Conservation Economics
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Module 2
What is Conservation?
Lecture 2
Human population growth and food requirements

Namaste! In the last lecture, we were looking at conservation in the anthropocene and we came with across with this formula:

I = P X A X T

So, the impact of humans on the environment is equal to their population which is shown here in P, the level of affluence of the society which refers to the amount of resources that each person on an average requires or uses, and the level of technology, that is there in the society.

Now, of late what we have observed is that the level of affluence does not increase very fast - it takes its own time. And the level of technology is somewhat also dependent on the population that we have because more the number of people that are there in a society the greater is the chance that somebody would come up with a new technology. So, essentially the level of population of humans has the highest bearing on the impact. In this lecture, we will explore what causes the growth of human population, how we can model it, and how we can also model the food requirements of humans.

One of the earliest thinkers to think about the issue of human population growth was Thomas Robert Malthus. He was an English cleric and scholar who lived in the 18th and 19th centuries. And in 1798, he published this book, An Essay on the Principle of Population, and this is considered as one of the most seminal works on human population growth. Till this date, it has influenced studies in population ecology.

So, what did Malthus have to say about the growth of human population? He observed that population grows in geometric progression, roughly doubling every 25 years. The human population grows in geometric progression. Now, what is geometric progression? Geometric progression means that every term in the sequence is a multiple of the previous term. That is we can write it as the nth factor or let us write it as

a[n] = a[n - 1] X k

That is if you take a ratio of the nth factor of the series and the n minus 1th factor you will get a constant k. And in this case Malthus saw that the population was doubling. So, the factor k here is 2, because 2 divided by 1 is 2, 4 divided by 2 is 2, 8 divided by 4 is 2, and so on.

So, every factor in this every term in the series is the previous term multiplied by this constant k which is 2. 1 into 2 is 2, 2 into 2 is 4, 4 into 2 is 8, 8 into 2 is 16 and so on. So, the population grows in geometric progression. Now, how much time does it take for this population to move from 1 to 2? And for this Malthus said that it roughly doubles in every 25 years. So, in 25 years the population doubles.

On the other hand, he observed that the food supply increases in arithmetic progression. So, in this year suppose you have 10000 tons of food, in the next 25 years you will only increase it to 20000 tons, in the next 25 years you will increase it to 30000 tons, in the next 25 years you will increase it to 40000 tons, and so on. This is an arithmetic progression.

In the case of an arithmetic progression, we say that the nth term of the series is equal to the n minus 1th term plus a constant k. So, if you subtract the n minus 1th term from the nth term you will get a constant which is k. And in this case what Malthus is observing is that this k is equal to 1. So, 1 plus 1 is 2, 2 plus 1 is 3, 3 plus 1 is 4, 4 plus 1 is 5, and so.

Now, in such a scenario in a very short period of time the population will increase to such an extent that it will overrun the food supply - which means that in a very short period of time there will be no longer sufficient food available for everybody. Now, in such a scenario what will happen? There will be an imbalance and it will be corrected by what he called as positive checks.

Positive checks include things such as vice, misery, famine, war, disease, pestilence, floods and other natural calamities. So, essentially what you mean by positive checks are those mechanisms that reduce the size of the human population by acting from outside or those mechanisms that reduce the human population, but these are those that we do not consider to be good mechanisms - such as misery or vice. So, he said that if the human population increased to a very large extent and there is a shortage of food there would be things such as famine. And in a famine there will be a big chunk of human population that will perish. Or there will be things such as diseases and in the diseases a big chunk of human population would perish. And he correlated these to the increase in the human population.

He said that this is not the only way out. There is also another option which is that the imbalance may also be corrected using preventive checks.

Now, what are preventive checks? Things such as foresight, late marriage, celibacy, moral restraint, and so on. So, essentially the preventive checks that Malthus was proposing in his theory are the ones that do not kill anybody, but are able to reduce the size of the population through self control. Through things such as celibacy or late marriage, people are able to reduce the rate of population growth by having fewer number of children or by not having children. So, this is also an option that is available to the humans.

Essentially the Malthusian theory is more like a doomsday theory. He said that either you do these checks - either you try to reduce your own population or otherwise your - the human population will be brought down by nature by using so many of the positive checks such as famines or floods or diseases or pestilence or through certain moral checks such as vice or misery. For instance if the human population is too large and everybody is not getting sufficient food, people will turn into misers. People will develop vices, and because of which there will be a certain section who will try to hold the resources and others will die off. So, this is a sort of a doomsday theory that Malthus had proposed.

And to quite a large number of population ecologists, it did look like a very correct theory because if we plot the world population through time, we will find that it does follow some sort of an exponential curve which is a geometric progression. So, for every population it is doubling in certain periods of time. Now that period of time has not come exactly to be 25, but more or less the more people that are there in the world, the faster is the population growth.

And we can represent it mathematically by saying that if P[t] is the population at time t, then we can say that the rate of growth of population is proportional to P. So, the rate of growth is change in the population per unit time it is proportional to the population P and k is the factor that corresponds - that joins both of these. So, k in this case is a positive constant and upon integrating we can get that

P[t] = P[0] X e^(kt)

where P[0] is the population at time 0.

So, if you put t is equal to 0, e to the power of 0 becomes 1 and so, P[t] becomes P[0]. So, P[0] into e to the power kt. And with this we can also derive the doubling time. Doubling time is defined as the time that is required to double the population size. In Malthusian theory, we have seen that the doubling time is roughly 25 years - that we saw here - the population roughly doubles every 25 years. So, there is a doubling time in which the population is doubling.

And we can write that P at time td which is the doubling time is equal to twice the P at time 0. Now, putting these terms into this equation

P[t] = P[0] X e^t

we have

P[t] = P[td] = 2 X P[0]

So, 2 X P[0] = P[0] X e^kt

Now, P[0] and P[0] get cancelled out, so

2 = e^(k X td)

If we take natural logarithm of both the sides we will get

log 2 = k X td

or td = 1 / k X log 2

Now, if you remember this k is a positive constant. So, k here is a constant, log 2 is a constant. So, it tells us that the doubling time is a fixed number. Similar to what Malthus also predicted. So, doubling time: Malthus had said that it is 25 years and in our equation also we are seeing that it is coming to be 1 by k which is a constant multiplied by log 2 which is also a constant. So, we have a constant doubling time which is telling us that yes, the population doubles every fixed time and it is going through a geometric progression.

However, of late scientists have observed that this theory is not completely correct. Because it leaves out quite a large number of intricacies. It is a very simplistic model.

The first criticism is that the population growth is not as Malthus has suggested. So, if we look at the time that it has taken for the world population to double, earlier it was like 697 years for the world population to double from 0.25 billion to 0.5 billion. Then it came down to 594 years, then it came down to 260 years, and what we are observing is that nowhere is it touching this golden figure of 25 years.

So, according to Malthus the population was growing a bit too fast. In reality we are not seeing a very quick growth of population similar to what Malthus had predicted. And at the same time the doubling time is not fixed, the doubling time has been changing. So, it was as high as around 700 years, it was as low as 37 years, and currently it is close to 95 years. So, yes the population is increasing - there is a doubling, but this doubling time is not a constant. So, there are certain other factors that are also playing a role.

Then, if you look at the growth of agriculture, we will observe that even the rate of agricultural growth is not what Malthus has suggested. Now, remember that Malthus had said that agriculture grows as arithmetic progression. So, from 1 it increases to 2, then 3, then 4. It does not move in a geometric progression - there is no exponential growth of agriculture and which was kind of true in the days of Malthus because in those days we did not have modern technology, there was hardly any crop breeding on the lines of genetics, there was hardly any artificial fertilisers or pesticides that were available. So, roughly the only way in which the agricultural production could go up was by bringing more and more lands into cultivation.

Now, if you - if any society tries to bring in more lands for cultivation there is another issue that starts to play. If we consider a town - here we have a town and in most of the cases the town was surrounded by the agricultural fields. So, what we are observing here is that here you have the place where people live and surrounding this is the place where you are having agriculture, and surrounding it even further you would be having things such as the forest.

Now, what this figure is suggesting is that suppose you wanted to increase agriculture, you wanted to increase these green areas further, so that they entered into the yellow areas - that is you are trying to convert more and more of the forest into the agricultural land. The problem that comes and that starts cropping up in a very short period of time is that if you put this portion into agriculture, it is at a much greater distance from the city or from the town that it is supposed to provide the food to. So, it becomes difficult to transport the food grains that would be produced in such areas that are far off from the towns or the cities and bring them to the towns and cities where there are the markets. Essentially what we have observed through centuries is that people put those lands under cultivation that are close to the towns or the villages and the far-off lands were kept as forest to provide for things such as wood.

Now, in the days of Malthus, when we did not have modern technology the only - probably the only way in which the agricultural production could go up was to bring more and more of these forests into forms of agriculture - which as we have seen was not very profitable. And so, the rate of agricultural production increase was very less. So, more or less it went on an arithmetic progression in the days of Malthus.

But now, if we look at the growth of agriculture, in any short period of time, we will see that yes, it actually grows in an arithmetic progression. So, here on the x axis we have the years, on the y axis we have the global cereal production, and it is increasing very slowly, and its not showing a nature of doubling. But then if we look at the long term changes in the yield of different cereals, we will find that yes, the curve looks very similar to the growth of human population. This is an exponential curve, this is showing a geometric progression on a large time scale. Now, why is that so? One major thing that has got to do with it is the level of technologies that we developed in the 19th and the 20th centuries.

So, from say this 1270 to somewhere around 1700 there is hardly any growth in agriculture, there is hardly any change in the cereal yields. But then we started bringing in more and more technologies, we came up with fertilisers, we came up with pesticides, we came up with better storage facilities, and also we came up with more efficient manners of transportation and more efficient means of converting the forest lands into agricultural fields. And we are seeing the effect of all of these here.

So, from 1900, we have shifted from roughly 2 tons per hectare to around 8 tons per hectare - an increase of 4-fold in around a century. So, on a long term scale we can observe exponential increase in agricultural production as well - which is not what Malthus had said. Malthus said that there is only an arithmetic progression growth in case of agricultural production; we are observing a geometric progression on a long-term scale.

Third, Malthus did not incorporate the new land that becomes available with time. So, if you look at how the land throughout the world is being used for different purposes - what is the land use. This is a depiction of the current land use in terms of countries that if were completely put into that particular land use would represent roughly the land use situation in the world.

So, if you put the whole of North America and South America into livestock production - that is roughly the amount of land that we are using for livestock. 27 percent of the land in the world is being used for livestock production. Croplands are just 7 percent. So, if we take this East Asia we will get to the figure of roughly 7 percent of the world's area. As much as 26 percent of the world is covered with forest. Barren land is 19 percent, glaciers are 10 percent, all the built-up area including villages, towns and cities is just 1 percent. So, all the built-up area including all the infrastructure is just 1 percent. And 8 percent of the land is under shrubs and total amount of glaciers is just 10 percent.

Now, what is happening over the time is that more and more of forests are being converted into either livestock areas or into croplands. Similarly, more and more of this barren land is now being made available for crop production. Similarly, a lot of these shrub lands are now becoming available for crop production.

A very good example in this case is the Terai region of our country. Now, before the invention of DDT, the Terai region, which is the place where the Himalayas meet the northern plains was all full of marshes. And we had a very dense infestation of malaria in those areas. Now because of this dense infestation of mosquitoes and the prevalence of malaria all of this land was hardly put to any use. So, it was just left as forest - it was left as marshy land.

But with the invention of DDT nearly all of this land was brought into the fold of cultivation in our country. So, if you consider areas of Western Uttar Pradesh or Northern Uttar Pradesh - that is most of the - or a large portion of the sugarcane growing area of our country, specially in Uttar Pradesh and Uttarakhand - that is comprised of these Terai areas.

Similarly, a big chunk of our desert area was brought into the fold of cultivation through the Indira Gandhi canal. So, Indira Gandhi canal has brought in a big chunk of Rajasthan under the fold of cultivation. Now, these sorts of things were not possible in the days of Malthus. So, this is also another criticism of the Malthusian theory - that it does not incorporate the new land that has become available.

What is the quantum of this land? The ah share of land area that is used for agriculture in different countries is different. And we can observe that in certain countries such as India a big - a much bigger chunk of land is being used for agriculture as compared to say Canada. But if you consider the world - or most of the parts of the world, we would observe that there is an exponential increase in the total agricultural area in the long term, wherever we look at.

Even in areas such as Greenland or most of Africa or India or China, you name the country and in most of the countries the total agricultural area has been increasing - which tells us that roughly in every country we are bringing in those lands that were not used for agriculture, now into the fold of agriculture. In North America, most of the prairies which were grasslands were brought into - were brought under cultivation. In Africa, quite a lot - a large chunk of forests were cut and those areas were brought under cultivation. In Brazil - we will look at the case of Brazil in one of the lectures as well -a big chunk of forests were cut down to make way for ranches and to make way for cash crops. Similarly, in quite a lot of Southeast Asia, most of the palm oil production that is going on in the world today is happening in places that were earlier forests. So, this is something that Malthus had not considered in his time because these were roughly not possible in his time.

And in agriculture we see both an increase in the cropland area - the cropland area has also increased in an exponential fashion - and also the grazing area. And here we will observe that most of this increase was in the last 2 millennia. So, there is an exponential increase in the grazing area as well.

Another criticism of Malthusian theory is that it neglects the role of technology. So, Malthusian theory had said that agricultural production only increases in arithmetic progression. But then, if we look at the long term cereal yields in any country, we have seen that it has increased exponentially because of the technology. Similarly, if you look at the pesticide application per hectare of croplands, here again we will find that in quite a number of countries there is a very heavy use of pesticides in the cropland. Now, these pesticides were just not available in the days of Malthus. So, this is something that Malthus could not have foreseen. And if we look at the pesticide production or the imports in different countries we will find that they have been increasing with time.

If you consider different fertiliser applications all over the world, here again we will find a very similar trend. Through time the consumption of fertilisers such as nitrogen fertilisers - they have been increasing. You name the continent, you name the area, and they have been increasing. They have been increasing in Asia, they have been increasing in America, they have been increasing in South America, and so on. In the case of Europe, there has been a slight decrease because in certain areas people are now shifting to organic cultivation. But more or less the trend is unequivocal - the trend has been increasing. If you look at other nutrients such as phosphorus - phosphorus application has also been increasing. The amount of water that the world has been using for agriculture - it also has been increasing. So, all the inputs of agriculture - they have been increasing with time. If you look at fertiliser use in kg per hectare of arable land in India, the United States and the rest of the world - it has been increasing.

And a lot of this increase has led to increased yields. So, if we plot say the application of fertiliser on the x-axis and the yield on the y-axis - and both of these axes are showing it in a logarithmic field - so, it is going from 1 to 10 to 100 to 1000 and so on - it is the logarithmic scale on the x-axis and it is the logarithmic scale on the y-axis - but then the evidence is clear - the more the amount of fertilisers that you apply to the croplands, more will be the agricultural productivity or the crop yield.

This increase in agricultural production was not possible in the days of Malthus - he did not foresee it. This is another criticism. Also, in those days the agricultural production could only have increased by bringing in more and more land under cultivation because the productivity was more or less constant. Now, with increasing productivity what we are observing is that less and less amount of land can give us the same quantity of food grains. So, by increasing the productivity, it is also possible that we might be able to leave certain forests as they are. So, if the human population is increasing and we need to provide them with more and more amount of food grains, there are two options. Option 1, bring more land under cultivation as was there in the days of Malthus. Option 2, use the same amount of land, but increase the productivity - which is what is the focus these days.

If you look at the global arable land or global crop production and if you plot it on the y axis and through time how much is the amount of land that is needed for maintaining the same production of crops - if we are plotting it we'll find that it has been coming down. So, after 50 years the world is using 68 percent less area or less land to produce the same amount of food. Productivity reduces the land requirement.

Other criticism that these days we are putting into the Malthusian theory is that the population is not related to food supply, but to total wealth. Population is not related to the food supply but to the total wealth. What we mean by that is if you consider a society - as the wealth increases we start observing demographic transition. Now, what is demographic transition? We had seen it in the last lecture as well. In the early societies, we have a situation where the death rate is very high. Now, why is the death rate very high in the primitive societies? Because we do not have means of technology - we do not have modern healthcare - that is available, and also most of the works that people do are extremely labor intensive. So, there is a greater probability that people get exposed to say snakes or to other wild animals. There is also a greater chance of death because of sun strokes because people are - because most of the people are working outside. So, in the early - in the early primitive societies - we find a high death rate. To compensate for the high death rate these societies also have a higher birth rate. Now, because there is a high death rate and a high birth rate, so the population more or less remains stable.

Now, with increasing wealth - not because of increasing food supply, but because of increasing wealth - what happens is that more and more people now have access to technologies, more and more people now have access to better health care. And when you have a society that has more access to technologies and better healthcare, what happens is that the death rate starts to fall. When the death rate starts to fall and the birth rate has remained constant, we have a situation where the birth rate is greater than the death rate. Now, it is important to note here that the increase in the population is not because of an increase in the birth rate - the birth rate is the same as what was there in the primitive society. But because the death rate has gone down the difference of birth rate minus death rate that has increased and because of this increase we find that the population starts to grow.

As more and more people have access to this wealth, in a short time they start to realise that yes, the population is growing too fast and earlier where the impetus on every couple was that out of every say 6 or 8 children around 5 children are going to die - so, we need to have more children so that we can ensure that at least a few of them are able to reach till adulthood. But when people start to observe that most of our children are able to reach their adulthood, then there is a less incentive to have more number of children. And so, with increase in wealth we start to observe that first the death rate had gone down, then people start to reduce the birth rate as well.

Now, in all this period till the birth rate comes down to the level of the death rate or to a very reduced level, there is a difference between birth rate and death rate - because of which the population grows. But when the birth rate also comes down then we again have a situation where the population becomes stable.

So, as against the Malthusian theory which stated that the population will always show a geometric progression in its increase, in actual reality we observe that with increasing amount of wealth there is a change in the population growth patterns.

Then, Malthusian theory also did not consider population increase due to lowering of the death rates as we have seen. Also, preventive checks do not pertain only to moral restraint. The Malthusian theory had emphasised a lot on moral restraint, things such as celibacy, things like not having a marriage or things like having a late marriage. So, moral restraint was probably the only option that was available to people then to reduce their population, but these days we also have access to contraceptives. This is again something that the Malthusian theory does not consider.

Another criticism is that the positive checks may occur even in low populated countries. Now, if you remember, Malthusian theory had stated that positive checks include things such as famines or floods. So, essentially positive checks are those things that nature brings in to reduce the population. And Malthusian theory - because it was a doomsday sort of a theory - it stated that if you do not check your population growth someday nature will come in and bring the population down through these positive checks.

But then what we have observed through time is that positive checks such as earthquakes or floods or tsunamis not only come in those areas that have high populations, but they are also very prevalent in those areas that have a low population such as countries such as Japan. So, this is another criticism. But, if Malthusian theory is unable to explain what causes the growth in the human population, what other theories can be used to help us find out what is causing the growth in the human population?

In this context, we can have certain glimpses from wildlife population ecology. Population growth is not something that is specific only to the human population. We observe population growth in a number of other organisms as well. And especially in the case of wildlife management it is very crucial to know what is the level of population for any species. For instance if you wanted to conserve a species such as tiger, and if you did not know what is the level of population, and if the population is growing or not, you would not be able to make the right decisions. Essentially, if you have a target species and it has not reached to a level that you feel confident that it will not become extinct anymore you would try to increase its population. On the other hand, if you have a species that has increased its population to such an extent that now it is becoming difficult to manage this species you would want to bring the population level down. On the other hand, if there is a species that has reached to a level where you are confident you would want to maintain it at that level. So, a good understanding of the levels of population and what causes population changes is crucial for wildlife management. And a lot of studies have been made in the case of wildlife population ecology. So, can we make certain assumptions or can we understand some of these phenomena from wildlife population ecology?

In the case of wildlife population ecology as well we start with our equation of the exponential growth. Now, let us suppose that a population is showing an exponential increase or it is showing a geometric progression which would say that

P[t+1]/P[t] = R[0]

Now, this is the same thing that Malthus had said that the population of humans doubles every 25 years. So, R naught is equal to R0 and the steps of taking time intervals is 25 years. So, at the t plus 1th step you have a population that is twice that at the t-th step which is what is this equation.

So, N at time t is the population size at time t, N at time t plus 1 is the population size at time t plus 1, and R naught is the constant which in the case of population ecology we call it the net reproductive rate. So, net reproductive rate can also be expressed as the number of female offsprings that are produced per female per generation.

Now, this is represented in terms of females because females give birth and so, if we know the number of females that have been born per female in this generation it gives a very good idea of the rate of population growth. This is how we represent it in the case of population ecology:

N[t + 1] = R[0] X N[t]

which is the geometric progression.

If we take any constant R naught, say R naught of 1.5, we will find that the population increases and the rate of increase increases make every generation. So, from the 0th generation with a population size of 10, in the first generation we have a population size of 15, so there is an increase of 5 here.

Now, from the 1st to the 2nd generation there is an increase of 7.5. So, let us write it here. So, here the increase is 5, here the increase is 7.5, here the increase is 11.25. What we are observing here is that with every generation the increase - the net increase which is the population at the nth generation minus the population at the n minus 1th generation, it is increasing, which is a common characteristic of the exponential growth as well.

But then in a short while - in just 10 generations you have increased from 10 to around 400. Now that is not sustainable. Population size - when you plot it versus generation - this is the exponential increase, this is the geometric progression, but then in reality we hardly see any such population increases in nature.

Now, here we are talking about the wildlife population, we are not talking about the human population so far. Because in the case of human population we have seen this curve - that it increases exponentially. But in the case of wildlife populations we see certain differences.

So, this is a theoretical model. But in practice what we observe is that R naught is not constant: it varies with the population size. A good way to understand this is by a thought experiment. Suppose there is an island and this island has plenty of food, and this island has absolutely no predators. And you leave two mice, a male and a female - on this island. Now, these mice have plenty of resources, there is no dearth of food, there is no dearth of space, because all the islands is available for them. There are no predators to keep their population in check. So, the population of these mice with a starting generation comprising of only two individuals - it will start to increase exponentially, because with every generation we have more mice. And more mice would mean that in their next generation they would have even more number of offsprings, which is this classic curve which shows the exponential increase.

But then after a few generations what would happen is that you would have so many mice that now the food would start becoming a limiting factor. So, earlier when you had this island with plenty of food and you had only two mice, each mouse can could eat as much as it wanted. But now the size of the mice population has increased, so much that now not every mouse would be having access to sufficient amount of food.

Similarly, the space that was available earlier was plenty because this island was - because all of this island was available for the mice. But now the population has increased so much that you will now start to see some amount of competition for space. So, there is competition for food, there is competition for space. And so, the mice will now have to fight each other for the resources.

They will not have access to all the resources that they actually need to maintain this sort of a population curve. And when that happens this curve will then start to flatten out. So, it moves like this, but then it will start to flatten out and ultimately it will reach to a flat stage. We are coming to that now.

This is known as the logistic growth equation. Now, the logistic growth equation states that the growth will increase in an exponential manner, but then after some time as the population starts to reach the carrying capacity then the rate of population growth will start to diminish so that afterwards we have a constant population.

This is how we represent the logistic growth equation: it states that

dN / dt = r X N X (K - N) / K

Now, consider the first case where N is very much less than K. N is the population at any time t, K is the carrying capacity. Carrying capacity means the maximum number of individuals that can be sustained by the environment. In the case of our example of the mice on the island, we are referring to the maximum number of mice that can be sustained by the island, that can be provided for in terms of food, water, space, by the island - that is the carrying capacity.

Now, if N is very much less than K which is in the starting - suppose you had a carrying capacity of say 10000 mice, but you only started with 2, so you have 2 which is very much less than K. In that case, K minus N is approximately equal to K because N is very much less than K, so K minus N is roughly equal to K, which means that K minus N divided by K is approximately equal to 1.

What we are saying here is that this K minus N by K - this portion is roughly equal to 1. When that happens we would have the situation that dN by dt is equal to r into N, because this portion is equal to 1, so we will only have dN by dt is equal to r into N, which is the equation that we began with. The rate of increase is proportional to N which is this one - you will have an exponential growth of increase in the population.

But then what happens? When the population increases so much that it is now close to K. So, let us look at the other extreme. Other extreme is that N has increased so much that it is now approximately equal to K. What we are saying here is that the number of mice is not just 2, but say it has raised to around 9500 or say 9900. Now, the carrying capacity is is 10000 and the mice population is 9900. So, the environment is roughly just able to support this mice population. And when it crosses 10000, then some of the mice would have to die. In this case when N is approximately equal to K, we have a situation that K minus N is approximately equal to 0 because K and N are very close together. So, K minus N is very small and we can say that it is tending towards 0. Which would mean that K minus N divided by K is approximately equal to 0 or it is a very small figure.

When that happens this K minus N by K is roughly equal to 0. So, dN by dt is approximately equal to 0. What this is telling us is that dN by dt - the rate of increase in population with time - dN by dt is approximately equal to 0 is telling us that the increase in population with time is roughly equal to 0. Now, if the increase in population is roughly equal to 0 it means that the population has now stabilised; the population is now constant, and it is constant at a level that is roughly equal to K.

So, the population increases, but then it becomes roughly equal to K which is the carrying capacity. This is how the curve will look when we plot it. In the beginning we see that the curve goes on like this. This is the phase where we are seeing an exponential growth. Then, we see a phase where there is a constant growth, and then there is a phase where the the rate of growth is decreasing with time.

If we are discerning things out of wildlife population ecology there are two kinds of things that we should be concerned about. One is the problem of statics: what determines the equilibrium conditions at the average values? What determines what will be the population, what will be the growth rate of population at any point of time? What that means is that when we talk about the human population what we are asking is: how much is the human population? What is the rate of growth at this point of time? And is there anything that we can do about it?

The other thing is the problem of dynamics: how does the population change with time? So, the factors that are working today - the population that we have today - it is going to change with time. How much would this change be? Can we predict what will be the population in say the year 2100 or 2150 or after that? And what would be the factors that would be regulating this population in that point of time? Say here 2100, what would be the growth rate? What would be the factors that would be regulating this growth rate and the level of population?

So, in this lecture, we started with the impact of humans on the environment. And we recapitulated that the impact is equal to the amount of population into affluence into the level of technology. Then, we also saw that the level of affluence does not increase very fast and technology is also dependent on the population base that we have, because the more number of people that are thinking the faster it is possible to have a newer technology. So, the rate of population growth is the biggest factor that can play a role in deciding the amount of impact that humans are having on their environment. So, we need to understand how the human population has been increasing and what are the factors that are leading to this increase.

From there we went to the Malthusian theory. And Malthus had predicted - he was an English cleric - and he had predicted that - or he had observed that the human population grows in a geometric progression that is in every 25 years the human population doubles. Whereas, the agricultural production grows in arithmetic progression. So, there is only an addition to the agricultural production say in every time span. It does not grow in a geometric progression. And if such a thing happened, then we would very soon have a situation where the human population has increased to a level that it does not have sufficient food. And when such as a situation arises then nature will start to act through positive checks. He referred to things as positive checks - things such as there would be war, there would be pestilence, there would be a famine, there would be floods, and these are all different ways through which nature will act to reduce the human population.

So, remember that he said that if the food supply is less as compared to the population, then we will be having floods. Now, through time we have observed that this is not the case - we also have floods in areas where you have a very low population density and sufficient amount of food. There are also a number of criticisms, but this was one major factor in his theory - that if the food is less and human population is more, then positive checks will start to play. And he upholded people to go for preventive checks which the humans can use themselves - things such as celibacy or things such as late marriage, so that the human population does not increase to a level that it surpasses the food production. Now, through time we have observed that, yes, Malthusian theory does explain some points - it is, but, a model - a simplistic model - there are also a number of nuances that it does not consider. Things such as the human population does not double every 25 years. If you plot the the ah the doubling time over the centuries, you will find that it was as high as say 700 years to as low as say around 35, 40 years. Similarly, the agricultural production is not just moving in an arithmetic progression, but as more and more of land is being brought into agriculture, better technologies, more fertilisers, more application of fertilisers, we have been able to put even the agricultural production into an exponential phase.

Similarly, the positive checks not only occur where there is a scarcity of food supply, they can also occur in other places. So, there are a number of criticisms to the Malthusian theory. One way out is to look at how different wildlife populations behave. And in the case of wildlife populations, we have observed that the logistic growth equation applies in a number of circumstances.

The logistic growth equation states that if the population is very much less as compared to the carrying capacity of the environment then the population will grow exponentially. Then as the population becomes closer to the carrying capacity the rate of growth will start to go down and ultimately the rate of growth will become 0 in which case the population will become a stable population. So, we see an S-shaped curve in which the in the beginning we have a flat phase followed by exponential which we also call as the lag phase, followed by a log phase, followed by a stationary phase and sometimes also a collapse of the population. This is something that we observe in a number of circumstances.

Now, the exponential phase or the log phase can be continued if the carrying capacity of the environment can be increased which is what the humans have been able to do for quite some time through modern technology and by bringing more and more land under their control. But this can only be done to a certain extent.

Then, we also observed that in the case of wildlife populations there are certain extrinsic and intrinsic factors that play a role in determining the rate of population growth, and humans being no exceptions we can use these extrinsic and intrinsic factors. But also we can make use of incentives because man is a rational organism - man is rational thinker, so we can make use of incentives. We can make use of demographic transition by providing more and more amount of food and resources to populations, so that demographic transition is accelerated and we bring the human population to a level where the birth and death rates both are low.

So, that is all for today. Thank you for your attention. Jai Hind!