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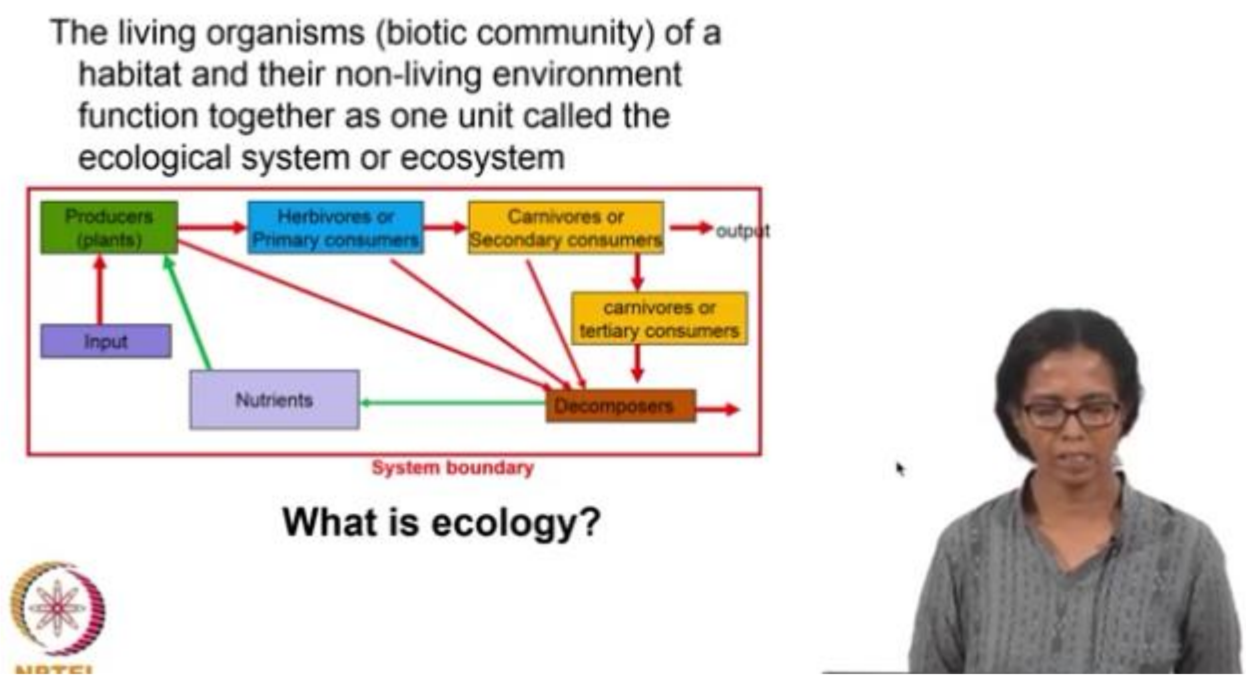
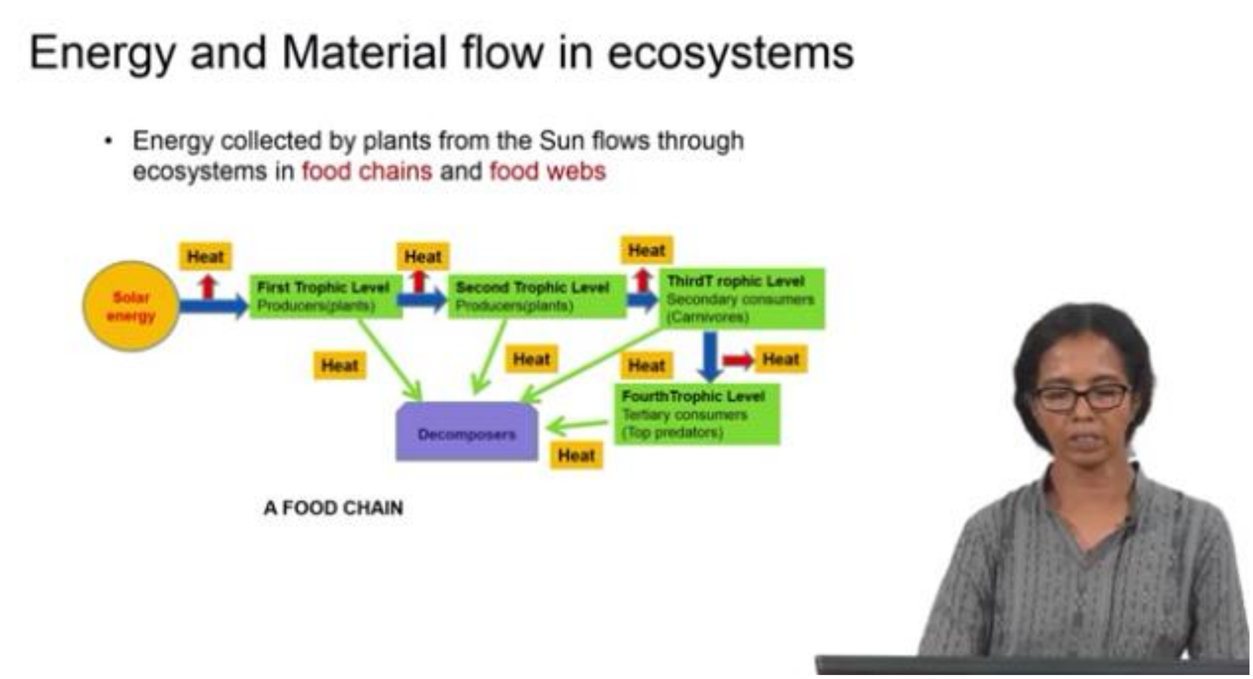
Ecology
Energy and Material flow in ecosystems and ecological efficiency
Prof. Susy Varughese
Department of Chemical Engineering
IIT Madras



So, the last class we looked at what is meant by ecosystem. So, as you can see in this figure, we have the, there are boxes which are representing the primary producers. What is known as a typical food web or the connections that are available in the ecosystem, so in which you see the plants, the primary consumers or the herbivores, the carnivores, secondary or the secondary consumers and or the tertiary consumers, all consumed by finally the decomposers when the living organisms die and then they recycle the nutrients.

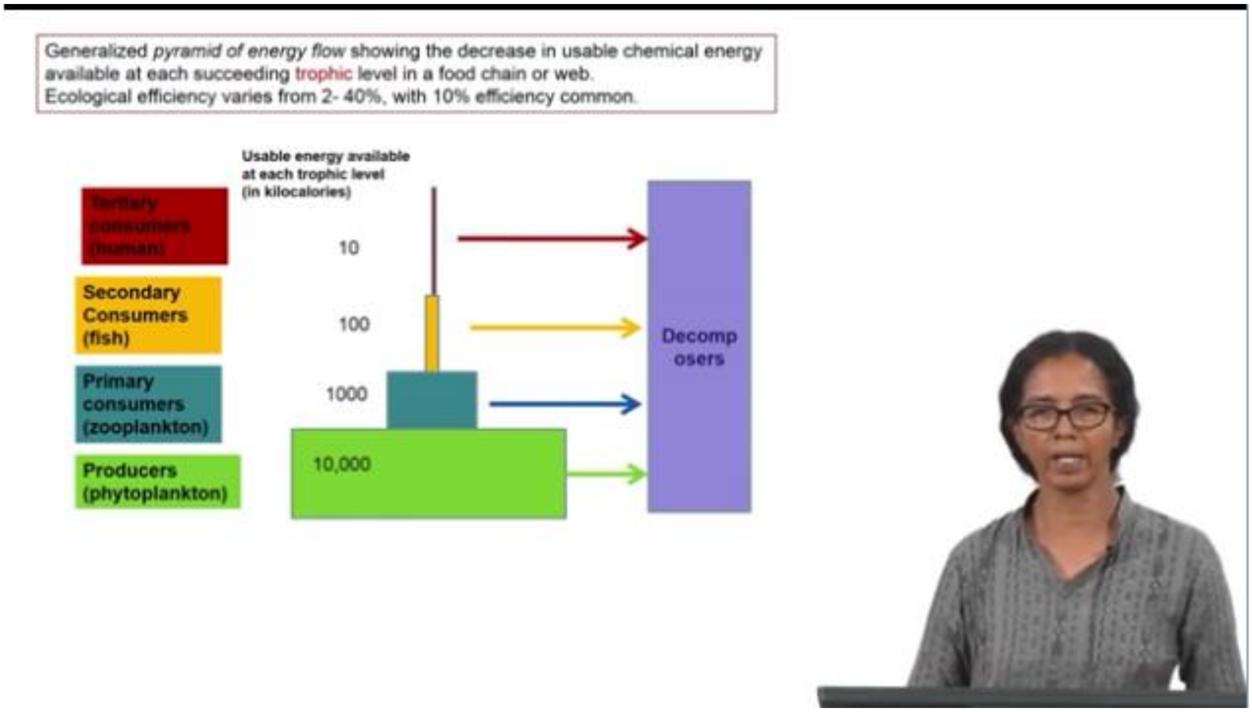
So, this figure has various arrows which represent mostly the energy and the material flow through an ecosystem, so the ecosystem is controlled by the energy that is coming from the sun and which is taken up by the primary producers which flows into the primary consumers and then secondary consumers.

So, based on the energy flow in the system it is classified as either producers or consumers, as one can see plants are the only producers in this system and all others are consumers, and eventually the decomposers break down the biomass and then it comes back as nutrients again back to the producers. So, we will see how the energy and the material flow through biological systems.



So, the energy and material flow in ecosystems is generally represented through the food chains and the food webs. There is a simple food chain is shown in the figure here, so which has actually the solar energy received by the producers or the plants which are known as the first tropic level. So these tropic levels are defined based on the energy that is arriving at a particular level. So, from the primary producers or the first tropic level, the energy flows into the next tropic level that is the secondary, second tropic level where the first primary consumers are seen. So, the primary consumers from the primary consumer, in all these stages you see some amount of heat is lost from the system which could be due to various processes that dictates at that particular level.

So, what one needs to remember is that what is the, what we need to think about, as you know, engineers or scientist who look at the system, is that in this living systems, when energy is flowing, for example, if there is a energy being put into machine we calculate the efficiency of this machine by looking at the output by the input and in the percentage efficiency we represent. So is it possible to represent the efficiency of this energy flow in the ecosystems, so that is what is more important to understand to also appreciate the value that ecosystems are providing.

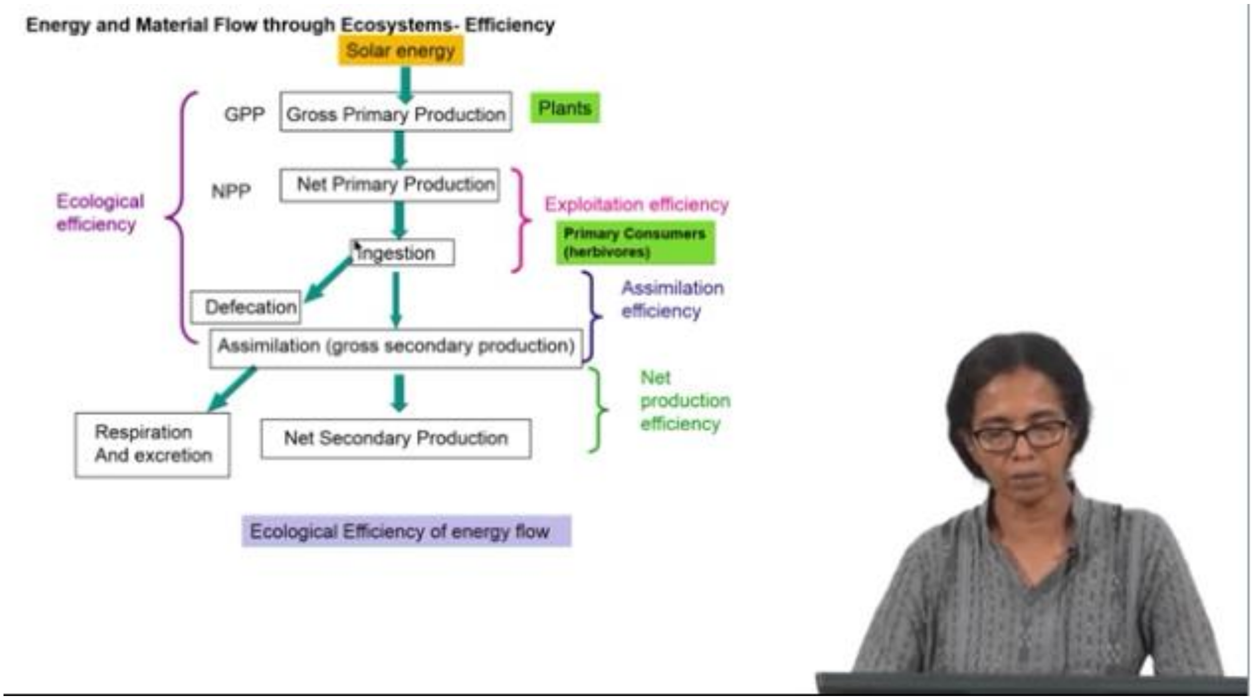


So, we will look at the energy flow in a little more detail. So, the generalized energy flow diagram is also represented as as a pyramid. Where energy you can see as the lowest level of the pyramid help the producers, it is represented as usable energy available at each tropic level in kilocalories. Now if you look at this picture, we can see that the primary producers have the highest amount of energy that is reduced to receive, if it is assume to be about 10,000 kilocalories, the energy that is flowing into the next level that is the primary consumers is only one-tenth of that which is about 1000 kilocalories.

So if you look at the next level that is the secondary consumers, it is only 100 kilocalories that is flowing into the system, so this is a typical system of aquatic ecosystem if you look at phytoplankton or the producers there, zooplankton feed on phytoplankton, and then zooplanktons are fed by fish, so they are the secondary consumers here. And the energy that is flowing into the fish which is the secondary consumer is only one-tenth of that is flowing into the primary consumer which is about 100 kilocalories.

So, when it comes to the tertiary consumer, let us say, an example as a human, it could also be officiating a bird, it could be another big fish that is feeding on a small fish. So any of this tertiary consumers, for example, the energy that is flowing at that level is only 10 kilocalories. So when in comparison to what the producers are making which is about 10,000 kilocalories, only 10 kilocalories is flowing, flowing into the tertiary consumers. So that is the pyramid is shrinking in as it is going to the top level, as the energy flow is becoming less.

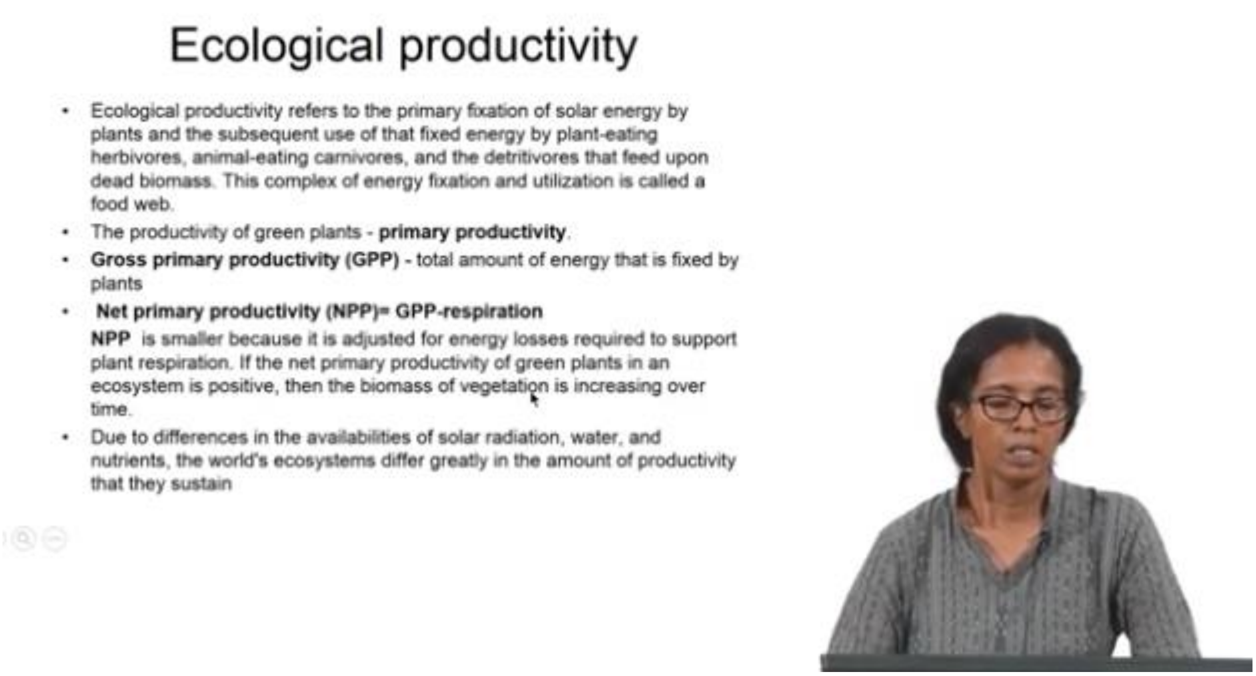
So, in the ecological efficiency in living systems varies between 2 to 40% with 10% efficiency as an average or a common efficiency. And all this, at all this tropic levels there is a connection to the decomposers they also have some efficiency with which they decompose the dead matter and then produce the energy, so you know at all this level some amount of energy is lost that is heat which is not shown.



So, this how do we estimate? So, is it a just a qualitative statement or it is a quantitative number that you can arrive at? So, it is possible to quantitatively determine the energy that is flowing into the system and how effectively various living organisms or an ecosystem itself is using this energy to produce the biomass or the material that they have as living systems. So this is what is represented in this diagram here, so where you can see the solar energy that is received by the plants, so which will be calculated using at quantity called gross primary production, we will go into the details of this gross primary production and net primary production.

So, the gross primary production and from there net primary production, if you reduce the amount of energy that is lost during respiration by the plants we get net primary production, so then that is the efficiency of the plants or the amount of energy that is flowing into the plant system. So, from the plants or the first level of producers, energy is taken up by the primary consumers or the herbivores, so they ingest the plants which they eat and then some amount is defecated, and some amount is used for various activities and for example movement, respiration, and reproduction etcetera. So basically, you get the net secondary production from a for a primary consumer or a herbivore from this, so this is the net production efficiency at that level because after all the amount of energy that is flowing into the system all of that is not consumed or utilized by the primary consumers for converting it into energy. So you can see that there is an exploitation efficiency, that is the effectiveness with which the animals or the herbivores are collecting the plants. So, they may have adaptations for to exploit this situation that existing on the grounds, so some of them maybe specialist on collecting. Let us say you have deer or some other species there, so some of them maybe specializing on a special type of plant which may have adaptation or a particular region you can see it and they may have an adaptation to, let us say eat short grass or long grass

or specific kind of plants that you are seeing in a particular situation they may be able to consume plants with thorns etcetera.
So that involves their exploitation efficiency, how efficiently they can exploit the plants to get the maximum energy from there. So, from there it is again there is another efficiency level that is the assimilation efficiency. How much of it is assimilated into the or gross secondary production that happens in the body of the herbivore. So this is after defecation, so whatever is ingested need not be used for the converting into body mass of the organism, so some amount is lost from the system as by defecation. So whatever is remaining is called as the assimilation efficiency or assimilated quantity which is a gross secondary production.
So, from the gross secondary production again the respiratory losses and the excretion losses are reduced, and then you get what is known as the net production efficiency of the primary consumer or the herbivore.

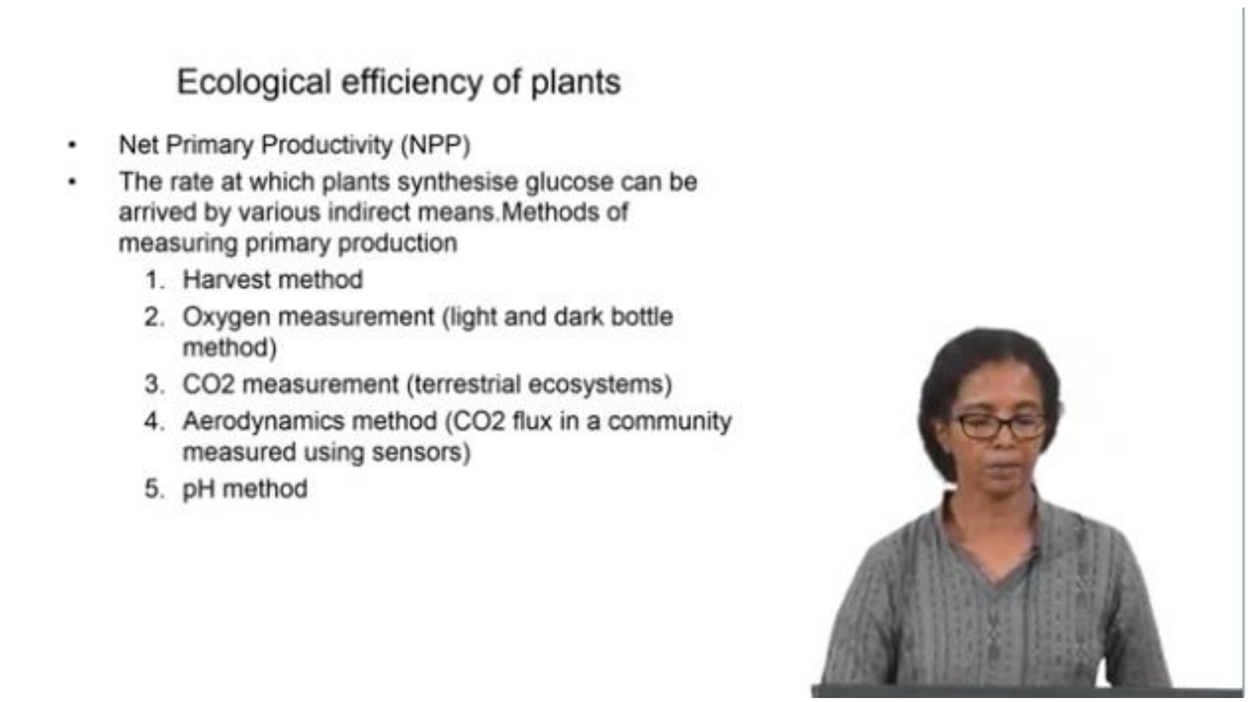


So, what is ecological productivity? Ecological productivity refers to the primary fixation of solar energy by plants and the subsequent use of that fixed energy by plant-eating herbivores, animal eating carnivores, and the detritivores that feed upon that biomass, so it is a complex form of energy fixation and utilization that is happening in this chain of events, and this is known as the food web.
So, in a food web, it need not be unidirectional energy flow, from each level there may be multiple, for example from the plants there may be multiple herbivore species which are consuming the energy, consuming the plants and then converting it into energy for their own use and growth. From the herbivores again there might be multiple carnivores so it could be feeding upon the herbivores, so there would be, and there might be multiple chains interconnected in an ecosystem which forms what is known as a food web which is much more complicated than considering only

one flow, one single flow of energy through single species. So, there will be multiple species which are making it a complex system.

So, the productivity of the green plants is generally referred to us, primary productivity, so which is referred to as gross primary productivity which is a total amount of energy that is fixed by the plants. And as I said net primary productivity is what is normally referred to as the, to refer to the efficiency of plants so which is nothing but the quantity of the gross primary productivity minus the amount that is used for respiration.

The NPP is normally smaller than GPP, because it is adjusted for energy losses required to support plant respiration, if the net primary productivity of green plants in an ecosystem is positive, then the biomass of vegetation is increasing over time, that is the meaning of it. Due to differences in the available solar radiation, water, and nutrients, the world's ecosystems defer greatly in the amount of productivity that they can sustain, so which is, so we will see how this net primary productivity can be calculated.

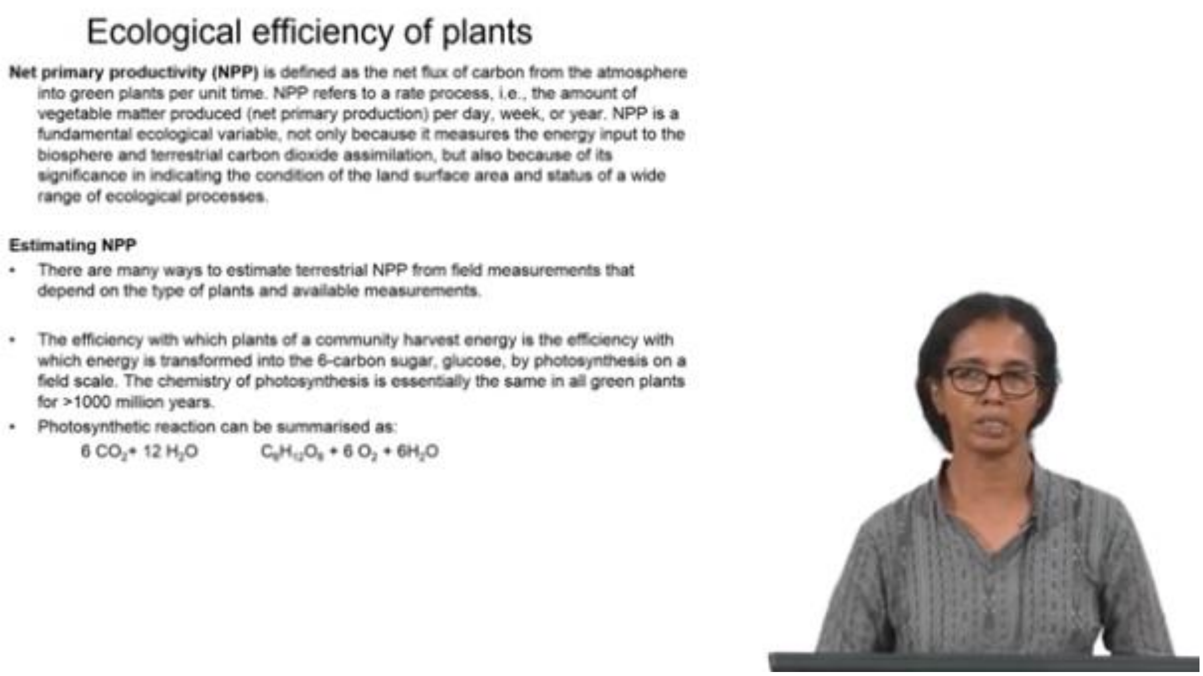


So the ecological efficiency of plants, as I said is calculated using net primary productivity or NPP. So this is nothing but the rate at which plants synthesize glucose. How do we arrive at this number is by various indirect methods of, you know, estimations. So experimental methods of estimation, so these methods are known as one is harvest method, we will soon see in detail what is a harvest method is supposed to do.

Second is oxygen measurement, which is the amount of oxygen that is released during respiration by the plants. Carbon dioxide measurement which is the amount of carbon dioxide released by the plants during respiration and oxygen is actually the amount of oxygen that is produced during photosynthesis, and carbon dioxide is the amount of carbon dioxide that is released during the, in the case of terrestrial ecosystems that is carbon dioxide released in the, to the atmosphere during the respiration by the plants.

Similarly, aerodynamics method is the, in a natural ecosystems, sometimes it is difficult to measure this, you know in a laboratory you can keep plants in a container and enclosed space and then measure the amount of carbon dioxide or oxygen that is released by the plants. And then you can estimate for a particular plant at its different growth or stages, but for a natural ecosystem let us say forest or a grassland or a scrubland, it is difficult to estimate the productivity or the efficiency of that ecosystem itself. S,o how do we do that? So, basically one can measure the carbon dioxide flux in a community using multiple carbon dioxide sensors, or oxygen sensors that you can place in the community and keep measuring the quantity of carbon dioxide that is flowing through the system, and calibrating it against a standard protocols, to see over a period of time how the carbon dioxide fluxes vary. And during the day, during the night and over a certain number of days that you have to monitor the system to see how much carbon dioxide fluctuation you can see in the ecosystem. And from there you can do indirect measurements which we will see again, how we can estimate this carbon, from the carbon dioxide how do we estimate the net primary productivity.

In the case of aquatic systems, since carbon-dioxide released could, reduce the pH of the water by becoming acidic. It can determine the amount of carbon dioxide released by the aquatic systems, so from there again you can indirectly measure the net primary productivity.



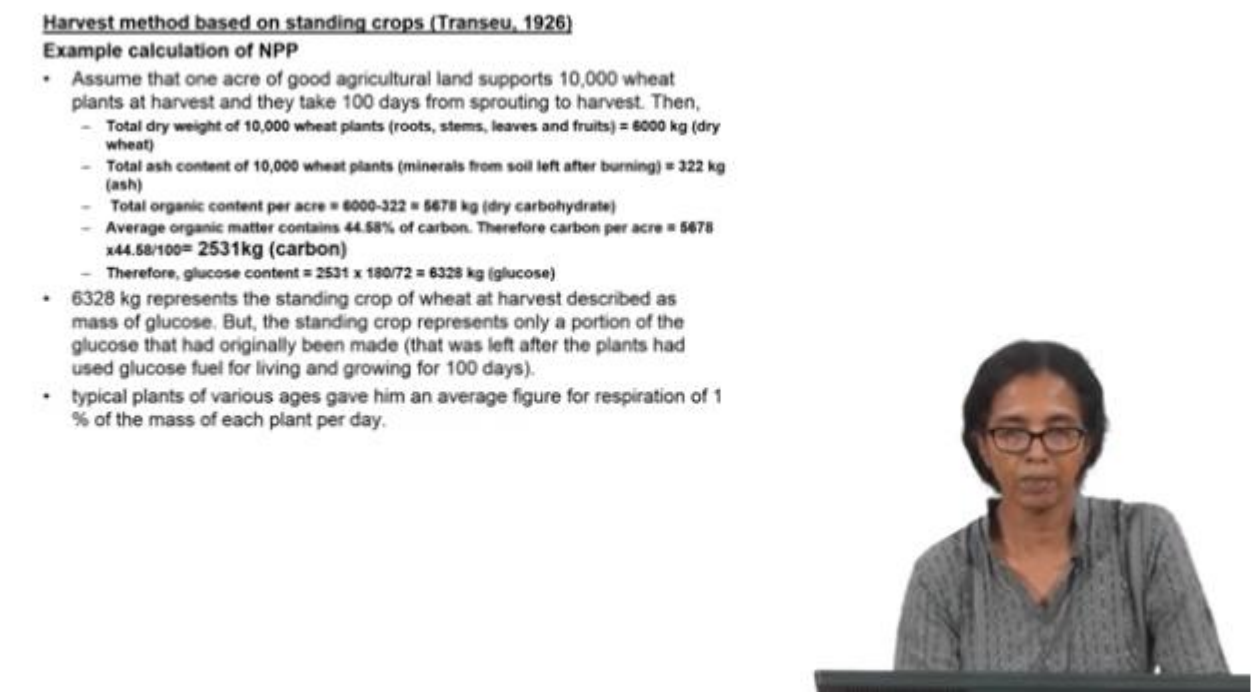
So, how do we estimate the net primary productivity of plants or the, so it is nothing but the net flux of carbon from the atmosphere which is taken up by the green plants per unit time. So that is a way to say that how much carbon is taken up by the plants, so the NPP refers to a right process that is the amount of vegetable matter produced that is net primary production per day or week or year. Net primary productivity is a fundamental ecological variable, not only because it measures the energy input to the biosphere and terrestrial carbon-dioxide assimilation but also because of its significance in indicating the condition of the land surface area and status of white range of ecological processes. So, it is a very, very important quantity in ecology to estimate what is the capacity of an ecosystem for absorbing the carbon-dioxide or assimilate the carbon-dioxide that is released into the atmosphere.

For example, we all are worried about the amount of carbon dioxide increase in the atmosphere today, and the only source which can naturally absorb carbon dioxide are the ecosystems like plants which can take up carbon dioxide and then convert it into glucose and biomass. So the efficiency with which the ecosystems are functioning is very important and if we compromise the efficiency of the ecosystems, let us say we cut down forest, so the forest may have different efficiency in comparison to croplands or agriculture fields. Or let us say garden, in comparison to a garden, a natural forest has much more efficiency, we will soon see how this is different. So the efficiency with which carbon dioxide can be assimilated by plants is important for us to see how much carbon dioxide can be fixed in plants, the existing plants today.

So, how do we estimate the net primary productivity? There are many ways to estimate terrestrial or on land net primary productivity from field measurements that depend on the type of plants and available measurements. The efficiency with, so there are direct measurement methods also, for example, leaf area index, LAI is one method which can be used over measuring the amount of NPP production by satellite imaging. You can see the intensity of the color variations or green color variations over a large geographic area, and then it can be integrated to get the surface area that is covered by green plants and estimate the NPP of that particular land mass.

The efficiency with which plants of a community harvest energy is the efficiency with which energy is transformed into the 6 carbon sugar that is glucose by photosynthesis on a field scale. So we are not talking about a single plant or single cell, we are talking about an ecosystem which maybe constitute to draw many different kinds of plants, different plants of different age, different plants of different size, different genes, different family, different species. So the chemistry of photosynthesis is essentially the same in all green plants for more than 1000 million years. So, we do not have to worry about whether there are different methods of synthesis of glucose, so the photosynthetic reaction is essentially nothing but 6 carbon dioxide molecules combining with water molecules in the presence of photons, which are coming from sun to form one molecule of sugar or glucose plus 6 oxygen molecules and 6 water molecules again back into the atmosphere. So in this process so what we see is, what is known as transpiration which is nothing but release of this water molecules during the photosynthesis along with oxygen.

So 6 oxygen molecules per every 6 carbon dioxide molecule taken in is released by plants that we have to remember that each grass plate, for example, or anything that you think as very lowly and small, and which we think we can convert to non-green area is actually doing an efficient job of converting this carbon dioxide into oxygen by this synthesis process. You may sit down and calculate, for example, if you take a small grass somewhere, how much carbon dioxide conversion it may be doing during a day or let us say its lifetime of let us say few months or year.



So, how do we estimate this NPP? So, is it a real number that we can arrive at? So example, calculation of NPP this was actually one of the earlier methods suggested by Transeu in 1926 which is known as harvest method based on standing crops. Standing crops means the plants which are standing in a field, so this was done for an agricultural field this could be done for estimating forest efficiency etcetera, but in the case of forest we cannot uproot the plants. So in the case of agriculture field it is easy to uproot the plants at the end of the growth of the plants, so you can calculate at the end of the harvest period what could be the efficiency with which this field has collected solar energy and converted into biomass, so that is the meaning of this NPP here.

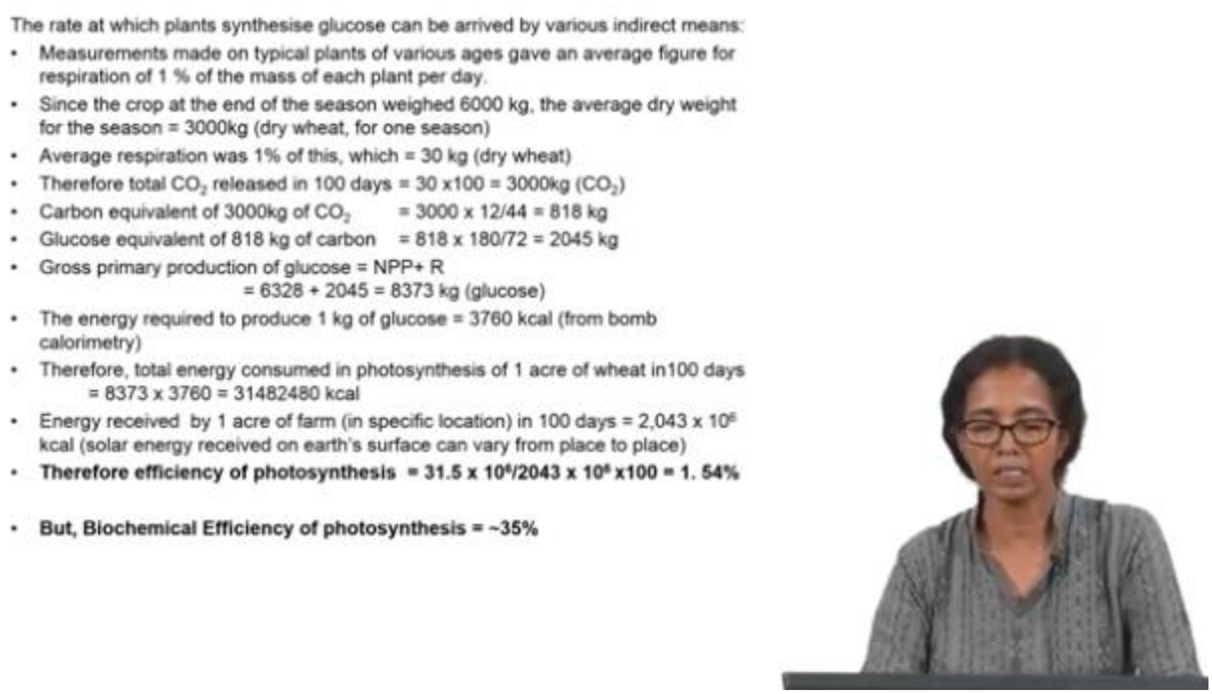
So, let us say, we assume an acre of good agricultural land which could be wheat or maize or rice or whatever that you are growing or grown it. And at harvest let us say it takes about 100 days from sprouting to harvest, so what we do is take up all the plant mass including the root, the stem, the leaf, root, stem, leaves, fruits, everything and dry the plants of over that one-acre land. So the total dry weight let us say for this, let us say there were 10,000 wheat plants in an acre of land, so the total dry weight for that let us say is about same. So this is actual estimation which is being carried out in a, for a field which is consisting of maize or wheat, so let us say it was about 6,000 kilograms. So one can estimate for different fields, it may vary, different plants it may vary, different climatic zones it may vary, and different agriculture fields also it may vary depending upon the nutrient availability, the water availability, light availability etcetera.

But this is an example calculation to see how much is getting converted. So, this is a statistical number, and you can also see that for large number of cases this works out almost similar.

So when this, the dry weight of the plants are collected then for this 10,000 plants so then we need to deduct how much of it is actually is, what we need to find out is how much glucose has been generated by this field. So to calculate that we need to get rid of the, all the inorganic matter from the plants, so plants are also taking minerals and nutrients from the soil, so the total ash, so if you burn this 10,000 dry wheat plants, we will get the amount of minerals that will be left. So that will be left after you know in a furnace if you burn what remain as ash will be about 322 kilogram for this 10,000 wheat plants, and out of this 6,000 kilogram 322 is inorganic material, so the remaining part is the organic content per acre which is about 5,678 kilogram which can be considered as dry carbohydrate.

So now the average organic matter contains about 44.58% of carbon, so therefore carbon per acre is about 2,531 kilogram. So, the glucose contain if you want to find out we have to calculate it using the molecular weight of glucose and the molecular weight of, the number of carbons that is involved there. So you can see that it is about 2,531 multiplied by 180 which is a molecular weight of glucose divided by 72 for 6 carbon so you get about 6,328 kilogram of glucose being generated in that one acre of wheat plant that is harvested.

So, this quantity represent the 6,328 kilogram represents what is known as standing crop of wheat at harvest described as mass of glucose. So that much glucose was assimilated by this standing crop of wheat in that field, but the standing crop represents only a portion of the glucose that had originally been made, that was left after the plants had used glucose fuel for living and growing for 100 days. So they were also breathing maybe moving in wind then growing and things like that, so some energy must have been also spent for so respiration and other purposes. So it is estimated that about 1% of the mass of each plant per day is use for respiration, so that amount has to be deducted from the amount that we have got. So the rate at which plant synthesis glucose can be arrived at some indirect methods.



So, measurements made for typical plants of various ages gave an average figure of about 1% for mass of each plant as use for respiration. Since the crop at the end of the season, so again for a field, normally the NPP is calculated as grams per meter squared per year. So it means for unit area per unit time, the time could be as I said earlier it could be day or month or year. So in the case of crop plants, it may be like you may have two seasons in which you may plant things in that particular area. So for that particular area if you want to calculate what is a primary productivity because we are not calculating for a plant, we are calculating for a you know an ecosystem if you want to do that means for any area so then it is better to calculate for the seasonal variations as well.

So, if you have two seasons, let us say that will be taken into account here. So the average respiration loss is about 1% of this amount that is used for, so that is considering two seasons, you have 3,000 kilogram of dry wheat for one season and average respiration was about 1% of this which is about 30 kilogram of dry wheat. So that much is lost from the system, so the total amount of carbon dioxide released in 100 days that is the harvest period for this wheat is about 3,000 kilogram. And the carbon equivalent of this 3,000 kilogram, carbon dioxide will be equivalent to something like 818 kilogram. So, this is based on the calculation of the atomic weight of carbon, 12 divided by the molecular weight of carbon dioxide which is multiplied by the total amount of carbon dioxide released.

So, the glucose equivalent of this 818 kilogram of carbon that we have to back calculate to find out it is about 2,045 kilogram. And the gross primary production of glucose will be this NPP + this respiration so which will be equivalent to that 6,328 that we had plus this respiration loss which is about 2,045 that is about 8,373 kilogram. So this is the gross primary productivity of that land. So, the energy required to produce 1 kilogram of glucose, how do we determine that? So, normally we know that any biomass, any organic mass if you burn it, you will know the glucose equivalent, the calorific value or the kilocalorie, how do we express, for example, if we eat food, how do we know the calories involved. So it is equivalent to something that you can burn in a calorie meter, for example, bomb calorimetry and find out how much of energy being produced by burning that 1 gram or 1 kilogram of substance. So, in this case 1 kilogram of glucose when you burn in a bomb calorie meter you get something like 3,760 kilocalories, so that is equivalent of glucose.

So, therefore, we have about 8,373 kilograms of glucose at the end of one year of the plant growth in the field, you know 100 days of growth. So, therefore, total energy consumed in photosynthesis of one acre of wheat in 100 days is about 8,373 multiplied by this kilocalorie of glucose which is about the quantity that is shown here. So, the energy received by, so now we need to know what is efficiency, so the total energy consumed in photosynthesis of one acre of wheat in 100 days is given as this. Let us say the so now if you want to find out the efficiency, efficiency is nothing but output by input x 100, so the output is nothing but this quantity that is 3.1 x 10^6 kilocalories of energy, and what is energy received in that area that is just this solar energy that was received by the plants.

So, we need to find out what is the solar energy received for that one-acre land, one-acre farm, so in each specific location have a different intensity of solar energy that is falling. So you need to figure out whether it is in a tropics or whether it is in subtropics of or is it in Arctic or Antarctic or where is this land that is located for calculating the NPP. And so you can calculate that the energy received by this particular farm in 100 days let us say it is about 2 x 10^6 kilocalories that is solar energy received on earth surface and that particular area, it can vary from place to place.

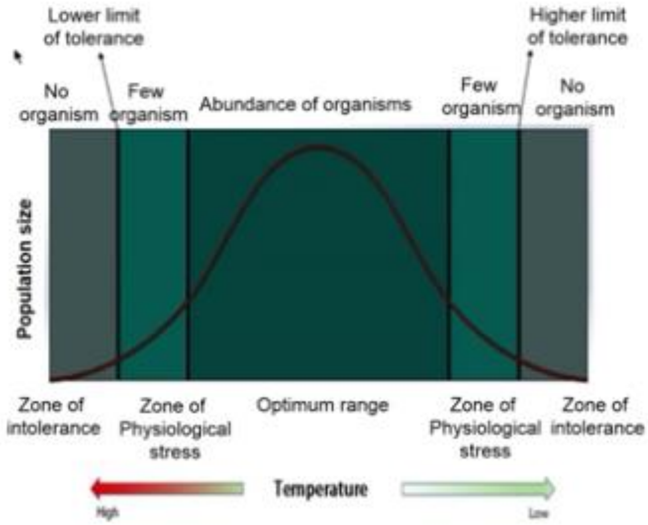
So, the efficiency of photosynthesis by plants here is about the input is 31.5×10^6 kilocalories as we estimated that is the amount of energy consumed in photosynthesis of one acre of wheat in 100 days divided by the total energy received by the land that is $2,043 \times 10^6$ and into 100 will give us the efficiency in percentage. So we get about 1.54 percentage efficiency for this wheat farm of one-acre land which is grown for about 100 days. That is the efficiency with which plants are harvesting solar energy and converting it into useful biomass.

However we can find that the biochemical efficiency that if you calculate, that is a biochemical process that is going on in the plants, so if you know the photochemical, photosynthesis pathways and if you know how the photons are traveling through the pathways and then converting it into energy, the approximate efficiency one can estimate is about 35%. So what happened? So why do plant so such low efficiency? Though the photosynthetic efficiency, the biochemical efficiency of photosynthesis is about 35%, so there are various reasons why the plants may not give us the best efficiency, as I said earlier it is could be due to the limitations of each and every location. So, for example, the efficiency with which plants assimilate the, it depends upon the kind of nutrients that is available, the light availability, the water availability, all this actually dictates the efficiency of each area.

So basically the efficiency of the plants will depend upon this and also the major aspects that affect the efficiency of, why it defers from biochemical efficiency is that, the whatever is received by the plants need not be used. Of all this solar light that is falling on the plants need not be used in photosynthesis, some amount may be used up in heating the plant surface, some maybe scattered from the photons that are heating the plant surface maybe like scattered of some of them maybe bouncing up, the surface may not be clean it may have dust and other particles sitting in the, transpiration is not happening effectively. So, all this can complex the efficiency of plants in receiving and using the energy.

And for example, the solar light for example throughout the day it is not falling with the same intensity in a particular location. So, for this, you will also see the adaptations that is given in each plant and to maximize the amount of the energy that can be harvested by particular plant. So the shape, the size, of the leaves, the orientation of the leaves, how many leaves and the arrangement of leaves in a tree or a plant is based on the efficiency with which energy can be harvested. So one can look at this below, for example, if you go below a tree and look at how these solar light filters through those leaf system, you can see how effectively the plants are arranging their leaves in different slanting positions to cater to the needs of the plant in harvesting the energy. So for example, morning light maybe slanted more and mid noon light maybe falling directly above, and evening sunlight again maybe slanting position. So there are different leaves in a plant which are oriented in different directions with different shape of the leaves to either minimize transpirational losses and mid noon transpirational losses will be high, so it will be trying to minimize this.

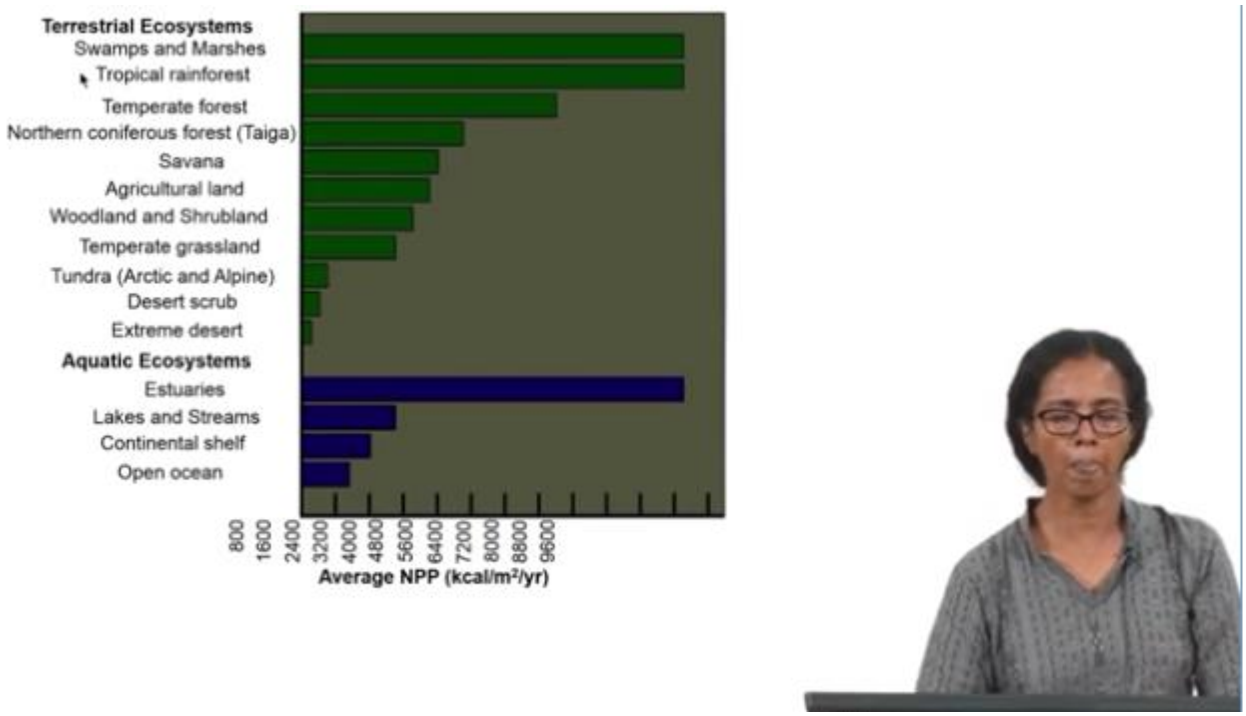
So, the adaptations in plants are essentially to maximize the energy harvesting by the plant, whether it is a desert cactus or whether it is a tropical rainforest tree or plant which is growing in the defuse sunlight in a tropical rainforest all of them have adaptations for harvesting the sunlight of different wavelengths sometimes to get the maximum conversion of energy into glucose.



So as one can see, for example, organisms utilize energy under conditions which are, which they can actually, can tolerate, so in this diagram, for example, you can see temperature is given on the X axis so the variational of the temperature to extremely cold or extremely high, organisms do not tolerate the temperature, so the population size, for example, if it is in for the case of, so now when the energy is transferred to other organisms or even if you are looking at the population size of let us say plants or organisms they will go through an optimum range when the temperature is very comfortable for them.

So, there are two zones which are zones of intolerance and zones of physiological stress. So in the physiological stress region, few organisms can be seen, number will be less and as the temperature goes to extremely high or extremely low no organisms can be seen whether where the sound of intolerance is there. So the higher limit of tolerance and lower limit of tolerance basically dictates the number of organisms or number of plants that you see in a particular system.

So similarly, nutrients, water availability, all these factors can be drawn on a graph like this and show where the optimum range of number of organisms or number of plants can grow. So it could be light, it could be temperature, it could be water availability, food availability, various factors that can dictate the abundance of organisms.



So, based on the productivity of the net primary productivity that we have defined for a particular area or an ecosystem, scientist have estimated the efficiency of different eco systems. So you can classify them into terrestrial that you see on the land and aquatic ecosystems, and this is very important chart which is showing how the efficiency of, the average NPP in kcal/m^2/yr is shown on the X axis here and different ecosystems how they fair when we estimate this NPP.

So as you can see the among the terrestrial ecosystems, swamps and marshes or wetlands form the highest in terms of productivity along with tropical rainforest, they have something like 9,600 kcal/m^2/yr as their net primary productivity. As you know that is the amount of glucose that is produced per square meter of area per year.

And if you compare that with a temperate climate forest it has less NPP or efficiency, net productivity is lower compared to that of rainforest or marshes and swamps, or if you look at northern coniferous forest which is again in colder climate, so again the temperature is dictating the primary productivity of plants there, so you can see the efficiency is reducing.

Then comes Savana, Savana are grasslands, grasslands the efficiency is dictated by the availability of water, so again you can see that the factor that affects mostly the productivity in Savana is rain, so the NPP is lower in the case of grassland in comparison to rainforest or a marsh.

Then comes agriculture land, so agriculture lands of even productivity less than grassland, natural grasslands, and natural forest definitely much much lower than tropical rainforest. And woodlands and shrublands of lower than that, agriculture lands the limitations are, the limiting factor, so that is we call the limiting factor for growth or net primary productivity is mostly nutrient availability, water availability are the major factors that dictate the productivity of agriculture lands.

Agriculture lands are you know overused systems where nutrients are taken out from the system multiple times, and then that is the reason why we keep on adding different nutrients or fertilizers into the land. And over a period of time the nutrient, the lands viability for even holding the nutrients were also reduces because the helpful other bacteria and other ecosystem that is thriving in the natural soil will be also be damaged by the use of fertilizers and pesticides. So the productivity of the agriculture land in terms of NPP will keep on reducing as a function of time if you introduce artificial pesticides and fertilizers into the land.

Similarly, grasslands which are in temperate climates like in Europe, they have or in Northern US they have again lesser productivity, then we have the Arctic and Alpine ecosystems which are in Tundra regions they are again limited by the temperature, very cold climate as you could see that they are under stress condition, so the productivity is very low.

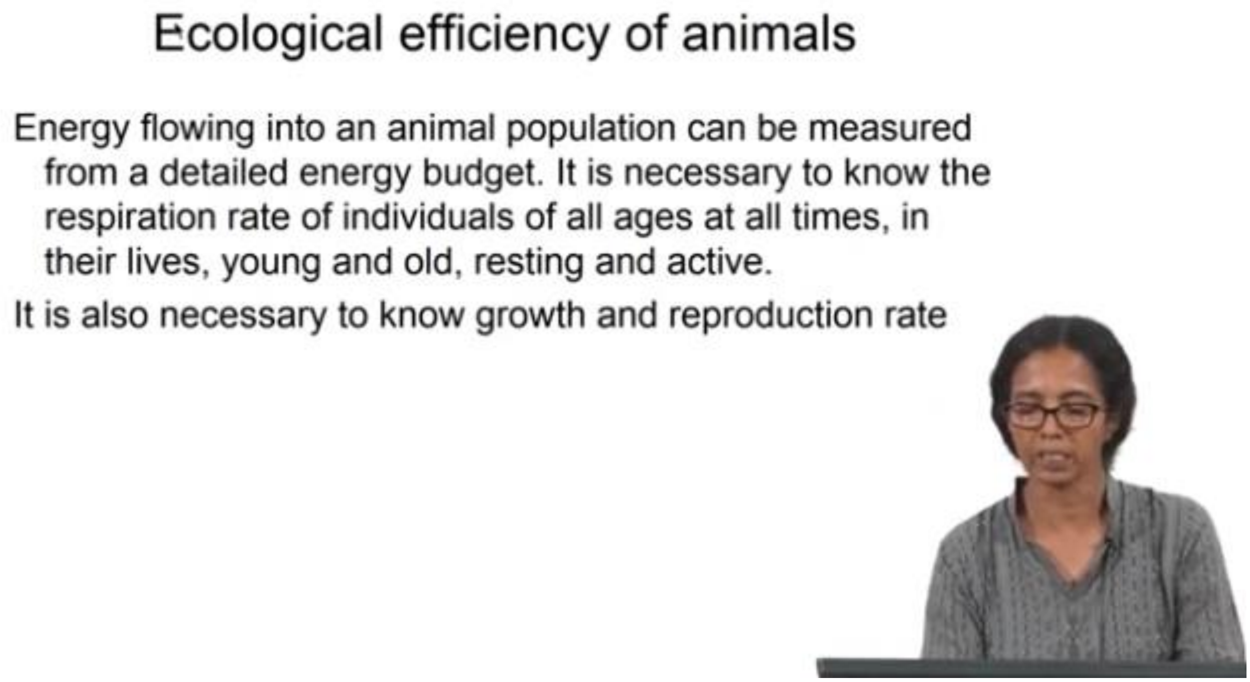
Similarly desert scrub they also have very low productivity again due to high temperature. So as you could see from the previous figure, the high-temperature and low-temperature regions, the organisms are stressed, and the plants are also stretched. So you will not get the productivity, and the number of plants that could contribute is less, so you do not see much plant diversity in deserts and Tundra, and extremely desert again you have very, very limited productivity due to the absence of plants there.

Now if you look at aquatic systems, the highest productivity which is comparable to swamps and marshes and tropical rainforest in the terrestrial ecosystem is estuaries. Estuaries are places where the rivers meet the ocean. So, these are exclusive ecosystems which require high levels of protection status also this chart is also indicating based on the net primary productivity of this ecosystems they need to be given the priority in terms of protecting this ecosystems.

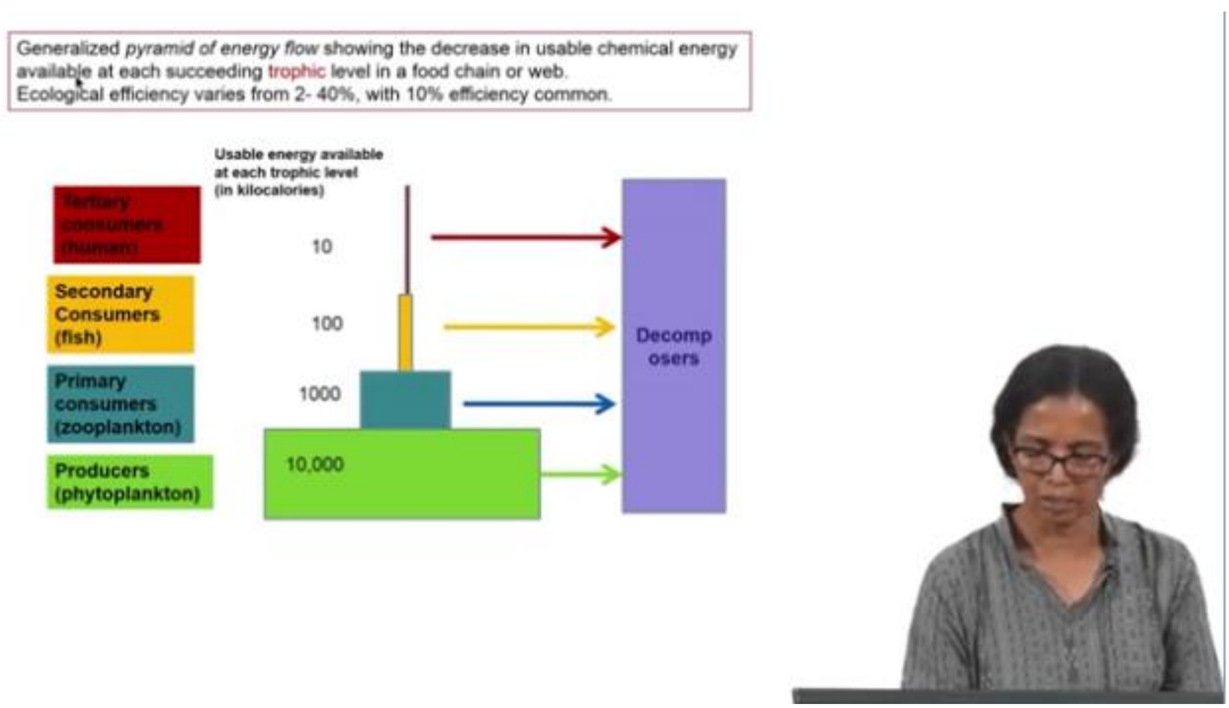
So in terms of this, the productivity of the land is also very important, and each of this ecosystem have also unique biodiversity that is existing there. So it also does not mean that you know Tundra or desert does not need to have a protection for the ecosystem and the different life forms that thrive there. They are unique to those ecosystems or because of the adaptations they have, and they have evolved over you know thousands of millions of years to live in those kind of circumstances, so it is important to protect those diversities as well because they are contributing in unique ways to the biosphere maintenance.

So, in the case of aquatic ecosystems, estuaries forms the highest protective systems, they incomes lakes and streams, then comes continental shelf and then open ocean, so in the aquatic ecosystems I would also like to add the coral reefs which also have almost the same productivity as the tropical rainforest in the aquatic or the marine environment.

Open ocean also again have lower productivity which is almost closer to the grassland or less than grassland kind of productivity. Because there is not much plant left that you can see in the open ocean.

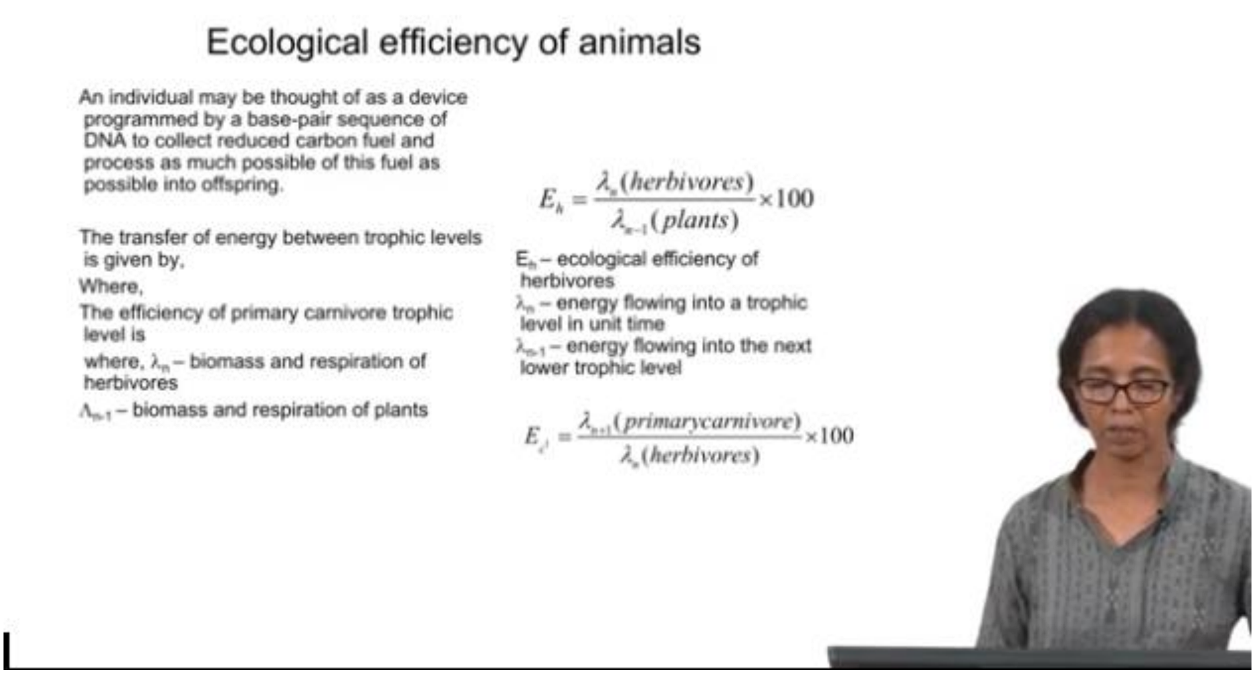


So, when we talk about, so the plants they take up energy from the sun and then the efficiency with which it is converted to glucose what we call as the net primary productivity or the efficiency of the plants. So now when it comes to the next level of the tropical, tropic level that is where the energy is flowing from the producers into what is known as the primary consumers or from the primary consumers to the secondary consumers.



So, these are where we consider as the efficiency of the animals. So how do they take care of? So, the energy flowing into an animal population can be measured from a detail energy budget, so there is something called an energy budget that is required, we will not go into the details of this, so but at the just the glimpse of what is meant by the energy, ecological efficiency of animals. So it is necessary to know the respiration rate of individuals of all ages, so we are calculating it for a population, an animal population not for individuals because it does not make sense. If a young animal or a sub-adult animal or an adult animal or an aged animal, they all have different metabolic rates and different requirements of food and calories. So the energy that is flowing through the system, through these individuals who could be varying a lot, so that is why it is for an animal population it is estimated.

So, what is important here is to estimate the respiration rate of individuals of all ages at all times in their lives young and old resting and active. So also we know that the respiration is also associated with the metabolic rate, so when it is resting they have a resting metabolic rate, and when they are active, they have a different metabolic rate and which will be translated into the amount of oxygen that is being taken into the system and carbon-dioxide released. So and it is also necessary in the case of animals to know growth and reproduction rate. So this is something that is in the case of plants, for example, we do not have to take into account movement for example, but in the case of animals lot of energy is expended on movement from one place, or moving from one place to another, so the mobility is one factor that comes in.



So, the ecological efficiency of animals is calculated, and individual may be thought of as, a device program by a base-pair sequence of DNA to collect reduced carbon fuel and process as much possible of this fuel as possible into offspring, that is a definition of an animal.

So, as you would have thought it is something else, but we are also machines which are taking up this carbon fuel from the plants and converting them into offspring that is what the definition of an animal in ecology.

So, how efficient this energy is transferred? why this animal is the question that is addressed in terms of ecological efficiency of animals? so it is written as the transfer of energy between tropic levels. We can write it as some quantity called that is given by Eh which is the ecological efficiency let us say we are calculating ecological efficiency of the herbivore then it is given by the energy that is flowing into tropic level in unit time divided by that energy that is flowing into the next lower tropic level divided by the tropic level that is below it. So the energy that is flowing into the next level and the level that is below is what is giving you the efficiency.

$$E_h = \frac{\lambda_n(herbivores)}{\lambda_{n-1}(plants)} \times 100$$

The efficiency of primary carnivore, for example, is some lambda n which is a biomass and respiration of herbivore divided by lambda n-1 biomass that is respiration of plants. So, you can see at each level you will be looking at the level that is below and at the level that is just above it to see how much energy is flowing into that system, so that is the ecological efficiency of the plant, so we will stop.

Thank you