Nematodes and Other Multicellular Organisms in Contaminated Soil

CHE 650

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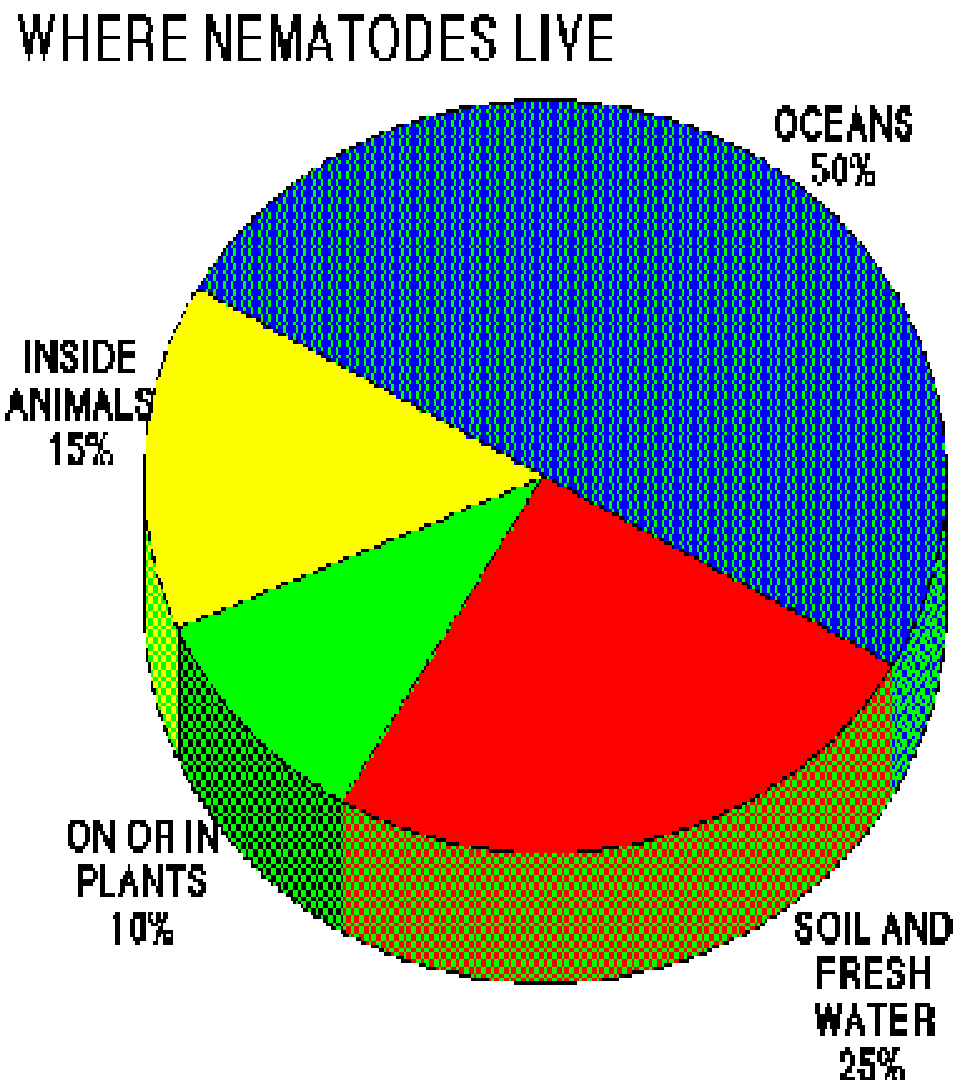
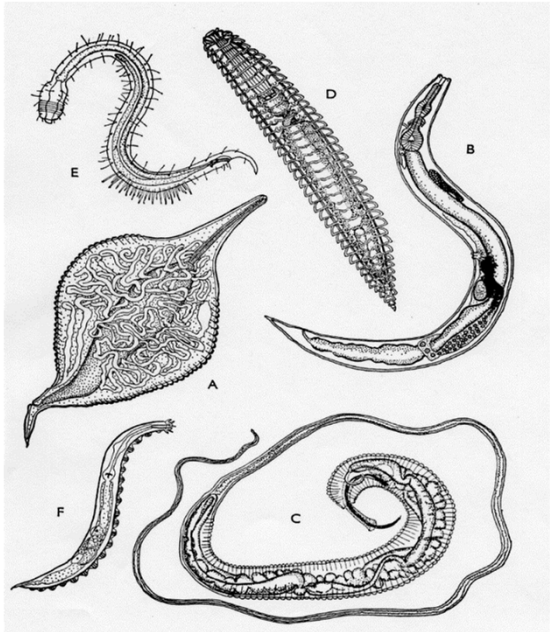
Ecological Classification of Soil Fauna

- **Microfauna**
  - ❑Protozoa
  - ❑Nematodes (body width)
- **Mesofauna**
  - ❑Nematodes (body length, biomass)
  - ❑Microarthropods (collembola, mites)
  - ❑Rotifers, Tardigrades, Enchytraeids
- **Macrofauna**
  - ❑Macroarthropods (insect larvae, centipedes, millipedes)
  - ❑Earthworms

Coleman et al. 2004


WHERE NEMATODES LIVE
OCEANS
50%
INSIDE
ANIMALS
15%
ON OR IN
PLANTS
10%
SOIL AND
FRESH
WATER
25%


D
B
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Nematode characteristics

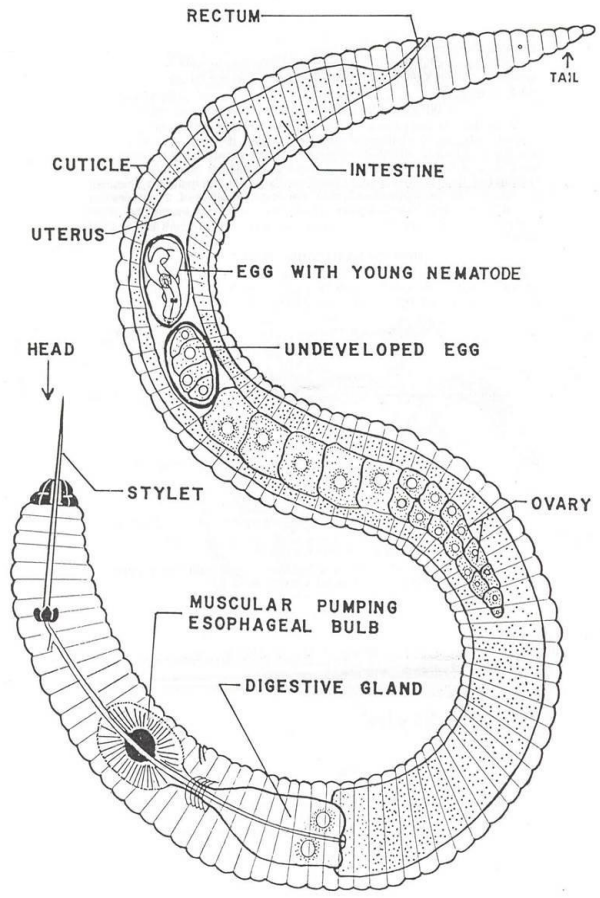


FIGURE 1.—PLANT DESTRUCTIVE NEMATODE

- Size: from microscopic to giant
- Biggest *Plancentonema gigantissima* which parasitizes the placenta of the sperm whale with a length of 28ft and a diameter of 0,98 in

- Simple morphology
- No circulatory system
- No respiratory system
- No skeleton

“Good”-vs-“Bad” nematodes

Bacterial feeders-
Fungal feeders
Predators

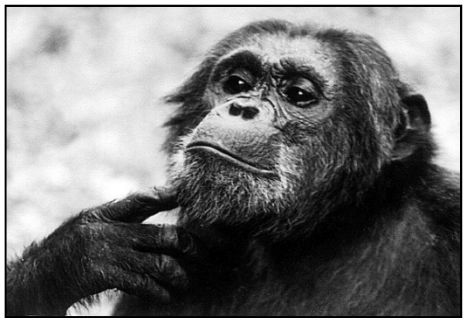
“Good guys”

- Animal-parasites
- Plant-parasites

“Bad guys”

Model Organisms

Primates



- Rats and Mice

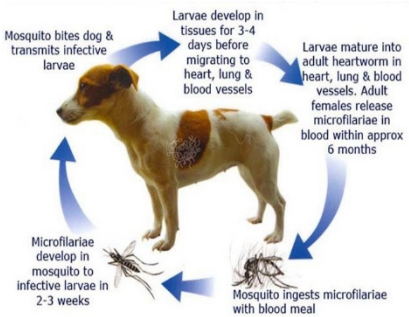
- Nematodes!!!
- The nematode *Caenorhabditis elegans* is one of the most well-studied living species and has served as a biological model organism for genetic and developmental studies

It was the first multicellular organism for which a complete DNA sequence was obtained

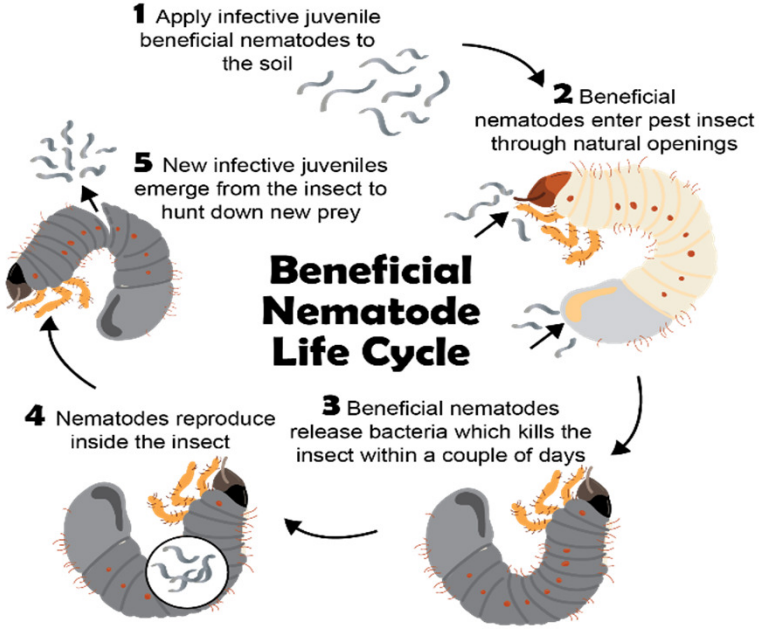
Nematodes- animal parasites

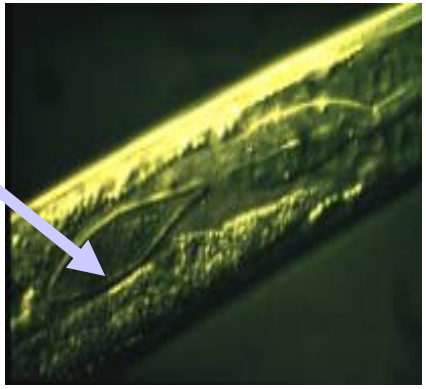
- Animal Parasites
  Canine heart worms,
  Ascaris
- Human Parasites
  Pinworms,
  Hookworms

- Entomopathogenic nematodes which Insect parasites:
- mosquitoes, mole
- crickets, citrus weevils,
  codling moth



Entomopathogenic nematodes





Plant-parasitic nematodes

Over 6000 known species
Attacks almost all plants
Cause 5-20 % losses to crops

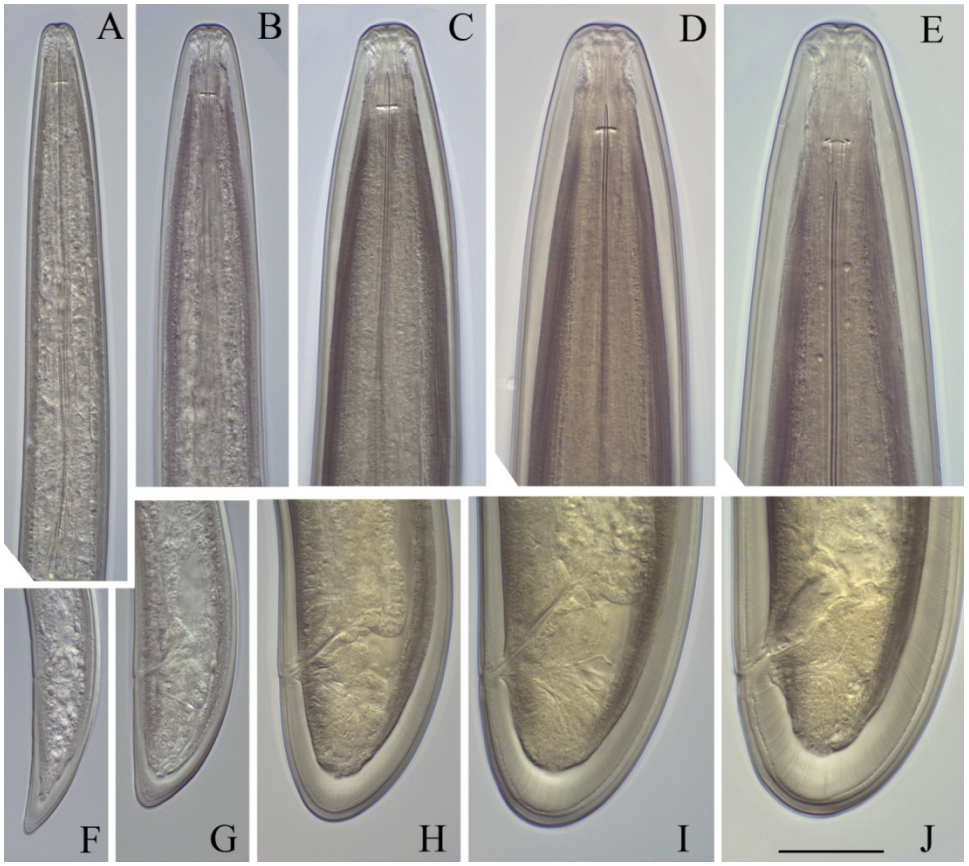
Systematic families and genera of nematode vectors of plant viruses

- Longidoridae

- *Longidorus* 159 (8)
- *Paralongidorus* 79 (1)
- *Xiphinema* 248 (9)

- Trichodoridae

- *Trichodorus* 55 (4)
- *Paratrichodorus* 34 (9)



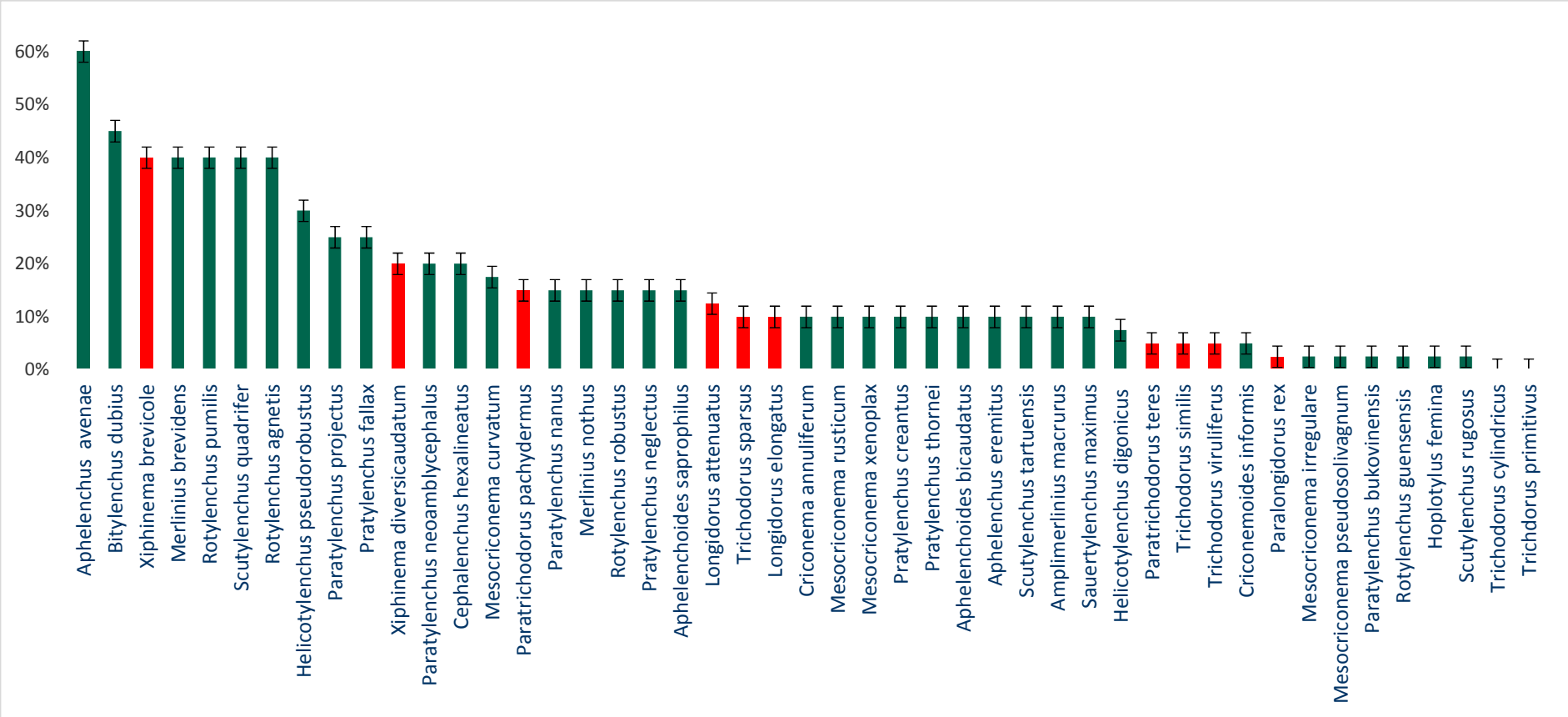
Plant parasitic nematodes associated with biomass production for *Miscanthus x giganteus*

- A survey of *Miscanthus* × *giganteus* throughout the Poland and Ukraine was conducted to determine the occurrence and distribution of plant-parasitic nematodes associated with these biofuel crop and evaluate the resi to biomass reduction
- During 2016-2017, rhizosphere soil samples were collected from 40 plots of *Miscanthus* × *giganteus* in:
- seven localities in **Ukraine**: Kyiv (50.29'N, 30.57'E), Ksaverovka (50.03'N, 30.16'E), Veremiyivka (49.63'N, 33.35'E), Grytzyv (49.98'N, 27.21'E), Yaltuchki (48.99'N,27.46'E), Kurakhove (47.96'N, 37.26'E).Dołyna.(48.58'N,23.54'E)

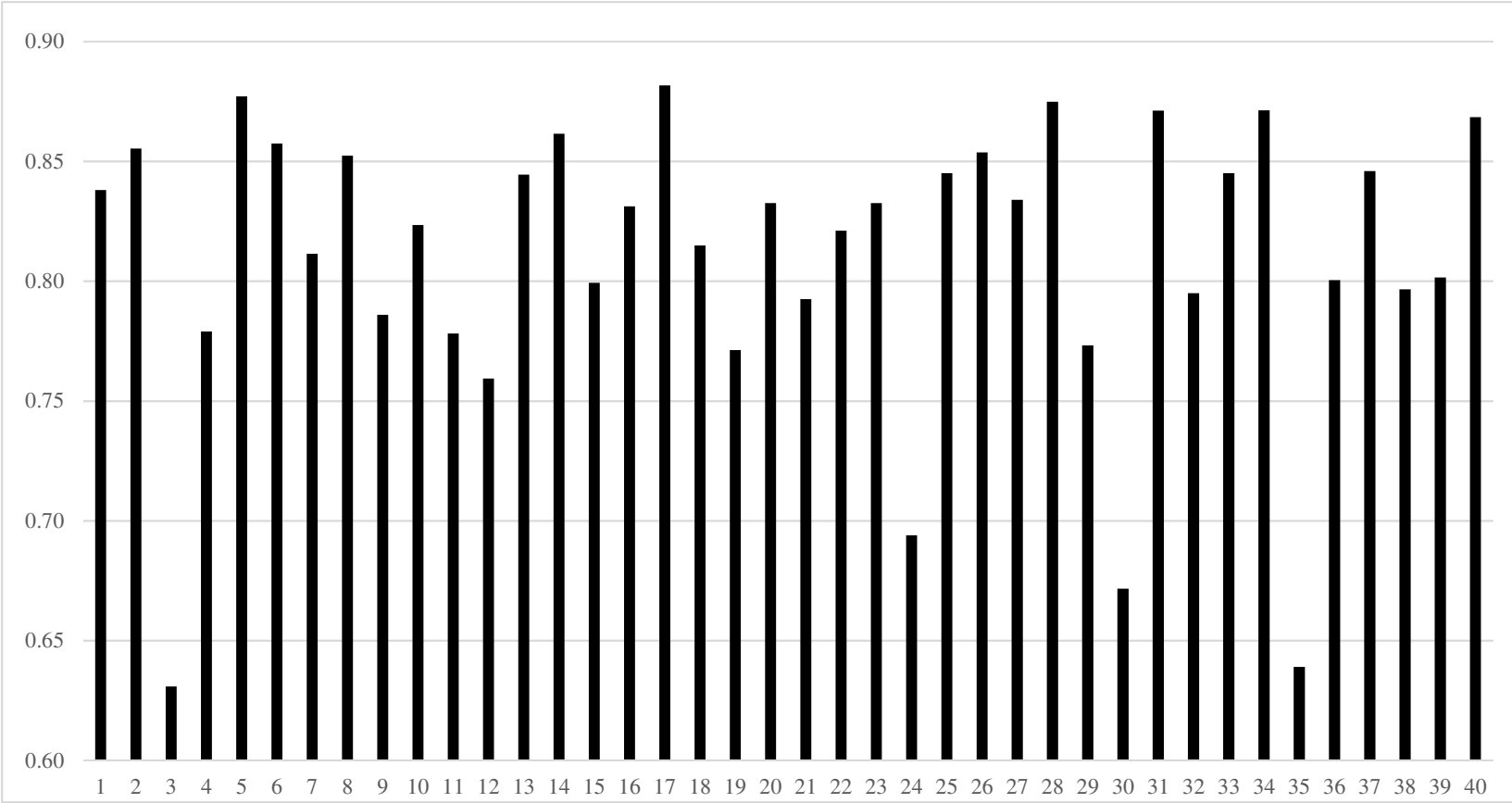
and

- nine localities in **Poland**: Rekowo (54.62'N, 17.23'E)
- , Karzniczka (54, 48'N, 17. 23'E),
- Lisewo (54.09'N, 18.83'E), Poznań (52.43'N, 16. 90'E), Starogard (53.94'N, 18.48'E), Skierniewice (51.96'N, 20.13'E), Iwonicz (49.79'N, 21.79'E), Przemyśl (49.79'N, 22.81'E)

Frequency of nematode occurrence in *M. x giganteus* rhizosphere



Shannon evenness index



Nematode Contribution to Soil Structure and Function

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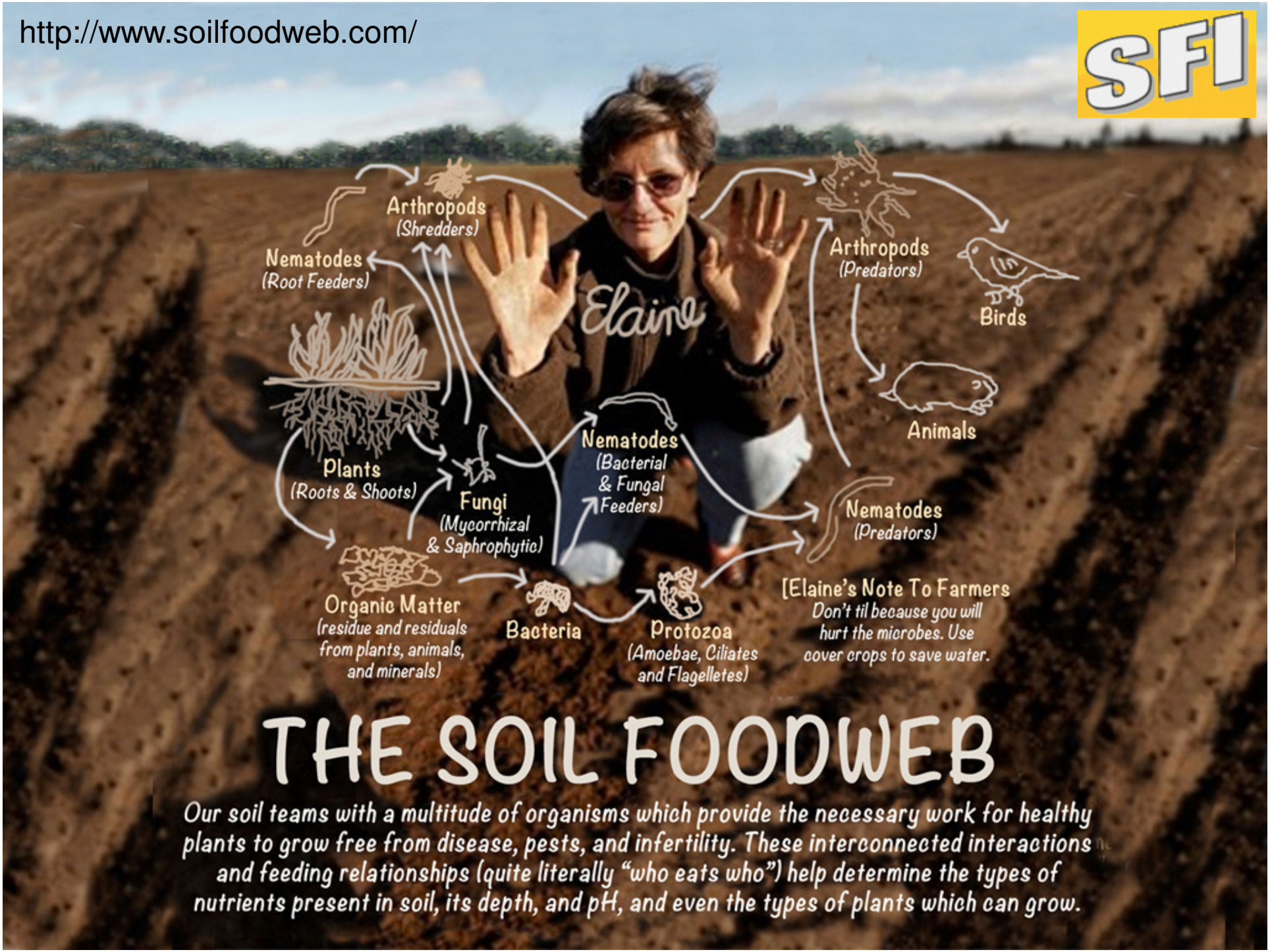
Effects of Soil Fauna on Ecosystems

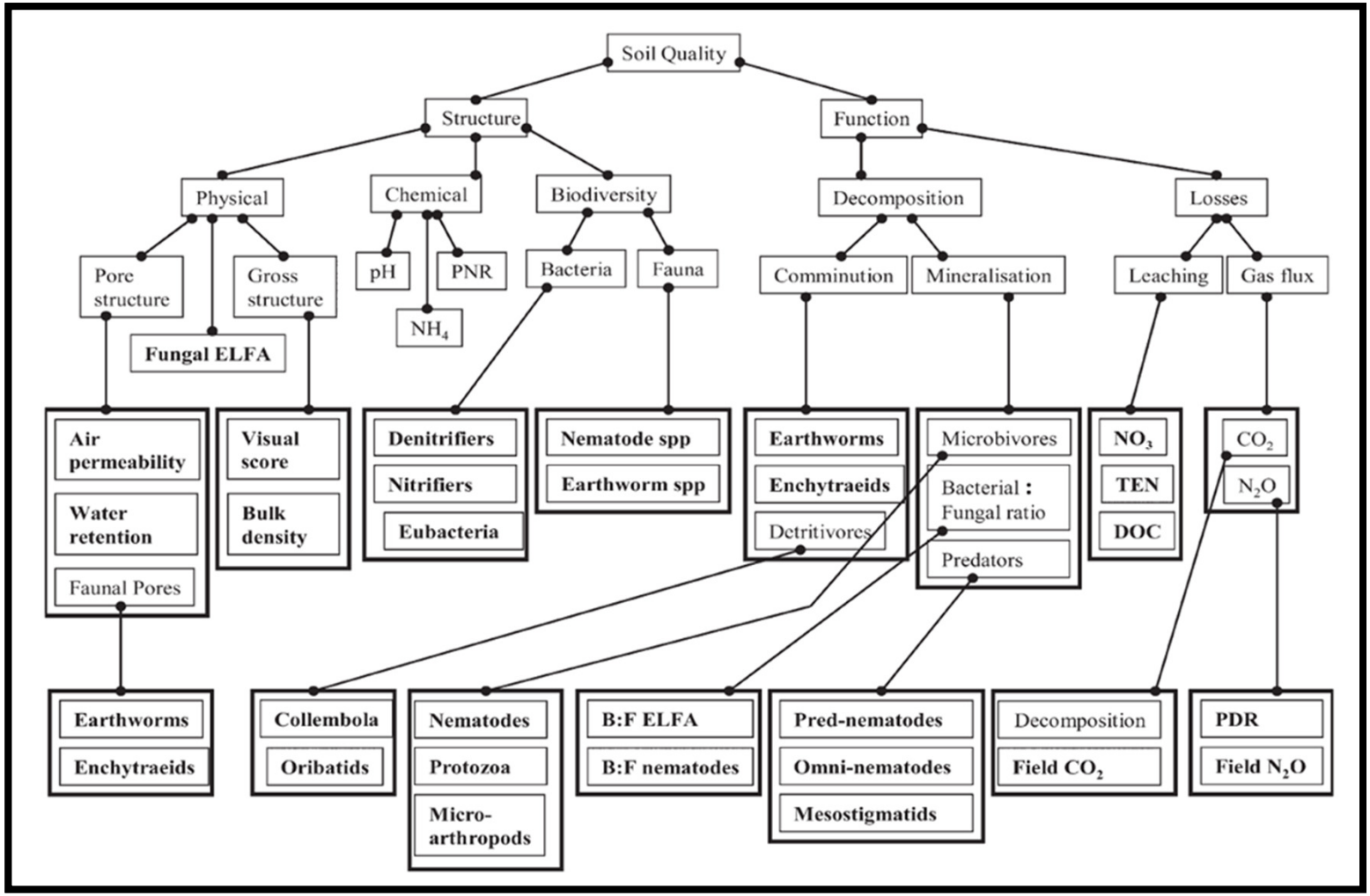
- **Consumption**
  - ❑Alter primary production
    - Root herbivory/plant parasitism
  - ❑Regulate/stimulate microbial populations/activity
    - Grazing on bacterial/fungal communities
  - ❑Stimulate decomposition
    - Fragmentation of plant residues (macrofauna)
  - ❑Alter/stimulate nutrient turnover
    - Excretion of NH_4^+ waste

- **Activity**
  - ❑Redistribution of organic matter/microorganisms
  - ❑Modification of soil structure
    - Earthworms considered a keystone species in many ecosystems

http://www.soilfoodweb.com/



Soil Quality

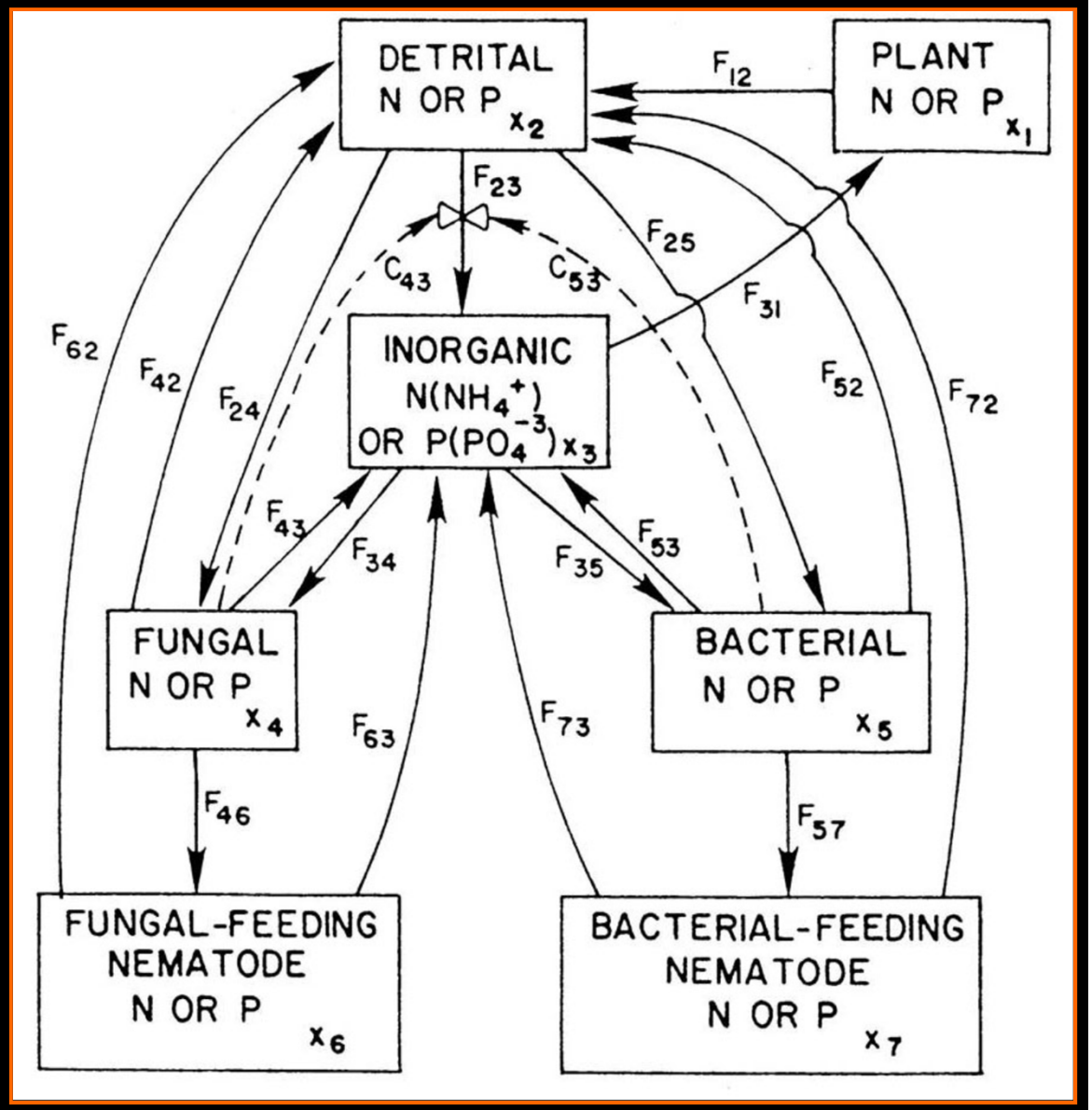


Ferris et al. 2012. Journal of Nematology 44:115–126.

Role of Nematodes in Nutrient Cycling and Decomposition

- Direct excretion of microbial-immobilized N as ammonium (NH_4^+) waste
- Stimulation of microbial activity
  - Regulation of the size and composition of the microbial community (e.g. bacterial population kept in log-phase of growth for longer periods)
  - Acceleration of turnover of microbial biomass and soil organic matter
  - Redistribution of microorganisms to unexploited substrates

Conceptual Model



Ingham et al. 1985. Ecological Monographs 55:119-140.

Nematode Community Responses to Environmental Disturbance

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Nematode Community Ecology: Applications

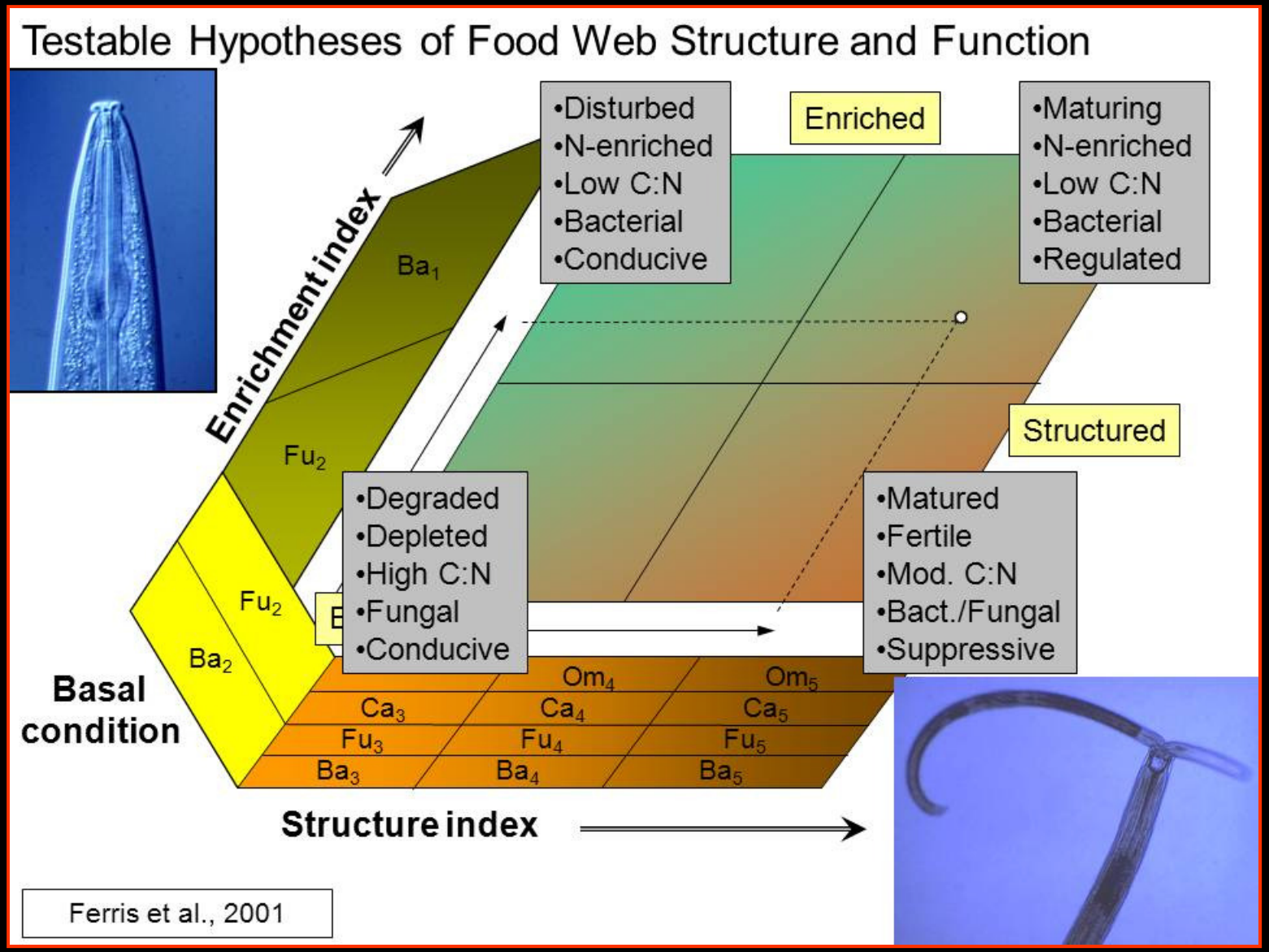
- Ecological indicators
  - Based on knowledge of food webs (functional emphasis).
    - Site/system characterization: identification of community measurements that discriminate management systems or levels of disturbance (**descriptive**).
    - Elucidation of system responses to disturbance: based on experimental manipulations and predictive modeling of cause and effect relationships (**explanatory**).
  - Primary research areas
    - **Global Change (Tallgrass Prairie)**
    - **Natural vs. Anthropogenic Disturbances (TGP)**
    - Sustainable agriculture/soil quality
- Soil biodiversity
  - Taxonomic inventories (structural emphasis)
  - High-throughput sequencing

Nematodes as Ecological Indicators

- Reflect the structure and function of ecological processes (e.g. **soil food web** structure).
  - All trophic levels are represented.
  - Microbial-feeding nematodes are key intermediates between microbial populations and macrofaunal predation.
- Responsive to changes in soil condition (disturbances).
- Easily monitored: populations are quantifiable; individuals are distinguishable.
- Habitat is definable and buffered; migration is minimal.
- Molecular biology, development, genetics, and physiology are better described than for most soil organisms.

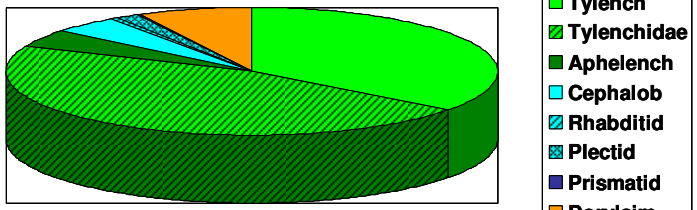
Nematode Indices

- **Trophic Group Abundances & Ratios**
- **Diversity**
- **Maturity Index** (Bongers. 1990. Oecologia 83:14-19)
  - Colonizer-Persister (**C-P**) Scale – 1 through 5
  - MI = $\sum$ C-P (taxon *i*) × freq (taxon *i*)
- **Structure & Enrichment Indices** (Ferris et al. 2001. Applied Soil Ecology 18:13–29)
- **Metabolic Footprints** (Ferris. 2010. European Journal of Soil Biology 46:97-104)

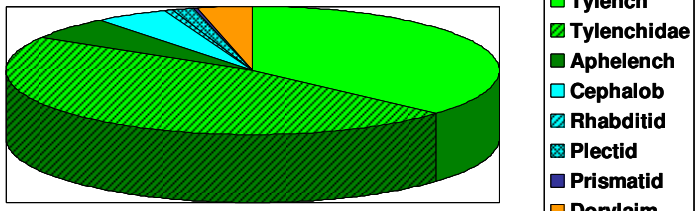


Ferris et al. 2001. Applied Soil Ecology 18:13-29.

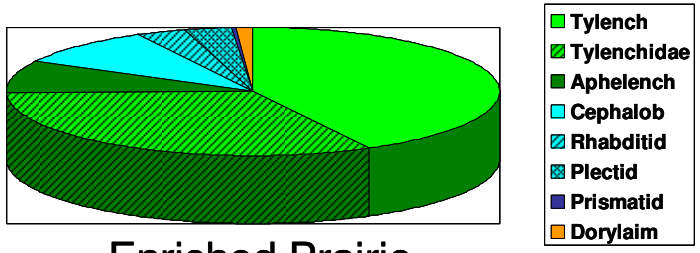
Effect of Land Use Change on Nematode Community Structure



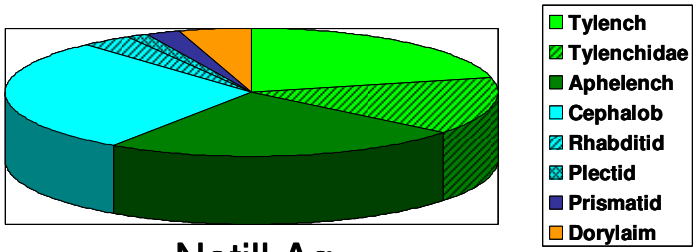
Burned Prairie



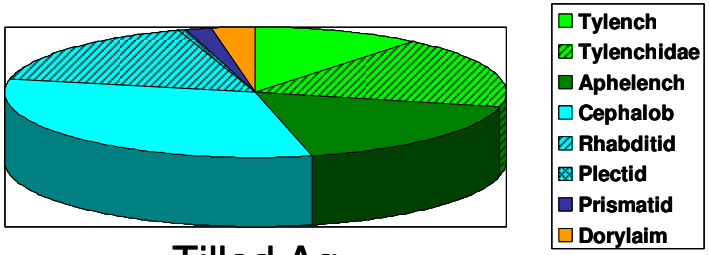
Unburned Prairie



Enriched Prairie



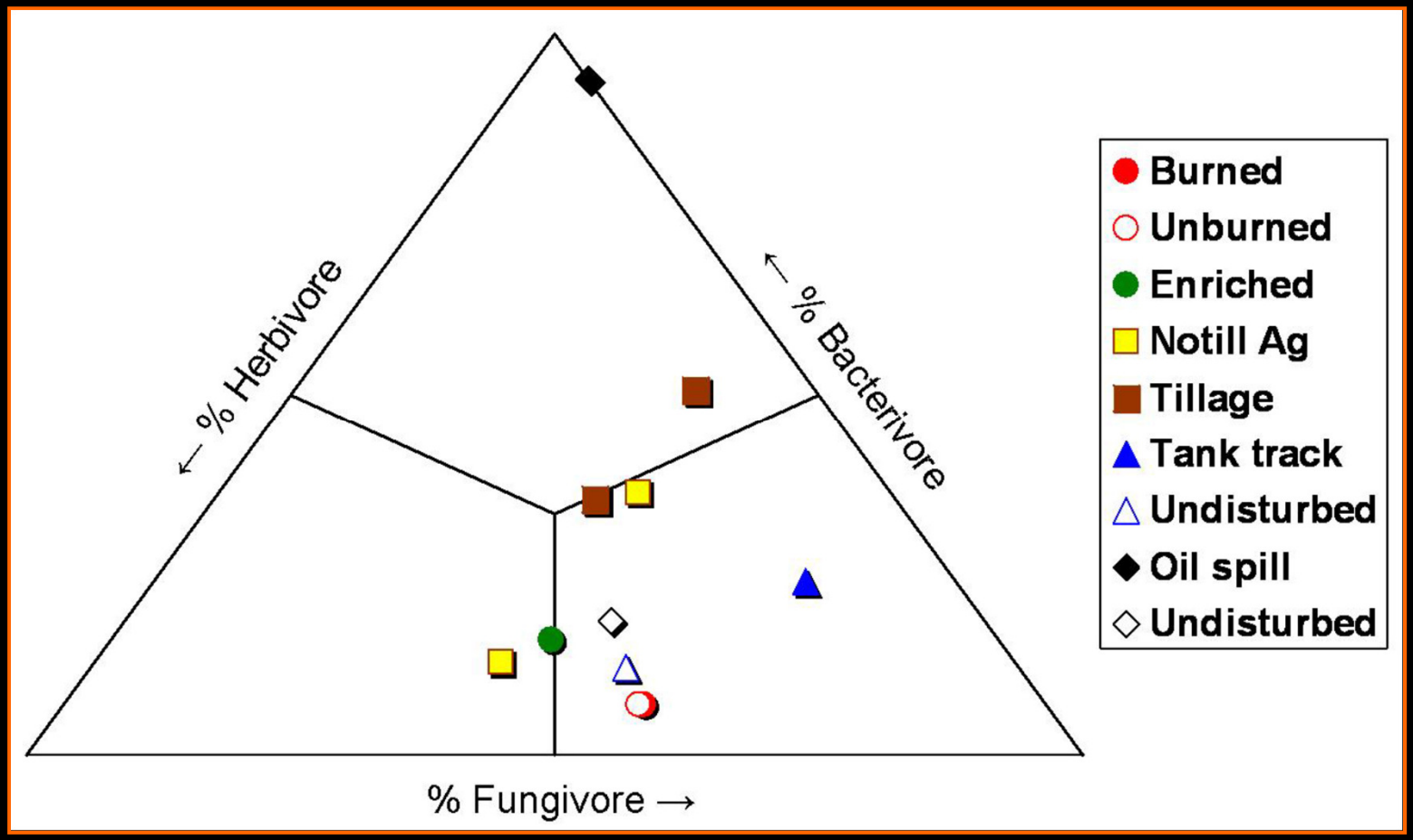
Notill Ag



Tilled Ag

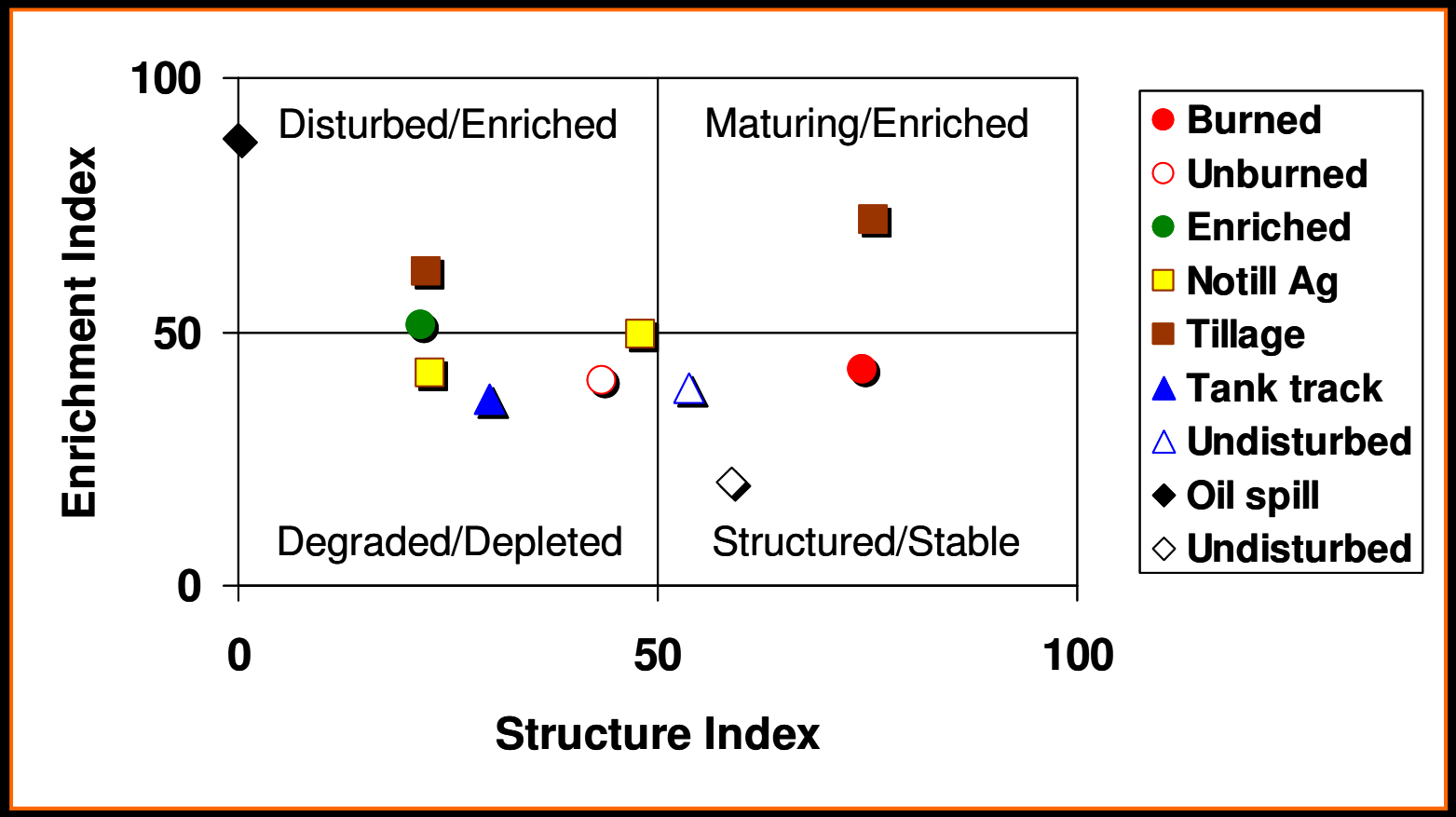
Todd et al. 2006. *Journal of Nematology* 38:20-27.

Nematode Community Analysis: Enrichment Profile



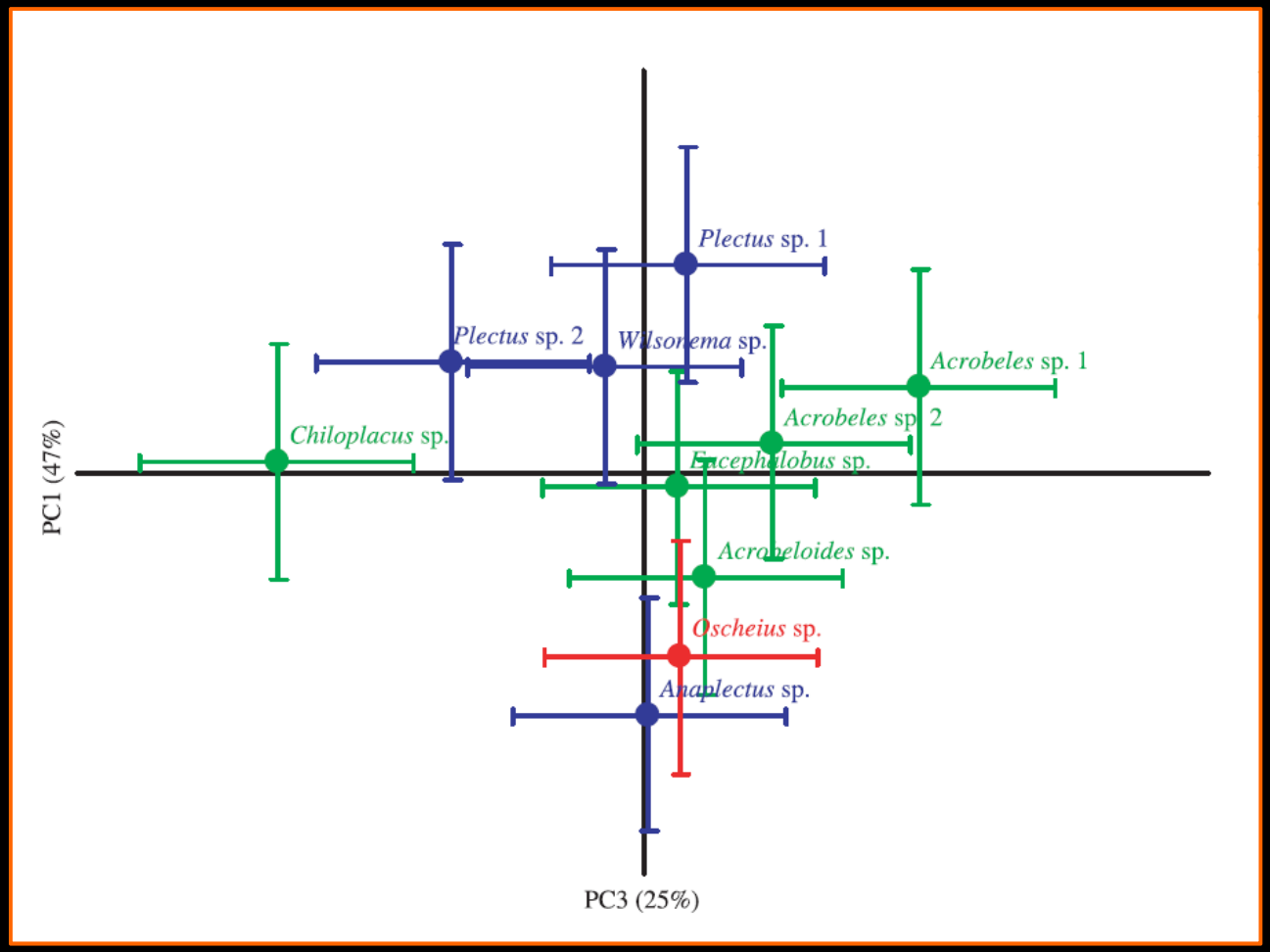
Todd et al. 2006. *Journal of Nematology* 38:20-27.
Sublette et al. 2007. *Soil & Sediment Contamination* 16:181–208.
Althoff et al. 2009. *Applied Soil Ecology* 43: 122–130.

Nematode Community Analysis: Faunal Profile



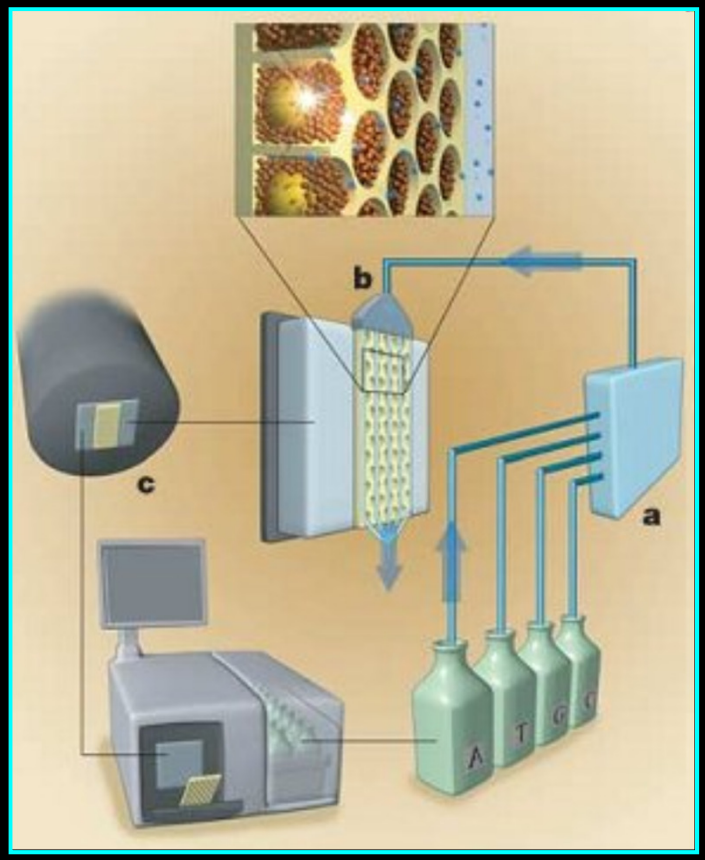
Todd et al. 2006. *Journal of Nematology* 38:20-27.
Sublette et al. 2007. *Soil & Sediment Contamination* 16:181–208.
Althoff et al. 2009. *Applied Soil Ecology* 43: 122–130.

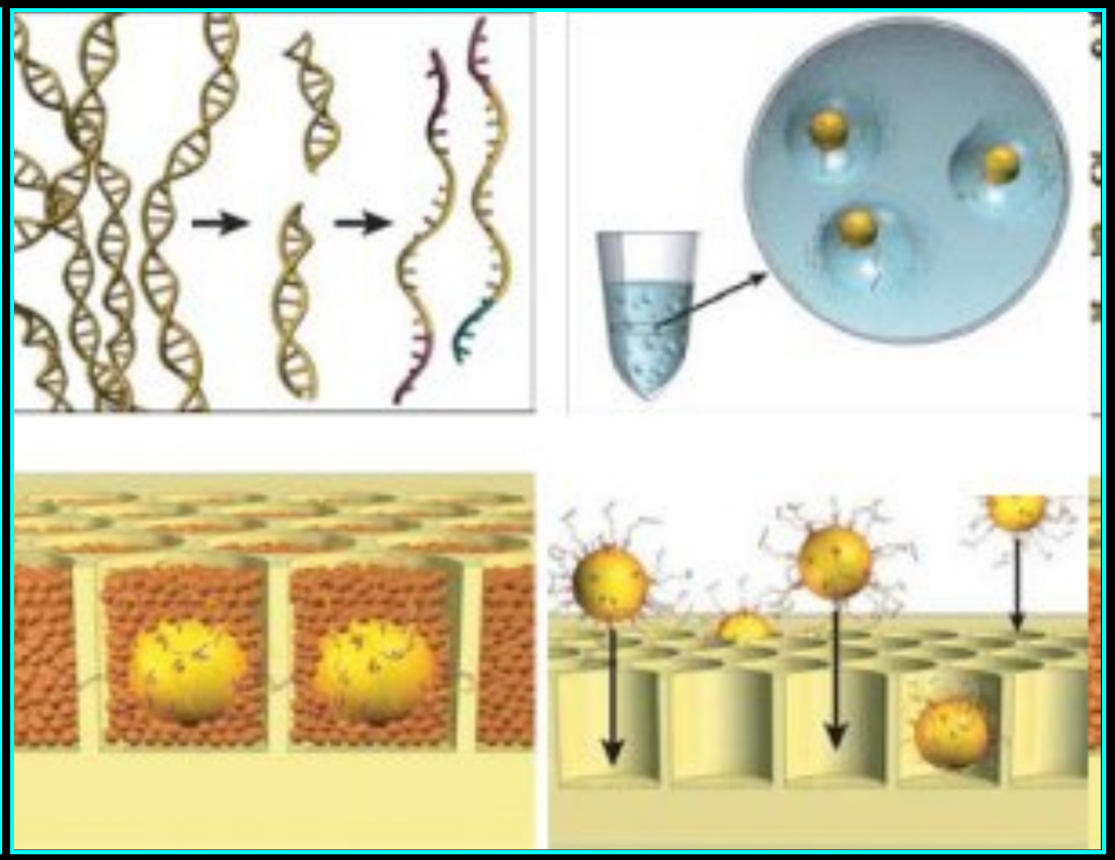
Family-Level Resolution is not Sufficient



Jones et al. 2006. *Molecular Ecology* 15:2601-2609.

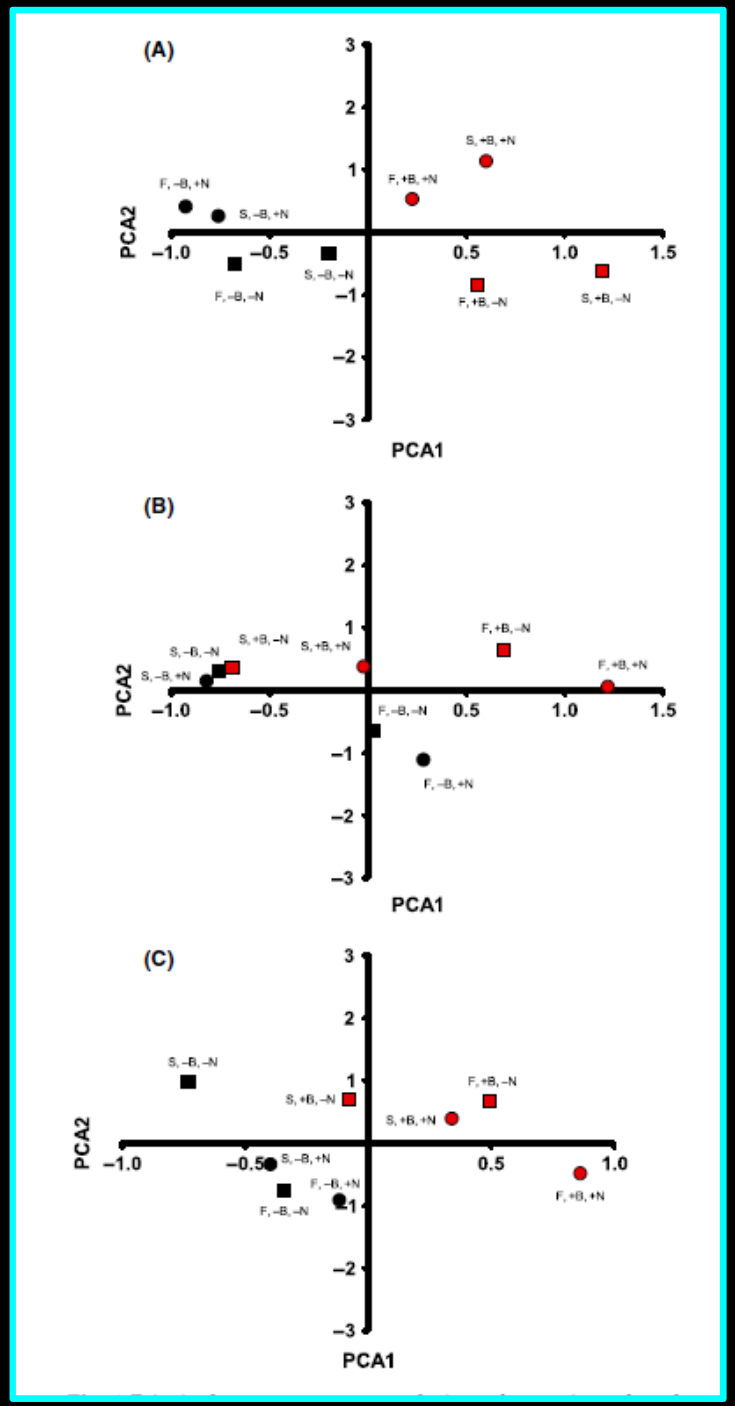
454 Pyrosequencing





http://scott.sherrillmix.com/res/images/454_machine.jpg
http://scott.sherrillmix.com/res/images/454_beads.jpg

Principal Components Analysis of:
(A) Specimen-based counts
(B) Sequence-based counts
(C) Copy-number corrected counts



Darby et al. 2013. *Molecular Ecology*.
doi: 10.1111/mec.12480

Copy Number Variation

- Ribosomal RNA operon copy number varies by >2 orders of magnitude among nematode species.
- Somatic cell count varies with nematode size (e.g. 95 body wall muscle cells in *C. elegans* vs. 5×10^4 somatic muscle cells in *Ascaris*).
- Germ cell number varies among species and individuals, as well as seasonally.

SPRINGTAILS AS BIOINDICATORS OF SOIL HEALTH

u1

Collembola = 1-5 % of total soil animal biomass in temperate ecosystem
6500 species in the world

Size 0.01-2mm

soil mesofauna

$> 10^5/m^2$

$> 10^4 /m^2$

$> 10^2 /m^2$

Slide 33

u1 Springtails are small arthropods (0.01-2mm) with hidden month parts (Enthognata), belonging to soil mesofauna. In the temperate climate they are most numerous in the forest ecosystem (up to 1 milion/m2), less numumerous in grassland ecosystem and the least numerous in different agricultural ecoystems (more then 1000 per m2).

up, 9/14/2017

u2

- Epedaphic
- Hemiedaphic
- Euedaphic

Slide 34

u2 Springtails live mostly in the upper soil layer (up to deeph of 5 cm). We can distinguish different life-form groups: epedaphic springtails (living on the soil surface, large and pigmented species), euedaphic (living in the deeper soil layers, smaller, white species and hemiedaphic - living mostly in litter with intermidiate characteristic between epedaphic and euedaphic)

up, 9/14/2017

Role in ecosystem

- After microorganisms they are important decomposers.
- Many springtails feed on bacteria and fungi (also pathogenic) – role in plant protection.
- They occure ussually in high numbers and biodiveristy. Particular species, as well ecological groups and whole community respond to many biotic and abiotic factors -

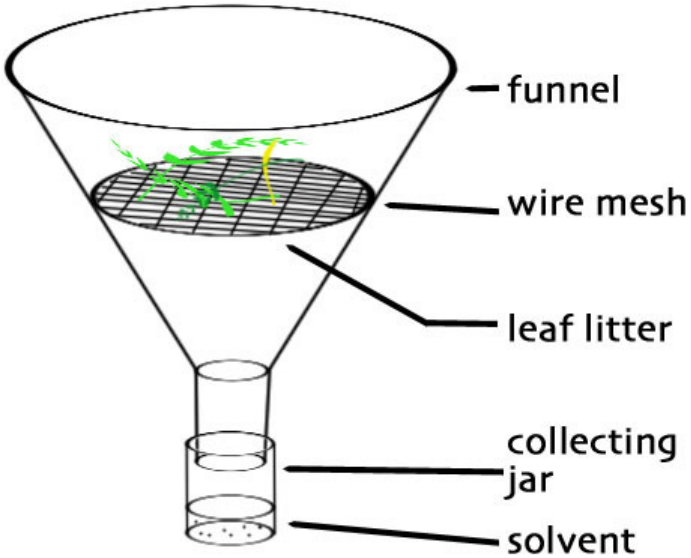
u6

-		+
Abiotic factors		
Drying	pH	Soil moisture
Soil compaction	Soil temperature	Humus, Soil organic matter content
		Nitrogen content
Biotic factors		
		Plant diversity
		Microbial and fungal biomass
Antropogenic factors		
Soil pollution Agricultural practices (tillage, mineral fertilization, crop protection practices)		Organic fertilization Non-till farming

Slide 36

u6 As you can see springtails respond positively or negatively to different environmental factors ...
up, 9/14/2017

SAMPLING METHODS



Euedaphic and hemiedaphic species

Epedaphic species

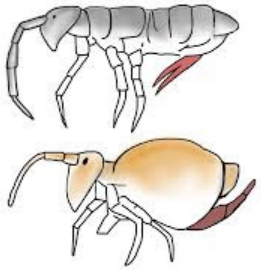
Slide 37

u3 Simple Barber traps - epedaphic species
up, 9/14/2017

u4 Euedaphic and hemiedaphic species - tullgren funnels
up, 9/14/2017

BIOINDICATION

- u5 Particular species of springtails differ strongly in their sensivity to environmental stress (Ponge et al. 2003).



- Major ecological indices:
- Species diversity; Simpson, Shannon-Viever, Pielou indices;
- Collembola/Acari Ratio
- QBS – C and QBS – Ar (Soil quality index based on the evaluation of soil arthropods)
- Biomarkers (different evolutionary adaptations of particular species)

-

Slide 38

u5 In order to evaluate the soil health we can use different ecological indices....

up, 9/14/2017

u7

Bioindication of land – use intensivity

(2016)

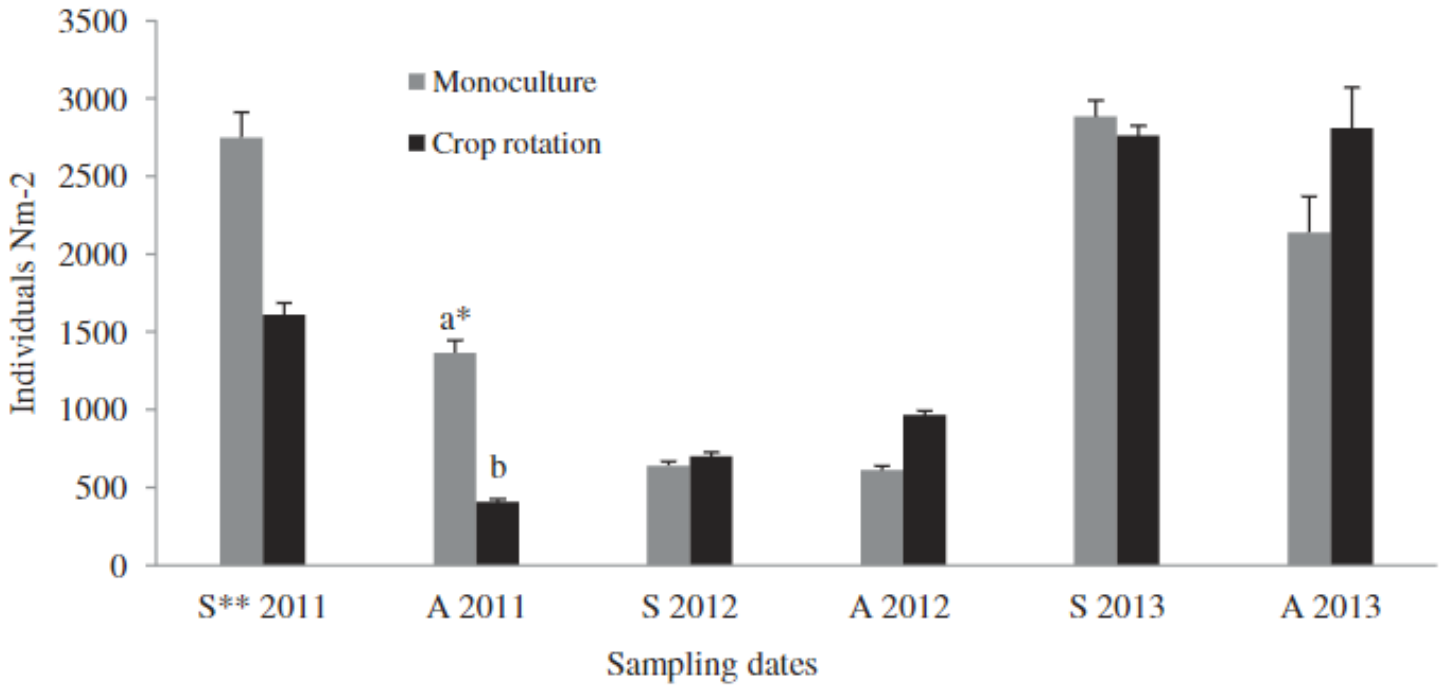


Figure 1. Springtails' abundance in monoculture and crop rotation in 2011–2013.
*significant difference (ANOVA, $p \leq 0.05$), **S – spring, A – autumn.

Slide 39

u7 Some examples of using springtails in biodiversity....

up, 9/14/2017

(Twardowski et al. 2016)

Table 6. Soil quality index based on the evaluation of springtails (QBS-c).

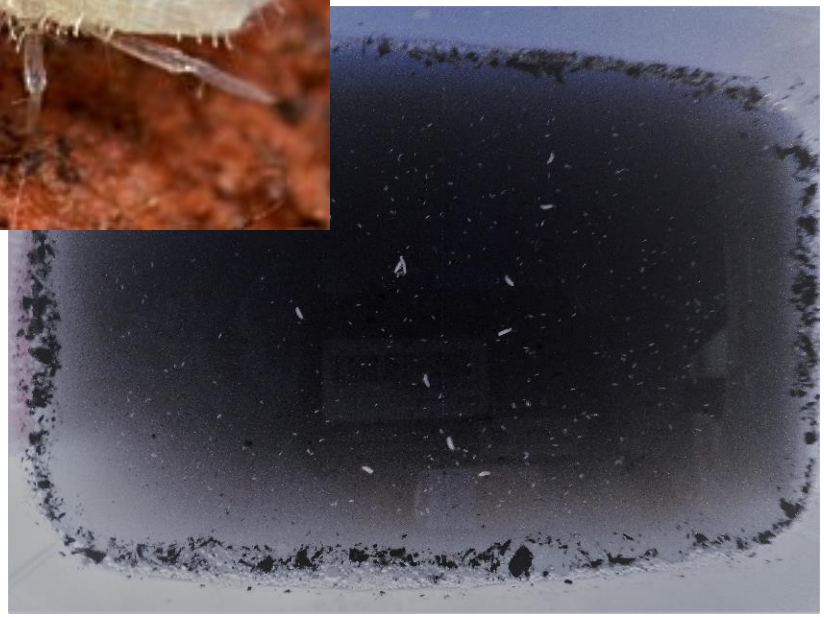
	Monoculture	Crop rotation
Spring 2011	116	189
Autumn 2011	129	129
Spring 2012	114	196
Autumn 2012	120	188
Spring 2013	191	220
Autumn 2013	94	162
Mean	127.3	180.7

u8
u9

Use of Collembola in ecotoxicology

F. candida

S. curviseta



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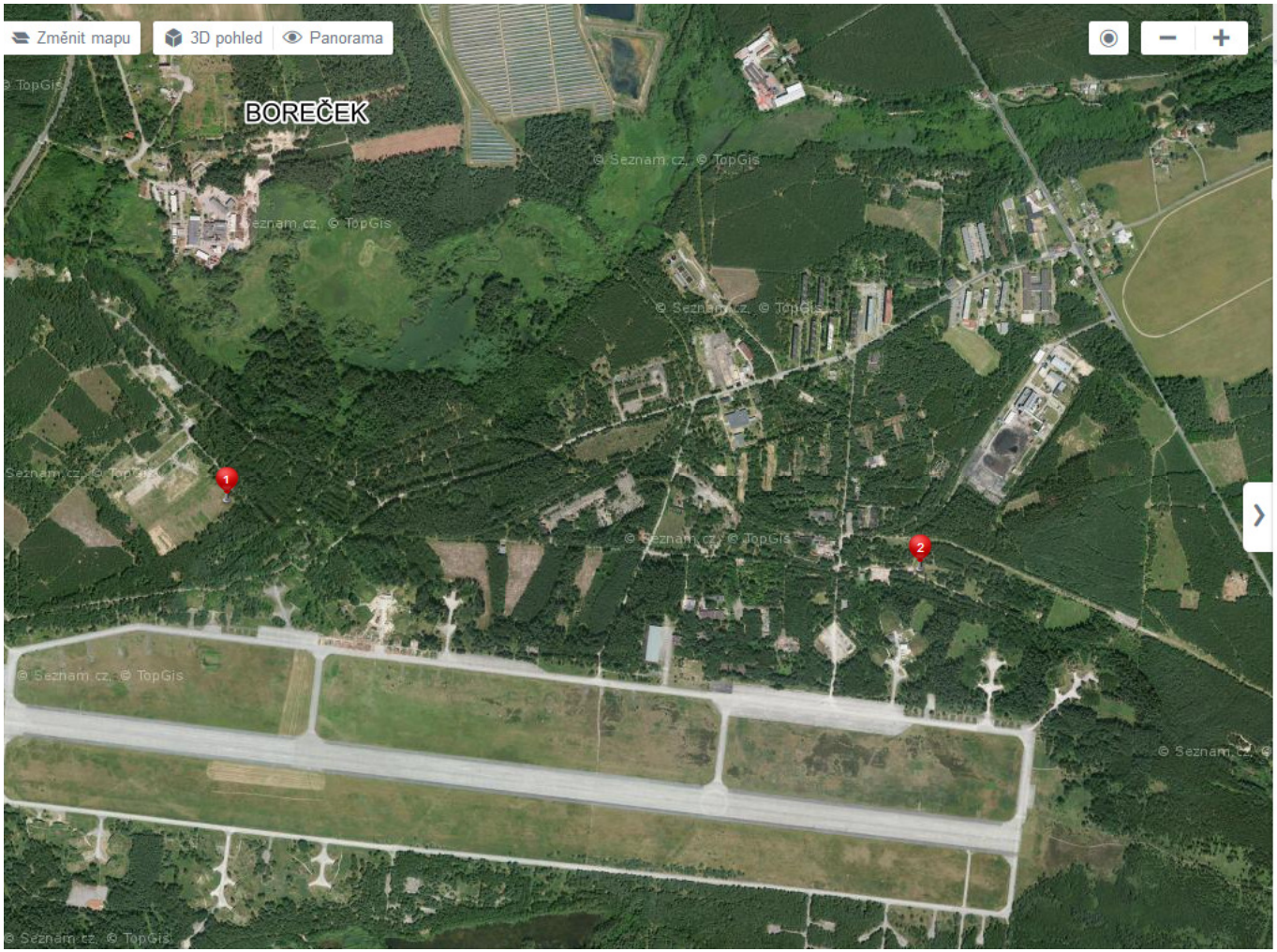
u8 Some springtails are using as model species in ecotoxicology (e.g. Folsomia candida and Sinella curviseta).
up, 9/14/2017

u9 Commonly used tests are: reproduction test, avoidance test, survival test)
up, 9/14/2017



Hledání | Plánování | Batůžek

Control site
50°37'31.387"N, 14°43'23.039"E
50.6253850N, 14.7230664E

Contaminated site
50°37'26.027"N, 14°44'49.228"E
50.6238964N, 14.7470078E

- Smazat body
- Přidat do oblíbených
- Sdílet
- Exportovat

Conclusions

- The objective of any phytotechnology is not only removing of the contaminant(s), but also restoring the continued capacity of the soil to perform or function according to its potential (i.e., to recover **soil health)**
- Hence, indicators of soil health are needed to properly assess the success of the phytotechnology
- The sensitivity of nematodes and springtails to disturbance makes these groups of soil organisms ideal candidates for evaluating the success of the phytotechnologies (e.g. *Miscanthus x giganteus* biomass production at contaminated sites)

Acknowledgments

- NATO SPS G4687

NATO OTAN NORTH ATLANTIC TREATY ORGANIZATION

- Collaborators from liaison institutions from Poland:

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