Conservation Economics
Dr. Ankur Awadhiya, IFS
Indian Forest Service
Department of Biotechnology and Bioengineering
Indian Institute of Technology, Kanpur

Module 2
What is Conservation?
Lecture 1
Conservation in the Anthropocene

Namaste! Today we begin our new module: What is conservation? This module will have 3 lectures, Conservation in the Anthropocene, human population growth and food requirements, and unsustainable development. Let us begin with conservation in the anthropocene.

We have seen before what conservation is. Conservation comes from the two Latin word roots con which means together and servare which means to keep. So, literally conservation means to keep something together. What is this something? Conservation in the context of wildlife and in the context of natural resources means the preservation, protection and restoration of the natural environment and wildlife.

So, we are trying to do preservation, protection and restoration. There are three components of conservation: preservation, protection and restoration and we do the conservation of natural environment or natural resources and wildlife. Now, when we say conservation in the anthropocene, what is anthropocene?

Anthropocene is a proposed epoch. What is an epoch? An epoch is a time period in the history of Earth.

So, conservation is a proposed epoch which dates from the commencement of significant human impact. It begins from the beginning of significant human impact on Earth's geology and ecosystems including, but not limited to anthropogenic climate change.

So, it is a time period and this time period begins from the beginning of significant human impact on earths geology and on the Earth's ecosystems and it includes, but it is not limited to anthropogenic - which means manmade - manmade climate change. So, it includes manmade climate change it includes global warming, but it also includes a number of other things.

Now, what are those other things the first such impact is over consumption. Consumption by itself is not bad, but over consumption is striking. What is over consumption? Most of the natural

ecosystems and most of the natural systems have a rate of growth. So, if you consider a forest the trees in the forest are growing; you also have the next generation that is coming from the seeds. Similarly if you consider the oceans or any other water body you will have fishes and these fishes also have a natural rate of population growth.

Now, if humans remove this population at a rate, which is less than the rate of population growth, in that case the population of these trees or these fishes will either remain constant or they will go on increasing with time. But over consumption states that if you remove these organisms at a rate that is greater than the rate of the population growth - in that case the population will start to decline and that is known as over consumption.

So, one human impact on the environment is over consumption and these days we are over consuming literally everything. We are over consuming the fishes because of which the stocks of fishes in most of our oceans are going down. We are over consuming forests because of which we have seen massive deforestation. We are over consuming water resources because of which a number of water bodies are diminishing. We are over consuming the soil resources because of which there is a heavy amount of soil erosion and quite a lot of land is turning barren. We are over consuming most of the resources. So, over consumption is one major human impact on the environment.

Another one is habitat destruction. Habitat as we have seen is the natural home or the abode of an organism. If we damage that habitat - if we destroy that habitat - and why will we destroy any habitat - because of over consumption.

So, there is an animal that lives in the forest - let us consider elephants. Elephants live in the forest. Humans want to have access to wood and if humans take off most of the wood and if they convert these forests into a barren land, in that case the habitat of the elephant will be destroyed. So, habitat destruction is also a major human impact on the environment.

Another one is desertification. In desertification we are over consuming the water resources at such a rate that we are turning lands into deserts. A major factor in desertification is also overgrazing. Through overgrazing the cover of vegetation from the land is removed and when once this cover is removed the Sun's rays are able to heat up the land very quickly and dry up the land. So, excess removal of water as well as over grazing are leading to desertification.

Also we have ocean acidification. Ocean acidification means that we are converting the pH of oceans towards acidity which means we are reducing the pH of the ocean bodies. How are we doing that? A major factor is the release of carbon dioxide. When we are burning fossil fuels, when we are cutting down trees we are doing two things. One is that we are releasing carbon that was stored in the fossil fuels for a very long period of time - out into the atmosphere. When we are burning coal, when we are burning petrol, diesel, natural gas - we are releasing the carbon

that was stored inside the Earth into the Earth's atmosphere. And at the same time the second thing that we are doing is that we are removing those things that were removing carbon dioxide from the atmosphere. Plants remove a major chunk of carbon dioxide through the process of photosynthesis, but then out of our greed for land we are also destroying the forests.

So, on the one hand we are increasing the amount of carbon dioxide that is being released into the air and on the other hand we are also reducing the sinks of carbon dioxide. What happens when both of these things happen together? The level of carbon dioxide in the air starts to grow and when you have too much of carbon dioxide in the air it has to go somewhere. And carbon dioxide can dissolve in water. So, some part of this carbon dioxide also dissolves in the ocean waters. And when carbon dioxide meets with water it forms carbonic acid. And when you have an acid that is growing in concentration in the oceans the pH level of the ocean drops and this is known as ocean acidification.

And this is a very major impact on a number of ecosystems because quite a number of organisms that live in the oceans have calcareous shells made of calcium and calcium compounds say calcium carbonate. If you make the oceans into an acidic body what happens is that this calcium carbonate - it reacts with the acid and it dissolves - it converts into a bicarbonate and it dissolves in water. And so quite a lot of ocean reefs are getting affected. At the same time when the acidity of water - when the pH of water turns acidic this water is now no more capable of supporting a large number or a large variety of organisms - because every organism has a level of tolerance for a number of things. Not all organisms can survive in acidic waters.

So, when you turn the water acidic those organisms that are not able to tolerate acid waters - they will die off. So, ocean acidification is also a major human impact on the environment.

Next we have ozone depletion and a major cause of ozone depletion is the use of chemicals that are known as chlorofluorocarbons. These chlorofluorocarbons have been used for quite some time as refrigerants and also as propellants. Even in the case of a number of shaving foams we have been using chlorofluorocarbons as the agent that propels the foam outside from the can. Now these chlorofluorocarbons - they react with the ozone that is there in the stratosphere - and they deplete the ozone layer. Now once that happens - ozone is something that protects all life on Earth from the UV rays of the Sun - from the ultraviolet rays of the Sun. So, if the ozone layer thins or when it collapses, what happens is that more and more of UV rays from the Sun are able to reach to the Earth. And these UV rays can have negative impacts on a number of organisms. For instance they can lead to skin burns. They can even lead to some forms of cancers. They can increase the amount of or the rate of formation of cataracts in the eyes of different organisms. So, ozone depletion is another big human impact that we are seeing in anthropocene.

Now remember that most of these things did not occur before the impacts of humans was felt - because things like chlorofluorocarbons - they do not occur naturally on the Earth. This is a

completely manmade chemical and we have produced this chemical at such a vast scale that it has led to ozone depletion.

Next we have changes in the bio geochemical cycles such as nitrogen cycle. Bio geochemical cycles are the cycles through which nutrients move through the biological realm of the Earth which is the biosphere meaning all the plants and animals, it moves through the geological realm of the Earth which means that it is moving through the soil. So, this is a cycle through which the chemical nutrients are moving through the biological and the geological realms of the Earth. Common examples are things like carbon cycle or nitrogen cycle or phosphorus cycle or water cycling.

Now when we consider nitrogen cycle - nitrogen is a nutrient that is required for the growth of plants. It is also required for the growth of animals. Now, plants get nitrogen in the form of nitrites and nitrates from the soil. And how do these nitrites and nitrates form? Because we have nitrogen in the air - as much as 78 percent of the air is nitrogen - and when this nitrogen reacts with oxygen during lightning it converts into a nitrite or a nitrate and with rainfall it comes down to the Earth. Similarly, we have some organisms which are known as nitrogen fixing organisms. Common examples are Rhizobium, which is a bacterium, which lives in the ah root nodules of leguminous plants. Also other organisms like Nostoc and Anabaena also perform some amount of nitrogen fixation. So, these were two major routes - two major natural routes through which nitrogen from the air was converted into nitrites and nitrates and made available to the plants.

Now, what humans did was through the use of chemical cycles such as Haber process or Ostwald process, we are artificially converting the nitrogen in the air into nitrites and nitrates and using them as fertilisers - which is fine to some extent, but then an overuse of these fertilisers is also having a negative impact. Why? Because these chemical fertilisers affect the chemical structure of the soil; they affect the organisms that live in the soil. And when they are used in an excess amount quite a lot of these fertilisers also get washed down to areas where we do not want them. So, if these nitrogenous fertilisers - when they get washed down into a water body - then it essentially pollutes the water body because we did not make these nitrogenous fertilisers to be dumped into the water bodies.

Now, when these nitrogenous fertilisers are made available in the water bodies they have certain impacts. They will lead to a very rapid growth of plant material in the water bodies as well. And what will that lead to? If you have a water body - suppose you have a pond and there is a very heavy growth of algae - what will happen? The algae is taking up space in the water body. So, less and less of space is now left available for the other organisms such as fishes. A number of these water plants can also entangle the animals that are that normally live in the water bodies. And when we have a very rapid and profuse growth of these plants - after a while these plants will also die. And when they die - so much amount of organic carbon is there in the water body that needs to be degraded. And when the degradation of these plant bodies occurs it also takes up

the oxygen that was there in the water. And once that happens the level of oxygen in the water body goes down because of which a number of organisms are going to die. So this is a major impact. We call it as eutrophication of the water body which is the adding up of nutrients into the water body and this has very drastic and dramatic effects on the water body.

So, changes in the biogeochemical cycle such as nitrogen cycle through the use of mostly fertilisers is also a major human impact that was not present before the anthropocene - because earlier we did not have these chemical processes - Haber process or Ostwald process. And so the nitrogen that was brought to the Earth was brought in a very small quantity as compared to what we are putting into our soil and into our water bodies in the anthropogenic age.

Loss of biodiversity and extinctions because of a number of these factors and also because of the rampant poaching that humans do. There is a big loss of biodiversity: we are seeing a large wave of extinctions of organisms. Changes in the distribution of organisms, changes in biodiversity - why do we see changes in the distribution of organisms? Because of the changes that we are making to the surface of Earth. So, for instance if there is an organism that requires a water body and if humans come and they over consume the water that is there with the water body - this water body will dry off. Once that happens the organisms that lived in that particular place will either have to move to some other place if they are able to. Suppose they are flying animals or they are animals that can do locomotion on the ground - they will shift to some other places. But a number of other organisms will just perish. And so there will be a change in the localisation of biodiversity because in this area earlier we had say hundred species and now we do not have those species - probably we have some new species that have come up into this area. These are changes in the distribution of organisms - changes in biodiversity.

Then we have climate change. And a major causal factor of climate change is the release of greenhouse gases especially carbon dioxide. Now carbon dioxide - when it is there in the atmosphere - it acts as a greenhouse gas which means that it traps the heat of the Sun in the atmosphere. So, what it does is that it permits the short wavelength portion of the electromagnetic radiation - especially the infrared rays to come inside, but then when they are released back as long wave radiations - it traps them and slowly and steadily the temperature of the Earth increases. Now, once the temperature increases - it also has a number of other impacts because our winds or water currents are all related to the differences in temperatures that are there in different regions of the Earth.

If you increase these temperatures - if you take it with the natural distribution of temperature on the Earth - what happens is that the wind patterns change, the climatic patterns change. So, we might see things such as excessive drought or excessive rainfall that leads to floods or very high increase in temperatures which may lead to things like heat stroke or very drastic climate change events such as cyclones. All of these increase in their intensity - the increase in their duration and the increase in their probabilities. This is climate change. We also have non manmade climate

change, but the level of climate change that is being brought about by human activities these days is so high that it has overwhelmed the natural levels of climate change. So, this is another major human impact on the environment.

Other impacts include soil erosion changes in geomorphology, deposits derived from concrete lime mortar or other calcareous materials outside the cave environment. So, changes in soil erosion, changes in geomorphology are also major human impacts on the environment.

Then we have changes in stratigraphy due to increased sediment load and deposition because of deforestation, construction activities and so on. Now, changes in stratigraphy - it means that there is change in the levels or the layers of soil that are naturally present. And why do we see these changes? We are observing these changes because of a huge amount of sediments that are being brought - through mostly the river systems and the water systems - into the lakes. So, earlier suppose we had every year - we had 1 millimetre layer of soil that was coming naturally, but then because of deforestation and because of agricultural activities and other activities now we are seeing not 1 millimetre, but say 10 millimetres of soil that are coming. This is leading to changes in stratigraphy.

Then changes in the elements in the atmosphere: C 12 or carbon 12, that is released from fossil fuels; radionuclides that are released from nuclear fallout and atomic reactors. We are not just seeing changes in the amounts of elements that are there in the atmosphere, we are also seeing a change in the radioactive levels of different elements that are there on the planet Earth.

Now, changes in C-12 concentration - why does that happen? Because the fossil fuels that we are using were made from carbon that has been stored for many years - many thousands of years or many millions of years. Now, in that long period most of the radioactive carbon which is carbon 14 has disintegrated and has converted into other nuclides. So, the amount of radioactivity that you will have in the carbon that was stored for a very long period of time will be much lesser than the amount of radioactivity that we see in the current carbon - because carbon fourteen is regularly being produced in the atmosphere. Now, if we release a large amount of carbon twelve - because we are burning the fossil fuels - that is changing the carbon twelve carbon fourteen ratio that was there in the atmosphere. Now this will not have a very drastic impact on most of the organisms, but yes this is a change that is brought about by human beings on their atmosphere. So, this is another indication of the beginning of anthropocene. When we start seeing changes in the radioactive ratios in different gases or in different elements - that would give us an indication of when anthropocene begins. And similarly we are seeing radionuclides that are released from nuclear fallout and atomic reactors and a number of these radionuclides just did not exist before humans brought them on Earth.

Then we are seeing changes in soil - because of water logging, desertification, buildup of pesticides and other chemicals, and a lot of this has to do with agriculture. Because of

agriculture, when we are storing water in certain areas, when we are constructing canals - it is leading to water logging in certain areas. Also when we are doing excessive irrigation for water thirsty crops - and if the soil is unable to tolerate that much amount of water, then it might lead to water logging.

Then we are seeing desertification in those areas where we are excessively taking out water and we are also letting animals perform overgrazing. That is leading to the soil turning into desert soil. Then there is buildup of pesticides and other chemicals that are being sprayed especially for agriculture, but also because of those chemicals that are being released due to industrial activities. That is leading to major changes in the soil.

Introductions and invasive species: what humans have done is that they have been a medium of bringing different species from one part of the Earth to another part of the Earth. Now, some of these introductions are done voluntarily. So, for instance a species such as lantana was brought from Africa into India because there were some humans who thought that this is a beautiful looking plant and we should have them in the hedges, we should have them in the gardens here. And so this plant - Lantana camara, it was brought from Africa into India and when it came to India it became an invasive species - because the other species in Africa were able to tolerate this species - they were able to keep this species in check, but our species were did not evolve with this species - Lantana camara; they did not know how to deal with this species. So, what happened was that in a very short period of time this lantana entered into our forest and slowly and steadily it replaced the native species in a number of areas and it became the predominant species. Now this is an introduction of a species that was done through volition because humans wanted to bring this species from one place to another place. But then we also have a number of involuntary species introductions especially because when humans move from one place to another place a number of organisms are also able to hitchhike on the aircrafts, on the ships and they are able to come from one place to another place. Similarly, major introductions also happen in the form of food articles. So, for instance if there is a person who is going from say Africa to Australia and is taking certain food items - say certain fruits with him or her into Australia. So, what is happening is that the seeds of these fruits are also coming this with this person into Australia and when these seeds reach into this place then it is possible that this species of plant gets introduced into Australia. Now, nobody wanted to introduce this species into Australia, but then involuntarily because humans are moving from one place to another place and they are taking things with them - then it is leading to the introduction of species. Another good example is the movement of a number of organisms through ballast water. Now this is something that we will see later on in a lecture, but in short what happens is when you have a ship that is moving from one place to another place, for maintaining the stability of the ship, whenever the luggage in the ship is removed - whenever the cargo is removed, some water from the ocean or the water body where the ship is residing is pumped inside the ship so that it maintains its level - it does not rise and sink with the load. It has to be maintained at a constant level. So, whenever you are putting the load inside this water will be pumped out - the same

amount of weight as that of the cargo that you are putting in - and when the cargo is removed water is pumped inside.

Now what happens is that when you are pumping this water inside the organisms that are living in this water also are able to enter into this ship in the form of the ballast water and when the ship moves to another area and when this water is pumped out the organisms that were there in this ballast water are now released to the new environment. Now, it is possible that if these ships were not moving or if these ships were not using the ballast water it is quite possible that these organisms would have never moved from one place to another place. But then because of these ships that are using the ballast water, we are now seeing introductions of a number of organisms across continents and a number of these organisms are also invasive species which means that they grow at a very fast pace. And they also are able to overwhelm the natural species that are present in the new location - and in a short while we will observe that they have overwhelmed the local populations - they have led to a rapid decline or a collapse of the indigenous species - and they have established themselves. So, this is also a major impact of humans on the environment.

Then we have pollution including light pollution that we are seeing because of the humans. We are observing coral bleaching. Now coral bleaching - it means that because of changes in the water of the oceans especially because of acidification and because of pollution a number of corals die off - and when they die off the colour of the coral changes - it becomes white in colour. It becomes bleached. Bleaching is an indication of the death of corals. Now corals are those species or coral reefs are those formations that support a number of other species - because fishes can lay their eggs inside these corals, a number of other organisms can find their safety inside these corals. So, corals are very important formations for biodiversity and when coral bleaching occurs we also observe a rapid and a massive decline in biodiversity in those areas. Coral bleaching is also another human impact on the environment.

One more impact is wars. And wars are not just tragic from the human point of view, but they are also tragic from the environmental point of view because they release massive amounts of noxious substances into the environment which leads to a massive decline in biodiversity. So, these are some human impacts on the environment that we are observing in this epoch called anthropocene.

Traditionally we take the beginning of anthropocene as the day on which we had the Trinity explosion in 1945. So, this is the beginning of the nuclear age and this date is taken as the beginning of anthropocene.

Now, over time humans have become more and more conscious of the the impacts that they are having. And so, these days we also see - especially in the 1960s we started talking about things such as The Population Bomb. We started to realise that our populations are growing at such fast

paces that it is now becoming impossible for nature to tolerate us. And so we started talking about the population bomb - that if we do not control our populations in a very short period of time we will over consume so much of resources that we will have nothing left. We started talking about - are there certain limits to growth? We all want to have growth - we all want to have development, but is there a limit to growth? Because if we have a large population and because of development we are providing them with so much amount of resources that - if we have a large population with a large amount of affluence because of development it will lead to an overconsumption of a number of resources. So, is there a limit to the growth? Is there a limit to the development? We started talking about these things.

And we started talking about how do we quantify the impacts that humans are having on the environment. And we came up with this formula:

I is equal to P into A into T.

I here is the impact of human activity on the environment. P is the population in the area and this area could be as large as the whole world.

So, what this formula is saying is that if the population increases the impact of humans also increases. So, I is directly proportional to P. I is also proportional to the affluence. Now affluence is the average consumption of each person in the population. So, affluence is telling us how much amount of resources are being consumed by one person. Affluence is generally measured through values of GDP per capita.

And what affluence is telling us - is that if you have more amount of resources - you are over consuming the resources - the more affluent you are the more amount of resources you are using. And so the amount of impact that you will have by using a large amount of resources will also be large.

So, I is also proportional to A. And I is also proportional to the technological advancement or a measure of how resource intensive the production of affluence is. So, I is equal to P into a into T. If you increase the population you will have more impact, if every person in the population starts to use more amount of resources you will have more impact, and with a more - better technology you will be able to provide these resources to the people. Or this technology may also be at times used to overcome the impact.

But in most of the cases what we have seen so far is that with more and more technology we are also increasing the impact - because of the need for more and more materials and because of an enhanced efficiency of the processing of these resources. So, I is equal to P into A into T. Now, let us now observe how P and A and T have been changing through time.

If you look at the world population we find that the world population for a very long period was nearly constant. Then it started to increase and then roughly around the time of Industrial Revolution, we see that it has started to rise very quickly. So, this is now the exponential growth of population and now it is going at a very fast rate. And in the next few years it will reach somewhere near 10 billion - currently we are around 7 billion.

So, the world population has been increasing very fast. So, the P component of I is equal to P into A into T has been increasing and the rate of increase has also been increasing. So, it is now an exponential increase in population. If you look at the density of populations there are a number of areas, where the human population density is very large. In those areas where we have a large human population we have seen that the impact of humans will be large and so these are the areas where also the impacts of humans will be large. Now if you consider our country - our country is one of the more densely populated areas of the world and because we have a large human density - because we have a large human population we need a lot more resources to feed these people. So, essentially the amount of agricultural expansion has been increasing with time. Now with the need for more agriculture we need more land because of which we are cutting up more and more of the forest. We want to provide affluence to all these people because of which we require more and more resources because of which again we are cutting down a number of forests and we are using those areas for things like mining.

So, any area that will have more population will also have more impact and what we are observing here is that not only the population has been increasing with time and the rate has been increasing with time, but also there are certain locations on Earth where the population density is very high and that has an impact on the total human impact on the environment. The population densities have also been growing over time in a number of areas.

Now, let us have a look at affluence. Affluence can be measured by how much amount of resources are made available to each and every person to consume. If a society is able to produce more resources those resources are available for people to consume. So, we can have an indication of the amount of affluence through a measurement of the amount of industrial productivity.

We can observe here that the productivity of a number of items has been increasing and we can see that around 1600 or 1650 AD we see a rapid change. Before that this curve was roughly horizontal and after this it has been rising exponentially. So, this can be an indication of where we started to have more impact on the environment.

Affluence can also be measured in terms of money that people have and if you look at world GDP over the last 2 millennia we see that here again we are seeing an exponential growth. Roughly after around 15 - 16 hundred AD we start seeing an exponential growth. So the affluence has also been increasing with time.

When we say I is equal to P into A into T the P component has been increasing the A component has also been increasing.

Now, if we wanted to know how much is the impact of people in different areas we can look at GDP per capita in different countries of the world. And here we will observe that the areas such as the United States or the UAE - they have - or most of the western Europe or Canada - they have a very high GDP per capita which means that the affluence in these areas is large.

And the GDP per capita has also been increasing with time, and this rate of increase has also been increasing with time. What that means is that not only is the affluence increasing, but the rate of increase has also been increasing - which means that in a very short period of time we will reach very unsustainable levels of affluence. If nothing is done to stop the impact then probably it will lead to drastic consequences.

Now, let us observe what is happening in terms of GDP per capita if we consider two different time periods. So, in this curve the GDP per capita in 1960 is represented on the x axis and the GDP per capita in 2014 is represented on the y axis. Suppose the rate of growth was the same everywhere. So, that would have led to countries that would have been on this line - this line at 45 degrees is showing that if you had say 500 GDP per capita in 1960, you also have 500 GDP per capita in 2014 - which means that there is no change in the GDP per capita - there is no change in the affluence.

Now, what we are observing with this curve or with this chart is that most of the countries are on the left side of this curve, which means that most of the countries have - or are observing increase in the GDP per capita. There are only a few countries in the world which are actually seeing a decrease in the GDP per capita, but in most of the countries the GDP per capita has been increasing by which you can say that the affluence level in most of the world has been increasing with time.

Now let us have a look at the T component - the amount of technology that is available to the society. Now we can use certain indicators to assess what is the rate of technological progress. We can look at Moore's law - Moore's law is an indication of the number of transistors that are there in a microprocessor and it says that the number of transistors in a dense integrated circuit doubles approximately every 2 years. So, what Moore's law is saying is that if you look at an integrated circuit the number of transistors will double every 2 years. Now this was an observation that we had earlier in the 1960s. What is the position at present?

Well we are observing that actually the number of transistors has been roughly doubling every 2 years and we are observing an exponential increase, which is an indication that we are seeing a technological progress that is also increasing exponentially, which means that the T component

of the equation I is equal to P into A into T has also been increasing and the rate of increase has also been increased.

Other indicators include things such as the the super computing power that we have. So, if we make a plot of the super computing power in terms of FLOPS, we will find that here again we see a roughly exponential increase. Increases in the microprocessor clock speed - this is another indication of technology. Here also we are observing an exponential increase in the microprocessor clock speed with time. So, T has been increasing and this rate of increase has also been increasing with time.

The sequencing cost per DNA - the number of human genome base pairs that are sequenced per US dollar - that is also increasing - which means that for every dollar we can now sequence more and more amount of the genome which is a good indication of the technological progress.

So, what we are observing here is that in the equation I is equal to P into A into T, P is increasing, A is increasing, and T is increasing - and all three of these are increasing exponentially - which means that the impact has also been increasing at a very fast pace.

Now, if you look at the impact of humans, we can divide the human history into 3 different stages. In the early society - in the aboriginal society we had small P, small A, and small T - small population, less amount of affluence, less technology. Because there was a small population, so, there were less number of mouths to feed. There was a less requirement of resources because the affluence was low. People just did not feel a need to have more resources - they just did not know about having resources such as air conditioners or computers. The affluence was very less and the technology was also missing. So, in those days even if there were some people who wanted to have more and more resources, the technology was not present to enable them to extract these resources from the environment. So, the P was less, A was less, and T was less and so, there was a little impact on resources - and the resources were in plenty.

There was a little need - there was hardly any need to conserve the resources - though in certain societies certain fruit or food or fodder trees may may have been conserved as religious trees. So, what was the thinking of humans in those times? The thinking was that nature - or mother nature is providing us everything in plenty. And there is nothing that we need to do to conserve because our requirements are so less - and the amount of resources that there is available - it is so large in comparison that even if we do all the exploitation that we can, that is not going to have any impact.

So, in the aboriginal societies we see that there was hardly any talk of conservation although a few trees such as the fruit trees or the fodder trees - they were revered as religious trees and so they were conserved. We had a feeling - a very small feeling of conservation that was mostly religious - that had little to to do with the amount of impacts that we have on the ecosystem. That

is the first stage of development of the society.

Then we moved to stage number 2. In stage 2 we started seeing modernisation of the society. With modernisation of society - it actually began with technological improvements - if you have better technology you can have more resources. If you have more resources you can increase the affluence of people and if you have more and more people who are more and more affluent, they are protected from diseases, they are having a large lifespan or their lifespans are increasing and at the same time they do not have to work so hard because technology is there to help them out. In such a situation the population will also start to rise. So, with the beginning of modernisation we start seeing a growth in population, a growth in affluence, and a growth in technology - and so there is a growing impact on the resources due to unabated exploitation and resources are now getting scarce with time.

So, with the development of modernisation we actually started feeling a crunch - that yes our population is growing fast, it is growing more and more affluent and we are getting more and more technology, but then now there is a dearth of resources. For instance we had means to convert iron ore into iron, but then now we were seeing that the iron ore that was available in the surroundings that has now become exploited. And so now we require more sources of iron ore - because we have technology to convert it into iron and we have a population that has been increasing and this population wants this iron. Similarly with affluence there was a need for a number of new items. People wanted to build fancier homes. So, they wanted more amount of wood, but then the local forests are now empty because we have a better technology to cut these forests and we cut these forests. And so now, these forests are gone, but then there is an increase in population and with increasing affluence they also want more and more of wood. What do we do?

So, modernisation was also a time of expansion. There was an increase in need to conserve the resources, but then this need was not a very hard pressed need - because for the time being the need for resources could easily be met through expansion of the empire. So, we start seeing the expansion of empires such as the Roman Empire or the British Empire and in a number of these situations what these empires did was to make other areas their colonies - which meant that the people in these empires had now access to resources in other areas as well. So, there was little need to conserve the resources and there was a possibility to get these resources from other areas and this was done through an expansion in the empires and through the development of colonies.

But then we moved into the third stage - which is the modern society. Now, in the modern society the population is large because it has been increasing with time, the affluence is large, the technology is large, but then all the areas that could have been brought into the hold of the empire - they have already been brought into the hold of the empire. Now we do not have any more land to bring to the empire. What do we do now?

So, there is a large impact of resources - because of unabated exploitation the resources are extremely scarce, but then there is no more land to bring into the fold - there is no more land to exploit and so, now the resource conservation has become extremely imminent - because we do not have any other option - we do not have the option of bringing in other lands to get these resources.

And so the only option that is left is to conserve what we already have. And so scientific management of resources gets born as a discipline to meet the needs of the society. The modern society is now putting a lot of emphasis on conservation and on sustainable use of resources.

But then we to make use of these resources in a sustainable manner we not only require this feeling or this devotion to conservation, but we also require means to perform these operations. So, we need not just a willingness, but also the technology and also the economic inputs that will make this possible. Most of the world from the mid nineteenth century is now in this stage. So, conservation has become a very important part of life these days.

Now, not everything is going that bad because we can also see a number of silver linings. There is a more and more - greater - emphasis on recycling of resources, recycling of things like plastics. If we see the percentage of plastic that was recycled in the nineteen eighties - there was hardly any. But today we can see that almost twenty percent of the plastics is getting recycled. Now of course, the amount of production has also gone up. So, if we look at the amount of waste that we were generating in the 1980s that was nothing compared to the amount of waste that we are generating now. But at least now there is an emphasis to recycle things - there is an emphasis that we should not dump these plastics out into the atmosphere - or out into the environment - out into the water bodies. We should not just go and burn them off to release noxious fumes into the environment. There is a much greater emphasis on recycling things and on disposing these waste items in a more prudent manner.

Another silver lining is that the rate of population growth has already peaked. We are now in a stage where the rate of population growth is decreasing with time. Now even though our populations have been increasing, but the rate of increase has now gone down and the rate of increase is now going down very quickly. In a short period of time we might even move to a stage of a stable population. If we look at the population growth we can see that this is an S-shaped curve. And in this S-shaped curve we are currently in the middle. We can now project that the world population will stabilise at around 10 or 11 billion people.

The rate of population growth is determined by the slope of this curve. The slope of this curve was very high in this region and it goes on decreasing when we reach here. So, the slope is less and we are right now in the middle. We have already crossed the peak population growth rate and the growth rate of population is now going down - which is a good news.

Another thing is that we are observing reducing fertility rates in a large number of countries. The fertility rate - or the number of children that a woman would have on an average - that is also going down. Your parents or your grandparents had many more siblings and we are also observing changes in the population pyramid. So, in the 1950s we had a population pyramid that had a much greater base as compared to the top, but now we are shifting to a population pyramid that does not taper. This is also an indication that the rate of population growth has been decreasing - and it will further continue to decrease when these children reach their adulthood. We are also observing demographic transitions in most of the areas of the Earth.

Now, what is a demographic transition? A demographic transition tells the story of a society in terms of different stages. In the first stage we have a society in which we have a high birth rate and a high death rate. Now because you have a high birth rate every woman or most of the women on an average have a large number of babies and most of these babies also die off very soon - because there is a high death rate. And this death not just happens in the time of childhood - it also continues into the adulthood.

Now, why do we have a society like this? Because we do not have advancements in medical care. So, there is no way to fight diseases and a number of people die out of diseases. Now because the death rates are high, if the society has to continue, it should maintain a high birth rate as well. So, this is the first stage in which you have a high birth rate and a high death rate.

Now, with advancement of technology people start working on ways to reduce the death rate - and the ways to reduce these death rates are medical advancements. So, we come up with ways of treating diseases - we come up with antibiotics, we come up with antiseptics and so on. And slowly and steadily we are able to bring the death rates down. But then we have not done anything for reducing the birth rate.

So in this state we have a society that has a decreasing death rate, but still continues to maintain a high birth rate. So, more number of babies are born and less number of people are dying. In that stage we will start seeing an increase in the population. So, the total population will start to increase. In the first stage the high death rate and high birth rate were able to counter each other and the total population growth was less - which is what we saw for most of the presence of humans in the human history. But then starting from say around 1500 AD we start seeing a large increase in population - because we have now now started to bring the death rates down now. With this exponentially increasing population people then start feeling that yes - this population is growing so fast that in a short period of time it will overwhelm the resources that we have - and so, now the society starts to look at ways to reduce the birth rates as well. And how does society reduce the birth rate? Well it comes up with things like contraceptives, it comes up with education - and with more and more people going out to work and being being productively employed, there is a less and less incentive for people to have more and more number of babies. Why? Because in earlier times every couple used to think that ok, if I have more number of

babies, I have more hands that are going to help me out in the fields - that are going to help me out in my profession. But now with the increase in technology we have things like tractors available for us. So, even if a farmer has a single child he or she might be able to perform all the duties of the field without the need for any more hands - because we now have access to machines. Similarly in the earlier times people used to think that because of the high death rate it is possible that a number of my children are going to die off, but now everybody knows that yes we have such good medical facilities that most of my babies are going to survive and so, people make this conscious decision that we should have less number of babies. And so, in this third stage the birth rate also starts to fall. Now in this case the death rate is still falling - because we are still working on medical advancements. But now the birth rate has also started to fall and so, the population growth will now turn towards a plateau. And in the fourth stage we have a low birth rate and a low death rate. And so, the population now stabilises. There is no further increase or decrease in the population and the population stabilises.

So, this is a demographic transition that we have observed in a number of societies - and the silver lining is that with the increase in technological progress we are observing this demographic transition in more and more areas - we are observing that we have brought down the death rates and we are also bringing down the birth rates.

So, anthropocene is an epoch in which humans have put a very huge amount of impact on the ecosystems - a very huge amount of impact on the geology. But then the silver lining is that we are now shifting towards reducing these impacts.

That is all for today. Thank you for your attention. Jai Hind!

Conservation Economics
Dr. Ankur Awadhiya, IFS
Indian Forest Service
Department of Biotechnology and Bioengineering
Indian Institute of Technology, Kanpur

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!

Conservation Economics
Dr. Ankur Awadhiya, IFS
Indian Forest Service
Department of Biotechnology and Bioengineering
Indian Institute of Technology, Kanpur

Module 2
What is Conservation?
Lecture 3
Unsustainable development

Namaste! We carry forward our discussion on Conservation, and in this lecture we will have a look at Unsustainable Development. Now, let us begin this lecture by remembering what Gandhi had said, "The world has enough for everyone's needs, but not everyone's greed.

Here Gandhi is emphasising that we have enough resources, but these resources are only sufficient to meet the needs of everybody, but not the greed of people. That is he is emphasising that the resources that we have are limited and while they can be used to fulfil everybody's needs; so, that everybody is well off they cannot be used to fulfil the greed's of people. So, if somebody wants to have more and more of all the resources, then that is not something that can be permitted, because that becomes unsustainable. So, here we are getting an idea of sustainability. If you use resources in such a manner that you are using them to fulfil your needs, it is a sustainable use. But, if you are using things to fulfil your greed, then it is probably an unsustainable use.

Now, technically we define sustainable development, as development that meets the needs of the present, without compromising the ability of the future generations to meet their own needs. So, when we talk about sustainable development we are saying, that we need to have a development and this development should be sufficient to meet the needs of the present. Again it's the same thing - everyone's needs. So, we want to have a development such that we are able to meet the needs of everybody, but without compromising the ability of future generations to meet their own needs. Now, why do we not want to compromise the ability of the future generations to meet their own needs? Because, again that if we are compromising the ability of our future generations, then probably we have shifted from the domain of needs to the domain of greed. And we are using so much of the resources that our children, and our grandchildren will no longer be able to meet their own needs. So, then we will call it an unsustainable development.

So, sustainable development is the development that meets the needs of the present without compromising the ability of the future generations to meet their own needs. And, we have seen before that if the world goes with an unsustainable development then, we have issues; we have

problems of conservation. Some examples of what an unsustainable development can lead to are over consumption - overuse of resources again. Overuse of resources because, we have shifted towards meeting the greed's of some people or greeds of majority of people. That leads to an over consumption. If you have an over consumption you will be clearing off a large portion of the forest to make space for agriculture, to get more and more amount of food, if you go for an over consumption you will deplete the resources, you will deplete the fish stocks, you will deplete the environment, you will deplete the ground water.

So, that is a result of unsustainable development: over consumption. Destruction of habitats which is bringing huge survival questions for a majority of species, desertification because the ground cover has been completely removed, because of the need for food, the need for water and also because of over grazing - that leads to desertification. Ocean acidification because, we are using so much amount of fossil fuels that we have increased the amount of carbon dioxide that is there in the atmosphere. And some of this carbon dioxide is now getting into our ocean waters - it is making the waters acidic. So, that is another consequence of an unsustainable development. Depletion of the ozone layer, changes in the biogeochemical cycles - we have shifted to an unnatural biogeochemical cycle - loss of biodiversity, extinction of species, changes in the distribution of organisms, changes in biodiversity, changes in climate, erosion of soil, changes in geomorphology all of these are some consequences of unsustainable development.

Changes in stratigraphy, changes in the element composition, changes in soil, introduction of invasive species, pollution, bleaching of corals, wars; so, a number of these things are arising, because of the greed of human beings. If everybody was targeting to fulfil their own needs, then the issues would not have arisen.

So, these are some consequences of unsustainable development. Now when we talk about the concept of sustainability - when we say that sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs - then we are talking about two primary concepts. Here the first one is that of the needs of the present. What we are trying to say here is that there is a difference between needs and greed. So, the first concept is the concept of needs, in particular the essential needs of the world's poor to which overriding priority needs to be given.

When we talk about sustainable development we are not saying that we should refrain from development and we should put the world's poor in a position, where they no longer have control over their own lives. No, that is not sustainable development. Sustainable development says that needs of everybody and strictly the needs of the poor people need to be met. So, all the human needs - all the human requirements have to be met.

The second concept is the idea of limitations, or the idea of having a trade off. So, this definition is emphasising that there is always a tradeoff. We can go on meeting the needs, but if we

increase our needs to certain extent then the meeting of those needs will start to affect the ability of the future generations. Then probably that is not right.

So, there is always a trade off. You have to decide how much do you need today and how much needs to be left for the future generations. There is always this trade off that goes, there is always this idea of limitations, which is imposed by the current state of technology and social organisation.

On the environment's ability to meet the present and the future needs - the ability of the environment to meet the needs of the present as well as of the future generations is limited and so, this has to be kept in mind whenever we are trying to meet the needs of the present generation, or whenever we are trying to leave resources for the future generations.

We recognise three pillars of sustainability; we can talk about environmental sustainability, economic sustainability and social sustainability. So, these are the three pillars of sustainability: environmental, economic and social sustainability. What are these?

When we talk about environmental sustainability, we talk about things such as ecosystem services. Ecosystem services are the services that are provided to human beings by a well functioning ecosystem. So, these are things such as reduction of pollution, provisioning of services such as goods, things such as wood, fodder, fuel. We also have things like maintenance and regulation of the local climates and the microclimate. The benefits of biodiversity including things such as pollination or protection from certain diseases, availability of medicinal plants - these are all different ecosystem services which are provided by an ecosystem that is functioning well. And when we talk about environmental sustainability, we need to ensure that the ecosystem services are provided to the present generation and also to the future generations - which means that the ecosystems should be in a position where they are able to work properly. So, that is a part of environmental sustainability.

Then, we talk about things such as green engineering and chemistry. How can you manufacture goods or services in a manner that is less polluting to the environment? So, for instance, could you, say, replace a few chemicals that are inside a bottle - inside a plastic bottle, in such a way that when these chemicals leach out into the environment then they cause lesser degree of harm? When we start thinking about these things then we are talking about green chemistry. Can we replace plastics with biodegradable materials - bioplastics? So, this is also another concept in green engineering. In environmental sustainability we also talk about the quality of air and water, especially the levels of pollution that are there. We talk about reducing the effects of stresses such as pollution, greenhouse gas emissions and so on. So, if you want to maintain the sustainability of the environment you need to keep these stresses down to a certain level. We talk about resource integrity by minimising waste generation to prevent accidental release in the future.

So, when you talk about environmental sustainability there are two options, one to go with the business as usual, where you are generating a huge amount of waste. And, you are probably keeping this waste in a landfill or keeping them in containers, you are storing, say, chemical wastes or radioactive wastes in containers. And whenever you have such a situation, then it is possible that the future generations are going to pay for our misdeeds. Because, it is possible that in a near or a far off future, some of these chemicals may start to leach out. In that case we are putting a liability to the future generations.

So, when we talk about environmental sustainability, we say that no, we should go for such processes that the amount of waste generation is minimised, so that there is a lesser need to keep these wastes in a storage, which could cause an accidental release or issues for the future generation. So, we want to have the resources today, but we want to have them in such a manner that we are not creating a liability for the future generations. That is a part of environmental sustainability.

When we talk about social sustainability, we talk about things such as environmental justice, empowerment of communities that are burdened by pollution. In social sustainability, we have things such as the rights of the local communities. Suppose there is a big mining firm and it says that ok, I need these forests because below these forests we have a huge amount of minerals - we have a a a huge stock of ores. Now do you just permit this company to go cut the forest and start digging out the ores, or do you also ask the local communities?

Now, there could be certain communities who have been protecting these forests - because these forests are part of their culture. So, do they have a right or not? And if we say that these people also have a right, then we are talking about social sustainability. Similarly, in one of the later lectures we will have a look at things such as industrial pollution. If there is a company that is releasing chemical waste into the seas, and the fishermen who are catching the fish that are laced with these poisonous chemicals - they are losing out their jobs. The local community that is feeding on these fishes is falling ill. Do these people also have a right? And when we say that they also have a right to life, we are talking about things - which is social sustainability. In social sustainability, we talk about protection, sustenance and improvement of human health. Because again when we talk about the ability of the future generations to meet their own needs, then if the future generation is healthy then they will be in a much better position to meet their own needs.

And so, we need to ensure that we are not spreading pollution or industrial effluents to such an extent that it is impacting the health of any community. So, this is a component of social sustainability. Or things like increasing the participation of stakeholders - and here again the future generation will be in a much better position to fulfil their needs, if they have been involved in the decision making process - if they have been trained in the decision making process, if they know how to say bargain for things, if they know how to negotiate for things. So,

when we talk about social sustainability it is important to ensure that all the stakeholders get the right they have and they get a voice.

Whenever you need to make any decision - whether any industry should be set up, where should it be set up, what will be the modalities of collection of the effluents, or treatment of the effluents then the local people have to be involved. And when we talk about such stakeholder rights, we are talking about social sustainability.

Education about sustainability - the future generations will be in a much lesser position to meet their dreams, if they are uneducated. So, in social sustainability we also say that people need to be educated about sustainability. Sustainability is something that should be incorporated in the textbooks, sustainability is something that should be taught in the schools. Because, when people are educated about sustainability they will be in a much better position to assert their rights and they will have a much better control over their lives. Another thing that we talk about is the protection, maintenance and access to resources - protection of resources, maintenance of resources and access to the resources.

Let us take the example of a tiger reserve. Currently there are certain communities that are living alongside a tiger reserve. And their livelihoods are dependent on the tiger reserve because there are people who want to see tigers - they come to these tiger reserves and tourism industry is providing jobs to these local communities. Now, what will happen if all the tigers get forced out? If there are no tigers in a tiger reserve, there would be hardly any tourists who would want to visit the place. So, the protection and maintenance of tigers - here tigers are a resource - they are a natural resource and maintenance and protection of these tigers is critical to ensure that the future generations are also able to derive their livelihoods or employment through this resource. Similarly people need to have an access to the resources. Now, suppose the government comes up with a policy and says that ok, there is this tiger reserve, but all the facilities of tourism will be say set up and maintained by a third party. And we are not allowing the locals to have an access to this area or to the resources. In that case the ability of the future generations of these communities to derive their livelihoods and employment from these tigers or these tiger reserves will go down.

So, in social sustainability we need to ensure that the resources are protected, the resources are maintained in a good fashion and people also have access to these resources. We talk about promotion of sustainable living - that is also a component of social sustainability. Because, if people shift to living in a sustainable manner, then the next generations are in a much better position to meet their own needs. So, this is also another component of social sustainability.

Next, we talk about economic sustainability. In economic sustainability we talk about job security. If there is a resource - does it provide job security to people, or when we are talking about a tiger reserve is the condition such that people have a job one day and next day they can

be kicked out? If that is the situation - if the local people do not have a job security, then probably this is not a sustainable development. Because, the locals - or the people who are dependent on these tiger reserves - also need to be sure that they will be in a position to utilise these resources to meet their needs. So, in economic sustainability we talk about job security, we talk about incentivisation of sustainable practices. We have seen before that incentives are things that induce people to act in a certain manner. If you - if the society wants to promote sustainable living, then sustainable living needs to be incentivised. A good way out is through the provisioning of taxes and subsidies. If somebody is going towards an unsustainable living, then probably the government may tax that person more - which is why the government taxes polluting vehicles in a big way.

By these taxations the government is incentivising people to refrain from using these oil guzzling vehicles and pollution spewing vehicles. In a number of cases these incentives are also positive incentives such as subsidies. So, in a number of cases the government subsidises the purchase of electric vehicles, the government gives you a subsidy if you put up solar panels on top of your roof.

So, economic sustainability talks about the use of incentives to promote sustainability. It talks also about the market practices for sustainability: how do you tinker the market in such a manner that sustainability gets promoted. We will look at the functioning of markets in later lectures, but here it is important to emphasise that the demand for things depends on a number of factors, including whether people have been exposed to it and how culturally or socially acceptable is the using of a certain resource. Now, if through education or through awareness people get this idea that the use of solar panels is sustainable, or the use of SUVs is bad for the environment - that would impact the demand of these resources. And demand would also have an impact on the supply of these resources, on the prices of these resources.

Economic sustainability also talks about the market practices for sustainability, it talks about natural resource accounting. When we do an accounting for any industry is it only the profit and loss statements that we are interested in, or are we also interested in accounting for how sustainable was the manufacturing process?

Natural resource accounting incorporates things such as the sustainability accounting for industries; it also incorporates accounting for how much amount of resources do you have. Does the country say for instance perform an audit every few years about how much is the stock of forest that is available in the country, how much is the amount of groundwater that we have in the country, how much is the level of fish stocks in the country? When we incorporate accounting for all of these different natural resources, we are talking about economic sustainability.

Life cycle cost assessment: a very good example in the case of life cycle cost assessment is

plastics. Plastics are so ubiquitous because they are cheap to manufacture. So, it is very easy and it is very cheap to manufacture, say, a plastic bag or a plastic bottle. But once they have been used and once they have been thrown out, then it is difficult to collect them: especially because they are light in weight and they litter easily. It is difficult to carry them to say a sorting facility because again because of their light weight they use a very large volume - and so, transportation becomes difficult. It is difficult to sort them out into different categories because there are so many different kinds of plastics. There are so many different kinds of additives that we are adding to plastics - there are so many different kinds of plasticizers that are added. We have thermoplastics, we have thermosetting plastics - both of these cannot be mixed together, if you are aiming to recycle plastics. Then, when if these plastics are recycled, then there is a cost to recycling, if these plastics are put into a landfill, then there is a cost of land and water. Now, the person who is manufacturing the plastic or the industrialist who is manufacturing these plastics or these plastic bags is not paying for all of these - it is the society that is paying for these.

So, the municipal corporation of your city will be paying for say collection of garbage or processing of garbage or disposal of garbage. When we say that the municipal corporation is paying, it is the taxpayers who are paying, it is you and me who are paying for the disposal of these plastics - it's not the industrialist. So, if we emphasise that plastics are cheap - because they are cheap to manufacture, then it would be one story and if we emphasise that throughout their life cycle from their cradle to their grave, the plastics have such and such cost involved - the cost of collection, the cost of transportation, the cost of processing and the cost of keeping them stored for say 1000 of years - because they just do not degrade. When we incorporate all of these costs into the accounting we are talking about the life cycle assessment of plastics. And once we incorporate life cycle assessment, we will see that a number of biodegradable products are much cheaper than plastics. It is only because we do not consider the life cycle assessment that we say that plastics are cheap. If we incorporate life cycle assessment, we realise how expensive they are. Now, incorporation of life cycle assessments is important for conservation, but it needs to be done. And when we talk about life cycle assessments, we are talking about economic sustainability.

Then, in economic sustainability we talk about cost structures to reduce the risk and to promote new technologies. So, for instance if there is an industry which is a polluting industry, and this industry has an option to say install an equipment that would process these pollutants - but the installation of these equipment will entail certain cost. There could also be a requirement for putting money into research, for development of such technologies which will be able to control this pollution. Now, these sorts of things need to be incentivised. So, you need to incentivise industries to install such equipment, you need to incentivise the research institutions to perform research into developing these technologies. And, when we say that all of these are important and they need to be funded, say, by the government, we are talking about economic sustainability.

And when we incorporate all these three - the social accounting, environmental accounting and the financial accounting, then we are talking about the triple bottom line. Now, bottom line generally refers to the last line in the profit and loss statement. And it tells what is the level of profit or loss that a company has had in a particular year - that is the bottom line. But, then the triple bottom line says that not just the profit and loss, but you also need to see, if the social accounting and environmental accounting have also been a part of the functioning of this industry or company.

When we talk about sustainability, there are two different schools of thought. There is one school of thought that says that ok, we need to have sustainable development. But, we can say do a trade over or a trade off for meeting the needs of the present in a much greater way than meeting the needs of the future generations. That is weak sustainability. And there is another school of thought that says that no matter what happens the development has to be sustainable. You cannot trade the needs of the future generations with the needs of the present generation - that is the strong sustainability. So, weak sustainability assumes that natural capital and manufactured capital are essentially substitutable - natural capital such as forest and the manufactured capital such as say iron ore - weak sustainability says that both of these are essentially substitutable, which means that if you are destroying your forest, but, by destroying the forest you are having more and more industries or you are having more and more roads, or you are having more and more production of iron, then it is ok if the forest get destroyed. That is weak sustainability - it assumes that natural capital and manufactured capital are essentially substitutable. And it considers that there are no essential differences between the kinds of wellbeing that they generated. So, they are one and the same - the only thing that matters is the total value of the aggregate stock of capital, which includes the natural capital and the manufactured capital, which should be at least maintained or ideally increased for the sake of the future generations. It says that if we get rid of our forest, but we have developed an industry in its place, so through this industry the future generation will be able to meet its own needs - so there is no need to conserve the forest. That is weak sustainability - that natural capital and manufactured capital are essentially substituting. In such a perspective it does not matter whether the current generation uses up non renewable resources or dumps carbon dioxide in the atmosphere, as long as enough machines, roads and ports are built in compensation. This is weak sustainability.

The strong sustainability school assumes that natural capital and manufactured capital are essentially non substituting. It says that you need to maintain natural capital and you also need to maintain the manufactured capital. And you need to maintain both of these; you cannot just say that we will be maintaining the manufactured capital at the cost of the natural capital. That is the strong sustainability. It considers that there are essential differences between the kinds of well being that they generate. So, essentially you cannot substitute the joy of seeing a tiger by say providing a longer road. So, this is what the strong sustainability argument says - that the benefits that we receive out of the natural capital are very different from the benefit that you receive out of the manufactured capital. And so, when we talk about sustainability, we need to

maintain both of these capitals separately. Both natural capital and manufactured capital need to be at least maintained or ideally increased for the sake of the future generations. So, it says that the natural capital and the manufactured capital both need to be maintained and both need to be ideally increased for the sake of the future generations. That is if you look at the differences between strong and weak sustainability, the key idea in strong sustainability is that the substitutability of natural capital by other types of capital is severely limited, they are not substitutable. The weak sustainability on the other hand says that natural capital and other types of capital such as manufactured capital are perfectly substitutable and you can trade off one for the other. Strong sustainability says that certain human actions can entail irreversible consequences. A good example is climate change. It says that if you go and releasing large amounts of carbon dioxide into the atmosphere that would lead to global warming because of the greenhouse effect - and that could lead to climate change. Now, climate change essentially is an irreversible phenomenon and so, it will lead to consequences that are also irreversible. Weak sustainability says the technological innovation and monetary compensation can be done for environmental degradation. That is, on the one hand the strong sustainability argument would say that you should not release so much amounts of carbon dioxide because that will lead to climate changes and that would lead to negative consequences for a large number of people, on the other hand weak sustainability says that ok, even if there is climate change, we can provide monetary compensation to the people who are affected by climate change. So, weak sustainability would say that ok it is fine that there is climate change. You can always compensate people for it we can provide them with money. And, they should be happy with it and so, there is no need for the present generation to say stop climate change.

This is a major difference between ah the strong and the weak sustainability. The strong sustainability says that conserving the irreplaceable stocks of critical natural capital for the sake of future generation is essential because a number of stocks of natural capital are irreplaceable - you cannot replace them with anything else. The weak sustainability says that the total value of the aggregate stock of capital should be maintained or ideally increased - not natural capital. So, this is a difference between strong and weak sustainability. The key concept in strong sustainability is critical natural capital - it tries to emphasise again and again that the natural capital is critical. On the other hand the weak sustainability just says that optimal allocation of scarce resources is good enough.

The strong sustainability says that scientific knowledge is required as an input for public deliberation - it talks about procedural rationality. It says that scientific knowledge is crucial, and we need to develop these procedures. On the other hand the weak sustainability only talks about technical or scientific approach for determining the thresholds and norms - it is talking about instrumental rationality. So, on the one hand the strong sustainability is asking how are we going to conserve these natural capital, but weak sustainability is only saying that ok even if the national capital is going down we just need a method to measure this loss of natural capital, so that we are able to compensate for it by providing money. It only talks about a technical aspect, it only talks about an instrumental rationality not a procedural rationality.

Sustainability these days has come into our common currency, especially after the Earth summit of 1992. In the earth summit the countries came together and they agreed to agenda 21 - which is the sustainable development in the 21st century. This talks about sustainable development goals. These include things such as no poverty, or reduction of poverty - so, here we are talking about a social sustainability as well as as an economic sustainability. It talks about removing hunger - because, if you create conditions where people are no longer poor or hungry, then probably they - as well as their next generations - will be in a much better position, to ah fulfil their own needs and requirements. It talks about things such as good health and well being - which is crucial not just for the current generation, but also for the future generations. It talks about quality education to people. It talks about gender equality, clean water and sanitation, affordable and clean energy - not just clean energy - the energy needs to be affordable, so that more and more people have access to the energy.

But, then in the quest for making energy affordable, we just cannot go on with the non renewable sources of energy. We have to shift towards clean energy - and we need to to create such conditions that clean energy also becomes affordable. So, we need to invest into research into clean energy, we need to invest into those industries that are producing - say - the solar panels. We need to provide incentives to people - we need to provide subsidies, so that clean energy becomes affordable. So, affordable and clean energy is a sustainable goal. Decent work and economic growth - now we are starting to talk about economic sustainability: everybody should have an opportunity for a decent work, and should also have the opportunities of economic growth, industry innovation and infrastructure.

So, you need to have infrastructures, you need to have industries, which will make it possible for the future generations to meet their own needs. Reduced inequalities, sustainable cities and communities - so not just sustainability at the level of the industries; but also sustainability at the level of cities. Is your city in a position where it is doing rainwater harvesting? Is your city, for instance, having a sewage treatment plant, and even more preferably a sewage treatment plant that makes use of bio remediation - because that is one of the most sustainable ways in which we can process the waste. So, the sustainable development goals talk about sustainable cities and communities.

They, talk about responsible consumption and production - consumption needs to be responsible - which means that over consumption needs to be avoided. So, there is responsible consumption, but also responsible production. Responsible production is production in a manner where we are not overusing the natural resources - we are not generating a huge amount of waste. We are doing the production in some of the most efficient manners - we are doing production that uses clean energy. That is responsible production.

So, the sustainable development goals talk about responsible consumption and responsible

production. They talk about climate action: What are we doing to mitigate the climate change? It talks about life below water. It talks about water habitats - the aquatic habitats - are they functioning well? What about the fish stocks? Are we over consuming the fish stocks? That also needs to be kept in mind.

Also in one of the sustainable developing goals, it talks about life on land which includes biodiversity. Are we doing our development in a manner that conserves biodiversity, or are we doing our development in a way that is getting rid of biodiversity? It talks about peace, justice and strong institutions - because once we have peace, once we have justice, and once we have strong institutions, then it creates a society in which people have much more control over their own lives. It creates a society where everybody is able to develop himself or herself. And it creates a society in which not just the present generation, but also the future generations will be in a much better position, to say, do innovation or to have more control over their own lives.

The sustainable development goals talk about maintaining peace. If there is a war then probably the next generation will be in a much worse position to maintain their own needs. It talks about justice, it talks about institutions, and it also talks about partnerships for the goals - because of late we have realised that sustainability cannot be done at the level of just a single country. If for instance there is one country that is releasing a huge quantity of greenhouse gases, it is over using coal - then the consequences will not just be faced by that country, but also by the world in total - because climate change is a global phenomenon. If there is a a country that is burning a huge quantity of coal - then the acid rain that results will not just fall in that country, but will also fall in the neighbouring countries. If there is a radioactive substance release from one country, then this radioactive elements will move through wind and water to reach other countries, they will affect people in the other countries as well. So we require strong partnerships and we require common goals.

These are the sustainable development goals. Can you relate these to the 10 principles of economies? One: people in society face tradeoffs - and when we talk about sustainability, we are talking about the tradeoff between meeting the needs of the present generation and meeting the needs of the future generations. Sustainability says that we need to meet the needs of the present generation, in such a manner that the future generations are also able to meet their own needs. This is a tradeoff. Tradeoff of course, and you need to cost what you give up to get something.

If you want to do development in such a manner that your children and your grandchildren are also able to have control over their own lives, then you will have to forgo something. Cost as we have seen is what you give up to get something. And, if you want to perform development in a manner that your future generation is secure then probably you will have to reduce your own consumption.

So, tradeoffs lead to costs and sustainable development talks about these costs. Third: that people

respond to incentives. So, if you want to promote sustainable development you will have to incentivise sustainable development, and you will also have to disincentivized development that is not sustainable. And we have seen that taxes and subsidies are very good mechanisms. But we also have social incentives.

Is the society boycotting an industrialist who is polluting the surroundings? Is the society honouring an industrialist who is - say making an express effort to reduce pollution? When you go and buy an equipment - do you only look at the cost or do you also see, whether or not that industry is making the equipment in a sustainable manner?

We can also look at the energy audits of the industry - do you also look at the natural resource audit of the industry? If you do all of these then probably, you are incentivising sustainable development and disincentivizing unsustainable development.

So, people respond to incentives, industries respond to incentives - and it is not just the role of government, but also of each and every consumer. Then, we saw that markets are usually a good way to organise economic activity and so, if we want to promote sustainable development, we will also have to act at the level of the market. And markets can be influenced. Markets can be influenced by influencing the buyers and by influencing the selling.

Governments can sometimes improve the market outcomes, through interventions - and these interventions can be at the level of taxation, subsidies or direct command and control. So, we can make use of different principles of economics to ensure that we have a sustainable development. So, what kinds of things should be we promoting? And what sorts of things are being promoted?

One thing that is being promoted for sustainable development is clean technology. Clean technology refers to any process, product or service that reduces negative environmental impacts, through significant energy efficiency improvements, sustainable use of resources or environmental protection activities.

Clean technology is any process product or service - so, we can have it at the level of a process, we can have it at the level of product or we can have a clean technology even in the service industry. And, what does clean technology do? It reduces negative environmental impacts. And how does it reduce the negative environmental impact? By doing significant energy efficiency.

Here we are talking about such processes, or such products, or such services that keep in mind that the energy efficiency needs to be increased. Now, the best thing about increasing energy efficiency is that it also makes the industry or the process more profitable. So, for instance there are two methods of manufacturing a chemical. And the first one takes say 1 mega joule of energy. And the second one takes 10 mega joules of energy for the same quantity of product. Now, if the industry shifts towards the process that is taking just 1 mega joule of energy, then

probably the industry will also be doing significant cost cuttings, because of reduction in its energy usage - the bill for energy will go down. It is important that we incentivise such processes because, in the beginning it might be difficult for the industry to shift to a more energy efficient process or protocol. Because, it might require, say, installation of a different equipment. But, in the case of clean technology we try to increase the energy efficiency - or it promotes the sustainable use of resources, or it promotes environmental protection activities.

So, for instance if there is a product - or let us say that there are two packets of tea and one says that it has been sourced from those areas that are doing organic cultivation. And the second one does not do that. In that case if you purchase the one that has been sourced from organic farms, then you are promoting sustainability.

Or there could be say a chocolate that says that it has been taken from those farms, or those countries that do not permit child labour. Or if you purchase a mobile phone that says that when it was manufactured, we took care that the greenhouse emissions were net zero. If we are using these services or if we are using these processes or these products, what we are doing? We are promoting clean technology, which will lead to sustainability. Now, things in clean technology include renewable energy, water purification air purification, sewage treatment, environmental remediation, solid waste management, energy conservation and appropriate sustainable technologies.

Let us have a look at some clean technologies that have been incentivised. One is environmental friendly energy and energy storage, including things such as power generation with renewable energy, use of photovoltaics or solar panels, use of solar thermals - solar thermals are those power plants that make use of the heat that is given out by the Sun in the form of infrared radiation. It concentrates that heat and it uses that heat to run a turbine. So, it is different from a normal solar cell. Or energy generation using geothermal energy, which is the heat that is stored inside the Earth. Or power generation using wind energy, or power generation using bio energy or power generation using sewage gas. Another clean technology is the environmental friendly use of fossil fuels. In this case you are using the fossil fuels, but you are using them in a way that is more environmental friendly.

Remember that when we talk about clean technologies, we are only talking about increasing the energy efficiency, or shifting from a 100 percent fossil fuel to a less amount of fossil fuel. It is not necessary that it should be a a 100 percent shift. Because, clean technologies are to promote an incremental step - it is a gradual process. So, in the case of environmental friendly use of fossil fuels, we are still using fossil fuels. And it is important to remember that fossil fuels are non renewable energy resources.

They are limited and so, they need to be avoided, but then in cases where they cannot be avoided, we can at least shift to an environmental friendly use. Such as a combined cycle power

plant - in a combined cycle power plant, we use several heat engines together to increase the efficiency. So, in this power plant we are still using the fossil fuel, but by using a number of heat engines, we are increasing the efficiency.

Another is cogeneration plants where we have a simultaneous generation of electricity and useful heat. Now, this heat could be used to say heat up the buildings. So, cogeneration plants ensure that the heat that was released in the generation of electricity - that is also tapped - and that is also used, so that the heating cost somewhere else can go down.

Or shift to high performance power station. Or carbon dioxide reduced power generation. So, you can shift to a process that is still using fossil fuels -but you release less amount of carbon dioxide. Or we can shift to storage technologies such as mechanical storage of energy, electrochemical storage of energy, electrical storage of energy, thermal storage of energy. Storage technologies are clean technologies because they permit people to generate more and more amount of energy through renewable means, when they are available, store that energy and use them when the renewable energy is not available. A good example is solar cells - solar cells or solar panels will only work during the day time, when the Sun is there, but what about the night time? If you wanted to shift to solar panels, then you would have to devise a mechanism through which the energy or the electricity that is generated during the daytime can be stored. Now, this storage can be through means of a mechanical storage, for instance you can use the solar energy in the daytime, to run pumps and shift water to a higher level. And, in the night time this water can be made to run through turbines and get the energy back. So, in this way we will be able to store the electricity that was generated through sustainable means, or through renewable energy. Or we can go with electrochemical storage which is batteries - or we can go through electrical storage or thermal storage.

Another clean technology is efficient grids such as smart grid local - local and district heat grid. When electricity is moved from one place to another there is a huge loss that occurs, because this electricity is converted into heat energy. Through a smart grid, we can reduce the amount of energy losses during transport of electricity.

Another clean technology is in the circular economy section, such as waste collection and transportation. If you develop an infrastructure for increasing waste collection and transportation, you are working in clean technology. If you devise a method of base separation and sorting - so that the plastics can be recycled, then we are talking about a clean technology.

Or utilisation of waste through say recycling. If you devise a method through which plastics can be recycled into other product, then we are talking about clean technology. Or thermal waste treatment - we have waste disposal safeguarding and removal of contaminants and hazardous waste, that is also a clean technology. Reduction or utilisation of landfill gas - when we talk about a landfill the organic material that is put into the landfill is slowly converted into methane

and is released. Methane is a very potent greenhouse gas. It acts in a way that is very similar to carbon dioxide, but is much more effective than carbon dioxide in trapping the Sun's heat. If this gas can be reduced or it can be utilised in some way - because methane can always be burnt! So, if you devise a technology through which these landfill gases can be burnt to generate electricity, we are talking about clean technologies. Or, environmental remediation - bringing the environment back to the normal pristine state, such as land rehabilitation or ecological restoration. If we for instance devise a technology through which the holes that are left on the ground after a mining operation - they can be filled back again or they can be replanted. Then we are talking about a clean technology. Or sustainable water management such as water procurement and treatment including groundwater monitoring and water purification. If you devise a technology that can monitor the amounts of groundwater that you have - that is a clean technology, because that permits us to use water in a more sustainable manner. If you devise a technology that can purify water, especially the sea water, then we are talking about sustainable water management because, we will reduce our dependence on groundwater, which is a very crucial natural resource.

If we say tap out most of the groundwater, then it takes hundreds of years for the reservoirs to fill back again. And, if we did tap all the groundwater resources then probably we are leaving out less for the future generations. But, if you devise a technology through which ah sea water can be purified and used - in that case we will reduce our dependence on groundwater and that will be a sustainable use of groundwater.

Or things about water utilisation - that is if we could have ways of increasing the efficiency of the components of the water distribution system, reducing the losses there, working on a on a better water distribution grid - these are all different clean technologies. Or increasing the efficiency in water utilisation - can we talk about water efficient technologies in the residential sector, can we talk about say systems that use less amount of water? Can we talk about water efficient technologies in the commercial sector, or have clean technologies in the sustainable mobility sector, such as alternative fuels, biofuels, natural gas, hybrid drives, electric drives fuel cell drives? Now, many of these reduce our dependence on petroleum. Or alternative drive technologies - efficient combustion engines, environmentally friendly vehicle design or infrastructure and traffic control. If you have an inefficient traffic control, then probably a lot more people are spending their time, in the intersections with the traffic lights. And that is also leading to the usage of fossil fuels that could be avoided. Through an efficient traffic control, an intelligent traffic control, integrated traffic infrastructure, these can be avoided. Electricity charging stations, natural gas fuelling stations - if we are promoting these we are promoting clean technologies.

Or sustainable mobility management such as car-sharing. If you develop an app that that can promote people to go for a car-sharing arrangement or a car pooling arrangement, we are talking about a clean technology. Or vehicle fleet management.

Similarly, we also have clean technologies in resource and material efficiency. Cross sectional technologies such as biotechnology, nanotechnology, mechanical engineering and process technology, new materials such as compound materials and bioplastics. Compound materials in a number of cases are able to increase energy efficiency by reducing the weight of the equipment. Biomaterials such as bioplastics are very good alternatives to petroleum based plastics, and they are biodegradable. Or we can talk about material efficient processes, such as optimisation of existing processes or utilisation of new materials, or reduction of the operating supplies. So, in this case we are saying that we will be using the same process, but we will try to increase the efficiency so, that less amount of raw materials are required.

Or sustainable designing such as eco design, which is an approach to designing products with special consideration for the environmental impacts of the product during its whole life cycle, or life cycle assessment. As we have seen, if we did a proper life cycle assessment, then we will come to the conclusion that plastics are very expensive. So, life cycle assessment is also a component of clean technologies. Or increasing the energy efficiency, such as industry specific energy efficient production processes. Automation control technologies, efficient engines, recovery of feed that would otherwise have been lost to the environment, or making use of more efficient appliances electric appliances, information and communication technology appliances or illumination - if you are shifting from a a standard incandescent bulb to say an LED bulb - it is an efficient appliance. This is a clean technology. Or energy efficient buildings - if you look at the technical part or the equipments or build a building shell - which means insulation and windows so that you are able to reduce the amount of heating and cooling that is required in the building - that is a clean technology.

What we are seeing is that especially after the Earth Summit, and especially after agenda 21, a number of governments have been promoting sustainable technologies or clean technologies in a number of different sectors. So, sustainable development is not very difficult, but it does involve a tradeoff - it does involve a cost and if the society is ready it is easy to do.

That's all for today. Thank you for your attention. Jai Hind!