Dr. Nancy N Rabalais

Nobel Conference 45

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Thank you very much. I'll remove your notes so I don't introduce myself again. [laughter] It's a real pleasure to be here. I was just in Minneapolis/St. Paul 2 weeks ago giving some similar presentations to the University of Minnesota and the National Caucus of Environmental Legislators. So hopefully we'll get to talk to some of my transferring science to policy aspects of what I do, which I consider very important.

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I asked a Nobel laureate specifically about the carbon footprint and the nitrogen footprint because I wanted to ask you what is the second most pressing issue on a global scale, other than carbon? [laughter] Anybody have an answer? Nutrients, nitrate and phosphorus which is what I'm going to talk about today. And you have to have nitrogen, phosphorus, carbon, oxygen, hydrogen to make organisms and make human beings and to balance ecosystems. So that's what I'm going to spend some time talking to you about today.

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Let me see. I want to talk about a huge ecosystem. It extends from Idaho, Canada, the western part of New York State into the Gulf of Mexico. It's a huge ecosystem. It's a continuum of water. It's water that leaves Itasca. It leaves areas far in the west. It enters the Gulf of Mexico. It's maintained along the Louisiana/Texas coast. It even gets out onto the east coast at times during flood conditions and you can detect the Mississippi River water. Lowered solidity as far as South Carolina at times. So it's a big ecosystem. And it's a water continuum ecosystem. And that, I want to try today to piece all the pieces together to show you we all know that everything's hitched to the star and everything we do affects everything else but we're going to focus on nutrients today.

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The biggest change, of course, has happened since the Industrial Revolution. The amount of, OK, how do I get it up here? The amount of nitrogen that gets into the ecosystem now is much greater now than it was before. These big-block arrows used to be very small. But now we're industrially fixing nitrogen gas into fertilizers, which are going into the land, which are volatilizing, going up into the atmosphere, coming back down. We also are burning fossil fuels. They're getting up as nitrous oxides are coming back down. And all of these arrows, including this one right here, which is the nitrogen going to the coastal system and to aquatic systems, was much smaller in the past than it is right now. And it's causing major disruptions in ecosystems, both aquatic, fresh-water ecosystems and in oceanic ecosystems.

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This is very, well, anyway, it's what it is. [laughs] This is the Keeling Curve, the increase in CO_2 since about 1960 until present. All the rest of these lines are changes in the amount of nitrous oxides that are being produced through the burning of fossil fuels. This line is the planting of legumes, which fix nitrogen into the soil. This is the human population growth. And this one is the increase in the application of fertilizers. So you can see there is just as an accelerated, and just as dramatic, and just as precipitous a change in the amount of nitrogen that we're putting into the environment now than we did historically. The other thing that we're putting in besides CO_2 and nitrous oxide and all these things, the other thing is phosphorus. There is a limited amount of phosphorus on the earth. And it can be recycled to a point. But right now we're mining it. We're taking more out of the ground and putting into artificial fertilizers and putting that onto the land and it's running into the sea.

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So the pre-industrial, there wasn't as much accumulation of phosphorus on the sediments. And most of it was natural from weathering. And now, and at that point, very little of it was getting to the ocean. And now post-industrial, artificial fertilizers, we mine much more phosphorus than we did before, much more of it's coming off of the ground. Much more of it's accumulating into the landscape and obviously almost three times more is reaching the coastal ocean.

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The other issue is that in landscapes like the Midwest, we're reach-, we've reached a sort of a plateau, a buffering level where we're not accumulating as much phosphorus but in developing countries around the world, they're going through the same process right now. Through application of artificial fertilizers in generating more phosphorus on the lane, holding it, and then more to the coastal ocean. So it changed a lot of things and nitrogen and phosphorus are great because when you put them on your lawn, it's greener and you have to cut the lawn more often. I don't really know why somebody would want to do that. [laughter] But, you also can put nitrogen and phosphorus on corn crops, which I'm sure is very important here, and even on soybeans, even though they fix their own nitrogen, and you can get a much greater crop yield than you would without those fertilizers.

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So they're beneficial but at some point they become limiting to the system. The beneficial parts are that they increase production. They increase phytoplankton, which is good. It feeds the marine food web. It gets into larval fish. It gets into larger fish. It gets into sperm whales and whale sharks. It generates more zooplankton, which feed more fish. And we can have some tremendous fisheries in coastal areas offshore of large rivers where a lot of nutrients are entered into the coastal ocean.

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On the other hand, these increased amounts of phytoplankton can, the increased amount of nutrients can lead to filamentous green algae on top of sea grass beds. It can shade the water so that things don't grow as well. And that would include things like natural sea grass beds. They get covered with filamentous algae. They also get covered by phytoplankton and surface waters and they don't get enough light. And they decay and waste away and then you don't have habitat for juvenile fish and, and the large biodiversity that lives in these areas.

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The other thing that this amount of phytoplankton sinking to the bottom does is it increases the organic load. And bacteria decomposed that carbon and lead to conditions of low oxygen. And you end up having dead, decaying organisms and sometimes the potential for fish kills. And so this low oxygen, this quote, dead zone, which I'll talk about the real definition in a little while, is the focus of this presentation from the continuum of water from way up in the water shed to out into the coastal ocean.

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So this is the water shed. And we are right here. We're a little bit, oh, this is not that perfect. We're about there, I think. Extends into Canada, as I mentioned, to New York state all the way into the western states. It covers 41 percent of the lower 48 United States and the coastal part of it is an area of low oxygen in the Gulf of Mexico that forms every summer now since probably about the 1950s, it's not natural in the Gulf of Mexico. And you can see the landscape is primarily agricultural activity. Over 58 percent of the land is in crops or pastures. Not as much forest anymore and not as much pastureland. So it's an agriculture landscape, which is somewhat unique to the Mississippi River Watershed because other watersheds such as the one in Chesapeake Bay doesn't have as much agriculture source nutrients. It as more atmospheric or more wastewater. Long Island Sound in New York has mostly wastewater nutrients, so it depends on the, the ecosystem, the water continuum, how you would get the nutrients into the system and how you might try to abate the affects.

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So what happens when the Mississippi River flows into the Gulf of Mexico, it brings a lot of fresh water. That fresh water sits on top of the salty water, which is down here, and you get a two-layered system for most of the year. And then in the summer, the surface waters get warmed and that two-layer system becomes even stronger, so if you swim in a lake in the summertime, your head might be nice and warm, your shoulders and your feet are kinda chilled by that colder water. That's what happens in the Gulf but it also has the salinity difference as well.

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So when the, the river also brings a lot of nutrients, nitrogen, phosphorus, and one that I'll barely talk about, silica, which is important to the growth of diatoms, come in, fuel the phytoplankton. The phytoplankton are eaten by the zooplankton. Zooplankton are eaten by fish and it feeds the marine and very important commercial fisheries in the Gulf of Mexico and elsewhere. Some of the phytoplankton cells die, sink to the bottom. The zooplankton produce fecal pellets, which sink to the bottom. And over half of the productivity in the surfaces waters reaches the bottom. And bacteria decompose that organic matter and use up oxygen just like you and I when we're digesting our lunch, which we just had a little while ago, so that the oxygen is depleted at the bottom. It can't get from the top to the bottom because of that two-layer system and you end up having large areas of less than 2 milligrams per liter, which is our definition, or less than 1, or sometimes anoxic, or no oxygen on the bottom.

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And the reason we use that 2 milligrams per liter definition is because if you're a trawler, shrimp trawler in the Gulf of Mexico, you put your boards over the side and drag your nets. If the oxygen's less than two, you will not catch any brown shrimp, white shrimp, demersal fish, red fish, red snapper or anything. You won't catch anything. So that's our behavioral definition. Some things have to move out when the oxygen gets as low as three. Some things don't die until the oxygen reaches one but that's our operational definition.

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And to show you how this cold water, salty water is different through the water column, I just want to show you some instances during the summer where we have low salinity on the surface and high salinity on the bottom. We have somewhat warmer temperature on the surface. A little bit cooler on the bottom and cool, I mean 25 degrees. I'm not talking 4 degrees. When Lars was talking about scuba diving, I do not go scuba diving in 4-degree sea. I'll go scuba diving in 25-degree sea but not the 4 degrees, like you have up here. [laughs] And I have a spider. I have a little wolf spider. Isn't he cute? [laughs] She. [laughs]

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So we have a lot of oxygen, this is not even technical. I haven't broken anything technical yet. [laughs] We've got a lot of oxygen on the surface and none well below the water column and here's just another example. Low salinity, higher salinity. Higher temperatures, lower temperatures. And you can see here the oxygen drops to close to zero for the lower half of the water column. So it's not just on the bottom. It's through the whole water column. And if you don't have this layered system, then you will not have hypoxia. Because the oxygen's gonna diffuse naturally from the surface to the bottom. So you have to have the layered system and you have to have access carbon reaching the bottom. Because you can have stratification and if you don't have excess carbon, you're not going to develop the low oxygen.

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So you have to have those two pieces. So let's go back to the coastal part of our ecosystem, the city of New Orleans, most of the river flows in this direction and enters the Gulf of Mexico through the birdfoot delta. This is a sediment plume, so you can see lots of sediments. The sediments drop out fairly quickly and what you don't see her are the nutrients to dissolve nutrients organic and inorganic that move from east to west along the shelf. The other river here is the Atchafalaya and it enters through another delta. It carries about one third of the total flow of the Mississippi River, joins the Red River. So we basically have two points where the water comes into the Gulf. But because of the dominant wind direction, most of the water moves from the east to the west along the Louisiana/Texas continental shelf.

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And this larger area is the, you going to get rid of my bug? [laughs][President Ohle removes bug from microphone] Well, I'm not as distinguished as a Nobel Laureate, you can tell that right away. [laughs] So the effects are seen to the west of the river. Even the, and you know the river mostly is high in the spring, it's lower in the summer, unless you have some horrible light summer floods like you have in the last couple years.

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So even though there's less fresh water coming in the summer, the winds shift and go from the south and holds that fresh water on the shelf. So you have this layered system most of the year until hurricanes come through, mix it up. Winter storms come through, mix it up. So it stays mixed up most of the winter and then it starts to develop again in the spring and summer. And it's most wide-spread, severe in the spring and summer.

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So in case you need a pinpoint, know where St. Peter is, this my little stick pin. This is Cocodrie, Louisiana. And this is where my beautiful marine lab and our research vessels and our environmental education and all the great things we do down there in the name of the States' Universities for Research and Education. So come visit sometime. The lower level, we talked about sea level rise in hurricanes. The lower level of this building is 18 foot above sea level. And the last storm brought 9 foot of water up until our lower facility and it was just water with short stubby pilings holding up this huge infrastructure that we have. So we're dealing with a lot of the same issues that were talked about with water as well.

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So here's what the low oxygen zone or the dead zone or hypoxia, low oxygen, looks like in the summertime. This was July 2007 and we do these cruises. We hit all of these stations systematically. We leave Cocodrie. Go to the Mississippi River, see what the end member is. We go up in the river, take water samples so we can see the dilution of the nutrients as we move downstream. We work ourself back and forth with instruments and try to get as far as we can to the west before running out of time, money, or energy. Well, just time and money. We always have enough energy to do this. So this is what it was like in 2007 about 21,000 square kilometers, or about the size of the state of New Jersey. Christine Todd Whitman, the former EPA administrator looked at me once at a meeting while she was giving a talk and said something like, 'I'm really tired of this being compared to the size of the state of New Jersey.] [laughs] Of which she was the former governor so I'm shooting for Massachusetts now or Maryland. But it did make her aware of the issue. And she took a stalling task force and moved it up in prominence within a year in the previous administration. So that was good to pick on her a little bit.

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It's from very near shore to further offshore depths of about 5 meters or 15 feet out to 60 meters at the deepest, which is about 180 feet deep. It's mostly between 15 and 100, 105 feet deep. And if you were to drive from Chicago, Illinois to Des Moines, Iowa, you would cross this same distance. And if you took a piece of saran wrap and put it over all of that landscape and tucked in the sides and started sucking out all the oxygen, you would see things starting to flee. And that's why we don't have sufficient productive fisheries in this area in the summer.

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How do we know all of this? We have one cruise that we do once a year. It's an expensive proposition where the cost of the ship and personnel and everything else, we have a standard grid of stations. I do not, as contrary to some popular belief, add more stations so I can make the area larger every year. [laughter] We do do our best to cut it off. And that means we're actually going further west every year now because it's getting bigger. We have transects that we go on once a month and every other month we check the water off the Atchafalaya delta. And at this location we have underwater observing systems that have oxygen meters near the surface, the middle and the bottom so we have different varieties of temporal and spatial skills to piece this story together.

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And then on top of all that, we have wonderful data from the Mississippi River, primarily from the U.S. Geological Survey. And we also take some of our own samples up near Baton Rouge. These are our research vessels. This is 116 but now it used to be 110 foot. That's what happens when you go in for a facelift, sometimes you get longer as well. [laughs] And this is our smaller vessel, the Acadiana 57 foot and we have done our survey on both of these vessels plus small outboard boats to go do our diving. We have a series of electronic instrumentation that tell us the water temperature, the depth, the dissolved oxygen, the amount of photosynthetic radiation getting to the bottom, the amount of fluorescents or chlorophyll. The amount of turbidity in the water column. And then we have smaller ones that we use because we wanna take it all the way to the bottom and get the bottom conditions because you can't put this one in the mud like you can. At least my electronics technicians don't like me to put this thing in the mud.

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And we also want to get the surface water so we have a very technical way of getting surfaces waters. [laughter] This is our high-tech bucket and it's high-tech because it only has clean seawater in it and it has a piece of green tape around it, which means it has not had any contaminants. Otherwise it'd have a piece of red tape. But we use [laughs] this water to look at nutrients, chlorophyll and all the other things we're interested in. This is one of our oxygen meters offshore. This is just in June of this week. And to calibrate the oxygen meters, we take water samples underwater. We've also used things like remotely operated vehicles that have oxygen meters on them to tell where things live on the bottom in relationship to what oxygen concentrations. And we also like to play in the mud. The Benteke Colleges [sounds like] from training and so mud is part of, in my blood and so every chance I can, I play in the mud. We take a lot of sediment cores. We do experiments under water. And then we have our scientists who like clean water and only take light levels and stay on the boat and don't get muddy. [laughs]

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So the consequences of all this, so who cares? Well, there’s a lot of animals that live in the Gulf of Mexico that care and there’s a lot of biogeochemical cycles that are altered because of changes in oxygen levels. The fish kills are not that common. This is usually when the low oxygen mass reaches the shore and traps the fish and kills them, which is a fish kill. The entre to that is something called a jubilee where the fish get trapped but not killed and you can dip net all the shrimp and red fish an every you want all day long and it’s a very nice thing except when a jubilee goes bad, it’s a fish kill.

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As the oxygen starts to fall low, other organisms such as brittle stars come up out of the sediment. They’re normally not seen. This is a polychaete worm, one of my favorite animals in the whole world that are showing stress. A dead crab, a dead polychaete worm and dead or decaying bacteria, sulfur-oxidizing bacteria. People ask what’s the effect on the fishery? We still have a very productive fishery, but we’re at a teetering point between goo and not good up here with more nutrients at some point with water quality goes down, then the fisheries go down. And we have some decadal average reductions in the amount of fish or shrimp caught. This is brown shrimp catch, pre-unit effort, that shows that there may be some reduction in the fishery from hypoxia but also tied to climate. Fresh water in the marsh, amount of marsh, prices of fuel, amounts of imported shrimp and things like that. So it’s hard to tease apart.

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One of the things that is obvious is the distribution of fish. The Mississippi River Delta at one time was called the fertile fisheries crescent because of a decreasing bullseye pattern of more to less fish. When there is not much low oxygen, you can see that the croaker which are the number one bottom fish, but when you do have hypoxia, you have a very different distribution because of this expansive area of low oxygen. So you can’t catch any of those right here. The same thing with shrimp, if you don't have hypoxia, you have widespread distribution. They can get from the near shore to the offshore and grow to larger sizes. But when there is hypoxia, you can see there’s a large area that’s covered with hypoxia that you just don't catch any shrimp. So the economic factor is difficult to say because some shrimpers just don't go out and try to shrimp because the cost of fuel is too high and the distance they have to go is too far.

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The driving force, getting back up into the upper end of the water shed, the driving force for the size of the low oxygen, the footprint, how large it is every summer, and we have 25 years’ worth of data on that, we just had our silver anniversary cruise last summer. I don't remember getting any silver, though. Oh, well, have to work on the golden anniversary. Wait, will I still be diving then? I’m not sure. [laughs] So the biggest predictor is the amount of nitrate load that comes down the river in May before we do the cruise with a year term. So there’s some holdover in the system, either in the land or in the nutrients in the Gulf of Mexico that carry over to the next year.

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Nitrate load is a combination of both the discharge, the amount of water, and the concentration of the nitrate. And over time there’s been a tripling of the amount of nitrate load driven primarily by an increase in the concentration. So the concentration’s gone up more than the amount of discharge has gone up, so we’re getting more nitrogen per volume now than we did in the past.

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We’ve been doing this, as I mentioned, for 25 years. N-D in most graphs stands for no data. This stands for no dollars, no data. [laughter] We didn't have funding that year. We also have years where we have drought conditions, a summer drought, a spring draught. We also have years where we have hurricanes, primarily before the cruise and it hasn’t had a chance to set back up so the size is smaller. We also have hurricanes during the cruise, which we did these 2 years and it was, it was fun. I keep telling people, come with me in the Gulf of Mexico, come help me do the research. It’s so nice. It’s so beautiful. It’s so sunny. You’re going to be able to fish all day. And we’ve been barely holding onto our bunks and the sides of the rail these last 2 years.

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And then we have this one. It’s physical oceanography, it drove it all onto one side, it piled it up. The footprint was smaller but there was much more and it was much more severe. So you have to take into account this variability. In other words, this is weather and this right here is climate. And the climate change here is an increase in nutrients.

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So what’s been going on up here? Well, or across the Mississippi River Watershed? Initially in 1620 there were huge expanses of virgin forest. Couple of centuries later, and then a century later. Now we do have second growth, but we have removed a lot of the natural vegetation in the area. We’ve also decreased the amount of wetlands across the watershed, filling in of potholes and draining wetlands to grow crops. And so we have less and less wetlands. And the reason we want to have mor wetlands is because the more wetlands you have, the less nitrogen is going to run off the fields. And the less marsh you have, the more nitrogen is going to be exported from that area. So wetlands are very important. It’s one of the remedies as well for some of the nitrate pollution.

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We’ve also lost huge amounts of grasslands, primarily in the middle of the continent and then to the west. You can see the numbers are all really close to 100 percent. And some of the reason we would want some of these natural prairies or natural rangeland would be that they had much deeper roots and they hold the nitrogen in the soil. Whereas if you look at a wheat crop and the amount of roots there or even corn crops or soybeans, there’s much less crop structure to hold water in place. And if you had this sort of coverage, you’d only lose 11 kilograms per kilometer squared per year in nitrogen. And if you have fallow crop land, you lose a lot of nitrogen from the soil. So some of the solutions in this case are more sustainable agriculture, different kinds of crops and different sorts of plowing techniques.

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The other thing, of course, is plowing. And we've done much better now with soil conservation. A farmer does not want to lose the soil into the nearest stream. We want to keep it there as much as possible so there's a lot less soil loss now than there was. But you can see in the Tennessee valley from historic to present what kind of soil we've lost. Helps build wetlands in Louisiana, which is great, but it doesn't help in the Midwest with the agricultural community.

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The other thing that happens along the river is flooding. And these are just different aspects of flooding and we also have large navigation interests that use the Mississippi River. So the Mississippi River is no longer a natural river. It's been channelized. It's been leveed. It doesn't floor over the levees as much as it did historically and the water is not getting into the bottomland hardwood forests and it's not being taken out of the landscape naturally. So what we've done is we've basically changed the landscape from a landscape that can absorb nutrients naturally to a landscape that's highly artificially managed and having too many nutrients put on them. You can see from the changes in the corn and soybean percentages over time how much more of the land is in that intensive agriculture production. And also those lands are also the lands that are tile drained. Under these lands there's extensive tile drain networks that move the water off fairly rapidly and it takes a lot of the dissolved fertilizer with it. And it's beneficial to move the water off because the corn grows better in better drained soils. So there's reasons for doing this but these are also reasons why there are more nutrients getting into the Mississippi River than historically.

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And you can see the changes in land use and the amount of nitrogen in the river versus presently. There's a very close one-to-one relationship between fertilizer use by county with the concentration of nitrate in the Mississippi River. It's a very strong correlation.

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So the one thing that’s happened in the watershed is that the amount of fertilizer has increased substantially since the 1950s. In the Mississippi River Watershed, as opposed to others, municipal, industrial, and golf courses, I don't want to forget the golf courses, don’t contribute much. We get some atmospheric nitrate from fossil fuel burning. Most of that is in the Ohio River Watershed. And a lot of what’s generated in that watershed actually ends up in Chesapeake Bay or Long Island Sound and causes problems to the east.

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We have atmospheric ammonia deposition, fertilizer and manure volatilization, the ammonia goes up and it almost comes immediately back down. It doesn’t travel long distances. Manure has always been a part of the nitrogen and phosphorus. It historically spread across the landscape, now in more confined animal feed operations. The amount of legumes, soybeans, alfalfa has gone up. But you can see the biggest increase and the one that’s most tied to changes offshore and changes in the ecology has been the increase in fertilizer.

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So we can find ourselves right here. When I talk to the National Council of Environmental Legislators 2 weeks ago, I asked them to try to pinpoint their district on this map. It gave them food for thought, not corn, but food for thought. And you can also see that most of the activities from which these nutrients are derived are agricultural-based activities. Not to say that urban and atmospheric is not important, but the driver, no matter how you do the budget, is agriculture.

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So what’s happened downstream is mostly in the nitrogen. And this is 1970 data we have. Similar values in 1950, 1930 and 1950. So the biggest change has happened since the 1950s. It’s stabilized somewhat now but you can see the high variability. It’s just like the temperature curve. All that variability and then a longer running average. So most of the change has taken place in this period right here. And now we just have an aggravated situation.

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Total phosphorus is somewhat going up because discharge is so important. The amount of fresh water can drive that layered system. More fresh water, strong layers. So we see that the discharge hasn’t actually changed that much over not just this time period but two centuries. So it’s, I’m sorry, it’s the nutrients, man.

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So what we have are higher concentrations in the spring and following 2007 increase in corn crops for biofuel and the same thing happened this year. The concentration of nitrate in the flow is even higher than it was historically. So even the same amount of water now carries more nitrogen to the Gulf of Mexico. And what you see in this sediment plume, you see the sediment, but you don't see the dissolved nutrients. And we know we’ve been getting more nutrients. We know from some of these sediment cores that we’ve been getting more phytoplankton. We know that the carbon has accumulated in the bottom. We know there’s higher respiration rates and we know we have more hypoxia now than we did historically.

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We also know that for the same amount of nitrate loaded into the Gulf now, we can have the same size or larger area of hypoxia than historically. So we’ve reached a critical point where the ecosystem has had regime shift and it’s more imperative now to try to take care of this problem before it gets even worse.

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To show you some of these paleo indicators, again, playing in the mud. My graduate student, Jen, sectioning off some mud. She plays in the mud, too. She looks at these little organisms called foraminifera, which are single-cell calcareous test organisms that you use to, in geologic formation to find oil. But this tells us that this particular animal used to be very common. And since the 1900s, we don't find it anymore. And that’s because it’s not tolerant to low-oxygen conditions.

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Other things we look at are the remains of the diatoms. This is a diatom right here. How much silica that’s in their test has accumulated over time. And you can see a slight rise here but down. And then up and it follows exactly the nitrogen load from the Mississippi River. Other things are the increase in carbon. And this is, we talked about this last night at dinner so I'm going to put some of you through this misery again. But this diatom causes something called amnesic shellfish poisoning, which can cause permanent short-term memory loss or death. And those numbers have increased over time. It's a big problem in the Gulf of Mexico and on the west coast and in the northeast coast. And it responds very well to nitrogen.

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So the silicate's gone down. And then nitrogen's gone up, which means they're in balance right now. And that leads to a hypothesis that if you have this ratio is more than 1:1, you have lots of diatoms, like this one right here, heavily silicified diatom. You have lots of diatoms in the food web. You get lots of fish. You get lots of productivity. But you also get too many of them, they sink to the bottom. If it's less than 1:1, then you end up having things like harmful and noxious algal blooms, red tides, brown tides. If you don't have enough silica to generate the diatoms, you get other organisms instead and you end up with similar water quality problems because those phytoplankton blooms aren't grazed preferentially by zooplankton, they sink to the bottom, and they also lead to low oxygen.

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So the system is in a very delicate balance right now. It's not just the Gulf of Mexico water that's a concern to me. It's the water in your back yards. It's the water in your water wells. It's the water in your lakes in Minnesota and Iowa and Illinois and Indiana. Because these excess nutrients can also lead to, the common name is blue-green algae. The scientific term is cyanobacteria, that they have toxins in them, respiratory toxins, toxins that effect the blood. They're just irritants. They can cause illness, diarrhea, vomiting. I've had a research associate just collect a sample of this water before and get deathly ill that night. Not this kind of deathly ill, but there have been deaths related to these cyanobacterial toxins. And this excess nitrogen also leads to poor water quality for drinking. There are drinking water standards for nitrate and if you exceed those then a community has to find alternate sources of water or put tertiary treatment, which is very expensive, onto their water treatment plants.

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So this is, that's basically the continuum of the ecosystem at some point. And I wanted to step back a little bit and talk about how the science has led to policy, which is, was one of the topics we were talking about earlier. We started out with this basically scientific curiosity, how big is it, how long does it last. And we had a senator from Louisiana, Senator Borah who gave us some money and we started a program and we found out, well, it's there a lot more than we thought it was. It's bigger. It lasts much longer in the summer. And that eventually led to funded directed research programs. Now in the meantime, the management community might've known about this. They might not have wanted to know about it. But it did, eventually the management community was engaged and they also supported the directed research program.

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So in this adaptive management plan here, the science, we had six large reports that put together the science. We came up with an integrated assessment on hypoxia in the year 2000. We started this in 1996, I think. It became a federal/state tax force action plan to try to reduce the amount of nutrients in the Mississippi River to reduce the size of the low-oxygen area to 5,000 square kilometers. Well, we're over a 5-year running average, we're way away from that goal. But it's still a goal. One of the problems is that it was all incentive-based and voluntary and we're finding out that that's not necessarily working as well as it should. It's an adaptive management. We use the data for modeling and then we reassess the situation and say, are we making a difference? What can we do differently?

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So there was a 5-year assessment that took 7 years. And it was an independent science advisory board of the Environmental Protection Agency. And it was, I sometimes refer to it as a witch hunt on the science because the science was really under attack at that point. And they had a lot of really good scientists who were objective and who were not from the Gulf of Mexico. I don't know how that fits together but . . . [laughs] But the science advisory board supported the science. They said, yes, the science is strong. Nitrogen's a problem. Phosphorus is also a problem. And, yes, we need to do something about it and we need to keep that goal. However, it still said that the best way, at least management wise now was with incentive-based voluntary actions.

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The report also targeted the Midwest and said, that’s where the biggest problem is. That’s where you're going to get the bang for your buck and you need to start doing something there. So we want to target tile drains and we want to do this and at the same time, this little guy that’s making poor personal choices with his corn intake doesn’t have as much of that corn to intake anymore because a lot of it’s going into biofuels and ethanol. So it’s a very complex economic system as well that drives the amount of nutrients that get to the Gulf of Mexico.

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It’s not just the Gulf of Mexico. In this period from 1960 to 1980, in developed countries like the U.S., and a lot of places in Europe, that’s where you saw the biggest changes over time in what are called symptoms of eutrophication. The excess algae, the noxious and toxic harmful algal blooms, the increase in the number of dead zones. But what we’re seeing now is this whole, oops, I am not going to crash. OK. [laughs] That just happens. Don't worry. [laughs] OK. [laughs] So developing countries now are having these same problems that we had. And we, you know, we’re not even taking care of our own problems and we’re pointing to people and saying, you know, you’ve got to take care of your problems or you're going to be in the same mess we’re in. We can do that. We’ve got to fix our mess as well as use the science from that to help guide other countries so that they can have clean, healthy waters as well.

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There are many of these areas around the world. The area in the Northern Gulf of Mexico is the second largest, human causes, coastal area of hypoxia in the global ocean. The largest is the combined areas of the Baltic, the Northwest Shelf of the Black Sea used to be the second largest, but they had an economic collapse, unfortunately, with the break-up of the Soviet Union. Nutrients had gone up. Nutrients went down. No subsidies. And the hypoxia disappeared. Now I’m not recommending a total collapse of the corn economy in the Midwest to solve the nutrients problems but it does show that if you increase nutrients, you degrade water and if you decrease nutrients, you can improve that water quality.

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We also talked about climate change or global change. Global changing includes that which is also what people do and then we're going to have some changes in the climate just because of the changes in water temperature and the amount of CO_2 in the atmosphere. So human beings can create more water or take away water. They can put my nutrients into the system. They can enhance the productivity. We're going to have more harmful algal blooms and more bottom-water hypoxia. But just by temperature and salinity alone, temperature, you can increase that strength of the layered system. You can, with increased temperature you have less oxygen dissolved in the water. You can speed up the metabolic process. There's lots of things can happen that we don't quite know the relative importance of right now with regard to climate change and hypoxia.

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You can increase the winds and change the wind patterns. And this is happening off the coast of Oregon and Washington State that shifts in the wind patterns now driven by climate changes have started to force low-oxygen oceanic waters onto the shore, trapping and killing a lot of really important commercial fisheries and basically destroying the complex epi-funnel [sounds like] ecosystem that lives there. So you put these two together and you might have a lot of problems.

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The Mississippi River, and I can quote the famous IPCC report of 2007, has predicted that the Upper Mississippi Watershed will have increased precipitation, earlier snow melt, and there will be more drainage from the land in the upper part, less drainage from the land in the lower part. But you put that with increased nutrients, increased drainage, and you are, we are, it's going to happen that hypoxia will be aggravated under those climate change conditions.

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It was also mentioned that hurricanes will become more fierce and severe, more frequent. We've certainly seen that in the Gulf of Mexico. I'm not recording hurricanes as a way to alleviate hypoxia. It does turn over the water column but it sets back up in about a week and we start all over again. But this is just an added problem that we're going to have along with sea level rise in these coastal ecosystems.

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I want to share one more thing with you. We've all, not we've all, but many of us have studied in school the nitrogen cycle, the phosphorus cycle. You go from NO2 to NO3 to NH4 to NH3. You've got oxygen. You've got known oxygen. You got denitrification, nitrification. You go crazy trying to learn this for a general exam. [laughs] But there's another nitrogen cycle. And these nitrogen molecules have dollar signs on each side of them. And they're called nitrollars. And those nitrollars start down here because the Gulf of Mexico has, or has had a lot of natural gas, it's very cheap. So a lot of the ammonia, anhydrous ammonia that is made that goes into the fertilizers that come up here as nitrollars, not nitrogens but nitrollars, are generated in the State of Louisiana. It gets onto the land. It runs back down the river. It causes algae to grow. It causes a low-oxygen area where you don't have shrimp. So these nitrollars move a long way, these nitrogen molecules. You can get it into hogs in Utah, Arkansas, South Carolina, North Carolina where the nitrollars end up in Albemarle Sound, the Neuse River and you have dead zones there as well.

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There are a lot of nitrollars that flow from Washington, D.C. into the farm economy, which is worth a lot of nitrollars. A lot of nitrogen molecules, a lot of value there. I don't know if you noticed but there's no arrow with nitrollars coming in this direction to the Gulf of Mexico to support the shrimping industry which is worth its own, but not quite the same amount.

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These P-ollars, these P-dollars, phosphorus is mined in Florida. It's barged across the Gulf of Mexico because it's got a lot of cheap natural gas to make phosphorus fertilizers which go up into the watershed. The corn, the corn to chickens maybe. The chickens over here. Or it comes back down here and one thing that also happens in the Gulf is that we have a tremendous fishery of cheap fish, menhaden, which get ground up into chicken meal. Goes back up the Mississippi River and comes back down and helps fuel this algal bloom that creates these low-oxygen areas.

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So the point here is that society and global economy and global needs and people are all connected in this nitrogen cycle, this P-cycle and this carbon cycle that we heard about earlier. And it seems overwhelming at times, but then there are the questions like, what can you do? I ask my classes, who drives? Who rides their bicycle to school? OK. Who drives a fuel-efficient car? Who drives one of those gas-guzzling SUVs? And, you know, everybody's going like, no, not me. Well, really? I am. And the same thing about diet. How many steaks have you had this week? And, you know, have you had any wheat-based pasta with carrots and things like that? So, you know, we do talk about those choices. Those are personal choices that not only affect the carbon footprint but affect the nitrogen footprint as well.

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I would like to thank the organizers of this conference for inviting me here. It's so far been a great experience. I've broken just about everything technologically that I can and now I've had a spider on my microphone. I don't do this alone. I've got lots of collaborators and I've got lots of great technicians that go with me in the field. And I have lots of really good funding agencies. And if I could, I'd give them all a big warm hug right now but I just have to say thank you.