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[ANNOUNCER:] Welcome to HHMI's 2016 Holiday Lectures on Science. This year's lectures--Ecology of Rivers and Coasts: Food Webs and Human Impacts--will be given by Dr. Mary Power of the University of California, Berkeley, and Dr. Brian Silliman of Duke University. The third lecture is titled "Floods, Droughts, and Food Chains." And now, Dr. Mary Power.

[Applause]

[POWER:] Thanks a lot. So our first lecture emphasized how fish with really different traits in really different rivers could either control or not control algae. And a number of questions came up about how the environment controls these organisms and their interactions, and that's what we'll stress today.

We'll talk about the same river ecosystem under very different environmental regimes. And the emphasis will be on how you can have the same cast of characters, but the rules within the food web that determine how long the chains will be, these trophic cascades, will vary from year to year. So the river we'll look at is one I've studied for 25 years now. Time passes fast when you're doing ecology.

Here in northwest California, it's the Eel River. The Eel is actually the third largest river in California. People don't tend to know it as well because it's not densely populated, not that much agriculture--forestry, but no agriculture up there. It covers about 10,000 square kilometers of this whole drainage basin. And it dumps into the Pacific Ocean. Of course, being in coastal California, it has what we call a Mediterranean climate. That's the winter wet/summer dry seasonality that the Mediterranean has, but also California and Australia, South Africa.

So it's a very extreme seasonal difference. But we tend to have predictably dry summers, and that's when most of the biological activity occurs. The winter floods are still quite important. Of course, that's the high water the salmon are using to home back from the ocean and get up to their spawning areas in the head waters of these rivers. But the floods also do something very interesting to the bed of the river. They can mobilize it all. If you're watching cows graze a pasture, imagine if you saw an earthquake that churned the pasture up, so the cows were thrown hoof over horns and just ground up, and all the grass was buried.

Well, that's what goes on when rivers scour their beds. The whole substrate mobilizes. Anything that was attached to those rocks is scraped off. So you start after the scouring floods have happened the previous winter. In the early spring, you don't see much rock-bound biology on those stones. There's silt that's falling out here as the river is subsiding and warming up. So this is the dry season coming on. Water's getting clear, but not much life until a few months later, you get huge blooms of algae following winter floods. So here are boulders and bedrocks that didn't get as severely scoured. And there were little basal cells left, that then grew vegetatively to lengths of several meters, sometimes 10 meters, across the stage. I call this Rapunzel's hair, for those of you who remember that old fairy tale. The algae are thin. They are actually about the diameter of human hair. But they can get really long. They're branched.

So a lot going on in these algae, as we'll find out. But here's what the seasonality looks like. If the river is flowing, the algae's staying green, healthy, keep growing, but in the slack water areas, when we get into July, it's getting warmer, and some of those algae are stressed in more stagnant environments. They detach. They form these floating mats. Then both the turfs, the attached algae, and the floating mats wither back, and they form this funny-looking stringy, knotted remnant at the end of the summer.

So this strange architecture, which we see many years, is because these algae are infested with a little insect that weaves itself a little cocoon or shelter. I call it a tuft. So I call this the tuft-weaving midge. Midge are actually fly larvae, and we'll see their life cycle soon. The mother midge, the adult midge, looks a little bit like a mosquito--same large taxonomic group. But these guys usually don't bite. And she finds a floating mat, a favorite habitat for laying her eggs. The eggs grow into larvae that increase in size, weave that little tuft shelter, poke their head out, graze algae, and eventually pupate and emerge back as winged adults from the water.

So that's their life cycle. And when we see this change, we notice that the midge numbers explode when those floating mats form. They get really abundant emergences of midges. And then, when we see the mats wither back, they're full of larval midges that are still living in them. But we don't know from observation alone whether the collapse of the algae is caused by the grazing midges or whether the midges just collapsed because they lost their algal habitat. So you don't know which causes which without doing an experiment.

And in this river, we also didn't have any idea of whether fish were important. We didn't have those big algae-grazing fishes I mentioned in the first lecture. But there are carnivorous fishes--the juvenile salmonids, this is a little steelhead--and a minnow that eats a lot of insects as well. So to look at the effect of fish, we built boat-shaped enclosures around the boulders that were covered, when we started these experiments in June, with long turfs of algae. That's where most of the fish hang out, in that cover, and that's where most of the invertebrates are as well.

So these are the rich little islands in a gravel-bedded river. We've done these experiments five years between '89 and '97. And we start them by building the boats and locking them into the natural stream bed and then electroshocking out all the fish. The shocking stuns the fish, but it doesn't harm them, so they just are temporarily kind of motionless, and then you can get them out and release them in the open river, and they swim away; they're fine. So here are the enclosures and other different enclosures. And you can see that they're built around these algal-covered rocks. Some of these enclosures, we kept as fish-free exclosures, no fish. And others, we added the minnows, the steelhead, both, or neither to those other enclosures.

So when the fish were present, to my great surprise... I was not expecting strong fish effects in this system. But we saw the algae collapse in just, again, five or six weeks; the algae that has started out 40 to 60 centimeters collapsed down to a close mat that was nowhere more than 1 or 2 centimeters high, covering the rock. And if you look closely under water here, you can see that it still has that knotted stringing appearance, as if it's filled with midges. If you looked into a fish exclosure from the top, you'd see the algae has changed color. It's been overgrown by globular, kind of red-colored blobs, which turn out to be a different kind of algae. And if you go underwater, the algae that was bright green, grass green, has now become a dingy yellow.

So what's gone on? Just at the larger scale, here's what the whole biomass did. When fish were absent, we maintained the biomass of *Cladophora*; it stayed erect. And here it is being tugged up because this brown, globular thing, which is an alga called *Nostoc*, it became three orders of magnitude, 1,000-fold higher, when fish were absent than when fish were present. So here's a colony that's filled with its own oxygen floating up to the surface. So the blue here have fish, very little algae. No fish, lots of algae.

So what caused this? Well, to my surprise, the presence of fish was also accompanied by the presence of lots and lots of midges. There were many, many more of these tuft-weaving midges where fish were present. And this was a shock to me because, like Brian's tethering, I had done midges in bondage experiment. I'd taken cotton thread, tied it around the midge, and put the midge into surface or benthic, surface or bottom habitats or in algae or in gravel, just to see where the river was dangerous, where it wasn't as dangerous, to measure predation on them. And the fish love eating them when they're wiggling around on a thread. But when they're in those algal tufts, the fish in our system can't recognize them as prey.

There is another predator that can deal with those midges, though. And that's an odonate larvae and other small predators. So this one in particular is important and interesting. How many of you have seen damselflies flying over fresh water? This is the juvenile form. And it feeds as a larvae--it's a predator. It has a mask of teeth that it folds over its face, and then it peeks over the mask and studies what is going on in that tuft for seven or eight minutes, until it detects movement, and then it sends its jaws--they unhinge right from here; this is all jaws--it sends those jaws into the tuft, grabs the midge, and withdraws it in a surgical strike. It doesn't even disrupt the algae.

So it's very hard to detect their predation unless you watch them for seven or eight minutes. And not that many of us, even naturalists, are Zen enough to watch an insect or seven or eight minutes until it does something. But we were motivated to do that because of this larger experiment to see if there was a causal relationship between that predator and the fact that, with fish, you didn't have so many of that predator, and you had midges. But without the fish, you had no midges and a lot of those predators, fewer midges.

So yes, in fact, it is a four-level trophic cascade, a stronger one than I ever anticipated seeing the first time I did these experiments. You have larger fish that can suppress a small predator that, if released, can suppress a very important herbivore that can bow down the algae and create a barren world like that. And in the absence of those larger fish predators, you have the damselfly nymphs that become very common. They're not common in the open river. They're getting eaten there, too. They're not common when fish are enclosed. But when they're exclosed, these guys have cover from fish predation. Their numbers increase. They control the herbivore, and the algae are released.

So that was very encouraging and exciting. So we went out and did a lot of these experiments in the next two years, and we got incredibly disappointing results. We couldn't replicate our finding at all. No matter whether fish were present or absent, in all of these 24 enclosures, the algae collapsed down to detritus within three or four weeks. Fish didn't make any difference at all. So what do we do? What's changed? And we finally woke up and noticed that we had entered one of those multi-year California droughts.

So when we did the experiments in '89, we'd had winter scouring floods. But we hadn't had them before the 1990 or the 1991 summer experiments. Both of those winters were drier. And what changed was that, in the absence of flooding, huge numbers of a big, armored caddisfly, which is an herbivore. So this is a grazing insect that crawls around, lugging this armored case, and mows down algae if it's abundant. After a flood, you might see one or a couple per square meter. But after a drought, you might see almost up to 100 per square meter. Their densities are much, much higher when they haven't been blasted out of the winter river by scouring floods.

So this grazer, then, became the story. The algae would start to bloom as the water settled and cleared, but it would get bald patches gnawed into it by these herds, these grazing fronts of *Dicosmoecus*, the big, big caddisflies. This is one of the world's biggest caddisflies. And you can actually make really cool earrings out of them after the insects emerge, so it's cruelty-free. So the caddisflies are grazing and turning the world barren.

So then we did the right experiment for a drought year, which would be, we are taking 24 cages, and we're stocking them with the caddisfly or the steelhead fish, the predator, or both, or neither. So here's steelhead and caddisflies together. Here, both are absent. Here, there's just the steelhead. Here, there are just the caddisflies. So what's going on in these enclosures is that that says that most of the impact on the algae during this drought is from the caddisfly, not the steelhead.

Here's what the enclosures look like when *Dicosmoecus* is present. Here are the data for algal biomass on the y-axis and no *Dicosmoecus* here, *Dicosmoecus* here. And I'm showing you two lines. The bottom line is steelhead are present; the top line, steelhead absent. And this top line shows that steelhead still have an effect, and it's still negative. There's more algae when steelhead are absent. But it's not nearly as strong as the direct two-level control by the big grazer, a big grazer which, in our system, can outgrow all the predators. There are just a few that can eat it.

So when you have disturbance, flood disturbance that resets the food web, you get algae that get a chance to grow before the animals build up, and they become long and luxuriant. Then you get the midges and other grazers colonizing the algae. Then the insect predators and the fish predators come in as the river subsides and as the insects recover from the flooding and as the fish move down on their migration out to the sea, in the case of the steelhead. So you get a nice four-level food chain that supports fish and allows them to grow.

But in this drought year, same characters are present. But these guys are a bit hungrier because the algae energy is all going up to be directly controlled by the second trophic level. They're getting this energy, so both the bottom-up flow of food to fish and the top-down control of fish indirectly to have a trophic cascade effect. Those are both weak or nonexistent following drought.

Okay, so that's what the winter hydrology does. And here's what it looks like. We plot hydrographs, or trace stories of what the water does over time, against time. Here's October to October. That's the water year in a seasonal environment. And here's discharge, how much flow is moving through the river on the y-axis. And it's also biomass because... blue is water flow. Here is our scouring flood. It has to go past a threshold, and then the bed all mobilizes. And then the river is settling down for the summer drought, which is the biologically-productive period in Mediterranean ecosystems. And the algae get a chance to grow big, but then they're tracked by grazers. The grazers are tracked by predators.

Now, these guys are dropping towards late summer. The edible grazers are getting eaten or emerging. And the predators are either emerging if they're damselflies or migrating out to sea if they're salmon. And here come the invulnerable grazers. They took a long time to build up their biomass because, instead of allocating growth... energy to growth, they're allocating it to building a stone case using their silk to glue it together and lugging it around. So defended grazers are growing slower, but once they take over, once their numbers do build up, they're the top of the food web because they're defended.

So that's why disturbance can knock these guys back and allow more food to flow up to predators. Disturbance in this sense, even though it has a negative connotation in English, is a really good thing for ecosystems. It kind of shakes and resets the tablecloth so predators can eat. So here's the drought hydrograph. We don't even get close to scouring floods in years like this. And the grazers have overwintered, and now they're getting big, armored and inedible, except that they're eating the algae and just keeping it barren and low. And we can also remove disturbance by impounding and artificially regulating water. And we've done that all over the world, but especially in California.

So downstream from these dams, you tend to find lots of either armored grazers or grazers that glue little silk tents to rocks and then graze underneath them. They're also allocating to defense and also slow to build up, but not edible once they take over. So here's the food web now, a fraction of the food web that we'll talk about next because I want to tell you about an even scarier situation than not feeding salmon very well. And that is what happens when the summer drought is severely low.

So this is where my work comes under the influence of marijuana and other factors. One of them is the multi-year California drought. And I want now to take you to the base of the food web and look at the wonders of algae. You probably have seen algae growing in gutters. You probably haven't realized that there is incredible adventure and beauty in that little slimy world down there. But there is. Algae can be thought of, in my view, as the good, the bad, and the structural.

So the good are diatoms that grow on rocks. But diatoms can also grow on plants. We call them epiphytes if they do that. Epiphytes... "epi" means "surface," like your epidermis is your surface skin. "Phytes" means "plants." So things that grow on plants are called epiphytes. And so when that Rapunzel's hair gets going, it increases surface area a million-fold for things that attach to it, like diatoms. So this little package of the *Cladophora*, the green alga buried by tasty diatoms, is really good for the food web. Grazers love it. But these structural algae assemblages can also get overgrown by cyanobacteria. And I say "bad" in quotes. Every time we take a breath, we should thank cyanobacteria for putting oxygen in the air, right? But they also, unfortunately, and through no intention of theirs, some of them are quite toxic to humans and other vertebrates, so we have to be concerned about them when they proliferate in water.

So let me take you through seasonality and show you what can happen in a severe drought. You start out in the early spring and early summer, with *Cladophora* growing in a clean, green state. It starts out--I like to say she has green hair in her youth. She becomes a blonde in middle age. And Rapunzel, in her later age, decides to be a redhead. And what this color really is, is thickening layers of diatoms. When Rapunzel turns to a blonde, she has a monolayer of diatoms that are just basically coating one layer over the surface filament shown here.

But by the time she's a redhead, she's deeply, thickly encrusted with diatoms. And that's not good for the *Cladophora*. But it's great for the grazers because these diatoms are the really nutritious things. If you had a handful of diatoms and sniffed it, you'd say, oh, they smell fishy. But it's really fish that smell diatom-ey because all the healthy oils that we get from eating salmon, the polyunsaturated fatty acids, the PUFAs, and other really good things like carotenoids--carrots are healthy because of the orange pigments. That's why diatoms are also orange, yellow.

So all those things are great for us and for invertebrate and vertebrate grazers nutritionally. So the midge, our friend the midge that lives in this tuft, just loves eating diatoms. And if you look at midge poop, you see lots of empty diatom shells. Another neat thing about diatoms is they live within a glass case. And I do mean glass, as much silica dioxide as your great grandmother's cut glass pickle dish. They use glass in a very unique way to make a little shell for themselves. But the shell has a lot of holes in it, so the midge enzymes can get the good stuff and just leach it out. And then they defecate out the empty cases, and we can tell what they're eating.

Also, you can tell, if you're a good natural historian, that when a midge settles into a rusty turf of *Cladophora*, it cleans up its neighborhood by grazing it green right around its tufts and its little stringy corridors here. So you can see that they're eating away the rusty diatoms and turning the algae green again close to home. And then look at their guts.

So obviously, they're loving it. But here's a way to measure quantitatively what it's doing for insect production. What Samantha, who's a Berkeley undergrad, is doing, is setting up these emergence traps. You can take PVC pipe, cut windows in it so the temperature inside's the same as the temperature outside. And the windows have screens, so insects can't get in and out. Then you put the traps so the top is just above the water's surface, and you cover that with sticky, transparent plastic, with the sticky glue pointed down.

So light gets through that plastic. The midges come, and other insects come up to the surface. They pop out. They try to emerge. But unfortunately for them, they get caught, and you get to count them and measure them. So you can tell how much bug meat is emerging from the river on rusty *Cladophora* where there's 25 times more coming up, or yellow or green *Cladophora* or other kinds of algae that are green and don't get these diatom epiphytes. So they're loving the rusty *Cladophora* and emerging. If the... some of those midges were feeding aquatic predators, but if they emerged, it's still good because they're feeding bats, birds, spiders, lizards and a very thriving riparian food web.

Okay, so this food source that I'm talking about is happening here in summer. And it really depends on having low but enough flow. We do call it normally the summer drought period, but this is the summer severe drought period, where the flow gets so low that in the sunny, big pools, the water stops moving and gets warm and stagnant. And that's partly given to us by the California drought. People are debating how much forest cover is affecting that. But another serious issue--and please think about this in terms of what we do as a society about marijuana--a lot of it's from illegal, burgeoning groves in the Emerald Triangle. Those are the counties of Northern California that grow a lot of marijuana. And each plant needs six to ten gallons of water a day. And they are growing. They're needing that water right in July when the river needs the water most.

So some of these groves are drying up tributaries of the rivers and letting the rivers get stagnant and warmer because of the lack of flow. When that happens, if we have algae in the river, it will die, form these stressed floating mats, and the color here is yellow, but you probably could see some pink in there, too. That's not a good sign. The temperature in these mats is getting high. Here's the water temperature that may be just 10 centimeters below, but in the water. And it's staying moderated by the water, staying around 20 degrees, which is comfortable swimming temperature. This would actually be uncomfortably warm for you to swim in. It's getting into the 30s. And this is what the temperature is in the sun-warmed, trapped waters on top of the mat.

So what's happening to the algae? This is too hot up here for diatoms or for *Cladophora*. So they're dying. And now, I want you to see if you can empathize with a diatom, because here--remember, this is what the diatom looks like when it's healthy with all its carotenoids. But here's what it looks like when it's dying. It's lost those orange pigments. That green is unhealthy. And the green was its chlorophyll, which is now unmasked, as the carotenoids have gone away. And they're bleeding their guts, their chlorophyll into the matrix, and all that nitrogen and phosphorus is going into this debris from cell death. But who's in that debris to pick it up but cyanobacteria, that actually are perfectly fine at those warm temperatures.

Many cyanobacteria like it hot, so we're going to have more cyanobacterial blooms in a warming world, and we've got to think about that. Here's the little knot that--here's a micrograph of it. It unfurls, grows, colonizes the good, rusty growth of algae, and blankets them with black carpets of cyanobacteria. And so here's a front, a growing front, where the cyanobacteria are the black growths here. The rusty red algae is here. And it's just spreading and taking it over. Well, if a dog jumps in the wrong backwater and gets this stuff in its fur and licks itself, as they do, they die, unfortunately, in 30 minutes, 20 or 30 minutes, in convulsions because these particular algae in the cyanobacteria in the Eel River are neurotoxic. So that's not good. It's getting our neighbors' attention. And we need to figure out as a community, as people who all care about these rivers, what to do about it.

So we'll talk about that at the end. But first, let's just sum up the food web stuff that we've learned. We're not looking at different organisms now. We're looking at the same organisms, but their numbers and their performances are changing as the environment changes. So here's what we've got after winter scour and adequate summer base flow. We've got the nice food web that feeds fish with edible algae. And if we didn't get that winter scour, we've got a food web where predator-resistant grazers take over, but the algae are still edible, and there aren't very many. But if we have severe summer drawdown, whether we had a big flood winter or a dry winter, a big flood winter, it's almost worse because there's more algae to rot. You get overgrowths of the good algae by potentially toxic cyanobacteria. So this is really a worry. Here's the more general message. You have the same web members, but we all know that traits will work well under some environmental conditions and not so well under others, obviously.

So drought, flood--there are many shifts and many environments that will change the strength of a path, a food chain or a trophic cascade, through the same web, given context-dependent environmental changes in the performance of the web members. So that's a way of thinking about the first conclusion. Here specifically, we see that you need disturbance in rivers. You need that flood scour flushing to maintain fish. And you can also use flushing to clean up the water and flush things. The one good thing about rivers is they're really resilient in the sense that if you can clean up the sources of pollution to rivers, they're self-cleansing because of that unidirectional flow. Of course, then the sea might have to deal with what they're sending out.

And what do we do to sustain them as healthy rivers? Speaking of the sea receiving it, the question about sea otters, I wanted to mention that some of the deaths of sea otters have recently been found to be due to blue-green algae that have been exported out of the Monterey Rivers because they've looked at the livers of dead sea otters. Now, I'm not saying this is accounting for those massive deaths. But they're finding over 20 dead sea otters because of river toxins from the agricultural rivers. So that's... and harmful algae are part of that picture, and that partly is controlled by what we're doing to rivers and watersheds.

So what we're doing locally is actually, despite the worry in the situation, this is some of the most fun I've ever had on the river, because I'm meeting wonderful people who care about the river as deeply as I do and know it as deeply as I do, but in different ways. So we're sharing traditional knowledge and long-term residents' and homesteaders' knowledge. And what these guys want to know is what algae do I need to thank, because they're growing my fish. Actually, they don't need to know. They often don't--we always take algae for granted when it's doing its job, right, because it's eaten, and you don't see it very much. But it's really doing a lot of good in the world. And if you look at the microscope, they're very beautiful. But then they also do need to know which algae they need to be concerned about and keep their dogs out of those backwaters.

So we're really having a lot of quite fun engagement and getting a lot of help from citizen-scientists, tribes, and other partners in the basin. That's just great. That's what I mean by "eyes on the world." But we call this eyes on the Eel. It's great, great fun. And also, we've got a lot to learn. It's been extremely interesting to compare notes with tribes. Here's Ron Reed and Bill Tripp from the Karuk Tribe, and they've visited our site. We've visited their sites a number of times. It's a good partnership because they have knowledge that's maybe 1,000 years old of how they manage forests to save flows into the late summer for the fish.

And Californians are starting to listen and starting to learn. And they're also interested in the modern science that says maybe things have changed enough that we wouldn't do exactly the same thing now.

But let's all see how we save rivers and forests and help our watersheds deal with all of these problems that we'll face under climate warming. So thanks, and I again welcome your questions.

[Applause]

[POWER:] Yes?

[STUDENT:] When the *Dicosmoecus*, when they come in, even during the winter influx, do they still affect the environment as heavily as they do in the droughts?

[POWER:] I think if I were to talk about their individual effects, yes. But there aren't as many individuals. So I think what a species does to a food web is partly how abundant it is and then partly how strong each individual acts against or for something. And so you multiply those together. So it's the fact that there's just maybe 100-fold fewer that makes their effect less. That's a good question. Yes?

[STUDENT:] To add on to that question, since during the drought, the caddisfly consume most of the algae, what do the tuft midges do to survive since, in the food chain, it didn't really show any other sources of energy for them.

[POWER:] They don't survive. Their numbers are way down. So it's not just the loss of food; it's the loss of cover. What they do is, it's kind of--you have to feel sorry for them. They get detritus. There's a little bit of silt, and they use their own silk to knit this stuff together. They make little jackets of silk, but they're very unprotective compared to the strong *Cladophora* tuft.

So they're more exposed to predators, and they're not eating as well. It's just lucky that they can rebound because mother midge can lay many thousands of eggs, so when they have a good year, their numbers are huge. When they have a bad year, there are a few females left. And a few are sufficient to repopulate it again if it's a good year. So that's how the midges make it, yeah. Yes?

[STUDENT:] So you said that some cyanobacteria are bad, but others are good. So what are ways that we can distinguish between the two?

[POWER:] Well, it's a complicated question. I have to say I have all respect and, I would say, love for cyanobacteria. They're just amazing organisms. And there's a lot of great science to read about their evolution and what they did to the Earth. So without the success of cyanobacteria in coming up with a very successful form of photosynthesis, we wouldn't have an oxygenated atmosphere. They're ancient. You've got to respect them because they're, I guess, 2.4 billion years old. They used to be thought to be 3.2, but some of the old fossils had fallen by the way in terms of people believing in them. But at least they're several billion years old. That's...

If you look at a timeline on the HHMI ruler, maybe you can get a sense of perspective on that. And then many of that brown, globular thing I showed you was also a cyanobacteria that isn't so toxic. So if they're in normal concentrations, they are doing an interesting thing for that river, which is they fix atmospheric nitrogen --not all, but many do. And all the ones I showed you today do that. And that's good for the river because our river is very nitrogen-limited, nitrogen-hungry. If you add more nitrogen, that's part of the reason you're getting more production, is the activities of those cyanobacteria. So to make it even stranger, let me tell you that the favorite diatom that turns it rusty red, has endosymbiotic cyanobacteria in it. There's a partnership. The shell has a diatom host. And then there are little deep-green cyanobacteria that are very ancient cyanobacteria. They've lost some of their functions because the diatom's taking care of those. But they're adding nitrogen to the diatom and making it more nutritious. So in that case, those cyano-endosymbionts aren't toxic.

So it's very diverse and interesting. And in terms of good, bad, and ugly and all that, you know, it's just kind of playful to say that. It's a way we can have fun with it and maybe remember it. But organisms are just doing their job, trying to stay alive. And we have to figure out whether we need to fight them or learn how to coexist with them.

[STUDENT:] Thank you.

[POWER:] Yes?

[STUDENT:] I was wondering if you could explain, like, how traditional methods help maintain the environment?

[POWER:] Yeah, I'd love to talk more about that. Thank you. What many tribes, and the Karuk are real leaders in this, say is that our great grandparents and our grandparents, in the case of those guys, manage the forest, often with cool fire right when the rains started. In the early wet season, they'd have cool burns. And in the forests of California, we get conifers that are Doug fir. And all of the trees except Doug fir can take fire. So the redwoods can take it. They stump sprout, and they have thick bark. So can the broadleaf trees, the madrones, the oaks, the bay. All of these trees do fine with fire, and sometimes they do better because fungi and epiphytes are burned off, and it leaves the trees healthier after a cool fire, the kind that they would use traditionally. But in the European land care management, we haven't allowed those cool fires. People get annoyed by the smoke, for example, or they are afraid of them.

So the Doug fir then fill in even a mature forest. They can grow slowly and fill it in. And then if we've done the clear cut and fire suppress policy that's happened throughout much of the west, you also get the same thing, a forest that's locked up. You can't walk through it. You can't see through it. You can't look under your knee and say, yep, no deer up that hill, which is what they wanted to do. But also, then you get the mega fires, and the trees aren't as healthy. They don't grow as well. And there's a huge leaf area to suck water out of the rivers and evapo-transpire it into the sky, so that dries up the stream. So in addition to marijuana being one of the culprits, it's the Doug fir-ification of the Eel basin and similar basins that is part of the land use that we may need to rethink to deal with drought. Yes?

[STUDENT:] So the harmful algal blooms that you mentioned can be toxic and are known or highly suspected to affect certain organisms. There was recently an experiment on how they affect spatial navigation in California sea lions. So is it possible that... do you know if these toxic algae could potentially affect bird flight? Because if they can't navigate, then how will they be able to migrate or navigate in the air?

[POWER:] I don't know about that. I know flamingos--some flamingos eat crustacea, but some eat algae. And I think they have adaptations, I believe, to deal with cyanobacteria. So there are actually some fish that can eat cyanobacteria, too, including some that are very liver-toxic; African fish can eat it. So some vertebrates are either resistant or have enzymes that can break down the toxins. And I don't know about birds in general, whether they'd be affected. That'd be an interesting area for research, especially with birds that feed from the sea a lot, where the poisons might be concentrated in their prey, albatross and stuff, yeah.

[STUDENT:] Thank you.

[POWER:] Yeah. Yes?

[STUDENT:] So I was wondering what's currently being done in the realm of environmental policy, specifically by the government of California, to deal with the diversion of water, just because I thought the point about the marijuana was very interesting and how the diversion of water culminates in this phenomenon. So is there anything being done?

[POWER:] Yes, there is a lot of management at the state... mostly the state level, and some county level. And so it's not being managed yet, but they're thinking about it. First, they're just trying to get a handle on how much water is diverted. And then... it's a little bit worrisome because this is a kind of a frontier mentality where both the tribes and the European Americans, which call themselves settlers--the ones that are really kind of homesteading there are very independent-minded, and they don't want people looking over their shoulders, as you can imagine. So it's kind of the Wild West in some ways. And they're going to have to change that.

But on the other hand, there's a lot of goodwill and neighborhood spirit. Everybody wants the salmon to continue. And so there's movement in the state to figure out how to account for and watch water use and water disappearing. You can see the marijuana groves from Google Earth now. And some Fish and Wildlife agents, who are very heroic, have jumped out of helicopters to see, if we see this damage from Google Earth in these many greenhouses, how many plants are there. So they've done all that.

But the other thing that's working, I think--there are two reasons to hope. And one is that groups are persuading neighbors to store their water in the winter in... not in dams, not in holding ponds, because those collapse and send more fine sediments into the river, and that's been a problem, but in fiberglass or Plexiglas tanks, huge tanks. So if you store the winter water and then meter it out in the summer, that will be a lot less damaging. Then the other thing is we're hoping that legalization will make marijuana a lot cheaper so that the motive to grow it in the really damaging ways in the hard-to-get-to more wilderness areas will subside. Cross fingers.

[Applause]
[Music plays]