An Introduction to Evolutionary Biology

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What are the isolation mechanisms?

Hi, so in our last discussion, we saw how speciation happens. How a new species is formed depends crucially on which definition of species we are talking about. And we specifically said that in the context of the speciation research, much of the emphasis is on the biological species concept. Which means that speciation essentially becomes how reproductive isolation comes into being. So, in today's discussion, we are going to talk about the various mechanisms of reproductive isolation. and in the next discussion, we are going to look at in what ways those mechanisms evolve.

So, this particular treatment is based on Futuyma and Kirkpatrick's 2022 edition of the book Evolution, the textbook. So, before we dive into this, what exactly do I mean by reproductive isolation? So, reproductive isolation is the phenomenon by which members of different biological species, remember that concept, they are prevented from producing offspring or it ensures that any offspring that are produced are sterile. Now, the mechanisms, individual mechanisms that lead to this, These are either known as isolating mechanisms or as reproductive isolating barriers. And today we are going to look at the various kinds of reproductive isolation mechanisms, and these can be grouped in many ways, but I will be following a particular grouping which is given in Futyama and Kirkpatrick's book, which is itself after Coyne and Orr's book called Speciation. It is a very nice book, a comprehensive treatment of the entire process of speciation, slightly old, about 21 years old. But even today, you know the examples that they give, and the way they weave the entire thing is just masterful. So, according to the classification that Coyne and Orr came up with, You can divide these reproductive isolation mechanisms into three major groups. So, the first, there are two major processes, or rather, two major groupings.

Prezygotic and postzygotic are divided into two parts: premating and post-mating. So, that makes it three groups. We will start with the first one, which is pre-mating, prezygotic barriers. Essentially, these are features that will impede or cause trouble with the transfer of gametes to members of other species. One way or the other.

So, the first way in which this can happen is through time: temporal isolation. So, suppose you have multiple species that can otherwise exchange genes, But simply because they are not together at the same time, they are unable to exchange genes. So, I will give you an example. So, this is a bird, a small seabird known as the banded drummed storm petrel, and you can find it in many places, but, The one that we are talking about is in the Southern Hemisphere. So, as you can see, they are found throughout the Atlantic and Pacific Oceans.

So, in the southern hemisphere, there are at least five archipelagos where these individuals, all of whom are in the same place, are located. But there are five populations that are at different times. So, one population is present at one time of the year, while the other population of the same species is present at another time of the year. A DNA sequencing study by these people, Friesen et al., showed that at least one Two of these places have populations of the same species coming at different times.

There has been no genetic exchange between these populations for a long time. A very, very, very long time, you know, some millions of years or something like that. I am not 100 percent sure about the timing, but for a very long time, there has not been any genetic exchange. So, this is one example of how species or organisms can be in the same place. yet they never meet each other and therefore, they are never able to exchange genes.

The second thing that we can talk about is habitat isolation. They are geographically in the same place. But because of some reason, their habitats have become isolated, and therefore they are not able to meet. So, here is an excellent example of this. So, these are two different species of ladybird beetles; you find them in Japan.

So, the first one, Epilachna niponica, that grows on thistles, this one. The second one, Epilachna yasutomii, grows on this plant called blue cohosh. Now, although in this picture the left one looks larger than the right one, in reality, it is the other way around. This one is much larger in size than this one. So, although visually they look similar, if you find them side by side, you can clearly see the size difference.

Now, it turns out that both species, They feed and mate on their respective host plants, and they are isolated only by this factor and nothing else. So, these guys will not go to that plant, and vice versa, and that is it. If you actually take them to the lab, put them on the same host plant, and make them mate, They can very easily mate, and they can very easily produce fertile offspring. But because the fact that in nature, these two plants are separated from each other and There is not much dispersal happening; that is how these plants and these beetles remain separated and continue to be two species. So, this is the second one.

The third one is what is known as immigrant inviability. So, in this, what happens is that you have populations of the same species that get specialized to their habitats. And therefore, when they go to a different habitat, although they are capable of mating with those organisms, You know about the populations there, but when they go to a new habitat, They are not even able to establish themselves in that habitat; therefore, they do not get a chance to mate. So, I will give you an example. So, there is this gall wasp called whatever, Belonocnema treatae, And this thing grows on oak trees and forms these, can you see these green ball-like things? These are known as galls.

So, it forms these tumor-like galls on oak. Now, it turns out that this wasp can grow on three different species of oaks. Three completely different species end up specializing in their hosts. Now, if you take the females from one oak species of the same species of gall wasps, If you take them from one oak species and put them on a different oak species, Then the females and the offspring are unable to initiate this gall formation. So, they are able to go there, but they are not able to initiate the gall formation because They are not able to initiate the gall formation; therefore, they are not available for mating with the local males.

And as a result, you know, the populations of the same species. which have ended up becoming specialized in the three different oak species, they cannot exchange genes with each other. They are simply not able to find each other to mate, so that is one kind of thing. The other kind of isolation mechanism that occurs is what is known as sexual isolation. And sexual isolation simply means that males and females, They are not able to mate with each other properly or at all, depending on various kinds of cues.

So, the first kind of cue, which is a very common kind of cue, is sound. You know that many organisms have special mating calls, and if the proper mating call is not heard, If the conspecific mating call is not heard, then the female will simply not respond. A big example of this is the Tungara frog. As you know, the males of frogs give these mating calls. This one is special because of the pouch that you can see.

It is very funny. There are lots of videos of this on YouTube; you should check them out. So, it turns out that the female Tungara frogs are going to respond only exclusively to their conspecific mating calls. Any other mating call is constantly ignored. Another major cue for sexual isolation can be chemicals; you know, pheromones, sex pheromones, and so on. So, again, many, many organisms tend to use it, particularly moths; it is very, very well known.

So, for example, here is a particular species of, you know, moth. These are known as the European corn borers, and there are two different forms of the same moth. They are the same species, but it turns out that they end up producing slightly different chemicals. And because of that, you know, in this particular case it is the female that produces the sex pheromones and The males respond to them, and because these two forms of the same species produce slightly different chemicals, Therefore, the males do not respond to, or rather, the males do not respond to the pheromones of the other females. Therefore, these two end up becoming sexually isolated.

The third form of sexual isolation, the third cue, is visual. This is extremely common. So, as you know, many organisms engage in courtship for mating purposes, which is performed by the males. We talked about it when we discussed sexual selection. And, if the courtship is not proper or if one of the sexes is not displaying the appropriate visual cue, the other sex will simply not respond.

Just to give you one such example, this is a butterfly known as Heliconius pachinus, which is found in Costa Rica and Panama. Now, as you can see, this has some very visible, very, you know, remarkable patterns. The males recognize the females; it has been shown by their wing color patterns. So, if you just change the wing color patterns, most heterospecifics will have different wing color patterns. The males will simply refuse to recognize them.

So, this is about sexual isolation. Another kind of stuff that happens primarily occurs in plants, and that is pollinator isolation. So, you know that many plants depend on other animals for pollination, and many of these pollinators are actually extremely specific. In other words, they will pick up the pollen from one species and they will deposit it only in the same species. It basically means they will only visit one species of flower and not another species of flower.

And because of that, the pollen never gets transferred across species. So, I will give you one example. So, there is this stuff called monkey flowers, you know, two species: Mimulus cardinalis and Mimulus lewisii. And one of them, cardinalis, can be seen to be pollinated by hummingbirds, whereas the other one, lewisii, is pollinated by bees. And it turns out that if you physically take the pollen from one species and put it on the other, They can form, you know they can fertilize; fertile offspring can be formed.

So, potentially, they can interbreed with each other. But because their pollinators are extremely faithful, So you know, hummingbirds will not visit lewisii, and bees will not visit the other one, cardinalis. Therefore, they end up not being able to exchange pollen. and that is why there is no gene flow between them, even though they are interfertile. So, just to summarize these four or five things that we talked about: we have the premating prezygotic barriers.

You can also subcategorize them in terms of ecological isolation, where the potential mates do not meet each other. So, this can be in terms of temporal isolation, habitat, or immigrant inviability. And then you can also have a situation where the potential mates meet in the sense that they are in a similar geographical area. But they are not able to mate, or they do not mate, whatever. And this can happen either because of sexual isolation due to various kinds of cues; we talked about three of them or, in the case of plants, it can happen because pollinators are extremely species-specific or plant-specific. So, this was about pre-mating and prezygotic barriers. Now, in many cases, mating does occur, but the zygotes are not formed. So, these are the post-mating but pre-zygotic barriers.

We will discuss a few. So, one of the things that we know is that there is a huge diversity in the structure of the genitals of different species. So, for example, I am just showing you a very well-known case in insects: that of different species of Drosophila. So, this figure over here shows you that inside, this is the male genital organ, and Inside the male genital organ, there is a structure known as the genital arch. And this genital arch is very important because it is involved in transferring sperm to the females. Now, what I am showing you here is the structure of the genital arch in three different species of Drosophila.

So, this is Sechellia, this is Mauritiana, and this is Drosophila simulans. And as you can see, there is quite a bit of difference between these three structures, right? In fact, this is the way in which these three species can be, you know, identified from each other. But if the genital structures are different, then how do they work? What exactly happens? So, it turns out that there are two things that can potentially happen here. The first thing, of course, is that if the genital structures are different, then that can prevent the you know insemination or copulation simply because of mechanical incompatibility. So, you can think of one genital as the lock and the other genital as the key.

So, until and unless the lock and the key match with each other, there will not be a transfer of, you know, gametes. And because the two species mostly, or many times, will end up having different kinds of genital structures, even if They come close to each other, and even if they try to mate, they will not be able to physically initiate the copulation. The other situation that can potentially happen is that even if the lock and key are matching, Even if they are able to initiate copulation, you know something does not feel right, so to speak. In other words, as long as the genitals are not appropriately complementary to each other as in the same species, The female or the male is going to have a physiological or behavioral response. Because of this, there will typically be premature termination of copulation.

So, even if copulation initiates before the sperm are transferred, or you know the copulation will break up, or in some cases, Because of, you know, mismatches, even if copulation happens, there are post-copulatory reproductive fitness issues. So, these two mechanisms are not exactly you know antagonistic to each other, They are not mutually exclusive, and sometimes they can work in tandem. In other words, sometimes what can happen is that even though the lock and key do not match properly, The organisms can continue copulation, but even after copulation, the amount of sperm transfer is not 100%. Or even if the sperm transfer is happening, something might end up blocking it afterward. So, just to clarify, I mean we have already given examples of that, but even in the case when the transfer of sperm has happened, There are many situations where the gametes are not able to fertilize each other, and this is what is known as gametic isolation.

So, I will give you one very well-known, well-studied example. So, these are what is known as the abalone snails. They belong to a genus called Haliotis. About 70 species are known in this particular genus, and they are found almost all over the world.

Now, these are external fertilizers. So, what that means is that the male releases sperm into the water. The female releases the eggs, then the sperm and the eggs need to find each other, and the sperm needs to fertilize the egg. Now, there are 70 species with external fertilization. Obviously, multiple species can and do exist in the same area. So, potentially, the sperm of one species can end up finding the egg of a different species.

However, these guys have a very peculiar way by which they are able to prevent the fertilization of heterospecific gametes. How does that happen? So, it turns out that fertilization in this organism requires the interaction between two proteins. Why is that so? That is because the egg cell, since this is external fertilization, is not sitting there unprotected. So, on top of the egg cell, there is a proper proteinaceous layer. and the sperm cell needs to bore through this proteinaceous layer in order to access and fertilize the egg.

So, for this to happen, the sperm produces a protein known as lysin, sperm protein lysin. The egg has a protein known as VERL, Vitelline Envelope Receptor for Lysine. Now, these two proteins need to interact with each other; only then is the sperm's lysin going to be able to bore through that layer. Now, turns out that these guys, the haliotis snails, They have somehow evolved extremely specific interactions between the lysins and the VERLs at the species level. In other words, the lysin of one species can interact only with the VERL of its same species; it cannot interact with the VERL of another species, it is not able to bore into the egg and, you know, cause fertilization. So, this is one way by which the gametes are able to fertilize even if they come close to each other. This is a case in which, up to the protein level, it is well known how gametic isolation happens, which is why I am showing you this case. But in general, gametic isolation is pretty well known across, you know, many taxa. So, just to summarize the post-mating prezygotic barriers, you can have mechanical isolation.

Reproductive structures of the sexes simply do not fit, or you can have copulatory isolation, even if they somehow do. Fitting with each other, behavioral or physiological responses of the sexes are preventing proper copulation or the transfer of sperm. And in the third one is gametic isolation, where even if the sperm and ova are coming close to each other, They are not able to fertilize each other, so we are done with the prezygotic barriers. Now, we are going to look at the postzygotic barriers, which are what happens after fertilization has occurred. So, again, you know, in this particular case, what happens is that the hybrids are formed.

But for whatever reason, they have reduced fitness, and this reduced fitness can happen in many, many ways. So, we will just talk about two or three. Typically, this is subdivided into two classes. When the hybrid's fitness reduction is due to the external environment, it is called extrinsic. and when the hybrid's fitness reduction is due to an internal property of the hybrid, That is when it is known as intrinsic, you know, a post-zygotic barrier.

So, let us look at them one by one. So, the first form in which there can be extrinsic post-zygotic incompatibility or isolation is what is known as ecological inviability. In other words, the hybrids are formed; the hybrids by themselves are fully functional, but because of some properties of the hybrid, They are going to have reduced fitness. So, I will give you an example. So, there are two species of Heliconius butterflies, which, as we know, are toxic. In other words, if the predator eats them, it either dies or, in most cases, it has to end up vomiting the whole thing that is, it creates a physiological reaction in the predator, and because of this, they are distasteful. These butterflies are distasteful to the predator, and hence the predators end up avoiding them very religiously. And it has been shown that the predators identify these butterflies through their wing patterns. Now, it turns out that in nature these two butterflies actually hybridize rather readily. So, the males and females of the two species will happily mate with each other and produce babies, but, The intermediate forms actually look very different from either of their parents.

So, what Merill et al. did was take small, butterfly-shaped models that had the colors. Color patterns of either two parents or the hybrid were placed in forests. And what they wanted to check was what the rate is at which predation is happening on these. And when they did that, here is one parent, here is another parent, and here is the hybrid. And as you can see, the two parents look very different from each other, and the hybrid is somewhat intermediate.

Between the two parents, what will happen now? Remember that the predator's avoidance of these butterflies is a learned behavior. Therefore, for learning to happen, the population size has to be really high. If the population size is not high, then the predator will either not learn, or it will learn but will forget very quickly. Now, both of these parent species are present in large numbers. Therefore, the predator's avoidance behavior is learned quickly and is maintained faithfully for a long time.

But whenever hybrids form, they are typically going to be in much lower numbers. And these guys are rarer in the population, and that is why the birds, first of all, do not recognize them as distasteful. They end up attacking them, and because the learning is not reinforced, they keep on attacking them. As a result, you can see that the overall attack rate on the hybrids is almost double that of either parent. As a result, the fitness of these hybrids is much lower; they basically get eaten out.

So, this is an example wherein, although physiologically the hybrids are perfectly well functioning, They are simply in the wrong environment, so to speak, and therefore, they end up getting selected against. The other way in which the ecology of the organism can reduce fitness is through what is known as behavioral sterility. So, we know that for mating to happen, there are lots of behaviors that are very, very important. If the male or the female is not behaving properly, copulation will not happen. Now, in many cases, what happens is that the hybrid, although it is physiologically fine, does not have the appropriate behavior.

And because of that, it fails to secure mating. So, I will give you one example. So, this is one species of grasshopper called the Bow-winged Grasshopper. And this is another species called the common field grasshopper. Now, we know that grasshoppers have these mating calls. And we also know that the mating calls of each species are very, very specific.

Now, it turns out that the mating calls or the songs of the hybrids are actually intermediate between both parental species. and the male hybrids they are actually behaviorally sterile, although physiologically they are perfectly fine, they are behaviorally sterile because all females, either the parents or the offspring, I mean the two kinds of parents or the hybrid females themselves. None of them can recognize that particular song, and because of that, these males, the hybrid males fail to get any kind of mating, and they end up becoming behaviorally sterile. So, the other way, as I said, in which the fitness of the hybrids can be low will be intrinsic. So, it is not dependent on the external features, and the most interesting thing you know. The most common thing that often happens is what is known as hybrid inviability. In other words, the hybrid is the zygote that is formed, but the zygote does not, you know, it is not born.

It is either not born or it dies very, very young. So, many examples, I will just give you one example from the Drosophila literature. So, this is one species of Drosophila, Drosophila melanogaster, and another species, Drosophila simulans. Sister species are closely related species. Now it turns out that if you take Drosophila melanogaster females and cross them with Drosophila simulans males, then the hybrid males will die as larvae. But if you do it the other way around, you take Drosophila melanogaster males and cross them with Drosophila simulans females.

Then it will be the hybrid females that will die, and they will die as eggs themselves. They would not even hatch to become larvae. So, this observation comes from the work of Sturtevant. I mean, I am sure all of you remember Sturtevant. This is the person who came up with the concept of linkage as an 18-year-old undergraduate in Thomas and Morgan's lab.

So, what Sturtevant showed is that intrinsic hybrid invariability can be complete, but sometimes it can also be partial. That basically means that not all the hybrids die, but a large fraction of the hybrids do die, which results in very low fitness. And it can also be sex-specific, which means sometimes the male sex gets affected and sometimes the female sex gets affected. Sometimes both of them get affected, and it can also occur at different life stages, as I am showing you over here. Sometimes it is eggs, sometimes it is a larvae that die and do not come from this study, but in general it can also be asymmetric which basically means that also coming here, actually, that you know if you cross the males with the females. Of once in one combination, you will get one result. You take the same two species, but do it the other way around. Females of one and males of another, you end up getting slightly different results. So this means you can also, if you remember, when we were talking about ligers and tigons, not in the context of invariability.

But you know we saw that you take males of which species and females of which species. That ends up giving you slightly different results in terms of what the nature of the hybrid is that you are getting. And what this is showing is that that can also have an effect in terms of the rate of viability. In some cases, you can get complete viability in one type of cross but inviability in the other type of cross, or vice versa. So, this is about hybrid inviability. The other thing that can happen is that the hybrid is viable, it grows, but then it turns out to be sterile.

And of course, the most well-known example of that is the mule, which is, as we know, obtained by crossing a horse with a donkey. Now, sterility, like viability, can be total or partial, which means that they can either fail to produce any offspring. The hybrids can have the ability to produce offspring, but that ability is seriously reduced, resulting in partial sterility. The sterility can be due to multiple reasons, and these can include things like You know if the two species have, let us say, chromosomal rearrangements.

So, for example, if you remember, we discussed the fact that sometimes, you know. One chromosomal segment can simply get inverted; that is what is known as an inversion. Or sometimes what can happen is that in one species, let us say, some chromosomes have one segment from one chromosome. And another segment from another chromosome that has been interchanged, which is reciprocal translocation. Now suppose you have two species; otherwise, they are very similar sister species, let us say, but, In one case, there have been inversions, and in the other population, there are no inversions. So now, when these hybrids are formed and when the hybrids are trying to reproduce, And meiosis is trying to happen, then at the places, I mean one set of chromosomes will have the inversion.

The other set of chromosomes will not have the inversion or translocation, whatever. In those cases, the binding of the homologous chromosomes for the sake of meiosis can become seriously affected. And if that effect is, you know, severe and meiosis ends up failing, then that can be one way in which sterility can be induced. The same thing can happen if, let us say, the two species have slightly different genes, and these genes produce proteins. which ends up having an interaction with each other, because of which the cell is not able to survive. One of the most common ways in which this happens is if the two species have very different chromosome numbers.

Then their hybrids, you know, when they come, when they are formed, there will be some chromosomes. which will not have a homologous chromosome to pair with, and because of that, when meiosis happens You know you are going to have kids, you know gametes with very different chromosome numbers, which Again, it might end up leading to a complete breakdown of fertility. So, this is about, you know, the postzygotic barriers; just to summarize it for you. So, it can be either extrinsic or intrinsic; extrinsic when the low fitness of hybrids is due to environmental reasons.

That can be either due to ecological inviability or behavioral sterility. And when it comes to intrinsic, intrinsic is when low hybrid fitness is independent of the environmental context. It can be either due to hybrid inviability or hybrid sterility. Now, before we finish this discussion, I would like to make three observations about reproductive isolation. So the first thing is that although we talked about them as a list, it is not at all essential that they are mutually exclusive.

These various mechanisms are mutually exclusive to each other. As a matter of fact, we know that in many cases, for any two species, multiple of these mechanisms might be operating simultaneously. So, just to give you one example, we will go back to the monkey flowers that we talked about. So, if you remember that these are two different flowers, One of them is pollinated by hummingbirds, while the other is pollinated by bees. Now, it turns out that in this particular species, generally this one, this lewisii, occurs at a higher elevation than cardinalis. And there are some places where they do co-occur, but if you forget about the co-occurrence part, Much of the isolation between these two species is simply due to the elevation alone.

In other words, because they are at populations that are at two different elevations, for those, the fact that they are not together is sufficient for no gene transfer to happen. Now, if you look at only that subset that is found together at intermediate altitudes, There, 98% of the separation is because of the pollinator preference, which we talked about. So, cardinalis is only and exclusively pollinated by hummingbirds, which do not visit lewisii. And the bees that visit the lewisii do not visit the cardinalis.

So, that is the primary mechanism for when they co-occur. But even on top of that, if you actually end up you know trying to mate them, There are three other things that can still end up reducing the probability of gene flow. So, for example, if you put the pollen of both species simultaneously on the pistils of these flowers, Then the conspecific pollen has a much greater chance of fertilizing the ovule. So, that is what is known as pollen precedence. Similarly, even if, let us say, fertilization has happened, the germination success of the hybrids is slightly lower.

And even if germination has occurred, the fertility of the hybrids is slightly lower. However, if you actually end up seeing how important these last three things are, They play a small role even if they exist alongside the two big ones. So, the main point I am trying to make here is that multiple mechanisms. Reproductive isolation mechanisms often end up working in tandem with each other. This makes the gene flow between these things even more difficult in practice.

The second thing that I want to talk about is an observation by JBS Haldane. We have talked about Haldane, if you remember, which is known as Haldane's Rule. What is Haldin's rule? So, Haldin said that if two species or two populations mate and there is hybrid sterility or hybrid inviability, Then, typically, that is limited to the heterogametic sex. Now, what do I mean by that? So, if you remember, in human beings and in all mammals, we have the XY system of sex determination. So, the females are all XX, and the males are XY.

So, that is why the males are the heterogametic sex; they produce two different kinds of gametes. Whereas the females are the homogametic sex, they produce only gametes that contain the X chromosome. Now, you have a similar thing in birds where it is actually reversed. where the females are heterogametic and the males are the homogametic sexes. So, Halden's rule suggests that hybrid sterility or inviability will be limited to the heterogametic sex.

This means that primarily males are found in mammals, but primarily females in birds and butterflies. Now, it turns out that this is actually rather widely observed in many, many systems. Although there are one or two exceptions known here and there. So, for example, one of the exceptions is something that we just talked about a few minutes ago. which is in the context of Drosophila. So, if you remember, I showed you that Drosophila melanogaster males, When they mate with Drosophila simulans females, the hybrid females die.

And yet, this is a case where Drosophila is heterogametic like us: males are XY, whereas females are XX. So, it should have happened in the males, but in this particular combination, it happens in the females. But such one or two exceptions notwithstanding, Haldane's rule, in general, is widely observed. The final thing that I want to talk about is the speed with which reproductive isolation ends up setting in. Turns out that there is a huge variation in the time taken for reproductive isolation from setting in to becoming a rather strong factor.

Now, as we saw, reproductive isolation in many cases is not 100%; that is why I am not saying it is going from 0 to 1. But I am saying, starting from, you know, when it started to evolve to the point where it has become a really strong mechanism. So, for example, we have already seen that when speciation occurs due to polyploidy, As it happens, you know, many plant species can obviously adapt within a generation very quickly. In many cases, it has been shown that one can start with a single or a few ancestral forms. And then, over a relatively short span of time, these can rapidly diverge into many, many species.

And this is what is known as adaptive radiation. So, just to give you a very famous example of adaptive radiation, there is a very famous and huge lake in Africa called Lake Victoria. And in that lake, it has been shown that about 15,000 years ago, There were five ancestral species of a particular kind of fish known as cichlid fish. And over just 15,000 years, we have more than 450 species that have evolved, which means that An average time of about 2,300 years per speciation, about 2 millennia, or 2.3 millennia.

That is actually extremely, extremely rapid, and that sits on one side of the scale of adaptive radiation examples. On the other side of the scale, we have things like, you know, sister species of Drosophila. So, for example, Melanogaster, Simulans, and Mauritiana, and all those things that I was talking about. Contemporary genetic estimates suggest that they have taken about 200,000 years to evolve from one species into another. If you look at birds, for example, or rather, on average across all taxa, Typically, the estimate is that if you have populations that are geographically isolated, which means that geographically, they are not even exchanging genes then in order for them to evolve total reproductive isolation, It takes between 1.1 and 2.7 million years, which is 11 to 27 lakh years, and that obviously is a huge number. But if you look at birds, it has been shown that some bird populations have that evolved or diverged from each other more than 5 million years ago, Even today, if you bring them together, they are able to exchange genes and are fully fertile. And if you think birds are an exception, look at plants; it has been shown that there are some trees that can. still form hybrids even though they diverged from those species between 10 and 50 million years ago.

So, all this is telling us is that the process of reproductive isolation is not a very simple one. There has to be some, you know, variation in them, and the way they set in is not. How do I say there is a lot of complexity in the way they are set up? And in our next discussion, we are going to look exactly at this particular question: what is the way in which These mechanisms of reproductive isolation, what is the way in which they end up evolving? So, see you in the next discussion. Bye.