZONS, MAX 2 CM LITTER LAYER
   B'. YOUNG MIXED FOREST, MULTISTRATA, OPEN CANOPY - MAZAMA ASH, 0 HORIZON DEVELOPMENT
   C. REGENERATING STANDS - GRASSES, SHRUBS - MAZAMA ASH, SOME LITTER ACCUMULATING ON MINERAL SOIL SURFACE
   SIMILAR EARLY SUCCESSIONAL STAGES AS IN GRASSLANDS ABOVE

BACTERIA AND FUNGI IN THE TWO WATERSHEDS

STAGE	FUNGI	BACTERIA	RATIO F:B
l.A.i	SAP - PENICILLIUM ECTO + VAM - GLOMUS** PATH - RHIZOCTONIA	NITRIFIERS*** MICROCOLEUS*** AGROBACTERIUM	AROUND TREES 10 INTERSPACE AREAS 0.1 - 0.5
1.A.ii	AS l.A.i EXCEPT NO ECTOS, VAM ONLY	ADD RHIZOBIUM	ALWAYS BELOW 1 USUALLY IN RANGE OF 0.1 - 0.5
l.B.i	AS 1.A.ii	FEWER N-FIXERS	CHEATGRASS AREAS RATIOS EVEN LOWER 0.01 - 0.5
1.B.ii	SAME AS 1.A.ii		
l.C	MESIC SOILS FUNGAL COMMUNITY ALTERED	MORE ANAEROBIC BACTERIA, DENITRIFIERS	RATIO CLOSER TO 1, POSSIBLY UP TO 10 BACTERIAL ACTIVITY GREATER THAN FUNGAL
2.A.	BROWN ROT, FUNGI, ECTOMYCORRHIZAL FUNGI, MATS, ROOTS ROTS	AMMONIFIERS, FREE-LIVING N FIXERS, FRANKIA	RATIO ALWAYS GREATER THAN 10, SOMETIMES MORE THAN 100. FUNGAL ACTIVITY GREATER THAN BACTERIAL
2.B.	LESS DIVERSITY IN FOODWEB SPECIES, COMMUNITIES		
2.c.	SAME AS l.A.i.		

The ratio of fungi to bacteria in grassland soils is less than zero (bacterial dominated). In forests, the ratio is usually above 10. Values between 1 and 10 indicate productive agricultural fields.

Another common generalization is that fungi in early successional stages, such as agricultural soils or grasslands are VAM, "sugar" fungi or pathogens, and are more "r" selected. Fungi in forests are ectomycorrhizal fungi, cellulose decomposers (white rotters), or lignin decomposers (dark septate fungi), and generally considered more "K" selected.

Growth of fungi on spread plates show significant changes in fungal community composition in different ecosystems, in different habitats, but there has been no comprehensive effort to document what saprophytic fungal community exists in which types of vegetation, following specific types of disturbance. This type of work is being done for mushrooms and truffle-forming fungi (Luoma, Castellano, Trappe's work).

RESPONSES OF BACTERIA AND FUNGI TO DISTURBANCE

DISTURBANCE TYPE	STAGE	RESPONSE
1. DROUGHT GRASSLAND ECOSYSTEM		How drought might differentially affect each part of the landscape is not known, therefore, one general response is outlined.
	North, south slopes	Communities of bacteria, fungi and crusts ar highly resistant to seasonal drought: long-term drought would result in altered community structure of all groups, ultimate1 a reduction in biomass of bacteria and'fungi and thus nutrient retention in, the soil, wit an increase in reliance of the ecosystem on crust C and N fixation.
	SWALE: MULTI-STRATA	Very little work has been performed in riparian areas with respect to bacterial/ fungal responses. Crust formation would be come more important in holding soil in place and preventing erosion during periodic wet periods. Fungi would be selected if shrubs became a more important part of the plant community. Plants tend to produce deeper roots, and alters the distribution of bacteria in the profile.
	WETLAND/STREAM	Little effect until the stream begins to dry then similar responses to above.
FORESTED WATERSHED	MATURE MIXED FOREST YOUNG MIXED'FOREST	Alters species composition, at first selecting for drought tolerant fungi. With continued drought, both bacterial and fungal biomass would be lost, most likely, reducing nutrient retention in the soil.
	REGENERATING STANDS	Unknown
2. FREEZE/THAW GRASSLAND ECOSYSTEM		Freeze/thaw generally affects bacteria and fungi in two ways: By breaking aggregates, nutrients become more available resulting in increased resources, but

	decreasing soil stability. By killing low temperature-intolerant individuals, community structure is altered.
North, south slopes	Bacteria are selected preferentially over fungi when the soil freezes and then thaws, since fungal hyphae are probably broken by the soil shifting that occurs. Crust communities are highly resistant to freeze-thaw disruption.
SWALE: MULTI-STRATA	Very little work has been performed in riparian areas with respect to bacterial/fungal responses. Crust formation would be come more important in holding soil in place and preventing erosion during periodic wet periods. Fungi would be selected if shrubs became a more important part of the plant community. Plants tend to produce deeper roots, and alters the distribution of bacteria in the profile.
WETLAND/STREAM	Little effect until the stream begins to dry, then similar responses to above.
FORESTED WATERSHED	
MATURE MIXED FOREST YOUNG MIXED FOREST	Alters species composition, at first selecting for drought tolerant fungi. With continued drought, both bacterial and fungal biomass would be lost, most likely, reducing nutrient retention in the soil.
REGENERATING STANDS	Unknown
3. SEASON	
GRASSLAND ECOSYSTEM	Bacteria, dominant in these grasslands, and fungi undergo a predictable seasonal fluctuations in activity, biomass and community composition. All disturbance must be 'assessed knowing this cyclical seasonal cycle. In all systems in the high desert region, activity and biomass begin to increase in the early spring as temperature moves into optimal regions for most species, and as spring rains occur. As the summer drought begins and plants begin to senesce, bacteria and fungal activity decrease sharply. Numbers and biomass decrease in th summer, although if rain continues through the summer, the dip in biomass may be minimal. If temperatures remain warm throug the fall and rains begin, biomass and activity can show a secondary seasonal peak. If temperatures decrease sharply and precipitation appears as snow, the secondary

peak will not be observed. If no snow cover occurs in the winter, activity and biomass will dip to the lowest levels in the year.

North-facing slopes

Since temperature fluctuations are not as severe, summertime reductions in activity ar biomass are not as low as on south facing slopes.

South-facing slopes

Winter temperatures are usually warmer and thus wintertime reductions in biomass and activity may be less drastic. However, more freeze-thaw events can occur, which will ter to select against fungi, and be advantageous for bacteria.

SWALE:
MULTI-STRATA

Very little work has been performed in riparian areas with respect to bacterial/fungal responses. Maintenance of bacterial and fungal biomass to hold aggregate structures and prevent erosion are of critical importance. Especially in grassland areas, crust formation can be practically the sole force preventing erosion.

WETLAND/STREAM

Very little work has been done on seasonal fluctuations in these areas.

FORESTED WATERSHED
MATURE MIXED FOREST

Fungal biomass dominates in these ecosystems but seasonal fluctuations can be quite different from grassland systems. As tree roots begin to move storage materials back into the sap, rhizosphere organisms undergo an increase in activity. Warm periods durin this time can result in activation of the entire soil, resulting in intense periods of biological activity as early as March. As the spring flush of activity, with temperature and moisture at optimal levels, activity and biomass of fungi is maximum, although bacterial responses may be limited. Components of the soil may never show decreased activity in the summer, but may remain highly activity regardless of drought conditions.. There is generally a secondary peak of activity in the fall as rain and sno occur. Because snow generally accumulates o the ground, freeze-thaw is not as great a factor in altering fungal and bacterial biomass ratios and fungal decreases are rarely seen. In fact, fungal activity can b at it's highest level for the entire year under the snow pack, and decomposition may b

	most rapid during the winter.
YOUNG MIXED FOREST	The buffering effect of the forest on temperatures in the summer, and on snowpack in the winter are extremely important.
REGENERATING STANDS	Intermediate between grassland and forest systems.
4. FIRE	Landscape position combined with fire intensity have not been investigated for their combined impact on soil organism responses.
GRASSLAND ECOSYSTEM	Effects of landscape position combined with fire intensity on soil organisms have not been investigated. The effects of fire intensity on soil organisms has been investigated in related systems. The assumption is that similar responses would occur, given similarity of conditions. Light intensity fires burn little of the organic matter layer. The litter layer may experience an increase in temperature which in some cases may be beneficial, resulting in increase activity and biomass of especially the bacteria. High intensity fire burns away the food resource for both bacteria and fungi, while at the same time killing these organisms through high temperatures. High intensity fires can result in severe set-backs in the nutrient retention capacity of soils, and may take many years for soil biodiversity to return to pre-fire conditions.
SWALE: WETLAND/STREAM	Very little work has been performed in riparian areas with respect to bacterial/fungal responses. The expectation with respect to fire is based on the degree to which the soil and litter is warmed, heated, or burned away.
FORESTED WATERSHED MATURE MIXED FOREST YOUNG MIXED FOREST	Just as for grassland systems, except that the impact on the organic matter is even more critical, since the fungal dominance of the forest floor is strongly correlated to the presence of litter. Removal of litter will strongly select for bacterial dominance, and the inability of the soil to support conifers.
REGENERATING STANDS	It is critically important to develop and maintain fungal dominance in regenerating conifer stands, otherwise the system will remain in the grassland stage.

5. CLEARCUTTING

Not a factor in grassland systems. In forests, the removal of the trees results i the loss of many of the ectomycorrhizal species from the soil, especially mat-formers. With *every* clearcutting event so far examined, at least a ten-fold loss of fungal biomass has occurred. If some as-of now unrecognized factor causes continued lo of fungi, re-establishment of conifer seedling in the system becomes extremely difficult, if not impossible. If the funga component of the soil begins to recover within five to ten years of after clearcutting, re-establishment of trees appears to proceed without difficulty.

6. PLOWING

The effects of plowing seem remarkably consistent across most vegetative systems. In all cases examine plowing results in the mixing of litter and surface organic matter into the soil, the breaking apart of soil aggregates and the release of protected organic matter. This mixing and exposure is more advantageou for bacterial than fungal activity and results in increased bacterial dominance in soil. Plowing resul in mixing of carbon present in litter into the nitrog in soil. When carbon and nitrogen are spatially separated, such as in forest soils with litter layers fungal hyphae are capable of bridging the gap between the soil N and the litter C, resulting, at least in part, in the dominance of fungi in forest systems. When the soil is plowed, this spatial separation is lost. When C and N are in close proximity, bacteria with enzymes with greater'affinity for most substrate than fungi, can outgrow most fungi, resulting in bacterial-dominated soils. Each time the soil is plowed, a pulse of rapid decomposition of soil C and occurs, and bacterial dominance becomes greater. At some equilibrium point, depending on the original sto of C and N, the annual inputs of organic matter and t periodicity of plowing, the stores of soil C and N wi be come depleted. As this happens, both bacterial an fungal biomass begin to decline. Bacteria and fungi are in large part responsible for formation of micro- and macro-aggregates and as the microbes are lost, so will not be held against erosional processes. Soil pore structure is lost, and root penetration of the soil will decline. Since bacteria and fungi are responsible for most of the incorporation of plant litter material into soil organic matter, especially these eastside soils with few earthworms, nutrient retention in the soil will decline as well. As has been clearly shown in studies in the Great Plains of the US, even with chemical fertilizer inputs, soil nutrients are eventually mined from the soil and not replaced (Cole et al. 1983) as soil foodweb diversity and microbial biomass is lost (Moore et al. 1992).

7. GRAZING

All vegetation is grazed to some degree and most plants are adapted, to greater or lesser extent, to herbivory. Plants, and indeed most likely ecosystems, which have evolved with large ungulate grazing herds (e.g., buffalo) are adapted to thrive in the face of grazing pressure. Ecosystems not adapted to large grazing herds are more fragile with respect to grazing as a disturbance. Existing undisturbed grasslands in eastern Oregon and Washington have extensive cryptobiotic crusts. Further east, in Idaho and Yellowstone National Park, less of the soil surface in grasslands is covered by crusts. In addition, the native grass species indicate greater adaptation to grazing as a normal part of the ecosystem.

GRASSLAND ECOSYSTEM

Eastern Oregon crust-dependant grasslands are fragile with respect to grazing, based on work being performed in the National Parks in Utah (Canyonlands, Needles, Arches) by Belnap, et al. (1994). Destruction of crust communities, especially since the only N-fixing species occur in the crusts, ultimately lead to soil and ecosystem degradation. The response of such ecosystems to grazing intensity appears to be related to crust destruction. The greater the loss of crust, the greater the loss of native species, the greater the likelihood of cheatgrass, shrub or other non-native species invasion.

The situation in Idaho and Yellowstone National Park may be quite different, more similar to shortgrass prairie responses with respect to grazing. While cryptobiotic crusts occur in the shortgrass prairie, other N-fixing plant species occur in these systems. When a plant is grazed, there is an short-term pulse of labile exudates into the rhizosphere, as evidenced by an increase in bacterial activity. Within a day, however, root exudation is reduced, and microbial activity is decreased while the plant shunts more of it's resources to shoot production. If a previously grazed plant is again grazed, the response is not a great as in a previously ungrazed plant. Some evidence exists that these pulses of exudation cause a shift in bacterial community structure around the roots, which then influences mycorrhizal colonization. As plant biomass is depleted by grazing and as soil is compacted with overgrazing, soil microbial biomass is depleted, with all the concomitant effects outlined under the section on plowing.

SWALE:

MULTI-STRATA

Very little work has been performed in riparian areas with respect to grazing and bacterial/fungal responses. Crust formatio would be more important in holding soil in place and preventing erosion during periodi wet periods.

WETLAND/STREAM

Effects on the soil organisms has not been studied.

FORESTED WATERSHED

MATURE MIXED FOREST

No information on grazing as a disturbance eastside forests was found.

YOUNG MIXED FOREST

REGENERATING STANDS

Unknown

8. COMPACTION

In general, compaction reduces the size of pores within the soil, decreasing the amount of air capable of moving into, or carbon dioxide moving out of the soil. In addition, the abilit of soil organisms to grow into the soil, to find soil nutrients and for water.to penetrate into t soil profile are reduced as compaction increases The greatest effect is often seen on the populations of bacterial and fungal predators. Single compaction events, such as occur in off-road vehicle use, or in clearcutting, may result in an ephemeral reduction in bacterial or fungal activity *or* biomass, but may not compact the soi to the extent that continued reductions in bacterial or fungal growth are seen. However, i compaction is great enough to prevent movement o the predators of bacteria and fungi into the soi long-term effects on decomposition and nutrient cycling processes are likely since N mineralization and stimulation of microbial grow' will be reduced.

GRASSLAND ECOSYSTEM

Current knowledge indicates microbial responses . compaction is similar in both grasslands and forests.

SWALE:

Very little work has been performed in riparian areas with respect to bacterial/fungal responses

FORESTED WATERSHED

See above.

9. AIR POLLUTION

OZONE

Studies with ozone indicate that soil organisms are affected indirectly by atmospheric gas composition as mediated by plant (wheat) responses. Ozone impacts carbon allocation to roots, and thereby negatively impacts mycorrhizal colonization of the root system, with long-term effects on that plant's ability to compete for nutrients (Fitzpatrick and Ingham, in prep). Increases in ozone concentrations have been documented around every city, which suggests that these effects occur even around cities of the size of LaGrande OR, Jackson Hole, WY, for example. Studies have not been published on the ozone impacts on forest plants, although similar effects on ectomycorrhizal fungi would be expected.

Key Environmental Correlates

1. Temperature

Continuous
Unit of Measure: degrees C
Minimum: 10-15 C
Maximum: 45 C
Applies seasonally? Yes
Which **seasons?** As temperatures drop, the activity of these organisms decrease, often producing spores to temporally escape the stress of low, o: high temperature. Metabolic activity usually has a Q_{10} relation.
Theme name:
Attribute:

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2. Organic matter

Continuous
Unit of Measure: Amount and quality of carbon and nitrogen present
Minimum: None present; or low quality (high C:N)
Maximum: depends on aeration.
Applies seasonally? Yes
Which seasons? Organic matter is the food resource for fungi, and thus th quality of that organic matter, which varies seasonally, strongly influences the fungal community structure, biomass and activity.
Theme name:
Attribute:

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3. Soil moisture

Continuous
Unit of Measure: Percent moisture, or grams water per gram of soil

Minimum: 0.95 g water per gram soil
Maximum: 0.50 g water per gram soil (estimate)

Applies seasonally? Yes
Which seasons? Moisture is critical in the spring. Soil generally dries i the summer, which can stimulate spore formation.
Theme name:
Attribute:

Key Ecological Functions

1. Decomposition of intermediate and recalcitrant C:N substrates

2. N retention in soil

3. Substrate for nematode predators

4. Source of N for mineralization; most plant available N must cycle through the fungal biomass is forest soils.

Key Assumptions

Soil conditions must be appropriate for saprophytic fungi to grow and perform their functions. Because there are many, many species of fungi present in soil, the argument is that because there are many fungi that perform the same or highly similar functions, there is little worry about depleting this functional group. However, the principle of Competitive Exclusion says that no two species occupy exactly the same niche or perfor exactly the same function in an ecosystem. Therefore,. each species of saprophytic fungus occupies a unique niche, and if enough species are deleted from an ecosystem, some critical function will be lost. Critical functions performed by these fungi are decomposition of all types of organic material in various conditions.

Controlling factors for saprophytic fungal function are predator grazing, by nematodes and arthropods' root exudate production, litter and wood production,, soil structure, and abiotic factors, such as temperature and moisture. Once these fungi are deleted from a system, they must be spread from existing sources by microarthropods, small mammals, and birds.

Key Unknowns and Monitoring or Research Needs

Research is required to determine species required in different abiotic conditions, with different vegetation types and in different soil types. Rapid decomposition rates in forest systems rely on the presence of saprophytic fungi. Decomposition by fungi can be slowed to extremely low levels 'if arthropod grazing is extremely high, this reducing nutrient cycling once decomposition is slowed.

Disturbance affects saprophytic fungi. Intense fire depletes fungal biomass, drought reduces their activity, pesticide applications can reduce their biomass and activity' and plowing will increase bacterial competition, reducing fungal biomass. Speed of re-colonization from outside sources once local extinction has occurred is not known.

Dispersal

Dispersal mode: Phoretic on arthropods, small mammals, birds, commercial inoculation.

Requirements for dispersal: Presence of bacterium in undisturbed soil, feeding by dispersal agent, dispersal agent **capable** of moving from inoculum source to site where **local extinction occurred.**

Degree of Confidence in Knowledge of Species

Variable

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 **Panelist** Name: Elaine R. Ingham

Species or Species Group: Bacteria:
Beneficial bacteria in the rhizosphere of leguminous plants:
Rhizobium

Geographic Area and/or Habitat Type:
Habitat: Nodules in root systems of legumes

Rangeland structural stages:
open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata.

Forested habitat forms:
Stand initiation, stem exclusion open canopy, stem exclusion closed canopy understory reinitiation' young forest multistrata, old forest multistrata

Specific vegetation types within each habitat form if known:
Early forest stages, grasslands' agricultural fields with legumes such as Trifolium, Lupine, Trefoil, Alfalfa, Bean

Specific soil types if known: All

Elevation, aspects,' slopes: All. Reduced populations in places where hos plant species have not existed recently.

Disturbances: Changes in plant species, soil moisture, temperature (freeze thaw), available N, season, disturbance such as fire intensity and periodicity, grazing, pest effects, drought, plowing, fertilization, road effects.. Work by Einarsson et al. (1991) shows that these bacteria are required for establishment of lupine on nutrient-poor, eroded, sandy soils In the first year, 56% of the first year plants survived, and were successfully nodulated.

Representative Species: Rhizobium melliotii

Key Environmental Correlates

1. Legume presence
Categorical
Suitable Categories: Plant species present
Applies seasonally? **Yes**
Which seasons? Greater numbers of organism present in soil in 'the spring, summer. Bacteria must be present in the spring to colonize plant roots. Legumes compete poorly with other plants if bacterium is not present.
Theme name: **Attribute:**

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2. Soil moisture

Continuous
Unit of Measure: Percent moisture, or grams water per gram of soil
Minimum: 0.05 g water per gram soil
Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? Yes
Which seasons? Moisture is critical in the spring. Soil generally dries in the summer, and the bacterium becomes senescent.
Theme name: **Attribute:**

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3. Temperature

Continuous
Unit of Measure: Degrees C
Minimum: 0 C (survives), requires 15 to 35 C for activity
Maximum: 40-45 C
Applies seasonally? Yes
Which **seasons?** Metabolic activity generally a Q_{10} relation. As temperature increases, activity increases up to a threshold level where the organism is killed.
Theme name: **Attribute:**

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4. Available N

Continuous
Unit of Measure: Inorganic N pools/concentrations, mineralizable N
Minimum: unknown
Maximum: 20 to 50 ug total inorganic N per gram soil
Applies seasonally? Yes
Which seasons? Spring, summer
Theme name: **Attribute:**

Key Ecological Functions

1. Nitrogen fixation; if soil N is low and the plant requires N-fixing bacteria, especially specific species of N-fixing bacteria, **the plant will** not survive without the appropriate bacteria present. Therefore, **plant** species composition can be strongly affected by presence/absence of specific species of bacteria.

2. N retention in soil

3. Substrate for protozoan predators

4. Substrate for nematode predators

5. Source of N for mineralization

Key Assumptions

Soil conditions must be appropriate for these N-fixing bacteria to coloni plants. Numbers are 'controlled by predators, such as protozoa and nematodes' by root presence, soil structure, and abiotic factors, such as temperature and moisture. Once these N-fixing bacteria are depleted from system, they must be spread from existing sources by microarthropods, sma mammals, birds, and perhaps by human inoculation from commercial sources.

Work by Einarsson et al. (1991) shows that these bacteria are required fo establishment of lupine on nutrient-poor, eroded, sandy soils. In the first year, 56% of the first year plants survived, and were successfully nodulated.

Key Unknowns and Monitoring or Research Needs

Research required to determine species required in different abiotic conditions, with different vegetation types and in different soil types. Some plants require specific species of Rhizobium, or related genera of N fixers in order survive, to compete with non-native plants, or weedy species of plants. Without the appropriate species present, the plants will not survive, may not set seed may not compete well with other species, or may be susceptible to pathogen attack.

Impacts of various disturbance regimes on native N-fixing bacteria such a fire, drought, pesticide applications, are not known. Effectiveness of commercial Rhizobium strains for N-fixation with native legumes such as trefoils, is unknown. Rapidity of re-colonization from outside sources once local extinction has occurred is unknown.

Dispersal

Dispersal mode: Phoretic on arthropods, small mammals, birds, commercial inoculation.

Requirements for dispersal: Presence of bacterium in undisturbed soil, feeding by dispersal agent, dispersal agent capable of moving from inocul source to site where local extinction occurred.

Degree of Confidence in Knowledge of Species

Reasonably High for some species, non-existent for others

References

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COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 **Panelist Name:** Elaine R. Ingham

Species or Species Group: Beneficial bacteria
Cyanobacteria/cryptobiotic crust communities

Geographic Area and/or Habitat Type:
Biotic crusts on the surface of soil in open canopy areas without historical use by grazing herds.

Rangeland structural stages: open herbland, open low-medium shrub, open tall shrub.

Forested habitat forms: Stand initiation, stem exclusion open canopy.

Specific vegetation types within each habitat form if known: All rangeland open canopy **stages** of xeric forests, especially juniper and Ponderosa pine in the Columbia Basin.

Specific soil types if known: Sandy, sandy loams, light clay-loams

Elevation' aspects, slopes: These organisms are extremely important in stabilizing slopes and preventing erosion.

Disturbances: Compaction, grazing, available N, fire intensity and periodicity, grazing, plowing, fertilization, road effects, air pollution.

Representative Species: Microcoleus

Key Environmental Correlates

1. Grazing - an important negative correlation occurs between the existence of biotic crusts and grazing herds, especially in desert systems where few or no native N-fixing plants occur and the only source of N-fixation is through these cryptobiotic crust organisms.

Categorical
Suitable Categories: Intensity and periodicity of grazing events
Applies seasonally? **Yes**:
Which seasons? There is less impact on crusts in the winter when the soil is frozen and compaction/trampling is less likely.
Theme **name:** **Attribute:**

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2. Soil moisture
Continuous
Unit of Measure: Percent moisture, or grams water per gram of soil
Minimum: 0.05 g water per gram soil (depends on species)
Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? **Yes**
Which seasons? Biotic crust organisms are adapted to highly zeric conditions, and the moisture in early morning and evening dew can be adequate for allowing N-fixation to occur. Moisture in the spring is critical for crust initiation and spread.
Theme name:
Attribute:

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3. Temperature
Continuous
Unit of Measure: Degrees C
Minimum: 0 C (warming in winter of the dark-colored crust generally raises the crust temperature above freezing' allowing fixation to continue even in the winter.)
Maximum: 55 C (extremely high temperatures trigger dormant cell formation)
Applies seasonally? **Y e s**
Which seasons? Metabolic activity is generally a Q_{10} relation. As temperature increases, activity increases up to a threshold level where t organism is killed. These organisms have resistant stages that tolerate extremely high temperatures.

The dark color of the crusts results in solar heating, such that temperatures will rise above freezing in the crusts, allowing nitrogen fixation to occur, even when the rest of the soil is frozen. Since water will not be limited in winter, the greatest rates of N-fixation are like1 during these time periods. Nitrogen-fixation most likely does not occur the summer when drought and temperature limits organism function. Howeve cool mornings and evenings' with dew, may allow periodic N-fixation to occur. In many of the rangeland systems of the Columbia Basin, no other nitrogen-fixers exist.
Theme name: **Attribute:**

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4. Available N
Continuous
Unit of Measure: Inorganic N pools/concentrations, mineralizable N
Minimum: unknown
Maximum: 20 to 50 ug total inorganic N per gram soil (estimate)
Applies seasonally? Unknown
Which **seasons?** Fertilization seems to detrimentally impact crust formatio and survival.
Theme name: **Attribute:**

Key Ecological Functions

1. Nitrogen fixation; may be the only source of new N in most **xeric** ecosystems.
2. Stabilization of soil by Microcoleus, prevention of erosion
3. N retention in soil
4. Substrate for protozoa and nematode predators
5. Source of N for mineralization, plant available N.

Key Assumptions

In systems where large herds of grazing animals did not historically exist, such as the Columbia Basin, the Intermountain West, and the desert Southwest, soil nitrogen has been maintained by the presence of biotic crusts. Compaction and trampling (i.e., grazing herds) destroys these crusts, and thus leads to ecosystem degradation and' appears to directly lead to the eventual conversion of the vegetation to woody desert shrubs. There is work being performed in Africa that indicates the loss of cryptobiotic crusts was the critical factor in desertification.

There is a significant difference **between mineral** crusts which form as the result of rain-splash on unprotected soil, or salt-crusts in high saline soils. Mineral crusts need to be broken to allow water infiltration. But mineral crusts can form only after biotic crusts have been destroyed. It is the loss of the biotic crust, with the loss of N fixation in the ecosystem that leads to degradation.

Biotic crusts consists of three major components: Cyanobacteria, such as Microcoleus, lichens, and predators such as protozoa and nematodes, which mineralize the N fixed by the bacteria and lichens. The first stage in crust establishment is the stabilization of soil by strands of cyanobacteria. Once the soil is stabilized, packing of the cyanobacteria into filaments is critical to initiate anaerobic conditions which allow fo N-fixation to occur. Lichen colonization and growth results in the bumpy appearance of most cryptobiotic crusts. Increased water filtration occurs once lichen growth alters the texture of the soil surface (bumpy appearance), and more moisture will be held by colonized soil than by soil not colonized by biotic crust. The dark color of the surface allows periods of activity during the long winter months, when moisture and sunlight is available.

Any disturbance of the crust destroys first, the water-holding and **water-**infiltration capacity of the crust. Greater disturbance destroys the packing of the cyanobacterial filaments, destroying the. ability of the crust to fix **N,** and finally, even the cyanobacterial strands themselves will be destroyed' leading to massive erosion problems.

N becomes available to plants once the cyanobacterial strands and filaments' and lichens are eaten by predators. The crust is eaten by deer elk, birds, small mammals, and even coyotes or wolves. The fixed N is the released through fecal deposition. The cyanobacterial component is also eaten protozoa and nematodes, and through release of ammonium, followed by nitrification, the fixed N becomes available to plants.

Soil conditions must be appropriate for these N-fixing bacteria to coloniz soil. Crust bacterial numbers are controlled by predators, such as protozoa and nematodes, by root presence, soil structure, and abiotic factors, such as temperature and moisture. Once these N-fixing bacteria are depleted from a system, they must be spread from existing sources by microarthropods, small mammals, birds, and perhaps by human inoculation from commercial sources.

Key Unknowns and Monitoring or Research Needs

Research is required to determine species required in different abiotic conditions, with different vegetation types and in different soil types. Some species of cyanobacteria or lichen may only be able to colonize specific soil types, although little data is available at this time. For desert systems to aggrade, N-fixation must occur and thus destruction of biotic crusts results in degradation of these ecosystems. For range grasses to survive, biotic crusts must flourish. Without crusts, the existing plant species will not survive, may not set seed, will not compet with cheatgrass, and will be susceptible to pathogen attack.

Impacts of various disturbance on biotic crust organisms such as fire, drought, pesticide applications, have 'not been studied. Speed of re-colonization from outside sources once local extinction hasoccurred may take decades.

D i s p e r s a l

Dispersal mode: Phoretic on arthropods, small mammals, birds.

Requirements for dispersal: Presence of the bacteria and lichens in undisturbed soil, feeding by dispersal agent, dispersal agent capable of moving from inoculum source to site where local extinction occurred.

Degree of Confidence in Knowledge of Species

Low

References

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COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 **Panelist Name:** Elaine R. Ingham

Species or Species Group: Competitive bacteria
Bacillus

Geographic Area and/or Habitat Type: Different species of this'genus occur in particular habitats.

Rangeland structural stages
open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata.

Forested habitat forms
Stand initiation, stem exclusion open canopy, stem exclusion closed canopy understory reinitiation, young forest multistrata, old forest multistrata, old forest single stratum, snags, downed logs

Specific vegetation types within each habitat form if known:
- Thermophilic species occur in hot springs, and around thermal vents and often keep the water clear by removing toxic or noxious compounds, and prevent organic matter build-up by competing with photosynthetic species that occupy this niche and clog such areas with organic matter

- Other species may be unique to forest habitats, riparian habitats' wetlands, grasslands, shrubs and agricultural areas, but so little work ha: been done that the specificity of these associations and their importance is not understood.

- Beneficial species are known, for example Bacillus thurenaiensis produce: a toxin which kills gypsy moth larvae. Undoubtedly more biocontrol specie? occur in this genus, but without further study, these associations will not be discovered.

- A Bacillus has been reported which is antagonistic to a number of root rots caused by fungi.

Specific soil types if known: All soil types
Elevation' aspects, slopes: No restrictions known

Representative Species: Thermophilic - Bacillus thermoohilus
Beneficial - Bacillus thurensiensis

Disturbances: soil moisture, temperature (freeze-thaw), available N, season, disturbance such as fire intensity and periodicity, grazing, control of insect pests, drought, plowing, fertilization, road effects.

Key Environmental Correlates

1. Temperature
Continuous
Unit of Measure: degrees C
Minimum: 10-15 C (depends on species)
Maximum: Thermophiles - above 80 C, beneficials - 45 C
Applies seasonally? Yes
Which seasons? Metabolic activity usually has a Q_{10} relation. When stressed by high or low temperatures, these organisms produce spores. Thermophiles function at high temperatures, usually by protecting their enzyme systems from denaturation at high temperature.
Theme **name:**
Attribute:

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2. Organic matter
Continuous
Unit of Measure: Amount and quality of carbon and nitrogen present
Minimum: None present; or low quality (high C:N)
Maximum: depends on aeration.
Applies seasonally? Yes
Which seasons? Inputs of organic matter usually occur with litterfall and these bacteria respond to increased substrate availability.
Theme name:
Attribute:

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3. Presence of host plant
Categorical
Suitable Categories: Plant species present
Applies seasonally? Yes
Which seasons? Bacterial density follows a seasonal cycle of generally greater numbers in soil in the spring, decreasing in the hot,, dry summer, especially in agricultural and grassland ecosystems. Beneficial bacteria protect root systems from pathogenic varieties of bacteria, fungi, protozoa, nematodes and arthropods.
Theme name:
Attribute:

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4. Soil moisture
Continuous
Unit of **Measure:** Percent moisture, or g water per gram of soil
Minimum: 0.05 g water per gram soil (depends on species)
Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? Yes
Which seasons? Moisture is critical in the spring. Soil generally dries i the summer, and bacilli produce resistant spores.
Theme **name:**
Attribute:

Key Ecological Functions

1. Decomposition of labile and intermediate labile C:N substrates
2. **N** retention in soil
3. Substrate for protozoan predators
4. Substrate for nematode predators
5. Source of N for mineralization

Key Assumptions

Some plants require specific species of Bacillus or related genera in orde. survive, to compete with non-native plants, or weedy species of plants. Without the appropriate species present, the plants will not survive, may not set seed, may not compete well with other species, or may be susceptible to pathogen attack.

Soil conditions must be appropriate for toxin-producing, biocontrol bacteria to express their function. Numbers of the bacteria, which requir some level of stress to produce the toxin, are controlled by predators, such as protozoa and nematodes, by root exudate production, soil structure and abiotic factors, such as temperature and moisture. Once these bacteri are depleted from a system, they must be spread from existing sources by microarthropods, small mammals, and birds. <u>Bacillus thurenaiensis</u> (Bt) ca be introduced by human inoculation of commercial cultures.

Key Unknowns and Monitoring or Research Needs

Research required to determine species required in different abiotic conditions, with different vegetation types and in different soil types. Rapid decomposition rates in some systems may rely on the presence of Bacillus, either to utilize some forms of plant material, or to provide a control for arthropod feeding of the decomposer populations. Decompositio can be slowed to extremely low levels if arthropod grazing is extremely high, this reducing nutrient cycling once decomposition is slowed.

Impacts of various disturbance regimes on these bacteria such as fire, drought, pesticide applications, are not well studied. Speed of re-colonization from outside sources once local extinction has occurred is not known.

Dispersal

Dispersal mode: Phoretic on arthropods, small mammals, birds, commercial inoculation.

Requirements for dispersal: Presence of bacterium in undisturbed soil, feeding by dispersal agent, dispersal agent capable of moving from inoculum source to site where local extinction occurred.

Degree of Confidence in Knowledge of Species.

High for some species,low for others

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COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 **Panelist Name** aine R. Ingham

Species or Species Group: Competitive bacteria in the rhizosphere: Pseudomonas

Geographic Area and/or Babitat Type:

Rangeland structural stages:
open herbland, closed herbland, open low-medium shrub, closed low-mediun shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata.

Forested habitat forms:
Stand initiation, stem exclusion open canopy, stem exclusion closed **canc understory** reinitiation, young forest multistrata, old forest multistrat old forest single stratum, snags, downed logs

Specific vegetation types within each habitat form if known: Pseudomone are found in the root systems of all plants. Associations between sub-species of Pseudomonas and specific plant species are being researched. Some species are beneficial for the host plant, 'and compete with pathoge species. Other pseudomonad species are pathogens.

Specific soil types if known: Some generalist species apparently occur across all soil types and all ecosystems,' while most species have **specif** plant or organic matter associations.

Elevation, aspects, slopes: All

Disturbances: changes in plant species, soil moisture, temperature (free thaw), available **N,** season, disturbance such as fire intensity and **periodicity,** grazing, pest effects, drought, plowing, fertilization, roa effects, air pollution.

Rhizobacteria have the potential to suppress plant growth, according to work performed by Kennedy et al. (1991). Of more than 1000 pseudomonad isolates from roots of wheat and downy brome, 81 inhibited downy brome while not affecting wheat. Three isolates chosen for field studies, two reduced plant populations of downy brome by reducing aboveground Plant production by 31 and 53% of that seen in controls. Wheat production was increased by 18 and 35% because of the suppression of downy brome. Thes types of results clearly show that understanding the bacterial **compositi** of the soil is important in order to understand the effect on plant community composition.

Representative Species: Beneficial species

Pseudomonas fluorescens Pseudomonas aeruginosa

Pathogenic species

Pseudomonas ceoacia Pseudomonas svrinsae

Key Environmental **correlates**

1. Presence of host plant

Categorical
Suitable Categories: Plant species present
Applies seasonally? Yes
Which seasons? Bacterial density follows a seasonal cycle of generally greater numbers in soil in the spring, decreasing in the hot, dry summer, especially in agricultural and grasslands. Beneficial bacteria protect root systems from pathogenic varieties of bacteria, fungi, protozoa, nematodes and arthropods.
Theme name: Attribute:

2. Soil moisture

Continuous
Unit of Measure: Percent moisture, or grams water per gram of soil
Minimum: 0.05 g water per gram soil (depends on species)
Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? Yes
Which seasons? Moisture is critical in the spring. Soil generally dries **the summer, and** the bacterium becomes senescent.
Theme name: Attribute:

3. Temperature

Continuous
Unit of Measure: Degrees C
Minimum: 0 C (species dependent)
Maximum: 40-45 C (depends on species)
Applies seasonally? Yes
Which seasons? Metabolic activity generally a Q_{10} relation. As temperatur increases,. activity increases up to a threshold level death occurs.
Theme name: Attribute:

Key Ecological Functions

1. **Some species** are beneficial for plants because they compete **with** root pathogens; other species attack roots and cause disease. Work by Kennedy et al. (1991) shows that plant species composition is often affected, if not controlled, by rhizosphere bacterial composltlon.

2. N retention in soil

3. **Substrate** for protozoan predators

4. **Substrate for** nematode predators

5. Source of N for mineralization

Key Assumptions

Soil conditions must be appropriate for these bacteria to colonize -plants Numbers are controlled by predators, such as protozoa and nematodes, by root presence, soil structure, and abiotic factors, such as temperature a moisture. Once these bacteria are depleted from a system, they must be spread from existing sources by microarthropods, small mammals, birds, an perhaps by human inoculation from commercial sources.

Key **Unknowns** and Monitoring or Research Needs

Research is required to determine which species of bacteria are **beneficia** for which species of plants, and which perform best in different **abiotic** conditions and different soil **types.** Some plants require specific specie of <u>Pseudomonas</u> in order to compete with root pathogens. Kennedy et al. (1991) performed a field study in which manipulation of rhizosphere bacteria clearly affected plant species composition. Without the appropriate beneficial species present, the host plant **Will not survive,** may not set seed, may not compete well with other species, or may be susceptible to pathogen attack.

Diseases of crop plants which are **caused** by pseudomonads are much better researched than other pseudomonads.

Dispersal

Dispersal mode: **Phoretic** on arthropods, small mammals, birds, commercial inoculation.

Requirements for dispersal: Presence of bacterium in undisturbed soil, feeding by dispersal agent, dispersal agent capable of moving from **inocul** source to site where local extinction occurred.

Degree of Confidence in Knowledge of Species

High for some species, non-existent for others

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COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 **Panelist Name:** Elaine R. Ingham

Species or Species Group: Bacteria: N-immobilizers

Geographic Area and/or Habitat Type:

Rangeland structural stages:
open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, **closed** tall shrub, multi-strata.

Forested habitat forms:
Stand initiation, stem exclusion open canopy, stem exclusion closed canop understory reinitiation, young forest multistrata, old forest multistrata old forest single stratum, snags, downed logs

Specific vegetation types within each habitat form if known:
Each ecosystem has a particular community of bacteria present in the soil An important component of this bacterial community are the bacteria that-immobilize nutrients and retain N in the surface layers of the soil Particular species composition of bacteria in any soil type, vegetation, hydrology, or climatic conditions are not known. With further **study,** tht compositions **can be** assessed, helping improve management recommendations for the maintenance of systems with particular types of productivity and vegetation type.

Specific soil types if known: All

Elevation, aspects, slopes; All

Disturbances: changes in plant species, soil moisture, temperature (freez thaw), available N, season, disturbance such as fire intensity and periodicity, grazing, pest effects, drought, plowing, fertilization, road effects, air pollution.

Representative Species: <u>Klebsiella olanticola</u>

'Key Environmental **Correlates**

1. Temperature
Continuous
Unit of **Measure: degrees C**
Minimum: 10-15 C (depends on species)
Maximum 45 c
Applies seasonally? Yes
Which seasons? Metabolic activity usually **has** a Q_{10} relation. With stress, these bacteria produce resistant-stages and spores.
Theme name: **Attribute:'.**

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2. Organic **matter**
Continuous
Unit of **Measure:** Amount and quality of carbon and nitrogen present
Minimum: None present; or low quality (high C:N)
Maximum: depends on aeration.
Applies seasonally? Yes
Which seasons? Amount and quality of substrate inputs from plant litter (fall), **and from** root **exudates** (year round) is an important factor influencing bacterial activity.
Theme name: **Attribute:**

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3. Presence of host plants
Categorical
Suitable Categories: Plant species present
Applies seasonally? Yes
Which seasons? Bacterial density follows a seasonal cycle of **generally** greater numbers in soil in the spring, decreasing in the hot, dry summer, especially in agricultural and grassland ecosystems. Beneficial bacteria protect root systems from pathogenic varieties of bacteria,. fungi, **protozoa,** nematodes and arthropods. It is critical that beneficial **bacteria not** be depleted by human management,
Theme **name:** **Attribute:**

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4. Soil moisture
Continuous
Unit of Measure: Percent moisture or grams water per gram of soil
Minimum: 0.05 g water per gram soil (approximate)
Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? Yes
Which **seasons?** Moisture is critical in the spring. Soil generally dries i the summer, and the bacterium produces resistant spores.
Theme name: **Attribute:**

Key **Ecological** Functions

1. Decomposition of labile and intermediate labile C:N substrates
2. N retention in soil
3. Substrate for protozoan predators
4. Substrate for nematode predators
5. Source of N for mineralization

Key **Assumptions**

N-immobilizing bacteria are critically important in retaining N in the surface layers of all soil. Without bacteria to retain inorganic N in th soil, much more N would be lost to the groundwater and through erosion. These bacteria are then consumed by bacterial predators, and the N immobilized in their biomass is released through mineralization processes **This** mineralized N can make up between 40 and 90% of the N required by plants for growth..

Soil conditions must be appropriate for bacterial growth to allow immobilization **to occur.** Numbers of the bacteria are controlled by **predators,** such as protozoa and nematodes, by root exudate production, sc structure, **and abiotic** factors, such as temperature and moisture. Once **bacteria are depleted** from a system, they must be spread from existing sources by microarthropods, small mammals, and birds.

Key **Unknowns and** Monitoring or Research Needs

Impacts of various disturbance regimes on immobilizing bacteria are poor1 known. Effectiveness of commercial strains to increase N-immobilization has never been attempted. Rapidity of re-colonization from outside **sourc** for **each** species once local extinction has occurred is unknown.

Research is required to determine the species composition of N-immobilize in different **abiotic** conditions, vegetation types **and soil types. Rapid** immobilization rates in some systems may require completely different set of bacterial species to be present, because substrates present in conifer **versus alder systems** is so completely different. Immobilization can be almost completely lost if the immobilizing bacteria are lost in **a grassla** **or** agricultural field. Arthropods can over-graze **these bacteria, or** pesticides can kill them, resulting in poor retention of needed nutrients within the soil.

Dispersal

Dispersal mode: Phoretic on arthropods, small mammals, birds, commercial inoculation.

Requirements for dispersal: Presence of bacterium in undisturbed soil, feeding by dispersal agent, dispersal agent capable of moving from inoculu: source to site where local extinction occurred.

Degree of Confidence in Knowledge of Species

Reasonably High

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COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 **Panelist** Name: Elaine R. Ingham

Species or Species Group: Bacterial Pathogens
Erwinia
Zvmomonas
Asrobacterium

Geographic Area and/or Habitat Type:

Rangeland structural stages:
open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata.

Forested habitat forms:
Stand initiation, stem exclusion open canopy, stem exclusion closed canopy understory reinitiation, young forest multistrata, old forest multistrata, old forest single stratum, snags, downed logs.

Specific vegetation types within each habitat form if known:
Each ecosystem has a particular community of pathogenic bacteria present in the soil. The pathogenic bacteria present depend on soil type, vegetation hydrology, climatic conditions and past pathogen outbreaks. The plants present must be susceptible under the current conditions, and often, stress from some other source allows bacterial pathogens to successfully overcome host resistance. The degree to which any plant or animal species is limited in it's distribution as the result of pathgen presence has been little studied. But, these limiting interactions are clearly expressed in crop-pathogen studies that have been on-going in the US for the last several decades.

Specific soil types if known: All

Elevation, aspects, slopes: No restrictions known

Disturbances: Change in plant species, soil moisture, temperature (freeze-thaw), available N, season, disturbance such as fire intensity and periodicity, grazing, pest effects, drought, plowing, fertilization, road effects, air pollution.

Representative Species:
Erwinia cartovora
Aorobacterium tumefaciens

Key Environmental Correlates

1. Temperature
Continuous
Unit of Measure: degrees C
    Minimum: 10-15 C (species dependent)
    Maximum 45 C (species dependent)
Applies seasonally? Yes
Which seasons? Metabolic activity usually has a Q_{10} relation.
Theme **name:** **Attribute:**

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2. Organic matter

Continuous
Unit. of Measure: Amount and quality of carbon and nitrogen present
    Minimum: None present; or low quality (high C:N)
    Maximum: depends on aeration.
Applies seasonally? Yes
Which seasons? Inputs of organic matter usually form a reservoir habitat for pathogens to overwinter, or survive without their plant host present.
Theme name: **Attribute:**

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3. Presence of host plant

Categorical
Suitable Categories: Plant species present
Applies seasonally? Yes
Which seasons? High bacterial densities occur on the plant host, **when disease occurs and depends** on the severity and incidence of the **disease-**causing organism in the system. In general, the healthier or less stresse the host plant, disease incidence in lower and less severe.
Theme name: **Attribute:**

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4. Soil moisture

Continuous
Unit of Measure: Percent moisture, or grams water per gram of soil
    Minimum: **0.05 g water** per gram soil (species dependent)
    Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? Yes
Which **seasons?** Depending on the disease being examined, moisture may play an important role preventing plant stress. Disease may require **water film** in other instances.
Theme name: **Attribute:**

Key Ecological Functions

1. Cause of disease and death in plants, animals
2. Competition with non-pathogens for colonization sites on roots, plant surfaces and in animals.
3. Substrate for protozoan predators
4. Substrate for nematode predators
5. Source of N for mineralization

Key Assumptions

Pathogenic bacteria are important.in restricting the distribution of a number of plant and animal species.

Key Unknowns and Monitoring or Research Needs

Diseases of wildlife and native plants are poorly understood, and in a number of cases probably explain the current distributions of wildlife and plants. Humans understand these interactions poorly and have little to no understanding of the prevention or cure of these diseases. Especially whe re-establishing locally extinct species from populations outside the area, these disease-causing baceria could be extremely important in restricting re-establishment. Local sources and reservoirs of disease **are rarely** known.

Research is required to determine disease-causing bacteria, their vectors, and mode of infection. Especially critical is an understanding of disease causing organisms that might prevent re-establishment of locally extinct species.

Dispersal

Dispersal mode: Carried by seeds, plant debris, alternative hosts, arthropods, small mammals, birds, and humans.

Requirements for dispersal: Presence of bacterium in diseased plant and animal material. Dispersal agent often required to move the pathogen fron diseased host to susceptible host.

Degree of Confidence in Knowledge of Species

High for some species, nonexistant for others

References

Campbell, R. 1985. Plant Microbiology. Edward Arnold, Oublishers, Baltimore, Maryland. 191 pp.

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COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 Panelist Name: Elaine R. Ingham

Species **or Species** Group: Vesicular Arbuscular Mycorrhizal Fungi
Glomus
Gigaspora

Geographic **Area and/or Habitat Type:** Vesicular arbuscular mycorrhizal fun (VAM) occur on most grasses, row crops, a wide variety of herbs and shrub and on a few species of trees. A few plants, especially herbaceous plant **have** quite narrow fungal symbiont ranges, and this narrow range can resul in a restricted distribution of the plant if the fungus is not widely dispersed. However, most plants associate with a wide range of VAM species, and inoculum for plants is rarely lacking.

Each ecosystem has a particular community composition of VAM spores in th soil and VAM colonizing the roots of the particular vegetation that is present. VAM species composition depends on soil type, vegetation, hydrology, and climatic conditions.

Rangeland structural stages:
open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata. (for halophytic grasses in Alvord desert, OR, see H 1987; for burned areas of Snake River Birds of Prey area, Idaho, see **Wicklow,** 1989).

Forested habitat forms:
Stand initiation, stem exclusion open canopy, stem exclusion closed canop understory reinitiation, young forest multistrata, old forest multistrata

Specific vegetation types within each habitat form if known: Herbaceous plants, woody shrubs, riparian deciduous trees, transient colonization of young conifer roots.

Specific soil types if known: All

Elevation, aspects, slopes: All

Disturbances: Changes in plant species, soil moisture, temperature (freez thaw), available N, season, disturbance such as fire intensity and periodicity, grazing, pest effects, drought, plowing, fertilization, road effects, air pollution.

Representative Species:
Glomus mossae
Glomus vesiculatum
Glomus deserticulum (desert habitats)

Key Environmental Correlates

1. Temperature
Continuous
Unit of Measure: degrees C
Minimum: 10-15 C (species dependent)
Maximum 45 C (species dependent)
Applies seasonally? Yes
Which seasons? Metabolic activity usually has a Q_{10} relation. Spores are formed outside the roots in response to seasonal factors, including temperature, most likely.
Theme **name:** Attribute:

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2. Organic matter

Continuous
Unit of Measure: Amount and quality of carbon and nitrogen present
Minimum: None present; or low quality (high C:N)
Maximum: Depends on aeration.
Applies seasonally? Yes.
Which seasons? VAM colonize plant roots, and the type and amount of organ matter exchanged with the plant is critical for VAM survival. VAM form vesicles (possibly a dormant stage) and arbuscules (exchange site for C from plant and P, N, water, micronutrients from the fungus) in the roots, most likely in response to plant responses.
Theme name: Attribute:

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3. Presence of host plant

Categorical
Suitable Categories: Plant species present
Applies seasonally? Yes
Which seasons? Fungal colonization of roots and production of spores foll a seasonal cycle. In annual plants, colonization starts as soon as the seed germinates, and increases throughout the year until the roots begins to senesce with the **on-set** of reproduction and seed set, when spores are produced in greatest number. The most rapid rate of increase in colonization occurs during most rapid root growth in the spring.

In perennial plants, VAM colonization is found in the new year's roots, **while less colonization is** found in older, suberized roots. Colonization **rates are usually greatest** in the spring, although in some plants; **colonization may continue throughout** the year.
Theme name: **Attribute:**

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4. Soil moisture
Continuous
Unit of Measure: Percent moisture, or grams water per gram of soil
Minimum: 0.05 **g water** per gram soil
Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? Yes

Which seasons? Moisture is critical in the spring. Soil generally dries the summer, increasing the production of spores outside the root and vesicles inside the root. Percent of the root system colonized generally decreases in the summer as compared to the spring.

Theme name: **Attribute:**

Key Ecological Functions

1. VAM mine the soil for P, N, micronutrients and water in return for C fixed by plant photosynthesis. The cost to plant may be minimal, given the competitive edge the fungus gives to most plants.

2. Competes with pathogens for colonization sites on roots and may preve root **disease.**

3. May de-toxify certain types of pesticides, herbicides, and pollutant5

4. May sequester heavy metals in fungal hyphae, preventing heavy metals from damaging or killing plants.

5. Food source for fungal-feeding nematodes, arthropods.

Key Assumptions

Lack of appropriate VAM species may restrict the distribution of plants, the required VAM species are not present. With plants whose VAM range is wide, this is less likely to be a problem. Some weedy plant species are highly competitive and can use VAM associated with their roots to out-compete less-competitive VAM species. Thus, effectiveness of VAM species may be important as well.

A recent four-year study by Herrera et al. (1993) in southeast Spain shot that woody legumes whose rhizobial and mycorrhizal symbionts were optimiz in a previous study, were useful for revegetation of water-deficient, lot nutrient environments. Only the native shrub legumes were able to become established and that survival was improved by biotechnological manipulati of the rhizobia and mycorrhizal fungi.

Key **Unknowns and Monitoring or Research Needs**

The associations between VAM species and plants are poorly documented. F example, Kincaid's lupine may occur only in un-disturbed native prairies because the VAM symbiont cannot tolerate plowing disturbance. **Thus,** the plant is lost when the ground is plowed, because without the VAM fungal symbiont, **the plant cannot** compete with other plant species for soil nutrients. Work in the copper mines of Virginia, Tennessee, and Kentucky showed that the inability to re-establish plant species in these mined areas was because VAM were lost from the soil when soil was stock-piled during the mining operations (Odum). **Nancy** Scott Collins has shown simil problems with re-generation of plants in mine spoils in **Canada.** Thus, th

VAM allow plants to obtain resources not otherwise available to them, and allows them to grow and reproduce in conditions under which they would otherwise not survive.

Research is required to determine disease-causing bacteria, their vectors, and mode of infection. Especially critical is an understanding of disease-causing organisms that might prevent re-establishment of locally extinct species.

Dispersal

'Dispersal mode: Carried by seeds, plant debris, arthropods, ants (Friese and Allen, 1993) and on occasion, wind.

Requirements for dispersal: Dispersal agents.

Degree of Confidence in Knowledge of Species

High for some species, nonexistent for others

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253-257.

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 **Panelist Name:** Elaine R. Ingham

Species or Species Group: Ectomycorrhizal mat-forming fungi
Hvsteranaium
Gautieria

Geographic Area and/or Habitat Type: Ectomycorrhizal mat-forming fungi were believed to be restricted to few conifer forest systems until a few years ago when Griffiths,.Cromack and Ingham began to take a look at these ectomycorrhizal species. The ectomycorrhizal species that form perennial thick mats of dense hyphae, altering soil properties have been found have throughout the world. Ectomycorrhizal mats have been shown to occur in conifers, **oak** and eucalyptus (Cromack et al. 1988). Recent investigations have established that these mat-forming fungi occur in high densities in Grand fir, Douglas-fir, Ponderosa pine, and larch stands in the Blue Mountains around LaGrande, OR. They have been found in Yellowstone National Park in these same vegetative types. Mat-forming fungi have not yet been found on juniper.

On the roots of these plant species, a normal succession of ectomycorrhizal species occurs. Establishment of mat-forming fungi appears to occur about 25 to 30 years into normal succession, about the time Doug-fir seedling establishment occurs. Mat formation occurs after seedling establishment if the mat-forming fungi were lost from the stand. If shelterwood trees are left, the mat-forming fungi are not lost from the stand, and seedling establishment is more rapid around the shelterwood tree (Ingham, unpublished data).

Once the canopy begins to close in Douglas-fir forests, every dominant tree appears to be connected to at least several mats, while sub-dominant trees are not necessarily connected, or connected to few mats (Ingham, pers. observation). This leads to questions about the importance of mat-forming fungi for productivity which have not been answered.

Mat-forming fungi appear to dominate during the most productive years of conifer stand development, from 30 to 150 years old trees and increase both total and labile N in the forest floor (Aguilera et al, 1993). Significant portions of the forest floor are colonized by mat-forming fungi even in old growth conifer stands, however, and contribute to system productivity (Ingham, unpublished data, Aguilera et al, 1993).

These fungi are not found in any Rangeland structural stage.

Forested habitat forms:
If shelterwood trees are left, these fungi are found (between 5 and 15% of the forest floor covered depending on density of shelterwood trees) during stand initiation. If older trees do not remain, then the mat-forming fungi disappear and must be re-established.

Mats are always found in stem exclusion open canopy (5 to 15% coverage of forest floor), stem exclusion closed canopy (15 to 30% coverage), understory reinitiation, young forest multistrata (30 to 45% coverage), and old forest multistrata (30 to 100% forest floor coverage) in most conifer species. Exceptions appear to be juniper, which has not been shown to support mat-forming fungi, although juniper stands have not been extensively investigated.

Specific soil types: All conifer, oak and eucalyptus soil types.

Elevation, aspects, slopes: Not known in alpine areas. Percent floor covered by mats decreased with elevation in one study.

Disturbances: Clearcutting appears to be the one disturbance that can completely remove mat-forming fungi from the forest floor. Mat-forming fungi benefit their hosts when soil moisture is low (apparently improve plant water use efficiency in drought conditions) or when soil moisture is high (mats produce hydrophobic materials, preventing saturation of the soil profile, increasing aeration for the plant roots). The mats themselves are perennial structures and appear highly resistant to changes in soil moisture, as long as their host plants remain. Temperature. In areas where the forest floor is snow-covered during the winter, mats continue to function throughout the winter (Ingham, pers. comm). Areas where the soil undergoes freeze-thaw throughout the winter have not been investigated for the effect on mats-forming fungi. Studies are being performed on the effect of available N on mat-forming fungi. Intense fire can remove the organic **layers** of the soil. In Yellowstone National Park, where the temperature was intense enough to melt the mineral soil and form glass pellets, the soil was essentially sterile, although re-colonization by air-borne organisms was rapid on the surface of the soil. However, these mat-forming fungi do not survive in such organic matter depauperate areas, and it will likely be hundreds of years before mat-forming fungi will re-establish in these intensely burned areas. There is a direct relationship between the intensity of impact on the soil organic layer and the loss of any fungus from the soil. If the soil is only slightly warmed, and the overstory trees are not lost, there will be only a stimulatory effect on these mat-forming fungi. The effect of arazinq,' especially compaction, is under investigation in the Blue Mountains of Oregon (cooperative effort with Jim McIver, Art Tiedeman, Torge Torgeson of the Blue Mountains Natural Resource Institute). Pesticides undoubtedly affect mat-forming fungi,. although no field studies have been performed. Plowinq destroys mat-forming fungi, although each spring in natural systems, mats can be nearly demolished by small mammal feeding (a major food resource for small mammals). Mats, however, recover from this disturbance rapidly, and by the next fall, regain their original extent. In forests where small mammals have been removed, mats may continue to increase in size, sequestering greater and greater amounts of nutrients, and may possibly be detrimental to continued forest productivity. Further studies are required.

Representative Species:

Hvsteransium (mesic systems, in upper 20 cm of soil/organic layers)

Gautieria (drier systems, lower in soil profile)

Key Environmental Correlates

1. Temperature
Continuous
Unit of Measure: degrees C in the soil
Minimum: 0-4 C (depends on species)
Maximum 35 C (species dependent)
Applies **seasonally? Yes**
Which **seasons?** Metabolic activity probably has a Q_{10} relation. Spores are formed in truffles in response to seasonal factors in either or both the spring and fall.
Theme name: Attribute:

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2. Organic matter

Continuous
Unit of Measure: Amount and quality of carbon and nitrogen present
Minimum: Requires organic matter layer to be present.
Maximum: No maximum value known.
Applies **seasonally? Yes.**
Which seasons? Mat-forming fungi can survive on organic matter alone and do not require the host plant. If both host and organic matter is lost, the fungi will not survive. However, to form mats, both the host plant and organic matter are necessary. Mats respond to litter fall, expanding into new litter within a few days, and perhaps within hours, of new material becoming available. Thus, a seasonal cycle of activity seems apparent. Small mammal feeding is also an important response variable, however, which cannot at this time, be differentiated from the seasonal temperature response. -Since small mammal feeding is at a maximum in the spring, when temperatures are increasing, both factors could be involved in increased growth rate and enzyme production by mat-forming fungi.
Theme **name:** Attribute:

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3. Presence of host plant

Categorical
Suitable Categories: Conifers, oaks
Applies **seasonally? No.**
Fungal colonization of roots by mat-forming fungi is related to stand age: in closed canopy stands, every tree is colonized by mat-forming fungi. In open canopy stands, those seedlings in the open, well away from other competing vegetation may not necessarily be colonized by mat-forming fungi, although they will be colonized by other ectomycorrhizal fungi.
Theme **name:** Attribute:

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4. Soil moisture

Continuous
Unit of Measure: Percent moisture, or grams water per gram of soil
Minimum: Not known

Maximum: Not known

Applies seasonally? Yes

Which seasons? For establishment of ectomycorrhizal mat-forming fungi, moisture is undoubtedly critical, requiring adequate rainfall to wet the soil, such that roots will grow, allowing colonization of the root. However, once established, mats are remarkably resistant to disturbance imposed by moisture, and in turn, increase the resistance of the host plant to moisture stress. Drought tolerance of the host plant is increased by both mat-forming fungi and other ectomycorrhizal fungi. Because mat-forming fungal hyphae are hydrophobic in the spring, the mats provide large pockets of aerated soil for root growth when the soil is saturated. Thus this is a more important factor in highly mesic areas, such as along river banks, and for oaks growing in wetland, or seasonally inundated or saturated areas.

Truffle production by these mat-forming fungi is a critical food resource for small mammals. Truffle formation is highly responsive to moisture. In those years when rainfall is limited and soil remains dry (no quantitative estimates available), limited numbers or no truffles will be formed. This must impact the small mammal populations, and affect higher levels predators. Studies are being conducted on the relationship between fungal food resources and small mammal feeding (Trappe, Oregon State University, and Carey, National Forest Service, Olympia, WA).

Theme name: **Attribute:**

Key Ecological Functions

1. Mat-forming fungi mine the soil for P, N, micronutrients and water in return for C fixed by plant photosynthesis. The cost to plant may be minimal, given the competitive edge the-fungus gives to the plants.

2. Competes with pathogens for colonization sites on roots and may prevent root disease.

3. May de-toxify certain types of pesticides, herbicides, and pollutants.

4. May sequester heavy metals in fungal hyphae, preventing heavy metals from damaging or killing plants.

5. Major food source for small mammals, fungal-feeding nematodes, arthropods.

Key Assumptions

Lack of mat-forming fungi clearly restricts the presence of conifers, oaks, and eucalyptus. All seedlings which survive for more than a year in closed canopy conditions must be associated with a mat. All dominant forest trees are associated with at least several mats.

Truffles formed by mat-forming fungi are an important food resource for small mammals, and for other organisms on which higher level predators feed. Without these organisms present in high numbers, the entire forest ecosystem will have reduced productivity.

Key Unknowns and Monitoring **or Research Needs**

There are a number of questions about the importance'of mat-forming fungi for forest ecosystem productivity which have not been answered. How do the spores of the fungi reach the roots of the plants? What dispersal agents are the most important, and how can management enhance this association? Different mat-forming species seem to be more efficient, or at least more prevalent in different abiotic conditions, such as more Gautieria present in drier conditions, while more Hvsteransium mats are present in more mesic, higher organic matter soils. What is the metabolic relationship between host plant and fungus? Do different fungal species compositions select for different plant host species? Effects of various types of disturbance also need to be further investigated.

Dispersal

Dispersal mode: Carried by nematodes, arthropods, and small mammals.

Requirements for dispersal: Dispersal agents.

Degree of Confidence in Knowledge of Species

High for some species, nonexistent for others

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COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 **Panelist Name:** Elaine R. Ingham

Species or Species Group: Saprophytic Fungi
<u>Penicillium</u> (r-selected)

Geographic Area and/or Habitat Type:

Rangeland: Less fungal as compared to bacterial biomass
open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata.

Forests: More fungal as compared to bacterial biomass
Stand initiation, stem exclusion open canopy, stem exclusion closed canopy, understory reinitiation, young forest multistrata, old forest multistrata, old forest single stratum, snags, downed logs

Specific vegetation types within each habitat form if known: Brown-rot fungi use lignin; White rot fungi use cellulose, for examples.

The ratio of fungi to bacteria in grassland soils is less than zero (bacterial dominated). In forests, the ratio is usually above 10. Values between 1 and 10 indicate productive agricultural fields.

Another common generalization is that fungi in early successional stages, such as agricultural soils or grasslands are VAM, "sugar" fungi or pathogens, and are more "r" selected. Fungi in forests are ectomycorrhizal fungi, cellulose decomposers (white rotters), or lignin decomposers (dark septate fungi), and generally considered more "K" selected.

Growth of fungi on spread plates show significant changes in fungal community composition in different ecosystems, in different habitats, but there has been no comprehensive effort to document what saprophytic fungal community exists in which types of vegetation, following specific types of disturbance. This type of work is being done for mushrooms and truffle-forming fungi (Luoma, Castellano, Trappe's work).

Specific soil types if known: All soil types
Elevation, aspects, slopes: No restrictions known

Representative Species:
<u>Penicillium citrinum</u> (grassland soils)

Disturbances: soil moisture, temperature (freeze-thaw), available *N*, **season,** fire intensity and periodicity, grazing, drought, plowing, fertilization, road effects, air pollution.

Key Environmental Correlates

1. Temperature

Continuous
Unit of Measure: degrees C
Minimum: 10-15 C (species dependent)
Maximum: 45 C (species dependent)
Applies **seasonally? Yes**
Which seasons? As temperatures drop, the activity of these organisms decrease, often producing spores to temporally escape the stress of low, or high temperature. Metabolic activity usually has a Q_{10} relation.
Theme name: **Attribute:**

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2. Organic matter

Continuous
Unit of Measure: Amount and quality of carbon and nitrogen present
Minimum: None present; or low quality (high C:N)
Maximum: depends on aeration.
Applies seasonally? Yes
Which seasons? Organic matter is the food resource for fungi, and thus the quality of that organic matter, which varies seasonally, strongly influences the fungal community structure, biomass and activity.
Theme name: **Attribute:**

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3. Soil moisture

Continuous
Unit of Measure: Percent moisture, or grams water per gram of soil
Minimum: 0.05 g water per gram soil (species dependent)
Maximum: 0.50 g water per gram soil (estimate)

Applies seasonally? Yes
Which seasons? Moisture is critical in the spring. Soil generally dries in the summer, **which** can stimulate spore formation.
Theme name: Attribute:

Key Ecological Functions

1. Decomposition of intermediate and recalcitrant C:N substrates
2. *N* retention in soil
3. Substrate for nematode predators
4. Source of N for mineralization; most plant available *N* must cycle through the fungal biomass is forest soils.

Key Assumptions

Soil conditions must be appropriate for saprophytic fungi to grow and perform their functions. Because there are many, many species of fungi present in soil, the argument is that because there are many fungi that perform the same *or* highly similar functions, there is little worry about depleting this functional group. However, the principle of Competitive Exclusion says that no two species occupy exactly the same niche or perfor exactly the same function in an ecosystem. Therefore, each species of saprophytic fungus occupies a unique niche, and if enough species are deleted from an ecosystem, some critical function will be lost. Critical functions performed by these fungi are decomposition of all types of organic material in various conditions.

Controlling factors for saprophytic fungal function are predator grazing, by nematodes and arthropods, root exudate production, litter and wood production, soil structure, and abiotic factors, such as temperature and moisture. Once these fungi are deleted from a system, they must be spread from existing sources by microarthropods, small mammals, and birds.

Key Unknowns and Monitoring or Research Needs

Research is required to determine species required in different abiotic conditions, with different vegetation types and in different soil types. Rapid decomposition rates in forest systems rely on the presence of saprophytic fungi. Decomposition by fungi can be slowed to extremely low levels if arthropod grazing is extremely high, this reducing nutrient cycling once decomposition is slowed.

Disturbance affects saprophytic fungi. Intense fire depletes fungal biomass, drought reduces their activity, pesticide applications can reduce their biomass and activity, and plowing will increase bacterial competition, reducing fungal biomass. Speed of re-colonization from outside sources once local extinction has occurred is not known.

Dispersal

Dispersal mode.; Phoretic on arthropods, small mammals, birds, commercial inoculation.

Requirements for dispersal: Presence of bacterium in undisturbed soil, feeding by dispersal agent, dispersal agent capable of moving from inoculum source to site where local extinction occurred.

Degree of Confidence in Knowledge of Species

Med

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COLUMBIA RIVER BASIN - **PANEL SPECIES INFORMATION**

Date: December 29, 1994 Panelist **Name:** Elaine R. Ingham

Species or Species Group: Fungal pathogens
Rhizoctonia
Cronartium comandrae (comandra blister rust)

Geographic Area and/or Habitat Type:

Rangeland: Specific fungal pathogens occur on each range species open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata.

Forests: Specific fungal pathogens occur on each tree species Stand initiation, stem exclusion open canopy, stem exclusion closed canopy understory reinitiation, young forest multistrata, old forest multistrata, old forest single stratum, snags, downed logs.

Using the blister rust as an example (Jacobi et al. 1993), rust incidence varied from 14 to 64% in 24 stands in the Shoshone National Forest in Wyoming, and from 0 to 36% in 190 plots in the Medicine Bow National Forest. Distance to diseased trees and stress were important for predicting incidence of disease. The disease occurred on open, upper slopes and on dry ridge tops.

Specific vegetation types within each habitat form if known: Each plant species has it's particular fungal pathogen, with particular physiological adaptations for the plant host. Fungal pathogens on specific plant specie are identified by growth on specific agar media on spread plates. Significant changes in fungal pathogen community composition occurs in different ecosystems, in different habitats, in different disturbances.

Specific soil types if known: All soil types
Elevation, aspects, slopes: No restrictions known

Crist et al. (1993) reviewed work showing that fungal attack and decomposition of ungerminated and germinating seeds can significantly affect seed bank dynamics and plant community composition. Granivores, in turn, **can also** be affected, by feeding on seeds in which fungi are growing The fungi themselves, or fungal metabolites may be toxic or detrimental to granivore survival.

Representative Species:

Rhizoctonia solani (pathogen of grass)
Phellinus weirii (pathogen of Douglas-fir)

Disturbances: soil moisture, temperature (freeze-thaw), available N, season, fire intensity and periodicity, grazing, drought, plowing, fertilization, road effects, air pollution.

Key Environmental Correlates

1. Temperature
Continuous
Unit of Measure: degrees C
Minimum: 10-15 C (depends on fungal species)
Maximum: 45 C (depends on fungal species)
Applies seasonally? Yes
Which seasons? Metabolic activity usually has a Q_{10} relation.
Theme name: **Attribute:**

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2. Organic matter

Continuous
Unit of Measure: Amount and quality of carbon and nitrogen present
Minimum: **None present;** or low quality (high C:N)
Maximum: depends on aeration.
Applies seasonally? Yes
Which seasons? Organic matter is the food resource for fungi, and thus the quality of that organic matter, which varies seasonally, strongly influences the fungal community structure, biomass and activity.
Theme name: **Attribute:**

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3. Soil moisture

Continuous
Unit of Measure: **Percent** moisture, or grams water per gram of soil
Minimum: 0.05 g water per gram soil (depends on species)
Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? Y e s
Which seasons? Moisture is critical in the spring. Soil generally dries i the summer, which can stimulate spore formation.
Theme name: **Attribute:**

Key **Ecological Functions**

1. Cause of disease and death in plants, animals

2. **Compete with non-pathogens for colonization sites on roots, plant** surfaces and in animals.

3. Substrate for nematode and arthropod predators

4. Source of N for mineralization

Key Assumptions

The right types of plants and conditions must occur for pathogenic fungal attack of their plant hosts. Pathogenic fungi are important in restricti the distribution of a number of plant and animal species. Fungal disease of wildlife and native plants are poorly understood, and our understandin of various fungal diseases is limited, especially our knowledge of the alternate host reservoirs.

When re-establishing locally extinct species from populations outside the area, disease-causing fungi could be extremely important in restricting r establishment.

Controlling factors for pathogenic fungi are predator grazing, by nematod and arthropods, root exudate production, litter and wood production, soil structure, and abiotic factors, such as temperature and moisture. Once these fungi are deleted from a system, they must be spread from existing sources by microarthropods, small mammals, and birds.

Key Unknowns and Monitoring or Research Needs

Research is required to determine species required in different abiotic conditions, with different vegetation types and in different soil types. Research is required to assess naturally existing reservoirs of disease-causing fungi, vectors, and modes of infection.

Disturbance affects pathogenic fungi. Pathogens are basically r-selected organisms, which take advantage of the reduction in competition following disturbance to attack other-wise unavailable substrates. Intense fire depletes fungal pathogen biomass, drought reduces activity, pesticide applications can reduce fungal pathogen biomass and activity, plowing increases fungal competition, reducing fungal biomass.

Dispersal

Dispersal mode: Carried by seeds, plant debris, alternative hosts, arthropods, small mammals, birds, and humans.

Requirements **for dispersal:** Presence of bacterium in undisturbed soil, feeding by dispersal agent, dispersal agent capable of moving from inoculu source to site where local extinction occurred;

Degree of Confidence in Knowledge of Species

High for some, poor for others

<u>References</u>

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COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 Panelist Name: Elaine R. Ingham

Species or Species Group: Protozoa: Bacterial-predators
Bodo, Acanthamoeba, Colpoda

Geographic Area and/or Habitat Type:

Protozoan community composition is an indicator of certain disturbances. Relative abundances of the three groups vary predictably in grassland, shrubland, forest and desert. Protozoa are ecologically more important in grasslands, agricultural fields and perhaps deserts than in forests.

The smaller protozoa, such as flagellates, tend to be more important in drier habitats, while ciliates are most important in wetter conditions, such as alpine, wetland, or riparian areas. Testate amoebae are found in relatively high numbers in forests, at, least as compared to agricultural areas, grasslands or deserts.

Protozoa are important in rangeland structural stages:
open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata.

Protozoa are less important in forested habitat forms:
Stand initiation, stem exclusion open canopy, stem exclusion closed canopy, understory reinitiation, young. forest multistrata, old forest multistrata, old forest single stratum, snags, downed logs

Specific vegetation types within each habitat form if known: All

Specific soil types if known: All

Elevation, aspects, slopes: All

Disturbances: Changes in plant species, soil moisture, temperature (freeze-thaw), available N, season, disturbance such as fire intensity and periodicity, grazing, pest effects, drought, plowing, fertilization, road effects, air pollution.

Representative	Species:
Flagellate	Bodo
Amoeba	Amoeba amoeba
Testate amoeba	Difflusia, Centrooixis
Ciliates	Colooda terrestris, Glossslockneria

Key Environmental Correlates

1. Temperature
Continuous
Unit of Measure: degrees C
Minimum: 10-15 C
Maximum: 45 C
Applies seasonally? Yes
Which seasons? To escape low or high temperatures, cysts are produced. Metabolic activity usually has a Q_{10} relation.
Theme name: Attribute:

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2. Bacterial prey density

Continuous
Unit of Measure: Numbers of bacteria: species composition of bacteria
Minimum: No bacteria present or threshold level for each soil type.
Maximum: none known
Applies seasonally? Yes
Which seasons? Bacterial densities are usually greatest when plant inputs are greatest (spring and fall), when abiotic factors are not limiting (temp, moisture). Both Weekers et al. (1993) and Casida (1989) showed that bacterial species composition affects the species of protozoa present. Pigmented bacteria appear to be inhibitory for species of Acanthamoebae, while nonpigmented enterobacteria increased amoeba1 production, as well as increasing the ammonium production during the predator-prey interaction (Weekers et al. 1993). Casida (1989) showed that addition of bacteria which prey on bacteria did not affect protozoan predation of bacteria, that autochthonous bacteria added to soil were not preyed upon, while Bacillus and Escherichia coli were actively reduced by the soil protozoa.
Theme **name:** **Attribute:**

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3. Soil moisture

Continuous
Unit of Measure: Percent moisture, or amount of water present per gram of soil
Minimum: 0.05 g water per gram soil (species dependent)
Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? Yes
Which seasons? Moisture is critical in the spring. Soil generally dries in the summer, and protozoa produce resistant cysts.
Theme name: **Attribute:**

Key Ecological Functions

1. Mineralization of N immobilized in bacterial biomass. May be responsible for up to 50% or more of plant N available in certain agricultural systems.

2. Substrate for predators (nematodes, rotifers, earthworms, enchytraeids)

3. Consumption of bacterial prey and control of bacterial community structure. Weekers et al. (1993) showed that different species of amoebae have different consumption efficiencies and different ammonium production rates on different bacterial species. Pigmented bacteria were inhibitory to amoebae.

4. N retention in soil

5. Important in controlling bacterial diseases.

Key Assumptions

Rapid decomposition rates in some systems may rely on the presence of protozoa to graze bacteria and keep bacteria in log growth phase. Decomposition can be slowed to extremely low levels if bacterial grazing by protozoa is extremely high. This result in a high level of N mineralization following by reduced decomposition and then reduced N availability to plants.

Soil conditions must be appropriate for protozoa to be active. Numbers of bacteria can be controlled by protozoa (Casida, et al, 19 ; Weekers et al. 1993). Some flagellates can survive on dissolved organic sugars, like bacteria, but these have not been shown to be an important component of the protozoan population in any system. Flagellates are eaten by amoebae, and amoebae and flagellates are eaten by ciliates, developing a food-web within the soil.

Plant available N in agricultural systems is in large part determined by bacterial-protozoan interactions. Once protozoa are depleted in a system, they must be spread from existing sources by microarthropods, small mammals, and birds.

Numbers and species of bacteria can be controlled by protozoa. Competition between protozoa and nematodes for bacterial prey occurs. Evidence exists that bacterial communities and densities will be controlled by either protozoa or nematodes.

A protozoan index for assessing the health of soil has been suggested, since an aquatic protozoan index exists. Protozoan composition responds rapidly to disturbance, but the meaning of changes in numbers or composition has not been correlated with disturbance.

Key Unknowns and Monitoring or **Research Needs**

Research is required to determine species required in different abiotic conditions, with different vegetation types and in different soil types.

Disturbance generally affects protozoa. Decreased numbers are generally observed after freezing, fire, plowing, pesticide applications, and fertilization of agricultural fields. Species composition changes with disturbance types, intensity and periodicity needs to be researched.

Dispersal

Dispersal mode: Phoretic on arthropods, small mammals, birds, nematodes.

Requirements for dispersal: Presence in undisturbed soil, presence of dispersal agent, dispersal agent capable of moving from inoculum source to site where local extinction occurred.

Degree of Confidence in Knowledge of Species

Low

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COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 Panelist **Name:** Elaine R. Ingham

Species **or Species Group:**
Bacterial-feeding nematodes
Acrobeloides (agricultural)
Acrobeles (agricultural)
Panasrolaimus (grassland)

Geographic Area and/or Habitat Type: The relative proportion, and usuall greater numbers of bacterial-feeding nematodes occur in grassland, deser and agricultural fields than in forest stands. There is a distinctive gradient of bacterial-feeding nematodes across disturbances such as down logs, snags, and gaps in forests. Gradients occur in grassland and dune systems, although the disturbances which affect nematode distribution ar related to presence/absence of plants and particular plant species and s disturbance. Soil disturbance is likely a significant factor in forest systems as well, but not as well studied as in agricultural fields. Similar assessments have not been made in shrub or desert systems.

Greatest numbers in rangeland structural stages:
open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata.

Not as important a component of the system in forested habitats:
Stand initiation, stem exclusion open canopy, stem exclusion closed cano understory reinitiation, young forest multistrata, old forest multistrat old forest single stratum, snags, downed logs

Specific vegetation types within each habitat form if known: Species composition probably changes with plant species in all systems, but the specific interaction of plant and nematode community composition has rar been studied.

Specific soil types if known: Higher numbers in sandy, xeric soils than clay, saturated soils.

Elevation, aspects, slopes: No known relationship

Disturbances: soil moisture, temperature (freeze-thaw), available N, season, disturbance such as fire intensity and periodicity, grazing, competition with plant parasites, drought, plowing, fertilization, road effects, air pollution.

Representative species:
Acrobeloides (agricultural)
Acrobeles (agricultural)
Panaorolaimus (grassland)

Key Environmental Correlates

1. Temperature
Continuous
Unit of Measure: degrees C
Minimum: 10-15 C (depends on species)
Maximum: 45 C (depends on species)
Applies seasonally? Yes
Which seasons? Escape from low or high temperatures by formation of resistant stages or juvenile development may be arrested. Metabolic activity usually has a Q_{10} relation.
Theme name: **Attribute:**

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2. Bacterial prey density
Continuous
Unit of **Measure:** Numbers of bacteria: species composition of bacteria.
Minimum: No bacteria present; or below threshold level for the particular soil type.
Maximum: Typical predator-prey cycles can occur, and prey may "escape control by these predators
Applies seasonally? Yes
Which seasons? Bacterial densities are usually greatest when plant inputs are greatest (spring and fall), when abiotic factors are not limiting (temp, moisture).
Theme **name:** **Attribute:**

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3. Soil moisture
Continuous
Unit of Measure: Percent moisture, or grams water per gram of soil
Minimum: 0.05 g water per gram soil (species dependent)
Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? Yes
Which seasons? Moisture is critical in the spring. Soil generally dries i the summer, and nematode metabolism slows, and resistant stages develop.
Theme name: Attribute:

Key Ecological Functions

1. Mineralization of N immobilized in bacterial biomass. May be responsible for up to 40% of plant available N.
2. Substrate for predators (predatory nematodes, rotifers, earthworms, enchytraeids, mesostigmatid mites, prostigmatid mites, collembola, symphylans)
3. Consumption of bacterial prey and control of bacterial community structure.
4. Important in controlling bacterial diseases. Competitors with root-**feeding** nematodes (for space most. likely) along root.
5. N retention in **nematode biomass**

Key Assumptions

Rapid decomposition rates in some systems may rely on the presence of bacterial-grazing nematodes to keep bacteria in log growth phase. Decomposition can be slowed if bacterial grazing by nematodes is extreme1 high. This results in a high level of N mineralization following by reduc decomposition and then reduced N availability to plants.

Soil conditions must be appropriate for nematodes to be active. Numbers bacteria can be controlled by bacterial-feeding nematodes, although there is competition between protozoa and nematodes for the bacterial prey. Sc evidence exists that bacterial communities and densities will either be controlled by protozoa or nematodes, but rarely both. Some seasonal alteration in control is possible, although no direct evidence exists. Bacterial-feeding nematodes also eat amoebae, flagellates and-ciliates ar apparently can exist on diets of these protozoa alone.

Plant available N'is in large part determined by bacterial-nematode interactions in grassland systems (protozoa appear more important in agricultural systems). If bacterial-feeding nematodes'are depleted in a system, bacterial pathogen populations can become a problem, although evidence for this interactions is somewhat anecdotal.

The Maturity Index, suggested by Bongers and now assessed in several different ecosystems (dunes, agricultural, forests in the Netherlands, Scotland and the US), shows an extremely good correlation with productivity, time since catastrophic disturbance, and disease incidence.

Key Unknowns and Monitoring or Research Needs

Research is required to determine species required in different abiotic conditions, with different vegetation types and in different soil types. Disturbance generally affects bacterial-feeding nematodes. Decreased numbers are generally observed immediately after freezing, fire, plowing, pesticide applications, and fertilization of agricultural fields, but bacterial-feeders generally respond quickly to disturbance and are the second group of nematodes to return to a disturbed area. Species composition changes with disturbance types, intensity and periodicity nee to be researched.

Dispersal

Dispersal mode: Phoretic on arthropods, small mammals, birds.

Requirements for dispersal: Presence in undisturbed soil, presence of dispersal agent, dispersal agent capable of moving from inoculum source tc site where local extinction occurred.

Degree of Confidence in Knowledge of Species

Med.

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Zak, J. and W. G. Whitford. 1988. Interactions amoung soil biota in desert ecosystems. Agric. Ecosystems Environ 24:87-100.

COLUMBIA RIVER **BASIN -** PANEL SPECIES INFORMATION

Date: December 29, 1994 **Panelist** Name: Elaine R. Ingham

Species or Species Group: Fungal-feeding nematodes
Aohelenchus avenae
Tvlenchus

Geographic Area and/or Habitat Type:

Forest nematode communities are comprised of a greater proportion of fungal-feeding nematodes than are present grassland or agricultural soils A gradient of fungal-feeding nematodes occurs across vegetation patches i grasslands and across downed logs, snags, and gaps in forests, while significant gradients of fungal-feeding nematode species or numbers do no' occur in agricultural fields. The disturbances which affect nematode distribution are-related to presence/absence of plants and particular pla: species and soil disturbance.

Fewer fungal=feeding nematodes in range:
open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata.

Fungal-feeding nematodes are the most important portion of the nematode community in forested systems: Stand initiation, stem exclusion open canopy, stem exclusion closed canopy, understory reinitiation, young fore: multistrata, old forest multistrata, old forest single stratum, snags, downed logs

Specific vegetation types within each habitat form if known: Species composition changes with plant species in all systems, but the specific interaction of plant and nematode community composition has rarely been studied. Nematodes numbers are incredibly high ion downed woody material, although numbers vary with type of tree and part of the tree (bark, sapwood, heartwood, root).

Specific soil types if known: Higher numbers in high organic matter, well developed profiles and mesic soils than in sandy, xeric soils.

Elevation, aspects, slopes: No known relationship

Disturbances: Changes in plant species, soil moisture, temperature (freeze thaw), available N, season, disturbance such as fire intensity and periodicity, grazing, competition with plant parasites, drought, plowing, fertilization, road effects, air pollution.

Representative species:
Aphelenchus avenae (agricultural)
Eudorvlamius (agricultural)
Tvlencholaimellus (forest)

Key Environmental Correlates

1. Temperature
Continuous
Unit of Measure: degrees C
Minimum: 10-15 C (depends on species)
Maximum: 45 C (depends on species)
Applies **seasonally? Yes**
Which seasons? As temperatures drop, the activity of these organisms decrease. To escape low or high temperatures, resistant stages can be formed, and juvenile stage development may be arrested. Metabolic activity usually has a Q_{10} relation.
Theme name: **Attribute:**

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2. Fungal prey density
Continuous
Unit of Measure: Fungal biomass or length; fungal species composition
Minimum: No fungi present
Maximum: Typical predator-prey cycles occur and prey may **"escape"**
Applies seasonally? Yes
Which seasons? Fungal biomass is always high in forest soils, yet active biomass is usually greatest following litter inputs, which can be continuous in conifer systems, and at harvest (agriculture) or in the fall in grassland or deciduous systems.
Theme name: **Attribute:**

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3. Soil moisture
Continuous
Unit of Measure: Percent moisture, or grams water per gram of soil
Minimum: 0.05 g water per gram soil (depends on species)
Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? Yes
Which seasons? Moisture is critical in the spring. Soil generally dries i the summer, nematode metabolism slows, and resistant stages develop.
Theme name: **Attribute:**

Key Ecological Functions

1. Mineralization of N immobilized in fungal biomass.

2. Substrate for predators (predatory nematodes, rotifers, earthworms, predatory mites, orbatids, collembola, symphylans)

3. Consumption of fungal prey and control of fungal community structure.

4. Important in controlling fungal diseases.

5. N retention in nematode biomass.

Key Assumptions

Rapid decomposition rates in some systems may rely on the presence of fungal-grazing nematodes to keep fungi in log growth phase. Decompositic can be **slowed** if fungal grazing by nematodes is extremely high. This results in a high level of N mineralization following by reduced decomposition and then reduced N availability to plants.

Soil conditions must be appropriate for nematodes to be active. Fungal biomass **can** be controlled by fungal-feeding nematodes, although there is competition between fungal-feeding mites and nematodes for fungal prey. Some evidence exists that fungal community structure and density will be controlled by either nematodes or arthropods, but rarely both. Fungal-feeding nematodes can sometimes feed on plant-roots if the fungal prey is too low to sustain the fungal-feeding nematode populations.

Plant available N is contributed to by fungal-feeding nematode interactic with fungi, although these interactions seem to be of much less importanc in grassland systems or agricultural systems. No-till agriculture howeve increases the importance of these fungal-predators, since fungi comprise much larger part of the soil biomass when the soil isn't plowed.

If fungal-feeding nematodes are depleted in a system, fungal pathogens ca become a problem.

The Maturity Index, suggested by Bongers and tested in several different ecosystems (dunes, agricultural, forests in the Netherlands, Scotland and the US), shows an extremely good correlation with productivity, time sinc catastrophic disturbance, and disease incidence. Fungal-feeding nematode for the most part begin to appear at an intermediate time since catastrophic disturbance, thus representing a more mature, stable ecosyst structure.

Key Unknowns and Monitoring or Research Needs

Research is required to determine species required in different abiotic conditions, with different vegetation types and in different soil types.

Disturbance generally affects fungal-feeding nematodes. Decreased number are generally observed immediately after freezing, fire, plowing, pestici applications, and fertilization of agricultural fields. Fungal-feeding nematodes generally take some time, between months and years, to return following disturbance. How species composition changes with disturbance types, intensity and periodicity needs to be researched.

Dispersal

Dispersal mode: Phoretic on arthropods, small mammals, birds.

Requirements for dispersal: Presence in undisturbed soil, presence of dispersal agent, dispersal agent capable of moving from inoculum source to site where local extinction occurred.

Degree of Confidence in Knowledge of Species

Reasonably high for some species, non-existent for others

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COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 Panelist **Name:** Elaine R. Ingham

Species or Species Group: Plant-feeding nematodes
Pratylenchus
Meloidosvne

Geographic **Area and/or Habitat Type:** Increases in plant-feeding nematodes quite often indicates disturbance, for plant-feeding nematodes are usuall but not always, opportunists. Competition with other bacterial- and fungal-feeding nematodes usually limits plant-feeding nematodes early in succession, once the beneficial nematodes become established. Agricultur systems often experience economically catastrophic effects of plant-feedi nematode build-up when the same crop species is maintained in the same place annual cycle after annual. Similar problems can be encountered in tree nurseries, when the same plant species is kept in the same soil seas after season. Crop rotation, regardless of whether cereal **crop, grass,** o tree, is necessary.

Some plants are inhibitory to plant-feeding nematodes, although the inhibition is lost is the same nematicidal plant is used rotation after rotation, with the same crop plant year after year.

Grassland systems tend to have similar plant-feeding nematodes species lists, while plant-feeding nematode communities in forested systems are similar. Again, plant-specificity occurs, and each plant species may have it's own particular sub-species of each plant-feeding nematode pest. For example, citrus nematode is a significant pest on orange trees, but not a particular pest in lime.

In general, the more complex the soil communities of bacteria, fungi, protozoa nematodes and arthropods, the less likely plant-feeding nematodes will be a problem. Clearly, however, plant species are restricted from some habitats by the presence of plant-feeding nematodes in those soils. For example, when Trifolium is placed in light gaps in old growth forest areas, the numbers of plant-feeding nematodes on the roots rapidly increases, and kills the plant. Whether the plant "attracted" plant-feeding nematodes from the surrounded soil, allowed the plant-feeding nematodes in that forest soil to rapidly multiply, or plant-feeding nematodes already present in the seed could rapidly multiply because no Competing organisms occurred in that soil, is not known. There could be other soil factors which stress the clover plant and lower the resistance of the roots to plant-feeding nematode attack. **But** in any **case, one** important reason that clover is not found in old-growth forest light gaps, or in old growth forests is the response of root-feeding nematodes which kills the plants.

Plant-feeding nematodes are excluded from ectomycorrhizal fungal mats, at least in those cases where nematode populations have been examined in mats This suggests that active antagonism between certain fungi and plant-feeding nematodes occurs in healthy ecosystems. In addition, no plant-feeding nematodes have been found in coarse woody debris, even when tree roots grow into these areas.

Habitat areas:
Rangeland structural stages
open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata.

Forested habitat forms
Stand initiation, stem exclusion open canopy, stem exclusion closed canopy, understory reinitiation, young forest multistrata, old forest multistrata, old forest single stratum

Specific vegetation types within each habitat form if known: Species composition of plant-feeding nematodes probably changes with plant species in all systems, but the specific interaction of plant and nematode community composition has rarely been studied in any but row crops.

Specific soil types if known: Higher numbers early in disturbance, with increased stress of plants. Specificity of certain species for saturated, mesic or xeric soils.

Elevation, aspects, slopes: No known relationship

Disturbances: Plant species present, soil moisture, temperature (freeze-thaw), available N, season, disturbance such as fire intensity and periodicity, grazing, competition with plant parasites, drought, plowing, fertilization, road effects, air pollution.

Representative species: Pratvlenchus penetrans, Meloidosvne chitwoodii

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Key Environmental Correlates

1. Temperature

Continuous
Unit of Measure: degrees C
Minimum: 10-15 C (depends on species)
Maximum: 45 C (species dependent)
Applies seasonally? Yes
Which seasons? To escape low or high temperatures, resistant stages can be formed, and juvenile stage development may be arrested. Metabolic activit usually has a Q_{10} relation.
Theme name: Attribute:

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2. Plant root density and type

Continuous
Unit of Measure: Root length, age, composition
Minimum: No roots present
Maximum: None known: certain plant species are nematicidal and can reduce plant-feeding nematode numbers
Applies seasonally? **Yes**
Which seasons? Greatest increases in plant-feeding nematode numbers and increases in diversity in the spring and summer. Plant-feeders can'be especially detrimental and even restrict plant species distribution if nematodes continue to feed into the summer when the plant.becomes stressed by additional factors such as drought, increased competition for nutrients
Theme **name:** Attribute:

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3. Soil moisture

Continuous
Unit of Measure: Percent moisture, or grams water per gram of soil
Minimum: 0.05 g water per gram soil (depends on species)
Maximum: 0.50 g water per gram soil (estimate)
Applies seasonally? **Yes**
Which seasons? Moisture is critical in the spring. Soil generally dries i the summer, and nematode metabolism slows, and resistant stages develop.
Theme name: **Attribute:**

Key **Ecological Functions**

1. Plant-feeding nematodes can-cause plant death'and can restrict plant species distributions.

2. Substrate for predators (predatory nematodes, rotifers, earthworms, enchytraeids, mesostigmatid mites, prostigmatid mites, collembola, symphylans)

3. competitors with fungi and other rhizosphere organisms for root exudate: and space **along** and in the root.

Key **Assumptions**

Inputs of carbon into some ecosystems can be restricted or altered if certain plant species are excluded, especially nitrogen-fixing plants.

Soil conditions must be appropriate for these plant-feeding nematodes to be active. Numbers of plant-feeding nematodes can be controlled by predatory nematodes, and nematode-trapping fungi. However, no nematode-trapping fungi which carry out this function in the soil have been found in the western **US.** Evidence exists for competition between bacterial-feeding and fungal-feeding nematodes for space along roots.

The Maturity Index, suggested by Bongers and recently assessed in several different ecosystems (dunes, agricultural, forests in the Netherlands,. Scotland and the US), shows an extremely good correlation with-productivity, time since catastrophic disturbance, and disease incidence. Soon after disturbance, plant-feeding nematodes often occur in high numbers, since few competitor organisms are present. However, as soil foodweb complexity and diversity increases, competition for root resources increases, and plant-feeding nematode impacts decrease, until the more competitive species replace the early successional species. Plant-feeding nematodes could be extremely important in later succession, since their numbers build with time if the same plant species exists in the same place for long periods of time. This may explain senescence in older plant species, although this interaction remains an hypothesis in natural systems.

Plant-feeding nematodes are often spread from crop field to crop field, or from nursery to nursery in infected plant stocks, seed, or soil. In natural situations, nematodes are spread from existing sources by microarthropods, small mammals, and birds.

Key Unknowns and Monitoring **or Research Needs**

Research is required to determine species required in different abiotic conditions, with different vegetation types and in different soil types.

Disturbance generally affects plant-feeding nematodes. Decreased numbers are generally observed immediately after freezing, fire, plowing, pesticide applications, and fertilization of agricultural fields, but plant-feeders generally return immediately after disturbance since many of the species are opportunists. Species composition changes with disturbance types, intensity and periodicity needs to be researched.

Dispersal

Dispersal mode: Phoretic on arthropods, small mammals, birds, human tools such as shovels, tractors, boots, etc.

Requirements for dispersal: Presence in undisturbed soil, presence of dispersal agent, dispersal agent capable of moving from inoculum source to site **where local** extinction occurred.

Degree **of Confidence in Knowledge of Species**

High for some, poor for most

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COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: December 29, 1994 Panelist **Name:** Elaine R. Ingham

Species or Species Group: Rotifers

Geographic **Area and/or Habitat Type:** Wetland areas, closed canopy forest of any stage, moss layers

Habitat areas:
Rangeland structural stages
open herbland, closed herbland, open low-medium shrub, closed low-medium shrub, open tall shrub, closed tall shrub single stratum, closed tall shrub, multi-strata.

Forested habitat forms
Stand initiation, stem exclusion open canopy, stem exclusion closed canopy, understory reinitiation, young forest multistrata, old forest multistrata, old forest single stratum, snags, downed logs

Specific vegetation types within each habitat form if known: Present in all soils, but only active during when surface layers are moist. Highly ephemeral organisms.

Specific soil types if known: All
Elevation, aspects, slopes: All

Disturbances: soil moisture, temperature (freeze-thaw), available N, season, disturbance such as fire intensity and periodicity, grazing, pest effects, drought, plowing, fertilization, road effects, air pollution, freeze-thaw

Representative Species: No information about rotifer species in the Columbia river basin ecosystems.

Key Environmental Correlates

1. Soil moisture
Continuous
Unit of Measure: Percent moisture, or amount of water present per gram of soil
Minimum: Requires moist soil, above 0.15 g water per gram soil (estimate)
Maximum: These organisms do best in saturated soil.
Applies seasonally? Yes
Which seasons? Moisture is critical. Drying below field capacity most likely results in loss in activity, reduction in numbers and encystment to escape adverse conditions.
Theme name: **Attribute:**

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2. Bacterial prey density

Continuous
Unit of Measure: Numbers of bacteria: species composition of bacteria
Minimum: No bacteria present; or below threshold level for the particular soil type.
Maximum: none known
Applies seasonally? Yes
Which seasons? Bacterial densities are usually greatest when plant inputs are greatest (spring and fall), when abiotic factors are not limiting (temp, moisture).
Theme name: Attribute:

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3. Temperature
Continuous
Unit of Measure: degrees C
Minimum: 0 C (estimate)
Maximum: 45 C (estimate)
Applies seasonally? Yes
Which seasons? As temperatures drop, the activity of these organisms decrease. To escape low or high temperatures, cysts are produced. Metabolic activity usually has a Q_{10} relation.
Theme name: **Attribute:**

Key Ecological Functions

1. Mineralization of N immobilized in bacterial biomass. May be responsible for up to 50% or more of plant N available in certain agricultural systems.

2. Substrate for predators (nematodes, rotifers, earthworms, enchytraeids)

3. Consumption of bacterial prey and control of bacterial community structure.

4. **N** retention in soil

5. Important in controlling bacterial diseases.

Key Assumptions

Rapid decomposition rates in certain systems may rely on the presence of rotifers, at least during more **mesic** portions of the year, to graze and keep bacteria in log growth phase. Based on the similarity between the role that rotifers and protozoa play, feeding on bacteria and small organisms, rotifers may be important. In addition to bacteria, rotifers feed on small protozoa and small microarthropods. Decomposition can be slowed to extremely low levels if bacterial grazing by their predators is extremely high. This can result in a high level of N mineralization following by reduced decomposition and then reduced N availability to plants.

Soil conditions must be appropriate for rotifers to be active, requiring moist-to-saturated soil. The disturbance most affecting rotifers in terrestrial systems is moisture. Since soil must be well above field **capacity,** near saturated conditions, for rotifer populations to be high enough to influence bacterial numbers, rotifers are most likely to be important in riparian systems.

Rotifers likely serve as food for larger arthropods and nematodes.

While numbers and species of bacteria can be controlled by protozoa, little work has been done with rotifer-bacteria interactions in soil systems. Rotifers do play important roles in aquatic systems, but are un-studied in terrestrial systems. Most likely, these organisms would play an important **role in riparian soils.**

Key Unknowns and Monitoring or Research Needs

Research is required to determine numbers, rates of bacterial feeding, importance in releasing nitrogen when feeding **on** their prey species. Research needs to be performed to determine effects of other disturbances on rotifers. Species composition changes with disturbance types, intensity and periodicity needs to be researched.

Dispersal

Dispersal mode: Phoretic on arthropods, small mammals, birds, nematodes.

Requirements for dispersal: Presence in undisturbed soil, presence of dispersal agent, **dispersal** agent capable of moving from inoculum source to site where **local extinction** occurred.

Degree of Confidence in Knowledge of Species

Low