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Online Open Course - Species Distribution Modelling

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Module 9 SDMs and climate change projections

Welcome to module 9 of this online open course about species distribution modelling. In the first 8 modules of this course, we have learnt about the different aspects that you need to design a species distribution model: the data and the different algorithms that you can use to predict species distributions, and how to evaluate the outcomes of your model. With all that knowledge in our back pocket, we can now look at an important application of species distribution models: the prediction of species distributions under future climate change projections.

We all know that our climate is changing due to anthropogenic influences, and that this will affect all ecosystems and the species living in them. And as we learned pretty early on in this course, the survival of a species is largely influenced by the environmental conditions of the areas that they occupy. We also learn that we can use the relationship between the locations where a species occurs and the environmental conditions of those locations in a correlative species distribution model, and predict which areas are suitable for a species to survive.
This means that if the environmental conditions are changing, the distribution of a species will also likely change. Species distribution models are therefore a good tool to predict how climate change might affect species occurrences and survival.

Let’s first look at how species are affected by a changing climate. First of all, there are direct effects when the environment changes in such a way that it reaches beyond the tolerances of a species. For example, an increase in temperature can limit the survival of species that are not able to withstand warmer temperatures. But there can also be indirect effects of a changing environment, even if a species is able to survive in the new conditions. For example, a warmer and drier climate can change the vegetation in areas, which might reduce essential food sources for a species.

There are several ways in which species can respond to climate change. They can change their behaviour. For example, plants can change their timing of flowering and fruiting to follow changes in seasons, and animals can change their timing of migration or when they are active during the day. Changing behaviour is a form of adaptation, but species can also show evolutionary adaptations to be able to survive in new environmental conditions. Another response is to move to different areas where conditions are still suitable. And unfortunately, if none of these responses work, it is likely that species will go extinct. Species distribution models mostly come into play to study the two latter responses: the potential of species moving to new areas, or the decline in suitable habitats leading to the extinction of species.

So how do we combine species distribution models with climate change projections? You start with building a species distribution model as we have seen in previous models: you select your species data and environmental data, and put these into one or more algorithms. The output will give you the predicted distribution under current climate conditions. You then add another step to the model, in which you take the outcomes of your species distribution model under current climate conditions and project these with future climate datasets to obtain a prediction of where your species could occur in the future under a particular climate change scenario. Keep in mind that the correlations between species distributions and climatic variables under current climate conditions may or may not hold true for the future.

Let’s have a look at these climate change projections in more detail. Across the world, there are thousands of recording stations that measure daily temperature and rainfall. Through these measurements we have acquired a pretty good understanding of how climate has changed over time. But how do we know how these trends are going to continue in years that are yet to come? Based on the knowledge that we have about physical and chemical processes, and interactions between the atmosphere, the biosphere, the land and the oceans, scientists have built models that represent the earth’s climate system as shown in this diagram. These models include natural processes, such as the radiation that the earth receives from the sun, but also human impacts such as the emission of anthropogenic greenhouse gases. By simulating different scenarios, for example with different concentrations of carbon-dioxide emitted by human activities, we can predict how our climate is going to change, and estimate future values for variables such as temperature, rainfall and sea levels across a range of possible trajectories, some of which are more likely than others.

In 1988, the IPCC, the Intergovernmental Panel on Climate Change, was established to assess scientific information about the risk and impacts of human-induced climate change. The IPCC is advised by thousands of scientists and experts and so far has published five assessment reports. In 2000, they published a Special Report on Emission Scenarios, commonly called the SRES scenarios. These scenarios assume that no efforts are made to limit greenhouse gas emissions, and they were used in the third and fourth assessment report. In 2010, a new method for predicting different scenarios was published, and the new scenarios, the Representative Concentration Pathways or RCPs, were adopted by the IPCC in their fifth assessment report. I will explain the RCPs in a bit more detail.

There are four different RCP scenarios: RCP 2.6, 4.5, 6 and 8.5. The numbers refer to radiative forcings measured in watts per square meter by the year 2100. This represents the global energy balance, measured as the difference between the amount of energy from the sun that the earth absorbs and the energy that is radiated back to space. If there is more energy absorbed than radiated back to space, the earth will be warming. Each RCP defines a specific trajectory with projected outcomes in the year 2100 for how much the planet has heated up, and the concentration of greenhouse gases. So, how did we get to these particular predictions?

Let's first look at the annual carbon emission scenarios that match each of these pathways. This graph shows the emission of carbon in Gigaton per year. We are currently emitting around 10 Gigaton per year. The most negative pathway, RCP 8.5, predicts emissions three times as much as our current emissions by the year 2100. RCP 6 shows an increase in emissions for the next 60 to 70 years followed by a decline. RCP 4.5 shows a shorter period of increase before the decline, and the most positive pathway, RCP 2.6, shows a decline starting very soon. These predictions just illustrated possible pathways, and are an indication for what might happen depending on the actions that we take to reduce carbon emissions.

The pathways are based on assumptions about a range of factors that affect the earth's climate system, such as economic activity, the use of energy sources, population growth and other socio-economic factors. To highlight a few of these factors, for population growth, it is clear that an ongoing increase in the number of people on the planet will lead to the most negative pathway, RCP 8.5, while the other pathways depict a more stabilizing world population. If we look at the different types of energy that we will primarily use, all pathways expect a significant increase in energy use, but to follow pathway 2.6, 4.5 or 6 we need to increase our use of bio-energy and green energy and limit the use of fossil fuels. Another important factor that affects the climate system is land use, and this graph shows the amount of hectares used for grassland for each of the pathways. RCP 8.5 represents an increase in use of grassland, which is mostly driven by an increase in the world population. For RCP 2.6, the use of grassland is relatively constant, which is the result of a shift from more extensive to more intensive farming, while for the intermediate pathways, 4.5 and 6, changes in land use are much stronger implemented with a decline in grassland use. These are three examples of how various factors are taken into account in the development of the Representative Concentration Pathways.

To summarize, RCP 8.5 illustrates the pathway that we are likely to follow if we continue to do what we do today, the 'business as usual' pathway. This means that we won't take any actions to reduce carbon emission, the world population will continue to grow to about 12 billion by 2100, we will rely heavily on fossil fuels, and continue to use an increasing amount of land for cropland and grassland. It seems to be clear that this is a very unsustainable way forward, but we need to undertake action if we want to make sure the trend follows one of the other pathways. RCP 6 and 4.5 illustrate intermediate pathways that are based on scenarios in which we apply a range of technologies and strategies to reduce emissions, such as reduced use of grassland and fossil fuels. RCP2.6 illustrates a very ambitious pathway in which we reduce the usage of oil, stabilise the growth of the world population, and increase our production of bio-energy. This is the only pathway in which the temperature increase will be limited to a 1.5 degrees increase relative to pre-industrial values, which was the agreed limit in the 2015 United Nations Climate Change Conference that was held in Paris.

So the RCPs give us an indication what consequences our actions might have, and they showcase different scenarios with regards to global warming. These are used in combination with General Circulation Models, or Global Climate Models, to predict future climate, thus what temperatures and rainfall values we can expect in particular regions.

Across the world, there are 27 different research groups, who have constructed one or more general circulation models. You might wonder why there are so many different models, can we not just use one? Well, the basic structure of these models is the same, but each of the research groups make different choices about which submodels they include and which of the earth system processes they want to emphasize. This can for example be based on local conditions. Of course these research groups do share their knowledge with each other, and have set up a working group that compares the different models. This is the Coupled Model Intercomparison Project (CMIP), which has been an ongoing project since 1995. When you run a species distribution model and you want to project the results into the future, you have to choose which General Circulation Model you want to use. If you are modeling a species that occurs in a particular country or continent, you can select a model that was developed by the research group in that region.

So, if we look back at our overview of how to run a species distribution model in combination with climate change projections, I hope it is clear that for that climate change projection, you need to take into account two things: the Representative Concentration Pathway, and the General Circulation Model, or Global Climate Model that you want to use.

When we talk about current climate, we usually refer to a recent period of approximately 30 to 50 years. WorldClim data for current climate, for example, is based on climate data measured between 1950 to 2000, whereas the current Australian climate data refers to the period from 1976 to 2005. It is wise to check whether your occurrence data fits the same time frame as the climate data that you are going to use, and if needed, clean the occurrence dataset to eliminate historical records that were collected long before the time frame of the climate data. Future climate data is often indicated by a particular year, but it represents a multi-year average around that particular year. For example, WorldClim provides future climate projections for 2050 and 2070, in which the 2050 projection is the average between the years 2041 and 2060; whereas the 2070 projection refers to the average between 2061 and 2080. The future projection for Australian climate represents 10-year time intervals from 2025 to 2085 in which the projection for 2025 refers to the period of 2020 to 2029, and so on.

The approach of combining species distribution models with climate change projection has been widely applied to a variety of species, and the results are quite alarming. The general pattern that we see is that species are moving higher up in the mountains as areas at lower altitude are warming up, and species are moving towards the poles following colder climates. For example, many species of mountain frogs are affected by climate change as increasing warm and dry conditions reduces suitable habitats. This has already lead to the extinction of this golden toad that lived in the cloud forests in Costa Rica. Research has also shown that over 50% of European butterflies and birds shifted their range up north, some as far as 240 km from their original occurrence sites.

Before you go and explore how climate change might affect your species of interest, I would like to give you some food for thought and briefly discuss the uncertainties regarding species distribution models under future climate change projections. As I have mentioned in other modules of this course, models are only a representation of the real world based on our understanding of species and their environment. Because we do not have detailed information about the tolerances to different environmental variables for each species, we make assumptions based on their current occurrence sites. We are, however, limited in our understanding about how both animals and plants will adapt to changes in climate and their environment, and whether they are able to move to new areas with suitable environmental conditions. Another point to note is that species distribution models often focus on predicting the current and future distribution of one or maybe a few species, not taking into account the interactions between species. While some species might be able to adapt to climate change, if their food source goes extinct or disperses to other areas this might indirectly affect that species as well. As I explained in module 3 of this course, scale is an important factor of both species and environmental data that is used for a species distribution model. Climate variables are typically modelled at larger resolutions like 10 km grids, while species might respond at much smaller spatial scales, for example if their home range is smaller than the climate data resolution. Lastly, of course climate change is not the only factor that affects the distribution of species. Other impacts such as changes in land use can also drive species to go extinct or to move to other areas, for example if essential habitat is cleared as a result of deforestation or urbanisation.

I hope I have shown you in this module that species distribution models are often not used in isolation, but in combination with other models like climate change projections. These combined approaches are very powerful to predict how the distribution of species can be affected by our actions. The next module is the last module of this species distribution modelling course. We will have a look at some case studies and I will introduce you to the BCCVL, an easy online tool that you can use to run these kind of models without the need to write any code yourself! I hope to see you back there!

Attribution

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