Lecture 11

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In this session, we're going to begin talking about community ecology. This will be the first lecture of two.

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So the learning outcomes for the session.

We will be able to define biodiversity and species diversity, we will be able to describe the shape of species abundance distributions.

We will be able to describe patterns of biodiversity and define the term community.

We will be able to explain the broken stick hypothesis of community structure and explain the theory of biodiversity and ecosystem function relationships.

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Biodiversity as a shortening of the two words biological and diversity. It is often necessary to compare the species of two habitats, or to compare the change in the species in one area over time. We know that there are differences in habitats and ecosystems over space and time, and it is important to be able to measure that.

We can recognize diversity at a range of scales. This is useful because we assume that more diversity means a healthier ecosystem. We also think that the ecosystem might be more able to resist or recover from change if there are more species. It is insurance if there are more species, there is a higher chance that some will survive a disturbance.

We can consider genetic diversity, and this is variation within one species. Genetic diversity is also known as intra-specific variation and it is important to reduce the effects of inbreeding or genetic erosion. Generally, if there is very low genetic variability in a species, then they are less likely to survive problems such as disease. They may also have genetic problems that reduce viability or survival. Another reason genetic diversity is important is because it might allow changes over a gradient. So you might get the same species all the way up a mountain, but the individuals at the top have genetic adaptations to survive cold better than the ones at the bottom. These factors to help ecologists judge which species are most at risk of extinction.

Species diversity is also known as alpha diversity and ecosystem diversity is also known as beta diversity. We will explore these in more detail in this lecture.

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The simplest way to measure of diversity is by counting the number of species in an area, the most useful thing to do is compare it with another area. This is usually the first thing that is measured in ecological experiments. Most ecologists will combine the species number with how many individuals of each species to get the abundance. In the case of plants we might measure percentage cover instead of number of individuals. We can plot the graph of a rank abundance curve with the species arranged in an order from most common to least common, as I have done here.

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So when we plot a rank species abundance curve it will look a bit like this. The most abundant species are on the left of the graph. These are the ones that have the most individuals or the highest percentage cover. We can gain some understanding of the type of ecosystem we are looking at by considering the shape of the graph. You can see that there are a few very common species then many of average abundance, than a few that are very rare.

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Anne Magurran proposed a set of models of relative abundance. The commonness and rarity of species in an area is something that has great theoretical and practical importance in ecology. Most species are rare, a few are common.

The first model is the geometric series. The concept here is that the most abundant species takes a proportion. Let's say 50% of the resources. The next most abundant species will also take 50% that it will take 50% of the remaining the sources. The third species will take 50% of what is remaining after that. This pattern can be observed in species poor environments that have harsh abiotic conditions.

The next type is log normal. This means that the abundances of the species when you transform them logarithmically are normally distributed in a bell shaped curve. I have added an example here. You see that the abundances are now on the x axis along the bottom, and the number of species of each abundance are added together to create this shape. There are most species in the middle abundances so they are higher or more frequent than the very common or very rare species.

Finally we have the broken stick model, which forms an S shape. Theory suggests, it means that there is a more even distribution of resources to use than the other types, but there are not many examples of this in nature.

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There are some useful calculations to be able to express species abundances and compare between areas or over time. For example, this is the Jena biodiversity experiment in Germany, they have spent 20 years growing plant species in different combinations. Some have one plant species. Some have two plant species. Some as many as 64. Many scientists have worked on different questions on this experiment. However, to underpin any findings they need to show that each of these squares has a different species alpha diversity to the others. Note that each species combination is replicated four times.

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For each square plot in the Jena experiment, you could calculate a Shannon's diversity value you can then compare across your treatments. Very diverse communities would have a very high value of each one if each species had a similar abundance. But if one species was very common or dominant and there were others of quite rare species, you would have a lower Shannon's H. To further test this, we would use Shannon's evenness which is the Shannon's H value divided by the log of the number of species. The index is between zero and one. So values near one would mean that the species were very even in abundance, while near zero means one very dominant and lots of unevenness

There are a few other metrics that will test similar things.

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Beta diversity is the biodiversity of communities. So how many communities are in a certain place. It is quite a useful measure of species turnover. So, those that come and go in an area or how the communities change in space.

Sorensen's similarity coefficient is often used to calculate beta diversity using presence or absence data. So one for species presence, zero for absence. It is just comparing two sites or two areas. How much overlap is there between the communities in terms of species present

A more complex version of this calculation is the Bray-Curtis similarity index. It uses relative abundance data to calculate the similarity between samples. It is commonly used for genetics data. I use it often to compare the microbial community in different soil samples.

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Many factors can affect diversity. We have talked about many of these previously, but it is useful to know that they will all play a role in shaping communities through the conditions in an area, and the access and out of it.

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Using species in diversity can be time consuming and difficult.

At the beginning of this course we classified a community as a group of populations in a given location.

We also defined the niche concept, which states that for species to exist, they must have a slightly different requirement for resources and space or one will drive the other to extinction in that area.

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Now, when we are looking at species in an area there is a strong relationship between the area or size of a habitat and the number of species found in that area. You get a species area curve and this is true for almost all groups. This method is usually employed for one group only like plants or birds.

The slope and the intercept, which is where the line cuts the y axis are key properties of any line graph. The steeper the slope, the faster species increase with bigger areas. The differences between in the intercept and slope between different areas could be due to all sorts of things happening in these areas. For example, disturbance might have a stronger effect in a small area than a large one.

Also, could it be a sampling effect so that causes this pattern. We know that the more you look, the more you find. It is crucial that the same amount of effort is used across the different areas in order to gain a reasonable understanding

Species area curves assume that as an area increases in size, there should be more habitat complexity. So more niches and more species. It also assumes that while local extinctions do take place, there should be enough immigration and dispersal in bigger areas to cover the effect of extinctions.

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But what effect does diversity have on how an ecosystem functions? Species do have a value of their own, of course, people like to know they are there. Also, as we will see in the food web lecture some species are so closely linked with others that to lose one might mean losing many. But another compelling reason for conserving biodiversity is that the species may help ecosystems to provide functions such as decomposition and gas exchange and services such as clean water and pollination of crops.

Ecosystem functions are a measure of the performance of an ecosystem and functions are the mechanisms for services. The functions of interest really depend on what you are looking for. If I was interested in the surface of climate regulation, for example, I might look at the functions respiration, decomposition, biomass production and photosynthesis to try to be able to quantify how much carbon is being taken down into the soil. I would base this on the carbon cycle that we talked about in week two.

Here is a schematic from a project I was involved in. The aim was to look at ecosystem service delivery in the south of England. And you can see how biodiversity measures can be described by measuring functions which will then deliver final services.

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We can ask if there is a link between biodiversity and ecosystem function. This is a question that is of great interest to ecologists. In fact, if you put BEF then most ecologists will know that you mean biodiversity and ecosystem function. In order to influence government policy and land management decisions, simple, clear messages are best. So ecologists are interested in whether just a biodiversity, or some kind of abundance value is enough to be able to predict ecosystem functions. And then in turn services. This is a lot of work because the world is so patchy and climate seasons and land use change all the time. But it is an interesting goal. There is the added question of which functions are beneficial and which give a disadvantage to various goals.

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Why would there be a relationship between biodiversity and ecosystem functions? Surely, if you had a field of wheat which is one species, this would still fulfil ecosystem functions? Well, maybe not for these four very important ecological reasons.

A field of wheat only has one niche. Usually the individuals are genetically identical as well. They will all be the same height. They will all have the same root depth or will have the same requirements for space, water and nutrients. If you have lots of species, you would be more likely to have more opportunities for pollinators or more of the soil space used because of niche differentiation.

Then we have interactions where species might give each other a disadvantage or advantage. Remember how we talked about nurse plants and also antagonism.

And finally, we have seen that resistance and resilience to perturbations, such as drought can be reduced with higher biodiversity.

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So that is a clear link between land use biodiversity and ecosystem function. Here we can see from my data that as you move from intensive farming practices to semi natural grassland, which is the most natural grassland that we have in the UK, the species richness and the Shannon's diversity both increase, and this is closely linked with the amount of fertilizer and disturbance of the land. Intensive farming means high nitrogen and phosphorus inputs. So this will result in a highly competitive species mostly grasses, and they will outcompete the wild flowers and other small plants. This will reduce diversity as you see here. The graphs show different stages of recovery from agriculture. So the two bars in the middle show a progression from intensive arable land to untouched grassland. Recovery in some grasslands may take as much as 100 years.

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We have seen that very competitive species lead to low species richness, because they drive out lots of other species. But how does this translate to biomass? Well, actually we see a positive relationship between species richness and biomass, so that's just the dry weight of all of the plants in the region. In the 1990s, there was a set of experiments carried out across Europe, called the BIODEPTH experiments. They all found similar trends, that is a positive relationship between species richness and biomass and this graph along the x axis, we see the numbers increasing. So as you get more species richness, you get higher biomass. And each of these graphs is for a different country carrying out the same identical experiment. This is an extremely powerful way to carry out ecology to carry out the same experiment across different regions.

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David Tilman is a scientist from the US who pioneered a lot of these experiments looking at how plant species richness is linked with productivity and ecosystem functions. He showed that as you increase species number, the amount of energy and carbon uptake increases. In graph B on the top right, the ratio of energy yield of high to low species rich plants increases as time goes on. So the more species that you have in your area, the more bioenergy production will add together over time. So it's not just a one year thing that you see. And we can also see in these two graphs at the bottom. This is soil CO2 sequestration. So it is uptake of carbon dioxide. And then this is just from the root portion, and you can see here as well that you'd get this curve as species richness increases.

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Ecologists have looked to see if these relationships are true across different areas. This paper by Forest Isbell and colleagues used data from 17 biodiversity experiments to try to find general principles of the effect of species richness on ecosystem functions. And if we look at this graph, we see that as species number in an area increases. The number of species that contribute to ecosystem functioning also increases. This is because more species are needed to provide lots of functions. Different species promote or increase different functions. Also, if there are extreme weather events or some kind of disturbance, it is likely some species will be able to continue ecosystem functions if there are more species in the area. So this is what we mean about functional redundancy. Species that appear to be doing nothing may suddenly start doing something in a different year. So this is why we need this insurance.

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But there is a lot of debate, particularly with regard to productivity. This is because it is not always true that more species mean more biomass. Some species may have a bigger effect on the ecosystem than others, and that has nothing to do with biomass. One of the most obvious examples is legumes. In this graph we see assemblages with legumes in the black circles, and those without legumes in the white circles have a very difference when you look at nitrogen content of the leaves. This is what is on the Y axis. Other potential species specific effects includes tap roots that bring up water from deep soil layers and release it at the surface. Or rosettes that keep soil damp. Or the amount of wood in a plant stem, which could slow decomposition because wood is quite difficult to break down. Of course, it all depends on what you were interested in measuring but ecologists began to think that species richness alone is not very useful in explaining ecosystem functioning because different species do different things. But they still needed simple and meaningful ways to explain the effect of species on the ecosystem function.

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So they began to conduct experiments based on different ways of categorizing diversity. When you categorize species based on assumed effects on function, this is called functional diversity. There are all sorts of ways to do this and most people classify species based on their requirements for that experiment. A simple way of classifying is based on morphological type and many people have used grass forb, legume (g f l). This is useful because it keeps legumes in their own section and of course they have a big effect on nitrogen cycling. Unfortunately, you do not get many places with 100% legume cover. So it is not ecologically realistic to set up an experiment with all legumes in one treatment. Lots of groups have been proposed and have varying levels of support for how useful they are to predict ecosystem functioning.

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There is an enormous amount of literature testing the ideas of functional groups being useful for describing ecosystem function. Here we can see that when grouping species by grasses forbs and sedges, whichever type of wetland plant. There are very strong effects of functional group on losses of nitrogen from the soil. So that's leaching, it’s just loss. This experiment shows that there is no difference between having one species and four species. So you see this here. The letters mean that there was a significant difference. So there's a difference between a and b. But ab means that it is no different to b or a. So somewhere in between.

One grass and four grasses is also the same statistically. But there is a very strong significant effect of the Community type. So functional type therefore is more important than species richness.

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Ecologists have turned to functional types to explain species because they have a range of advantages. You do not need to be able to identify the species. So you don't need that much specialist knowledge which can save time and money. There are clear links with function than just having named species. So you're choosing your species for your experiment with a better idea from the beginning of what you expect to happen rather than just throwing in random species. Also functional type rather than species means that you can see patterns in biodiversity or functional diversity and ecosystem function over large areas and it doesn't matter if you don't have the same species over these areas because you're looking at the functional type. So you might be looking at the ratio of stress tolerant to competitive. You might be looking at the grasses forbs and legumes over the space and it doesn't matter what species.

There's also a mechanistic link with function. So, we can have a much better idea of how the plants in the community are actually affecting the functions that we see.

In recent years, there is increasing interest in plant functional traits. Traits or characteristics of the organisms mainly plants, but increasingly insects and microorganisms. People are trying to apply the traits theory to those as well. So traits can be morphological anatomical, physiological biochemical and physiological characteristics of the organisms of interest. So it's quite a useful way to stay away from taxonomy, which as we've said, can be expensive and time consuming. And it's got an enormous amount of support. So traits can be length of lifetime, so one year or many years. It could be tissue chemistry. So tissue nitrogen for leaf nitrogen roots nitrogen, carbon to nitrogen ratios and so on. And so we can link the amount of nitrogen in a leaf with the amount of nitrogen in the soil or that is available in the system and so on. And so there's a huge amount of support. There are enormous databases of plant traits, so they tend to focus on things like resource use of the plant. So does it take up nutrients rapidly and does it decompose fast does the nutrients cycle, very fast. Or does it have very woody or very carbon rich tissues leaves and roots. So that would make it difficult to decompose and it might be more conservative or slow in its resource use and so you can begin to build a picture of what your ecosystem is doing.

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Sandra Diaz and colleagues used these traits to create a global classification of plants. They looked for big global patterns. So here is a type of analysis, called a principal components analysis or PCA. It is used when there is so much different data that it is hard to find a clear message so you can combine all the data into two axes. Looking at the data, you can generally say what each axis explains. So here, each dot represents a species, and all their characteristics have been combined into the two axes. So each trait is one of these so the six traits that have been included in this analysis.

The red spots show that species are concentrated into two major types. This is called clustering.

The arrows show the direction of the traits that are included. So the stem density goes from low to high. You see the direction of the arrow. So this is the most dense- that is quite woody. And this would be very soft non dense tissues. It is clear in the analysis that the stem density is very important.

Because the two main clusters are on the left and the right so they run approximately along this axis.

And you can see in this graph that if you divide them into woody anon woody species that you get two very clear clusters. And so that is why those two groups have fallen in that way. And why stem density is so important. So this means we can divide most species in the world into woody and non woody.

The vertical axis, PC2, this one, seems to be best explained by nitrogen content and the unit mass is just a way to standardize across all the species. So high up on the graph is high nitrogen and low down is low nitrogen.

So the traits are very high tightly connected. Plants have a limited amount of resources. So it is important to note that there will be strong correlations between traits. This makes it easier to find common patterns. And what is interesting is in this bottom right graph is that when you divide the plants into angiosperms, which is deciduous trees or plants, and then gymnosperms, which are evergreen trees that have needle leaves, that there seems to be a nitrogen effect. So gymnosperms are low nitrogen in the tissues.

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So in summary, we've had a look at biodiversity measures and we have seen that scale is very important.

We've also seen that most species are somewhere in the middle. Medium abundance, but there are always some that are very common and some that are very rare. So the numbers of very common species are very high. So a lot of individuals or a lot of plant cover and some are very rare. So, you might only find one individual.

Ecosystem Functions are linked with biodiversity, but this does not mean that all species are ecologically equal. They do not all have the same effect. So therefore, we must consider them in terms of functional type.

And finally, the role of the species must be considered. But general patterns can be found.

Reading

Chapter 14 Begon

Magurran species abundance

Ehrlich & Ehrlich: value of biodiversity