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Webinar Transcript

Extreme Climate Events and Species Population Dynamics: Overriding Influence or Not Such a Big Deal?

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Shayna Carney: Good morning or good afternoon and welcome from the U.S. Fish and Wildlife Service's National Conservation Training Center in Shepherdstown, West Virginia. My name is Shayna Carney and I'd like to welcome you to our webinar series held in partnership with the U.S. Geological Survey's National Climate Change and Wildlife Science Center in Reston, Virginia.

The NCCWSC Climate Change Science and Management Webinar Series highlights their sponsored science projects related to climate change impacts and adaptation and aims to increase awareness and inform participants like you about potential and predicted climate change impacts on fish and wildlife.

To start things up, please join me in welcoming Shawn Carter from the National Climate Change and Wildlife Science Center who'll be introducing today's speaker. Shawn?

Shawn Carter: Thank you. It's my pleasure today to have Dr. Keith Nislow with us. He's a team leader and a research fisheries biologist for the USDA Forest Service Northern Research Station. He's also Adjunct Associate Professor at the Department of Environmental Conversation at UMass Amherst.

Finally, Keith is also acting as a Co-Principal Investigator at the Northeast Climate Science Center which is affiliated with our center here. Keith has degrees from University of New Mexico and Dartmouth, and he's been with the Forest Service Research and Development for the last 16 years.

Today, Keith brings us his expertise in research dealing with the relationship of ecosystem change in aquatic habitat and the distribution and abundance of fish and aquatic invertebrates. He's particularly interested in using basic science to assist restoration, conservation and management.

It's my pleasure to introduce someone I'm very fond of, Keith Nislow, for today's webinar. Take it away, Keith.

Keith Nislow: Thanks very much, Shawn, and thanks, everyone, at NCCWSC. It's my pleasure to talk to you guys today and everyone on the line about some of the work we've been doing and some of the issues that we're interested in.

My very first thought in starting to put this talk together after having given Holly the title, seems like many eons ago, was, "Wow! What a stupid title." We've all been in this situation where we send in a title for a talk, it sounds amusing at the time, and then we just sort of grimace.

I was faced with the choice, do I try and change it at the last minute, or do I double down and try and make some sense of it? Like a fool, I kept the title, and I'll try and make some sense of it to everyone online.

We're interested in extreme climate events. Obviously, they have an influence and draw attention way out of proportion to their actual frequency. In a sense some of the extreme events, particularly that have hit the Northeastern US in the last three to four years, have become now the poster child for potential climate change in the region.

Going back to my bad title, this actually was a bit of a controversy back in the early days of ecological science. We have an interesting debate between two general camps. We've got folks led by Andrewartha and Birch who stress an overriding influence of climate, particularly climate extremes in driving population dynamics and the distribution and abundance of animals.

In contrast in the no big deal school, although this is an overstatement, we had folks like G. Evelyn Hutchinson, Bob MacArthur, and a group that was really focused on equilibrium dynamics, carrying capacity, and population aggregation via density dependent processes.

It's a stretch to say that for these folks climate extremes and these climate events are no big deal, but much more focus on how populations got back to an equilibrium or carrying capacity and less of a focus on those extremes and driving dynamics. Obviously, as we've been moving forward in the last 50 years, we've lost the science.

We certainly realize that we need to bring these two perspectives together in order to understand the effects of these extreme climate events on population dynamics, a topic that has become even more important given the non-stationarity of frequency, timing, and duration of climate extremes that we expect in a changing regional climate.

This is some data up from the Northeast Climate Science Center, from Ray Bradley's lab and his post-doc. It deals with an aspect of climate that I'll be focused on a lot today, particularly the frequency of extreme-precipitation events. I'm an aquatic ecologist. I'm really interested in floods, and as I mentioned, these large floods really have been a hallmark of climate extremes in this region over the last four to five years, since the Climate Science Center has been in existence.

Obviously, there's lots of variability, lots of uncertainty in these predictions, but it does seem like it's going to be a blue world with respect to intense precipitation and the possibility for extreme climate.

This brings up some really important science questions from the perspective of fish and wildlife population dynamics. First, are there critical thresholds in frequency, duration, timing, and magnitude that increase risks to population? Then, from more of an operational standpoint, but also from the basic-understanding standpoint, what is the relative importance of changes in extremes versus changes in central tendencies with respect to climate? This has particular importance because of the difficulty in generating robust forecasts of climate-extreme regimes. From the wildlife and fish perspective, from the natural-resource perspective, we need to have a really good sense of what the importance of these events are if we're going to task modelers with coming up with better and better forecasts.

With respect to management implications, some obvious questions of interest are, how do these changes in extreme events influence predictions of distribution abundance? Maybe even more importantly, does considering extreme events change the prioritization and the relative value of specific management actions? Obviously here, in the Climate Science Center at NCCWSC, we're interested in actionable science, and this is our major concern. Are we going to ask managers to do things differently if we consider changes in these extreme events?

The rest of the talk, I just want to give you a bit of a road map. I'm going to be talking about population demography, conservation-genetics, habitats, and then I'm going to end with human responses. I am going to talk a lot about fish, which, that's the way I am and it's hard for me to get away from, but I hope to achieve some level of generality using fish and a few other texts and case studies. 8:27

Before I get too far in my talk, I want to acknowledge that the work I'm going to be talking about is very, very much a collective effort, involving a lot of great cooperators, from the USGS, particularly Ben Letcher, my longtime cooperator at the Conte Anadromous Fish Research Center, who pioneered a lot of this work on brook trout. Jason Coombs, my post-doctoral researcher, who's done a lot of the modeling and additional work, and Andrew Whiteley, who runs the Aquatic Conservation Genetics Laboratory here at UMass, which is co-supported by the Forest Service and UMass, and then, of course, acknowledge all of the institutions that have funded or supported this research, including the Northeast Climate Center, USGS, Nature Conservancy, UMass, Forest Service, and many others.

Not only am I going to be talking a lot about fish. I'm going to be talking a lot about a particular kind of fish, brook trout, in a particular place, our long-term study site in Westbrook, in Western Massachusetts. We've been at it for a long time now, pushing 20 years. We've got the site very well monitored. Lots of years of long-term, very intensive, individual-based data, which, over the past 10 years, we've branched out to include conservation-genetics perspectives as well. You'll hear a lot about this site at various points in the talk.

I'm going to start the talk talking about demography, and particularly talking about temporal variation. One of the things that's really interesting about a lot of the species that we deal with is that we do see a lot of climate-associated variability in population numbers, but we see populations persist.

Before we get into the potential effects of climate extremes and changes in climate-extreme regimes, I'm going to take a little time and talk about how populations and species that we're interested in deal with the kind of climate variability that they're experiencing now and have experienced over most of their evolutionary history. A really important concept here to start out with is the concept of stock and recruitment, which relates to the numbers of stock, number of spawners, number of adults, however you want to describe it, for whatever species you're interested in, yielding a certain number of recruits, the number of young that survive recruitment stage to become potential spawners.

I'm going to focus a little bit here on recruitment, because it's a really important life stage for many, many species, and it has an important intersection with climate and particularly climate extremes. We're really interested in recruitment, and it's often very important, because for many species, it's the most vulnerable life-history stage. You're dealing with small, inexperienced, competitively inferior individuals, whether you're talking about tree seedlings or fledgling birds, there in the middle of the screen, or fish larvae that are just rid of their yolk sac, and oftentimes they're in the process of transitioning from dependence on maternal resources to independence.

As a consequence of this vulnerability, we often see very high mortality during this stage, so very high variation in survival, leading to very high annual variability in recruitment, that is in turn tied to inter-annual variation in climate.

This is an example of what a larval brook trout in Westbrook might be experiencing as they begin to absorb their yolk sacs and emerge from the gravel. What we have here, in the stippled line, the stipple line shows a decrease, from high flows in the spring, April, down to base flows in the later spring, consequent increase in temperature. This is the period when young larval brook trout, brook trout frys, recruit from the fry stage to the young juvenile stage.

One of the things that we see time and time again in many stream-salmonid populations, like brook trout, is that high-recruitment years are linked to successful match between environmental conditions at recruitment and the stage the fish are in when they're ready to recruit. Conversely, when there is a mismatch between these fry requirements -- for example, if they emerge early, when flows are too high, water is too cold -- they can have very, very low survival and can even completely fail to recruit. You can have years, depending on particular flow conditions and particularly associated with extreme flows that can wipe out an entire recruit class.

Conversely, there are some species, like these floodplain trees, that depend on extreme events during critical recruitment phases to successfully recruit. These silver maples here lining the Connecticut river, they may go through many years of no successful recruitment, until they get just the right flood at just the right time to allow their seedlings and saplings to recruit to their population. 14:50

Just to follow on this a bit, we see this high annual variability, and it's variable to the extent that for many populations, we have many years where recruitment is zero or close to zero. As a further consequence, a lot of these populations may indeed be recruitment-limited. The number of individuals that get through that stage is going to determine how big a cohort you're going to have, how abundant that population is throughout the course of that cohort's existence.

Just to demonstrate that a bit, this is some work that I did with a colleague, John Armstrong, in Scotland. We were looking at when we would expect to see recruitment limitation. This is just a diagram that illustrates that. The left-hand side of the graph, you've got two levels of salmon fry recruitment, and what the graph describes is the change in numbers on the Y-axis, the log change in numbers of individuals, and the change in the size of those individuals.

As in almost all populations, this isn't just true for stream-dwelling salmonids. It's particularly true for forest trees. As individuals increase in size, they are reduced in number. That reduction, as you see leading from the recruitment part of the graph, in the lightly stippled lines, that's just density-independent mortality, so there's just some level of mortality going on. What we can see is that as long as that mortality or that survival doesn't exceed the carrying capacity of the habitat for older juveniles in the post-recruitment phase, that the number of individuals coming out of this juvenile phase, which is the size of the arrows on the right-hand side of the graph, is directly proportional to the levels of recruitment. This is an example of where recruitment is an overriding influence on cohort size or number of individuals.

We see a lot of recruitment variation and persistence, as I mentioned, to the extent that, in many populations, you can have a number of years of zero recruitment, zero survival during this stage, and yet these populations persist.

I'm going to talk about both the ability of these populations to persist to buffer many years of low recruitment, and some of the mechanisms that are involved in that buffering, in that compensation for low recruitment and low abundance, and then I'm going to talk about how that relates to changes in extreme event regimes.

One important mechanism that helps populations recover from low density at any stage is density dependence, and classic density dependence where we have increased survival and growth of recruits at low density as well as in some cases increased survival growth and fecundity of adults.

Both of those processes help populations recover from low density. You can see here this is the graph from a paper by my colleague, Sigert Hynimaneye, and he looked at how initial density of salmon fry influenced the total number of recruits, of juvenile recruits that we had at the end of this stage.

We can see two things here. The dark bars are in a low-flow year. I'm sorry, the dark circles are...we did this experiment in a low-flow year, so relatively benign year, no floods. The white circles are when we did this experiment in a year with a pretty major flood during the recruitment stage.

We see here the process, the outcome, of both differences in low regimes, in flood regimes, but also a really strong density dependence so that in that benign year that the performance, the survival, of fish at low densities was great enough to result in potentially the same output of fry as when we had lots of fry escaping that recruitment.

Increased performance, increased survival, growth, and fecundity at that density are a very powerful mechanism allowing these populations to respond to low recruitment and low abundance.

The other important mechanism, or another important mechanism, is a component of what we call the ecological storage effect. What this component is is essentially that in populations that have long-lived highly fecund adults like forest trees, like a large adult salmon, the storage or the ability of those adults to persist across multiple bad years of poor recruitment is a critical component to persistence.

This is really manifest, or it's possible, because as bad as recruitment can be it can't be less than zero. If you can't recruitment less than zero it means, again, particularly for these highly fecund species, which in a good year when everything goes right, when all the holes in the Swiss cheese line up, can have just absolute boons of recruitment and the good years can be much better than the bad years.

What I have illustrating here is this is the relationship between egg number...between length of individual brook trout and the number of eggs that females have.

What we can see is a very strong size dependence so that if you get to be two, three years old, reach 200 millimeters, your potential reproductive output, your fecundity can be an order of magnitude greater than fish that mature at 105, 125 millimeters.22:16

To pull this together a bit one of the ways that species can persist in the face of lots of highly variable climates and influential extreme climate events is to combine these aspects of compensatory scope.

What I've tried to do here is display this in three dimensions, and just to review, the factors that are involved in this recruitment variation persistence, long-lived adults, adults that live multiple years and are often more resilient in the fact of climate regimes than these vulnerable juveniles, these vulnerable recruits that I talked about.

Not only can adults be long-lived, but if they continue to grow throughout their lives so that their size is somewhat dependent on age and their growth is indeterminate, unlike us, fish, trees, continue to grow and as a consequence of that growth they can be very fecund, have a very high potential reproductive output so high in size dependent fecundity.

Then, finally, as I mentioned a couple slides earlier, strong density dependent, big increases in performance at low density.

To illustrate those factors, just draw a contrast and to get away from fish a little bit, let's consider your typical, neo-tropical songbird. It's the Blackburnian warbler, I think. Like most songbirds it's not particularly long-lived.

Its fecundity, or its variation fecundity, particularly compared to some of the other species we'll talk about, is tiny, very small variation in fecundity, so not a lot of scope for highly fecund adults to compensate for bad years.

Then, finally, not a lot of consistent evidence for strong density dependence in a lot of these songbird species. All of these factors combine to put species like Blackburnian warblers and other songbirds at the very corner of this three-dimensional space that describes the potential for compensatory response.

As I mentioned you can have orders of magnitude variation in fecundity as a function of adult size and similarly forest trees where you also have that same very high variation in fecundity particularly for forest trees. They're long-lived. They continue to grow, continue to get big, and for both the salmonid fishes that I've studied and forest trees that folks like Tony and many others study - very strong density dependence so very good performance at low density.

All of these factors giving species that are in this piece of life history space a lot of compensatory scope to buffer the effects of extreme events.

Given this very high variation in recruitment with simultaneous persistence, what are some of the management implications for dealing with changes in extreme event regimes associated with these kinds of temporal variations in populations?

One important one, or one thing that's really worth looking at, is can we define recruitment failure thresholds? We talked about populations' abilities to buffer individual bad years, individual recruitment failure events, but how many climate-related bad years are too many, and can we directly relate those frequencies and magnitudes to climate predictions?

I want to talk a little bit about some work that Yoichiro Kanno did when he was a post doc, working in Ed's lab, working with us on brook trout, and he used a matching model to look at brook trout abundance from a really good long-term population monitoring program from the Shenandoah National Park so a great data set. I think about 25 years of data.

He parameterized a model, environmental model, based on those data, and then in the model he changed the frequency of different kinds of extreme climate events in different seasons - low flows, high flows, winter, summer, fall.

Because he had that kind of data he was able to do some scenarios and look at how these populations would respond particularly with respect to their persistence under different regimes.

What he found was that under reasonable levels of extreme event frequency as we see now we saw a strong ability of these populations to exist. So low flows every five years, high winter flows every five years. We really didn't see a change in equilibrium adult abundance.

As we got into more extreme situations, higher magnitudes, higher frequencies, and different combinations, Yoichiro did start to see some thresholds that beyond which these populations would decline to very low and very vulnerable numbers.29:22

If we've got good population models we can try and look at the scope for persistence under different types of extreme climate event regimes, and that can help to improve our forecasts, get a better sense of that original science question I posed, "What is likely to be more important, changes in extreme events or changes in mean temps?"

Another interesting, from my perspective, imagined implication, implication for how these populations persist under recruitment uncertainty, is that we tend to focus a lot on resilient habitats with respect to population persistence.

But our understanding of population dynamics suggests that if we manage to maximize compensatory scope and storage for those species where it's really important we might do a lot of good, as much good as focusing on habitats.

One way to do this is to focus on individuals and/or life history strategies with high reproductive value, for example this giant lake trout that might have a potential fecundity of 20,000, 30,000 eggs.

We're justified in this focus in a wide range of research. Some of our own research in our study system in Westbrook has really pointed out the value of these large, potentially highly productive value individuals in the population.

We have here in the top graphic, the only graph, is we've got size state on the X-axis and the summed elasticity, which is how influential variation in survival of fish at any of those size classes is to overall population performance, in this case measured as lambda, the population growth rate, one if it's a stable population, above one, below one if it's declining.

What we found was in this model - and this is work that we published in 2007 in PLoS - is that the influence of these large high reproductive value individuals, even though they were a relatively small proportion of the population, was well out of proportion to their abundance.

It suggested that if we target management strategies for these large individuals that we might be lending these populations a lot of resilience in the face of variability. What's nice is that we've actually got some management tools to try and address this.

Almost everyone in fisheries has heard of slot limits, and this is in contrast to size limits where fish need to be a certain size before you take them, that where in contrast to the size limit in a slot limit you've got protection both for young fish, for small fish, that haven't yet recruited to be a spawning population, which is the classic justification for the size limit in managing a stable fishery, but you also have protection for those large high-value individuals. You're not allowed to take small individuals, but you're also not allowed to take large individuals.

Similarly, in forest ecology everyone is familiar with diameter limit harvest so these are two well-established management techniques that are done for all kinds of reasons but we suggest might also contribute to resilience from extreme events and the population variability associated with it.

If we get our models right and do this work correctly we can give managers an idea of just how much resilience they're getting from these management techniques. Exploitation isn't the only thing that selects against large body size, selects against these individuals that might be very important in resilience to extreme events.

One of the other things we found in our modeling exercise, modeling work at Westbrook, is that we've got three sites, the red, green, and blue lines here that are part of a connected system, so two tributaries and a main stem where individuals can move freely between those habitats.

The purple line describes the situation in one of our tributaries which is isolated by a waterfall from the rest of the system.

What we found really clearly was that we looked at probability of survival. Survival probabilities for these large potentially high-value fish were substantially lower in these isolated tributaries providing evidence that there's selection, potentially, against large fish in isolated habitat.

This selection against large high-value fish in isolated small stream habitats combined with access to high-growth downstream lake and ocean habitats. Allowing fish to move to gain these growth opportunities, which is again probably the fundamental reason why fish adopt migratory strategies in the first place, allowing fish to do that, allowing not just fish but individuals from any species to maximize growth opportunity if and when size is related to fecundity and reproductive value can help to contribute to resilient populations.

I'm going to move from temporal variation recruitment associated with environmental variability to spatial variation, and one interesting thing to note is that I've talked about, some temporal mechanisms that can restore or regulate the numbers of individuals, that can help regulate population size and keep them low.

One interesting thing is even though these mechanisms can help population numbers recover from low values they can't restore alleles. They can't restore genetic diversity.

As these populations go through bottlenecks, even if they're able to respond demographically in the way that we've talked about, they're still going to lose genetic diversity with some potentially important consequences.

This is a really interesting contrast with spatial compensatory mechanisms where you've got the potential both to restore numbers, the mechanisms I'll talk about, and to restore and conserve genetic diversity. This has some implications for populations in the stage of extreme events.

The basic idea here is that instead of good years compensating for bad years, good locations, locations where numbers are good for compensating for bad locations, this is supposedly tied to meta-population concepts where we have subpopulations potentially subsidizing each other and maintaining the overall population level.

And also more recently to what Dan Schindler described as portfolio effect where if you've got variation, environmentally associated variation in recruitment, you're encompassing a diversity of conditions that may respond differently to extreme events, you can enable persistence.

That's why this...if you've got this diversity across the landscape and subpopulations are connected can be a really important mechanism for keeping populations resilient. 39:17

I said I was going to talk a lot about Westbrook and brook trout. Now I'm going to talk a lot about Hurricane Irene, which was a major flood event that occurred in 2011, record flooding in western New England and a flood of record in many, many rivers, lots of damage, lots of impact, and along with this, of course, we saw some immediate reductions in trout numbers.

Oftentimes trout populations are quite resilient, particularly the adults, to pretty high flows. They're good at finding refuges. They're good at persisting under what seems like pretty intense conditions.

In this case we saw some substantial losses, particularly of our radio-tagged fish where we had really good records. They were adults. They were successful. It was a really big flood, and you can see from the picture, the top picture there, you've got lots of bed movement, lots of scour, lots of action, lots of power, and that's the thing that really gets trout.

We were interested, and we actually had the ability to try and look at how this reduction, this extreme event, put populations in jeopardy of reductions of genetic diversity with potential longer-term consequences.

Again, even though they could potentially recover demographically, what were the consequences? Genetically we were in luck because we happened to have genetic samples from a number of rivers that were subsequently impacted by Irene, before Irene and then after Irene.

On the left hand side this is the Millbrook watershed, which is in western Massachusetts, and on the right we've got a number of alleles, measurable allelic diversity in two sites, which, again -- I wish I could find a pointer, but I can't-- in the Millbrook above and below a barrier to migration.

While we saw reductions in allelic diversity at a number of those sites, what was interesting or the interesting result that seems to be emerging - and these data are still being analyzed - is that we were most concerned about sites - I don't know if you can see this - small headwater sites that were above barriers, which our thought was they would lose allelic diversity as a consequence of this reduction in number in the flood, but it couldn't then be subsidized from downstream.

Those were our major concerns, but what turned out is that the sections that seemed to lose the most allelic diversity were the further downstream sections more towards the main stem Millbrook, whereas our headwaters actually retained allelic diversity quite well.

This bears directly on this concept of the portfolio effect, because it's potentially a really good illustration of how extreme events, extreme climate event disturbances, if they manifest differently in different systems can be buffered against by the populations.

What we think we're seeing here is that even in very large floods, very, very small headwaters right at the threshold of perenniality may be less vulnerable because they experience, depending on the way the flood is generated, reduced increases in per unit power during flood generation.

Once you get to the mid-reaches, once you get downstream, you're going to see increase in power, bed movement, overbank floods, and that jives very well with what we actually saw on the ground with Irene that the streams and rivers that really got hammered were mid-reaches and not headwaters.

What's interesting, too, is that other kinds of extreme climate you could see the exact opposite. For example, droughts might be particularly challenging for headwaters again at this threshold for perennial flow, which is actually quite a bit of brook trout habitat.

Maintaining these connections between different habitats that respond differently to extreme events could be quite important.

With respect to management implications, well, I mean, it's like being against apple pie to be against increasing connectivity. Everyone wants to do it.

We all know it's important. It's a major management initiative, but again, by recognizing some of these effects and establishing them we can value them with respect to their resilience.

More interesting in a sense is that you do have some potential challenges or some potential conflicts for species with relatively narrow habitat requirements.

For example, cold water fishes like brook trout if you're prioritizing based on thermal resilience, and you're focusing only on the headwaters, or you're focusing only on one longitudinal strata in the network you're not going to get that portfolio effect of differential impacts at differential points in the system helping to make populations more resilient.

That's where some of these prioritization schemes, folks like Matt Tibold, in the Midwest that specifically consider stream order diversity in terms of prioritizing barrier removals can be particularly important even for species with relatively a narrow requirement if that stream order diversity also results in extreme events having differential effects in different parts of the connected network, and, obviously, incorporating this into model simulations is key.

Then, finally, you've got some interesting potentials for directly mitigating the effects of losses of alleles during loss of genetic diversity during extreme events, and we're working with that now with the genetic refuge experiment where we're bringing fish from anthropogenically isolated into ontogenetically isolated populations and trying to restore that diversity and seeing what effect that has on this.

I'll go relatively quickly through the rest of my slides. In addition to demographic and conservation genetic effects, obviously this has important effects of climate regimes on habitat themselves. 47:01

The real difference here is that with the demographic effect we're talking about climate events moving things up and down with respect to some carrying capacity. With respect to the climate regime's effect on habitats we're looking at changes in the carrying capacity itself.

A way to demonstrate this is, in contrast to the top graph that I showed earlier, the bottom panel you've got a lower carrying capacity for older juvenile fish, and that's going to result in a substantially lower ultimate population size, and that often results in changes in habitats.

Streams and rivers: extreme events always had some recognition of their importance, strong influence with the two-year flood in shaping channel planform, bed caliber, flood plain/channel connectivity, a lot of things we're interested in.

What about the more extreme flows associated with things like Hurricane Irene and that may become more frequent and more intense in the future?

An interesting point here is that you could potentially see a shift in some dominant habitat-forming mechanisms, mechanisms associated with importing wood, sediment, and other materials from terrestrial environments to streams, changing the relative dominance of chronic processes like single tree mortality, bank erosion, to more episodic mechanisms, for example, extreme winds and hill slope failure shown in that study, the picture to the left.

Similarly in forests, direct relationship with the frequency and magnitude of timing of extreme events with respect to the relative importance of climate associated events like fires, floods, wind flow, drought, versus the classic competition and successional dynamics.

In terms of management implications I think that the interesting thing here is to try and bring extreme event predictions and habitat goal expectations together and also underscore the need to combine empirical mechanistic models, both of which have strengths and weaknesses with respect to their ability to incorporate extreme events.

Empirical models, those events are in there. For example, all the mechanisms that determine a climate envelope for a given species, frequency and magnitude of extreme events is implicit, but mechanistic models can help make them explicit and help us look at thresholds for tolerance and perspectives.

This could be particularly useful when we've got a lot of work. For example, this is work done by Dave King in my lab on disturbance dependent birds establishing these relationships, the ability to tie these relationships between time sensitive disturbances, in this case actual manual treatment, but potentially natural disturbance, could make these models much more effective.

I'm going to end quickly with respect to some human responses, and when I'm talking about human responses to extreme events, I'm talking about responses to the events themselves and also responses to the risks, of either the perceived or actual risks of these events.

With the general point being that in highly settled regions like the north and northeast human response has the capacity to really override natural dynamics and do what I'm going to call - and I realize this is a value-laden way to describe it - very strong influence on whether or not you catalyze ‘virtuous’ versus ‘vicious’ cycles of response and impact from the perspective of natural resources.

Just briefly what I mean by that. Obviously, Hurricane Irene, as you guys know well, and other hurricanes, that not only affected habitats and natural populations but a big impact on people of particularly limited infrastructure.

One route, one virtuous cycle that could be catalyzed by all these road failures is recognition of their importance, real emphasis on right-sizing road stream crossings with the confidence and benefits of less damage next time.

We've shown pretty clearly that those road crossings that were right-sized for our groups, and Nat Gillespie, and National Park groups, those folks. That those were crossings that were right-sized, that were over the banks or width of the channel and on that graph in the presentation there, were much less likely to fail than the large majority of crossings that were less than bank-full size. You've got less infrastructure damage, and you also have more habitat connectivity and more resilient populations, what I would call a virtuous cycle.

In contrast, catastrophic flooding, roads go out, regulations lifted. Anything that's at hand gets thrown in the stream to rebuild the road, and you've got the possibility for more damage next time, more habitat fragmentation, and more vulnerable populations.

I wanted to close by referencing a riparian study by Anita Milman here at UMass, the Department of Environmental Conservation. Recognizing how important people's responses and attitudes are in moving things along different paths, is currently working on a survey of riparian landowners in Vermont who have been affected by Irene. Their responses are worth listening to and worth engaging if we want to more fully manage in the context of these kinds of changes and extreme events.

One of the things that we can really do with respect to looking at the multiple dimensions of resilience extreme events is to put this in the context of vulnerability and exposure. This is a graphic that Andrew, Ben, and I put together and what it shows is how with increasing exposure to any kind of climate impact, which is on the X-axis. The deviation of that horizontal line, which is ‘no sensitivity’.

So essentially, you're having no change in the performance parameter, in this case abundance, with increasing exposure to climate extremes or other aspects of climate. Then, the family of curves below that show increasing levels of sensitivity to a given level of exposure and we found this a really helpful framework within which to put both the different mechanisms of the resilience and the different management actions that can be taken to try and address that resilience.

Shayna: Shawn, I’ll turn it over to you. Did you have any closing comments or words for us?

Emily: Hi. This is actually Emily Fort (Shawn had to duck out) from NCCWSC, but just to say thanks to Keith and to everyone for attending. As always, we appreciate it.

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