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[ANNOUNCER:] Welcome to HHMI's 2014 Holiday Lectures on Science.

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This year's lectures, "Biodiversity in the Age of Humans," will be given by three of the world's leading experts in the study of biodiversity and conservation biology. Dr. Anthony Barnosky, of the University of California, Berkley; Dr. Elizabeth Hadly of Stanford University; and Dr. Stephen Palumbi, also of Stanford University. Scientists, advocates, and colleagues, they have dedicated their careers to documenting biodiversity past and present, and measuring the effects of habitat loss and environmental change, on species on land and in the ocean, to find ways to preserve ecosystems for future generations. The first lecture is titled "Learning from Past Extinctions." And now, Dr. Anthony Barnosky.

[applause]

[BARNOSKY:] Well thanks very much. I am really delighted to be here and I'm really looking forward to discussions with as many of you as possible over the next couple of days. My task this morning is to help you calibrate the present state of biodiversity with respect to what things were like before people really got into the act. And that means going into the fossil record. We have to go back into the fossil record to understand that, because we know that we—people—cause extinctions. Over the past few centuries we've seen over 900 species disappear. Over just the past 40 years, of those species that we still have on earth, we have been chipping away at their populations, such that we have killed about half of the individual bodies of wildlife on earth. Of the species that we have been able to evaluate, and that's about 75,000 species, almost one-third of those are in danger of extinction, they're threatened, over 20,000 species. It's these kinds of things that have led both scientists, and nowadays the general public, to be talking about the sixth mass extinction. So scientists have in fact been talking about this for about 30 years. The first book written on this was by Richard Leakey and Roger Lewin, published in 1996. It reflected the state of scientific knowledge at the time. Since then there's just been more and more in the news, and now even very common in the popular literature. A bestselling book now is "The Sixth Extinction" by Elizabeth Kolbert and it's a nice read if you want to visit with some species that are in fact in peril today. But the real question is where are we in this extinction crisis and is it possible to make it all work out?

So "The Sixth Mass Extinction." We call it "the sixth extinction" because we know as paleontologists that there have been five times in the history of complex life on earth where we have seen lots and lots of species go extinct very quickly. These are called the big five mass extinctions. On the left-hand column there, the event column is the name of the geological epoch in which they took place. In the "when" column is the years before present, when these cataclysms hit. And then the most important column to look at right now is the one labeled "percentage extinction," the one on the right. That shows you what percentage of the known species at those times disappeared off the face of the earth. So, two things to think about with mass extinctions. One, lots and lots of species go extinct. At least 75% of species you're familiar with go extinct. So think … your grandkids wake up in the morning, they look outside, and three out of the four species that you take for granted are no longer on earth. That's a mass extinction, okay. That's magnitude. We also have to think about rate of extinction when we're trying to calibrate where we are in terms of hitting the sixth mass extinction today.

So let's think about rate a little bit. We're going to plot extinction rates here on the vertical axis through time, on the horizontal axis we're going from 600 million years ago on the left, on up to the present. And that wiggly line there shows you the extinction rate as it has varied through time. The band at the bottom shows you what a normal extinction rate is, we call that background extinction, and think of that as sort of a normal birth/death rate if you want to make an analogy with people. You can think about a person is born, they have a lifespan, they die. That happens on … it's part of life, right? So that's sort of background, but there are sometimes when something really unusual happens, death rates really increase, and in today's world you could think of something like the Ebola crisis in certain parts of Africa right now where we're seeing lots of people die very fast. That would be analogous to what's going on with species in a mass extinction, okay.

So as I've said we've had five of these through time, they're labeled one, two, three, four, five on this diagram. And just for reference, the fifth of these took place about 66 million years ago, that's when the dinosaurs went extinct. So that's the magnitude of what we're talking about. And the question now is, all right, where are we in this sixth event? And that's where we really have to get into the fossil record and compare that with the modern record. Now one thing that becomes immediately apparent when you do that is that both for the fossil and the modern we're dealing with a very tiny subset of the known species. We have only assessed 4% of the species we have named in the modern world for their extinction risk. In the fossil record, the situation is probably even much worse in terms of percentages, probably much less than 1% of species that have ever lived do we have any fossil record for.

So keep that in mind as we carry forward, there's still an awful lot of work for you guys to do, okay? If we were to keep assessing species at the rate we have been for the past ten years, it would still take 250 more years just to assess every species, so, get busy.

Okay. There are some very big differences between the fossil record and the modern record that become important in comparing where we are today with the past extinction events as well. It's kind of like comparing apples and oranges, okay? And you can read down the list here and see that there's issues with comparing things over different time scales, with how we identify species, and so on. So what you have to do to make a reliable comparison is to find groups of organisms that we actually have good data for in both the fossil record and the modern record, and that happens to be mammals. Excellent records of mammals. We have a lot of information about modern mammals. We have a lot of information about fossil mammals. We can really make it kind of an apples-to-apples comparison with those.

So we're going to look very closely at that group. And one of the things that is a big difference is, in the modern record we have worldwide coverage in terms of geographic ranges of mammals and so on. You tend to think of the fossil record as being very spotty, and it is, it's much, much more patchy than the modern record is, but still, we have pretty good fossil coverage. This is … shows you all the places that this particular species of ground squirrels, *Spermophilus*, has been found in fossil deposits going back 30 million years, and it's a pretty dense sampling network and there are multiple localities at each of those dots. Incidentally, you can find teeth of this little guy in the fossil picking room if you take a break and go in there at some point. How do we get that fossil data, and what actually produces all those dots on the map? Well, a lot of work by paleontologists over the … really, the past 100 years or so. And I'll just walk you through the process of how we put together those big databases. It starts out exploring for fossils on the outcrops. And here we're out in the John Day National Fossil Beds Monument. This is Kaitlin McGuire, one of my colleagues, who happens to be an expert in that particular part of the world. Explore, find the fossils, then you have to get them out of the rocks, which is a fairly delicate process. You encase them in a plaster bandage often times to get them back to the laboratory where you can prepare them carefully, and then finally you've got a species identification, okay? So that's the mechanics of doing it.

Now, the other things you have to do is really have a good understanding of where those fossils come from in the rocks. So you start at a local area such as this one, and you explore it, find all the fossils and where they occur in the rocks, or at least as many as you can find, you never find all of them, and then you also have to independently date certain rock layers, and typically those are volcanic ashes, that provide the right minerals for radiometric dating. Then you put those two data sets together so you can tell how old the fossils are, roughly. At that point you can say, okay, I know where the oldest and the youngest occurrence of a particular species is.

So you have a local estimate of the range of that species through time, and in this case we're looking at the range of something you wouldn't want to meet in a dark alley, a hell pig, that has a skull about that big, okay? Then you repeat it for the next species, plot that, and so on, until you have all of the species in that particular locality. Now the compilations of data we actually use come from all over the world, so it's not just one locality. And you have to match up the strata from place to place. Nature isn't all that kind to us paleontologists because there's never a beautiful, complete section such as I'm showing you here. Instead you might have an area here where some rocks are exposed, another area over here where some rocks are exposed, so by using distinctive characteristics of the rock layers, and sometimes the radiometric dates, you can match up the strata from place to place. And then you go through geographic space and it's possible then to stack things in order, so that you end up with a more or less complete record of rocks for about the past 66 million years in our case, and also a fairly complete record of the fossils distributed through those rocks.

Okay, so what we've done then is put together information from hundreds of rock exposures, literally millions of specimens that are now in museum collections, and that has allowed us to identify the ranges of about 12,000 mammal species. So this is big data. We tend to think of this as paleoinformatics these days, they're in Internet databases that you all can work with, just Google Paleobiology Database, or Neomap, or Miomap, or Faunmap or the Neotoma Paleoecology Database and you can begin to manipulate this data. These each concentrate on different periods of time, so the paleobiology database is where one would go to get the most complete coverage for older time levels, Neomap, Faunmap, Miomap is where one would go to get the most complete coverage for the interval five million years to about 30 million years ago, and the Neotoma Paleoecology Database is where one would go to get the information for two millions years ago to the present. So that's how the fossil data is pulled together and assembled, and that's the database we have to work with.

The modern data has a different origin. The modern data comes from a group of thousands of biologists who study modern mammals and many other species. We're going to concentrate on mammals. The organization is called the International Union for the Conservation of Nature, and it is their charge to go out and assess the health of species on earth. They are the ones who have assessed 75,000 species and determined that 20,000 of those species are at-risk, and when we say "at-risk" we mean that they fall into certain IUCN formal categories. So the categories of concern are "vulnerable to extinction," that's the VU on the top right of this diagram, "endangered," that's EN, "critically endangered," that's CR, and "extinct in the wild." So those are classed together as threatened species, so when you hear a biologist talking about threatened species that's usually what they mean.

All right, so we have these lists of threatened species from the modern world, we have the extinctions from the fossil record, we can then put all those data sets together and begin to calculate extinction rates in deep time and compare those with extinction rates going on over just the past century. Here's how we do that.

So, very important to determine that normal background extinction rate, and that's where we really need these fossils going through millions of years, so this is just sort of schematically illustrated on this diagram. Expand that in your mind to 12,000 species from all over the world. There's only the ranges of 10 species shown on this. And what we're trying to do is determine a particular metric called "extinctions per million species years" or E/MSY. All we're doing with that is we're saying, if you have a million species, how many of those are going to go extinct in a single year? So if you had an E/MSY of one that means one out of a million species would be going extinct in a single year, okay. Another way you actually crank out those numbers is you just pick the interval of time you're interested in, and in this case we've picked an interval about 100,000 years long, and you count up the number of species that actually occur in that interval, 10 in this case, count up the number that actually disappear or go extinct in that interval, three in this case, that gives you the proportion extinct, which is .3, very important to divide that by the length of the time interval you've measured it over, and I'll tell you why that's important in a minute. So in this case it's 100,000 years. And then because we're really interested in how that would play out over a million years because that metric is supposed to be background over a million years, commonly people just multiply that by one million, okay. So in this case that comes out to an E/MSY of three.

Now here's the important thing to remember, that if you measure a really long time interval, a million years, compared to a very short interval, in the last example 100,000 years, you're by chance alone likely to get a lower background rate. So it's really, really important to make a statistical adjustment for measuring over different intervals of time. All right, so we do that. And here's sort of the way it comes out for mammals. There are 5,500 dots on this screen. You can count them if you don't believe me, all right. And each circle represents one mammal species, and the reason that there's 5,500 dots is because there's about 5,500 mammal species on earth today. A little more, but close enough. Now we can ask ourselves, knowing that the actual background rate that we've empirically determined from the fossil record is 1.8 extinctions per million species years, how many mammals would we expect to have gone extinct over the last century? And there's the answer—one. That would be a normal rate of extinction.

Okay, how many have we actually seen go extinct over the last century? Forty-three. So today's extinction rate is 43 times higher than it ought to be. Is that enough to send us into a mass extinction in a reasonable amount of time? Thus, an amount of time that people might care about? Well let's think about the next 100 years, let's say that all those threatened species of mammals, which happen to be about one-quarter of all mammal species, are really just dead species walking, that we have culled their number so much that they're doomed. What would we see over the next 100 years? We'd see that many more extinctions, a total of 1,200, which would mean the extinction rate is actually higher than the mass extinction rate you would get for the big five mass extinctions, if those mass extinctions happened in 500 years. The way the numbers work out, in fact, is that if we kept going as we are, mass extinction would be plausible within a couple more human lifetimes.

Now this is a way to think about what's going on here, I call it my extinction-o-mometer, and we start at 0% extinct species on the left, go to 100% extinct species on the right, that big vertical black line is the 75% benchmark. You can see to the right of that line we have all the big five mass extinctions plotted down at the bottom. And then what I've done is just gone from top to bottom, mammals, birds, reptiles, and so on, and shown you what the percentage of threatened species in each of those groups are. So you can see mammals 22%, birds 14%, and so on down the line. Things are looking of definite concern, and as I say if we continued, if we lost those species and continued those extinction rates, a couple more generations we'd be at that 75% line.

Okay, so that's the bad news. Okay, here's the good news. Look at those white dots, at those white icons. That's what's actually gone extinct, okay? We have lost, in most cases, less than 1% of the species that have ridden the planet with us for 12,000 years. We still have almost everything we want to save out there to save. And we actually know how to do it in many cases, but sort of the take-home message here is we are at a very special point in human history. We're at a decision point, where we can either decide to do things as we always have done, that is, with very little regard for the future and just think about the next meal, the next five years, and no longer, or we can think about where do we really want to be 50 years down the road and how do we get there? If we take that view, then it's actually very possible to keep these threatened species alive, possible to bring the sixth mass extinction to a screeching halt. If we don't take that perspective, it will be a very different world. So thank you and I'm very happy to answer questions.

[applause]

[BARNOSKY:] Questions? Hands up. Yes, over here?

[STUDENT:] For, like, the philosophical goals or reasons for protecting biodiversity, would you say it's purely aesthetic or are there other ones that aren't as clear, like preserving the beauty of the earth or are there less clear ones other than the aesthetic one?

[BARNOSKY:] Yeah, so there are actually many reasons for preserving biodiversity and you're going to hear about most of them in the coming lectures, but the short answer to your question is, you know, aesthetic morality is one. We actually get services back from other species that we very much need, both to keep us alive and to keep us happy.

[STUDENT:] Is paleontology a very physically demanding career as well as mentally demanding?

[BARNOSKY:] Yes. Yeah, that's the short answer, but as you see, you are out there generally in the hot sun, in remote areas, hiking around in the back country, living out of tents, carrying heavy packs, so I would say it's physically demanding.

[STUDENT:] I would like to know how you suggest we prevent the extinction rate from increasing?

[BARNOSKY:] We are going to have a whole lecture on that, so I will defer the long answer until our last lecture, but again, the short answer is, we have to both work on managing species that we know are at risk, but we also have to change the global society in ways that help us attack some of the big global problems that are underlying the extinction crisis. In the back here?

[STUDENT:] There were many times where, on the graph, where the extinction rate was above the background extinction rate. How do we know that the sixth mass extinction won't repair itself?

[BARNOSKY:] Well, extinctions do repair themselves. Biodiversity does come back. The problem from a human perspective is it takes millions of years to come back. So if we witnessed something like the sixth mass extinction, basically that will be what human beings live in for as long as we are a species. Can we get a microphone in the middle here? Okay good, yes?

[STUDENT:] I'm wondering why you think this isn't a concern to the general population and why isn't this compelling data covered in mainstream media?

[BARNOSKY:] You know, that is something that needs to happen a lot more. And in fact, it's beginning to happen. Twenty years ago, it was just scientists talking to scientists. Ten years ago it was mostly scientists talking to scientists. In the past three or four years, … I've just been Googling newspaper accounts and almost every day there's something new about extinction. With Elizabeth Kolbert's book I think it's really hit the mainstream a lot more, but we have a huge education problem here with the public. Once people are aware of this, I think it will become a greater concern, that's the first step to solving the problem. Okay, last question over here.

[STUDENT:] What does the sixth mass extinction, and any measures we would take to prevent it, mean for developing economies?

[BARNOSKY:] Actually some of, many of the means that we would use to prevent the sixth mass extinction would very much benefit developing economies in that it requires leapfrogging over some antiquated technologies that are much more applicable for, say, energy production than other parts of the world, it involves things like incorporating nature into economic models, which helps developing parts of the world, so this is really, can be a win-win sort of situation. Okay, thank you very much.

[applause]