Lecture 3

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Today we are going to talk about a biotic that is non-living effects on the ecosystems and organisms we will be particularly interested in temperature as it is probably the most directly important effect on organisms.

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The learning outcomes for this lecture are that you should be able to name key abiotic limits on organisms, be able to name the two ways animals respond to changing environments.

Be able to name some adaptations to abiotic stress.

Understand the concept of resistance and resilience

Slide 3

Our planet is extremely heterogeneous with oceans, mountain ranges, large continental plateaus and islands. This means that abiotic changes occur on a range of scales. There are extremely hot and dry areas, cold and dry areas, high altitude areas where the air is very oxygen poor and warm wet areas with very high humidity. Additionally, as you go further north or south away from the equator, you get seasons, which offer their own challenges to organisms and living in these areas. Due to the patchwork nature of the planet organisms must be adapted to survive in a range of conditions. This means that the distributions of organisms are extremely patchy in space and also in time. I've included this example of these birds to show how animals distribute themselves through the best places they can complete their life cycle. Birds are more mobile than most animals and can make choices about where they live. Sessile organisms, which means those that cannot move on their own, must gradually move through survival of offspring, if need be. And if a seed lands somewhere inhospitable the plant will not complete its life cycle in that place.

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The geographical range of an organism is limited by a whole lot of factors, working together. I've included a map here of the recently discovered snub nosed monkey in Myanmar, it has been assessed in terms of quality of habitat based on the factors listed here. So climate, habitat constraints, food, and interactions with other species and individuals.

When ecologists attempt to find where a species might be distributed, they need to take into account climatic requirements and other limitations such as vegetation type or location of water sources. Interactions with other species may be more difficult. So would probably be excluded from one of these maps. At a global scale, at higher latitudes so near the poles, animal ranges or distributions may be limited by the coldest temperatures of the year, while at lower latitudes near the equator competition might be a bigger limitation.

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So when we talk about conditions, a condition is an abiotic factor. These can shape the behaviour, spread, size and reproductive rate of organisms.

Fr example, temperature, moisture pH of soil or water and salinity- the salt content of soils or water. An organism can be a generalist and live in a wide range of conditions or a specialist with a very narrow range. Remember how we talked about niche differentiation in the previous lecture. This is one way of achieving that. So openness of an optimal range of conditions and then maximum and minimum where they may have to move or regulate in some way in order to achieve feeding or reproduction.

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While we can look at a map and say that certain locations are not within the range for a given organism, this can be changed by the presence of another type of organism forming microhabitats. Forests are a good example. They have an understory of small herbaceous plants that would not be able to grow if the shade from the trees was removed. Another example is nurse plants. In recent years, these have gained attention by researchers because they may be able to improve the growth of other desirable species. This is known as facilitation seen in this picture here. So some experiments have shown that in very inhospitable areas a nurse plant can increase the humidity and reduce the temperature under the aboveground portion and potentially also alter the soil nutrients and the soil microbial community and this will enable other species to grow underneath it.

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There are lots of ways that we can test the effect of abiotic stress on organisms. Some examples include enzymatic activity, respiration rate, survival and so on. In this picture you can see me measuring greenhouse gases that are coming from the soil, including carbon dioxide methane and nitrous oxide. The plastic roof has created a severe drought and so the very dry soil is releasing less gas than areas in the experiment of that did not have the drought. This is a key point of experimental design. When you create a treatment, such as a drought or a change in temperature, you must have a control that is the same in all ways except the change that you have created, then you can make a direct comparison, and say with confidence that the response you see, is because of that change.

The two main ways organisms can survive abiotic stress is by avoiding, so maybe going underground or flying or running somewhere else, or by tolerating which could mean a behaviour or biochemical shift to survive the conditions. Tolerating could be a risky strategy because it often makes the assumption that conditions will improve at some point, and thus the stress will reduce. If they wait too long though, some organisms might run out of resources and will not survive the stress.

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So life on Earth exists within defined limits. The isobars on these maps define different 10 degrees centigrade ranges and you can see that, while the ocean is relatively stable. There is a lot of variability on land. A lot of this is due to mountain ranges, such as the Andes in South America, and the Himalayas.

When you take water availability into account, for example, rivers and lakes, we can begin to make simple maps of expected species distributions. There are a few rules of thumb that can help with predicting species ranges. From sea level, every 100 meters you go up in elevation, there is a one degree centigrade drop in temperature. You can have an enormous range of species on one mountain just because of the rapid shift in temperature as you go up the mountain. And there's a whole ecosystem, known as alpine grassland for species that are specialized to live high on mountains and cope with long winters with a heavy snow pack.

Secondly, landmasses cause a continental climate. This means that as you move away from the ocean, land temperatures become more extreme hot dry summers, a very cold winters. This can be quite difficult for many species to tolerate and will require some measure of adaptation.

The ocean results in a relatively stable climate and moderate temperature and humidity. As you go further inland this effect declines. The air dries and the land surface reflects less heat. So, therefore, you get more extremes in temperature.

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As the temperature increases, rates of reactions also increase. This means in ecology, the metabolism of nutrients and nutrient cycling in the soil may speed up. I'm going to take soil as an example. Nutrients are cycled by microbes in the soil, if a plant leaves dead roots or leaves on the soil or an insect dies. This will be broken down by bacteria and fungi. These will place enzymes in the soil to digest complex molecules into simpler ones. These will then become available to plants. However, the rate of reaction of these enzymes is closely linked with temperature.

So I've placed an image in the top right corner as a revision of how enzymes work. And you can see that there is an active site where the molecule to be broken down the substrate will be perfectly shaped to fit. The enzyme convention, break it down into smaller components that can be used by plants.

As you increase in temperature, you get an exponential increase in enzyme activity. As you can see in this graph and low as you carry on along the x axis at the bottom, you get an increase in temperature. And the rate of reaction speeds up as it gets hotter until you reach about 45 degrees and then all enzyme activity stops. This is because the chemical bonds at the active site of the enzyme have been shaken apart by too much kinetic energy, the enzyme will be permanently changed and it will be unable to break down the substrate. We call this denaturing.

In a very hot climate plants and animals can have adaptations to keep cool, such as increased transpiration from the leaf, which is water loss in order to prevent overheating and the destruction of these enzymes.

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The paper that I want to look at here by Kearny and Porter in 2004 considers whether certain regions in Australia outside the fundamental niche of this nocturnal lizard *Heteronotia binoei*. Now, this lizard is only awake at night. And these maps are looking at the temperatures that it should be able to survive and be active and feed. And it they assume that there are no species interactions with predators or competitors. So this is the fundamental niche, where the maximum range that the species could be expected to be found.

This lizard needs 600 degree days above 20 centigrade to complete its development. This means that there needs to be 600 days over this temperature. And so the authors could calculate from their climate maps where the lizards could successfully breed. Outside this would be outside the fundamental niche. Southern Australia is therefore too cold. And we can see here in the top left image.

The 600 mark is white. And so anything blue will be below the 600 degree days. And so it is too cold to hatch eggs successfully.

Another constraint on the fundamental niche is potential activity TIME. Lizards are ectotherms. They are cold blooded, so they are very vulnerable to temperature as they cannot regulate their body temperature. Therefore, there are a number of reasons for this potential fundamental niche of an animal, and they must be taken together.

Metabolic costs of ectotherms are dependent on body size, body temperature and cellular machinery. So we are looking at graph C on the map, see here in the bottom left. Again, these lizards eat crickets and need more crickets in the hot and warm than the cooler south.

In this paper, the authors consider all these factors contributing to the fundamental niche, including water which is very limiting in Australia. And they use their findings in this paper to examine the fundamental niche if the climate changes in the future and where this species may be able to live. So that is a really exciting use of science and understanding the potential distribution, the fundamental niche, and the potential for these animals to move in the future if the climate changes and Australia becomes hotter. That's a really interesting study and I will put it on the drive so that you can read it if you're interested.

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Coffee plants, on a slightly different note, are crucial for people's livelihoods in developing countries and subtropical regions. However, they are very restricted in their temperature range. Also the range of temperatures to grow good beans for selling is even smaller. So the optimum is between 18 and 21 degrees centigrade. But in order to grow good coffee, you need a much smaller range.

Yield of coffee is therefore closely linked with climate in the subtropics where it is best grade. There is some seasonality. If there was a frost, which is where the temperatures up to nearly zero degrees centigrade and ice forms on the ground. This can kill the crop of coffee, and place severe financial hardships on growers. As climate changes the range of coffee is forecasted to shrink as in the map, shown here. So you can see that as the optimal range at the moment is quite large in Ethiopia. But in the left hand graph, you can see that the red, which is the predicted surface, is a lot smaller than the current range.

Understanding this range of identifying locations where coffee will still be able to be grown in the future is very critical to maintaining food security, identifying vulnerabilities of cash crops will be critical for people in the developing world.

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So let’s turn our attention to the cold. Chilling means that temperatures have reached a few degrees above freezing. Low temperatures can be a problem for many organisms. Their metabolic rate and enzyme activity will be very low, and they will need to use energy to keep warm. This may involve shivering or huddling together like these monkeys in the picture. They are huddling.

If the cold period goes on too long into the spring, this can cause many problems for plants and animals. I've listed here some of the potential problems.

But the main point is that if plants are damaged or don't have time to grow and produce fruits and seeds before it gets cold again, this can mean problems for their reproductive success and the ability of animals to find food in that year.

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Cold temperatures are often more limiting to life than hot. If we look at this set of graphs, the largest graph on the left a shows how tolerance limits change with latitude. This is a very useful paper and I can also make this available. In the middle, the zero latitude is the equator. So if you see the zero at the bottom on the bottom line. This is usually the warmest location. We can see that, while the temperature tolerance limits of hot end in red do not vary much with latitude of the cold and in blue, there is a very big effect of latitude. You can see that the lines are very steep.

At the equator cold tolerance is above 10 degrees centigrade above freezing. So organisms that live at the equator have very poor cold tolerance. At the poles, it is about five degrees below freezing. And that's because organisms in these areas regularly experience these kinds of temperatures and therefore must survive them. On the right, we can see how these limits are affected by elevation or altitude, at different latitudes. So at the top we have the equator. And we can see that as you go up the mountain, everything is quite far above zero. Whereas, by the time you get towards the poles the cold tolerance is actually very far below freezing. So as you get higher, organisms can tolerate the cold better.

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Now freezing temperatures are even more of a problem for species because certainly for plants and also some animals and microbes, ice crystals can form inside cells and damage cell machinery in plants. This can be catastrophic. Because photosynthesis depends on a very delicate and complicated set of machinery. Therefore, in areas with a cold winter or at high latitudes species have evolved a broad range of adaptations to cold. For plants, this is often completing a cycle of growing leaves fruits or flowers, then setting seed before the cold weather comes around again while in boreal forest, the trees have developed thick needles instead of leaves with a waxy layer that will stand the cold.

Many animals such as bears will hibernate, which means they must build up fat reserves when there is a lot of food available during the summer in order to survive the winter. Some organisms have developed biochemical adaptations to prevent freezing, such as this meal worm beetle that has developed a form of antifreeze to stop its cells freezing

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Many environments are subject to changes that occur regularly and this inbuilt variation comes in three ways. It could be cyclic, where variables go in regular cycles, such as day to night, which is called diurnal or seasonal changes. There are also directional changes where conditions or environments change gradually over time. Finally, there are stochastic or erratic changes. The things that occur randomly and possibly unpredictably, stochastic changes are a source of fascination for many ecologists and investigating the size of the response to the change and the amount and time taken to recover are a big part of ecology.

So this is where we talk about resistance and resilience. Resistance is how much a species will change in response to a change or perturbation, which is a disturbance, and resilience is how much it will recover and how quickly.

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Organisms adapt to survive through changes in their environment, especially if they are in a season or location and live for multiple years. Remember how we saw the deserts of the most water limited systems on Earth? They have a plant community that can complete an entire life cycle in a few days.

Rain will come once a year, but when it does plants can grow from seed, flower, set more seed and die, in the span of under a week. And here is an example of the Atacama Desert when two days after rain in 2017 and you can see how the flowers have just taken this opportunity.

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In higher latitudes seasons can be identified by changing day length. Many organisms are tightly dependent on one another and feeding and reproduction are dependent on certain events being timed exactly.

Phenology is the study of the impact of cycles, such as day to night or seasons on life cycle events like leaf buds appearing or birds laying eggs. There are lots of ways to predict when these events might occur, but because every year is different and the end of winter, and the last frost could occur any time over a three month window of time, a tool called degree days has been developed.

Degree days are often counted as the number of days since January 1st that are over a certain temperature for plants to grow. The threshold is often set at five degrees centigrade and for insects zero degrees centigrade. So by adding the degree days you can compare between years, even if the end of the winter is very different between years

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In this example, by Dr Sophie Bell, we can look at the timing match of oak bud burst caterpillars appearing and Blue tit chicks hatching. If the caterpillars hatch earlier or later than the oak bud burst, (when the leaves start to appear and they're very small and tender), they will not have food because they need to eat very young leaves. Now the blue tits must lay their eggs about 50 days before oak bud burst, so that the chicks hatch have a perfect time to eat the caterpillars. If they miss this window the chicks will not survive. Therefore, it is vital that there is a perfect match. If spring is late, this could mean that the blue tits do not raise any surviving offspring that year.

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To summarize this lecture.

Organisms must be able to avoid or tolerate abiotic conditions. This is critical in order to survive very unpredictable changes in temperature and moisture and duration of winter.

Geographic ranges occur through a mixture of different factors including temperature water availability and other organisms being present in the same location.

We have seen that cold temperature has a much more important role in determining species distribution than hot temperatures.

Seasons can result in a lot of different effects and many interesting problems for organisms.

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So today we are going to discuss the topic of nurse plants. How can organisms, change the habitat to make other organisms more able to survive.

And then we're also going to talk about organisms that impede or make problems for other organisms. How can they reduce the ability of other organisms to survive.

So I will see you later at our breakout session.

Reading

Chapter 2 Begon

Bruno et al. Facilitation

Kearney & Porter lizard niche. Have a look at the figures and the explanation