Slide 1 - So this is my last lecture in the series of three looking at conservation. So in lecture one and we looked at some of the human mediated threats that are causing extinctions around the world, about the protected areas that we're trying to use to prevent those extinctions and why they don't perform as effectively as they should. In the second lecture we looked at why particular species of vulnerable to extinction and the knock on impacts that has for protected areas and, again, why our biased understanding of a particular species may be may lead to conservation programs aren't as effective as they could be. And then finally in this last session we're going to continue to focus on species focus work and we're going to look at how small populations, which is one of the main problems in conservation So how do we estimate a minimum populations required for sustainability into the future. We're often in conservation, working with small populations which have been caused the threats I talked about in the very first lecture. So if habitat degradation and loss has caused a species range to decline we often have to conserve small numbers of individuals so small populations, so we have to look at what the problems that that can cause and how you can predict the extinction risk of those populations and whether or not we need to be worried about those particular populations going extinct in the near future.

Slide 2 - The learning outcomes of this are to look at the population, the problems are caused by small populations. Okay, how you monitor a particular small population, so this ties, a little bit into the exercise that went along with lecture to so we, in that we were thinking about how you can monitor the banteng and how you can assess their population sizes and how you can design a research program to better understand that species. So in this lecture we're going to have a look at some other methods of how you can monitor small populations, especially when they're difficult to study when they're shy or other things. We’re going to look how this population monitoring can be used to estimate important dynamics of that population so rates of breeding and rates of mortality. And then we're going to show how but those estimates of breeding mortality rates which they here called vital rates can be used to predict future population growth and the risk of extinction.

Slide 3 - So when we’re looing at small populations it's often called the small population paradigm. So these are the problems that are faced by small populations, just because of the fact that they are small. Small populations face greater risks than larger ones, and just due to the small number individuals that are in that population.

Slide 4 - There are three main areas of risk associated with being a small population and these things are often called stochasticity. As populations become smaller they become more at risk of chance events that are problems for those populations and can increase the risk of extinction. So the first one is genetics. I think this will be covering some of the other lectures are being recorded. But when there are a few individuals it is likely that you have lost some of the genetic diversity that was present when the population was larger because there's less genetic diversity in that population. Genetic diversity is the kind of the raw material that evolution acts upon and gives rise to adaptations to particular environmental conditions. So therefore if there's less variability present it means that in the future if the environment continues to change, which is very likely to do due to climate change and human impacts, there is less scope for that population to adapt to those changes to be able to adapt so if a lot of that you know variation has been lost and then it can't be used for that population to select for particular advantageous adaptations going forward into the future. There's also likely to be more inbreeding so inbreeding is when related individuals make with each other to produce offspring. This is a problem because within the natural diversity genetic diversity present in populations some individuals may well have deleterious mutation. So these are genetic mutations that have a negative impact on fitness However, if they are present at low levels in a population or if they're not very deleterious, if they don't cause death immediately or something like that, then they may persist in the population at low levels, because they don't cause negative enough impacts, to be selected out of the population entirely. They can also be what are called a regressive adaptation, so they only exhibit their negative consequences if an individual has two copies one from each of its parents. So it may be that some individuals in these populations have negative mutations. And if you're mating with a related individual it is much more likely that related individual has the same negative mutations that you have, if you have any at all than an unrelated individual would have therefore inbreeding can cause problems because it can give individuals two copies of those regressive mutations, but it can also increase the chance that the offspring have these negative mutations. So it can start to fix those negative those deleterious mutation within future generations the population. This picture here is a butterfly from UK called the Glenville fritillary, and this is the first study that gave strong evidence that inbreeding and small population sizes can give rise to negative effects for the conservation of a particular species. So for this butterfly mutations that were negative to its health started to be fixed in the population and survival rates started to drop and fecundity rates started to drop as well, so it had real world consequences for the conservation of this species because the population was small.

As well as genetic issues, we also have demographic issues and demographic stochasticity. So this is just based on chance events in the meeting and the population dynamics of a particular population and a lot of this can be caused by these chance events. So say that a certain number of individuals don't breed every year just due to the fact that they didn't manage to store enough resources and kind of eat enough to store enough resources to be able to breed that year. Or just the fact that they by chance didn't find a meat or something like that, so you know it's not just deterministic effects that cause variation in breeding rates, it can also just be chance things. In a large population, the fact that some individuals don't breed every year due to chance isn't much of a problem because likely lots of individuals will. But in a small population if just by chance, one particular year lots of individuals don't breed that has a very important impact on the population, because it's a much higher proportion of the total population that therefore isn't breeding. And so that's just one of these chance things that didn't happen, the other is sex ratio bias. So, whilst probably on average for most species there's a 50% chance that an individual will be male or female, when it's born, that definitely varies for different species and some have their sex decided by temperature such as sea turtles and other things, but if we just take that as kind of a general rule of thumb. However, and that will obviously very year to year just depending on chance, so it may be that a certain year that's more males and females. Again, in large population that probably doesn't have much of an impact on the population as a whole, however, if say there's only 10 individuals born in a particular year and a small population and eight or nine a male just by chance then there were very few females come into the population which can cause problems in the future. If this happened a few years in a row, it may be that the on and off females then produce young to sustain the population. And so again with chance events we get allee effects, which i'll talk about the next slide. But again, that can be problems that cause just by the fact that our population is small.

The final one I’ll talk about here is environmental stochasticity. So this can be chance events in the environment that cause problems for populations. Again all populations will be affected by environmental stochasticity. So say there's a drought in a savannah, just using the ecosystems, I work in, say there's a drought that causes low amounts of food available for herbivores so that isn't much grass available for the grazers because it doesn't green up in the wet season, because there isn't enough rain. Then that year there's poor resources which may cause weaker individuals to die may increase mortality rates and mainly to low breathing rates. But if there's a large population, especially if they're spread out over a large area with different habitat types, it may be the only a small part of that range is affected by the drought or that, even if it kills a few individuals it doesn't have too big an impact on the population as a whole, however, if that particular species has been reduced to a very small area that drought may cover the whole range of that species, so it may affect all of the individuals and so if it's killing 5 individuals from that population in a population of 100 yes we're losing some but we're not losing a high proportion but see there's only 10 individuals because our population is really small you know we've lost half of our population so it's very important to the future of the conservation of that species. Small range sizes, can also be affected by extreme weather events so not just droughts, but say our whole a whole species lives on a particular small oceanic island, is endemic to the island. If the island is affected by a cyclone or a hurricane, it could very easily wipe out that whole species in one go, whereas if species spread out over many islands, we can lose the population that one, but we have these other ones to kind of fall back on. So this is some of the problems that we get with small populations on why focusing on them is so important for conservation.

Slide 5 - So this is just outlining some of the allee effects which is again, one of these things that can affect small populations just by the fact that they are small. So generally in population modelling, we have a population size that increases up to a carrying capacity, which is K here. K is the number of individuals of that species that particular habitat can sustain due to food resources was resources whole range of things. Looking at the bottom graph ere the population growth rate starts at zero, we have no individuals, the population can't be growing. But it's positive all the way increases up to a maximum, which is about we normally think to be about half of our carrying capacity. And at that stage density dependent starts to take effect so individuals within that species are competing for resources. So it starts to reduce the population growth rate, because that competition can reduce the amount of resources that each individual gets it starts to increase mortality rates in the population and decrease breeding rate. The increasing of the the population growth rate therefore starts to decrease but remains above zero up to the carrying capacity. At the carrying capacity, the average population growth rate is zero so the number of individuals dying equals the number of individuals born. It won't stay exactly that number, it might go up but if it goes above the carrying capacity, the average population growth rate becomes negative because of that density dependence so pushes it back to the carrying capacity. And the same as the population decreases so say there's a drought it kills off a few individuals, but that means that we're below the carrying capacity, so the population start to increase again to K.

However, allee effects are things that happen when populations that are small population size it starts to either decrease the population growth rate with a weak allee effect or even make it negative with a strong allee effect. So say our population generally exists at quite a low density as we'll talk about with the Sumatran rhino on the next slide, and so say individuals only come together to breed. If we lose lots of individuals and the individuals, we do have a are very spread out very far apart, then, if they exist at an even lower density, then they can really struggle to find mates. There aren't enough individuals around for them to easily find a mate when it comes time to breed. So with allee effects, such as the difficulty of finding mate. in that example, when we get to a certain population size, the population growth rate actually becomes negative, so if we if we get to population size that goes lower than the point where that red line crosses the X axis on that top graph the population becomes negative good population growth rate becomes negative and it pushes the population towards as a size of zero, so it pushes us towards extinction.

Slide 6 - So this is another example of why small populations can be become. very vulnerable to extinction in certain circumstances. So the Sumatran rhino is thought to be affected by these allee effects. So back in 2019 the last Sumatran rhino in Malaysia died and it's now just restricted to

Indonesia. But it was thought that this species was existing it at low densities even in the absence of human impacts in quite dense forest it's solitary and the only really came together in times of when the female was in oestrus to breed. As these animals were hunted and as they lost habitat densities decreased further and it became very difficult for them to find mate. The difficulty of finding mates is an allee effect. The population growth rate went below zero and it starts to push it towards extinction accelerating the decline and possible extinction of species.

Slide 7 - OK, so now we talked about some of the population, the problems associated with small population, how do we actually estimate population growth and population if it's so important to the risk of extinction population size and the population, the change overtime. So the population growth rate, how do we actually estimate that. So we can just go out and count individuals but are you actually managing to observe all of the population it's probably unlikely. You may be just getting a portion of that population and are we able to estimate how much of the population we are actually measuring when we do that. When we do this, we also need to take into account whether or not we're sampling across the whole range of species. So, say, as in the first lecture when we were talking about how we a lot of our research is focused on protected areas, even though they cover a relatively small part of the globe. Say we just study a species in a protected area, it may be that the density there is higher than in the disturbed habitats outside the protected area. So if we count the individuals in the protected area and then extrapolate that estimates across the range, so we find a density of individuals per square kilometer and we multiply that by the whole known range, we may get a misleading estimate of the population size, because the population density might be much lower outside of that Protected Area, therefore we're overestimating the population size. And so if we can't observe the whole population in one go, another way of trying to estimate population size is to do is to find individuals repeatedly and to do this thing called mark recapture, which I will go on to an example of in a second.

Slide 8 - These are just two examples of how we can sample population sizes and how it iscontext dependent. So say we're studying elephants in a savannah, because they're very big and in open savannah we can use things like planes binoculars to go out and just count the number of individuals, because they're relatively easy to spot. Again, you have to consider the fact that it's like unlikely that the whole range of this animal is in the same habitat, so do need to factor in the differences in densities, and you also need to make sure that you're not counting the same individuals over and over again. So if you got on repeated days you need to make sure that you're not just counting the same ones every day you go out. However, I see we're trying to study this snail species here, which is very small, you can't just go out and count them all it's much harder to find we can do this mark recapture study design, where we get an estimate of the population size.

Slide 9 - And to do this, we can use this equation here. And so the capital N, is the whole, the total population size which we're going to estimate using this calculation. And the capital M is the number of members of the population that are initially captured. So we go on day one, and we capture a number of individuals and we tag them Okay, how we get capital M and the lowercase letters are the estimates, we get when we go and we do the same, you have to do exactly the same experimental design, because this method works, based on a ratio that you're capturing on the assumption that you're capturing the same proportion of the population of times. And so the lowercase n, is the number of members of the individual that are captured when you go out your second time, and the lowercase m and is a number of individuals that you capture in your second sample that were attacked and then we can then use this equation, to try and calculate the total population size.

Slide 10 - And so i'll show an example, because I know it can just be confusing to look at equations like this. So here we go, so this example with tortoises says we go out on day one, and we capture 10individuals and we mark them with this red dot. When we got on day two we captured 10 individuals again exactly the same experimental design has to be because we have to make sure our sampling effort is standardized. Of that second sample five of them were marked.

Slide 11 - And then we can then plug these numbers into our equation to calculate the total popular an estimate of the total population size. So where our capital M is 10 because it's the number of individuals caught on day one. Our lowercase n is 10, t's unlikely that you would get exactly the same number of individuals on both days. The lowercase m is therefore the number of target individuals, the number of individuals in the red dots that we caught on day two. And then we calculate our total population size using this equation here and we get an estimate the total population size of 10. So this is an idea of how we can estimate the population size of a species that is difficult to measure the population size directly. And so we think about this, how to think about your banteng study design, which was the activity from the second lecture I think about perhaps how you could use this in your estimate of the banteng population size. So with a large vertebrate it's quite difficult to directly capture the mark them, but if you're using a camera traps study design, can you identify particular characteristics of each individual, you can count them and then, if you did two different camera traps surveys and you can identify certain number of individuals from the first study in the second one, you could then use this to try and estimate population size as a whole if you're struggling to directly measure the whole population.

Slide 12 - Once we've estimated our population sizes, we can then use this to try and measure population growth and estimate what our extinction risk is into the future.

Slide 13 - And so, when we're doing this, one of the primary things we want to do is estimate the population groups of our of our target population. So this is r, which is the birth and immigration to our population minus the deaths and emigration, we see, so r expresses that percentage. So if you have a population of 100 black rhino and over a particular time period we see 10 births and five deaths, but there's no immigration or emigration, because they live on a fenced reserve. r is five and then this express the percentage so it's our it's five in a population of 100 so we have a 5% growth of our population, this is often done anually, but it can be done at whatever time period, you want, as long as as you're clear about the time period you're working with.

Slide 14 - This is just a diagram that shows the basic units and the basic rates that determine population size of your time and population growth rate. So we have birth and immigration that add to a population, and then we have deaths and emigration that take away from it, so the cumulative impact of all these together gives us our population growth rates and allows us to estimate both that and the population change over time. Once we have these vital rates so if we can estimate what the birth and immigration rates in the death and immigration rates are over time. We can then use this to try and estimate how our population is going to change into the future, which is very useful for conservation, because if a population is going to decline. We want to be able to act on that before it happens so if we can predict that's going to happen, we can try and calculate before it becomes a problem.

Slide 15 - So when we're doing this we have to construct a model of our population, this is often done by splitting a population into different age brackets. And this is based on groups individuals have similar ages that show similar birth rates and death rates, so this is an example from a black rhino population model. So the first year of a vertebrates life is often very important, because often have very high mortality rates,. They can be vulnerable to diseases and other things. So the first year is often occurs by itself, and then in this black rhino population, we have three pre reproductive life stages because after five years old rhinos can breed so for 0- 1, 1- 5 and 5- 9 breeding rates will be zero. So those are pre reproductive so they become groups, because they have similar birth rates of zero and death rates and then above five we have these reproductive three reproductive life stages, where death rates and reproduction rates are similar and we have a post reproductive life stage which is older than 33 so individual survive past that but they don't often breed. So we split our population up here into different groups based on similarities and vital rates.

Slide 16 and 17 - Once we've done that we can then construct a Leslie matrix which is a set of numbers that express the birth and death rates for each life stage. This big matrix in the middle contains each of these vital rates. So, ignore the the small matrices on the left and right for now. Across the top we have these F numbers, and these are the fecundity rates. So these are the per capita average number of female offspring born from mother from the age class X. So I know it's a bit confusing, but basically so each column in his matrix is one of those age classes, so if we're looking at this population model here we have six eight classes. And so f0 would be the number of one year olds that are giving birth, which is obviously going to be zero because there is a pre reproductive life stage. But that would be the birth rate for that age class. F2 would be the birth rate for this five to nine age class and they are able to breed, so that F2 would be, we have a particular number and that's the proportion of independent of female individuals in that age class be breeding every year. Okay, so that's how the fecundity rates go into all as the matrix and then the S numbers which got on the diagonal of this matrix are the number of the proportion of individuals that survive from time T, which is the year we're in now to time T plus 1. So this led the matrix assumes that each age classes, only one year, so if an individual survives, it has to progress to the next age class. If we look at our rhino model that's not exactly what we're doing here, so the areas at the bottom, where it says s two brackets one minus G2 or similar, those the number of individuals that are surviving but staying in the same age class because they're in an age class for more than one year. This Leslie matrix it assumes that every time individual survives a year it progresses, to the next age class.

Slide 18 - And so once we've constructed on Leslie matrix which includes our survival and fecundity probabilities we can use that to project our population into the future and what we do is we use this Leslie matrix in combination with a matrix that shows our population structure for time T for a particular year. So on the right hand side, here we have these numbers n0 to nw-1 where w is the maximum age that individual can reach. So the numbers in here are the number of individuals that are in each age class. Then to project how our population would change into the next year, based on our survival and for breeding probabilities. We multiply the leslie matrix with this matrix on the right and it gives us on the Left that has the, the number of individuals can each age class at time T plus one, which is just the next year. And that's represented here, so we multiply a by empty is our population at time T by unless the matrix and we get population at time T plus one.

Slide 18 to 21- And now to do this, we have to do multiplication but matrix algebra so the way you multiply match these together it's a bit different to how you would do just with numbers. So, to get our time T plus one our population size at time T plus one, which is our matrix on the right here. We multiply Leslie matrix the big on the left with the one in the middle, which is our population size at time T. So, to get the number at the top here 39.3. you multiply zero by 45, then you add that to 1 times 18 you add that to 1.5 times 11 and you add that to 1.2 times four. Once you added those four numbers together, it gives us our number 39.3

Slide 22 - So this just gives a summary of how we do this multiplication to get that final number. You plus all those numbers together and it gives you your population at time T plus one, so we recorded that were 45 in our youngest age class in our population but we predict 39.3 at time T plus one, so the next year we're going to have fewer for those individuals in that age bracket. This is our estimation of what our population structure is going to be in time T plus one. So in this population there's only four age classes, one is pre reproductive So you can see that the top left number in this matrix is zero so no individuals in the youngest age class of breeding. But in the second three fecundity rates have a positive probability of breeding. Now the numbers here can be above one because this species can have more than one young per year. So say with a black rhino they can only produce one young a year, so this number couldn't go above one. And because it can't females can't have more than one car at time, and so this number for black rhinos will be below 1 because only a fraction of individuals would be producing one calf each. However, this species can produce more than one young at a time so on average each female is producing one or more than that young per year. And then if we're assuming that each class here is one year the species can only survive to four years old. So, for the first age class 80% of individual survive to each class to which is the 0.8 number there for. 50% survive to age three. Only 25% progress to age stage 4 and when they get to the end of age class four all individuals die there's no probability that individuals can survive past the age of four.

Slide 23 - So that's the kind of structure this population and that's how we then use our vital rates and our current population estimate to predict how population change will how a population will change in the next year and then you can just do this over and over again. And you can mode how the population is going to change into the future. This is really useful for conservation, so what uses can there before this because we can predict how different populations are going to grow or decline into the future. So we can compare different populations, we can identify ones that are high risk of extinction based on current conditions. The other thing we can do is that we can try and predict the effect that comes conservation interventions would have on a particular population. So say we identify through is modeling that population is at risk of extinction when we do that we can try and say, well, what would happen if we try and improve survival of a particular each class so see wanted, so we see that a lot of juveniles are dying. We say, well, if we can intervene and prevent juvenile mortality say it's often caused by an invasive species, so we predict that controlling this invasive species will reduce juvenile mortality by this much will that have an impact on the population before we actually conduct the intervention which can be expensive, and if we find out that doesn't work and we potentially wasted that money. Instead we model what effect that would have on the population and then, if it if we can see that it probably won't have an impact on the conservation of the species. We can try it, we can try and model other interventions until we find one that we think would be useful for the conservation of this species, so it saves us time and money. By predicting what the effectiveness of conservation interventions would be.

Slide 24 - And so the methodology of using these population models to predict extinction risk is called population variability analysis so we're looking at how viable different populations are and it requires a lot of data. which can be difficult to come by, especially for wild species. And it can be overly pessimistic, it can often predict the declines when in real life and that population might be sustainable. However, it does provide evidence of management and can be surprisingly robust and it can be used as I was saying, to evaluate a range of different management scenarios.

Slide 25 - So this is an example of a population viability analysis that was done on elephants in Myanmar. And you can see how we can model what impact different conservation interventions would have on the population, so our baseline is just looking at vital rates as they currently are in the population, so the measured by death and birth rates and, as we can see over 200 years we predict that our population will be about the same level as it is now in the future. A lot of population models, you see how the start of this we kind of get ups and downs, and a lot of them have these things, called transient effects that are kind of just mathematical artifacts of the way that population, the way the model is set up. So it predicts short term variations in growth rate which may not occur in real life, but if we just want to look at the long term effects the long term growth rates they're not too important to look at here just if we look at the long term growth rates and the long term impacts and so for our baseline we predict the population won't have grown over 200 years. However, if we want to think about whether or not our conservation should focus on birth rates or mortality rates, we can use this model to compare that so we look at the green line this is modeling if there's a 10% decrease in juvenile mortality rates which we were talking about before can be important for particular vertebrate species. So that gives us an increase over 200 years but that increase isn't as big as if we were going to focus on adult birth rates in this population of this species. In this population model, we suggest that for conservation to be the most effective for this species, we we want to try and focus on increasing adult birth rates. Now, how we do that is an entirely different question, but it does show without actually having to carry out the conservation intervention which may be one expensive and to take a long time, we can predict what is the best thing to focus on for our conservation efforts.

Slide 26 - So quick summary small populations are vulnerable for genetic reasons, in the long term, and also, but can also be possible for other things in the short term, so demographic stochasticity and environmental stochasticity, as we said. The IUCN, which is the International Union for conservation of nature but also researchers and other people can use population models to establish extinction risk criteria. So the population modeling methodology that we run through very quickly here is used by international conservation organization. To assess extinction risk, the IUCN which produces the red list, which is kind of the go to resource for assessing extinction risk in particular species, they rely very heavily on these methodologies and similar ones. To try and assess extinction risk and they come up with their critically endangered endangered threatened categories. We can use these to just calculate basic population groups based on total numbers, as we did, or we can try and use more sophisticated population models to try and predict how populations will change into the future.

Slide 27 - And so the activity for this lecture isn't a go home and do it yourself want because these population models are quite complicated to set up and instigates and they require specialist software. And a lot of software is free, but you just need to know how to use it to be able to use to go to run these models. So along with this lecture recording i'm going to upload a recording of me running through one of these protocols on a software called R which is free to download but it requires a bit of experience and know how to be able to use. I'll just show how you can use these Leslie matrices very simple ones to predict how populations will change in the future. And how we can use them to predict the impacts of different conservation interventions that focus on different vital rates into the future. Thank you very much that's my last lecture I hope these three letters have been useful they're giving you a nice introduction to some of the basics of conservation.

How human impacts on the thing take actions and how we can tackle that on a kind of landscape scale and also on a species level scale thanks very much.