Lecture 4: Nutrient cycling

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Today we are going to look at water and nutrient cycling in natural ecosystems.

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I am mainly going to focus on water, carbon and nitrogen because these are the most important for life. I will briefly touch on other nutrients at the end.

By the end of this lecture, the aim is for you to be able to name the main parts of these cycles and understand the role they play in ecosystems.

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Now this is a simplified image of the water cycle, and the parts I want to focus on are precipitation, transpiration and groundwater storage.

So water is always cycled, it is never destroyed. Water is evaporated from water bodies such as the ocean or lakes, and then falls on the land as precipitation. When it falls on the soil, it can either sit on the surface and eventually run off into rivers, or it can be taken up by plants.

Plants play an important role in reducing flooding, which can be catastrophic in many areas of the world and is often a result of removing trees or other vegetation.

Plants will then lose water through their leaves as a by-product of photosynthesis, called transpiration. So that is the basic cycle, let’s look at these in a little more detail.

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Precipitation can add water in a number of forms, including rain, snow, fog and hail. Globally there is a clear relationship between net primary production, which is addition of plant material on a yearly basis, and average annual precipitation. This is true of all ages and types of biome.

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Plants take up water through their roots from water that either falls as rain and wets the soil, or is stored underground in the groundwater.

This is a picture of some work I did that showed that roots can move in soil to find water when there is very low rainfall. I was interested in whether the root shape was important. I found that plants with one large deep root, called a taproot, could reach deep water while those with very fine thin roots could keep them near the soil surface to collect small rainfall amounts before they evaporated. Here I used a 3D Xray to take pictures of the roots in the pots.

When we say something is plastic, we mean that they are able to change in response to a stimulus. So plant roots are plastic because they can allocate more root materials to forage for water and nutrients.

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We can categorise the amount of water available to plants in the soil by using soil moisture content. Soil is a combination of sand, clay and organic matter such as decomposed roots and leaves.

Field capacity is the term used to describe the maximum amount of water the soil can hold, without draining away, expressed as a percentage.

Permanent wilt point is the amount of soil moisture where almost all of the water is gone or is inaccessible to plants.

These definitions depend on the soil texture. Very sandy soils have large spaces between particles, known as pores. Water can drain freely, so they dry out very fast. High clay content means that particles are very small and they also have a negative chemical charge. This means water cannot flow very freely but the chemical charge may bond water particles to the surface of the clay, so plants cannot access it.

I’ve shown you a useful classification triangle here which is used to calculate field capacity or wilt point of a soil using the equations of Saxton and Rawls.

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Water availability is crucial for microbes. Water is very patchy in the soil- it might be intercepted by plant leaves or the root zone may have taken most of the available water. Water is needed to stop cells drying out and causing osmotic gradients that can cause bacterial cells to burst. Bacteria are thought to be more vulnerable to drought than fungi.

In this figure, Professor Schimel shows how microbial activity changes with soil moisture. Heterotrophic refers to organisms that need to feed on external food because it cannot make its own. This is different to autotrophs, which can create their own food from sunlight. The main example is plants, who harvest sunlight to make sugars.

If soils are too dry on the left of this graph, microbes may become dormant. There are high metabolic costs associated with surviving drought, as we can see from the yellow triangle on the graph, which is thicker at the low end of soil moisture.

When soils are dried and then rewetted, they often give off a big spike in carbon dioxide because the microbes have very high activity. This is called the Birch effect and does not last very long.

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Almost all of the water taken up by plants will be lost through the leaves in a process called transpiration. When stomata, which are little mouths, open up to take CO2 in for photosynthesis, they lose water at the same time. The ability to regulate this loss will determine whether the plant can survive drought.

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Now we’ll move on to the carbon cycle.

Carbon is the main component of plant and animal tissues because it is such a versatile element. It is the main building block for structures such as sugars, fats and proteins, and structural molecules such as lignin, which is found in plants.

Biomass is the term given to the mass of organisms per unit area or energy.

Net primary productivity(NPP) is the *rate* that an ecosystem produces biomass. NPP usually comes from plant growth, as it fixes carbon from sunlight through photosynthesis.

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So the carbon cycle is mainly driven by four processes. Carbon may be stable in one place, such as soil or plant biomass for a long time. Carbon that is not cycling is called a pool. Carbon that is cycling is called a flux. So we’ll talk about each of these processes in turn.

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The first is photosynthesis, which is a process that drives plant growth by converting sunlight, water and CO2 to sugars. These can either be metabolised or turned into structures.

CO2 is quite limiting on earth and as humans add more to the atmosphere in theory plants should grow faster. However, there is an enormous amount of research looking at the effect of increasing CO2 in these FACE experiments, which are across the world in a range of ecosystems. These experiments allow CO2 to blow across an ecosystem in the open air, and ecologists can measure plant, animal and microbial responses to increased CO2.

One key finding is that even though photosynthesis and growth may increase, once CO2 is not limiting, nitrogen often becomes limiting instead. This has effects on animals. Insects need to eat much more plant material to gain the same amount of body weight because the quality of the food becomes very poor.

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Respiration is the loss of CO2 into the atmosphere from plants and animals. It is a major component of the air we breathe out.

Understanding the variables that affect the amount of respiration in an ecosystem is very important for being able to calculate the overall net ecosystem CO2 exchange.

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Now, we’ll get into food webs later in the course. For now, consumption of carbon based tissues, either active or dead, are the main way of incorporating carbon into animal bodies. It then could be respired, used as energy or lost to defecation.

Plant and animal defences against being eaten are an important area of study. These can have far reaching effects and help increase pest outbreaks, because predators are deterred from eating the pest.

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Decomposition is when dead material is broken down into simpler components. This can be dead animals and plants, but also parts lost by living organisms such as hair, or shed skins from reptiles. In this photograph you can see the casts made by decomposers as they break down the horn of this water buffalo.

The products of decomposition are then either broken down further by other organisms, or taken up by plants.

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Now we’ll move onto the nitrogen cycle. As you can see, the nitrogen cycle is quite complex and there are a range of organisms involved in this. We will talk about the five main stages: fixation by legumes and microbes, decomposition, mineralisation, plant uptake, denitrification.

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Fixation of nitrogen in the soil from gaseous nitrogen is carried out by microbes. Many of these are symbiotic with plants. These plants are usually legumes, from the family Fabaceae. They have root nodules that contain the bacteria, which supplies nitrogen to the plant in a useable form. There are also non-symbiotic bacteria that live freely in the soil and also add plant available nitrogen to the soil. These are very important in low nitrogen soils, because they can help supply other plant species with nitrogen. This is an example of nurse plants which we talked about in the previous session.

There is a trade between the plant and the bacteria- plants supply the bacteria with carbon, while the bacteria supplies nitrogen to the plant. This is why it is a symbiotic relationship because the benefit is to both organisms.

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So the first step in the nitrogen cycle is ammonification, which is reducing organic nitrogen, (proteins and amino acids) into ammonia or ammonium. It is the first stage of decomposition.

Most microorganisms can carry this out, and they will create energy by removing the oxygen and converting these NH2 groups to NH3.

This happens much faster in hotter temperatures, probably because of the increasing speed of enzymatic activity when. What this means is that in high latitudes though nearer the poles, where it's very cold. We get a buildup of organic nitrogen, because the microbes are moving much slower.

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Nitrification is the conversion of ammonia to nitrate. This is mediated by specific bacteria.

*Nitrosomonas* converts ammonium nitrate, which is NO2, *Nitrobacter* converts ammonia to nitrate, which is NO3. These work together in the in the soil. However, they really don't like very acid soils. So, heathlands, like you can see in this picture, have very low nitrofocation. And so we can get again buildup of organic nitrogen or ammonia.

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Now plants, particularly prefer nitrate (NO3), and that's what they would prefer to take up from soil solution, they can take up other nitrogen forms but nitrate is preferred.

They use a nitrate reductive pathway. So that's an enzyme pathway to reverse the steps that we just talked about in order to make organic nitrogen. So proteins in their cells.

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Denitrification is the conversion of nitrate to gaseous nitrogen. So nitrogen gas. This mainly occurs under anaerobic conditions where there is no free oxygen. A wide range of bacteria can use nitrate instead of oxygen as a respiratory electron acceptor.

This activity means that the loop in the nitrogen cycle has been completed.

Now you see denitrification most commonly in waterlogged areas. And the bacteria tend to be facultative anaerobes, which means that they have a choice. They can choose nitrate, or they can choose dissolved oxygen in the water that whatever they use as a substrate, they will give off nitrogen gas.

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So important nutrients include phosphorus and potassium. Phosphorus is a major component of proteins, nucleic acids and ATP, which is the energy molecule, and a wide range of metabolic intermediates.

In mature soils large quantities of phosphorus exist as insoluble soil phytin, which is formed from organic phosphate liberated from plant debris during decomposition.

Roots can only take up soluble inorganic phosphate.

Phosphate recycles slowly as an immobile nutrient, which means that it tends to stay in pools for a very long time.

The potassium cycle is very important for enzyme activity. It is an enzyme co factor, which means that it helps enzymes to work.

It is also important in cell ionic balance. So keeping everything, keeping the moisture levels constant in plant and animal cells. It is very important because it functions in nerve conduction. The potassium cycle is simple potassium ions are cycled between the soil solution and plant cells uptake across route membranes is efficient. Within plant and animal cells potassium functions simply as the ion, potassium ions are released early in decomposition and they leak very readily through damaged cell membranes. It recycles very quickly. It is a very mobile nutrient

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So in summary, we've talked about how important water is and how plants and microbes need to find ways to access scarce resources or mitigate their function in order to conserve the water that they currently have.

Carbon is the majority of all living tissues. We've talked about all four of its different processes respiration photosynthesis decomposition and consumption.

We've talked about how nitrogen as an energy source and how it builds proteins. It is rapidly cycled but cannot be taken up by plants in many forms. So there needs to be some kind of symbiotic relationship.

And finally, phosphorus is crucial for building DNA is very scarce and soils and potassium is very important for what making enzymes work.

Reading

Chapter 19 Begon- focus on parts about carbon, nitrogen, phosphorus.

Freshwater nutrient cycling paper- as much as possible.