[music plays]

[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 fourth lecture is titled "Extreme Life of the Sea." And now, Dr. Stephen Palumbi.

[applause]

[PALUMBI:] Thank you very, very much. I'm thrilled to be here with my friends and colleagues, Tony and Liz, and I've got the pleasure and the privilege of introducing you to the oceans. You got a lot of mammals in the last couple of lectures, and we're a little bit more familiar with mammals. Part of what I'm going to do is talk to you about what's in the ocean, the kinds of threats they're under, the differences between the ocean and the land, and the kinds of adaptations we can see. The second lecture will be about what we can do about it and the sort of hidden survival skills that some creatures in the ocean actually have. Liz told you a lot about these tigers and their patterns of extinction; hundreds of species have gone extinct over the last couple of centuries … that's on land. What do we see on the ocean? The organisms there are really very different.

Well, it turns out that the oceans are under threat as well. They're the same threats, really, that we see on land, but the pace of those threats has been different, and the history of those threats has been different. So I want to go through that in a little bit and show you how things are the same, really, and how things are really very different from one another. What are the four major threats to ocean life, all over the planet? The four major ones are pollution, habitat destruction, overfishing, and climate change.

Now my second lecture is going to be mostly about climate change, but what I want to spend a little bit of time here is showing you how, for example, we have approached overfishing in the oceans and how that differs from the way we have been using land. Tony and Liz both told you a lot about the use of land by humans, and we have been using the land of the earth intensely for the last 10,000 years.

Now we've been using the ocean too. The last 40,000 years we've been harvesting the ocean, but our ability to hunt in the ocean is a lot less than on land, particularly with the sort of primitive hunting tools that Liz and Tony were talking about. So 40,000 years ago, we were hunting the ocean, 3,000 years ago we're having a measurable effect on coastal zones, but really only in places that had intense civilizations: the Mediterranean, India, China. It's really only been since the invention of mechanized fishing over the last 200 years that we've had the kind of reach into the ocean that we've had on land for the last 10,000 years. By 200 years ago we began to build ships that actually could get to other places in the sea. This drawing shows you a timeline of our use of the ocean. 10,000 years ago the oceans were more or less pristine places, we couldn't really take much out of them. The first sailing ships that really went around the world fishing were sail driven. They used hemp ropes. But as we invented steam-driven ships, dredges and trawls, we began to reach deeper into the ocean. We began to reach parts of the ocean that we couldn't get to easily before, and in the present, we're using most of the coastlines of the sea. We're using them in ways that we never could before: aquaculture, offshore installations, shipping. And as we project into the future, we see the same sorts of things happening in the ocean that have happened on land already. More and more of the ocean being used for greater and greater purposes. For energy, for a lot more aquaculture, for offshore urbanization. And all those pressures have reduced the amount of life in the sea and they have changed the habitats that we have in the sea, particularly in coastal zones all over the world.

This is a graph of the loss of coral cover and coral reefs around the world since about 1985. About 40% of the corals that were alive in the middle of the 20th century are gone now. Other kinds of marine habitats have also been lost. Just one more example, these are mangroves. Mangrove forests make up an incredibly important part of coastal zones in the tropics. They're important nursery zones for fisheries, they're important for fuel, they're important for, human communities. We've lost about 17-18% of those around the world, despite actual, very strong efforts to replant them all over world.

So threats to the ocean are present, they're increasing, particularly overharvesting. What has that done to extinctions in the sea? Well in fact there have been very few extinctions in the sea compared to the hundreds of extinctions that we have talked about on land. There are really only 15 recorded extinctions of marine species over the last couple of hundred years. The question is, why so few? What is it about marine species that means that we are reducing them to extinction at a slower rate? Well I'm going to take a page from Liz's talk and I'm going to talk to you about tigers and tiger sharks, and to compare them and see what's happened with them. Now tigers and tiger sharks are different from one another, right? The thing they have in common, by the way, if there's a hungry one you don't want to be in the same room with it. But they're enormously different. How are they different in terms of their extinction risk?

Well if we go through the biology we can see some of that. First we can see that the tigers have lost 93% of their historic range, Liz just told you that. Their current range is chopped up into little pieces and those tigers can't fly. They can't get from one part of the global range to another. But the global range of the tiger shark has not changed. The populations have dropped, it's true, but the global range is still most of the tropical and subtropical shorelines of the world. Also tiger sharks have more young than tigers do, they live longer, their population sizes are much bigger now than tigers. They've probably always been bigger. And they have a global range. They also can move, not all around the world, but big tiger sharks can swim from one part of their range to another, and that evens out the population and it makes it less likely that intense hunting in one place will wipe out a local population, because they'll move, they'll move back in.

So marine species all over the world have these general properties. They have high reproductive rate, large population size, global ranges, and they move a lot. And all of those traits together mean that they're under less extinction risk. Now that doesn't mean that they're not under risk, it just means that the extinction risk that we are applying is a little less than on land. Well, part of the reason for all of these issues is that the oceans are big. They are the biggest biological habitat in the known universe. The area of the oceans is two and a half times the size of the planet Mars. The oceans are deep. We think of them as pretty shallow, but the average depth of the ocean is 4 km, five times the depth of the tallest building on earth. And the volume is huge: 15,000 times the volume of all the lakes and all the rivers in the entire world. So the size of the habitat means that species that use that global habitat can be very numerous and spread out over a long, long time.

Well, it turns out too that, if we think about extinction on land, we don't tend to think about different types of extinction, but it's been very important in the ocean to really distinguish that there are other kinds of extinction than total species extirpation. I'm going to tell you about two of them. One of them is commercial extinction. That's when a species is hunted so severely that even though it still exists, it's no longer huntable. A great example is the grey whale. Grey whales were not hunted until about 1854, then there was a melee about hunting grey whales along the west coast of the United States. That hunting melee kept going until about the 1890s when it stopped. Why? Were grey whales extinct? No. It stopped because there were so few of them, about 1,000 left in the entire ocean, that it was no longer profitable to go after them, so that commercially they were extinct. We could not use them for commercial purposes.

The other kind of extinction is ecological extinction. That's when the numbers of species drops so low that they no longer play their normal ecological role in the community. Liz told you about a keystone species: the pika. This is another keystone species: the sea otter. Sea otters are awfully cute, I'd argue cuter than pikas.

[laughter]

They also, like pikas, are a keystone species, they're voracious predators. They eat sea urchins, and because they eat sea urchins, they keep the populations of sea urchins low. When we hunted them for fur on the west coast of the United States, the numbers dropped so low that sea urchin populations boomed. What do sea urchins eat? They eat algae. What did the sea urchins eat on the west coast of the United States? They eat the kelp forests on the west coast of the United States, so the normal ecological role of sea otters is to keep the kelp forests healthy. That failed when they became ecologically extinct about 1820 or so.

Well, the oceans are full of this kind of diversity, not just these mammals, but also the kelp and the sea urchins and all the other things we see. In fact, if you think about phyla, animal phyla, there's more in the oceans than on land. And an animal phylum is a major body plan, a major way an animal has built its body: worms, fish, sea urchins, corals, they're all in different phyla because they build their bodies in fundamentally different ways. The ocean has about 28 common phyla. The terrestrial world has about 11. The diversity of life is very high in the ocean. And many of the things that we think of as actually inventions of normal life, the things that we take for granted, evolved in the ocean first. For example, teeth. We take teeth for granted. We have teeth, lots of things have teeth, but who invented teeth? Where was the first tooth? The first tooth was in a shark. 420 million years ago, there were animals with jaws, primitive fish, but those didn't have teeth. Sharks invented teeth. It was a very good invention for them. They have used it for 420 million years very well, they've been through a lot of the mass extinctions that Tony talked to us about on the strength and the sharpness of these teeth.

Other kinds of things that have evolved first in the ocean? Predation: The first animals to get the idea that, oh, maybe it's better to eat other animals than to eat bacteria in the sediment evolved in the ocean. Legs: the first crustaceans and arthropods invented legs. Shells: in the ocean. Swimming: how did the first animals come off the bottom and start actually moving around up in the water column? They were shelled cephalopods, big, huge, heavy things. They filled their heavy shells with gas so they could float up above and swim. I talked to you about jaws and teeth. Sexual reproduction was invented in the ocean billions of years ago, the combining of male and female gametes. All these different sorts of diversity that occupy the ocean right now, and it means that the oceans are really full of this incredible set of adaptations to different sorts of environments. So I'm going to give you a little … a little shot of marine biology. It's a little late, you've been sitting here very patiently and so there's going to be 47 seconds of marine biology and rock and roll.

[rock music playing]

[PALUMBI:] There! So I dub you all now marine biologists. That was 100 different species and if you close your eyes you can see them all. The music for that, by the way, is my daughter's rock and roll band, "Direct Divide." These creatures live in incredible different places in the ocean. I'm going to take you to some of them, like the hottest spot on the earth for life. These are deep-sea cracks, called hydrothermal vents. It's where the tectonic plates of the world are separating and magma is boiling up. In these areas, superheated water, those black plumes, are coming out of cracks in the earth. That water is 650 degrees, way above boiling. Why doesn't it boil? Because it's also deep, but the pressure is very high.

Those incredibly hot waters, though, are rich in minerals, and that fuels a whole set of ecosystems there that people didn't even know existed until about the 1970s or so. There's a lot of different critters there. I'm just going to show you one. This is the Pompeii worm. It has the record for living in the hottest place of any animal on the planet, but it's only one end of that animal, it's the tail end. That lives next to these hot streams of water. The water there where it lives is the temperature of hot tea. The head is an inch away. It's living in the cold waters of the deep sea, it's living at ice-water temperatures. Now, that means, across this animal, this huge gradient of temperatures has to support life, and this animal knows in its genome how to make proteins that work at the temperature of hot tea and ice water. We don't know how to make those proteins, we can't use them in our bioindustries, but we're decoding the genome from this little worm so that maybe we can learn how to use those skills.

What about the coldest places on the planet where marine life lives? Well, the coldest place is actually the Antarctic Ocean. This is a shot from John Weller, this is a scene 80 feet deep in the Antarctic. Right down there, it's -2 degrees centigrade. It's colder than freezing, the ocean doesn't freeze because it's saltwater. Well, above there, the clouds and the sky, that's actually the ice on the surface of the water.

And those white growing life forms on the bottom are not life at all, those are ice crystals that are slowly growing in this supercooled water. Well they actually grow up over and entomb these starfish sometimes. The starfish themselves are fine, they've got fluid inside of them, but the fluid they have is the same salinity as the seawater, it doesn't freeze.

But what about these? These are icefish, they live there too, but their blood is no saltier than ours, and that blood would freeze if it was at those temperatures. Now since you're all marine biologists now, you know that a fish full of frozen blood doesn't do so well, and these fish couldn't live if their blood froze. How do they live there? They make up 95% of the fish biomass of the Antarctic coastal oceans. How are they so successful? It's a protein, it's one adaptive protein called an antifreeze protein that they have in their blood. The antifreeze protein binds to ice crystals. It coats the ice crystals so that, when they bump into one another, they don't stick and grow. It coats the ice crystals so other water molecules can't stick to the crystal lattice and then grow that crystal bigger, like those big white shapes in John Weller's picture. This particular antifreeze protein then gives them the ability to have fluid blood at supercold temperatures and means that they can take advantage of the other ecosystems in the Antarctic.

What can we do with this information? There was a question earlier about what's the value of these species beyond their aesthetics? Well some of the value is the kinds of things we can learn how to do from them. The genes from the ice protein, the antifreeze protein were actually found in Atlantic species called the Atlantic eelpout. They were cloned into yeast, the yeast are used to make a protein called the ice-suppressing protein product and that ice-suppressing protein product is now a tool that we can use to better the lives of people all over the planet in unmeasurable ways. It's about our ice cream.

[laughter]

Low-fat ice cream doesn't have enough fat in it to keep ice crystals from forming in your freezer unless it has a little bit of that ice-suppressing protein product in it, so small amount by the way that it's not on the label. But that's what keeps low-fat ice cream from freezing and getting ice crystals in your freezer. And so this is just an example, maybe kind of a silly one, but a real example of how looking at adaptations in the world can teach us how to do things that we can use in other settings.

What are other places in the world that people have delighted in exploring? This is William Beebe, he's standing next to a small container called a bathysphere that he worked in, in the 1920s and '30s. He wrote a bestselling book called Half Mile Down in 1934, and he and a friend dropped in that bathysphere down a half-mile deep in the Bermuda Trench to look at the amazing deep-sea creatures that he could find. I know people had drawn them up in nets, but never had anybody seen them in their real life. They found all kinds of amazing new critters there, and they found new ways of life there, for example gigantism. Species that are normally quite small in the shallows sometimes get to be huge sizes in the deep sea. This is an isopod. You may have seen them on land, they're pillbugs. You can see them on land, they're usually about a half inch long. This one is about eight or ten inches long. They live all over the bottoms of the deep ocean. They do not actually eat Doritos [laughter], but it just gives you an idea of the scale of these animals out there and the kind of gigantism that is seen in the deep sea.

Other kinds of mysteries that we've seen in the ocean have really puzzled biologists for a very long time. This is one; these are angler fish. Now you may have seen them in "Finding Nemo" with the little thing on the top of their head, which they use to attract prey. Well, across the history of biology, these fish for a century were puzzling marine biologists because there were never any males found. All of the angler fish that were brought up were females. Nobody knew where the males were or what they looked like, what they did, until a parasitologist started to study these strange little parasites that he found living, growing on the female fish … and that's the male. These males don't get very big. When they're very small, they're swimming around the deep, dark ocean. They find a female and they latch on and they never let go. Now before you start thinking that might not be a bad idea, then these males they lose their jaws, they just meld into the female. They lose their eyes, they lose their brains, they lose their guts, they lose everything to the female, and all they are for the rest of their lives is just a testis that hangs on her and she uses to fertilize her eggs. Now that's why these biologists didn't know that they were there, because they just didn't look like what they were expecting there to be. So the kind of diversity that you see in the sea is like that. Unexpected things found in unexpected places.

Well I started talking about the way we affect the oceans and the kinds of things it's doing to life in the sea. But it's also reflecting back on us as well, because we use the sea to a great extent. We use it for food, we use it for shipping, we use it for the habitat of about one billion people on the planet, and hundreds of millions of people get most of their animal protein from the sea. And so when we begin to affect the life of the sea, then it reflects back on us. In the Philippines, I went diving with a Filipino fisherman, we were looking for seahorses, he was a seahorse hunter. We had wetsuits, we had tanks, we had watches, we had flashlights. He had a frayed pair of swim trunks, he had a pair of goggles that were carved out of coconut husks and had bottoms of Coke bottles as their lenses. He went in the water, we went in the water. We found a seahorse after about an hour, we were looking at it, we were thrilled. He was looking for seahorses too. It took him eight hours in the water to find a few seahorses that night. He brought them back, he was able to sell each one for $0.25, and because of that his family ate that day. Now he didn't want to spend eight hours in freezing water after all night, looking for a few seahorses. He would have much rather spent an hour at it, but the seahorse population had been so dropped by overfishing that that's what he had to do. And those are the sort of things that happen when we overuse ecosystems that we rely on. We still rely on them, but we are straining to get that same service from them, and that means we have to work harder and harder and harder at it. Plus we also stress those ecosystems even more.

We can do something about it. We have learned that if we protect parts of the ocean in marine protected areas, the ocean version of the national parks that Liz was talking to you about, then the productivity of the ocean can bounce back. I was telling you that marine life has lots of mobility, it has high reproduction, and that means when you protect an area, it can bring in other species that weren't there before. Those species can have high reproduction, and actually the marine ecosystems can begin to bounce back. This is a fish that's called a bumphead wrasse. It's living in a marine protected area on the Great Barrier Reef, it's three or four feet long. Now the Filipino fisherman that I went diving with hadn't seen a three- or four-foot fish his entire life. Usually the fish that he was looking at were an inch long or so. But if you protect areas, even in the Philippines, those areas begin to come back. That shows the kind of power that we have over the ocean and the kind of power the ocean has to recover. Now I'm going to talk a little bit more about that in terms of climate change in the next lecture, but what I want to do is sort of leave you with another vision of the kinds of interactions we can have with marine wildlife. It's going to be short, it's going to be too short, and that's the point.

[music playing]

[PALUMBI:] Wouldn't you like that to continue? Thanks.

[applause]

[PALUMBI:] Questions? Yeah?

[STUDENT:] I was wondering how marine protected areas are managed and sustained?

[PALUMBI:] Great question. The question is how are marine protected areas managed and sustained? And the key thing is that they need community support because if they're not enforced and the community doesn't support them then nothing really happens. And in case of places like the Philippines or Indonesia, it's really the people in that village that have to enforce them. They create them, they agree to them, they actually have to give up fishing in those areas in order to put them in place, so they have to give up something right away, and they have to enforce them. In one particular place, it's one of the best places in the Philippines to go diving to see big fish, … there's people walking on the beach with guns to keep poachers out.

[STUDENT:] Do you think it's more important to preserve genetic diversity and the diversity of species on land or in the ocean? Well, where do you think we should primarily focus our conservation efforts?

[PALUMBI:] Well, the question is, should we focus our conservation efforts on land or on the ocean? I would say basically that, like most things, you focus your priorities on the places that you really need and there's areas in the land that we really need, there's areas of those ecosystems that are really critical, but there's parts of the ocean that we really need as well. So, I have to agree that tigers are really cute, and incredibly attractive, and that bumphead wrasse don't really have the panache of tigers. On the other hand, we're not eating tigers too much anymore and we're eating a lot of fish, so the ecosystems in the ocean actually produce a lot for us. One out of every two or three breaths you take comes from the photosynthesis that happens in the ocean, and unless the ocean ecosystems remain viable and healthy, then those services, the direct ones like fishing and the indirect ones like oxygen will get cut off. Can you do this question here?

[STUDENT:] How do scientists attempt to deal with such invasive species like snakeheads that actually terrorize certain ecosystems?

[PALUMBI:] The question is how do we deal with invasive species like snakeheads? And the same is true of invasive species on land and in the ocean. The basic answer is, once it's an invasive species, there is very, very, very little you can do about it. The key thing in management is to keep those invasions from happening. For example, a couple of decades ago, it was discovered that in the ocean, a lot of the reasons why marine species were getting around the world and invading was in the ballast water of cargo ships. A cargo ship is full of cargo, it's heavy. When it's not full of cargo there are ballast tanks that get filled with water so that the ship is heavy and doesn't roll over. That ballast water essentially is full of marine organisms, and that was what was causing invasions. We learned it, helped stop it, and things have dropped down. Great, so thank you very, very much.

[applause]