So hi everyone, this is the practical to go with the third lecture of my series looking at population modeling and i'm going to have a look at a kind of a mock up population model using that those matrix models that we talked about in the lecture. To have a look at a sort of an introductory way of modeling an elephant population as we talked about. So i'm going to using this software called R and R studio, which is a statistical program and that's often used in biology. Don't worry too much about actually the kind of nuts and bolts of how it works.But I will basically what what we do in this program is we write code in this script up here, let me run this code and it gives us outputs of numbers down the console on the bottom left, and it also gives us graphs and plots and things on the right hand side here.

And so yeah I won't run into too much detail about our works, but it's Just to give you an idea of how these population models can be run in practice. I've used this this software to construct a black rhino population model myself. It was a bit more complex than the one we're doing here, but the basic principles are the same. And so it shows you how people can use this kind of software which is really available, as I said in the lecture, but it does require a bit of learning a bit of experience to be able to use it properly to model a population in practice.

Okay, so we'll get going. So the first thing we're going to do is load in some Leslie matrices which are the matrices of vital rates, of birth and death rates that we talked about in the lecture, and so the things to talk about if we look at them here.

Looking at the printout here at the very bottom, this is our Leslie matrix so we split our elephant population up into four different groups. So as we saw with that diagram of the rhino population with the six circles and all the vital rates in the lecture, only in this one, we only have four age groups for elephants. On the top here, we would have our fecundity rates so as we can see the first three age groups, the yearling one to five years, five to 15 years don't breed. So it is only after 15 that this population of elephants is breeding. We then have our survival rates, these are a bit different to the example that we saw in the lecture. So the first number here, 0.92 shows us that 92% of yearlings survive and transition to being one to five years, because this is based on annual rates of survival and this first each group is only more to one all individuals or survive have to move into the next age group. However, it's not quite the same as for the other age groups, so this number here, which is the same row as the year they want here. This shows is that 73.6% of all one to five year olds are surviving but staying in the same age class because they haven't reached six years old, yet haven't become haven't crossed over the threshold into the next age bracket. However, every year 18% of those individuals are surviving and transitioning to the next age bracket which is this one to five to 15 years here.

And then the same to the next age bracket. 88% of all five to 15 year olds are surviving and staying in that age bracket and then almost 10% so 9.8% of these five to 15 year olds every year are both surviving and transitioning into that reproductive age class over 15 years old and then this is because this is the highest age bracket they can't progress from 15 plus to anything else.Every year 97% of all individuals that are over the age of 15 survive and that's the oldest age bracket they can be in.

And so that's just a description of the vital rates, we have here. And then the other matrix we have just introduces a bit of variability into our projections. So it's not going to be that exactly 97% of all of our 15 plus individuals survive every year it's not going to be exactly the same every year due to some that stochasticity that we talked about. It does affect small populations more heavily than others. However, it does affect all populations, it just has less of an impact on the overall population growth rate and size of those big populations. And so what we're doing here with this Fr is we're introducing some random variation into our survival and for quantity rates.

So basically what we're gonna do is we're going to tell so say we take the breeding rate here the top right we're going to tell our model to randomly very the amount of 15 year olds that are breeding by 20% every year. It's modifying the normal 3% by 20% of that so that three and a half percent will move by 20% of that so only going to move a little bit every year.But it just introduced some variation to our model so that it's not deterministic there's some chance in there. And that is often what population models want to do, because they want to try and reflect that real world situation where chances influencing the number of breeding and death events that happen every year it's not just based on that deterministic definitely 97% will survive every year.

And so, when we've done that we're just going to split our Leslie matrix up. The first one is mortality rates, the second one is just fecundity rates, you know it's wherever that is just to try and make it a bit easier to actually run the model. We're just going to run this model with one time step. So what we do here is, we are taking our starting population size and structure which is 100 yearlings 418 one to five year olds 1724 five to 15 year olds and 3244 15 plus year olds .And we're going to run our population model using our death rates are birth rates and by introducing some of this variation I talked about so we're just going to shift those vital rates by 20% randomly either direction. So, as we can see if we didn't have a one time step from time T to time T plus one we predict that the next year. This is going to be the population structure that we see so it's going to vary a bit, but it hasn't had enough time to vary massively from that first time set, because only one year and forwards. So we can just keep running this one. This one code over and over again, so when we're doing it here we actually. This just demonstrates that that variability can occur because we're taking this same population starting size, every time we run this this line of code. And every time we do it gives us a slightly different answer which is because of that variation we're including into our model so that stochasticity of it, rather than doing it manually into running it, year after year, like that we can do bit of code that does it for a particular times the future. We don't want to just do it once we want to do it several times, so that we can see, we can get an idea of how variability impacts our population projections into the future, because it's chance each population reduction is going to be slightly different so if we do it 10 times and we do it for 750 years in the future. And just want to put in a bit of code to specify how we store our results and also what starting population is, which is the same as when we run to that there's that one line so 100 dealings, etc.

And this bit of code here just runs a simulation 10 times for 750 years into the future. It may take some time to run it's got some to do.Okay now it's finished running and we can print out the output for each trajectory is for every year obviously this is quite difficult to see what this means, because just lots of numbers, so instead we can print out a graph for each projection.Okay, and so here, we see what our projections are for the growth rate of this population into the future. So each colored line here is a different one of the 10 different projections that we've done. As you can see, is zero they're all starting the same population size, because we have the same structure free to protection and they're all declining towards zero within our 750 years. And so the numbers, the kind of the vertical lines, the numbers are just showing what the population size was the year before they went extinct. before. This projection should have lasted 750 years but it stopped early because all projections reached extinction reaches population size zero before that 750 years, so we can see that. Under the current condition this population is very likely to go extinct over that time period, which we can work out by facing extinction probability. I just made a mistake that each of these numbers is just the number of the different projection. So each 10 productions just has is assigned a different number and each colour and each number just represents a different one of those projections. And the ones that have these vertical lines that drop down are the ones that go extinct.

And so it's not quite all of them going extinct actually because when we calculate our extinction probability, which is the it's just a proportion of the 10. And projections that reach a population size of zero over 750 years we can see that 80% of them go extinct so eight out of 10 have reached a population size of zero. So, two of them haven't got to extinction, but they have been maintained a very small population size, because, as you can see, all these colored lines almost reached zero.

So this population projection means that our chance of extinction are very high, and even if they're not because think they're going to be an unsustainable population level into the future.

The other thing we can do here is to have a look at the net reproductive rate and the Lambda so Lambda here is the long-term population growth rate so it's similar to the our that we talked about in our lecture we're predicting how the population size is going to change into the future. And if lambda is one, and there will be no population no long term so changing the size of the population anything below one, the population is going to decline anything above. And it's going to be increasing, as you can see our population growth rate is below one so we're predicting long term declines in this population.

OK, so now we've found the problem with our population or conservation of this population of elephants. We can start to try and see how different conservation interventions that affect different vital rates of different age groups. So, have a quick look here, these are the different Leslie matrix i'm going to use. So this was one for the first one. And so, in this one next we're going to increase the survival of elephants before breeding age. So the headings are bit off this first column refers to yearlings the next 125 years next one slide 15 this one is 15 plus. And so we can see that we've increased the survival of pre-reproductive life stages to all the individuals below the age of 15. If we compare the top matrix, the one we just used, and this one, the second one which i'm going to use in this projection here. So i'm not going to go through all the code again because it does exactly the same job, as the previous one it's just a different inputs, we also have the same variation that we include in the first one. But it's just we've just changed this vital rate to the only thing that's different is the survival of those pre reproductive life stages. Again, because it's exactly the same. And we can produce a graph. Right, so this time we're still getting a decline in our population, however, it doesn't seem like any of our populations are quite reaching zero, but they are all getting to below 50 individuals by 750 years or even smaller than that so again we're not quite reaching extinction, this time, but we are seeing very serious declines, so if we calculate our extension probability again, the proportion of trajectories that reached extinction is zero, but the population size is still very small we've gone from 5000 individuals to. Less than 50 for each one, so we have lost a lot of our individual, even though we haven't got our extinction rates, and this is why it's very important to produce graphs and things when you're doing this kind of population modeling because if you just look to the extinction risk, you might be like zero great news none of these populations going extinct, but the numbers are still very small.

So this time we're going to increase the survival of individuals before breeding by 25% rather than 10%. So rather than just increase it by 10% we're increasing it by a little bit more, this time i'm going to see what impact that has on our population projection so again I won't run through the code is exactly the same it's just a slightly different matrix that we're putting in as the input. So, again we're still seeing declines. Some of the population sizes are significantly bigger than our previous one, so we're having some populations maintained in the hundreds, rather than all below 50 and we're not seeing any extinctions but we're still losing a huge number of individuals. There is again 0 percent chance of extinction across these 10 projections, you would do many more projects and only when you were doing a population model in reality for this, you would do 500 or 1000 rather than the 10 we're seeing. We're seeing no extinction, but we are seeing huge the clients and again our Lambda is still below one so not being able to get all and above one which would indicate a population growth.

So this time what we're going to do is we're going to increase survivorship before breeding by 10%, which is what we did our first try. But also going to increase breeding success by 25% so not only in this one only has our survivorship of pre reproductive life stages increased but we're also increasing our breeding rate here from three and a half percent to four and a half percent. So, again i've run all the code because it's the same. So again, no extinctions but we are also seeing very declines in all of our trajectories. The chance of extinction is zero, none of the populations going extinct. Lambda is still below zero so we're still getting a prediction of a long term decline and growth rate, the things look at here now we've changed the reproductive rates is to see how that's changed.

So the other thing we can do is calculate the net reproductive rate, which is just the number of calves that females having over her lifetime that survive to being an adult. And as we can see females are producing fewer than one calf over their lifetime, the subject to being an adult so that means that the net reproductive rate of the population is below one and so that adds to the population decline, because the females aren't replacing themselves or more in the population and, by the time they die by reproduced increasing the reproductive rate, this time around, we have actually increased this net reproductive rates. From 70 something percent to about 85 but it's still below one so we're still seeing these declines so it's a slightly different measure of population variability and the Lambda which takes into account and a few other things as well, but it's another idea that our populations are still struggling, so this time we're going to reduce mortality by 25% and increase breeding by 10 so there's going be more emphasis on survivorship this time, so is reducing our mortality more important. So we just let it run. Okay, so this looks promising now so we were maintaining population we're still having declines, which is obviously a problem, but our population size is by 750 years are either in the thousands or they're there in the hundreds so we're still seeing the clients, so we still not reached a conservation intervention program that we think would prevent the client, but we are presenting its things now, so it seems like te emphasis on mortality is more important than emphasis on breeding in this case. Our Lambda is now quite close to one and i'm at reproductive rate is also getting into the 90s so getting getting close to what we need to maintain a population.

So, up till now, we just looked at breeding and survivorship of younger individuals so individuals before breeding age. Finally, this last one, and I set this up slightly so that the last one is the one shows the important vital right here, we're going to increase the survivorship of older adults. And so we also going to increase the breeding a little bit, but we're going to reduce we're going to put back the survivorship of all the pre reproductive life stages to what they were in the very first projection the original one. But what we're gonna do is we're going to increase survivorship of old adults just by 1 percent i'm going to increase breeding by a little bit as well and i'm going to see what impact that has on our population projection. It takes a little bit longer this time, which in population modeling as a good sign, because it might mean that the numbers are a bit bigger this time. And lo and behold at long last we find a scenario where our population is increasing, over time, rather than decreasing. So this time we don't have any extinctions, obviously, and we also have a positive growth rate, we have no problem of extensions of Lambda has gone above one so in the long term, our population is going to be growing.

Our net reproductive rate is also increasing so individuals are breeding of producing more individuals to replace themselves in their population by the time that they die on average. The thing to mention is that this population model and often in the case of especially mammal reproductive mammal published modeling is that they're often female only so there's a strong assumption that there's an assumption that males are not the limiting factor in population growth that females are and that females will, on average, always be able to find a mate. It's the length of pregnancies and raising juveniles, that is, the limiting factor in mammalian population growth, so therefore you can kind of get a good estimate of oppulation growth rates will be just by modeling females, which is what we're doing here. So at long last we found a scenario where our population is going to be growing in future, and then, if we compare the landers for our different model bronze and we can see that. Only this last one here is the one that's about one, so this suggests that the elephants it's the survival of adult females of the females that are can reproduce entering the reproductive age class that is vitally important for their conservation. So, focusing on allowing female adult females to survive and breed is more effective than trying to encourage breeding and also trying to encourage this available juveniles, so it means that it probably means that or suggests that because elephants are a long live species once they reach adulthood, they can produce lots and lots of cards before they die.

So that means that focusing on that age class is probably the most effective conservation intervention, we can do in this specific context and it's quite difficult to start to generalize results of these population models into different habitats and definitely across different species. But with these long lived relatively slow breeding animals like with elephants and also with my black rhino work, it seems like the survival of adults is very important and be able to maintain adults in that reproductive age class it's very important to their conservation okay so that's the end as practical in my lecture course hope you find it useful, and thank you very much.