US Fish and Wildlife Service | Climate Change and Adaptive Management

Welcome. My name's Mike Runge. I work for US Geological Survey at the Patuxent Wildlife Research Center. This presentation today is a presentation on climate change and adaptive management, how we can think about climate change from the standpoint of adaptive management, what kind of decision analytical tools there are that might help us think about climate change. This presentation is part of a curriculum on adaptive management which is part of a curriculum on structured decision making at the National Conservation Training Center.

So of course, climate change has become a dominant issue that we've been thinking about in terms of conservation. And that's affecting a lot of our thinking and a lot of our management decisions. Although I guess I would say at this point in 2012, we're still struggling to know what it really means to our management.

We know there's some changes afoot. We know we're going to have to think about these long-term changes that are happening to the environments that we care about. But I'm not sure we quite know what to do about it yet. But we're thinking a lot about it.

What I want to try to tie together-- and I think this is an active area in thinking about climate change-- is how can we bring the tools of decision analysis to bear on these topics. In the last couple years, there's been some papers that have addressed this topic and have thought about decision frameworks that can accommodate climate change.

Three of those references-- one was lead authored by Mike Conroy, one by Jim Nichols, and one by Eve McDonald-Madden. And they're all similar in the sense that they talk about using formal analysis, decision analysis, to think about aspects of climate change. And I'm going to be really picking up on some of the themes that are in these papers.

There is a new approach to ecology that's emerged in the last 10 years. And that is driven by this notion that the climate might be changing, that there's global system change that's affecting what we do. And what we're seeing is the coupling of different kinds of models.

So we're seeing these general circulation models, these climate models, that have been used to do these kind of long-range forecasts, centuries-long forecasts, of the climate. Those are being coupled,

more and more, to habitat models. And those habitat models are being coupled to demographic models, plant and animal models, to then begin to make projections in the long range in the face of climate change of what might happen to these resources of concern.

Let me give you a quick example of this kind of method that's emerging. This was one of the first that really put all these pieces together. This was some work that was done by a large group of USGS scientists and their collaborators in 2007. This was as a prelude to the listing rule for polar bears that the Fish and Wildlife Service was undertaking.

The service knew they had to evaluate the status of polar bears. And they knew that changes in the Arctic were really important. So they asked USGS to do a number of studies to try to synthesize knowledge about changes in the Arctic and how those might polar bears.

So certainly, this started with looking at these global circulation models and deriving sea ice projections from them. So in this graph here that you see, the one on the top left, what we're looking at is projections over time of the September sea ice extent in the Arctic. And this is many of those global circulation models-- I think there are about 20-- that are included in these projections, the different lines.

And the solid bold line is the mean projection, the ensemble projection, from those models of sea ice extent. The red line is actually the observed sea ice extent. These are the [? IPC3 ?] models, so they're now a little bit outdated. And what was even becoming clear by around 2000 was that the sea ice extent was actually declining faster than these models were projecting.

Anyway, so we have these projections of sea ice extent. And the picture is not good going out into the future. By 2050 and further, we're really looking at pretty substantial reductions in sea ice. This graph here at the bottom is the observed sea ice extent for a smaller period, from 1979 to 2006. And we can see that there has been pretty demonstrable decline in that sea ice extent.

Well, so the next piece is to start to say, well, what does that mean to polar bear habitat? So there was some work done that really looked at how those climate models can inform on understanding of sea ice extent and therefore polar bear habitat. So this was sort of coupling those climate models with habitat models for polar bears.

And this graph, which was one of the reports from a series of USGS reports in 2007, really looks at those trends at different seasons of polar bear habitat area. And again, the picture is the same, that

we're seeing really pretty sharp declines over the next 100 years projected.

Well, the next piece was to say, what does that mean to the demography of polar bears? So the habitat's changing. How much does that matter to the population dynamics of polar bears? And can we predict something like the probability of extinction for polar bears over, say, the next 100 years?

So there was some work done. Steve Amstrup led it. Bruce Marcot was involved. They developed a Bayesian network to take into account a lot of the factors that affect polar bear demography and develop parameters for this model from an expert judgement process. Put this together. You can't read all the details of what's in this model. But the point was you take all these factors-- and it includes those climate and habitat factors-- and from that you try to predict the persistence of polar bear populations.

And the results are shown here in this set of bar graphs. And essentially what you see is the x-axis of any of these graphs-- there's four different regions of the Arctic this is looking at. If you take the polar basin divergent ice ecoregion-- this is the bottom left region-- that's the one that includes the US portion of the Arctic. I've got that right. Is that right? Yeah.

Then this is saying the y-axis is the probability of extinction. And then you've got different time frames. And so what you're seeing is-- no, sorry. The y-axis is the probability of outcomes. And the z-axis going into the screen is various levels of outcomes. The red is extinction.

And so what we're seeing is that by even 45 years from now and certainly by 75 years from now, there's a high probability that the population of polar bears in that particular region will be possibly extinct or greatly reduced. So this is sort of a population viability analysis that was driven by a habitat model, that was driven by the coupled climate models.

OK, anyway, so the science is emerging that we can put all these kind of models together to begin to make forecasts into the future using the best available information to think about the viability of the species and habitats that we're interested in. And conceivably, we can also put management actions into this and start to say, well, how might we change these outcomes with management actions?

Well, the point here is-- so there's emerging science. There's merging understanding of how the global systems are changing. And we've got these tools to begin to anticipate these changes. How do we put that into a decision context?

Now, in the series of presentations that this lecture is part of, we've been exploring adaptive management and how you can make decisions in the case where those decisions are recurrent. And they're made over time. And there's uncertainty. And you might be able to reduce that uncertainty.

One of the things we haven't really said explicitly is that there's a fundamental assumption in the way we've been doing the optimization for these kind of models. And that's a stationary assumption. We've been assuming, in our traditional view of adaptive management, that the system in question, the ecosystem that we're managing, is stationary.

That doesn't mean that there isn't stochastic effects, that there isn't variance. But it means that the rules of the system aren't changing over time. There's no directional trend in what's happening in that system.

We might be uncertain about the parameters in that process, but we assume the process is stable. And learning over time will reveal what it is we don't know about that system. And all of the optimization you've seen so far has depended on that assumption.

So in the previous presentations from Clint and from Jill, when they were doing this backward iteration, this dynamic programming, and talking about for a long-term horizon problem, you step backward step by step. And you wait till that converges. And then that's the optimal solution for managing in the long term.

Well, the hidden assumption there is that the rules of the system aren't changing. But here's the deal. This is exactly what climate change is saying is the rules of the system are going to change over time. How do we deal with that? How do we deal with that change in our decision making?

And so that's really what I want to explore today. And I'm going to give you some sort of philosophical ideas about how we have to think perhaps about problem framing, decision framing, differently in the context of system change. And then I'll give you a little case study that was actually one of the papers that I mentioned earlier.

So climate change-- really, this is a special case of system change. And what I'm talking about here is I want to focus on really external system change that's outside the control of management. So I'm not really talking about what we now call climate mitigation, right, the actions that humans could take to try to stop climate change.

I'm talking about climate adaptation, the kind of actions that we can take to help achieve our objectives, when we have to live with climate change or live with system change. So we're not focusing on how to adaptively manage the system change itself, but how to manage in the face of it. And this can include both spatial and temporal aspects of system change.

So what are some of the challenges here? Do we need to change the scale of management? When we're talking about system change, particularly global system change, do we need to think about the scale of management differently? If so, how do we bring about the institutional change that would be necessary to support a change in geographic focus?

Do our objectives still-- I'll go back over each of these challenges in turn. Do our objectives still make sense? Do our alternatives still make sense? Are they adequate under a new system regime or do we have to think about new alternatives?

Can our models anticipate the system change? This is a key aspect. How do we build in that system change to our modeling?

And then how do we track the changing system? What do we do in our monitoring system? So I'm kind of stepping through these elements of a structured decision process-- framing, objectives, alternatives, models, monitoring system. And thinking, how does the whole notion of system change cause us to think about these elements differently?

So let's take a look at these. So scale of management in the face of system change. Does system change require us to think differently about the scale of management? If we're talking about global system change, it may be that one of the consequences of that is it changes what's possible to achieve locally. But maybe some of those goals are able to be achieved someplace else.

Now, I think this has been at the heart of what a lot of conservation biologists have been thinking. So maybe you're the manager of a refuge someplace that's focused on habitat for some endangered species. And you're the best place in the world for that species right now.

But there's every anticipation with system change that the best habitat for that species is going to move northward. Or it's going to move up in elevation. It's not going to be there, at that refuge, anymore.

So we've got these hard boundaries to this refuge. But system change, climate change, may cause the ideal habitat for that animal, let's say, to move to a different place. So if we want to manage for that animal, we have to think about doing it in a different place.

So maybe the refuge manager there who saw it as his or her purview to take care of this animal now has to think about where are the partners? Where are the landowners? Where are the parks?

Where are the refuges elsewhere that might be the refugia for this animal in the future? So the scale of management we may need to think about differently. We may need to take a broader spatial perspective in seeking our management goals.

What about our management objectives? Might we reconsider our management objectives in the face of climate change? Possibly-- as the previous example sort of illustrated, our local objectives may need to be sought someplace else. It may no longer be appropriate to seek the objectives for that species in that place anymore.

But I think there's an interesting question. How much do our objectives really anchor on past conditions? And how do we need to think about future conditions? So the example that came to me-- I don't know how significant an example this is. But it's kind of illustrative of the point.

My understanding is that there is a tradition of moose hunting in northeast and in northwest Minnesota. There was once-- there might still be-- some habitat for moose in the corners of the state. And there is a historic tradition of moose hunting that the state manages. And that's important to some stakeholders in the state.

Climate projection models show that habitat, moose habitat, going away, leaving Minnesota altogether. And so the anticipation is you won't be able to achieve moose harvest, moose hunting, objectives in Minnesota anymore. Because there won't be moose in Minnesota. So does that mean we don't have that objective anymore?

Or was it really a moose harvest objective in the first place? Maybe it was a large-ungulate hunting opportunity objective. And it just happened that moose was the traditional way of achieving that. But when we're faced with the possibility that you can't achieve that objective anymore, maybe what we realize is actually, our objective was something different.

And there is a substitute. Maybe if there's-- say, I don't know-- elk reintroduction in part of the state. Maybe that would serve the same sort of stakeholder objective. Anyway, I don't know how significant that particular example is. But you get the point that maybe we actually would think about our objectives differently when faced with the consequences of climate change.

Another possibility, another aspect of a decision analysis-- we think about alternatives. Well, will our set of alternatives change in the face of climate change? Do we need to switch our actions to new areas? Do we need to consider completely new methods, perhaps?

One example-- management of albatross in the Hawaiian Islands. Right now and in the past, that has focused on the protection of small shoals and not really on predator control on the main islands. But with projected sea level rise, a lot of those habitats-- it's thought that they're going to go away.

And so at some point, it may be that-- moving to the idea of predator control on main islands-- that may be the only place that you can think that there would be habitat that you could manage for albatross in the Hawaiian Islands. And so new management alternatives might need to arise that perhaps were never even really talked about before, because they weren't needed. So maybe in the framing of our problem, climate change, system change, causes us to think about new actions.

Probably the place we've thought about this the most is in terms of system models. In the face of system change, we need system models that anticipate that change, either explicitly or implicitly. And this is the interesting aspect, I think, particularly when we think about adaptive management in the face of climate change. How do we think about what that change is going to be? And how do we build predictions about that system change into the models we're using to make management decisions?

And I think this is probably the key aspect, the crux, of thinking about system change in an adaptive framework is to think about how are those system models going to change over time. How are the rules of the system going to change over time? And I think to the extent that we can articulate our hypotheses about system change, we can incorporate those models explicitly into our decision making.

Now frankly, I think this is probably the place where we've fallen down a bit in terms of thinking about climate change from a decision making standpoint. I think the narrative goes-- often, sort of in the public discourse, when we're willing to admit that the system's changing. Well, we say the system's changing, but we really don't know how it's going to change. So we're going to have to deal with it. And the

conversation kind of ends there.

But if we could go a step further and say, here's how we think the system's going to change. We think the likelihood is that it's going to shift in the following manner. Given that information, we might start to be able to make smart decisions about how do we manage through that transition into that new place. So building those predictions into our models is going to need to be a part of managing the face of climate change or any kind of system change.

Now, if we're talking about models of temporal change, there's a couple ways we could do that. We could take a passive approach. And we could have a set of models that capture uncertainty about the long-term equilibrium-- where the system's going to be, how the climate's going to be. How the particular environment or habitat we're interested in-- what it's going to be like in 100 years or if it stabilizes at some new place. But maybe we're not specific about the timing of that change. We don't have predictions about the timing of that change.

Well, what we could do there is we could capture that uncertainty in some different models. Maybe things will stay the same. Maybe this particular habitat's going to double or halve or something.

And we can use those explicit alternative models and passively update our confidence in those models as we saw how things were unfolding. That would be a reactive response to change. As the change occurred, we would change our decisions accordingly.

An active approach would be to have a set of models that was actually specific about the timing of change. And we could proactively anticipate that change and do something in advance. So if you knew-- and I'll give this example later when I talk about managed relocation or assisted colonization.

If you anticipated that this particular habitat for a species was going to go away in 25 years, well, you probably wouldn't wait for 25 years for it to go away before you did something. You might, 10 years ahead of that loss, start moving the species or start taking some kind of management action to deal with that. So we might proactively be able to respond to system change if we can develop hypotheses about the timing of that.

And I think that's a really important part. I think if we place system change and climate change in a decision analytical standpoint, the first step for us is to say, well, what do we think is going to happen? Let's build those into the model. If we've got uncertainty, that's OK. We can still be proactive and

adaptive if we're willing to articulate what we think's going to happen.

In terms of models for spatial change-- I don't have a lot of really coalesced thoughts for this, but the same sort of thing. I think we need to start thinking about how we make those predictions about how things can change over space. And that probably is going to involve asking us to think about translating those global trends into local-scale predictions.

So we see these global trends from these global circulation models. What does that mean? How do we downscale that to the local scale? And what does that mean to our management at the local scale?

But the other thing we have to be able to do is interpret local events in a global context. When we see certain kinds of changes happening at a global level, what does that mean in terms of the global context? This goes, I think, back to the first point I was making about changing the scale at which we think about these problems.

I think the last-- well, it's not actually the last element. But one of the last elements I was going to talk about here is monitoring. What about monitoring in the face of system change? Do we have to think about that differently?

Well, maybe not. As we've talked about in all of the other work in this class, we need to match the monitoring to the key uncertainties. The monitoring design has to be tailored to the uncertainties we would like to reduce.

So same thing here, it's just that if the uncertainties we're talking about are uncertainties about how habitats are going to change over a very broad spatial scale over time, then we're going to need to match monitoring to those kind of uncertainties. So we can detect the kind of changes that are important to us. So we need to find the appropriate scale.

There is an interesting question, though. And I'll touch on this a couple more times in this presentation. There's a difference between-- I'll use Donald Rumsfeld's quotes-- known unknowns and unknown unknowns. So there's that uncertainty that we can articulate in advance.

We say, well, we think the system's going to change in a certain way. We don't know if it's going to double or triple in terms of some particular property. But it's going to be one of those or somewhere in there. So we could articulate that uncertainty. That's a known unknown, let's say.

The unknown unknowns are those surprises that we can't anticipate. We don't have hypotheses for those now. How do we manage for those? And how do we monitor for those?

And I'm not actually sure that we can do that. I don't know how you design a monitoring program for something that you can't anticipate at all. But I think there's an important distinction. Because I think a lot of the dialogue and a lot of the conclusions that some people come to about climate change-- they're really thinking about unknown unknowns.

And at that point, I think that leads you to throw up your hands and say, geez, I don't know what to do. I guess what I would say is let's focus on those known unknowns and articulate the uncertainly we can, develop the monitoring that we need to resolve that uncertainty.

So the last point I want to make in this sort of philosophical overview piece about how system change or climate change affects how we think about decisions is the institutional challenges. I think some of the institutional challenges are pretty daunting. Because if we're talking about changing the scope of how we think about our management objectives and our management alternatives because we're recognizing that habitats aren't staying still. Where the best place to do management for something may no longer be where it once was.

We might need to secure collaborative commitments to manage for common objectives over time and across boundaries. So we may need to be talking about collaboration among institutions, among sovereign entities, for a common objective, that require collaboration that wasn't needed in the past.

And certainly, just setting those common objectives is a challenge in itself. But then coming up with the institutional arrangements that allow for that common management may be a challenging bit. Because we're going to need to foster learning across agencies and states and international boundaries in order to learn about these common objectives and how we can achieve them in the face of changing systems.

Interestingly, I think Fish and Wildlife Service and USGS and their partners have begun to initiate some of this kind of institutional change through the LCCs and other structures that have been created within Department of Interior and with partner agencies. Where in these landscape conservation cooperatives, where people are starting to say, well, let's think about things at these larger landscape levels, at a broader spatial scale with partners.

And let's begin to set up institutional arrangements that allow us to learn at those scales. And they begin to manage at those scales, at a broader scale than perhaps we have been doing. So that's good. I think we're going to face other challenges like that.

So that's a bit of an introduction to some of the things I think that may be affected. In essence, my belief is that decision analysis is decision analysis. It doesn't matter whether the system is changing or not. Decisions are still structured in the same way.

We still have objectives. We still have alternatives. We still have models, et cetera. But it may be that the issue of system change causes us to think a little bit differently about how to come up with those elements of a decision.

I want to talk next about the modeling piece. I've called this section scenario planning. Now, I'm not using the word in quite the same way that it's used in a lot of the climate science contexts. But let me comment about scenario planning.

The question has come up, well, is scenario planning different from structured decision making? Is it different from adaptive management? How do all these concepts fit together?

In my mind, scenario planning really is-- at its heart, it's about this predictive modeling in the face of system change. That's the heart of scenario planning is that you've got some predictions about how the system's going to change. And what you want to do in scenario planning is explore, perhaps, what's the consequences of different management actions going into the future.

Now, I think often scenario planning's not embedded in a decision context. It's often used in a sort of exploratory way. And I think there's some positive reasons to do this. The comments I was making earlier about how our objectives might change-- I think challenging people to think about their objectives in the long term-- lot of times, people don't know, maybe, what their objectives are in the long term. And so some of the scenario planning, this game playing with models, allows them to envision future outcomes. And start to think about, well, does that matter to me? How much does that matter to me? How much would I invest to avoid that outcome or achieve that outcome?

And so I think the interaction with the models allows people to get some sense about what they might care about and what they might do in the face of system change. And I think the other thing about

scenario planning is recognizing there's uncertainty in our predictions and wanting to grapple with the nature of that uncertainty.

Well, I want to talk a little bit about modeling in this setting and uncertainty in the setting. And what might our uncertainty be? What kinds of uncertainty are there with regard to temporal change in the system?

So I've made a little list here. And I'll go through each of these scenarios. It's kind of a spectrum of system change that I've been thinking about and talking to others about. So I think we can talk about known change to a new equilibrium. I'll talk about some examples of that.

We can talk about uncertain but anticipated change to a new equilibrium. We can talk about uncertain but anticipated change with no effective equilibrium in sight. And then we can talk about unknown change for which no hypotheses exist.

And I think when we're talking about uncertainty about climate change-- what I would challenge all of you to do is if somebody is talking about climate change and saying, well, we're uncertain. Try to diagnose-- what do they mean by uncertainty? What kind of change are they thinking about and what parts of it are they uncertain about? Because I think these different scenarios I'm going to talk about lead to quite different ways of thinking.

So let's start with the easy ones. Suppose when we anticipate the effects of system change, what we really think is just it's going to be known change to a new equilibrium. So the graphs I'm going to show are all kind of caricatures.

But the x-axis is time. And the y-axis is some mean system state. Probably the easiest way to think about this is think about this as maybe the carrying capacity of a particular habitat for some animal. Think about it that way. So the mean population size for a particular animal.

So here, this first example is saying, suppose we know it's going to about double. The capacity is going to be about double. And in fact, it's actually going to change to a new equilibrium. That's sort of within the realm of our experience. We've sort of seen habitat capacities at that level before.

So that's sort of easy. Things are going to change. But it's going to change to a place we've been before. So we kind of know what to do there. Well, that's one kind of system change.

Another kind that closely related is known change-- like we know for sure. We're not really certain about it. We're really quite sure that things are going to shift. We really believe our climate models and our habitat models. It's going to shift to a new equilibrium.

But that equilibrium is outside of our realm of experience. So here, this maybe presents some new challenges. Because maybe our objectives would change here.

Or maybe the management actions that we would use would change. Because we don't really have experience here. We've never really tried to figure out how to manage in that kind of setting.

But still, if we know that it's changing to that level, all we really have to do is figure out what in the long term it's going to be optimal, how it's going to be optimal to manage. And then how we should manage the transition. So we've got to manage through this transition to this new place. But if we know where we're going, that shouldn't be that hard to figure out.

So let's make it a little more-- well, here's an example, actually. These are northern pintails, a particular species of waterfowl in North America. What's shown here is the average latitude of the pintail breeding population. So during the breeding surveys in May, they record the distribution of pintails. And you can look at what's the average latitude of all the pintails in North America during the breeding season.

And prior to 1975, that was around, say, 53, 54 degrees latitude. And then there was this period where that latitude shifted north. And it's noisy, but it appears that it's kind of stabilized at a new equilibrium of about 56 degrees.

And so we don't really know exactly why this has happened. Maybe it's the Pacific Decadal Oscillation which happened to change phase in about that period. Maybe it's a change in agricultural practices in southern Canadian prairies.

There's a number of things that it could be. But essentially what you see is that there was a switch from one kind of equilibrium or mean level to a new level. But that new level wasn't really far outside of things that we experience before.

So actually, the models we use for harvest management for pintails are still-- actually, we can use the same models before and after this switch. They still work. The system we use for setting optimal harvest regulations can accommodate this.

So what about uncertainty? What if we're anticipating some change to a new equilibrium? We think that's going to happen. But we don't know what that equilibrium is going to be.

So you've got two graphs that are shown here, two traces that are shown here. Maybe these are alternative models. That might be the case for the system change. So carrying capacity might increase to level A or might increase to level B. We don't know which it's going to be.

Well, we could develop-- we could include those two models in our decision analysis and use those to make predictions. And say, well, what's the consequence of that uncertainty? What's the expected value of information?

We can ask those same questions. What action would be best under that lower model? What set of actions would be best under the upper model?

And we can say, what monitoring would we put in place to discern among those? You can see, actually, that discerning among them-- if you take a look at the graph-- we're not going to be able to discern between these two models right now. They don't make different predictions early on.

They're going to start to diverge in, say, 40 or 50 years. And then by 60 or 70 years, there'll be pretty stark differences. So we know that monitoring is probably not going to be able to help us discern among these until we get into this place here. But then maybe we would be able to learn about those things.

Anyway, so we can probably use the same techniques that we've been talking about this week. We just have to build in this temporal component, this temporal change component. But we've got alternative models. We've got weights on those models. And we can think about how we would manage in the face of that uncertainty.

There could be uncertainty. So in this first case, the uncertainty is about the new equilibrium point. Maybe we're pretty sure about the equilibrium point, but we're not sure about when it's going to occur. So we've got one model that says it's going to gradually occur, and another model that says, nah, it's going to be kind of quick. And we don't know which of those it's going to be.

And there's differences. Because in the one case, you've got a bit of time to manage through that transition. In the other case, you'd better get things squared away pretty quick. Because once things change, you're not going to have a lot of opportunity to adapt real quickly. So maybe that's a kind of

uncertainty that we need to think about.

There's been some talk about ecological thresholds. People talk about tipping points in system change and worrying in various ecosystems that these climate-induced changes might lead to tipping points where there's some sharp switches. So for instance, we might be uncertain about that. We might be uncertain about whether there's a tipping point.

In this first model I've drawn here on this graph, we're thinking that the system's going to change to a new equilibrium. But maybe there's a tipping point at that dashed line. And what's actually going to happen is it'll follow the same trajectory up till it hits that tipping point. And then there's going to be a big switch, kind of overnight. And then it will stabilize at some different equilibrium.

Well, these are some interesting models, because you can't discern them at all. Until you hit the tipping point, in which case it might be too late. So you can see I'm starting to step through kinds of uncertainty that get more and more gnarly in terms of how we think about how to make decisions.

But the point of all of this is I think we need to be explicit about the uncertainty we're talking about. I think we can do this. We may not be right, but we can encapsulate our best knowledge, our best understanding of things, about what we're anticipating is going to happen. And we can think about what would be optimal to do in the face of those predictions and our uncertainty about them.

Where it starts to get harder is in the next example. So maybe we've got anticipated change. We're anticipating a directional change in the ecosystem. But we don't foresee any stabilization. At least, we don't know where it's going to stabilize. And we don't think it's going to stabilize at a new equilibrium anytime soon.

So the best we could do, say, over the next 100 years is say, geez, it's going in this particular direction, but we don't know where it's going to end up. And we might have uncertainty around that.

Well, we can still devise a management system in this kind of case. What gets a little bit difficult in terms of optimization is-- as you saw in some of the other examples, when we're doing the optimization, we're sort of anticipating the actions we take today. How do they affect what we can do tomorrow and the next day and the next day? And then how do we care about the accumulated returns and where we're going to be?

When you've got this directional change, you don't know where it's going past that end time point. So I guess it's hard to say, where do you hope you'll be in terms of your management objectives after 100 years, when things could keep getting worse after that. So there's some challenges in thinking about these things. But if this is the best we can do, if this is what we think's going to happen, we need to make those kind of predictions and fold that into our decision frameworks.

The last kind of change I want to talk about is unknown changes, this unknown unknowns. And it goes up by a lot of different names-- Rumsfeld and unknown unknowns. Or people talk about black swans.

There's a book called *The Black Swan* and this idea that some of the most important uncertainties we have manifest as surprises. They're things that nobody ever anticipated. Nobody in Europe ever thought there could be a black swan until they traveled to New Zealand and Australia and saw that black swans existed. So nobody even conceived of such a thing. So the thing is those are surprises.

Well, how do we handle surprises? Certainly, there's going to be surprises with regard to system change, climate change. There's going to be things that happen that we just can't anticipate at this time. And can we manage smartly now for those?

Well, there is a body of decision analysis that deals with this kind of uncertainty, with what's called severe uncertainty. In the sense of Yakov Ben-Haim's info-gap decision theory. So there's some body of work. It also goes by the name of robust decision making. That's looking at how do you handle uncertainty when you can't really articulate what that uncertainty is?

But then I think there's sometimes people are even going beyond this. And I've heard people say something like this. Well, we just don't know. So we have to monitor to detect change. So then we can decide how to respond.

In a way, we're just throwing our hands up. And we're saying, well, something's going to happen. I don't know what it is, but we'd better monitor for it. And then we'll deal with it when it comes.

I'm not enamored of the idea of throwing our hands up. That may be the case. It may be that there's huge surprises on the horizon.

But I'm not willing to throw my hands up until I've done my best job of dealing with all the things I can articulate. Look, let's deal with the things that we can make predictions about, that we can articulate our

uncertainty about. And let's do the smartest things for those.

And then we'll have to deal with the other things as they come along. I don't think the notion of severe uncertainty or unknown unknowns is any excuse to just throw up our hands and stop doing and just turn to monitoring as our only possible option. So that's a personal opinion. But I challenge us, as a species, to do better than that.

So the point of all of that is when we talk about system change, I think we need to do a better job. We need to challenge ourselves to make predictions about what do we think that system change is going to look like. And given that, what should we do about it?

Let me show you an example that gets into a little bit less philosophical, little more practical application here. So this is a paper that was published last year in *Nature Climate Change*-- Eve McDonald-Madden, myself, Hugh Possingham, and Tara Martin-- where we were looking at this issue of managed relocation. Managed relocation, assisted migration, assisted colonization, assisted translocation-- it goes by a lot of names.

As far as I can tell, this is the most commonly referenced climate adaptation strategy. So people talk about, well, what are we going to do in the face of climate change to manage natural resources? And there's this idea of, well, we'll move species to a new place.

It's been very controversial in the literature-- amazingly controversial in the literature. There's all kinds of published stuff. And there's nothing like it.

If you want to induce a great argument, just get two or three conservation biologists together. And just say one of these terms. First they'll fight about the term. And then they'll fight about the concept.

Anyway, there's a couple published frameworks-- sort of decision frameworks-- for this-- 2008 in *Science,* 2009, in [UNINTELLIGIBLE] of the National Academy. Neither really deals with the adaptive question. So what we wanted to ask was, well, let's think about this managed relocation or whatever you want to call it. In the context-- what would an adaptive strategy for managed relocation look like? So that's what we try to work up.

So the thing here, if we start to think about this-- First of all, these are some very complicated, implicit assumptions in this whole idea of managed relocation. So what I'm graphing here-- I'm not sure you

can read the axes particularly well. The axes are time on the x-axis and population size on the y-axis.

One of the assumptions I think here is that you've got a source population. You've got the place where these animals are now. And you anticipate that that's going to go away. Climate change, system change, something-- this habitat's going away.

And where this species exists now, it's not to be able to exist there in the future. That's assumption number one. I think everybody's kind of clear on that.

The other assumption is that there's someplace else that in the end is going to be better for them. Maybe it's suitable habitat now. Maybe it's not. Maybe it's not suitable habitat at all now. Maybe there's some animals there. Maybe there's not.

But at some point, there's a place that's going to be better for them-- a destination. So I'm calling these the source and the destination-- a destination that may be better. Maybe it's actually going to improve as habitat for the species over time. Or maybe it's OK now and it'll just stay OK.

But at some point, the carrying capacity in this destination is going to be higher than the carrying capacity in the source. And so the idea then is, well, that might be smart to move these animals, help them move if they can't move themselves, from the source to the destination. So that's the second assumption, I think, that's embedded.

But notice there's some interesting things there about the timing. When does that switch occur? How fast is the source going away? How fast is the destination improving? Those things matter.

The next thing is that-- the idea is that you're going to move this population, let's say. We characterize it as there's a small isolated population and you've got to move it all at once. Obviously, it's a more complicated thing. You could do step by step movements and stuff like that.

But we were thinking of this simple case, like if you've got a population-- mountain pygmy possums, say, in the Australian Alps, that are really found in only a few very tiny places. And you're thinking you're going to pick them all up and move them to a new place.

Well, when you move them, we know-- through a lot of experience with translocation-- that there's a lot of losses when you translocate animals. There's losses when you capture them. There's losses during the transit itself. And then when you release them, there's also losses. A lot of the animals don't quite

make it or adapt to the new habitat.

So there is a cost to moving these things. So we need to account for that. But I think the idea is that when they get to that new place, there's going to be some recovery up to the carrying capacity of that new place. And so presumably there'll be some positive growth rate in those populations in the new place that allows them to recover from that translocation loss and get back up to carrying capacity in the new place.

So we put all those assumptions into a model and started to say, well, given all of that, can we ask when is the optimal time to move that population? So that's your decision. The decision here is, do you move them right away? Do you wait a while until they start to decline?

Do you wait till they've actually switched? Or do you wait till you're fully sure that the source has gone away and then move them? Do you wait till the destination is in really good shape? When's a smart time to move these?

So this is an optimal timing question. And we wanted to know, how does that optimal timing depend on all these various assumptions? But also what do we do if we're uncertain about some of these things?

So interestingly, then, the factors that are going to affect the timing of the move are pretty complicated. They depend on the current source-- the site dynamics at the source. They depend on the site dynamics at the destination. They depend on the interaction of those. The timing of those is pretty important.

If the source is going away before the destination becomes good, there's no optimal time to move them. Because if you move them too early, there's no habitat in this destination. If you move them too late, there's no habitat in the source. And so if there's no overlap there, then that's problematic. Anyway, so the interaction between the timing of source and destination changes matters.

How many individuals are in the system? The probability of the move working and the translocation cost and the potential for the population to recover. So all of these are factors, as it turns out. And they affect the optimal timing quite a bit.

So this graph shows the results from the case where we know how the system is changing. And I apologize-- the colors aren't great on this. But I'll walk you through this.

So the top row is the case where the carrying capacity in the source is dropping from, say, 100 to 0. And half of that's going to happen around 10 years from now. So it's happening between 5 and 15 years from now.

And there's a destination. And its carrying capacity now is 80. And it's going to stay that way.

So in this particular case, what we're looking at is the destination having a constant carrying capacity but the source being lost. And let's assume there's no animals in the destination right now. But you're talking about moving them to this new place.

And so in this first case, the switch occurs at about 8 or 10 years. At about 8 or 10 years, the destination has a higher carrying capacity than the source. Now, let's suppose that over here, on the right column, the translocation survival rate is 95%. So you only lose 5% of the animals when you translocate them. So there's not a big translocation cost.

Well, what does this [? say? ?] This optimal policy-- the x-axis is time and the y-axis is the population size. And basically, this says-- this is kind of a stark thing.

It says, keep them in the source until year 8. Then move them to the destination. Basically, there's no translocation costs. So just wait until the moment when the destination now has the higher carrying capacity and move them then.

In the case where the translocation survival rate is 30%-- that is, 70% of the animals are likely to die during the movement event-- it actually says, you know what? If the population size is big enough, if the population size is above, say, 40 animals, we should move them right away.

And the reason for that is we're losing 70% of them. We would like as long as possible for those to recover towards that carrying capacity. And so the sooner we can move them, the sooner they can start recovering from that translocation loss to get back up to the carrying capacity. So that's just showing that the translocation survival rate affects the timing of the move.

Now, how about the different dynamics in the destination and the source? So in the second case, same dynamics for the source. It's the source is declining at about 10 to 12 years from now. The destination now has a carrying capacity of 30. It's not really as good at all.

And so there, what it says is if the translocation-- same result, really. The translocation survival rate is high, it says the same thing. You're now waiting till year 13. But that's the point where they switch order. And so you're just waiting until-- keep them in the source until the source is worse than the destination, then move them.

And again, in the case where there's a high translocation cost, you're going to move them earlier. But that depends to some extent on the population size. You don't want to move a small population size too soon, because the 70% loss might wipe them out.

And then this continues. This third example has a slower loss of the source. And again, if the translocation survival rate is high, you just wait till those switch. Otherwise, you might move some earlier.

Anyway, so the point is we're doing a time-dependent strategy here. That's what's different than some of the things you've seen before. We're calculating what action should we do at what time. Because the system's changing and the habitats are different at different times, we needed what's called a time-dependent strategy.

OK, this is a case of certainty. What about if we're not sure what's going to happen? So this next set of results says-- it's similar scenarios. But it says, what if we don't know whether-- the source might actually just stay fine.

Maybe there's a hypothesis out there that says, you know what? It's not going to happen. The source is fine. You don't need to move them at all. And another hypothesis that says, no, it's going to decline. And it'll be gone in about 15 years.

Well, this is really, really interesting. So we developed an active adaptive strategy to say, what's the smart thing to do here if you're uncertain about which of those is the case? Now, here's the thing. If model one is the case and there's not any impact of system change here, then obviously, you should keep them in the source.

If model two is the case and you knew it, you would move them to the destination. And you would do that at about year 8. I think in this case, the translocation survival rate's fairly high.

So what if you're uncertain about those things? Well, here's the interesting thing. The only way you're

going to learn about which of these is the case is by keeping some animals in the source, right? So these differ in terms of the carrying capacity of the source.

Well, you can't measure. The animals tell you what the carrying capacity is. The population dynamics tell you what the carrying capacity is. So unless you have some animals in the source, you don't know what the carrying capacity is.

So the probing action here, the thing that accelerates learning, is making sure you've got animals in the source. So that suggests you should delay moving them, till you can make sure that model two is the case.

So what we've got here, the optimal strategy is time dependent. Those are the different contours. It's population-size dependent. But it also depends on the belief in the no-impact model.

So if you start out and your belief in the no-impact model is above 80%, it's just going to say-- like if you've got strong belief that things aren't going to change, then you keep the animals there. If you've got some belief, though-- or as belief starts to accrue in model two, so you move down on this y-axis here. Then it's more likely going to move them.

But the timing of that is fairly complicated. And in an active strategy, it depends really on the weight of belief in the no-impact or the impact model. And there's some kind of probing action that's embedded here in this active strategy because it anticipates where you could have acquired learning.

Anyway, the point is there's an example of an active adaptive strategy in the face of system change. Now, this was sort of pretend. There's not a real population that we're talking about here. But we were trying to capture the essence of this kind of decision and what are the key elements of this kind of decision and the timing of when you might do this kind of move.

So in summary, we can do optimal management in a changing system. I said at the beginning that up until this lecture, our assumption-- we didn't state it, but our assumption implicitly-- was that the system rules stay the same, that we've got the stationarity. Well, even if that's not the case, we can still do optimal management. What we just have to do is recognize that our management is now time-dependent.

So we have to develop what are called time-dependent optimal strategies. Because the optimal thing to

do this year, even if you're in the same system state, same population size or something like that, might be different this year than it is in 10 years. Because the system will work differently in 10 years or 50 years than it will now. And so we can build in those time-dependent optimal strategies.

And one of the fundamental issues there in doing that kind of thing is uncertainty about the system change. And thinking about, can we articulate known unknowns? Can we articulate our uncertainty about that system change? Do we have unknown unknowns?

What is the nature of that predicted change and our uncertainty attached to it? So we need to think really hard about how we think the system's going to change. We need to articulate hypotheses about that and then explore how that affects our management strategy.

But I guess the thing I want to leave you with is, look, we don't really have to change the notion of decision analysis very much at all. If we're making decisions, we still have actions. We still have objectives. We still have models.

Now, the models are probably where we have to think about things the most. Because we need to think about the temporal change aspects of it. But once we've done that, we've got the tools. We've already explored all the tools that we need to solve these kinds of things.

And I guess the thing that's important to me is we need to stop arguing about system change and climate change. Arguing about is it occurring? Isn't it occurring? What are the effects going to be? We've got uncertainty.

OK, those are interesting-- sort of-- questions. The real question to me is, what are we going to do about it? What management actions, what decisions, are we going to take? That's the thing we should be asking. We should get smarter about how do we embed these predictions about system change and the uncertainty associated with them in a decision context.

Now, the first challenge, of course, is always framing. And so I think there is some interesting questions, as I noted earlier, about whether climate change induces revision of all the elements of the problem. The scale, the objectives, the alternatives, the models, monitoring, and even the institutional structures themselves. Maybe it does. Maybe that's part of a framing thing that we need to think about.

But I guess what I want to argue is the adaptive management framework is precisely the right paradigm

for addressing climate adaptation. Because it can accommodate system change and all of our concerns about uncertainty. If we can articulate that uncertainty, we can fold into an adaptive paradigm. And we can ask, does that uncertainty matter to us, to the decisions we would make? And can we develop monitoring that will allow us to reduce that uncertainty and manage more smartly as we learn?

So I'll leave it there. And see if there's any questions from anyone here or in the classroom. Paul.

I have a question, Mike. I agree. I see no reason why we can't use adaptive management frameworks to address this. I would ask you a question, given everything you've summarized. Do you see a lot of the problems and the challenges and the contentious discussions we're having maybe many of them melting away? If we shifted in our modeling, in our thinking, from single-species-based approaches to synoptic variables that more reflect ecological integrity and the health of the systems? So move from an individual species to maybe a class of species, like a top predator.

I'm going back to your initial analogy with the moose issue. So it's from moose, which the focus was on, to a large ungulate. And maybe it's elk. Maybe it's bigger white-tailed deer. It could be a number of things, but that kind of thinking. Do you think it would resolve a lot of the issues and help us advance progress on this issue?

Well, I don't think any of these things are ever going to be easy. It might help. I guess the thing that's embedded in your question, really, is thinking about our objectives.

So do we have single species objectives? And maybe we don't. Maybe we never did. But we got away with it because things kind of were where they were. And we could focus our single objectives in one place and a single objective someplace else. And we didn't have to think about things more holistically.

But maybe in fact, our true fundamental objectives are broader than we've had to state before. The challenge there-- the opportunity there is once we get clarity about those objectives, you're right. It may be easier to solve these-- we may realize there are solutions that we didn't think existed before. The challenges-- we have to talk about objectives.

Now here's the interesting thing. Actually, my personal feeling about issues of system change and climate change-- there's all kinds of challenges in predicting system change in the modeling and the uncertainty and all that stuff. The real issues-- let's face it-- are about objectives. They always are. This is always the challenge in the kind of decisions we make is that people have different objectives.

And first of all, it's hard for us to articulate our objectives. And second, there's also conflicts about objectives. So a lot of the issues about climate change, we cast them in the public arena as disagreements about the science. But they're really disagreements about objectives. And I'm not saying anybody's right or wrong.

But there's a lot of stakeholders that have different views about how much should we worry about long-term things versus short-term things. How much is economic development-- how do we weigh that against biodiversity? All those kind of things. Those are the challenging things. And that's really why the question's hard.

But I guess I think that if we start asking these questions in the decision framework, rather than casting them as a scientific dispute. Then we get to the heart of the matter, which is dispute about objectives. Which we can talk about now more openly, rather than hiding from what the real issues are. So in that sense, I think that actually what a decision analysis framework does-- it allows us to confront the real issues that face us. And actually probably, hopefully open up constructive dialogue that's meant to get to some sort of agreed-upon action rather than just stalling forever.

When you're dealing with an issue like climate change and it involves a portion of the globe-- to be real-- and all the jurisdictions involved with it, how are you going to deal, or how do you expect to deal with so many competing values to reduce uncertainty in the model?

Yeah, and in some ways, that's what I meant about the comments I made about needing to think about the scale of the problem and needing to think about institutional arrangements. You can think of it as, well, what are the governance and institutional structures, say, within the United States? How does Park Service and refuges have to talk to each other differently in the face of climate change?

Well, that's easy. As hard as that is, that's easy compared to when you're now talking about sovereign nations that have very different economic interests, very different cultural interests, very different notions about who owns the blame for this in the first place so who should be part of the solution. There's no answers in the predictive models for that. Those are, of course, political conversations and values between different countries in particular.

I think the one thing we can do is I don't think we have to let that political discussion get wrapped up in a discussion of scientific uncertainties. They are two separate things. Depending on what our scientific

predictions are, those lead to different kind of recommendations under different sets of objectives. But we can get to some common ground about what the evidence says, what the science says, and what it doesn't say. We can get to some common ground about what we do know and what we don't know.

We can retain all our differences about values and objectives and still come to agreement about the science. And I guess I think we ought to do that. We ought to do that and say, look. So I'm pretty optimistic, pollyannaish about this.

But it would be nice if we did that and said, look, we've put all the best folks together in the world. Here is the state of knowledge about what things are happening and what those impacts are. And here's what we don't know. OK, we can agree that that's the state of knowledge about what we do and we don't know.

And then we can say, well, what are the consequences of that? We can build these kind of predictive models and can talk about the consequences and our uncertain about those consequences. And we can do all of that in a collaborative environment. Nobody has to give up their strongly held values to do that.

I think what that does is then it gives us a platform for having a discussion about the different values. And whether there is a way to find some common solution that multiple nations can live with. Or whether there's not. But we're talking about negotiations between basically, simultaneously all the nations of the earth and how we're going to treat the atmosphere. So obviously, in the end, those are really just political negotiations that reflect deeply held values from different people.

But part of your question was sort of the interaction between those values and the science. And I think part of the idea of decision analysis says, we can separate these components. These are two different pieces of a decision analysis.

And we can do our best to square away one of them to prepare us to be able to deal with the hard part, which is the values part. There's a classroom question. Yes, please go ahead.

Yes, from the classroom. We were wondering where does decision making fit in beside what's worth pursuing in a species context.

I guess I don't understand the question.

[INAUDIBLE]

Where does decision making fit in in identifying what to protect?

Yeah, Mike, my question was focusing on-- with the example of the polar bear. Where are we going to move polar bears? And so in context of decision making, how can we maybe best use that as a system to triage where we're going to put our efforts for what we can even try to save.

Yeah, OK, so that is an interesting-- that's a really important question. Because it's saying in some ways, with regard to conservation of biodiversity, we have sort of an overarching objective which is maintenance of-- persistence of a whole lot of species. Well, we've got limited resources to do that. And there's some strong system drivers that are pushing things.

And I think that has certainly led-- and so this idea of climate adaptation and, say, assisted migration. I think you're right. I mean, assisted migration of polar bears where? Where are you going to put them? Antarctica? I don't think that's going to go over very well.

There might not be management actions, management options. If we can't deal with climate mitigation, it may be that for some species, we really can't come up with any management options that are going to change the fate of that species in the long term or even the short term. But there may be other species that we can have an impact on. And so I think that raises these questions of, well, triage. Do we identify those things that we can affect and don't invest in the ones that we can't affect ultimately?

And that also raises questions when you're thinking about it at that broader scale is, well, if we've got to make those kind of choices, what is it that we need to preserve into the future? Is it as much biodiversity as possible? Or is it ecosystem function? Or is it the recreational opportunities that are associated with those? So again, we're back into the very difficult questions about objectives.

And this is the point I think I was making about the moose in Minnesota is that I think climate change challenges us to think much more broadly about what it is we're trying to achieve. So a species by species sort of assessment of objectives isn't quite going to do it. We're going to be forced to think about a broader view of what it is that we're trying to conserve.

But yeah, Clint, I think that certainly decision framework allows us to do that. But the way you've articulated it, we have to change how we're thinking about the problem. We're changing about how

we're framing the problem. And the system changes is forcing us into that. Paul, you had a question?

If somebody else has a question--

Anyone else? Another question? Is there any questions from-- more questions in the classroom?

Hi, Mike, one more from the classroom. And going back to the topic about model weighing and evaluating your suite of predictive models. Say you have a suite of predictive models about your system response. But you suspect or anticipate that the system is going to go through some fundamental change, like a shifting baseline or through a tipping point. So what can you do to use your existing models, or what you have to help diagnose or evaluate whether your system is changing, or about to go right through a change?

I think there's a couple ways. And I think this is something that maybe we haven't fully figured out. The first way is to have a set of models that sort of brackets the possibilities that you think could be the case. And so you've got one model.

One extreme model might be everything is going to stay fine, stay the way it is. And another model has things shifting to some baseline that's sort of a real extreme baseline at a far end. And then if you've got some monitoring in place-- so you've got a suite of models that really embraces all the things that you think could happen.

Then a monitoring system-- as things go along, you update faith in those models. And the model weights start shifting towards whichever is doing the best prediction. And that change in model weights follows the system change and kind of gives you an index to how much things have changed.

There's a possibility that the system will change in a way that you didn't anticipate, outside the bounds of the model set that you had created. So this would constitute a surprise, sort of unknown unknown. Now there, I think-- and this is the part that Eve McDonald-Madden and I have some active research on to try to think about-- is how do you know when your model set as a whole isn't doing very well?

And essentially, you can think about it. If you've got a bunch of predictions and your different models all say that the carrying capacity right now should be-- one model says it should be 50,000. Another says it should be 10,000. Another says it should be 75,000. But all of them are bracketed by 75,000 and, say, 10,000. And you don't have any hypothesis that says the carrying capacity should be 10,000.

But your monitoring is going along. And all of a sudden, you're seeing numbers down in the 2,000's, outside the bounds of the models set you had predicted. I think as years go by and you start to see that kind of stuff, then I think you're starting to accumulate evidence that none of the models in your set are really capturing what's going on. And at some point, that would trigger you into some kind of double loop where you need to really reassess what you know about the system. And start to think about inserting some kind of new model.

So I don't know if that quite got to all in your question, [? Toula. ?] The other piece of it is how do we develop predictive models of system change in the first place? And I think that's just a challenging bit about how do we assemble the knowledge we've got, our understanding about how climate's linked to habitats and animal populations, to think about how things might change, to integrate all of those kind of models that we've got, to begin to make predictions out into the future. Other questions? Another question from the classroom?

Mike.

Yeah. Is that God speaking?

This is your life. On the plots, you didn't have any time-- any numbers on the time axis, on the x-axis. What do you think is appropriate time scale for which to think about these types of decisions?

Boy, that's actually a really, really interesting question. And I don't think it's actually a scientific question. So I shouldn't answer it.

I have a personal view, which I won't share. But the time issue-- really, it's about objectives. We were talking earlier today in a different lecture about time discounting. In essence, the idea of time discounting is how much do we care about now versus some point in the future. That's a values judgment.

Was it Chief Seattle that said something about any decision we make needs to anticipate the outcome for the next seven generations? OK, so that was a values-based statement from that cultural perspective about the frame that's important to consider in any decision you make, seven generations. So that's a pretty low discounting rate, I think, compared to what our modern societies [UNINTELLIGIBLE] put.

We like to talk about 100 years from now. That's a very comfortable place for a lot of people to talk about endangered species. Probably that's the most common time frame where people will calculate the probability of extinction, 100 years.

I think the reason 100 years resonates is not just because it's a round number. I think it represents three human generations. And I mean, I can think about 100 years ago. Because 100 years ago, my grandmother was a little girl. And she had told me stories about what life was like for her when she was six years old. So I can imagine what it was like 100 years ago.

100 years from now, my grandchildren will be adults. If I have grandchildren. I hope I can imagine what life will be like for my grand-- and I care about that, right? I kind of care about thinking about-- personally, I think that's why 100 years resonates with people. Because we can imagine it. When we get beyond that, it starts to get to be hard to imagine things.

But these are values. These are values about how we care about now versus later. And how much we care about the future, how quickly it degrades. That's a values judgment. So the time frame we have to look at things, one, is a value judgment.

Now, there's another piece to this that's come up in a lot of the regulatory and policy discussions that I've been involved in. I think this is actually a red herring. Well, maybe that's not right. I think it's a misconception.

Some people have said the time frame should depend on our confidence in our predictions. So in other words, to depend on the quality of the data. So if our data are really good, and we can predict precisely into the future, then we should be looking at a longer time frame.

But if our data are bad, and we can't predict very far, then there's no point in looking that far into the future. Because we can't make predictions. And so there's no point in accounting for that stuff.

I think that's actually a pathological view of things. I don't mean to say these people are sociopaths. I mean to say that there's an error in that thinking that leads to exactly the wrong decisions.

Because it actually motivates not learning. Because it says, if we don't know much, then we only have to focus myopically on things. We only have a short time horizon, and that's easier to think about.

So why would we go learn about anything? Because if we learn about things and can make predictions further into the future, then we've got to deal with things further into the future. I think it just leads to some very strange logic.

I recognize that our predictions degrade as we go into the future. We're more and more uncertain as we make predictions further into the future. And so if we're trying to predict things 1,000 years from now, I'd say, yeah, we've got problems. It's going to be very hard to do that.

But I don't think that should be a reason for setting our time frames. I think our time frames are a value judgment. We should ask, what do we care? How long do we care about into the future?

And when we're thinking about conservation things, I think one of the aspects we should ask about is-- well, I'll say a couple different ways. How long in the future do we want to forecast economic benefits? How much do we care about understanding economic consequences?

How much do we care about understanding conservation biodiversity and our stewardship responsibilities? Those are values judgments. And that's how we should set the time frame.

That's a personal opinion. You're free to have another opinion, but that's mine. Other questions?

I have a question.

One more question.

So when should decision analysts take these considerations into account?

Say that again. How should--

So when should decision analysts-- when you're encountering a decision problem, when would you want to take these six considerations into account? The challenges that you laid out.

Yeah, so that's an interesting question. Because I think we've had a tendency as decision analysts to-- the decision comes to us. We help a decision maker work through an analysis. And if they don't mention that climate change is a concern, then we will just solve the decision as if the system's going to keep working the way it worked.

So I think there's a bit of an art to this question of when should we be asking these hard questions

about-- this assumption of system stability, can we live with it? Maybe I would say it this way, is as a decision analyst, you should recognize that this is one of the assumptions that would go into a decision analysis. This question about, is the system stable, or is it likely be changing?

And you should at least ask that question and evaluate the evidence. Because that will lead you to different ways of framing the problem. So maybe the lesson of all this climate change stuff is that we have to stop living with that assumption. Or stop making that an implicit assumption. And at least make it an explicit question we're asking. And that needs to happen early on the problem-framing stage.

Great. Well, thanks for your attention. And we'll see you back in the classroom.