COMMUNITY AND ECOSYSTEMS ECOLOGY[1]

Part 1: Introduction

An **<u>ecological community</u> consists of all species inhabiting a specified area**. The area is often arbitrarily delineated. Thus, a community ecologist is someone who studies these **biotic interactions**. By contrast, an **<u>ecosystem</u>** is a **self-sustaining unit involving the interaction between a community and their physical environment**. Imagine the complexity involved in studying an ecosystem. Accordingly, to make such studies manageable, ecosystems ecologists **<u>lump species together into aggregates</u>** and then **<u>analyze the relationships among the aggregates and the abiotic environment</u>**.

These two subdisciplines of ecology overlap considerably and as a result, we will see that many of the questions, methods and approaches used in these areas are similar. Where they fundamentally differ is in level of the biological hierarchy and in the complexity of the systems they study. These notes are organized to consider some aspects of community ecology first followed by ecosystems.

Part 2: Approaches to the Study of Community Ecology

There are two general approaches used by community ecologists. One is to attempt to study especially important species interactions – ones that are believed to play key roles in the structuring the relationships in a community. The other way is to take a much broader view and study the flow of energy and materials through the community. We will use this latter approach in these notes.

Energy Flows Through Communities: The study of energy flow is an important aspect of community ecology because these flows are largely restricted to organisms. That said, ecosystems ecologists also use this approach since the source of biologically useful energy is abiotic – it is derived either from solar radiation or inorganic chemicals[2].

Life, being a process, depends upon energy and so <u>the one attribute shared by all species in a community is their need for energy</u>. Each species obtains its energy from other species (except for plants) and provides a source of energy to other species; in short, each species eats and in turn is eaten by another. This interdependence among species is illustrated by a simple **<u>food chain</u>**: grass - grasshopper - shrew - snake - hawk. <u>Food chains</u>, however, <u>are generalizations of a more complex feeding structure known as a **food web**</u>. Grasshoppers are not restricted to feeding on grass nor do shrews only consume grasshoppers. **Food chains and food webs, however, are species-specific and therefore vary from community to community**. A general pattern of community structure emerges when the components of these food relationships are abstracted in the form of **<u>trophic levels</u>** that are free of the specific details of individual communities.

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[2] This latter energy source drives those newly discovered ecosystems at the depths of the ocean that do not receive any sunlight.

Trophic Structure of a Community: Each species can be assigned to one of the trophic levels listed below based on its food supply in the community. **Trophic levels** are abstractions that group together all species in a food web that occupy the same position in the food chain. Species which can feed at different levels are classified in the level they occupy most frequently, e. g., **omnivores** would be considered herbivores or carnivores (but not both) depending upon their most frequent food preference. Below is a list of commonly used trophic levels. It is divided into two primary groupings – autotrophs and heterotrophs. **Autotroph**s are those species that do not depend on other species for food while that do are termed **heterotrophs**.

- **Producers** Producers are autotrophs. They constitute the first link in the food chain upon which the entire community depends for its energy. Producers fix energy from nonliving sources and make it available to all other species. For the most part producers are photosynthetic bacteria, protists and plants – organisms that tap the sun's energy to produce energy-rich organic molecules. These are best referred to as **photoautotrophs**. Other organisms that are able to extract energy from inorganic molecules and store it organic molecules such as carbohydrates or lipids are referred to as **chemoautotrophs**. These types of producers are bacteria or archaea.
- **Primary consumers (herbivores): Herbivores** are animals that feed exclusively on plants. They, in turn, are eaten by **carnivores** (flesh-eating animals).
- **Secondary consumers (primary carnivores):** Animal species that feed exclusively on herbivores are called **primary carnivores**. Note that a primary carnivore is a secondary consumer.
- **Tertiary consumers (secondary carnivores): Secondary carnivores** are animals that feed on primary carnivores.
- **Quaternary consumers (tertiary carnivores): Tertiary carnivores** are the top carnivores that feed on secondary carnivores and are not eaten by any other animal species.
- **Detrital or Decomposer Food Chains**: Detritovores (decomposers) are organisms that feed on the organic remains of organisms. Many of these are microorganisms, but also many are multicellular organisms such as fungi, animals and some plants. The line between detritivores and organisms that parasitize living organisms is often very fine (if it exists at all). In any case, these types of organisms are often the basis of microbial food chains – ones where the detritivores themselves are then fed upon by a series of other consumers. The energy and nutrients they contain are used by decomposers, e. g., bacteria that start a second type of food chain - the detrital or decomposer food chain.

Note the following aspects of the trophic description of a community:

1. **Trophic levels are abstractions of generalized food chains**, which simplify the actual, more complex feeding relationships described in a food web.

2. In trophic analysis **individual species lose their identity** and are included in groups that have a common feeding pattern.

3. As hinted at above, there are two types of food chains: **grazing** and **decomposer**. The grazing food chain starts with autotrophs; the decomposer food chain begins with heterotrophs. Furthermore, the distinction between producer and consumer (autotroph and heterotroph) is not the same as between producer and carnivore, since some heterotrophs (herbivores) are not carnivores.

4. **There are at most only five different trophic levels in any community**. The top carnivores (tertiary carnivores) constitute the highest level and they are "consumed" by decomposers that comprise a separate food chain. The reason why there are only five levels in the grazing food chain will be described below.

Trophic Dynamic Approach to Community Structure

Trophic level analysis provides an opportunity to compare different communities because this type of analysis is free of the specific differences in species composition and vegetation type, e. g., grassland vs. forest, which confound comparisons. Various attempts have been made to find a trophic pattern that is general enough to apply to all communities and which would shed some light on the most significant population processes that shape community structure. These attempts are described below.

Comparison of trophic levels: pyramid of numbers

One of the first attempts to analyze trophic relationships and arrive at a generalized picture of community structure involved relating the different trophic levels to the number of individuals found in each level. The study of fresh-water aquatic systems, e. g., lakes and ponds, whose producers are tiny plants called **plankton**, revealed a **pyramid of numbers** with the number of individuals per trophic level decreasing with each successive level. Although this relationship applied well to aquatic communities**, it did not provide an accurate description of terrestrial communities**.

The reason why a forest ecosystem does not follow the pyramid of numbers at the producer level is that a single tree can support a large number of insect herbivores. Since the tree is much larger in size than the herbivores that feed on it, terrestrial ecologists suggested that number of individuals per trophic level is not the important parameter - rather size or mass is.

Comparison of trophic levels: pyramid of biomass

When a terrestrial, or more precisely, a forest ecosystem is analyzed in terms of the mass of its trophic levels (measured in grams per meter squared or **g/m^2**), the anomalous position of the producer level is corrected. This measure of trophic structure, however, is not without its difficulty as was illustrated by samples taken from the English Channel in which the mass of the producers was **less** than that of the herbivores which grazed on them. In this marine ecosystem the producers are called **phytoplankton** and the herbivores are called **zooplankton**. How is it possible for a greater mass of zooplankton to be supported by a smaller mass of phytoplankton? The answer is that the samples were taken over a very short period of time and so only represented the **standing crop** of both trophic levels, i. e., the relative mass of both types of plankton at any given time. What the standing crop relationship does not consider is the reproductive differential between the two levels, and this can only be determined by following both levels over a more extensive period of time, e. g., a year. **Phytoplankton have a higher rate of reproduction** than do zooplankton and this consideration gave rise to our final pyramid - one based on the annual rate of production of organic matter.

Comparison of trophic levels: pyramid of productivity

Although productivity could be measured in terms of biomass (g/m^2), what the trophic relationship is really concerned with is the passage of energy from one level to another. Biomass is only a crude estimate of energy since some portions of an organism's mass cannot be converted into energy by another organism's digestive apparatus. Consider the difference between 10 grams of earthworms and 10 grams of clams. Since most of the earthworm is digestible, the mass of the clam's shell is not equivalent to an equal amount of worm tissue. Lest you think this example too gross, consider the shopper's dilemma when attempting to relate price per pound and quantity of meat obtained in comparing lobster meat and a whole lobster. The same principle applies.

One way around this problem is to look at energy content instead of simple biomass. Energy is measured in heat units such as **calories** or (**kilocalories**) or more commonly in MKS energy units called joules. The two are inter-related by a simple conversion constant (there are about 4.186 joules per calorie)[3]. Since productivity is the rate of production (conservation is a better term) of energy, the unit of measure is **$kJ/m^2/yr$**. With this measure, the relationship between the phytoplankton and zooplankton is reversed with the phytoplankton having a larger base than the zooplankton. Consequently, **the pyramid of productivity provides a general pattern common to all communities** regardless of their species composition, whether they are aquatic or terrestrial, or whether they are fresh-water or marine.

Why is this pattern so universal? To answer that question we will first have to examine what happens to the sun's energy as it is used to support the producers in a grazing food chain. Not all of the sunlight that strikes the planet is used by plants and only a small fraction of that which strikes the plants themselves is actually converted into biologically useful energy through photosynthesis. The plants use this fixed energy for **maintenance**, **growth** and **reproduction** and the total amount of energy produced by plants is called their **gross primary production**. Since growth, maintenance and reproduction require energy, then producers have to expend some of the energy they have fixed on these processes. This energy is lost from their trophic level as heat and is referred to as **respiration**. Because of respiration, not all energy present in one

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[3] The calorie is used as a measure of energy **because all energy can be converted to heat**. However, for numerous reasons (many having to do with using consistent measurements), the joule has become the more commonly used measure in recent years.

trophic level is available to the next. Energy that is used for respiration is dissipated as heat and cannot be used again.

This said, the part of the producer's energy fixation that is available to the next trophic level equals what remains of the gross primary production after respiration, -- this is the producer's **net primary production**. Even so, not all of the net primary production ever **flows** to the next level. If it did, it would mean that the entire trophic level would cease to exist. So, a major portion of the net primary production goes into **maintaining a standing crop** and the rest is passed on to decomposers or herbivores. The same sort of analysis can then be extended to each other level of a trophic pyramid.

Ecological Efficiency

The transfer of energy from one trophic level of a community to the next can be measured in terms of its efficiency in the same way one might measure the efficiency of a machine. The efficiency of energy transfer is called **ecological efficiency** and it is measured by the following formula:

% ecological efficiency = Output (or Yield)/Input x 100

Estimates of ecological efficiency usually range from 10% - 20% and so are quite low. This **low efficiency of energy transfer between trophic levels accounts for the pyramid of productivity** and also the pyramid of numbers. Since only about 10% (the value used as a generalization) of the net primary production of producers is passed on to herbivores, this trophic level has a much smaller energy base upon which to operate and so it can support fewer individuals. The same argument applies to all other trophic levels as well. The reason that there are only five links to a food chain and five trophic levels is that there simply would not be sufficient energy to support a single population of **quaternary carnivores**, especially if they had to be larger than the tertiary carnivores in order to overcome them. Thus, larger individual size and less energy available as you ascend the trophic levels combine to limit the number of trophic levels to five.

Numbers of Species and Energy: One of the concerns of community ecologists is to explain why there are so many kinds of living organisms. Why don't we have more species? Why not fewer? The trophic dynamic approach to community and ecosystem ecology has furnished us with at least a glimmer of an answer. The low transfer of energy between successive trophic levels places a severe constraint on the kinds of animals as regards their classification into trophic levels. **Ecological efficiency will simply not allow the evolution of quaternary carnivores**.

Species Diversity and Community Structure: Trophic analysis has nothing to say about what limits the kinds of animals and plants within a trophic level, even though it can explain why there are just five different trophic levels. Some ecologists have suggested that within each trophic level there is a limit as to how far the resources that support that level can be partitioned. Hence, they argue that the kinds of species within trophic levels are determined by interspecific competition (the subject of the next class). This argument, however, ignores the possible role of predation in reducing the density of potential competitors so that they might coexist. Attempts to determine the most significant interspecies interactions by analyzing species aggregates are short-cut methods that most likely won't be useful until we have more information on controls at the population level.

Part 3: A Sampling of the Main Ideas and Approaches of Ecosystems Ecology:

Recall that an ecosystem is a self-sustaining unit involving the interaction between a community (interacting organisms in a particular environment) and their physical environment. It should be clear to you that the sorts of analyses used in community ecology (just covered) are also important aspects of ecosystem ecology.

We will now add to this now by considering in more detail the interactions that occur between living (biotic) and non-living (abiotic) components of ecosystems. This section will deal with the study of **nutrient and biogeochemical cycles.**

Nutrient Cycling

Life depends upon more than energy; it requires the chemical building blocks of organic molecules. These chemicals, e. g., phosphorus for nucleotides, nitrogen for amino acids, carbon for carbohydrates, are collectively referred to as **nutrients** and exist on this planet in finite amounts. Individuals only "borrow" them for a short time and must <u>release them to other organisms</u> either while they are alive through excretion, or upon their death through decomposition. Unlike energy that is degraded and lost as heat, <u>nutrients are used over and over again</u>, i. e., they cycle through the ecosystem. Decomposers are the vehicles that cycle nutrients through single ecosystems by degrading organic matter and incorporating it into their structure (which is then available for heterotrophs to use), or by releasing it into the soil where it is picked up by autotrophs.

Biogeochemical Cycles

Nutrients also are cycled **between** ecosystems in **global patterns** called biogeochemical cycles. As regards nutrients, **the biosphere is essentially a closed system** with the amount of matter entering in the form of meteorites and leaving via space launches being negligible (at least up to now for the latter). This means that the chemical nutrients necessary for sustaining life must be cycled between the biotic and abiotic components of the biosphere. The distribution of nutrients, however, is far from uniform and each chemical element has its own distribution pattern. In general, there are **two types of storage depots or reservoirs**:

- **short-term** ones which are available to living organisms and
- **long-term** ones which are largely inaccessible.

The different biogeochemical cycles are classified according to their principal storage depot.

- **Gaseous cycles**, e. g., the nitrogen and oxygen cycles, <u>use the atmosphere for their principal reservoir</u> while

- S**edimentary cycles** (phosphorus and the heavy metals, e. g., iron, copper and lead) use the earth's crust or lithosphere.
- Other cycles, e. g., the hydrological and carbon cycles, use the ocean as their main reservoir.

Carbon cycle

The intricacies of biogeochemical cycling can be illustrated by the details of the carbon cycle. At the level of ecosystem analysis the biotic components are condensed into just plants and animals (autotrophs and heterotrophs) with no regard for species composition or trophic level complexity.

The short-term reservoir for the carbon cycle is the atmosphere -- it contains carbon in the form of **carbon dioxide**. Plants draw upon this source to synthesize carbohydrate through the process of photosynthesis. Carbohydrates are then used by both plants and animals, and their utilization generates carbon dioxide that goes back to the atmosphere. The annual exchange rates for photosynthesis and respiration are about equal. Less than 0.1 billion tons of organic material accumulates as peat that will ultimately be fossilized. Carbon dioxide is also generated by volcanic action but the annual rate of addition of carbon dioxide to the atmosphere by this means is compensated by the weathering of rock due to carbonic acid in rainfall that takes carbon dioxide out of the atmosphere and eventually places it in the ocean in runoff water.

By far the greatest exchange of carbon is between the atmosphere and the ocean. Carbon dioxide reacts with ocean water to produce carbonic acid but this reaction is reversible so that the annual rate of exchange in one direction equals the annual rate of exchange in the other direction. Over long time periods, however, any imbalances between the atmosphere and the ocean are corrected by carrying the reaction described above even further. Suppose that carbon dioxide were to accumulate in the atmosphere at an increasing rate. This will tend to push the following equation:

$$H_2O + CO_2 \;\text{-->}\; H^+ + HCO_3^- <\text{--}> 2\,H^+ + CO_3^{2-}$$

further to right. Moreover, the carbonate (CO_3^{2-}) in turn can react with dissolved metals to form salts that crystallize out the ocean. This allows more carbonic acid to be formed and the process continues with carbonate salts accumulating until the exchange between the atmosphere and the ocean equilibrated.

In the past, major disruption of the atmosphere-ocean equilibrium occurred during episodes of glaciation. Since ice is pure water, the forming of an ice sheet over the ocean increased the concentration of carbonate salts in the ocean. This, in turn, drove the reaction described above in reverse, thus increasing the level of atmospheric carbon dioxide. The carbon dioxide acted as a thermal barrier to **infrared radiation** and so the temperature of the earth rose globally. This temperature increase helped melt the ice. As the sea level rose, the concentration of carbonate salts dropped and the reaction shifted to the right again. After thousands of years the atmosphere-ocean exchange equilibrated. The ability of atmospheric carbon dioxide to act as a thermal blanket is called the **greenhouse effect**. **Ultraviolet radiation** is not affected by carbon dioxide and so enters the atmosphere and warms up the surface of the earth. This heat is normally radiated back into space as infrared radiation. **High levels of carbon dioxide prevent the escape of infrared radiation and so the atmosphere retains heat**. This is the same principle that allows heat build-up in an automobile or a greenhouse since glass has the same effect on radiation as has carbon dioxide gas.

Human activity and biogeochemical cycles

Human activity, as the result of technology, industrialization and population growth, is beginning to impact on some of the biogeochemical cycles. Our current knowledge of the dynamic processes behind these cycles is so limited that it is impossible to predict with any degree of accuracy just what effects this human activity will have. I will indicate just three areas of concern, although there are many more environmental issues that demand our immediate attention.

The Greenhouse Effect

The carbon cycle is being disrupted by our burning of **fossil fuel**. Fossil fuel, e.g., coal, oil and natural gas, was deposited over millions of years during a unique set of circumstances that saw the rate of fixation of organic matter far in excess of the rate of decomposition. The rates of photosynthesis and respiration are now balanced so there is no appreciable formation of fossil fuel during the present time. Note that all the factors that promote exchange of carbon dioxide between the atmosphere and other components of the carbon cycle appear to be balanced - with one exception: <u>the release of carbon dioxide into the atmosphere as a result of industrial, agricultural and domestic consumption of fossil fuel</u>. Many environmental scientists fear that the rate at which we are adding carbon dioxide to the atmosphere is too high for the normal atmosphere-ocean interaction to buffer the increase with the result that the greenhouse effect will intensify. The higher global temperatures that might result could alter weather patterns as well as melt the polar ice caps. This in turn will cause the sea level to rise and flood many coastal plain localities as well as shift the rainfall pattern so that many of the world's most productive agricultural areas will be adversely affected. The most recent projection suggests that there is nothing we can do now to prevent the first effects that should be felt in about 50 years. What might happen when we have burned all of the fossil fuel is anybody's guess, but no one expects that when that happens the world as we now know it will still exist.

Phosphorus Depletion

The indiscriminate use of fertilizer to increase and sustain crop yields, rather than the slower method of crop rotation, will have a long-term impact on the phosphorus cycle as well as short-term effects on drinking water, and the premature aging of lakes (eutrophication). Since the phosphorus cycle is a sedimentary cycle, the long-term reservoir is the lithosphere, specifically the sediment on the ocean floor. Surface runoff carries phosphorus in fertilizer through fresh-water aquatic systems that eventually empty into the ocean. Current belief is that of all the cycles that might be disturbed by man, the one in greatest peril is the phosphorus cycle. Only geological upheavals will return phosphorus to areas that can be worked to release the phosphorus. In effect we are removing phosphorus from its short-term depots and placing it in long-term storage beyond the grasp of modern technology. Since phosphorus is an essential nutrient upon which all life depends, it may prove to be the limiting factor that is in shortest supply. Recent studies have indicated that iron depletion is limiting phytoplankton growth in the ocean, but this depletion is due to natural causes, not human activity.

Deforestation

Finally, the massive clearing of the Amazon, African and South Asian rain forests to accommodate population growth and economic expansion will not only lead to a level of species extinction paralleled only by geologic catastrophe, but also will tamper with the hydrological cycle. Tropical rain forests retain moisture and also return water vapor to the air in the process known as evapotranspiration. What effect the loss of the Amazon rain forest will have on global weather patterns is not known, but it is unlikely that other forms of vegetation will take the place of the forest and repair the damage. Tropical soils are rich in iron and the hot sun converts exposed soil to laterite that dries as hard as cement. This severely limits the opportunities for agriculture and reclamation of the soil.

Before our dramatic population growth and development of high technology, we, as a species, had a minimal impact on the environment and could afford to pursue economic goals with little concern for our environment. Now, however, our numbers and technological might enable us to inflict considerable damage on the self-maintenance ability of the **biosphere**, <u>that fragile interface where air, soil and water meet</u>, and which, as far as we know, is the only place in the universe to contain life. Our destructive action is proceeding at a rate faster than the growth of our knowledge about ecosystem structure and dynamics. How long can this situation continue before we have gone too far to repair the damage? We alone among all other species that have ever lived possess the intelligence and foresight to come to grips with our dilemma and institute corrective measures. Will we use our distinctive qualities for survival, or will we (hastened by our own activity) share in the fate that has befallen over 99% of all the species known to have inhabited the planet - EXTINCTION???