Course Name: I Think Biology

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W11L57_Biology and Climate Change - Part 3

Hello and welcome to the I-Think Biology NPTEL course. This week we are discussing biology and climate change. In the first lecture in this series, I introduced the concept of planetary boundaries. The planetary boundaries are nine processes that keep the Earth system in equilibrium, such that all biological organisms can continue to live and thrive on Earth. Shown in the image is a progression of how many boundaries have been crossed since the concept was introduced in 2009. So if we look at 2023, we see that six boundaries have been crossed, which means now we are entering a zone of great uncertainty on how the Earth system will respond to these changes.

Climate change is one of these planetary boundaries. In the second lecture, I looked at climate change in particular and more specifically at global warming. So the graph on the left plots global average surface temperatures over the last 2000 years. And if you look at the period between 1850 to 2020, which has been marked, you'll see this upward spike. And this warming has not been seen in the last 2000 years. And in fact, this is the warmest period in more than 100,000 years.

The graph on the right shows us the change in the global surface temperature, which has been observed and then simulated using human and natural factors. And as we can see, only when we account for human factors, does it explain the warming trend which is shown in the graph, which means that human activity is responsible for global warming.

In this lecture, we will look at the effects of warming on the biosphere and we will do so at three different scales, the global and the ecosystem level and at the individual level.

I should mention that these are categories that we have created for convenience and they are porous, which means that whatever is happening at the ecosystem level can very well be applied to the global level also. At the global level, we will look at range extension or geographical shifts in plants and animals. We will look at phenology or changes to seasonal timings and we will look at the phenomenon of forest dieback. But before that, I thought I would make a motivational slide for this lecture. And here is a quote by the executive secretary to the United Nations Convention on Biological Diversity.

And the quote says that climate change is a primary driver of biodiversity loss. And climate change depends on biodiversity as part of the solution. So clearly the two are linked and cannot be separated. And how are they linked? Is by the fact that about one third of greenhouse gas emission reductions which are needed can be achieved by improving nature's ability to absorb emissions. Because ecosystems are natural sinks for carbon.

So we have to make sure that we keep natural landscapes and areas intact and not allow diversions for agriculture, for logging, for infrastructure projects or for urbanization. And only then can we preserve biodiversity and in fact fight climate change.

So coming to the global effects of climate change. So climate change has seen to cause large changes in plant and animal distributions. And these are geographical shifts which are happening because plants and animals tend to occupy a particular niche where the abiotic factors are optimal for their reproduction and growth.

And now warming is causing a change in these particular habitats causing plants and animals to change their distribution. For instance, in the northern hemisphere, it has been, there has been a latitudinal shift and plants and animals are seen to move northwards. And if you look at things like mountains, in a mountain ecosystem, you're seeing elevational changes where plants and animals are moving upwards in response to warming.

So coming to specific examples, here is an example of changes which have been observed in flora, in the eastern Himalaya. The study site was in Tibet and they looked at three different mountain ranges within Tibet and what was seen by the researchers as shown in graph C is that there was a warming trend from 1985 to 2010 where on average they observed a warming of 0.03 to 0.05 degrees centigrade per year. With the effect that over the seven years of study in their plots, they saw that alpine vegetation increased in the number of species which were seen, in the frequency of occurrence of these species and even in diversity, which could only be explained by plants moving into these plots, into their study plots. And rather unexpectedly, they saw that endemic species increased their presence at higher elevations. This is surprising because endemic species typically have a very small range which they occupy and the fact that they were moving upwards meant that conditions were becoming suitable for allowing their growth.

The other study we are highlighting is long-term monitoring of birds in the eastern Himalaya and this is a whole range of studies which has been done by Professor Umesh Srinivasan at IISC and his co-workers where they have been tracking bird populations in Arunachal Pradesh over the last decade and this has been done mainly by mist netting and capturing birds, measuring their body parameters, marking them and releasing them and then you basically repeat the same process over the next breeding season.

So as I said, their study site was the Eagle Nest Wildlife Sanctuary and surrounding parts within Arunachal Pradesh and they looked at two effects, that of climate change and habitat degradation. And what they found was that the patterns of occupancy or occurrence of birds was consistent with upslope range shifts which meant that species which were below a particular hotspot in terms of elevation were now moving into that hotspot because conditions were suitable for such a movement and species which occupied a range in elevation above that hotspot were now seen to have a reduced occurrence or probability of occurrence meaning that they were now no longer found at that particular range and may have moved higher up in their range.

The other thing they noticed was that body size seemed to be getting smaller and this could be explained by the fact that as you get smaller in body size your surface area will increase allowing you to cool faster if the temperature is warmer. And we made this point about surface area and volume in the lecture on numbers and scales and I encourage you to go and watch that if you need to brush up on this concept. So these researchers made the point that these rapid shifts in range that they observed over the past decade could present a problem and could in fact cause a local extinction because species which were moving up in range might just run out of area or run out of mountain in which to move to.

And the other possibility is also that they could face indirect effects such as increased competition because a new species is now moving into their range and could be competing for the same resources. I'm highlighting one study done by this group but I should mention that they have other studies on the same topic and I encourage you to go and look those up.

So to summarize, plants and animals are shifting in their spatial distribution to track their climate niche. So basically biodiversity is being reorganized on a global scale and these shifts can cause local extinctions as species run out of space or there could be other effects such as they could face competition causing a drop in population. And the other point which has been made is that habitat change or in fact habitat degradation could be just as important in deciding the level of change which has been seen. So these are two effects of climate change and habitat degradation which kind of go hand in hand.

Moving on to another effect of climate change which is that of change in phenology. So phenology is just the timing of the annual cycles of plants and animals which is the seasonal, basically the seasonal changes in their life history and we can think of it as basically tracking nature's calendar. And this has been shown to be extremely sensitive to changes in climate, specifically temperature. And the schematic here makes the same point that in fact if you have, plants will have a definite phenology where in the springtime you will have young leaves come out or there's a leaf flush and in fact insects or caterpillars depend on this leaf flush in order to feed on them so there's an increase in herbivory or when plants flower or fruit you can have an increase in the number of pollinators or nectar feeding birds or when they fruit you can have feeders on the fruit which will drive the cycle and then going on to when plants drop their leaves there is leaf decomposition and the cycle continues.

So this phenology is a driver of ecological processes and any change in this timing will cause a change either upwards or downwards in any of these processes which has been shown here which is basically herbivory or pollination or seed predation or dispersing, making the point of the intimate interconnection which is seen in various biological taxa. So in fact phenological shifts are the clearest indicators of climate change or global warming and this has been shown here in one of the most famous studies on phenology which looked at the emergence of cherry blossoms which is a national event in Japan and this has been documented in their books since 1812 and in a study done by a researcher in Japan where he tracked all the records which had been mentioned.

For 2021 it was the earliest cherry blossom peak since 812, 1200 years ago making the point that plants are advancing either flowering or fruiting times and in fact on average it has been seen that plants advance their flowering time approximately by two days in response to every one degree rise in temperature. Researchers are also keeping track of phenology within India. The map shows study sites and there is a large concentration within South India and the Northeast and the graph shows the phenology for one particular tree species where it was tracked over a four year period from 2013 to 2017 and we see for leaves which is the bright the line in bright blue there is no seasonality which is seen whereas for fruits and flowers there is a peak between week 10 and week 20 and these studies still continue so these researchers will be tracking the changes which are now seen in response to climate change.

Another study which came out recently tried to simulate warming and this was done on the Tibetan plateau where they had plots either control plots or plots in which they induced heating by inserting heating rods or cables into the ground and then they looked at the effects of warming on plant communities within these plots on the microbial community and on soil invertebrates. So tracking the growing season as early, middle or late for these three taxa they saw that there was no difference between in the plant growth activity both for the control plots or the plots that experienced warming although there was a higher activity seen for plants. Coming to soil microbial activity which is basically looking the respiration which was measured which basically tracks their metabolism so although there was no change in the peak in the activity there was an increase in the peak which meant the microbes were more active and then looking at soil invertebrates there was indeed a shift in the peak and they were more active earlier in the season rather than later in the season showing us that warming does produce large changes in the ecosystem. This study is interesting because it is looking at soil microbes and soil invertebrates which is not normally done and these are very important indicators of the ecosystem. So phenology mismatch can lead to drastic changes.

So we now know from many studies that the timing of flowering or reproduction has advanced for many plant and animal species and this is important because especially for reproduction there is a limited period or an optimum time in the year when conditions are favorable enough for reproduction and so if this window of opportunity is missed out then this can have very large fitness consequences for the progeny which is produced and indeed this can lead to a mismatch between phenology for different species for example for plants or insects and which can then lead to a decoupling at the trophic level because if the timing is mismatched then trophic levels are also disrupted and this can lead to a biodiversity loss.

Shown here is data for that and so if we just look at the graph in C this tracks a predator-prey relationship for great tits which are birds and their prey which are caterpillars and the period shown is a 20 year period from 1984 to 2004 where we see that the emergence of caterpillars is now advancing year upon year and it's showing a downward trend. But as for great tits what has been plotted is their egg laying time and that is horizontal which means that there is no change in the date of egg laying and so which now means that when the fledglings emerge out of the egg and they are in need of highly nutritious food which is basically caterpillars, caterpillars might have already emerged and then pupated and there could be a severe reduction in the prey base for these fledglings causing a loss in the population of these birds.

Looking at insects in particular the infographic here is shown for insect pests but we can generalize for all insects so increase in temperatures can have varied effects on insects. For instance you can have an increased number of generations just because the growing season is now longer. You can have an expansion in geographic range. You can have a desynchronization between insects and their predators or natural enemies because their cycles are now different and of course you can have a loss of synchrony with the host plant on which insects lay their eggs.

So you can have a range of effects of warming on insects and this is shown here in this flow chart where you can have different effects which are direct effects which can lead to indirect effects on insects. Finally another effect of warming which has been seen globally is that of forest dieback. So forest dieback is basically tree mortality which is above the expected or normally observed rate and forest dieback has been seen because of prolonged periods of drought which plants, i mean trees have experienced and this can lead to either direct mortality or this can cause a disruption in the immune system of plants which means they are more vulnerable to pest attacks which can also then lead to mortality.

And as can be seen on this map forest dieback has been seen in all forests across the world and there has been a recorded instance within India also. And more recently forest species have shown increased mortality and there is one documented, one from a very specific and unique ecosystem which is that of the Shola grasslands in the Nilgiris which are basically very dense forest patches which are contiguous with these grasslands and both these habitats work in synchrony with each other and each is critical for the other. Now within these high mountain species frost is critical for the plant growth and with warming there are now less days with frost which means that plant growth is affected thus also affecting plant mortality. Moving on to ecosystem level changes we will look at two studies one is on ocean warming and coral reefs and the other is looking at the spread of Lantana camara. So coral reefs are found in the tropical zone as shown on this global map and they are very diverse ecosystems and they provide an extremely rich habitat which can house a very large number of creatures both because they provide spaces for both predators and prey within them and the other thing is that they create a physical barrier and provide protection against sea ingress or inundation for very low lying islands.

Corals are marine invertebrates and they grow as polyps and they have a very hard exoskeleton which is made up of calcium carbonate. They also form a symbiotic relationship with a photosynthetic algae and there are a number of species and they are called as Zooxanthellae and apart from providing the coral with the products of photosynthesis the algae also has fantastic pigments which is what gives rise to the rich colors that you see in coral reefs. So what has been observed over the last two decades is that corals can also bleach basically leading to the death of these very rich ecosystems and on the map you can see that the range of bleaching can be different so going from blue to yellow you have a higher range of bleaching which has been shown and this pattern of bleaching has been especially concentrated within 15 to 20 degrees north and south of the equator so tropical mid-latitude sites and it is largely due to thermal stress or warming but temperature doesn't seem to be the only effect which is driving bleaching and what seems to happen is that at high temperatures because the algae might be producing more reactive oxygen species which could cause harm to the tissues of the coral, the coral tends to kick out the algae because of which they now there's a loss of pigment but also b there's a loss of nutrients for the coral leading to the death of the coral and severe mortality within these corals and also bleaching of the coral.

So within India this has been studied in the Lakshadweep islands shown in the image is the Karavatti Atoll which is one island in the Lakshadweep and what has been seen is that there are three recorded instances of coral bleaching in the Lakshadweep 1998, 2010 and 2016, so if you look at the graph that plots seawater temperatures across the years I mean across the months for one year which typically peak in May and the dotted horizontal line shows you the bleaching threshold so if seawater exceed that temperature then coral bleaching is observed and this threshold which is at 30 degrees centigrade was exceeded in 2010 which is the thin red line and again in 2016 which leads to this large scale bleaching which was seen in the images below. Now the reef seems to be more resilient than was previously thought so there was some recovery seen after the 2010 bleaching event but the resilience of the reef is obviously compromised and its ability to now rebound back from a subsequent shock which could be another bleaching event is reduced so more warming can cause more and more bleaching.

The other study that we are looking at is of the spread of invasive species and this report looked at the spread of Lantana camara in the Himalaya specifically at a particular place in Uttarakhand. So shown on the map are the different regions and there's the subtropical region which is marked in pink and then you have the temperate regions both warm which are shown in yellow and cold which are shown in blue and the black dots mark the presence of Lantana in this geographical region. What the researchers then tried to do was try to model how Lantana will spread given different warming scenarios which is shown here on this graph. So the y axis is basically the area in kilometers squared and we can see that there's an increase which is expected under different warming scenarios which the researchers simulated and they also looked at the effect of habitat degradation so basically the change in the forest area and they also looked at the effect of fire on this. So these three effects will compound and act and cause an increase in the spread of Lantana camara as shown in the graph.

So Lantana camara is a huge problem in Indian forests and there are many reports on how it can lead to a loss in biodiversity across different forests in India and you can look up these reports which are highlighted here on the slide.

Finally we look at physiological effects of climate change and the study here is on a marine fish which is called an eelpout and what this study showed was that because of warming there was a serious constraint on the oxygen transport which led to a population decline of this marine fish in one particular location. The interesting thing was that even though the temperature range, the temperature increase which was seen did not threaten the survival of the particular fish but the population still declined and this was thought to be because the temperature increase is now affecting the growth and reproduction of this fish which has a smaller temperature window, optimal temperature window in which this can happen which is shown in these graphs.

So if you look at the graph at the top typically any organism will show the curve which has been shown in pink which is that our metabolic rate will increase with temperature up to a particular point and then will show a serious crash and similarly if you look at the performance of an organism say over its life it will have a particular temperature at which this performance will peak so we can think of performance as a parameter such as body size and so an optimal temperature will give rise to the best body size for a particular species. But if you look at other parameters such as the activity or the growth and reproduction, then we see that for these processes the temperature window is much narrower especially for growth and reproduction so if this temperature is exceeded that will lead to less growth and reproduction in the species leading to a drop in the population.

So making the point that rather than death being due to increased heat it's because there's a lowered scope for growth and reproduction which causes the population decline and so the takeaway is that you don't need a large rise in temperature to experience a sharp population decrease and we are actually seeing this even within humans because warming also places a large stress on our cardiovascular system and you see heat related deaths increasing in the summer globally.

The same point is made here for another study which was for a Himalayan species that of the Snow trout where they looked at the distribution of this fish in rivers across Nepal and then tried to model what would happen under various warming scenarios and they saw that the space available for this fish in which to breed would reduce because only certain rivers would have the temperatures which are conducive for reproduction and growth making the point that small temperature shifts can have drastic consequences for particular species.

So to summarize we looked at warming effects on the biosphere at these three different scales using different cases and I urge you to read up on all of these which I have mentioned here in this lecture. And finally we can think about the effects or how biodiversity will change under climate and global warming by looking at these various aspects. So we can look at and predict how land use changes will happen and how that will affect biodiversity.

We can look at physiology which is the case study which I just showed and so ask how are animals or a particular species responding to warming in terms of its body so energy and mass balance. We can look at population levels changes so look at demography. We can look at dispersal so basically how our species responding and changing their spatial distribution or we can look at interactions so insect plants, predator prey and finally we can look at questions of evolution so our species actually evolving in order to respond to climate change. And so using this kind of umbrella we can try and study the different aspects of biodiversity and ask how each of these facets is getting affected by climate change. So with that I will end my lecture and we can pick up any of these topics in the tutorial slot. Thank you.