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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 sixth lecture is titled "Dodging Extinction." And now, Dr. Anthony Barnosky.

[applause]

[BARNOSKY:] Well, I hope you've learned something from listening to Liz and Steve and what I hoped you've learned is this: people are incredibly powerful. We have actually used that power in ways that we didn't even know were killing species until recently. Liz and Steve have also showed you that we are really clever. I mean, conservation biologists these days are thinking about these cutting edge new ways to reassemble genetic diversity, to help corals respond to some of the threats we're throwing at them. And, you know, there are traditional ways the conservation biologists have been saving species as well. And the picture of these tortoises here is a great example. So the big guy is Lonesome George, lived on the Galapagos Islands until recently. He's actually an example of a population of a species, he's actually a subspecies that we ended up causing to go extinct.

The flip side of that are there are many other populations in that same species and, you know, Liz was talking about cute pikas and Steve was talking about cute otters; look at that baby tortoise. Now which one is cutest? The point of that, though, is we have rescued this species from the brink of extinction, okay. There were 250,000 of these tortoises distributed through the Galapagos Islands before we began to hit them pretty hard back in the 1500s. By the early part of the last century we were down to about 3,000 of them, and it was clear they were on the way out. Because people got concerned, and actually came up with ways to protect their breeding sites, and to actually go out to their breeding sites, collect the eggs, bring them back to safe places, rear the tortoises until they were able to survive on their own, and then put them back where they got them, the population is now built up to about 19,000 individuals, and there are many other species we've done this with.

So the point is, we know how to save species when we put our minds to it. That's one thing that is very hopeful going into the future. The other thing is as we've learned today, we know the underlying drivers of what's causing all these extinctions, and we know ways to fix that too. We have to also think about that very big picture, as well as the specific ways to save certain species and ecosystems. And those underlying drivers, basically, as we've already heard, Liz talked about growing human populations on earth, now she pointed out the three different scenarios by the year 2100, actually it doesn't matter which of those we have. The trajectory and the way population growth works means that we're going to be close to 10 billion people by the year 2050. After that we'll either level off, it'll go down a little, or it'll go up a lot depending on what we decide to do. But the reality of the world we

live in, that you live in, and that conservation biology lives in, is that there will be two to three more billion people on the planet by 2050.

Now you've heard about things like climate change. You've heard about habitat destruction. You've heard about poaching, logging, … all of those proximate extinction drivers actually sort into these three categories: of how we produce the power to keep the global ecosystem running, including the power to do what we would like to do as humans; how we are able to grow enough food to feed so many people on the planet; and how we make our money, how we regard nature either as an unlimited resource or as an investment account.

So let's think about, how do we get at those root causes, what do we do, can we fix them? And I will tell you right now, the answer's unequivocally yes, we can deal with all three of those. But it's helpful to think about just what that involves.

So power; by power I mean energy and all its forms. You know, all living organisms require energy to stay alive. The normal energy that the global ecosystem relies upon actually comes from the sun; sunshine hits plants, the plants convert that energy to chemical energy—that's the process of photosynthesis. That chemical energy is then something that can be consumed by other species, animals eat plants and each other, and then it all cycles around. There's a limit to that natural energy. The bottleneck is photosynthesis, and it turns out that the annual amount of energy that can be produced for the global ecosystem that all species have to share is 728 exajoules.

Okay, exajoule is just a great big measure of energy, okay. There was an earthquake in Japan in 2011, it wiped out two nuclear plants, it caused worldwide tsunamis. That released about 1.4 exajoules of energy. So you get the idea of how big 728 is. That's great, a big pie to be shared by all the species on earth. Here's the problem, we're eating too much of the pie. So humans now take about 30% of what was formally available to be shared with all other species. That's a pretty big slice of the pie, but it's not big enough. What we consume in one year is more than the sun and net primary productivity can produce for us. We consume 761 exajoules.

Where do we get the rest? I think you know the answer; we dig fossil energy out of the ground, which by the way, fossil fuels are basically fossilized net primary productivity. Okay, so we add it, there's our climate change problem. That's what's driving the changes that we see in climate because we're putting greenhouse gas emissions into the air, that acts like a big blanket that heats up the atmosphere.

Now here's the problem, and here's why I say we're between a rock and a hard spot. Remember that picture Liz showed you of all the people on earth and all of the animals that we use to support us, and how that relates to the wild animals on earth. Well, look at the white circle there. That white circle is what net primary productivity can support. That means if we want to keep seven billion people on the planet, we have got to produce extra energy each year. We can't just cut off fossil fuels, okay, which is the issue if we're talking about climate change.

Okay, now I've got to say, I've got nothing against fossil fuels. As a matter of fact fossil fuels have been very good to me. The highlighted guy is my grandfather. He was a coal miner for 40 years. My first job out of college was as a coal geologist, then I went on to work for an oil company, and then I finally became a paleontologist. The point being, we all rely on this energy in a big way, but now we know we have to do something different, and here's how we know. Where we have to come in reducing emissions is reduce our current emissions by about 5.1% per year for the next 50 years. And what you're seeing on this graph is the cumulative carbon emissions measured in gigatons, not the PPM that you might normally be thinking about, but actually the weight of carbon, on the vertical axis there, and then we're just projecting into the future to the year 2200.

And what the lines are showing you is, the green line shows where we have to go in the sense of reducing emissions, the red line shows you emissions from the dirtiest kind of fossil fuels, which is coal, the stuff my grandfather was digging out of the ground. And, by the way, he probably looks unhappy there because they were being paid by the ton, and he had to stay here and get his darn picture taken rather than making money. And the yellow line shows you the reduction in emissions we would get if we were able to replace all of the coal plants by 2030, all the coal plants in the world, replace them with the cleanest fossil fuels we absolutely could, which is natural gas. We'd only get about half way to where we need to get. So that gives you the scope of the problem. We basically … yes we have to use, in the interim, go to cleaner energy sources, but what we really have to do is by the year 2050 get completely onto carbon-neutral sources pretty much.

That means we have to change over our entire stationary energy system, which are power plants and the things used to generate electricity, and we have to change over our entire transportation energy system. Wow. That's a lot. Can we even do that technologically? Well here's the good news. Absolutely. We have the technology in hand, and we are already beginning to scale it up, to replace our entire stationary energy system, by a combination of solar, wind, water, and some nascent technologies using waves to generate energy and tides to turn turbines. We can actually make this transition. And people have actually counted up how many of these things do we have to build to make it work, and there's the numbers. They look pretty big, right.

However, when you compare the amount of work that we would need to do to build all these machines, with what we've done just since 1950, it's not very big at all. We have dammed 60% of the world's rivers since 1950, we have built enough roads to encircle the earth twice, just in the United States. We have gone from having no airplanes to this incredible air transport system around the world, so these are very doable things. This is why I say humans are powerful and clever.

Okay, transportation system—anybody ridden in a fully electric car? They're really fast. They're great cars. They're out there. They're being sold commercially, they work great. Hydrogen fuel cell technology is a little behind, but this is a model that's actually available for sale. So changing over to that is quite within our grasp, it's going to happen. An important thing to remember is even fully electric vehicles are linked to that stationary system, so it doesn't do you very much good to change over to an electric vehicle if you're still producing electricity from coal. Driving a fully electric vehicle in Denver, Colorado, which gets a lot of its electricity from coal, is equivalent to driving a vehicle that gets

about 34 miles a gallon. Driving one in California, which has a good proportion of clean energy, is equivalent to driving a car that gets 75 miles a gallon, so you got to do both.

Okay, some things, you know, we're going to have to have liquid fuels. My brother was an airline pilot, he has informed me that in no uncertain terms that airplanes cannot fly on electricity. How do we do that? Well in fact, the U.S. military and commercial airlines have already prototyped this. Biofuels work just fine with airplanes. The problem with biofuels that we have these days is we're using crops and cropland to produce them; we can't keep doing that for reasons I'll tell you in a minute. However, growing technologies now are using algae, microbes, and things that are very efficient in order to do this. So this is something that will hopefully happen as you guys go into the next couple of decades.

Okay now let's turn our attention to food. And the reason I say that food is the second part of the problem goes right back to this illustration that Liz showed you. All that purple, the vast majority of that purple, is where we grow food, either as crops or where we pasture the animals that we eat. That's the major land use, okay. The only arable land that is left is in the most highly biodiverse places on the land surface, that is tropical forests. Up to two-thirds of all land-based species live in tropical forests. If we expand into those, biodiversity is gone.

How do we avoid doing that? I mean right now there's seven billion people on the planet. If you do the math it takes about two acres of food-producing land to support each one of us. If we add three billion, it's not going to work, right? So, luckily, there are three ways to make this happen. And again, relying on nascent technologies, new techniques, but one is to simply improve the efficiencies of yields in places we already have under cultivation. 1960s, we had the Green Revolution. At that point, a billion people were almost certain to die if we didn't increase food production. What this graph is showing you is going from 1965 to the year 2005 and showing how food production was able to increase by making some changes that involve technology and cooperation. Western Europe and USA in the green lines; dramatic increases in yield, and that's measured in kilograms per hectare of crops. Other parts of the world, the purple and lighter green lines; still significant increases, but could be brought up even higher. And the red line is Africa, which is still producing in its croplands at about 25% at capacity, okay.

So we can produce 50-60% more food in the world just by bringing production up in environmentally sustainable ways. And that is an important point: environmentally sustainable ways. We know now that many of the products of the Green Revolution, i.e., the heavy use of fertilizers and overwatering, have caused a lot of problems. A few months ago Toledo, Ohio, was out of drinking water. You couldn't drink what came out of the taps because it was poisonous. The reason that happened is because excess fertilizers, i.e., nitrogen, ran off of farmlands in the region, drained into the lakes that provided the main water supply. That added more nutrients to the water, which causes algae to just explode, they like to eat just like anybody else, and what limits them are food. So as a net result you have hundreds of thousands of people without drinking water, okay.

On a bigger scale, Steve was talking about pollution and problems in the oceans. That comes from agriculture in a large part, and the same principle I just explained for Toledo, except scale it up now to all the coastlines in the ocean, where all these rivers drain out, the yellow and the red dots there, are

places that for parts of the year are dead zones. They support little or no marine life because of this excess nutrients. So actually by applying something that food security people like to call the Goldilocks strategy—not too much fertilizer, not too little, but just right—and the same with water, you can clean up all of this.

Okay, number two—this one pains my heart too, because my dad was a butcher, all right. So, two strikes, right? Fossil fuels, eat meat. But this is the reality. If we were to convert all of the croplands that are now used to grow crops for cattle and pigs and so on, put those into production for growing crops that people would eat directly, we would increase the number of calories available to the world by 50 to 70%. That's enough to feed a couple more billion people in itself.

And then the third fix with food; incredibly obvious, why don't we do it? We waste about 30% of what we grow. In developed countries, into the trashcan because your plate's too full. In developing countries it's more a problem of transportation and getting food to market before it spoils, getting it to where it needs to be. Those are fixable things. Just that produces 30% more food.

So if we do those three things we can actually produce enough food to feed 10 billion people without harming biodiversity more. The last thing is money; you know, we talked about poaching, we talked about overfishing and those sorts of things. People aren't doing that just because they want to poach and overfish, they're doing it because they make money off of nature. Expanding croplands into a virgin rainforest is actually much cheaper in the short run than implementing these more advanced agricultural techniques and producing more with where we're already growing food. That's what's driving cutting down rainforests for things like palm plantations, but that can be fixed in a couple of ways.

One way is by doing what I just talked about, increasing production where we're already growing foods. The other way is to think about not making a quick buck from an ecosystem service, but thinking about ecosystem services as this investment bank and we're living off the interest and that we have to have that interest coming in, in order to keep the direct benefits flowing. And ecosystem services, what do we mean by that? There's a few different ways you can look at it. Supporting services, which are things like soil formation, medicines, the sort of discoveries that allow us to have ice cream without ice crystals that Steve talked about. Provisioning, which is what we tend to value these days, which is just the food we can grow or the wood we can grow and sell. Regulating services—well, in order to grow that food we actually need pollinators, get rid of the bees, you're not going to have many crops.

And then as Liz and Steve were talking about, with people willing to pay to see species, that's sort of an aesthetic, a cultural thing you can put value on. So the point is, of all of these kinds of ecosystem services, we're only valuing the provisioning services these days. Nobody's paying for the rest of them yet. By integrating those, actually, into the global economy, you have a way of making it economically viable for essentially preservation of species, because you get more ecosystem services for more biodiverse landscapes in general. And the value is enormous, right. If we were able to value all ecosystem services and trade in them, that's about twice the amount of money that the entire world produces as a GDP in a year.

Okay, so these are, you know, those are the big-picture things that we need to be thinking about doing, and that, as I say, are very feasible to do. How do you solve these big things? And I'm talking about change the energy system, change the food system, change our economic system. Well, there are basically a few steps that have to make that happen.

The very first one is a lot of what we've been talking about today; just awareness that this is a problem that we need to solve. Once people start catching onto that, the rest actually goes pretty easily. So we're at that awareness stage. So, you know, even if you're not going to become a scientist or an engineer you have a huge role to play in solving these. You know, marketing. If you are into the arts, communicating these issues through film or writing or whatever media. Those of you who are into science and technology, huge role to play. You … I'll bet somebody sitting in this room is going to pocket $1 billion because they're going to come up with a slightly more efficient way to produce carbon-neutral energy or they're going to do that last tweak on producing economically viable algal biofuels. You know, tremendous opportunities in economics and thinking about ecosystem services. Tremendous opportunities in law and dealing with how do we interact with the environment. In medicine, how do human interactions with these last wild places influence diseases and so on. So the point here is everybody, no matter what you decide to do with your lives, can make a huge difference in solving these problems.

And then the last thing, is it all just pie in the sky? Come on, these are big things. Well I'll just point to a couple of examples here. Which one did not get a Nobel Prize? I talked about the Green Revolution. In 20 years we saved a billion people's lives. That involved pretty much the same thing we have to do now with solving any one of these three big issues I talked about, it involved a growing awareness. People said hey we don't want this to happen. It involved taking some nascent technologies and scaling them up. Norman Borlaug was one of the main movers and shakers behind that. He was a poor Midwestern farm kid, ended up interacting with various agricultural groups, went to college, ended up at the Rockefeller Institute, sent to Mexico to help them increase wheat production, started experimenting with plant breeding and so on, so all that was in place. And then it was clear that what needed to be done is to scale that worldwide. What does that involve? It involves working across international borders, across a whole variety of constituencies, NGOs, governments, private citizens. It involves dealing with the economics of agriculture, putting price controls in place. We did that, in 20 years basically.

The second example, a few years later, Mario Molina and Sherwood Rowland made this amazing discovery that the kinds of chemicals we were using in hairspray and other such things were causing the ozone hole to grow, which meant that lots of nasty radiation from space were starting to affect human health. Again, awareness, international cooperation, a treaty that all … most of the governments in the world now have signed onto. It involved doing things differently, it involved industry doing things differently. So it worked.

I put Mark Zuckerberg up here for a different reason. One of the biggest things that we have to do now is communicate. You guys have those tools to a higher degree than any time in human history. You know, when I was your age, maybe 300 million people across the world were connected by land lines.

Now 3.5 billion … half the human population is connected by the Internet and cell phones, many of them smartphones, and a huge number of those are connected by Facebook, by social media, okay. This is a powerful tool. And because the first step is communicating these issues, you are really in a position to do something about that.

All right, I'll wind up with this, you know. We are at a crossroads, as I've already said. About two years ago, Liz and I had the good fortune to go see this with our daughter who at the time was about your age. This is one of the last great wild spectacles on earth. This is Africa, Kenya and it's the great wildebeest migration. All those dark spots, as far as the eye can see, are millions of animals. They go through here in the same natural rhythm that they have for millions of years. That is still on earth to save. We can do this. We can make sure that your kids can do this if we do the things that we've been talking about today. If we decide the future isn't up for grabs and that we can go on regarding the future as "the future will take care of itself," we won't see this. I actually trust you guys and the rest of us to make these right choices because people, as I say, do want to do the right thing, when they know what the right thing is.

[applause]