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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, Berkeley; Dr. Elizabeth Hadly of Stanford University; and Dr. Stephen Palumbi, also of Stanford University. The second lecture is titled "Humans, Biodiversity, and Habitat Loss." And now, Dr. Elizabeth Hadly.

[applause]

[HADLY:] Thank you and welcome from me as well. I want to say that I'm just delighted to be here. I think that out of 30-some years that I've been working in the field of biology and paleontology and geology, now is the most critical time in my life. And I'm really excited to be able to talk to you because I think this is the world you inherit. And I personally have witnessed a lot of changes on this planet. And what I want to do over my next two lectures is give you some examples about the kind of work that I've done and that we're continuing to do in my lab, but I also want to implore you to think about how the kinds of things you're learning today, or you will learn about today, can influence the choices you make in your own future.

So my job today is to tell you a little bit about how humans really do impact biodiversity on the planet and to tell you what biodiversity is and why it matters. There are lots of levels of biodiversity, but as biologists, we like to divide them into these kind of four categories. There's the ecosystem level; and for this example I've chosen the Yellowstone ecosystem. Yellowstone Park, shown at the center there, with the black box around it, it's located in Montana, Wyoming, and Idaho, and that park is the world's first national park. It was founded in 1872. When it was founded, it's really remarkable to think about the foresight of the people that decided to establish a national park, because it was just one tiny part of a vast western wild set of ecosystems.

Now, you can see the western border of Yellowstone from space, and you can see that border because the forests on the western border have been cut down. So Yellowstone, even though the forests have been cut down there, the national park preserves everything within it. It doesn't allow us to do any kinds of alterations, except for those related to supporting the three-plus-million people that visit there per year. But the ecosystems shown in this yellow is protected indirectly by places like the BLM lands and national forest lands and wilderness areas. It's a pretty large system and it's large enough to encompass the range of the grizzly bear, for example. These large animals, the elk that migrate in and out of the park itself in herds of thousands of individuals. Microbes and hot springs: we don't drill hot springs here for thermal energy like hot springs everywhere else in the world. And all sorts of birds and other large and small animals.

This ecosystem then interacts, there are these iconic species. It's a place where we protect their interactions, but it's also comprised of individual species. And species vary across their range. Every species in the world, in a wild state, maintains what we call a geographic range. In the case of this grizzly bear, this purple range is its entire distribution in North America. What you'll note is that different grizzlies from different parts of the range look differently, there are different colors to them, they have different sizes, they actually hunt slightly differently. Some of them are keyed on the salmon run, others go for bison calves during the bison calving season. Notice the purple island to the far south of the rest of the range. That island is the grizzly bear range, and grizzly bear populations in Yellowstone. It's separate from the rest of the geographic range of this species. So even though the ecosystem is really kind of intact and working, note that members of the species can't easily flow north and south. There's also population variation.

So here what I've done is focus just on Yellowstone, and each one of those green polygons is the home range of an individual bear. All of these that I've shown are females. Females generally have … in grizzly bears they have the most productive part of the ecosystem, they live in the valley where the vegetation is really good and where there are lots of large animals for them to eat, and the males then have slightly larger ranges that encompass many females. So this population, these individuals forms the important kind of members of the Yellowstone ecosystem bears. And then every individual in that ecosystem, indeed every individual of all the species across the range, has their own genetic diversity. They have their own genotype composed of all of these kinds of … this DNA, and this turns out to be a very important part of biodiversity that's sometimes neglected when thinking about what biodiversity means. I'll give you some examples about all of these levels, but just keep in mind that we can't forget any of them.

So all of them are important. It's important, … in fact, in Yellowstone all of the native animals, the animals that were there before it was established as a park are still present unlike the rest of America. And part of the reason they're still present is because the wolves were reintroduced there. So, work that I did in excavating paleontological sites in Yellowstone established that in fact wolves were native. We went in there, we decimated every wolf at the turn of the century and all the way through the '20s, and then we established that in fact wolves really were native there, and they were reintroduced. So this is an example of a positive conservation effort with the use of the fossil record.

So there are threats to biodiversity. There are lots of threats. I'll detail some of the smaller versions, but basically the two big threats are climate change—we're headed for an uncertain, but very much warmer future—and ecosystem loss and transformation. Both of these big, big forces on our planet are caused by human population growth. The more humans we have … we have more and more every day on the planet. Human population growth is influencing the temperature in our climate and the amount of ecosystems we're transforming for our own use. We know that we can deliberately hunt animals to death. We know that we are tied to extinctions directly.

So, from about 40,000 years ago to 10,000 years ago, there was an event called the Late Pleistocene Extinction Event, and that extinction event is implicated as a combination of climate change, but most importantly human hunting. This example is a menagerie of animals that used to live in North America

prior to 10,000 years ago. Giant extinct things like gomphotheres, which were related to elephants; mammoths, and mastodons; this big giant ground sloth; the dire wolf seen there, much larger than our present-day wolves; the saber tooth cat. These animals used to live in North America, right around here. We caused their extinction. As a matter of fact, this extinction event focused specifically on large-bodied mammals. About half of the world's what we call megafauna went extinct at that time.

So, one of the forces behind this is that human populations began to grow. We got more and more innovative. We were pretty good at developing and using our tools. We got better as we evolved at communicating each other. That communication allowed us to hunt better and more effectively. Around 100,000 years ago, our ancestors, early modern humans, left Africa and colonized the globe. In Africa they co-evolved with large animal species, and what you'll see in Africa here, this is the number of animal species on the Y axis, and their relative body size on the X axis. So what you see are the survivors. This histogram shows the numbers of species of survivors in yellow, and there's just a few little species that are in the large-bodied size category. Large-bodied here means over 44 kilograms or 100 pounds.

So things, just a few species larger than that size went extinct in Africa. But humans continued to colonize the globe. They next went to Australia, 40-60,000 years ago, and boom, this really unique Australian megafauna composed of all sorts of marsupials. We saw the demise of giant kangaroos; we saw the demise of giant wallabies. And those animals went extinct again around 40-60,000 years ago, when we arrived there. We continued to expand into Europe, into Eastern Asia, and then by at least 35-15,000 years ago, humans made it to the Americas, across what was then at the time the Bering Land Bridge. And this is where we saw the loss of the big-bodied animals that I showed you on the previous slide. A pretty large hit to the megafauna in North America. And the same thing happened in South America. Again, a large loss of virtually all the large-bodied animals in South America.

So we know we can hunt animals to death. And let me remind you, this is early humans. There were no guns. They were hunting with spears. Eventually they used bows and arrows. These were primitive hunting techniques, and yet they caused the extinction of many mammal species around the world. We're a lot better at hunting now. This is an AK-47, and I'll tell you now that there are large cartels of poachers that go out deliberately and kill animals for profit. They trade in these body parts, and that is used to fuel all sorts of other nasty things, like drug running and human slave traffic. We're much better at killing animals, and it's not just the elephants and rhinos that are under extinction. If we continue our hunting of elephants the way we are now, in 20 years there will be none left, except those in zoos. In 20 years. Remember, elephants live as long as we do. Those individuals that we're culling are families that are being lost right before their eyes.

I'll also point out about, for example, rhinos; we were just in Africa this summer. The hunting of rhinos in Africa is so extreme that the only way to keep the rhino alive is that there's 24/7 armed guards hiding in the bush around every individual rhino around Kruger National Park. Unbelievable expense. By the way, they are allowed to shoot to kill for poachers. And the reason is because people want to come and see these rhinos and they're preventing the extinction of this animal before its time.

So it's not just the elephants and rhinos. Anybody know what this animal is? It's a pangolin. So there are eight species of pangolin in the world. Every one of them are threatened. They live in Africa and Asia: four species in Africa, four in Asia. They're mammals, but they have this really unusual scaly body. That scaly body is something they use to protect themselves. They have giant front feet, and if you look online, you should Google this and look for "pangolins walking." They walk kind of like little *T. rex*'s, they walk on their back two legs with their front feet up like this, they have massive claws, and that's what they use to get through the dirt and through termite mounds. And when they're threatened they just curl up in a ball. It turns out that that ball makes them really easy to poach. Why? Because when they're threatened by humans, they curl up in a ball, the humans just pick them up and put them in a bag. These can't be kept in captivity. And so little is known about pangolins, but yet they're the most heavily trafficked animal in the world. Every one of those eight species is headed for extinction.

So it's not just those big charismatic animals that are under threat. It's small animals that we know so little about. So humans are directly causing the extinction of animals. It's not just guns that kill animals. Now poachers in Africa have gotten very sophisticated. They have a lot of money. They fly over ponds, or sneak up to ponds, for example, watering holes where elephants will congregate. They poison the watering hole. Entire families decimated, and then after a few days, these poachers come, they take all the tusks and leave the bodies to rot in the sun.

There are 5,500 mammal species, a quarter of them are threatened. We learned about what those kind of threatened categories are from Tony, most of them are threatened by habitat loss. And what do we mean by that? So humans are causing habitat loss. Why do we do this? We cut down forests like this. Well, yeah, sure, we use the wood to make furniture and to build our houses. But I'll tell you in places like India, there's not enough wood for any construction. They don't build things out of wood anymore. Wood is so valuable and hard to find, they're building their buildings out of brick. Human population is another reason why deforestation is proceeding at such an incredible rate. And it's another reason why poaching is proceeding at such an incredible rate.

Now I'm going to shift scales here as I go through these slides, but what we're doing is we're starting 10,000 years ago and we're moving to about the present or out 2,000 years ago. So what we have here is the total world population of humans in millions of individuals. And you can see that, and we could come all the way back to over 100,000 years as we were leaving Africa. Human populations were really low, in the thousands to tens to hundreds of thousands of individuals. And we started increasing our population dramatically. By the year 1500, right, we had about 500 million people on the planet.

Now keep your eye on that yellow dot because I've shifted scale now, and this is a perspective of … that's the same 500 million people here, and that's the year 1500. Here's where we are today. Exponential human growth. Now, the scary thing, and this is important. It's a touchy subject, but it's really important for you to think about. If we brought our birthrates down … I'll show you what they are in a second, but instead of your mom and your dad, for example having two children, on average, we only had 1.5 on average … it's not really possible to have a half a child. But on average, around the 7+ billion people on the planet. We could keep ourselves below eight billion people. We could keep ourselves about the same way it is today. If we only replaced ourselves by the year 2100 we'll have 10

billion people on the planet. If we just replace ourselves, i.e., every parent, every couple has just two children. If we have just a half a child more than ourselves, we'll be up almost to 14 billion people, around 13 billion people on the planet. And guess what? If we continue our fertility rates the way they are right now, 27 billion people on the planet. That is not possible. It is not possible. So things will begin to happen to bring our birthrates down. And as a matter of fact, birthrates are coming down almost everywhere in the world, just naturally. Some of the birthrates in places like Japan are close to zero.

However, … however, our current fertility rates are still much too high. Let me give you this in a different perspective. So these are scaled exactly for our average body size, around 100 pounds, and the 7+ billion people on the planet. So I'm going to give you this in terms of biomass. So this is mammalian biomass. This is humans for scale. We have a lot of animals that we take around the world with us; cows, sheep, horses, pigs, rabbits, dogs, cats. Massive numbers. Actually, this impact in terms of biomass is larger than our own. These are the animals we eat. Wildlife? A fraction of biomass on the planet. And for scale, that little green dot is the biomass of all the elephants on the planet today. So, very tiny amount of biomass now. The productivity that fuels the planet and creates mammal biomass … very little of it goes to wild animals.

Well, what if we made it somehow to 27 billion people? Is it even possible? The answer is no. Twenty-seven billion humans is more biomass than we have on the planet today, period, with all of these sources of mammals combined. So humans transform landscapes in dramatic ways. This is … on the left is a version of Manhattan Island before we got there and started building these gorgeous buildings in downtown New York City. There's clearly a lot more biodiversity to the left of this than there is in downtown New York. But downtown New York is a pretty efficient way for humans to live. A lot of humans to live on the planet, but we have to eat in New York City, we have to, we have to somehow deal with waste in New York City. And so we transform other parts of the planet in different ways. As a matter of fact, we now, as of this year, we have officially transformed 51% of our planet, so more than half of our planet has been transformed, mostly for our crop production and for our grazing animals, and for us to live.

Now you'll note that the areas … this is what we see in purple, this is area that's been transformed for human use. We co-opted that for human use. And what you see is that the areas that are in tan, we haven't really capitalized on, right? Well guess what, those are tough areas to farm and to put crops in. The Amazon and the Congo are big swaths of land that we haven't yet completely transformed, but the Sahara Desert? Not an easy place to raise our crops. The tundra? Not an easy place to raise our crops. And what you'll see in Asia, south of the tundra, right, that big tan blob there? The Gobi Desert and the Tibetan Plateau. Central Australia, same thing. So we've taken all the easy land already and what's left is much more challenging.

The other important thing to note is, given our dominance on the planet, for what we've transformed and farmed and turned to monocultures or turned to big savanna grasslands for animals to graze in, is that protected areas are few and far between. There are protected areas on all our major continents and some of them are quite large, but even they are under threat, okay. So some of them in central

Africa, I went to central Africa to see the mountain gorilla. The central African massif where the mountain gorillas exist—there are 700 individuals left on the planet—are patrolled by armed guards because the people, the growth rate, the population growth rate, the fertility rate of individuals at the base of those mountains is 10. Every one of those children needs to eat, and these people go in because they're trying to eat, they go in and they snare animals and they kill animals just for protein. So, protected areas even like Yellowstone, which is set aside, protected, it's a pretty big intact temperate ecosystem, so it's a pretty big place. Even that area is isolated from the rest of the areas like it.

Now why does that matter? Why does this isolation matter? Well, we wish we could have more of these protected areas, but where it really matters is because the climate is changing. And animals and plants in these ecosystems, as climates change and they get warmer, they're going to want to move from the equator toward the poles, and there aren't corridors connecting these protected areas.

So, climate change. You've heard a lot about it and perhaps some of you know this as a hockey stick graph. I hope you don't get tired of seeing this, because it is your future. So here we have several different scales on the X axis. We go millions of years before present, then thousands, then just a few years, and then years into the future. And what you see are global average temperatures. These are taken from all sorts of proxy data. Zero is basically a baseline for most of global climate in the last five million years. I'm going to just pause for a second and say, mammals, mammal species—we heard about life spans of species from Tony, that there's a background extinction rate. Animals of different kinds, like invertebrates, versus mammals, versus plants, have different kinds of characteristic longevities in the fossil record. Mammal species have pretty short time intervals. A typical rodent from its sister species is maybe one to two million years apart. So mammal species are pretty young. They're generally almost all less than five million years old.

So all those animals that we share the planet with, they basically evolved in this timespan. The climates they witnessed are right here on this graphic. So they've hovered around zero. As we went into what's called the Plio-Pleistocene glacial period, climates, global climates cooled a lot. Then we went back and forth through the glacial/interglacial cycles, these big spikes in the blue line, until we ended up at the end of the Pleistocene into a period we call the Holocene, or the last 10,000 years of earth history. And what you'll see is climates warmed and then they kind of hovered right around this zero line for a while, and then suddenly, right around the Industrial Revolution, things started to change and our climate started to warm.

So 100 years into the future we're projected to see temperatures between two and four degrees warmer than today. And just for scale, you note that there has been no time in the last five million years where that's how warm the earth has been. Not only are these mammals not equipped in some ways, they don't have this memory of warm temperature in their genotypes; … we don't either. We as humans have never witnessed these temperatures.

So this is what climate change looks like. This is from a trip that I took to the top of Kilimanjaro. This ice sheet used to come all across what would be this center of the crater. There's tents for scale there.

This is … I was on the far right tent. And this ice used to come here. The porters that come up with us said every time they go up the ice is less and less. It's even less now—this was in 2008. So Kilimanjaro … Ernest Hemingway wrote the book The Snows of Kilimanjaro because this was this white view. It's no longer like that. So what you see on the bottom part here are panels from a bird's-eye view looking down into the crater. You can kind of make out that circle there. In 1912 these are all different ice fields at the top of Kilimanjaro. By the year 2011, just a few years ago, you can see a vast loss in that. This is the highest mountain in Africa. And within a couple of years, to maybe at the most a couple of decades, all the ice on the top of Kili will be gone. And it's not just climate change, right?

So the threats to the planet are not just this habitat transformation combined with climate change. It's also the spread of diseases. As we transform the planet, as we warm temperatures, we allow different diseases, different species to move around and to invade. We're polluting the planet. We create a lot of waste. We are not efficient at how we deal with our waste. Right now we use the air, the land, the sea, and all of our waterways as our dumping grounds. Oceans are becoming acidic. We're going to hear more about the oceans in great detail from Steve later on today. And as I said, protected areas are very much more isolated than they used to be. So it's this synergy. It's the combination of all these forces that will drive animals to extinction. I told you about the black rhino, about how rhinos, there are just a few thousand individuals left. The golden toad, extinct from a disease most likely, and combined with the lack of its cloud forest in Central America, but this is extinct as far as we know. And then over here we have the scimitar oryx. So this is an example of a species that's extinct in the wild. The only living representatives are in zoos. This is a zoo animal now and has no function in the wild at all.

So I'm going to go back to Yellowstone and I'm going to describe to you some of these threats to biodiversity even in this area that's been protected for so long. And they're going to fall under these categories, and I'll tell you that most of these threats I have witnessed during my 30 years working in this park. So diseases; diseases have taken hold. Whirling disease attacks trout there. Beetle kill: more extensive, more expansive, and more trees. The chytrid fungus—this is the fungus that attacks amphibians and it's present in many of the park ponds. Non-native species have invaded both waterways and land. After the fires of '88 massive numbers of invasive plants colonized areas that had been burned.

There are also trout … lake trout were introduced since the time that I started working there. The native cutthroat trout in Yellowstone Lake, basically inaccessible to other animals because of giant waterfalls. Lake trout—somebody planted that animal in there from the Great Lakes. It's native to America, but not to Yellowstone, and it is voracious, and it eats every cutthroat. Cutthroats have almost disappeared from Yellowstone because of that invasion.

Climate-related effects. This is really a synergy of this beetle. Beetle kill is decimating a lot of high-elevation trees. Drought, the combination of lower precipitation and warmer temperatures has caused ponds to disappear. Those ponds that are important for aquatic birds, for aquatic amphibians, for example, frogs, salamanders. Their numbers have dropped and some are disappeared. There's lower snow pack and an increased fire frequency. Threats to populations includes things like the wolf

population, both from hunting outside the park and also from diseases that they caught from animals like dogs. They've got mange that causes their decline as well.

And then human encroachment; even in this ecosystem, there's mining, there's development, there's pollution from those efforts as well. And just the sheer number of people that go into this national park is a problem as well. So I want to conclude this particular lecture with saying that protected areas are really important, but even in a place like Yellowstone we can't keep all of human impacts out. And so even in a place like this park and other protected areas in the world, we have to be alert to the kind of global impacts that we're causing.

[applause]