IF YOU BUILD IT THEY WILL COME: DISPERSAL CAPABILITIES OF SOIL FAUNA

Sarah R. Smith

Research Scientist

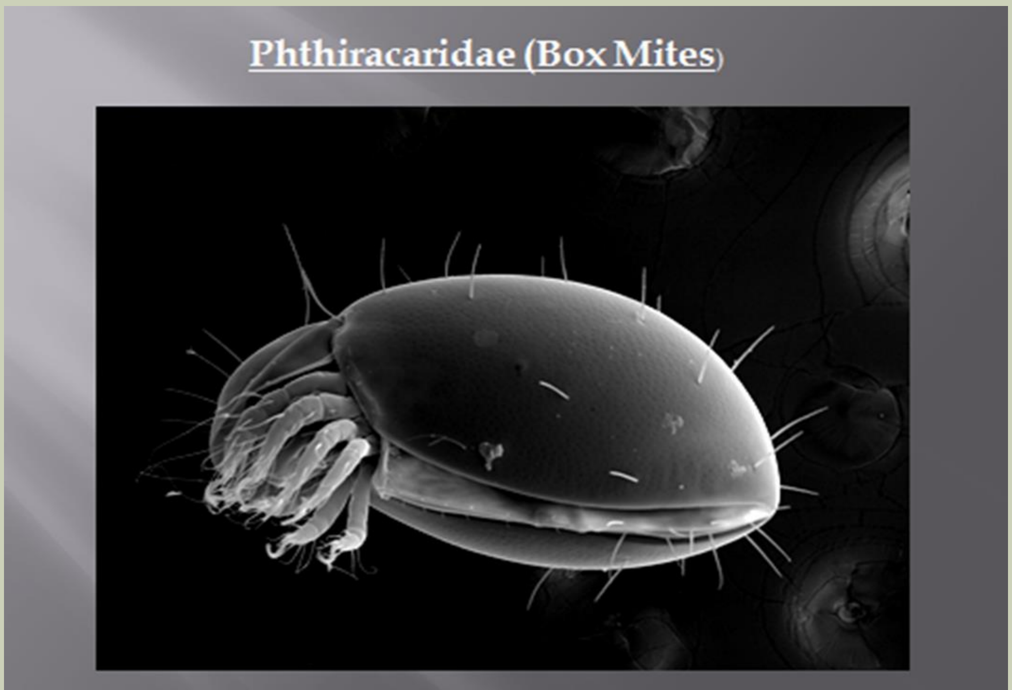
June 26, 2013

OUTLINE

- Why study soil fauna?
- Research interests: past & present
- Introduction to decomposer community and importance of soils
- Graduate work completed in Pinelands on soil fauna dispersion in a fragmented systems
- Questions/ Discussion

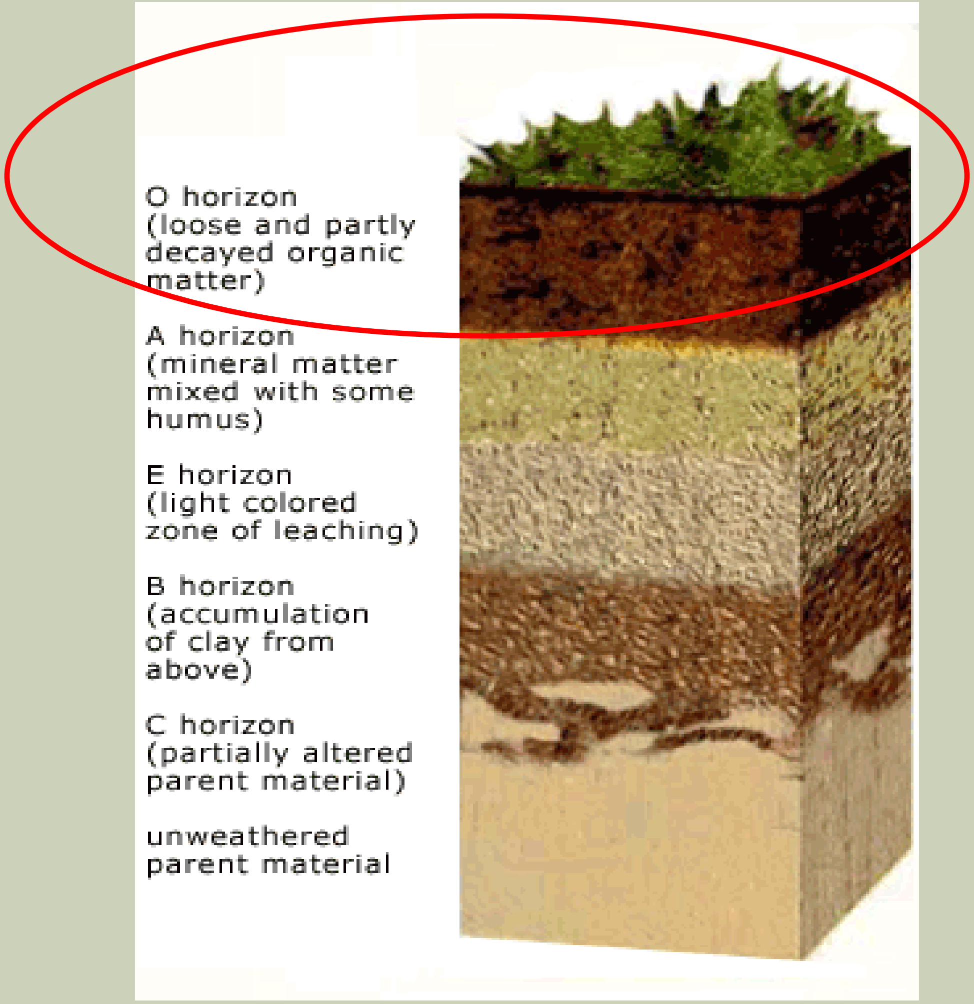
WHY STUDY SOIL FAUNA? AND SOILS IN GENERAL….“POOR (WO)MAN’S TROPICAL RAINFOREST”

IMPORTANCE OF DECOMPOSERS



FUNCTIONAL ROLE OF DECOMPOSERS: ECOSYSTEM SERVICES

- Soil is the main medium for which N and C transformations occur (Anderson, 1988)
- 60-90% of terrestrial primary production is decomposed in the soil, which thus performs an important "ecological service" (Behan-Pelletier & Hill, 1983)
  - Soil fauna contribute greatly to this process by:
    - Grazing on microbial biomass, which altered the rate at which organic matter breaks down.
    - Fragmenting organic matter and increasing its surface area for attack by microorganisms.
    - Controlling the grazing pressure of nematodes
    - Mixing soil and organic matter and introducing microorganisms onto fresh organic matter
    - Degradation of organic matter and mineralization of nutrients
    - Controlling populations of pathogens



Soils are alive so.....
Who's there?

Mesofauna:
Soil predators, pathogens, herbivores

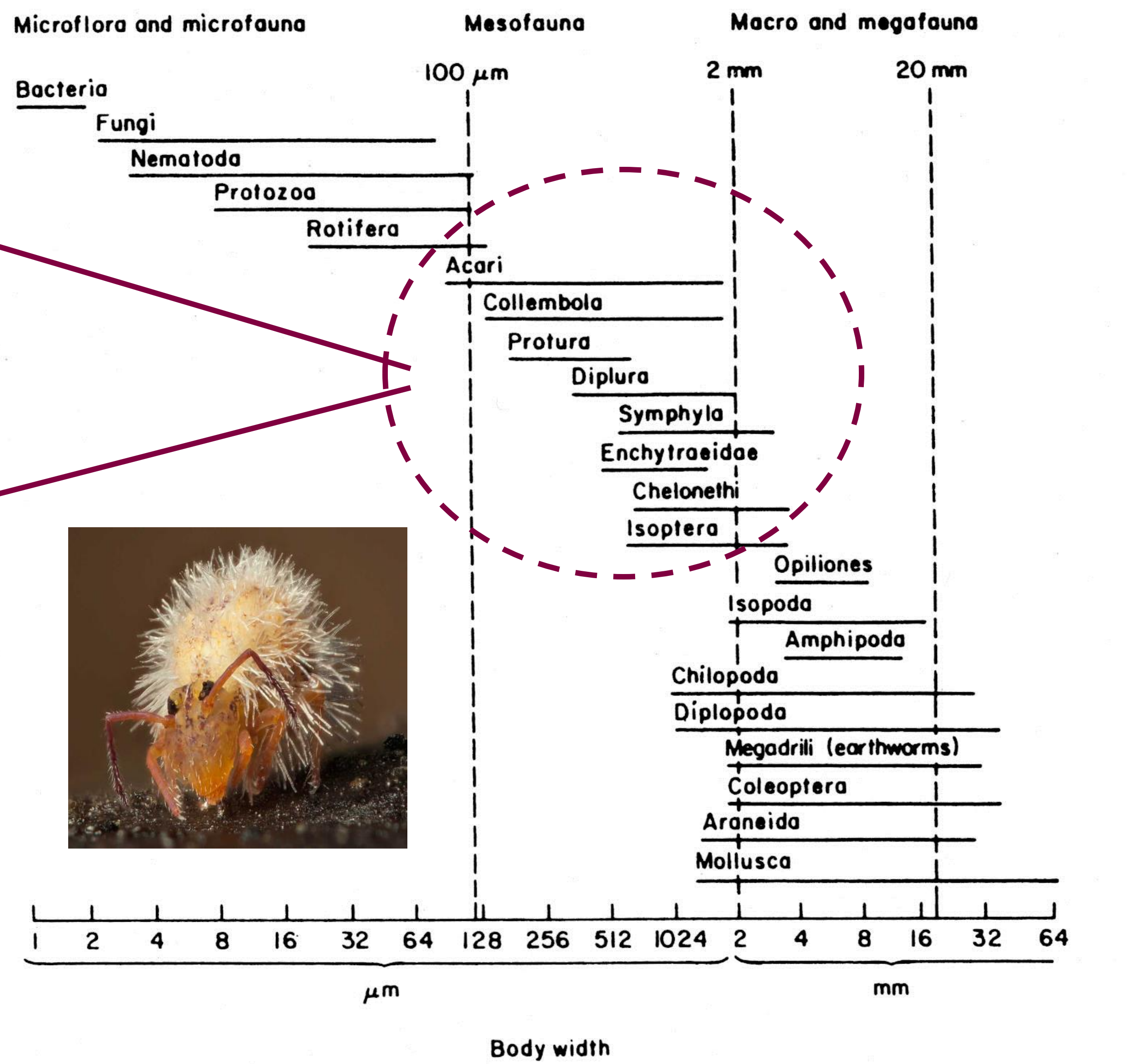
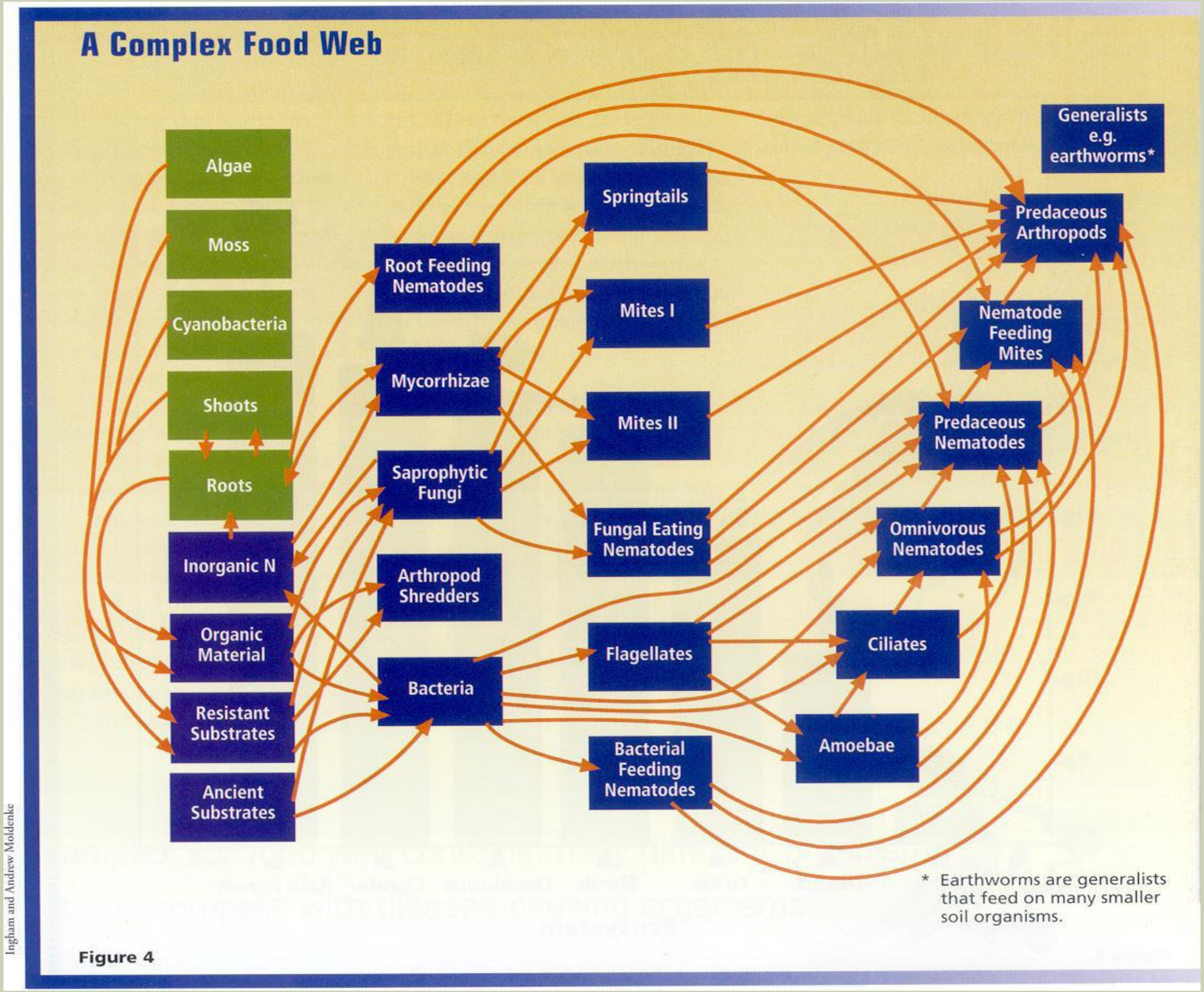


FIGURE 4.3 Size classification of organisms in decomposer food webs by body width (Swift *et al.*, 1979).

Biodiversity below-ground supports biodiversity above-ground. The thin layer where soil and litter meet is especially crucial to this process.



There is an increasing awareness that the feedbacks among aboveground and belowground biota are major ecological drivers in terrestrial ecosystems .

Spatial patterning of soil biota and biotic activity can have important aboveground consequences, and this is apparent with regard to both plant community structure and the growth of individual plants.

Most simply, spatial heterogeneity in soil resources results in microhabitat diversity, which can promote species coexistence through greater resource partitioning

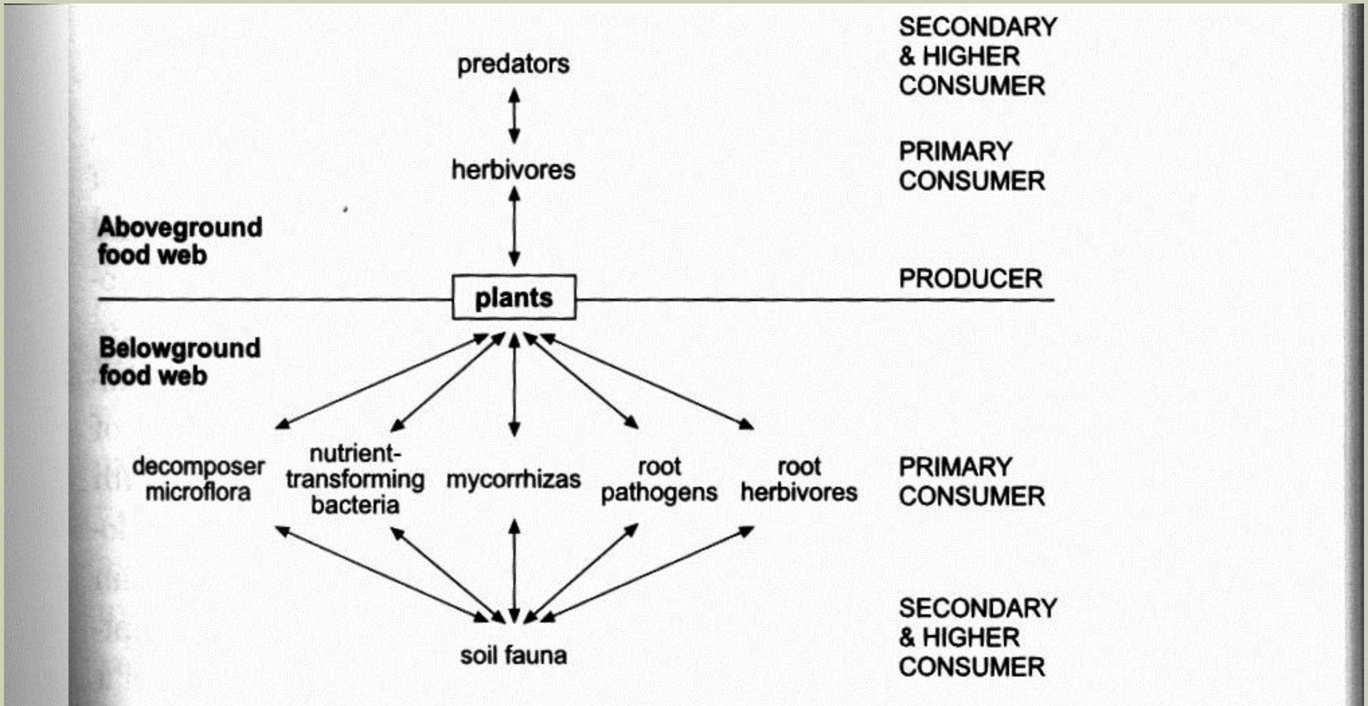


FIGURE 5.1. Routes by which belowground organisms may influence aboveground organisms, as outlined throughout chapter 5. Arrows indicate direction of possible effects, and all groups of organisms identified in this figure are capable of either directly or indirectly influencing all other groups of organisms.

Wardle, D. 1963

COLLEMBOLAN TAXA

- Over 8,299 described Collembolan species, arranged into >670 genera, 31 families, 15 super families and 4 orders.

The cuticle, hydrostatic endoskeleton, tendons and muscles all work together to manipulate the body in such a way that propulsion is optimal.

The force and distance of the “spring” is equivalent to a human jumping over the Eiffel tower!!

Poduromorpha

Entomobryomorpha

Neelipleona

Symphypleona

"The ultrastructure of the surface of Collembolan is one of the most striking features found in nature (Hopkin, 1997)."

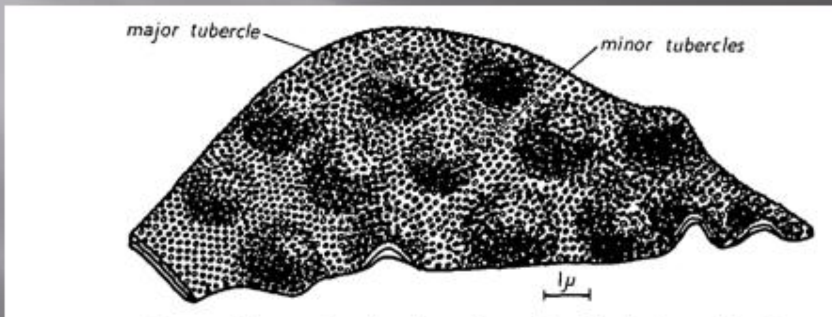
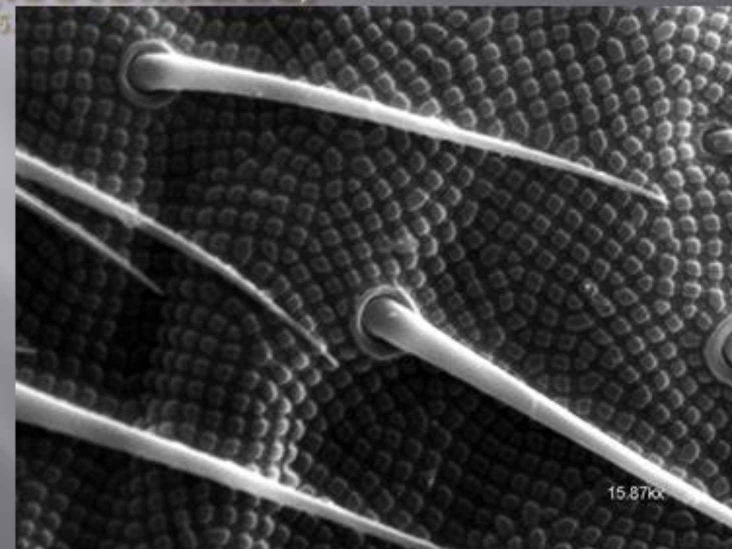


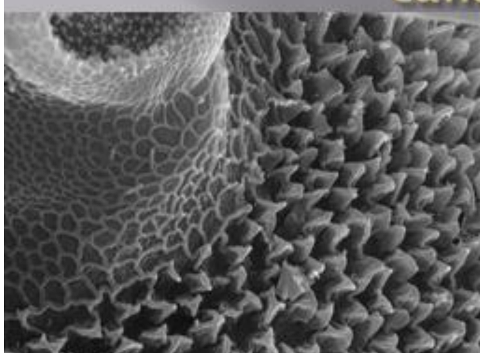
FIG. 1. Diagram showing the surface sculpturing in the cuticle of *P. aquatica.*

Noble-Nesbitt,1963

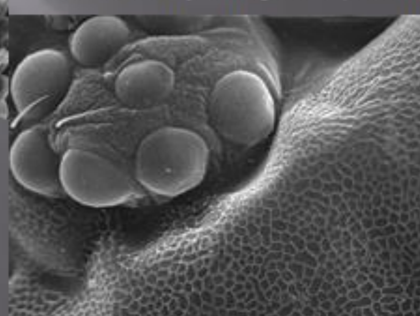
Cuticle Patterning (Isotomidae)



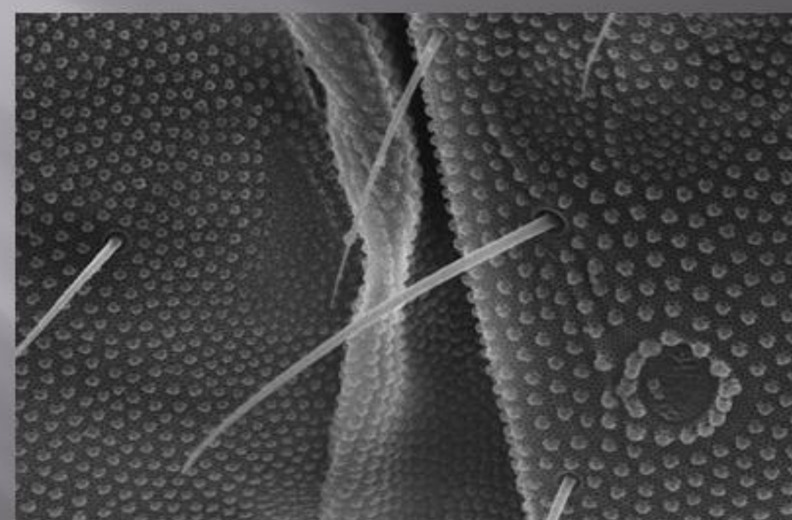
Sminthuridae cuticle near pore canal



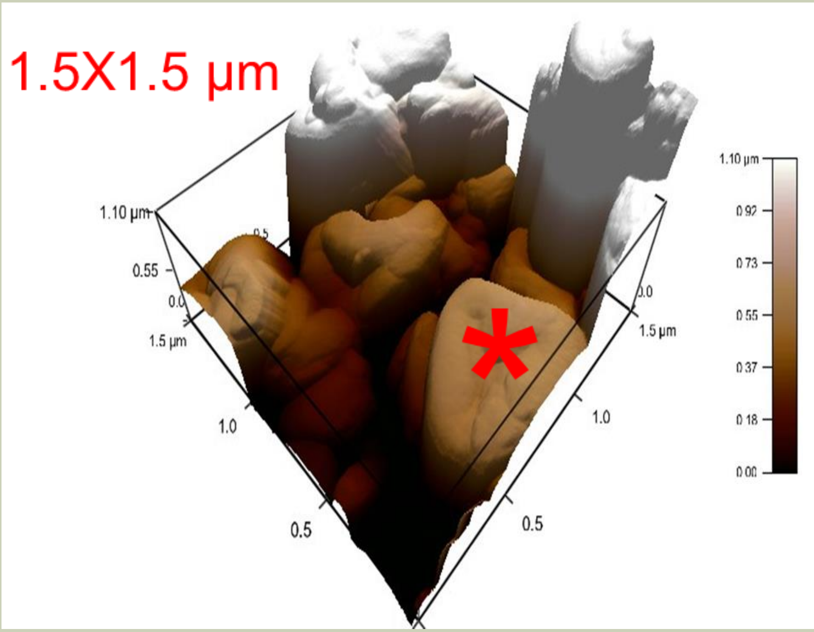
Sminthuridae eye-like patches(8 ocelli)

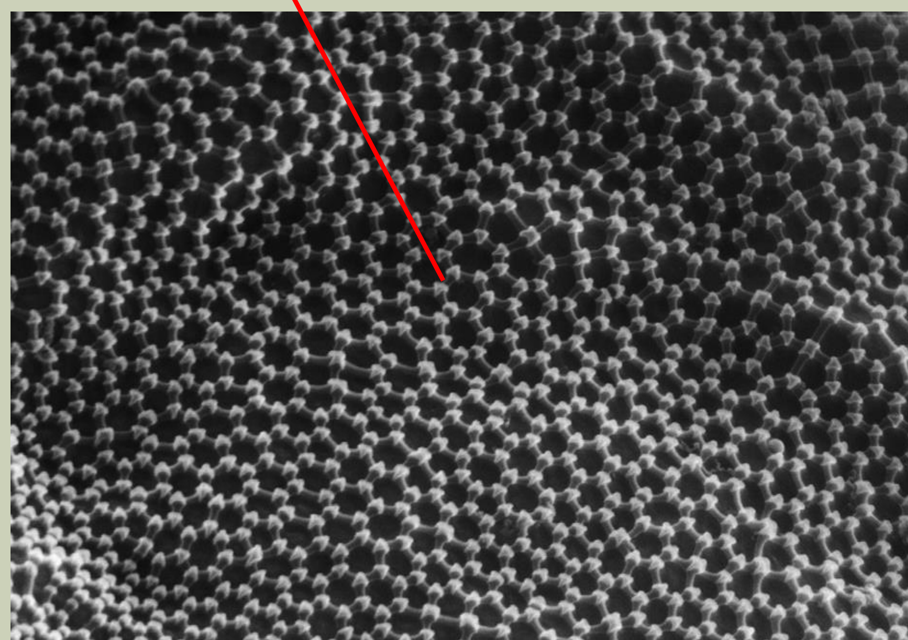


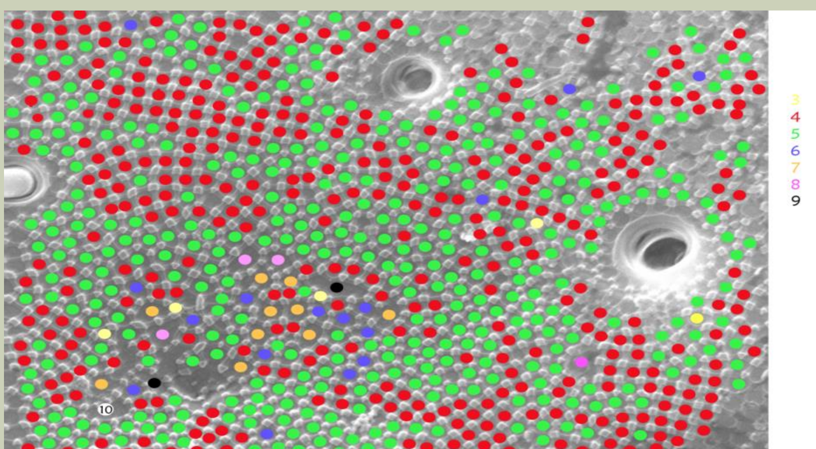
Sminthuridae Tuberculate Cuticula Patterning
7000x



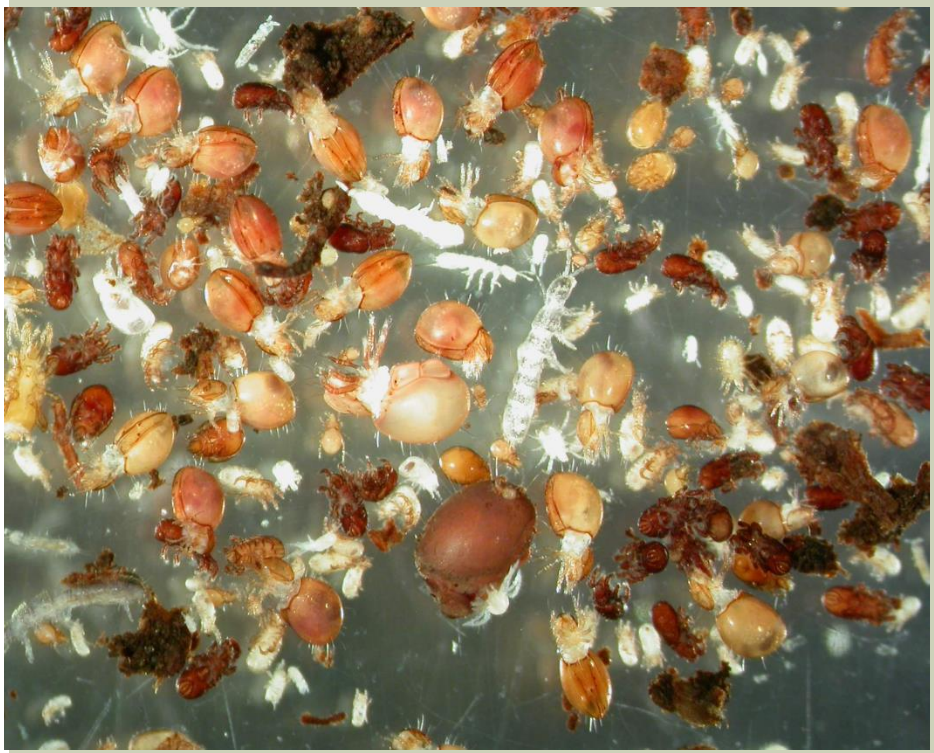
AFM images characterize the hardness and elasticity of the cuticular material. The 3D images of minor tubercles display. The height of the minor tubercles on Hypogasturidae.

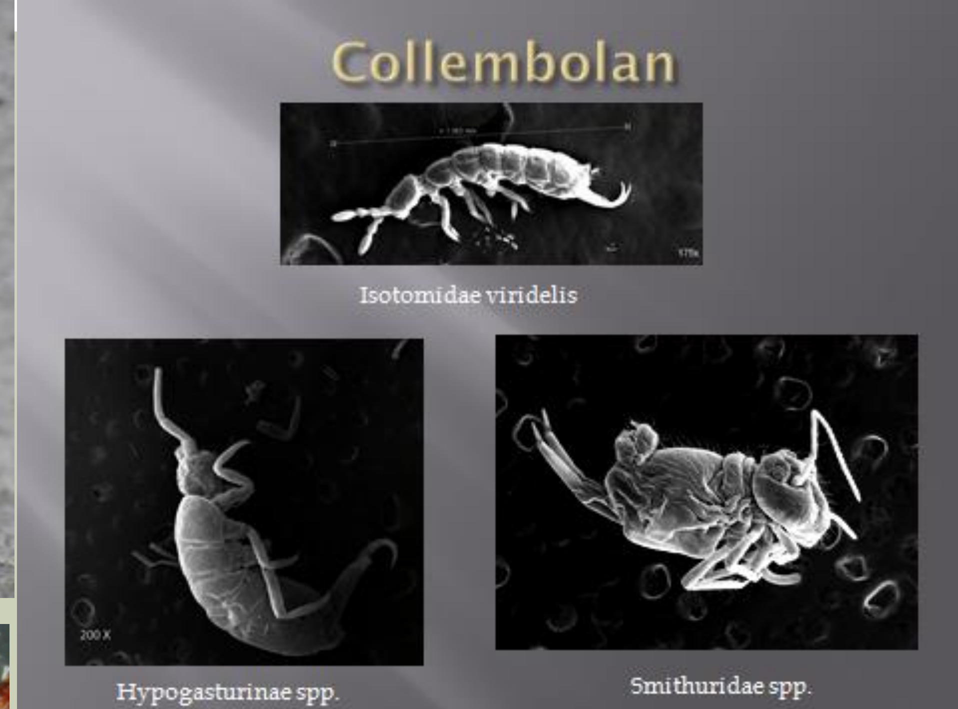







Natureimages.com




Collembolan
Isotomidae viridelis
200 X
Hypogasturinae spp.
Smithuridae spp.

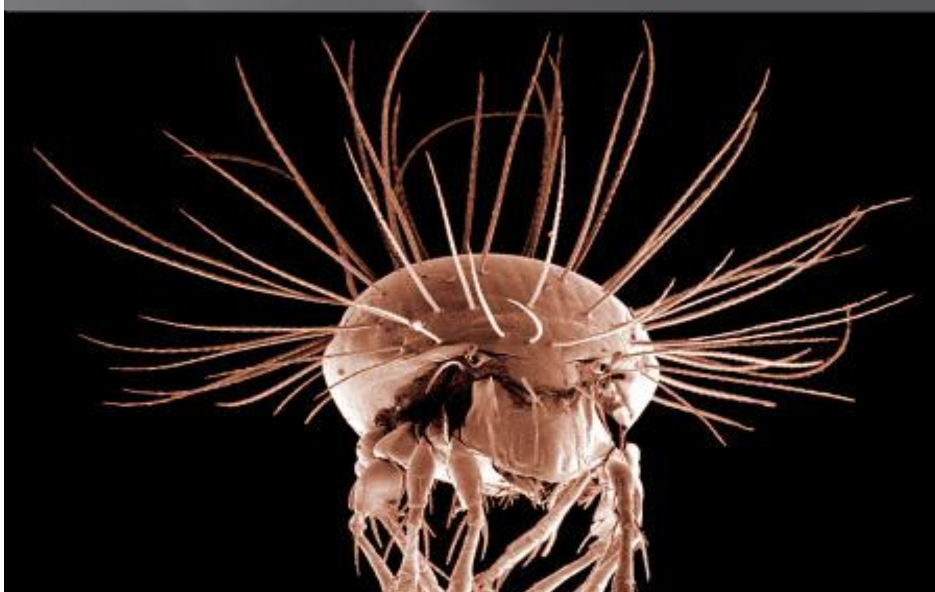

Pseudoscorpion: Microbusium spp.

ACARI: SOIL MITES

- Mites of the suborder Oribatida are the **world's most numerous arthropods living in the soil**.
- Densities can reach hundreds of thousands/ square meter!!
- They have long life cycles **(K strategists)** up to 7 years, females lay few eggs and many are parthenogentic (no males).
- Slow metabolic rates, slow development and low fecundity, **Oribatida are not capable of fast population growth and are usually restricted to stable environments**, in contrast to opportunistic groups (Collembolan).
- Oribatida comprise an important component of soil decomposers; their abundance, species composition and diversity in a particular habitat serve as good indicators of **"soil health".**

Predatory Mesostigmatidae Mite

Galumnoidea spp.



Neotrichozete spp

Predatory Mesostigmatidae Mite


Mesostigmata1


Nanhermannoidea

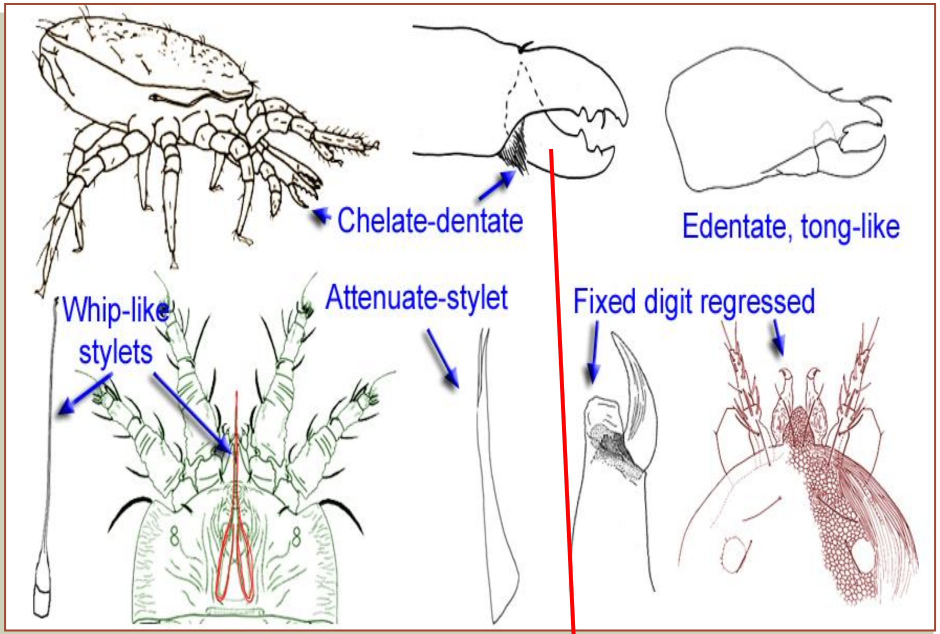

Oppiidae

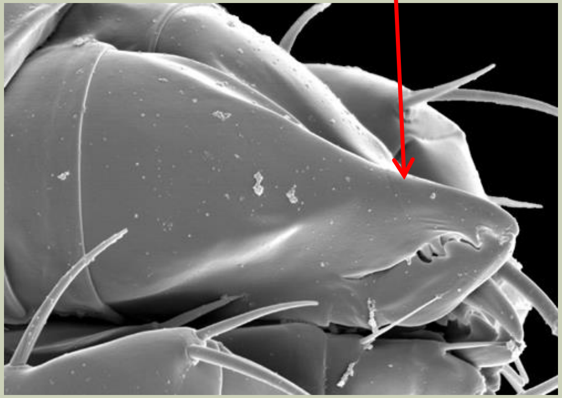

Prostigmata 2

FUNCTIONAL GROUPS OF SOIL FAUNA

- Saprotrophs (primary decomposers): Feed on non-living organic materials.
- Fungivores(secondary decomposers): Feed on living fungal hyphae and other microorganisms.
- Generalist: Feed on variety of resources and are not bound by digestive capabilities (i.e. Collembolan)
- Predators: Feed on smaller fauna and larvae forms of macroarthropods.
- Phycophages/ herbivores: Feeding mainly on lichen, algae and plant tissues (not separated for this study).

- Trophic guild is determined by a variety of diagnostics, mostly by examining the mouth parts of the organism.



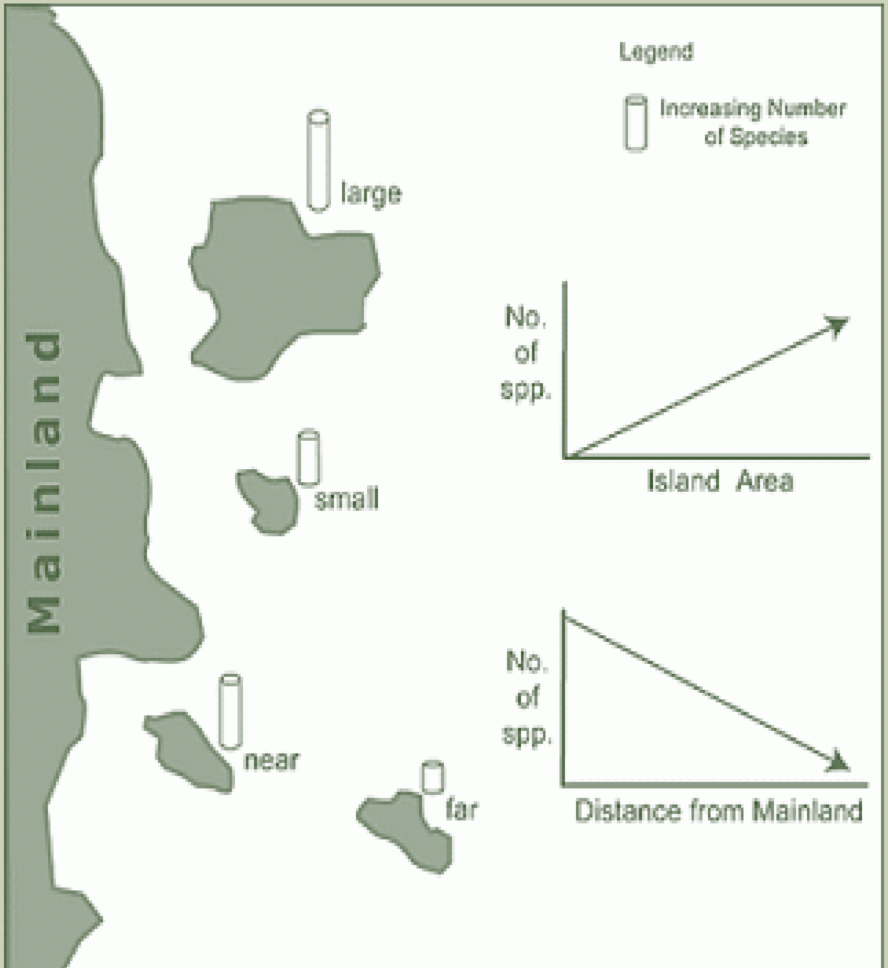


RESEARCH INTERESTS: PAST & PRESENT

- Boreal coniferous forest zone
- 86% of land area is forested
- Three main tree species: Scots Pine,
- Silver Birch, Norway Spruce
- EU Renewable Energy Directive:
- 20% by 2020 CO_2 reduction
- Impacts on soil health and ecosystem processes

Dighton, J., Helmisaari, H.-S., Maghirang, M., Smith, S., Malcolm, K., Johnson, W., Quast, L.,Lallier, B., Gray, D., Setälä, H., Starr, M., Luiro, J., Kukkola, M. (2012) **Impacts of forest post thinning residues on soil chemistry, fauna and roots: Implications of residue removal in Finland.** *Applied Soil Ecology* 60 (2012) 16– 22. Corrigendum: *Applied Soil Ecology* 62 (2012) 184

THEORY OF ISLAND BIOGEOGRAPHY MACARTHUR & WILSON, 1967



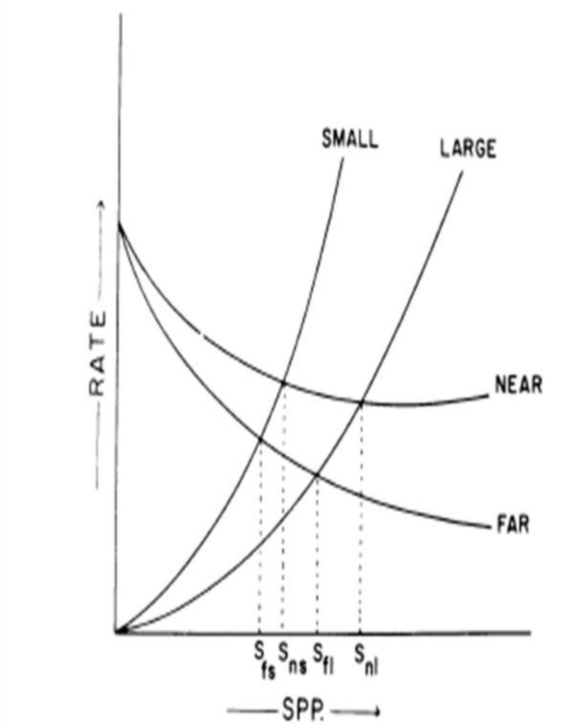
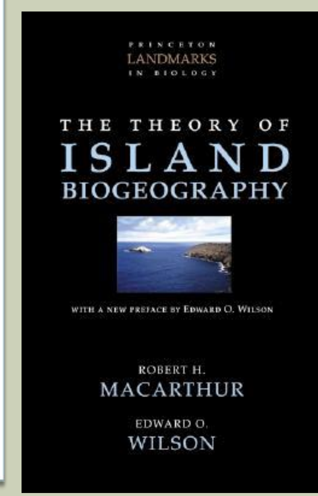


FIG. 1. The equilibrium model. Rate = extinction (ascending curves) or immigration (descending curves). SPP. = number of species, S_{ns}, S_{nl}, S_{fs}, and S_{fl} = equilibrium number of species for near small, near large, far small, and far large islands respectively (Mac Arthur and Wilson 1967).



HABITAT FRAGMENTATION & ISOLATION

Fragmentation as change in habitat configuration: Increased # of patches, decrease in patch sizes, increase in isolation of patches.

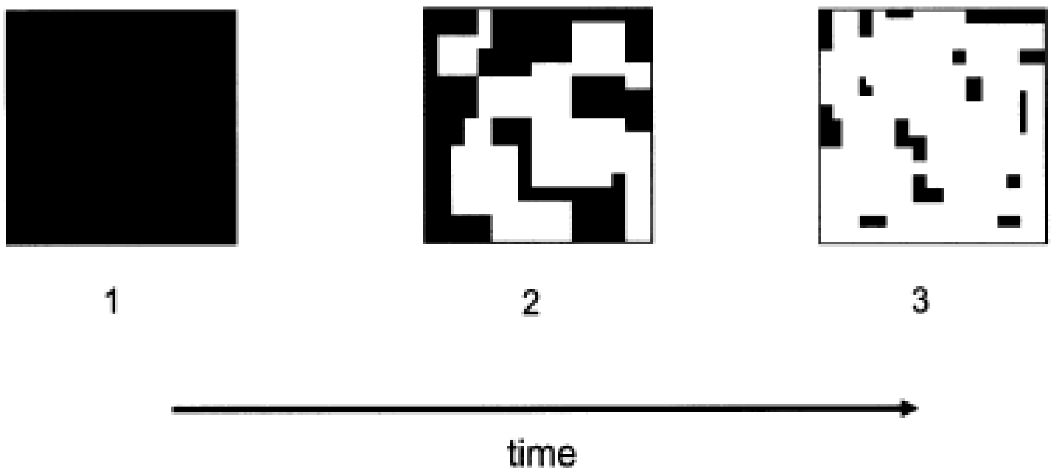


Figure 1 The process of habitat fragmentation, where "a large expanse of habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original" (Wilcove et al. 1986). Black areas represent habitat and white areas represent matrix.

Roads, clearcutting and agriculture fragment a tract of forested land in the ACE Basin.

http://nerrs.noaa.gov

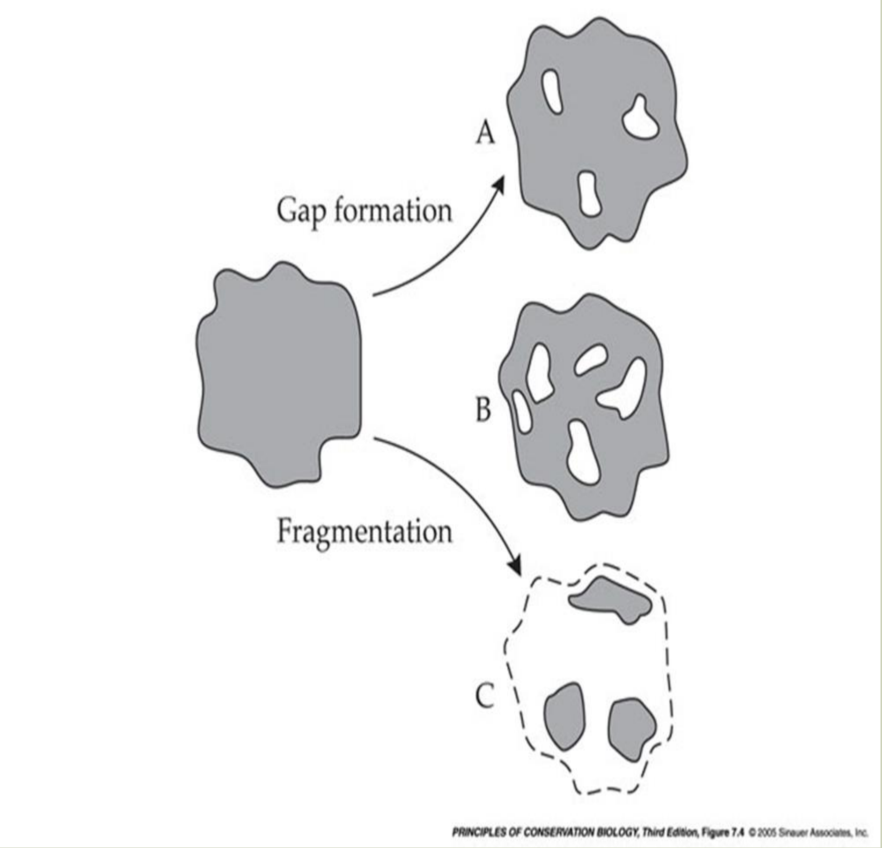
A recent search of the Cambridge Scientific Abstracts database revealed over 1600 articles containing the phrase "habitat fragmentation." (Fahrig, 2003)

GRADUATE RESEARCH AT RUTGERS UNIVERSITY

- Investigated the effects of habitat fragmentation on soil fauna communities within the Pine Plains located at the Warren Grove Gunnery Range.
- Investigated the colonization abilities of soil fauna by created sterilized islands located in a “sandy matrix” of unfavorable habitat
- Spatial- Temporal effects of fragmentation on soil fauna
- Empirical research suggests that soil fauna diversity, density and species richness is reduced in fragmented systems. (Adetola & Ola-Adams,2000)

TERRESTRIAL ISLANDS

- Research was conducted at Warren Grove Gunnery Range from July 2011- July 2012, with the support of Drexel University students (opening and closing a lot of gates for me in order to do my research!)
- Terrestrial islands are created when a section of (forest or patch of vegetation) is separated from the main intact forest.
- Using soil fauna as my model organism group I tested to see if the effects of habitat fragmentation could be observed in a disturbed section of the W.G.G.R.




4/6/1995
N
Warren Grove Field Site Location
Dept of Defense
Image U.S. Geological Survey
Google earth
Imagery Date: 4/6/1995 39°41'41.63" N 74°23'33.06" W elev 128 ft eye alt 1258 ft

Click to zoom in on the time slider.
5/26/2003
1995
2012
N
Warren Grove Field Site Location
Image © 2013 State of New Jersey
Google earth
Imagery Date: 12/31/2001 39°41'36.97" N 74°23'30.57" W elev 135 ft eye alt 583 ft

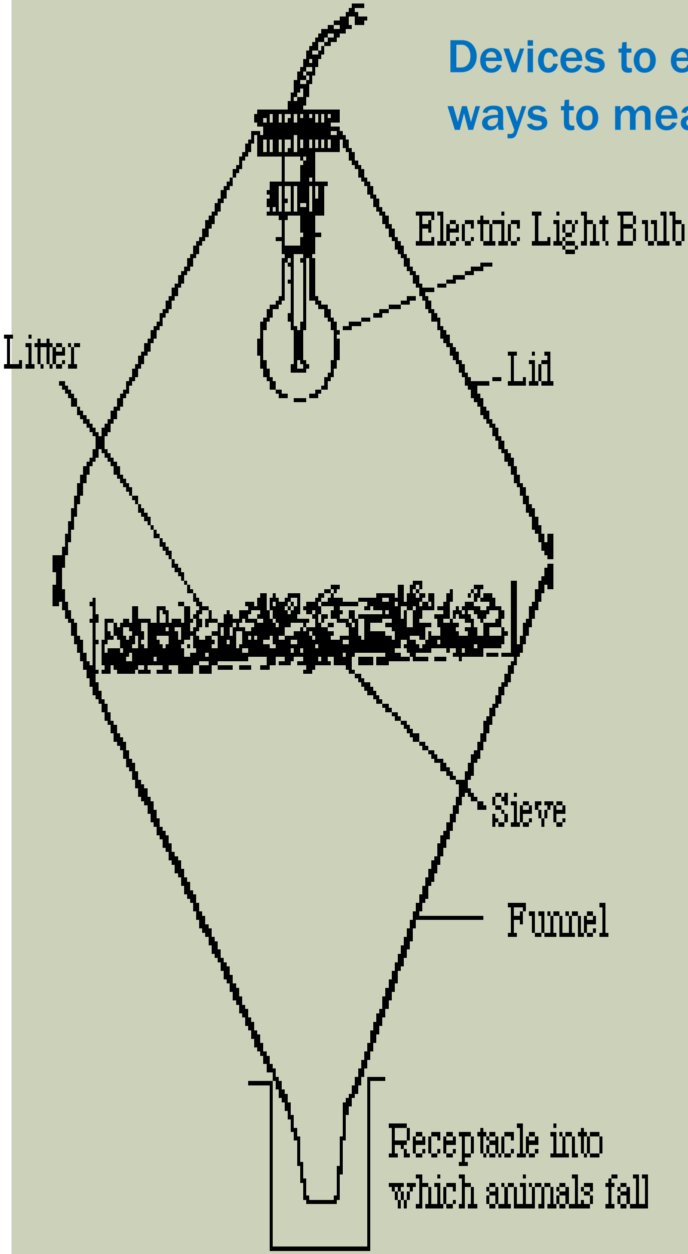

5/30/2008
N
Warren Grove Field Site Location
Google earth
Imagery Date: 7/4/2007
39°41'37.30" N
74°23'30.01" W
elev 132 ft
eye alt 583 ft


11/18/2010
Warren Grove Field Site Location
Google earth
Imagery Date: 9/20/2010 39°41'34.07" N 74°23'26.32" W elev 135 ft eye alt 583 ft

SURVEY DESIGN

- 12 regrowth islands
  - 3 Large + Close
  - 3 Large + Far
  - 3 Small + Close
  - 3 Small + Far
  - Mainland (intact) forest
  - Sandy matrix
- Soil fauna sampled bi-monthly July 2011- July 2012
- 1 core / island/sampling event
- 3 cores from the mainland
- 3 cores from the sandy matrix

Devices to extract soil fauna are relatively simple and inexpensive ways to measure soil health and diversity.



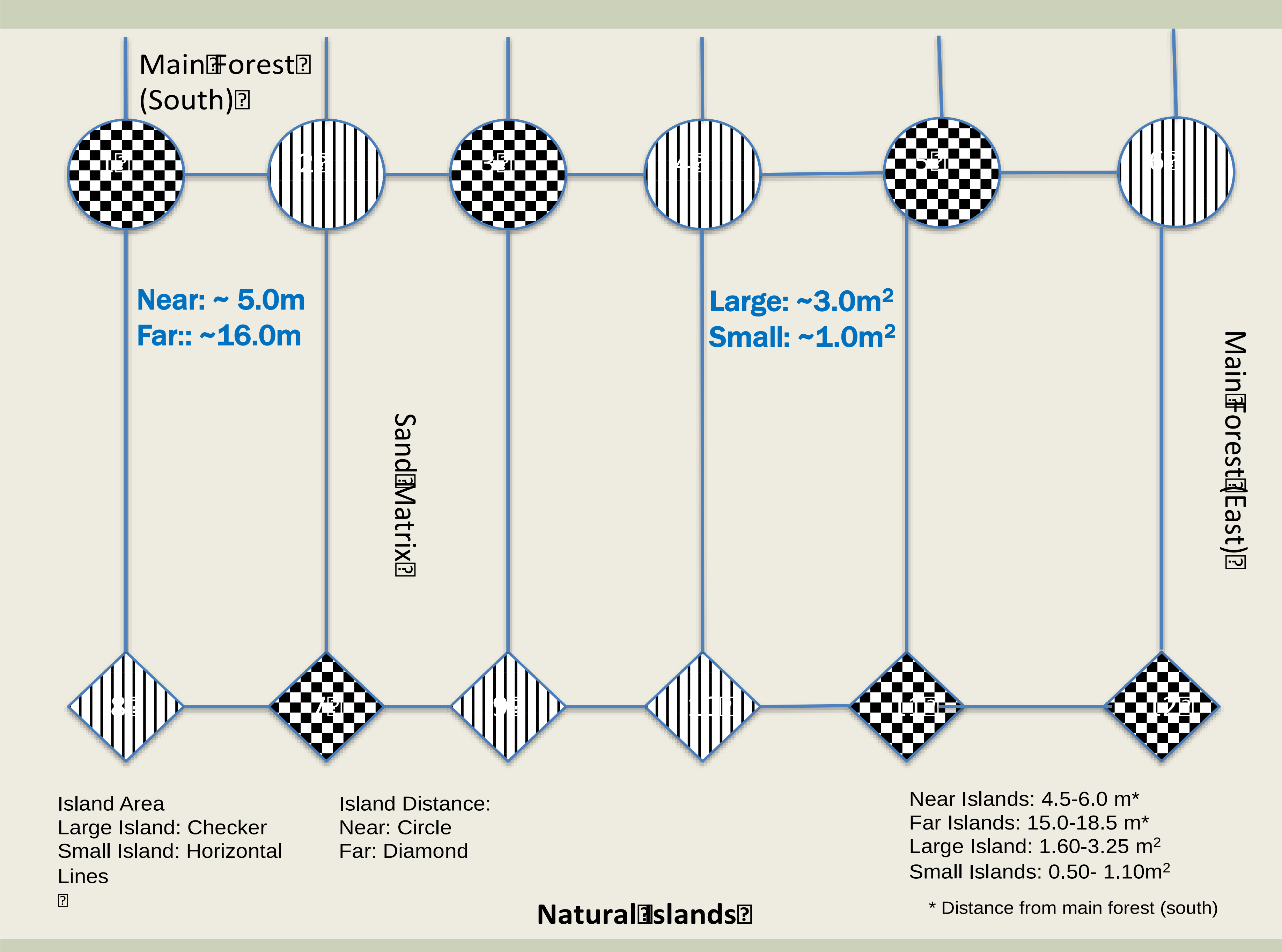
1
- Invert Soil Core in mesh sieve
- Organic layer first

2
- Soil fauna migrate downward
- Due to desiccating conditions

3
- Soil fauna collected in test tube

Time, patience and dedication are **necessary** to get through the taxonomy.

http://www.massey.ac.nz/~maminor/mites.html


Main Forest (South)
Near: ~ 5.0m
Far:: ~16.0m
Large: ~3.0m²
Small: ~1.0m²
Sand Matrix
Main Forest (East)
Island Area
Large Island: Checker
Small Island: Horizontal Lines
Island Distance:
Near: Circle
Far: Diamond
Near Islands: 4.5-6.0 m*
Far Islands: 15.0-18.5 m*
Large Island: 1.60-3.25 m²
Small Islands: 0.50- 1.10m²
* Distance from main forest (south)
Natural Islands

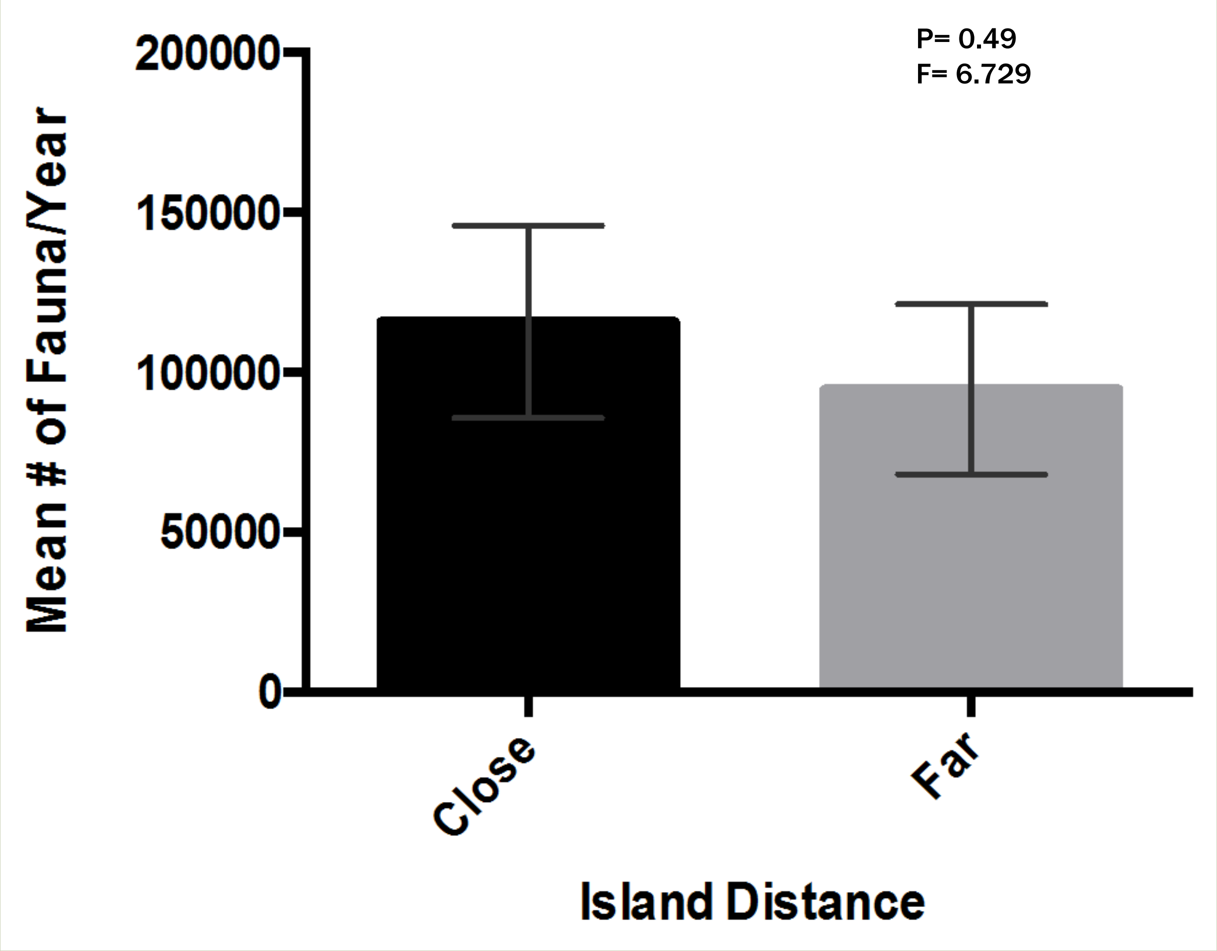
HYPOTHESES: NATURAL ISLANDS

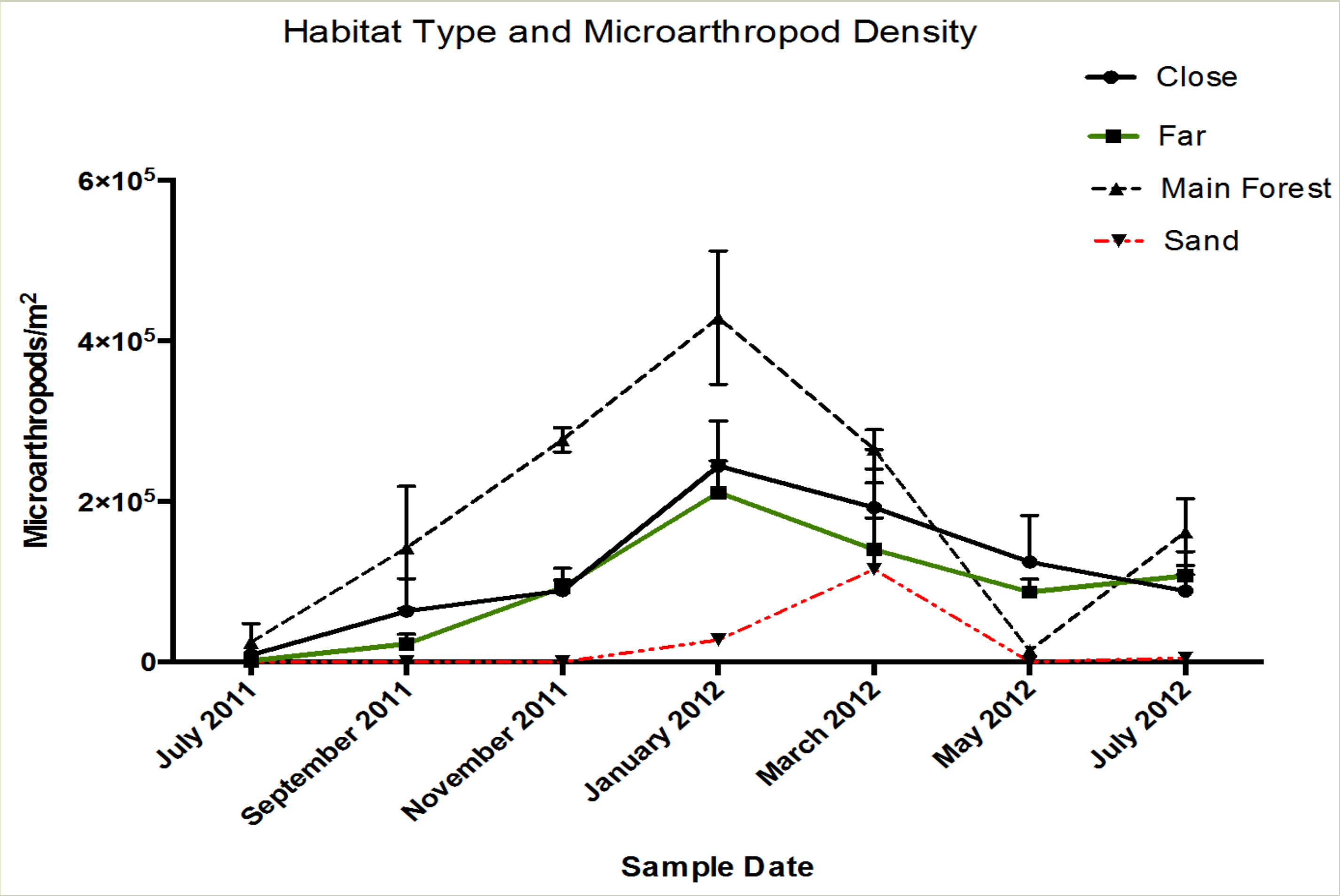
- H1: Islands that are closer to the main forest will have higher population densities of microarthropods than small islands.

- H2: Large islands will have higher population density and diversity.

- H3: The main forest will have the highest density and diversity of microarthropods.

DISTANCE AND MEAN DENSITY OF SOIL FAUNA ON NATURAL ISLANDS



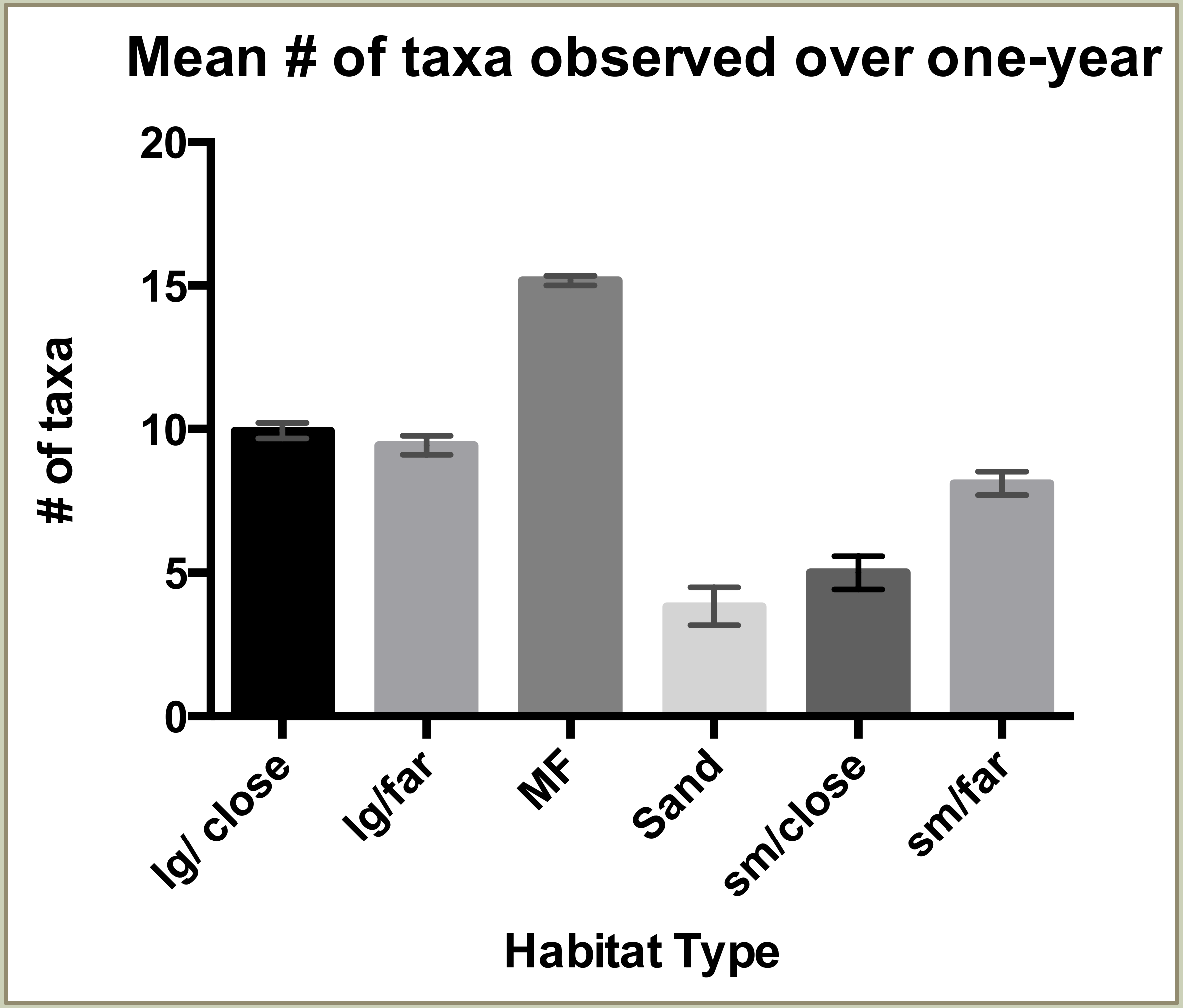


Including MF & Sand:
$P<0.0001^*$, $F= 14.68$

Excluding MF & Sand
$P= 0.28$, $F= 1.146$

Fauna Density & Sample Date:
$P<0.0001^*$, $F=8.03$

TWO-WAY ANOVA OF MEAN NUMBER OF TAXA OBSERVED PER HABITAT TYPE

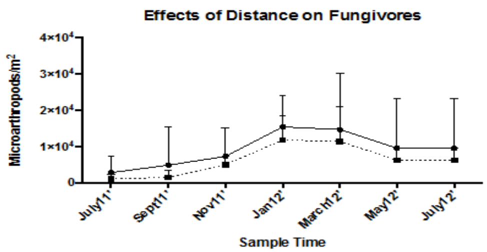


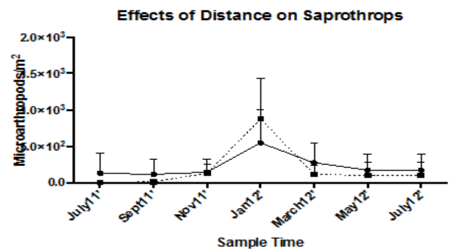
Interaction:1.96% p=0.88, F=0.66

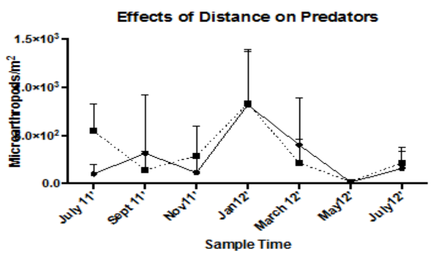
Date: 4.03%, p <0.0001, F= 6.76

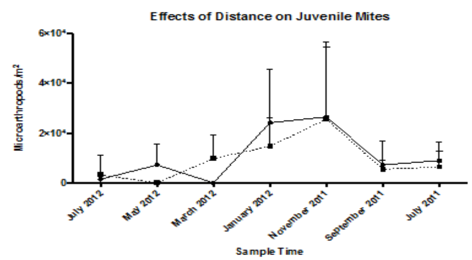
Habitat: 85.44%, p <0.0001, F=143.49

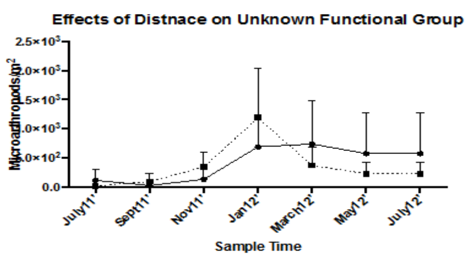
EFFECTS OF NATURAL ISLANDS DISTANCE ON FUNCTIONAL GROUPS WAS NOT DETECTED.

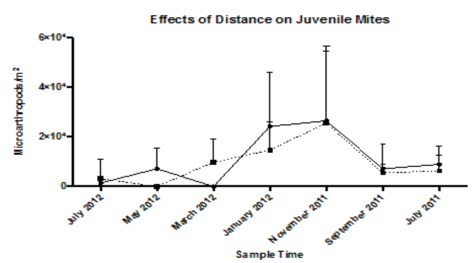


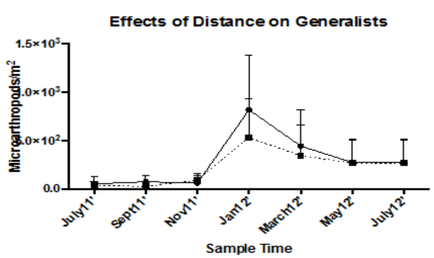




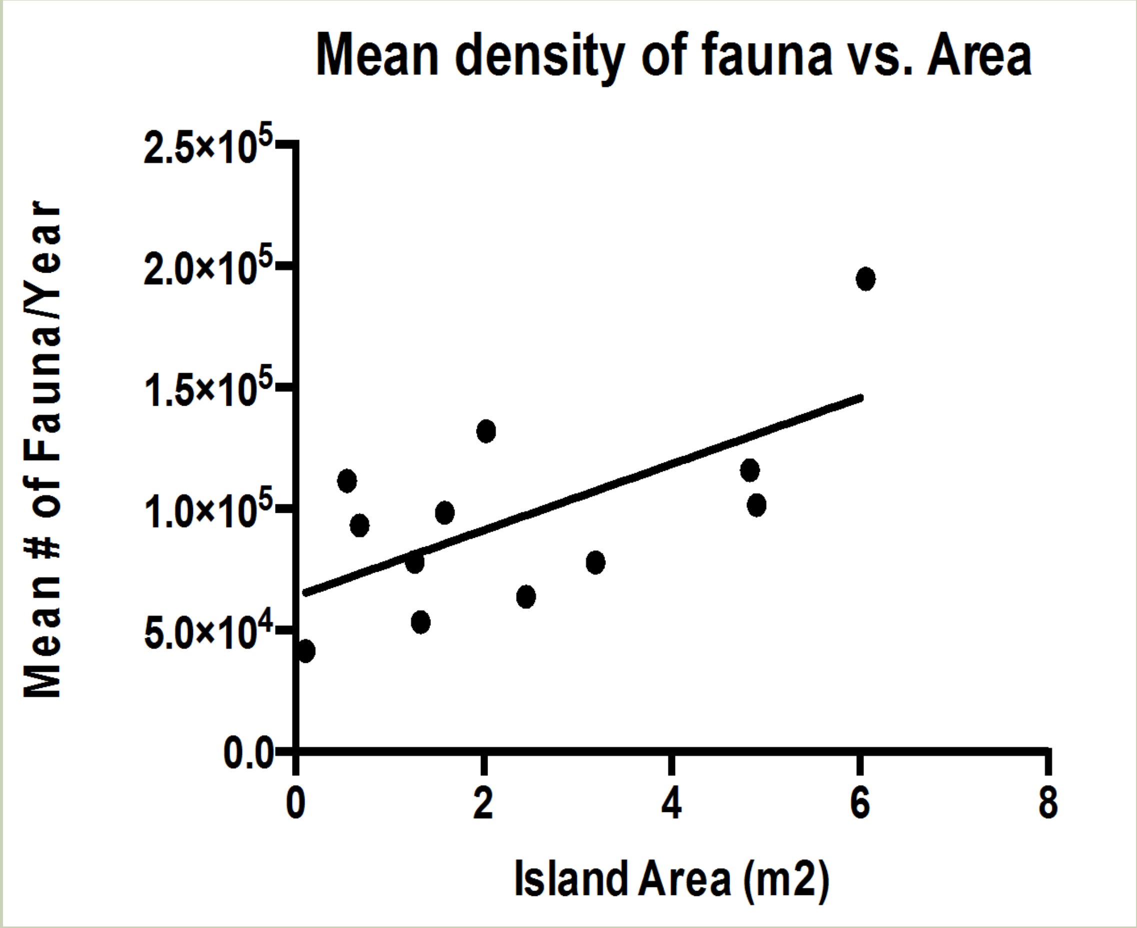






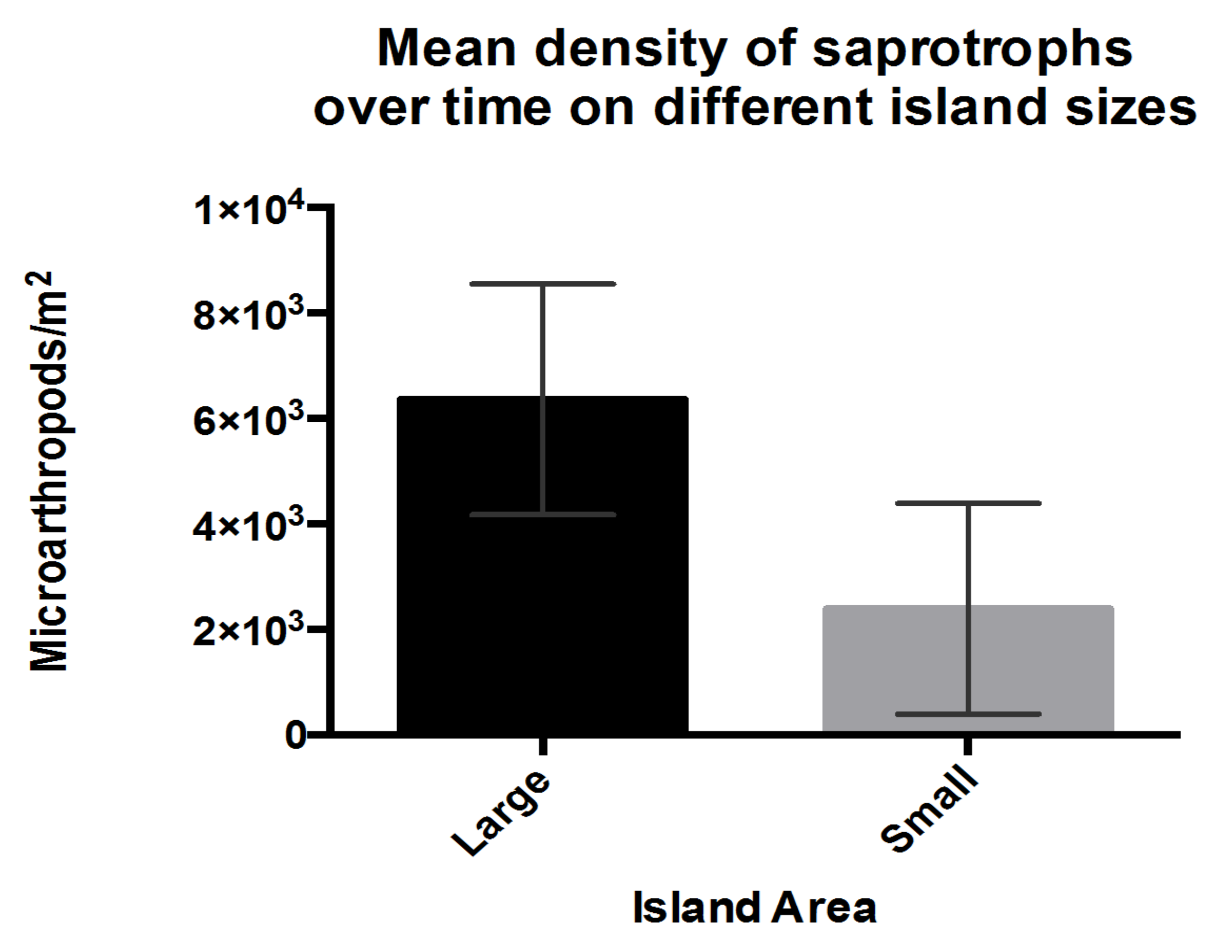


MEAN DENSITY OF FAUNA INCREASES WITH AREA ON NATURAL ISLANDS

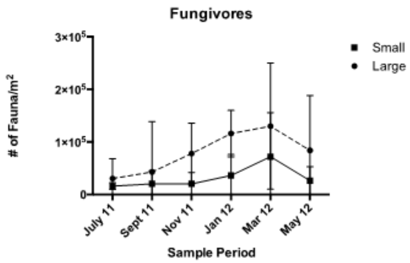


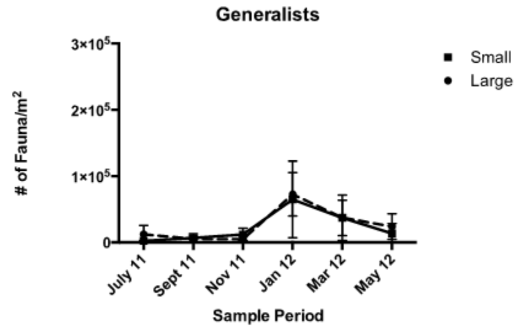
$R^2 = 0.42$*
P= 0.02*
F= 7.22*

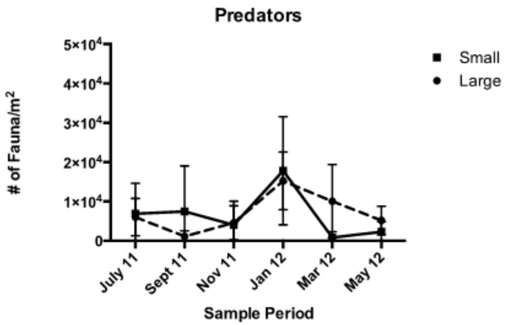
SAPROTROPHIC MITES & AREA

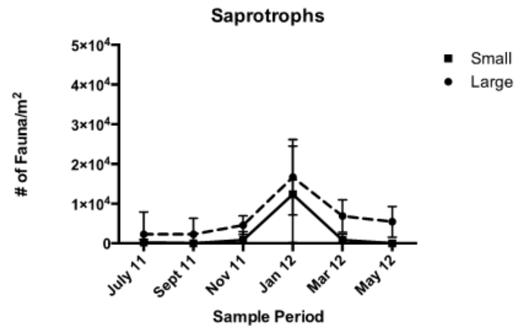


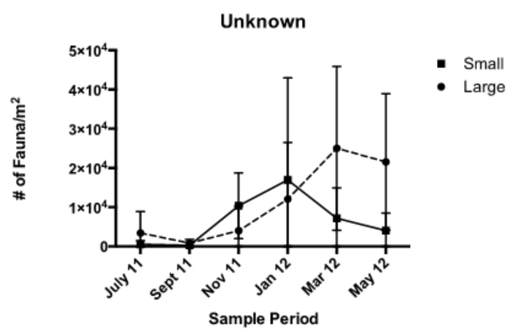
P= 0.002*
F= 10.35


Fungivores
3×10^5
2×10^5
1×10^5
0
# of Fauna/m^2
July 11
Sept 11
Nov 11
Jan 12
Mar 12
May 12
Sample Period
Small
Large


Generalists
3×10^5
2×10^5
1×10^5
0
# of Fauna/m^2
July 11
Sept 11
Nov 11
Jan 12
Mar 12
May 12
Sample Period
Small
Large


Predators
5×10^4
4×10^4
3×10^4
2×10^4
1×10^4
0
# of Fauna/m^2
July 11
Sept 11
Nov 11
Jan 12
Mar 12
May 12
Sample Period
Small
Large

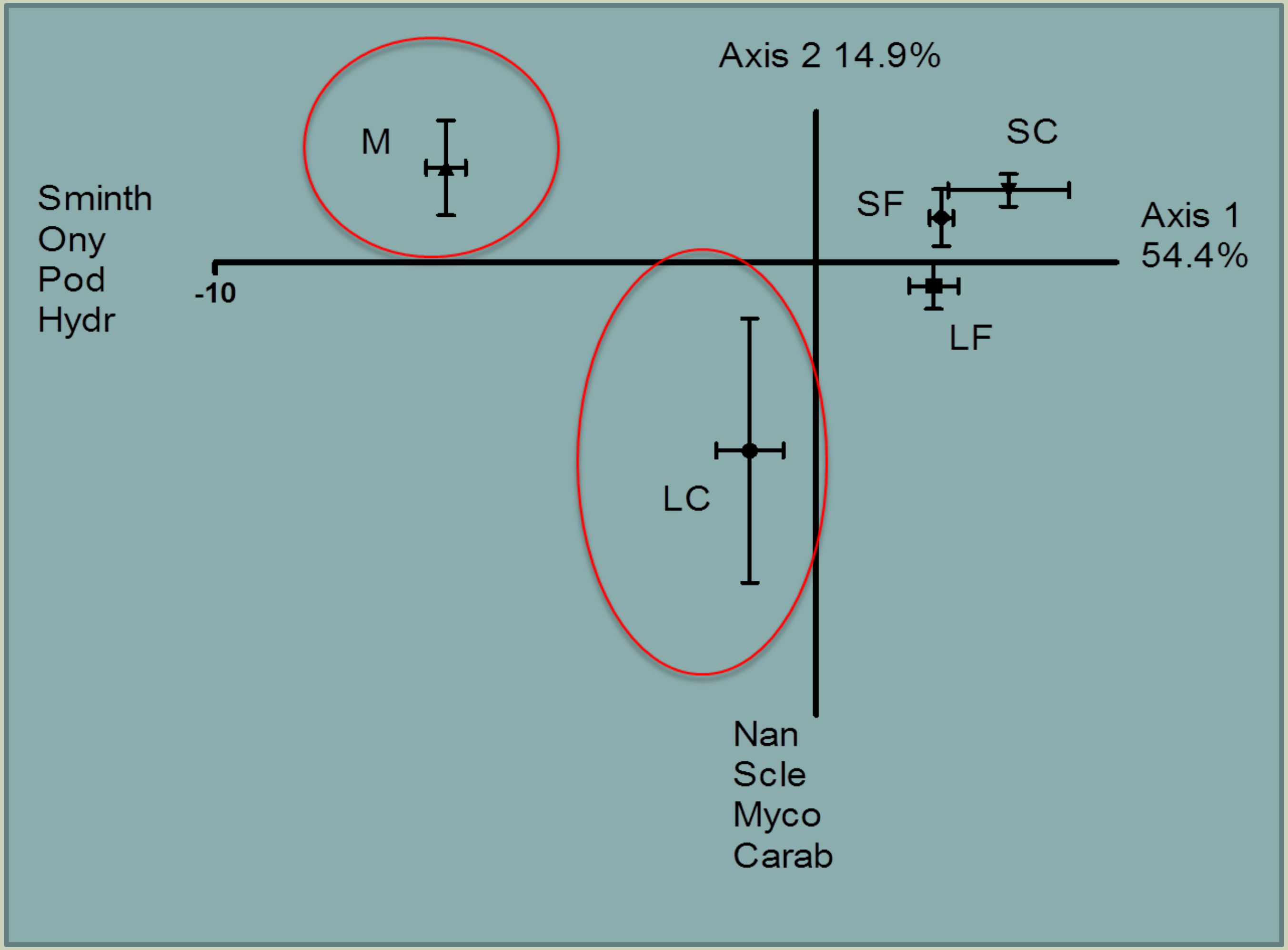

Saprotrophs
5×10^4
4×10^4
3×10^4
2×10^4
1×10^4
0
# of Fauna/m^2
July 11
Sept 11
Nov 11
Jan 12
Mar 12
May 12
Sample Period
Small
Large


Unknown
5×10^4
4×10^4
3×10^4
2×10^4
1×10^4
0
# of Fauna/m^2
July 11
Sept 11
Nov 11
Jan 12
Mar 12
May 12
Sample Period
Small
Large

ISLAND DISTANCE ON FUNCTIONAL GROUPS

- Microarthropods as a whole were positively related to island area. Densities of fauna appear to increase with area.
- Saprotrophs were the only guild that showed a significant difference in population density and island area.
- Predators, Fungivores, Generalists, and the unknown guild did not exhibit differences in their densities between island area.

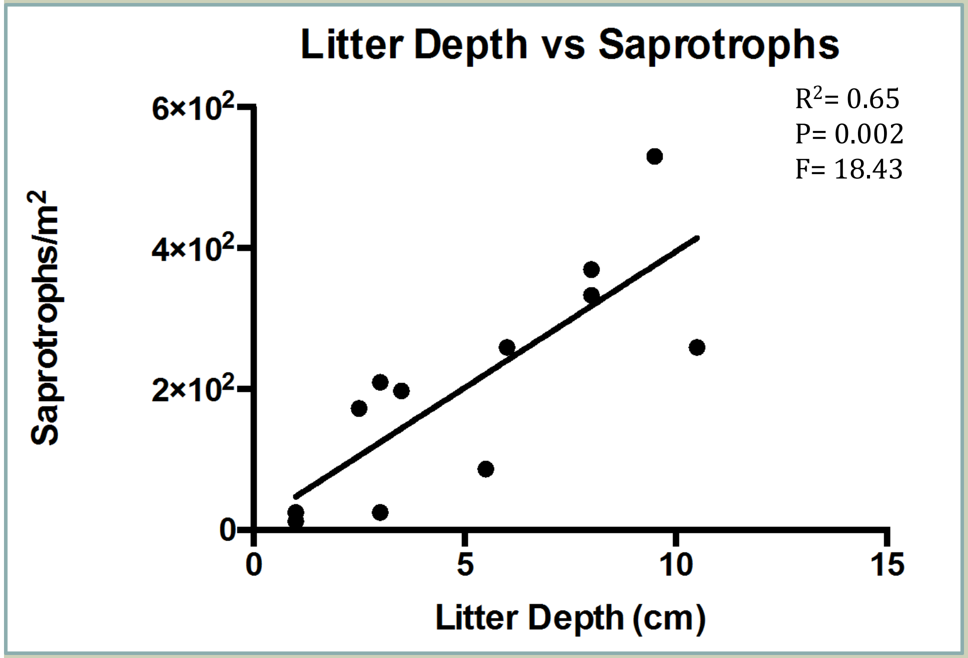
PCA ANALYSIS OF SOIL FAUNA COMMUNITIES

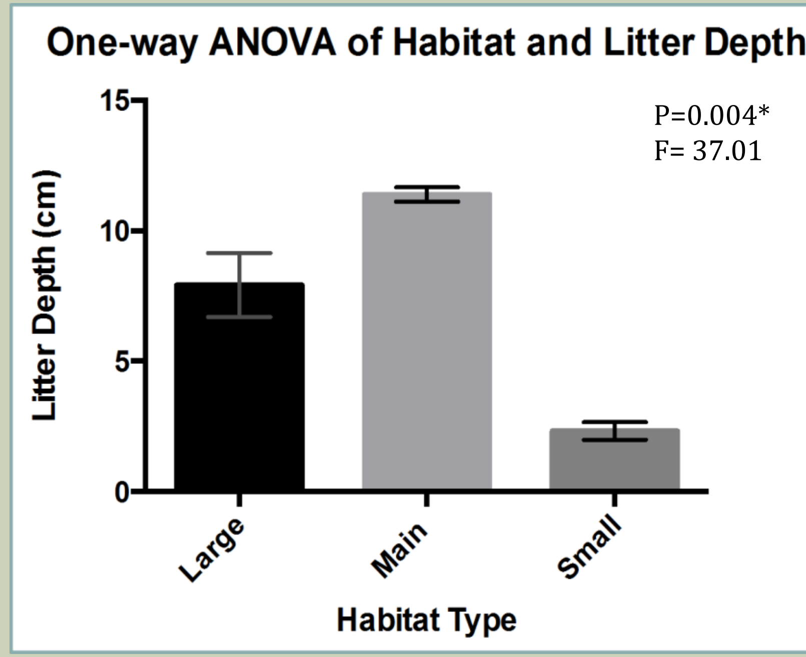


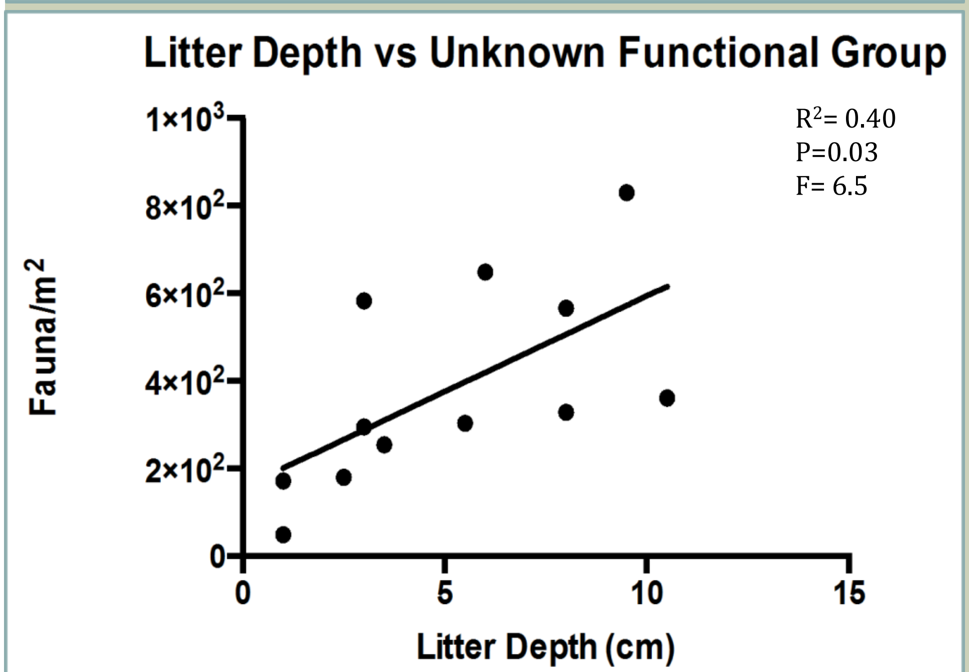
ENVIRONMENTAL PARAMETERS

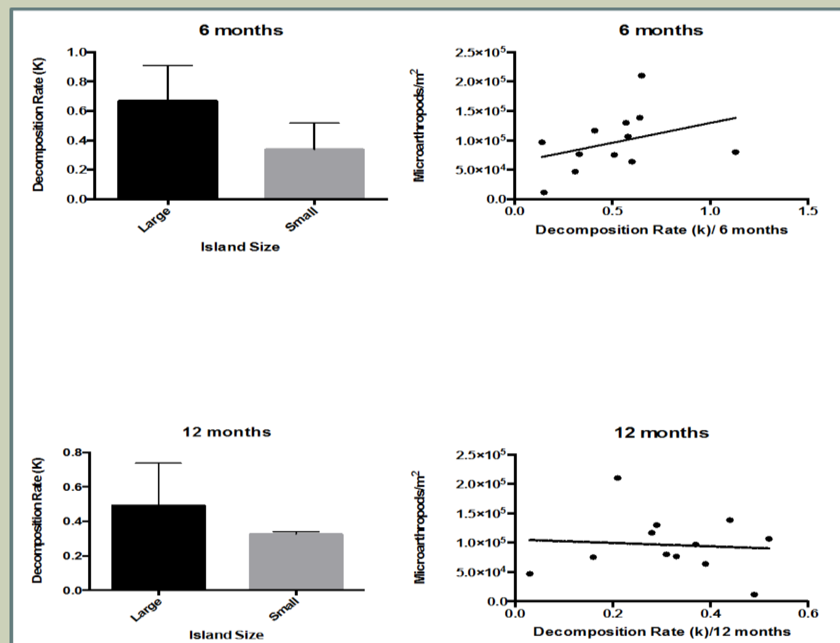
- Litter depth
- Soil moisture %
- Organic matter content
- Fungal hyphal length
- Soil respiration
- Decomposition rate

- Environmental parameters were analyzed by first testing whether there was a difference between habitat types
- Differences between habitat types lead to linear regression analysis of population density and the parameter being investigate.

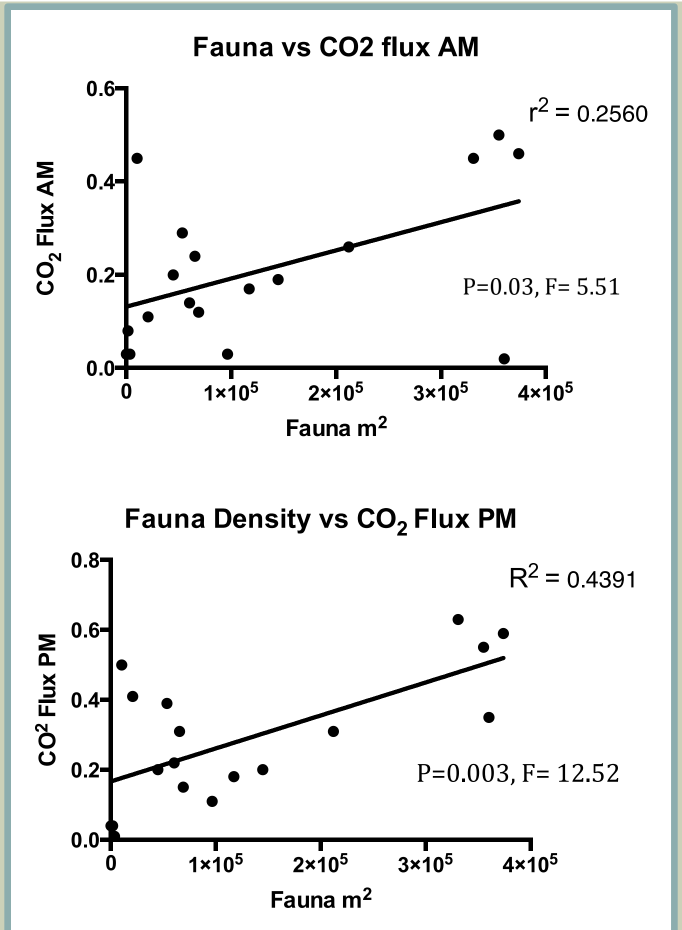

Litter Depth vs Saprotrophs
R^2= 0.65
P= 0.002
F= 18.43
Saprotrophs/m2
6×10²
4×10²
2×10²
0
0
5
10
15
Litter Depth (cm)


One-way ANOVA of Habitat and Litter Depth
P=0.004*
F= 37.01
Litter Depth (cm)
15
10
5
0
Large
Main
Small
Habitat Type


Litter Depth vs Unknown Functional Group
R^2= 0.40
P=0.03
F= 6.5
Fauna/m2
1×10³
8×10²
6×10²
4×10²
2×10²
0
0
5
10
15
Litter Depth (cm)


6 months
Decomposition Rate (K)
Large
Small
Island Size
6 months
Microarthropods/m²
Decomposition Rate (k)/ 6 months
12 months
Decomposition Rate (K)
Large
Small
Island Size
12 months
Microarthropods/m²
Decomposition Rate (k)/12 months

SOIL RESPIRATION AND FAUNA DENSITY



- Soil fauna density was positively related to CO_2 flux for both AM and PM measurements.
- This measurement does not discriminate between biotic organisms (roots, microbes, fauna)
- There was not a difference observed in rate of respiration between island sizes.

EXPERIMENTAL APPROACH TO ISLAND BIOGEOGRAPHY USING DEFAUNATED PATCHES

- Provide insight into the dispersal capabilities of microarthropods.
- Observe differences between taxa and their immigration success rate.
- Gain understanding as to which groups of soil fauna were likely the early colonizers of the natural islands.

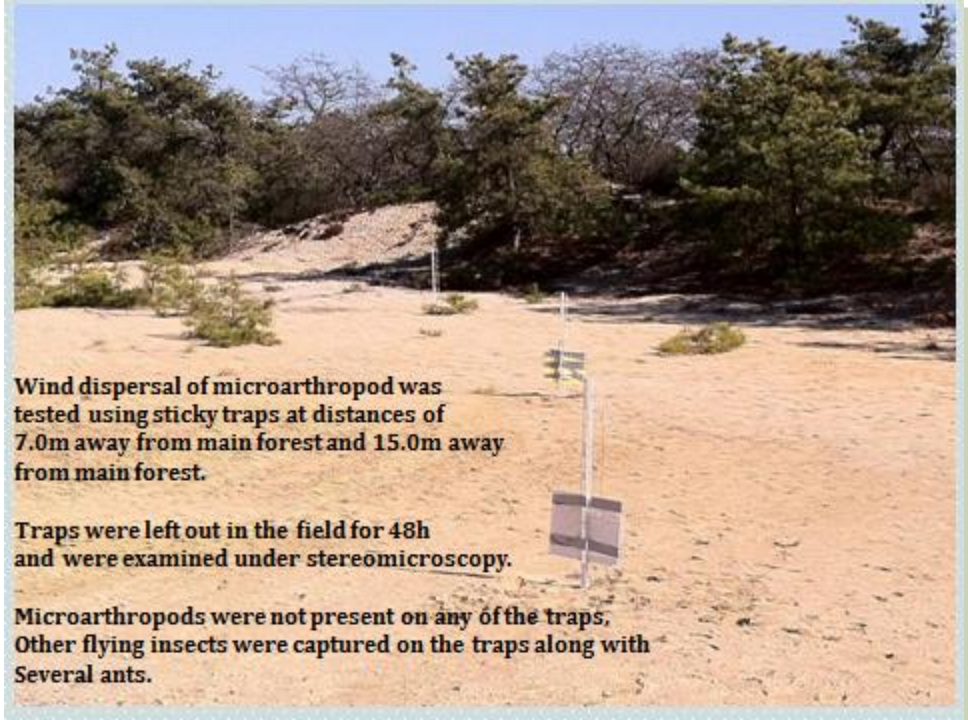
CONCLUSIONS FROM NATURAL ISLAND SURVEY

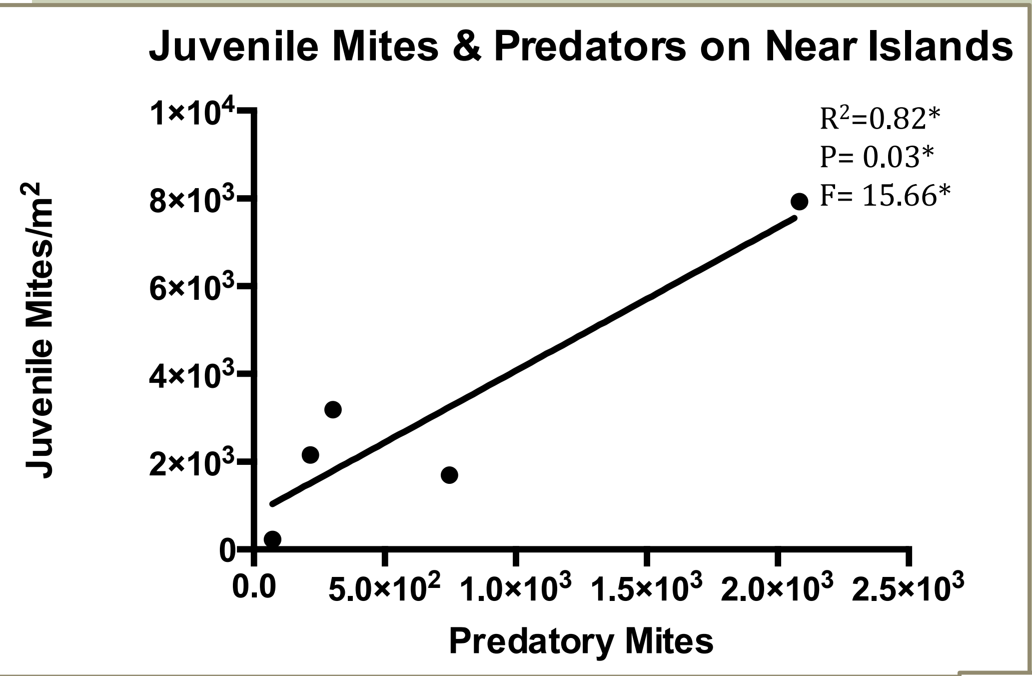
- Soil fauna densities were highly correlated with island area
- Saprotrophic mites & members of the unknown functional guild were positively correlated with litter depth
- Other environmental parameters measured did not appear to drive soil fauna densities (SOM, % water content, & FHL)
- Species diversity decreased from Main Forest > Large> Small> sand matrix
- Fauna collected from these islands had adequate time to colonize the islands and establish populations, however some species of collembolan were only observed in the main forest, possibly indicating limited dispersal capabilities across the sand matrix.
- The mainland and large & close islands communities appear to contain a different group of taxa compared to the other islands, which do not separate out when analyzed using PCA.

SOIL FAUNA IMMIGRATION AND DISPERSAL CAPABILITIES

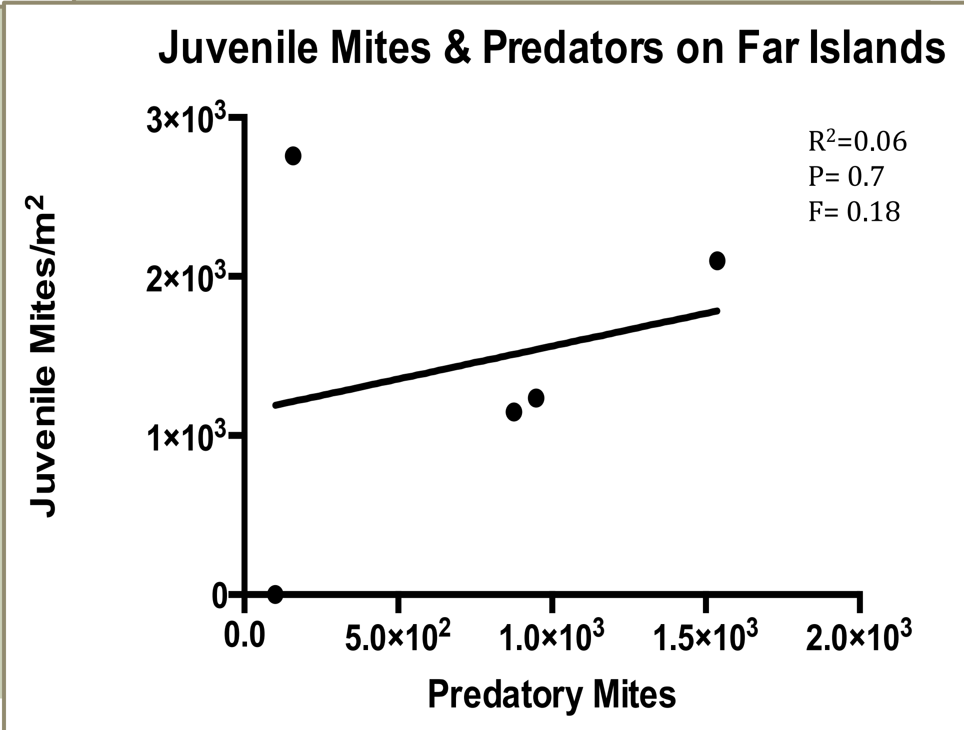
- Thirteen patches of soil were collected from the main forest and dried in an oven at 70C for 72 hours in an attempt to kill off any soil organisms present.
  - 6 close islands
  - 6 far islands
  - 1 patch as control (exclusion cage)
  - Soil fauna samples were collected bi-monthly from September 2011- May 2012.
  - Total of 5 sampling events

WIND DISPERSED OR PHYSICAL MOVEMENT TO THE PATCHES?

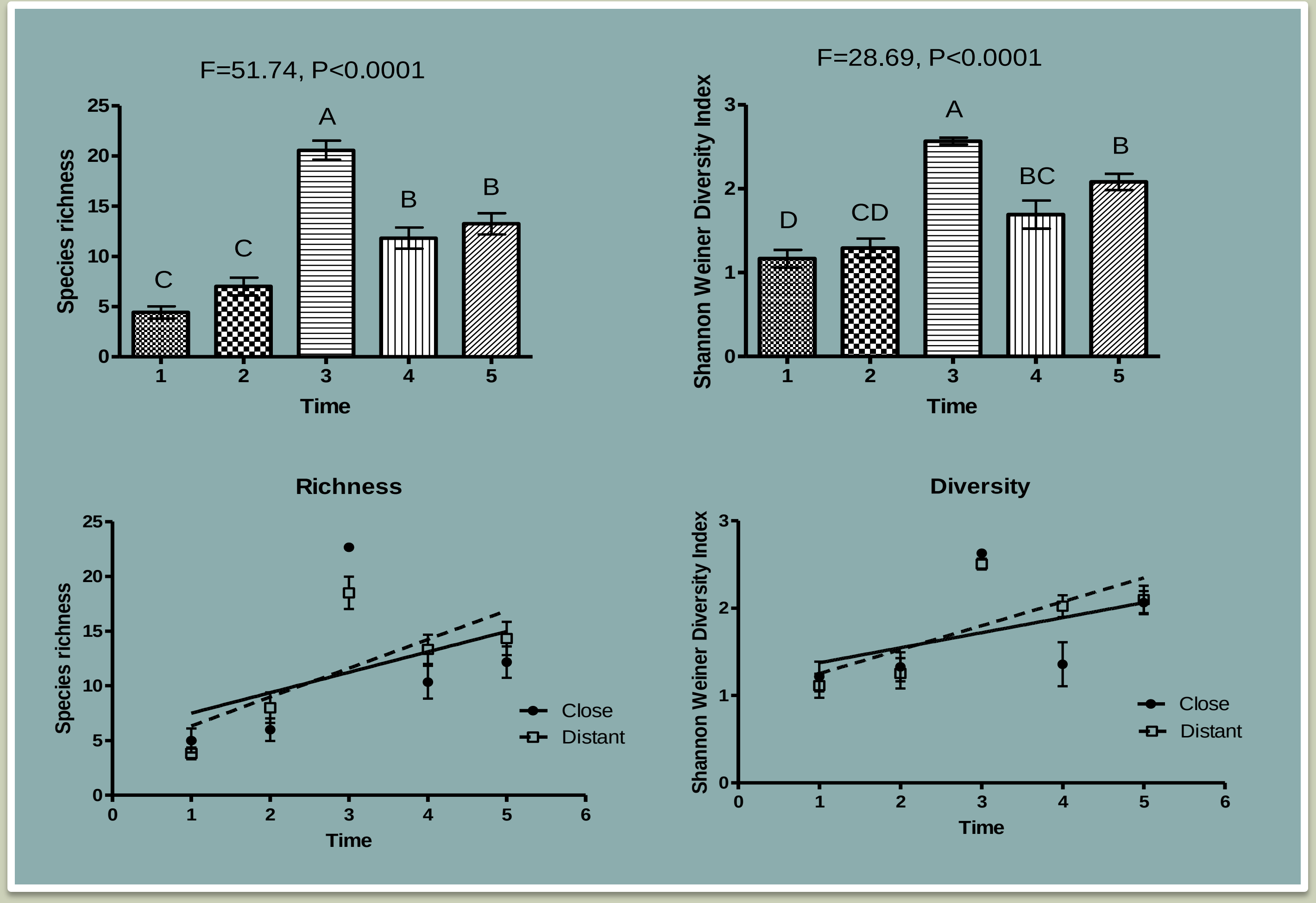


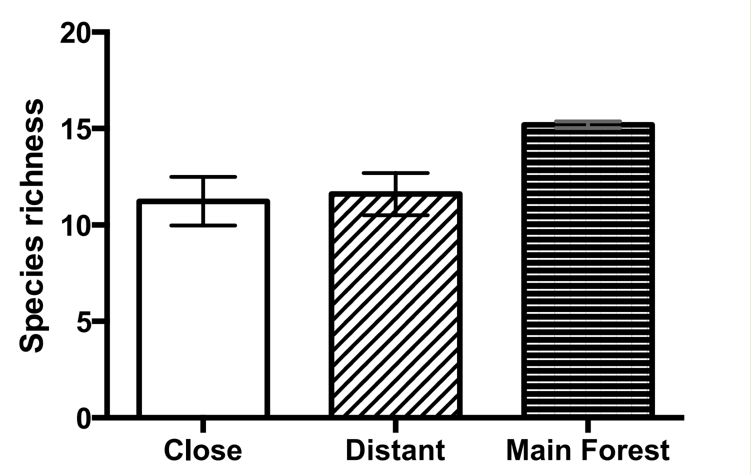


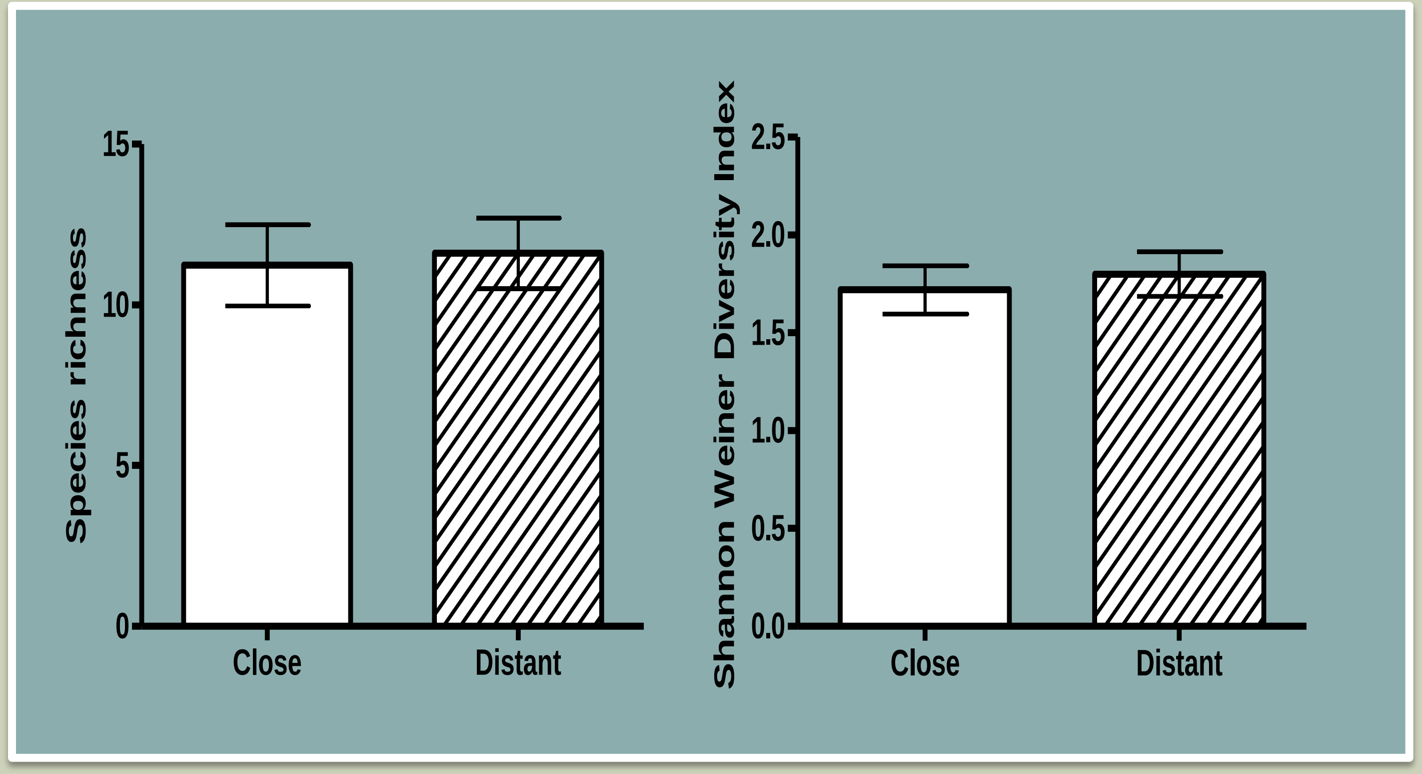
Mean density of juvenile mites was regressed
against the mean density of predatory mites.
each point represents the average # of fauna collected for each sample period.



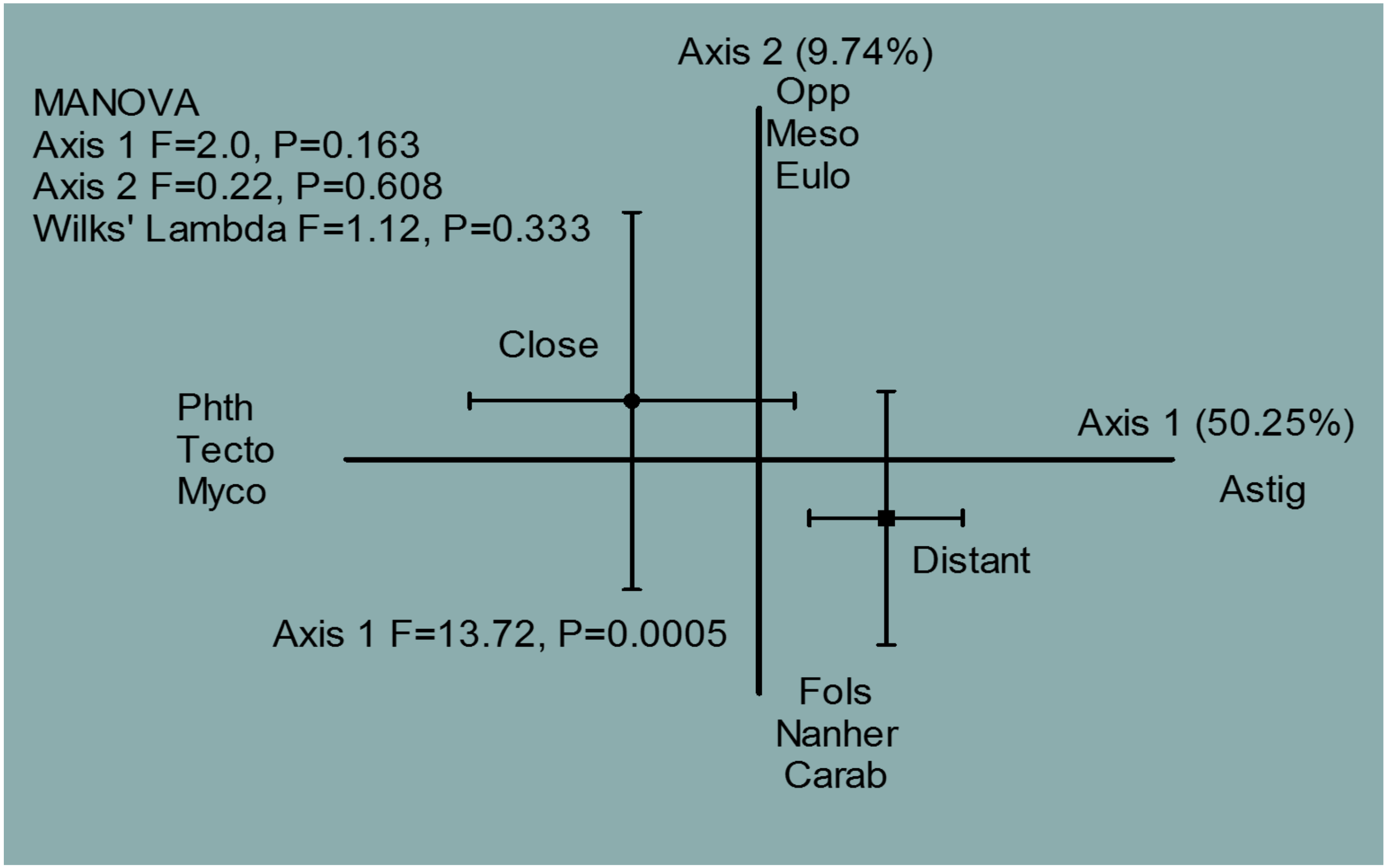
COMMUNITY ANALYSIS: STERILE PATCHES




Species richness
20
15
10
5
0
Close
Distant
Main Forest


Species richness
15
10
5
0
Close
Distant
Shannon Weiner Diversity Index
2.5
2.0
1.5
1.0
0.5
0.0
Close
Distant

ISLAND DISTANCE AND SOIL FAUNA COMMUNITY



CONCLUSIONS: STERILE ISLANDS

- Certain taxa of collembolan were found only in the main forest, indicating that they may have limited dispersal capabilities
- Diversity within each patch increased with time, indicating that soil fauna are actively moving throughout the fragmented habitat
- Questions still remain is this just passive dispersal or are they actively seeking out patches to serve as refuges as they move through a fragmented system?
  - Pheromone trails?

CAUSE FOR CONCERN?

- Recent Time article asks an important question: What if the world's soil runs out? (Time 12/14/2012)
- 40% of soils used in agriculture are degraded or seriously degraded
- Soils are being lost 10-40 times the rate at which it can be replenished. (We need our decomposers…healthy i.e. SOIL FAUNA)
- Soils are not part of the *"sexy sciences"* therefore little attention has been drawn to the massive extinction taking place right below our feet!
- Soils take thousands of years to form, yet we can destroy them in a matter of decades.




QUESTIONS/ DISCUSSION