

Soil Biodiversity

Students will...

- Understand how various soil types affect biodiversity.
- Learn the role that soil has in ecosystem biodiversity
- Be able to identify the various soil types
- Understand why different habitats and areas of the province contain different types of soils.

Introduction to Soil

Soils biotic and abiotic characteristics allow for soil to be used for many functions:

- habitat for invertebrates, microbes, mammals, amphibians and reptiles;
- act as an anchor for hundreds of thousands of plant species;
- provide nutrients to support vegetative growth; and,
- create a foundation for the construction of buildings.

For these reasons, it is important to study and understand the significance of soils role in promoting biodiversity.

Soil biodiversity is defined as the variety of life found in soil, including numerous species of invertebrates and microorganisms, soil flora, plant roots, mammals, birds, reptiles and amphibians. Soil communities are among the most species-rich areas in terrestrial ecosystems. Most of the organisms inhabiting soil ecosystems are found within the top 10 cm of the soil profile. However, there are many factors that influence the diversity of organisms within soil ecosystems.

Soil structure and texture both have impacts on the biodiversity within the soil and the diversity of plants and animals living on the soil. Soil texture is defined by the proportion of sand, silt and clay particles bound together by organic matter. The amount of organic matter found in soil has a large impact on the surrounding biodiversity as it impacts soil fertility, soil structure, workability and water holding capacity. These factors influence the volume and species of plants that are capable of growing in the soil, impacting the wildlife in the surrounding area. There are various classifications for soil texture, for example: loamy sands are soils with a high content of fine sand and silt. To determine soil structure, scientists use the soil texture triangle (Figure 34). The percentage of clay, sand and silt must be known and the intersection of the three lines coming from the percentage indicates the soil type.

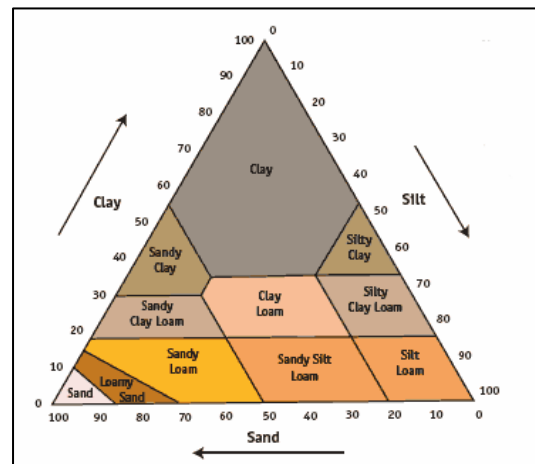


Figure 34: Soil texture triangle
(The Scottish Government, 2005)

Soil structure is the arrangement of particles in blocks or aggregates within the soil. Soil structure is important because it affects the stability of soil and its resistance to degradation under pressure. Structure is strongly influenced by texture, organic matter, compaction and biological activities. Much like soil texture, soil structure can also impact the organisms living within the soil. Good structure generally means the presence of large pores between particles. Soils with good structure increase water holding capacity, promote root growth, maintain aeration and drainage provide a better habitat for organisms and reduce erosion risk. All of these factors contribute to the biodiversity within and on top of soil. (See the Chapter 3: The Physical Nature of Soils in the Envirothon Soil Module for more information on soil texture and structure).

Soil Formation and Variability

The formation of soil from rock can take thousands of years, and for this reason, soil types vary throughout Ontario. There are several main factors that contribute to the formation of soil. Understanding the soil forming factors helps us better understand why soils differ from place to place and how they contribute to different habitat types and support different forms of life.

Soil forming factors:

- Parent material: differences in soil are first evident in the various forms of parent material, as the physical and chemical properties of the parent rock are reflected in the characteristics of soil.
- Climate: climate provides the energy that drives physical, chemical and biological reactions on the parent material. The most significant climatic factors are temperature and moisture.
- Presence of soil organisms: organisms within the soil are responsible for aiding the process of organic matter accumulation and conversion of organic nutrients into mineral matter that can be taken up by plants (discussed in further detail below).
- Relief: relief, the configuration of land in terms of its altitude and slope degree, can change the microclimate and drainage ability of soil and therefore also contributes to soil formation.

Due to the variations in soil formation, all regions in Ontario contain specific soil profiles (Figure 35). These differences in soil characteristics result in differences in habitat type and biodiversity. More information can be found in Chapter 2: The Process of Soil Formation in the soils module. Appendix D outlines the soil types of Canada, their identifying characteristics and where they are commonly found.

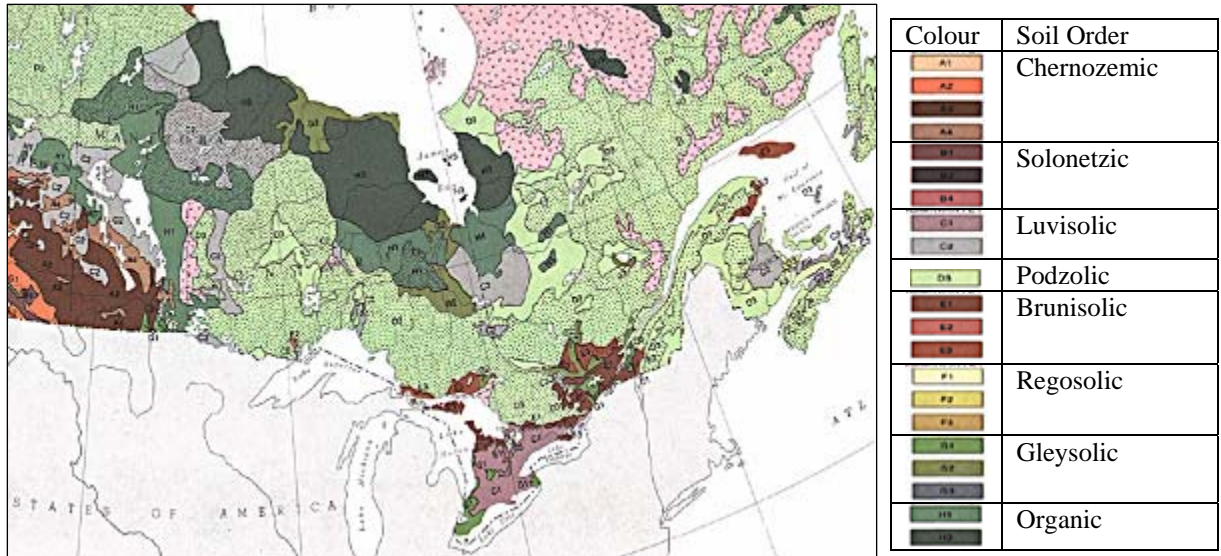


Figure 35: Soil Profiles of Ontario. (The Atlas of Canada, 2005).

Biodiversity within Soil

Soil ecosystems are one of the most diverse ecosystems on our planet. However, very few studies have examined the vast diversity of organisms living within the soil. Many organisms make up the diversity of life within soil ecosystems, including invertebrates and microorganisms, soil flora, plant roots, mammals, birds, reptiles and amphibians. The invertebrates and microorganisms make the majority of the biomass in soil communities. These include bacteria, fungi, protozoa, nematodes, mites, collembola, oligochaetes (earthworms), myriapods (millipedes and centipedes), mollusks and insects (ants, termites, beetles). Figure 36 is an example of the feeding relationship between organisms in a soil ecosystem.

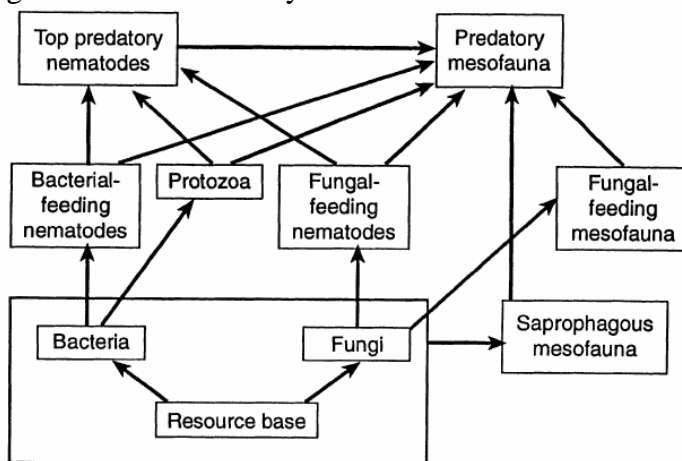


Figure 36: Feeding interactions between the classes of organisms found within a soil community. Arrows show direction of energy flow. (Wardle et al, 1998)

SOIL FACT

Soil biodiversity is extremely important for successful crop production. However, poor agricultural practices can degrade soil quality and promote the loss of topsoil. Agriculture has also resulted in local reductions and extirpations of fauna associated with these lands.

Soil ecosystems with higher levels of biodiversity result in more productive, sustainable communities. These communities are also more resistant to changes in surrounding biotic and abiotic conditions. Increased biodiversity leads to increased redundancy in an ecosystem. High redundancy allows one species to substitute for another, such that functions are continuously achieved, even with the loss of one species. With increased redundancy, soil ecosystems also have higher resistance to perturbations. More diverse systems are also more resilient following perturbations. Resilient ecosystems can withstand shocks and rebuild themselves when necessary. This is beneficial in changing environments.

The vast diversity of species found in soil communities impact soil quality and functioning by providing essential services to the abiotic components of the soil. Table 3 outlines the functions performed by soil biota and their importance to ecosystem functioning. Due to the extensive functions of soil biota, declining soil biodiversity and its consequences on soil food web interaction processes will have dramatic negative impacts on ecosystem processes, ecosystem stability, community composition and community stability.

Table 3: Soil biota functions that can be used to evaluate the links between diversity and ecosystem function.

Function	Comments
Degradation of organic matter	The most obvious function carried out by soil biota. Up to 80% of the organic material fixed by primary producer's flows to the detrital food chain.
Cycling of nutrients	As organic matter is processed, nutrients are released into the environment and become available for recycling back to primary producers.
Sequestration of carbon	Organic residues from decomposition become part of the stable structural carbon pools of terrestrial ecosystems.
Production and consumption of trace gases	As soil biota degrade organic material, recycle its nutrients, and sequester its carbon, they also carry out other functions that are important. Soil microbial activity leads to the production and consumption of a variety of trace gases (carbon dioxide, nitrous oxide, methane, carbon monoxide and sulfur gases), many of which are important greenhouse gases.
Degradation of water, air and soil pollutants	Soil and sediment biota processes (degrade, produce, alter) a variety of water, soil and air pollutants of anthropogenic origin, including pesticides and industrial compounds.
Development and maintenance of physical structure	Soil biota help to produce and maintain the physical structure of terrestrial ecosystems. Organisms are critical agents in soil formation. This role is expressed directly via the burrowing and tunneling activities of fauna and their production of sticky compounds, and indirectly via the production of structural organic matter.

There are several factors that can contribute to the biodiversity within soil. These factors include soil texture, soil structure, abiotic conditions (sunlight, rainfall, wind) and interactions with other organisms. As the knowledge of soil biology increases, the threats to soil biodiversity also become evident. Indirect effects on biodiversity include structural decay, erosion and organic matter decline. These factors influence habitat for organisms within the soil and contribute to biodiversity decline. Direct impacts on biodiversity include contamination of soils through salinization and pollutants. The impact of global change on biodiversity within soil ecosystems is not yet known, however, communities with high resiliency will not be impacted as greatly as communities with low resiliency. Climate change will have impacts on local communities as there is a strong connection between soil formation, soil structure and climate.

SOIL FACT

Earthworms have been known to have lived for as long as six years, but the average lifespan of an earthworm is about 20 months. This soil organism does not have lungs but breathe through its skin. Therefore any soil contamination will have dramatic impacts on local earthworm populations.

Soils Role in Terrestrial Biodiversity

Not only do soil ecosystems contain a vast number of invertebrates and microorganisms, they also impact the terrestrial biodiversity of plants and wildlife. As mentioned above, soil structure influences the water storing capacity, available nutrients and the types of microorganisms present in the soil. All of these factors directly impact the vegetation communities that are capable of growing in the given conditions.

The presence of certain soil organisms directly influences the ability of some plant species to grow due to direct relationships between microorganisms and nutrient availability. For example, the presence of nitrogen fixing bacteria is crucial for the survival of all legume species. Rhizobia, a nitrogen fixing bacteria, chemically convert nitrogen from the air to make it available for uptake by the vegetation. This type of relationship, in which one organism lives on another and is required for the survival of one of the organisms, is referred to as an obligate symbiotic relationship.

As soil structure and biodiversity influences vegetative growth, it also impacts the diversity of wildlife that can be supported in an area. Many animals are insectivores and rely on invertebrates found within the soil for survival. Other animals are herbivores and depend on vegetation for their main food source. Soil structure has the ability to directly influence both the vegetation and wildlife species that are capable of surviving in an area. Figure 37 shows the interactions between soil organisms, vegetation communities and terrestrial wildlife.

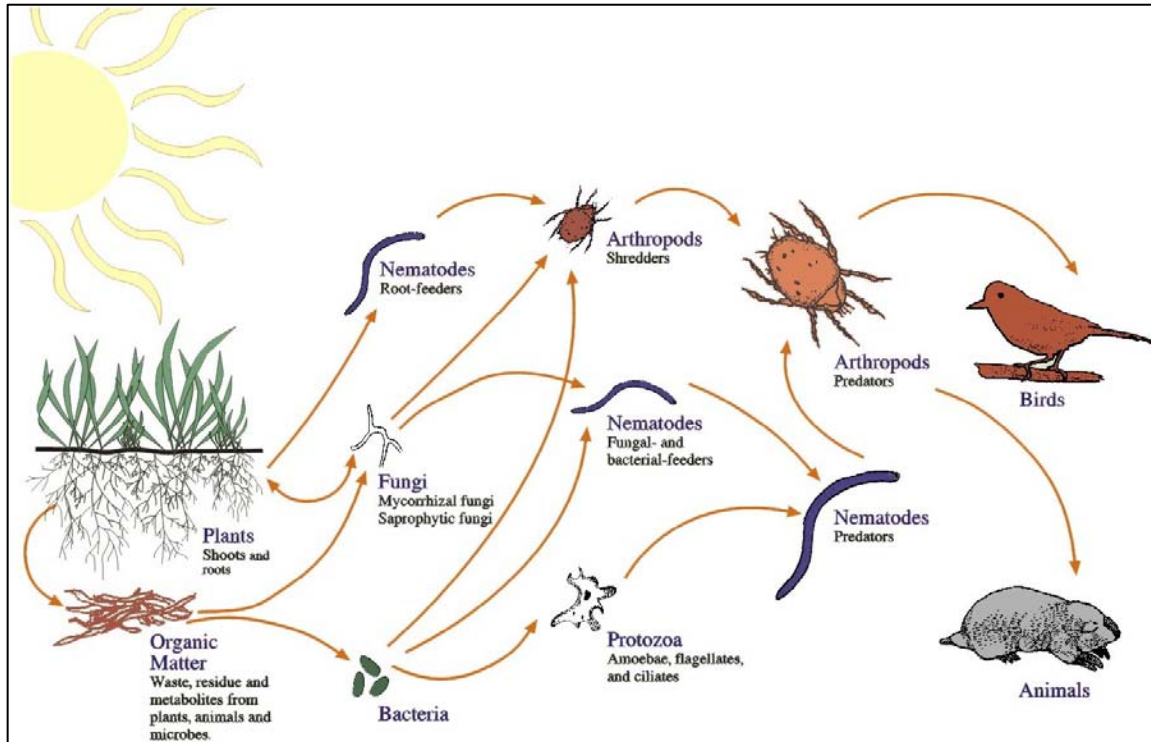


Figure 37: Relationships between soil food web, plants, organic matter, and birds and mammals. (Tugel et al, 1999).

Soil ecosystems also act as habitat for many fossorial species. Mammals such as voles, mice and groundhogs use soil to create burrows for protection of predators and areas to store food. Amphibians, such as frogs and salamanders use soil as an area to spend their winter hibernation. The snow on top of the soil provides an insulating layer resulting in warmer soil temperatures compared to air temperature. However, with changes in local climate, there is an increase in the fluxes of weather and temperature resulting in negative impacts on these amphibian populations. Soil is also used as nesting sites for some species, such as turtles which travel outside of water in search of sandy soils (Figure 38). The texture of sandy soils allows turtles to dig large holes to lay their eggs. The soil acts as an incubator until the eggs hatch.



Figure 38: Snapping turtle laying eggs in soil (Jung, 2003)

Soil Biodiversity in a Changing World

Changes in climate have profound impacts on soil structure. As discussed above, soil structure impacts soil biodiversity. Therefore changes in global climate will result in changes in soil biodiversity. Fluctuations in temperature, moisture and land use changes

will directly impact soil organisms. Increased carbon dioxide in the atmosphere will indirectly influence soil organisms through changes in plant communities. Not only will these changes impact the organisms living within the soil, but it will also change the species richness and composition of the organisms that rely on the soil organisms for survival.

Global change will bring variations in organic matter input, increases in atmospheric carbon dioxide, changes in microclimate, land use changes and changes in below ground processes. These changes in biotic and abiotic variables will impact soil structure and therefore soil biodiversity (Figure 39). As mentioned above, these changes will also impact the diversity of surrounding plant and animal communities. Changes in soil structure will have cascading effects on the surrounding communities. For example, if changes in climate result in the loss of one species of nitrogen fixing bacteria, the loss of a plant species that rely on the presence of that bacterium may result. This can then result in the loss of wildlife species that rely on the plant species if their adaptive capacity is limited.

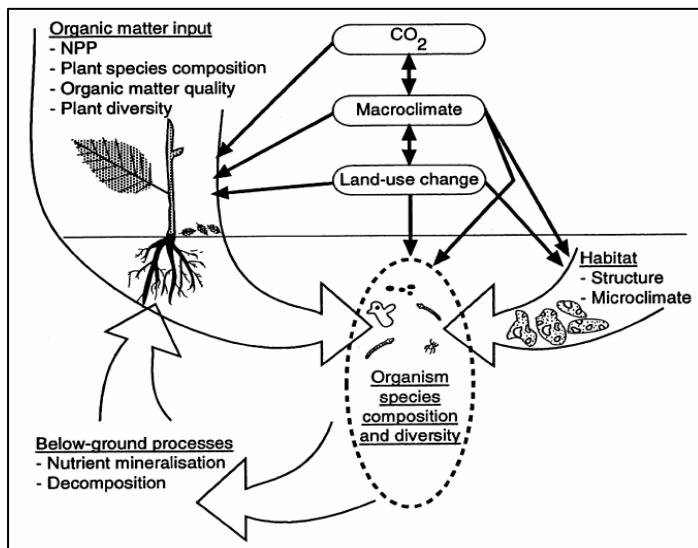


Figure 39: Diagram of relationships of soil biota and plants with global change (Wardle et al, 1998)

Similarly, global changes can have impacts on vegetation communities that can ultimately influence soil biodiversity. It has been predicted that global climate changes will result in diminished quality of organic matter input and shifts in vegetation composition through changes in carbon dioxide levels. Changes in the quality of organic matter input will influence organisms that are active in decomposition of organic matter, such as fungi. Changes in vegetation boundaries will result in some plant species inhabiting areas that were previously inhabitable. Unlike plant species, the limited capacity of soil microorganisms to migrate could result in changes in the functional composition of soil communities. Shifts in plant communities could strongly influence processes such as decomposition and nutrient mineralization through regulation of soil organisms. To fully understand the impacts of a changing environment on soil biodiversity more research must be focused on the impacts of changing conditions on soil communities.

Case Study: Biodiversity in Soil: The Ground Beetle

To demonstrate the vast diversity of invertebrates found within soil ecosystems, this case study will examine the presence of ground beetles (Family: Carabidae) in Ontario. In Ontario, there have been reports of up to 3800 species of beetles. Ground beetles account for nearly 15 percent of all beetles in Ontario, with approximately 500 species. This family of beetles lives on the soil surface, occupies every habitat (forest, meadow, mountain, bog and sand dune) and varies in size between 1.5 and 30 mm.

Ground beetles are mostly opportunistic predators, eating various forms of soil biota, both on and below the soil surface. In agricultural systems, the presence of ground beetles helps to reduce the number of other, possibly destructive, invertebrates. For this reason, these beetles have been used as a form of pest control. Studies have shown that high ground beetle populations indicate a healthy ecosystem.

One subfamily of the ground beetle, the tiger beetles (subfamily: Cicindelinae) has 14 species found within Ontario. Ten of those 14 species are relatively widespread and common throughout Ontario. However, the remaining four species are rare and their occurrences have been tracked by the Natural Heritage Information Centre.

The Beach Dune Tiger Beetle (*Cicindela hirticollis*) is a ground beetle species that inhabits in sandy beach and dune areas (Figure 41). It is one of the most widespread beetle species occurring across Canada, the United States and Mexico. Historically, this species was reported to be common in Ontario; however, there have been relatively few observations of this species along its proposed habitat, along the sandy shores of the Great Lakes and large rivers. Recent searches for this species along these habitats have proven unsuccessful indicating that this species may have disappeared from most previously documented sites. The cause of the decline is not yet known, however increased use of these areas by humans may have contributed.

The ground beetle is just one example of an invertebrate that lives in close association with the soil. Soil texture and structure impacts the fauna of ground beetles as well as the forms of microorganisms that will be found in a community. Ground beetles rely on other invertebrates within the soil as a food source and they themselves are a food source for insectivorous mammals. The eggs of ground beetles are laid in the soil and the larva lives in the soil until its adult stage. Therefore the soil plays an important role in the life of a ground beetle and small changes in soil structure or type could have large impacts on the survival of ground beetles.



Figure 40: Image of a Beach Dune Tiger Beetle (Nova Scotia Museum of Natural History, 2001)

Case Study: Bioremediation – The Use of Soil Biota in Environmentally-friendly Treatments for the Decontamination of Soils

As discussed in this section, soil contains a vast diversity of microorganisms, some of which function to ‘clean’ the surrounding soil. Bioremediation is the process that uses [microorganisms](#), [fungi](#), [green plants](#) or their [enzymes](#) to return an [environment](#) altered by [contaminants](#) to its original condition. The goal of bioremediation efforts is to “reduce the potential toxicity of a chemical contaminant in the soil by using microorganisms to transform, metabolize, remove or immobilize toxicants” (UNEP 2001). Bacteria and fungi found within soil are nature’s recyclers. They have a capability to transform natural and synthetic chemicals into sources of energy and raw materials for their own benefit.

Soil bioremediation is most commonly used at sites in which pollutants have been released or spilled. The rate at which microbial communities adapt their metabolism to toxic compounds is crucial in bioremediation.

In Ontario, uranium mining has contributed a great deal to water and soil contamination. Soil properties that affect uranium mobility and uptake by biota include aeration, carbonate content and cation exchange capacity. Acidic soils with low absorptive potential, alkaline soils with carbonate minerals and the presence of citric acid increase mobility and plant accumulation of uranium.

Microorganisms can degrade soluble organo-uranium compounds in soil using carbon and energy. Scientists have recently discovered a bacterium that can sequester or reduce uranium in soil, *Geobacter metallireducens*. Fungi (*Asperigillus ochraceus* and *Penicillium funiculosum*) were also able to take up large amounts of soluble uranium. Bioaccumulation of uranium in soil invertebrates has not been significant in any studies to date.

Only a small number of microbial organisms capable of bioremediation in soil communities have been identified. Extensive research is required to identify the best microorganisms for all contaminants. This knowledge is helpful when understanding the ability of soil to maintain a biological buffering barrier for pollution. However, scientists must also focus on any long-term impacts that bioremediation will have on the surrounding abiotic and biotic soil components.

Activity: Measuring Soil Biodiversity

Soil biodiversity can be measured in any area containing soil. This activity involves students going to areas with various landscapes (man-made fields, forests, meadows, etc.) and measuring the soil biodiversity. Collecting data in areas with differing land uses provides data for comparison of soil biodiversity. Collecting soil at various depths and comparing the biodiversity of organisms at each depth is also interesting.

Materials Required

1. Shovels
2. Plastic bags
3. Meter stick
4. Marker
5. Berlese-Tullgren funnel or funnel and beaker
6. Light source
7. Preservative
8. Invertebrate identification key
9. Dissecting scope or hand lens
10. Pencil
11. Calculator

Instructions

1. At each site, collect samples of soil using shovels for digging and plastic bags for collection. Try to collect soil samples at the same depth at each site for comparison, or if you want to compare the biodiversity of organisms at various depths in one site, remove the first sample at the first layer of soil.
2. Make sure you mark all samples with a description of the site and the depth the soil was collected at. Samples should contain approximately the same volume of soil.
3. Bring the soil samples back to the lab and place the soil in Berlese-Tullgren funnels (Figure 40). These funnels extract microarthropods from soil samples. Berlese-Tullgren funnels can be purchased from Carolina Biological Supply (www.carolina.com) or they can be made using lab components – i.e. funnel supported by beaker filled with preservative.
4. Use a light source to drive invertebrates to the bottom of the funnel, where they will fall into alcohol or another preservative. Each sample should be approximately the same amount of soil, so they each sample represents equal volumes of habitat. These samples should be left for at least 3-5 days.
5. Once all of the invertebrates are collected in the preservative, students can begin identifying the soil biota using dissecting microscopes. Identification only needs to be down to class or order for non-insects and to order for insects. Identification should be done using a dichotomous key provided by the teacher.
6. Record the abundances in each sample by counting the total number of each taxon.

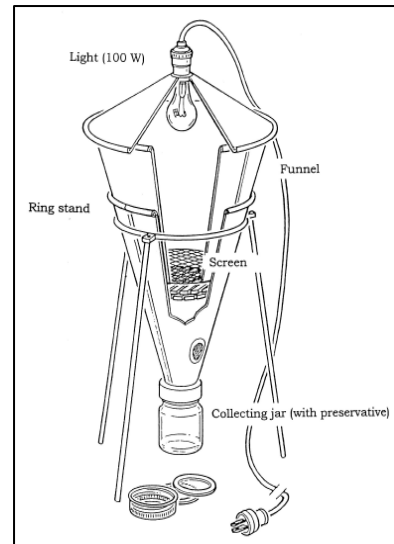


Figure 41: Berlese-Tullgren funnel (Ministry of the Environment, 1998)

There are two main measures of biodiversity. The first is species richness. Species richness is the number of individuals of each species in a given area. This is determined by adding up each species or taxa found in each sample. However, the greater the sample size, the more species you are likely to find.

Species evenness is also a diversity index. It measures biodiversity by quantifying how equal the communities are numerically. Species evenness is calculated using Shannon's Index, H' . This measurement is advantageous because it corrects for sampling effort. Rare species contribute very little to species evenness.

Shannon's index:

$$H' = - \sum_{i=1}^S p_i \ln p_i$$

p = the proportion of all observations in the i^{th} species category
 S = the total number of species

Shannon's index is unitless, however, the higher the value, the higher the species diversity. For a quick calculation, many websites have Shannon's Index Calculators in which the species name and the number of species for each group can be inputted and the species richness and Shannon's Index can be calculated (See: http://monticello.bc.edu/uei/sh_weave.php).

Compare the diversity of soil biota found in each habitat type or at each depth of soil.

Example:

	Number of Individuals	
	Community A	Community B
Species 1	98	33
Species 2	1	33
Species 3	1	34
Total	100	100

Community A

$$p_i = \frac{\text{number of individuals of species } i}{\text{total number of individuals in the population}}$$

Species 1=98/100=0.98
 Species 2=1/100=0.01
 Species 3= 34/100=0.34

Community B

Species 1 = 33/100=0.33
 Species 2= 33/100=0.33
 Species 3=1/100=0.01

$$\text{Shannon index: } H = - \sum (p_i * \ln p_i)$$

$H = -[(0.98 * \ln 0.98) + (0.01 * \ln 0.01) + (0.01 * \ln 0.01)]$
 $H = -[(-0.0198) + (-0.0461) + (-0.0461)]$
 $H = 0.112$

$H = -[(0.33 \ln 0.33) + (0.33 \ln 0.33) + (0.34 \ln 0.34)]$
 $H = -[(-0.333) + (-0.333) + (0.367)]$
 $H = 1.033$

Questions for Discussion: Activity

1. Where did the class find the highest biodiversity? Why do you think it was found in this habitat type/depth?
2. What factors contribute to the differences in biodiversity at each site/depth?
3. How does the diversity of organisms impact the surrounding wildlife in these areas?

Questions for Discussion

1. What direct effects are soil invertebrates likely to have on large animal food chains?
2. The composition and biodiversity of soil organism may have a greater affect on litter decomposition than previously recognized. In what ways can changes in the soil invertebrate community affect litter decomposition?
3. How does soil biodiversity change between seasons? Will you have the same diversity of organisms in the summer and in the fall?
4. How does soil biodiversity impact local agriculture? What would the impacts of changing biodiversity due to changing climate have on agriculture?