An Introduction to Evolutionary Biology

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Evidence for evolution 1: Change and Speciation

Hi. So, in the last module, there were two terms that we used rather extensively without really defining them formally or rigorously. So, before we go forward, it would be nice to have a slightly better idea of what those two terms refer to. These two terms are species and evolution. Now, it turns out that in evolutionary biology, the term species has not one or two, but many, many definitions. Why is that so? That is because different people have defined species concepts based on the specific use case for which they have used this concept.

So, because of that, although the concepts by themselves are consistent, when you take one concept, Or you know what a species is according to one concept and try to examine it in the light of another concept. You get into all kinds of trouble, which is why there are multiple books, of which I am just showing you four. There are thousands of papers where people have tried to examine these various species concepts, and you know that. And how they relate to each other.

So, since we are doing a very introductory course here, We are not going to get into all these philosophical and methodological issues. We are going to talk about two specific kinds of species concepts. The so-called morphospecies concept and the biological species concept. So, what are these? So, if you look at the way Carolus Linnaeus and Darwin thought about species, They essentially said that for the groups of organisms in front of us, we should look at their morphological characters. Group them based on those characters, which essentially means that all organisms which are very close to each other in terms of characters, they will form one species. Another group that has observably different morphological characters will form another species. Now, the good thing about this definition is that it is easy to understand. So, you can even look at, you know, museum specimens, and based on that, you can figure out, you know. which belongs to one species and which specimen belongs to another species.

It applies to sexual as well as asexual species; it even applies to fossil species. However, the primary problem with this definition is that there is a degree of arbitrariness in it. So, one taxonomist can say that this organism belongs to this species and that one belongs to that species. Another guy can come and say, "Oh no, no, no, we need to combine this to form a single species." But that organism actually belongs to a different species, and so on.

So, in other words, it becomes very, very subjective to the expertise of the taxonomist who is looking at the species. So, that is why people often prefer the other concept of species, which is the so-called biological species concept. which states that species are groups of actually or potentially interbreeding natural populations which are reproductively isolated from other such groups. Which basically means that if two groups of organisms are able to exchange genes with each other, they belong to the same species. If they cannot exchange genes and are reproductively isolated, then they belong to two different species.

So, this shows you that this concept was given by Ernst Mayr in the 1940s. which, as we have already discussed, is around the time when the modern synthesis is getting crystallized. Now, obviously, this is a more objective definition of a species. But there are many issues in terms of actualizing this definition. Why is that? Now suppose you have two different species of birds or two different groups of birds which, let us say, look a little bit different, and you think that they belong to two different species. Now in order to prove that what do you need to do? You need to actually try to make them breed, and you need to try and try and try a lot before you say that. These guys are not breeding with each other; they are not exchanging genes, and therefore, I am going to say that they belong to two different species. Sounds great. The point is, who exactly has ever done it? Who has the time to take all possible groups and you know in mate them and try to breed them in all possible combinations? Nobody does right.

So, which is why, although theoretically this is very nice, in reality it is very difficult to show directly that these are not breeding. Sometimes you can say you know the geometry of the genitals and reproductive organs is such that they cannot possibly mate. You can make those kinds of arguments, but when you are talking about groups, which are very close to each other in terms of their properties; even those arguments are not necessarily easy to make. The biological species concept has many other issues. So, for example, we are talking about the exchange of genes.

So, obviously, implicitly we are thinking about sexual organisms. What about asexuals that do not exchange genes ever? What about fossils? What about museum specimens? In those cases, even if you have the organism in front of you, You can never figure out whether they potentially exchange genes or not. So, which is why, although the biological species concept is something Most of you would have studied the species concept when you were in school. Realistically speaking, it is actually very difficult to use that concept to unambiguously differentiate organisms into different species. Particularly when they resemble each other quite a bit.

I mean you can probably take a fish and a reptile and say that these two belong to two different species. There is no way they are going to mate with each other, and you will probably be correct. But if you are talking about two different species of reptiles or two different species of closely related reptiles, I am sorry, fish; then it becomes much more difficult. Looking at species in these two particular ways also allows you to answer that famous, you know, statement that Many people are often known to make progress in biology. Which is that Darwin's Origin of Species does not really talk about the origin of species.

You might encounter this statement here and there. And the answer to this paradox is actually contained in this slide. So, when Darwin was talking about the origin of species, he was thinking in terms of the morphospecies. He was thinking in terms of, you know, a sufficient amount of change that is happening in a group of organisms such that At some point, they look very different from the ancestral form, and therefore, You call them two different species: the ancestral form and the evolved form. However, when you have the statement that Darwin's Origin of Species does not talk about the origin of species, The second species is actually the biological species in which there is reproductive isolation.

Now, Darwin, since he was not thinking in terms of reproductive isolation, therefore, he never really talked about any mechanism for the same, right. In fact, there is no mechanism that will automatically evolve or is guaranteed to evolve due to natural selection. So, in modern synthesis, what we say is, or rather what evolutionary biologists think, is that If you have changes accumulating over a long, long time, then at some point they may lead to reproductive isolation. And as we are going to see in a few minutes, we have tons of examples. Where such reproductive isolation can and does develop, there is nothing in the theory that says that, you know, accumulated changes over a long time will lead to reproductive isolation. It empirically happens, but there is no theory to say that this is definitely going to happen. Which is why people try to portray these two definitions of species as, you know, something. That is leading to an inconsistency in evolutionary biology; however, it actually does not lead to any such thing. These are just two different ways of looking at the species concept and as long as you are clear in your head about which species concept you are talking about, There would not be any paradox arising from it. Anyway, the other important concept is that of evolution: what is evolution? Now, many people have, you know, defined evolution in their own ways. I will take one such definition. This is a definition that is due to a famous evolutionary biologist named Jonathan Losos. It features in the Princeton Guide to Evolution, and it says that Evolution is the transformation of species through time, including both changes that occurs within species as well as the origin of new species. So, there are three or four terms in this definition that we should unpack. First, this is talking about the transformation of species. So, which means that there is some kind of change that will happen over time. It is explicitly talking about the fact that this will happen at two different levels.

One level is within species. So, this is the kind of stuff wherein, let us say, you are studying, say, the height of a particular species. And over time, across generations, the average height of the population has changed. has continuously increased or continuously decreased. So, that is what we mean by changes within a species. And when this thing happens for quite some time, according to the morpho species concept, at some point.

You will end up getting a new group. This might be due to, as I said, you know, accumulated changes in morphology; hence, morpho species. Or it might even be due to reproductive isolation setting in, in which case it will be a biological species; whatever, it does not matter. But the change will be so large that, at some point, it will lead to the formation of something new. So, this first part, where we are talking about change, which is incremental change occurring within a group, This is what is known as microevolution, and the second part is where we are talking about the origin of new groups.

This is what is known as macroevolution. So, this distinction is something that one should keep in mind as we progress further. We are going to talk a lot more about microevolution and macroevolution. Now, when it comes to this particular definition, there are a couple of points that one needs to remember. The first point is that this is talking about change at the species level and not at the individual level.

This is very important. Why? So, think about it. When, let us say, you were born, or when even I was born, we were about this size, right? However, today, when you and I are sitting here and chatting with each other, we are much larger than that. You know, somewhere between 4, 5, and 6 feet, are our heights. So, obviously, we went from this big to this big. However, that change is happening in us as individuals; that is not a change that is happening at the group level and therefore this change is not what evolution will be called. This is development from this body size we have developed to this body size. So, evolution explicitly excludes this kind of change; it only talks about changes that are happening at the group level. And therefore, related to the first point, evolution is explicitly about change. That is happening across generations and not within generations.

So, for example, suppose I take a bunch of babies about this size. And I track them for, say, 10 years, 15 years, after which time they become larger. So, their average height has gone from, say, about 1 foot to, say, about 5 feet. That change in average height, although it is at the group level, is still not going to be called evolution. Because we are tracking the change within the same generation.

In order for us to think about it as evolution, we have to look at the average height of the parental generation. and compare that with the average height of the offspring generation or the grand offspring generation, or the grand-grand offspring generation, and so on. In other words, the change has to be looked at across a generation time scale and not within a generation time scale. This is very crucial. So, with these two definitions, we are now going into the primary question for this module, which is that Why do we think that the process of evolution has happened in the past? And related to this, why do we think that it is still happening? So, before we start with the main question, we will have a quick recap of What we heard about this question in the previous module.

So, if you remember in this previous module, we talked about two historical theories of, you know, species diversity. Now, let me make it clear here that there can be many more, but these are the two that we talked about in module 1. And these two are what creationism versus, I will just call it Darwinism or the modern theory, whatever. So, according to these two theories, if we talk about the origin of life, then creationism says that Life originated as many times as there were species. In other words, each species was created de novo from scratch by God, the creator, or whatever some divine being whereas modern evolutionary biology says that life originated once or, at most, extremely few times. So, at some point I will explain, not in this lecture, but maybe in the next one. Why this extremely few times comes, you know, but most people think that it is just once. But if you are really logically rigorous about it, you will see that it is extremely few times. Now comes the question: where do we get all the diversity, the biodiversity around us?

Where does that come from? So, if you are thinking about creationism, then you do not really need a special explanation for this because This says that you know the divine forces created all the forms right at the beginning in their present avatar.

However, if you look at evolutionary biology, it says that there was, you know, one or a few ancestral species. And those species there have descended with modification from them, which basically means they have produced offspring. And those babies have produced further babies, and when this descent has happened in the process of this descent. There have been slight changes, small changes, and these changes interacting with the environment due to selection. And other forces, etcetera, have led to the formation of many species over a long time.

Therefore, the entire biodiversity that we see around us is a result of this descent with modification. And the third question is that if we look at all these species, do they have the capacity to change? Creationism says that. No, that cannot happen; all species originated in their final form, whereas evolutionary biology says that. Yes, species can, and they do change. So, if you think about it, there are multiple separate questions that we are dealing with here.

First question: do species really change? I am going from bottom to top: do species really change? Second question: Can species arise from pre-existing species? And the third question is whether descent with modification has really occurred or not. So, these are the three questions that we are going to investigate in this module over this lecture and the next few discussions. So let us tackle the first question: do species really change? It turns out that we actually have tons and tons of evidence direct empirical observation to suggest that this indeed happens. So, I will tell you and show you one very famous example over here. So, this is the famous industrial melanism case of the peppered moths, Biston betularia.

So, these moths are found in many places in the world. But the study I am talking about is in the context of England, and this is what these guys, these moths, used to look like. So, this is what is known as the forma typica, which means a typical form. So, you can see that these are light-colored with some little, you know, black patches on them, but mostly light-colored. Now, these guys in the pre-industrial revolution era remember that the industrial revolution started in England, right? So, in the pre-industrial revolution era of the early 1800s, the dark forms were actually extremely rare and it is these forms, the white forms, that are common. Now, somewhere around the time the industrial revolution started in the 19th century, or actually the late 18th century, what happens? Lots of factories are created when you have factories; these factories have chimneys. From these chimneys, you know they are burning coal as the primary fossil fuel. So, that coal is leading to soot that is coming out of these chimneys. And that soot is going and getting deposited in, you know, buildings and trees and everything around them.

So, as a result of the industrial revolution, there was a lot of soot deposition. because of which the bark of the trees became very, very dark. Now, prior to this, the barks in these areas were primarily covered by lichens. Okay, you know lichens, right? So, these are basically life forms that you typically find on rocks or tree bark and so on. So, these lichens essentially looked pretty much like this wing of, you know, forma typica Biston betularia.

Now, because of this, in the pre-industrial era, these typical forms sat on these barks. They actually kind of blended with the barks; they got camouflaged, and birds and other predators could hardly see them. However, once the Industrial Revolution happened and the soot deposition occurred on the barks, the barks became dark and When the barks became dark, this white form was actually extremely conspicuous against a dark background. And they became very visible to the predators. When that happened, the predation rate on these forms increased, and the darker forms.

The so-called forma carbonaria were at a massive advantage. And because of this, within a few decades, by the late 1800s, the dark forms started dominating. dominating in the sense that, in certain places, they shot up to 98 to 99 percent of all the You know forms, whereas in the pre-industrial era, they were like 0.001 percent or even less. So, by the late

1800s, once the bark became dark, these forms were at an advantage because Now they blend very nicely with the dark bark, and they cannot be seen by the birds.

However, there is another twist to the story. Remember that the people you know at some point understood that all the air pollution That is happening due to those chimneys that are bad for health. Therefore, at some point in England, they passed all kinds of laws to reduce the amount of, you know. Discharge from the chimneys, because of which the smoke becomes much cleaner. And the soot that was deposited over time actually starts going down. And when that happens, very interestingly, now the balance shifts in the other direction.

So, once again, the trees become whiter and the lichens come back. So, remember that lichens cannot exist if you have high levels of air pollution. So, the moment air pollution reduces, lichens come back. When lichens come back, these typical forms sit on them, and you know they become. Now these are harder to see; the typical forms are harder to see, whereas the carbon area forms become much more easily you know it's observable to the predators, and because of that. The number or frequency of the carbon area form starts declining steadily. Very interestingly, the exactly same thing plays out in North America. Because remember, at some point, North America also becomes highly industrialized. And at some point, they also pass laws, you know, which reduce air pollution. And once that happens again, the typical form comes back; the carbon area form actually disappears.

So, what this shows us is that direct empirical evidence indicates that species can, you know, change their properties sometimes extremely fast. This is just one example; there are, like, you know, millions of examples of this type in the literature. So, for example, you know about the evolution of antibiotic resistance in bacteria. The evolution of DDT resistance in mosquitoes, and so on and so forth.

I mean there are tons and tons of those things. Therefore, another big example of what I am showing you is from the natural environment. Another set of examples is from selective breeding. Remember, this is something that we humans have been doing for millennia. So, if you remember most of the crops and most of the vegetables that we eat today, Most of them are actually products of selective breeding, and one massive example of this comes from you know in the form of different vegetables from wild mustard. So, we all know about broccoli; we know about cabbage; we know about cauliflower. So, there is this thing called kale that is nowadays eaten in many parts of India too. But do you really know that all these forms are actually coming from the same form? Which is the wild mustard plant Brassica oleracea, right? So, what has happened is that in different places, different people have selected these plants for different parts of the plant. So, for example, cabbage is basically a terminal leaf bud that has become very much expanded. Broccoli is the flower buds, cauliflower is the flower buds, and kale is essentially just the leaves and if you look at the genetics of these organisms, if you take their DNA and sequence it, Cabbage, broccoli, and cauliflower all have exactly the same set of genes; they are the same species. But what is really happening over here is that, in front of our own eyes, these things have essentially changed their forms greatly. The other big example of this is from dogs. So, we all know that dogs were domesticated from wolf-like organisms by humans at some point and then different breeders bred them for different purposes. And this is just one example of the tremendous amount of variation that you see in sizes. So, this is a great den: the big one, and the small one is a chihuahua; both of them are dogs. Both of them can even exchange genes, but look at the amount of change that is present between them. So, the basic point that I am trying to make here is that It is totally proven beyond any doubt, with tons of examples, that species are not a constant entity.

They can, and they do, change over time. Now, one part of what Darwin was saying is obviously correct: species do change. But then the question is, does this change lead to the origin of new species or not? Remember, Darwin said yes, and obviously, whether the answer to this question is yes or no. It depends on which definition of species you are talking about, right? So, if you are talking in terms of the morphospecies concept, then the previous examples that I gave you—these two— Obviously, these are two different species of dogs over here. These are four different species of, you know, mustard or whatever vegetables over here, right? However, if you are thinking in terms of the biological species concept, it is because the dog And I mean the Chihuahua and the Great Dane are exchanging genes; you will argue that, no, this is not a species. So, that brings us to the question of whether you know this thing is an example of new morpho species, but not of biological species.

So, does that mean that new biological species can arise from existing species? What do you think the answer is? The answer, again, is a resounding yes. So, again, there are many, many examples; I will just share one with you. This is something that happened in Kew Gardens. So, this is a very famous botanical garden in London, and note the year 1900. This is the year in which Mendel's theory is being rediscovered by Hugo de Vries, Correns, and others.

So, what happened in Kew Gardens was amazing. So, they had two different species called Primula floribunda and Primula verticillata. So, in this particular case, Primula floribunda, you know they had 2n equal to 18 chromosomes, and the same for the other species. So, normally these are not supposed to interbreed, but they were actually able to interbreed, and they formed an F1 hybrid. which consisted of, you know, 9 chromosomes from floribunda and 9 chromosomes from verticillata. Now, normally if you have a hybrid like this, it will be infertile because the hybrid is supposed to reproduce.

Then the homologous chromosomes will not be there, and therefore it will not be able to, you know, do mitosis. And it will not be able to, I am sorry, no meiosis, and it will not be able to, you know, create the reproductive cells. However, in this particular case, something magical happened. What was the magic? The magic was that there was chromosome doubling. In other words, it had 2n equal to 18, but all the chromosomes were doubled, which caused 2n to become equal to 36.

But now every chromosome had a homologous chromosome. And, more importantly, due to the chromosome doubling in one step, you had the formation of a new species. which is today known as Primula kewensis because it happened in the Kew Gardens. So, as you can see, this still looks like the flower color is yellow. But if you look at the flower structure closely, you will see that the flower structures are actually very different.

And today, this is an established breed, and you can actually find it even commercially. So this is one example. Now, obviously, you are going to say, "You know, just one example; is that good enough?" Obviously not. The point is that there are many such examples in many different species. I have just taken one random example simply because this is somewhat recent.

So, what they did was take Schizosaccharomyces pombe, which is a kind of yeast, you know. And they were able to show that if you have, you know, certain genes modified, then in one step you will get. You know the formation of a new group, and this new group is going to be reproductively isolated. totally reproductively isolated from the previous group. So, the key message that I want to convey here is that it does not really matter how you define species, Whether morpho or biological species concept, it can be shown that one species. A new species can always originate from a pre-existing species, right? So, two things are done: do species change? Yes.

Do species originate from pre-existing species? Yes. But what does that mean? The fact that new species can originate from previous species. Does that mean that all the biodiversity that we see around us has arisen from the same process? Think about it; this is a logical question. I know that new species can arise from pre-existing species, but can I infer from that that all the new species Sorry, all the species that I see around us have arisen by a similar process. And if you think about it closely, the answer is no.

There is a logical fallacy here which is called affirming the consequent. and if you end up making this particular assumption then you are performing that logical fallacy. Now, what is that fallacy? So let me just give you an example. Suppose I say that if I shoot myself in the head then I will die. That is a reasonable thing to say.

Now suppose I tell you, or somebody else tells you, that I am dead. Does that necessarily mean that I have been shot in the head? Obviously no right why because although shooting in the head will kill me, but I can die in many many other ways right? I can die of old age, I can die from a shot to my heart, or so many other ways. Therefore, the fact that I am dead does not necessarily mean that I was shot in the head. Similarly, the fact that new species can arise from pre-existing species does not automatically mean that. That is the process by which everything in all the biodiversity around us has arisen. It is possible that they might have arisen, or at least some of them might have arisen, through some different process.

So, what you need is a separate set of evidence to prove that. The descent with modification is responsible for the entire biodiversity around us, and that topic, The evidence for descent with modification is what we are going to discuss next. See you. Bye.