Predicted Climate Change Effects on Fisheries Habitat and Production in the Great Lakes

Webinar Transcript

Speakers:
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Ashley Isham: Good afternoon from the U.S. Fish and Wildlife Service's, National Conservation Training Center in Sherpherdstown, West Virginia. My name is Ashley Isham. I would 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.

I have the pleasure of introducing today's speaker, Dr. David "Bo" Bunnell, and he will be presenting "Predicted Climate Change Effects on Fisheries Habitat and Production in the Great Lakes." Bo has been a Research Fishery Biologist at the U.S. Great Lakes Science Center for the past nine years.

His research focuses on trying to understand the mechanisms underlying the dynamics of pray fishes in the Great Lakes, with a particular emphasis on the interactions with invasive species, zooplankton and climate change. He received his B.S. in biology from the Centre College in Danville, Kentucky. His M.S. from Clemson University, and his PhD from Ohio State University. Bo, welcome.

Bo Bunnell: Thank you Ashley. Today we're going to try to make some linkages between climate change and fisheries habitat in the Great Lakes. I just want to say from the start that I am really just a spokesperson of a lot of really smart people's projects that we have melded together for one sort of synthesis that I'll present today.

Those include Chuck Madenjian and David Warner from USGS, Brent Lofgren and Marjorie Perroud from NOAA GLERL, Paris Collingsworth and Yu-Chun Kao from University of Michigan, Randy Claramunt from Michigan Department of Natural Resources, Carla DeMarchi from Case Western Reserve University, and Michael Murray from the National Wildlife Federation. You'll see these names come up as we move through the outline of this talk.

Starting from the global scale, many of you are probably familiar with the projections that have been forecast. As you look at the latest forecast from the IPCC, you see a couple of obvious trends. The first is that the projections for increases in surface temperature are much greater over land than they over water, and then the increases actually are greater as you move away from the equator.

When we think about large systems, freshwater systems that occur on land especially at northern climates, you can imagine they could be disproportionately impacted by changes in climate. As we look at the research that has been done to date, mostly looking backwards over the past 50 years or so in these large, deep freshwater lakes, there have been a few consistent changes.

First of all increases in water temperature, especially in surface waters, an increase in thermal stability and reductions in ice cover. However, as we look to biological responses or even changes in chemistry, the consistency has not really been as apparent so far. Just to give you an example of some of those changes in a few of these particular systems, one is Lake Baikal in Siberia.

This is a nice synthesis paper by Moore et al. in 2009 showing reductions in ice duration since World War II or so, so that today there's about 18 days longer without ice. Also, increases in mean annual water temperature, about two degrees celsius. As we move to the Laurentian Great Lakes, focusing on some work done in Lake Superior which is the largest, deepest, and northern most of our Great Lakes.

If we look at the affect of ice cover on other measures of the physical environment from 1979 to 2006, you can see, essentially, that when you have less ice on this side of the relationship you get an earlier stratification period and you get warmer water temperatures for different basins of the lake. Just to give you a sense of how some of these physical parameters have changed through time and how we might expect them to change in the future through a warming climate.

For those that aren't familiar with our study region, the Laurentian Great Lakes and its watershed highlighted here in brown is home to more than 30 million U.S. and Canadian citizens. It's contains about 20 percent of the world’s surface freshwater, and that, in turn, provides drinking water to tens of millions.

It has 17,000 kilometers of shoreline. To put that in perspective, that would wrap about halfway around the world's equator. On those shorelines are numerous recreational activities as indicated by this beach photograph from Northern Lake Michigan. When we bring it down to fisheries, they are a key economic driver within our region. Directly they spend about $2.5 billion in our most recent year of data. The multiplicative impact of that is about $7 billion.

So they are a key aspect of our economy and also, of course, the ecology of the Great Lakes. For our research, we really tried to take a mechanistic approach to try to take atmospheric climate and take that down to a level here on your right side, an effect on fisheries management. To do that we looked for ways in which climate effects could have an influence on fisheries.

A fairly simple example is we might expect less ice cover in the future. There have been previous papers that have shown a linkage between ice cover for species such as Lake Whitefish, that's a valuable commercial fishery in the Great Lakes, which have their eggs over wintering under the ice.

In years in which you have less ice cover to protect those eggs, you tend to get fewer recruits or fewer number of those eggs that ultimately survive and make it to be in the fishery. We can think about multiple climate-driven effects, and just for the sake of time I'm not going to walk you through this.

Again, the general idea, as will be illustrated throughout the talk, is we can think about measures of climate. Think about how those may be mechanistically influencing fish and ultimately how that may impact fishery management decisions.

Ashley: Excuse me, Bo?

Bo: Yes?

Ashley: Could you please speak up or move a little bit closer to the phone? We have some participants who are having difficulty hearing you.

Bo: Sure.

Ashley: Thank you very much.

Bo: Our overall conceptual framework then tries to take into account this mechanistic approach, and to do that we laid out a couple of different scenarios. First is a retrospective analysis where we use historical data to try to detect climate signals on biotic variables.

Secondly, we shift to forecasting. Looking forward, can we develop localized climate predictions for the Great Lakes region and take those forecasts and, first of all where we find climate signals in our historical data, try to forecast that response from say a fish in terms of its growth or its recruitment, or secondly where we have previous understanding of climate impacts on biota, we can apply that previous understanding to forecast the particular effect. Is that any better in terms of sound?

Ashley: Doug or Mark, can you hear Bo better? You can just text-chat it in.

Bo: Yeah, because I'm not seeing the text-chat.

Ashley: Yeah, that's fine. I can hear a lot better. Thank you.

Bo: All right, I'm just speaking louder then. That really sets the outline for today's talk. We'll have four mini-talks. The first two are retrospective analysis looking for climate signals, we'll then move into the forecasting component. First of all here in number three, where we provide some downscaled climate forecasts, and then fourth, some forecasts for how growth of a particular fish species could be affected by these climate regimes.

First is an analysis of primary production in chlorophyll-a, and this work was lead by David Warner from USGS, and Barry Lesht. Dave is pictured here with his family. The idea was to try to detect to what extent climate nutrients and dreissenid mussels are influencing primary production in the Great Lakes.

Why is it important or why do we care about lake productivity? At the global scale, there's been tremendous changes in lake trophic status over the past 50 years. Some lakes like Lake Victoria have been increasing in productivity, eutrophication as we say. Other lakes like the Laurentian Great Lakes have actually been undergoing an oligotrophication, a reduction in nutrients to the system.

This productivity affects ecosystem services such as drinking water, recreational opportunities -- you don't want to swim where you can't see your toes, for example -- and then ultimately production of harvestable fish. The linkage being phytoplankton supporting zooplankton, which in turn, supports baby fish, and ultimately the survival of the older fish.

We can think about phytoplankton production, or chlorophyll-a, which is a surrogate for phytoplankton production, in a couple of different ways.

The first is as a measure of timing. Typically, what limnologists and ecologists see are these different modes in terms of peaks of biomass, where phytoplankton tend to bloom first, followed by zooplankton and fish larvae. Since the days of the early 20th century, managers and ecologists have been aware of the overlap necessary between larval fish and zooplankton.

One concern about climate change is that you could get differential responses. In a less-than-ideal situation, you have earlier blooms of phytoplankton. The zooplankton and fish may not respond in the same way. You could end up with starvation of larvae or starvation of zooplankton. The second component, beyond timing, is magnitude. This is another fairly simple concept, illustrated here.

Essentially, the base of the food web is primary production. That algae that is produced, fixed carbon from the sun, and ultimately, as you move up each trophic level, we see a trophic efficiency rate of about 10 percent, on average. As you widen the width of primary production, or narrow it, ultimately you're going to have consequences on the fish and the zooplankton that are dependent upon that primary production.

Now, moving to the Great Lakes, both Lakes Michigan and Huron, where Dave's work was located, this just gives you a sense of that oligotrophication that's been occurring. We see declines in total phosphorus loading into the Great Lakes. This is a result of legislation back in 1973 between the United States and Canada, which eliminated phosphorus being put into washing machine detergents.

We've seen with that a concomitant decline, slowly, in total phosphorus measured in the spring. That phosphorus decline has been accelerating since the late 1990's. That is largely attributed to the proliferation of an invasive species called quagga mussels. The Great Lakes first had the zebra mussel invasion, which was well publicized. Now it's almost all quagga mussels.

We can see here by this graph, where chlorophyll A is measured in the summer, this is the time when Quagga mussels that live on the bottom of the lake should not have access to the entire water column. During the summer, of course, the lakes are stratified. You have a warmer epilimnetic layer on top of a colder hypolimnetic layer.

Essentially, mussels are not able to have all of that phytoplankton from the epilimneon and metalimneon rain down onto them for their filtration. Even in the summer time we see a dramatic decrease, over this period when quagga mussels proliferated, a dramatic decline in chlorophyll-a. Dave's research questions were, first, has the timing and magnitude of phytoplankton production changed in these two Great Lakes since 1998?

If so, to what extent can we attribute that to climate or other variables? The data for this talk is based on satellite-derived estimates of lake-wide chlorophyll-a and primary production. Satellite, here's the snapshot from May 20, 1998. The color of the water, through algorithms, can estimate how productive that particular lake is on that given day. This method of using satellites has been validated, and Dave was interested in looking at this over two different time periods.

First, the pre-stratification time period, that is when we assume mussels have full access to the water column. Then, the entire year, that is the entire ice-free portion of the year, when this technique can work. It doesn't work, of course, when ice prevents you from seeing what the color of the water is.

In terms of the explanatory variables, climate variables included spring air and water temperatures, spring precipitation, annual air temperatures within the basin and annual water temperatures in the lake. Also included the effects of nutrients. Phosphorus is the limiting nutrient in these freshwater systems, so he looked at not only how much phosphorus was loaded into the system in any given year, but how much was measured in the offshore waters by EPA.

Then, lastly, dreissenid mussel densities were included in the model. In terms of the timing, the analysis was simply, "Does the bloom occur earlier in warmer years?" In terms of the magnitude, he took a multiple linear regression approach, and then used the information criterion to try to determine what model was most parsimonious, that is, best explained the data without over-fitting the model with all of these parameters.

In terms of the timing, these are the estimates. The solid line is the estimate for chlorophyll A, the dashed line is the estimate for primary production. A couple of things jump out at you. First of all, primary production, the dashed line, in every year we see the peak in primary production is occurring after the date of stratification. The stratification date varies through time, but it's always this solid line I just showed you.

Chlorophyll-a really differed between 1998 to 2001, so above that red line, and 2002 and later. Earlier you tended to see peaks, sometimes before, sometimes after the stratification date. Some peak in chlorophyll-a might be associated with spring diatom bloom. After 2002, chlorophyll gets much flatter in most years. Some years there was a peak, but it occurred much later.

There was no evidence that the timing of phytoplankton production was related to water temperature between 1998 and 2008. The magnitude is a little bit different story, however. This is the average across these two different time periods for both chlorophyll-a and primary production. The first model for spring chlorophyll-a, the key driver was nutrients.

It was a positive effect, as you would expect it to be. Secondly, was a negative effect of dreissenid mussel densities. No climate variables were included in this best model. The model for spring primary production, the best model through the information criterion approach really was not meaningful from any biological sense, in terms of its r-squared was quite low.

Shifting then to chlorophyll-a over the entire ice-free period, again a negative effect of dreissenid mussel densities. Then, curiously, we have a negative effect of water temperature, but a positive effect of air temperature. Now, Dave did do the diagnostics for co-linearity and both of these were permitted to be included within this multiple regression model.

If we think about some of the potential explanations for this, and this is speculation, we can imagine a positive relationship between temperature and chlorophyll-a, because we know that up to a given point, carbon fixation increases with temperature, which is why we saw higher primary production in the summer than in the spring. Another potential explanation could be that in colder years, you have later stratification.

Therefore, you're increasing the time in which muscles have access to the entire water column, greater access to phytoplankton. Therefore, you would have reduction in chlorophyll-a. Alternatively, you might think about another top-down response where an inverse relationship, as was indicated by water temperature, could be the result of zooplankton grazing.

Zooplankton also are more productive, consume more, grow more, in the warmer temperatures than in the colder water temperatures. This could be an explanation for the negative relationship. For primary production, again it was a positive effect of climate, of air temperature, and a negative effect of dreissenid mussel muscle densities. In conclusion, in terms of the timing, there was not any evidence that the spring bloom has shifted earlier in warmer years.

That effect is usually swamped by an effect that emerged over 1998 and 2008 of dreissenid mussels and to some extent, also, nutrients that were available. In terms of the magnitude of phytoplankton, mussels were a consistent explanatory variable in three of the four models.

Climate showed up for both annual magnitudes, but future research is needed to try and disentangle these interacting effects of temperature and biotic interactions on the magnitude of phytoplankton production. We're going to shift now to mini-talk number two. One on crayfish recruitment. This was lead by Paris Collingsworth, pictured here. Paris, at the time, was a post-doctoral student at the University of Michigan.

He's now moved on to Illinois-Indiana Sea Grant, where he is a Great Lakes ecosystem specialist. This work is now in press in transactions at the American Fisheries Society. What Paris was doing was trying to understand to what extent climate factors regulate crayfish populations in Lakes Michigan and Huron. First of all, a little background, why do we care about recruitment of crayfish?

First of all, we need some level of recruitment to occur over time to replenish populations and fisheries. Unfortunately, that replenishment process, that recruitment, is highly stochastic and has been very difficult to predict. We know, theoretically, that the number of fish recruits must be related to the number of mature adults and the number of eggs that are produced but rarely, if ever, does that singularly predict recruitment success with any high predictability.

There's a long history in fisheries ecology and management to try and bring in other environmental predictors, biotic and abiotic, including climate, to try to improve predictability for fisheries recruitment. In the Great Lakes, we've seen crayfish support valuable recreational fisheries that I alluded to earlier. Actually, some of the planktivorous crayfish also support their own commercial fisheries.

But there's been a strong trend over the past 20 or so years of declining crayfish recruitment in biomass in several of the Great Lakes, including the ones, Lake Michigan and Huron, that were the focus of this work. I'm calling this work "The Tale of Two Lakes." This is the time series that Paris analyzed for Lake Michigan.

You can see that the bulk of the biomass is composed of bloater and alewife, two different species. At present times, they are near record lows, in terms of biomass. Despite the record low levels of crayfish biomass, we have not seen declines in the fish eaters, the piscivores, that eat those crayfish. We've seen stability in terms of Chinook salmon biomass, and lake trout biomass, based on model data provided by Michigan State University.

Contrast that with Lake Huron, it does appear that we have...Sorry, this is the axis. This is biomass on the y-axis. There has been a general decline, with the caveat that we've seen a resurgence in bloaters in Lake Huron in the very recent years. What I want to draw your attention to is this dark purple and light purple. This is the alewife in Lake Huron, which was a consistent, a large part of the biomass, but has been nearly extirpated since the early 2000's.

Alewife has remained low level since then. What that has meant is lake trout have done fine, if not improved, with the decline of alewife, but Chinook salmon have faired much more poorly because of that. What we're interested in doing is trying to understand this variation in alewife and bloater, using both traditional Ricker stock-recruit models, but also in cases where we found temporal auto-correlation in the time series, like we did for bloater, we had to use Bayesian time-varying approaches.

Again, the idea is to determine what factors, beyond the number of adults can we find that influence recruitment. Also, are we finding common factors between these two lakes? For alewife then, I'm going to show you a chart like this for both species, we have the explanatory variables on the left that were fed into the model. These are the ones that included climate variables. These are the putative mechanisms.

For example, we expected long cold winters to be negatively related to alewife recruitment, based on work done down in Lake Ontario, showing evidence of over-winter mortality in the first year. We also looked at other factors, beyond climate, such as the number of Salmon eating predators. This includes the salmon and trout that I showed you, earlier. We're expecting that to be negative.

And lake productivity, tying back into what Dave showed, the idea that the more chlorophyll, the more nutrients we have, that should translate to more food for the larvae. To boil Paris' work down for alewife into one slide is right here. First of all, the height of the bars is essentially the weight of evidence for a particular explanatory variable. The higher the bar, the higher the weight. Like salmon, for example, was consistently found in all of the top-ranked models, using AIC.

Salmon being in Lake Michigan, by far the most important variable in explaining alewife recruitment with smaller contributions from the climate variables. In Lake Huron, we don't see any variable really stand out to any degree. We did see some evidence of lake level having a positive effect, but when we step back and look at the overall R-squared of the model, we see a very low predictability for Lake Huron alewife recruitment.

When we shift to bloater, there's really only one climate variable that we can include in the model. Bloater is a little different than alewife, in that it spends most of its time off-shore, in deeper waters, that tend to be more stable and more cold, consistently. The idea being if winter and spring temperatures, when the eggs are incubating are warmer, then it accelerates incubation rates and reduces exposure to egg predators.

Other factors included things like alewife biomass, the sex ratio of the population. Bloater has another strange characteristic of being skewed towards females, up to 90% in some cases, and adult condition. When you throw these into an AIC model, selection approach, unlike alewife, where we found differences between lakes, we found pretty consistent patterns between Lake Michigan and Lake Huron.

The sex ratio, a balanced sex ratio, is correlated with strong recruitment. Some evidence of condition positively related to bloater recruitment in both lakes. Negative effect of alewife. In terms of this particular focus of our research, unfortunately, there's no evidence for any climate signal in the bloater time series. To conclude Paris' work, looking backwards, climate signals were really difficult to detect for Lake Huron and Michigan crayfish.

Alewife recruitment was more explained by salmon predation. Lake Huron, the model was just biologically unsatisfying. For bloater, recruitment in Lakes Michigan and Huron was explained by common factors, sex ratio and alewife, but no evidence of climate signal. What this did within our own project, was really limited our ability to forecast recruitment of alewife and bloater based on future climate scenarios, which is something we were disappointed about.

What do those climate scenarios look like for the Great Lakes region, in terms of what might we forecast for water temperature, for precipitation, for ice cover? This work was led by Brent Lofgren. We love this slide. This is a picture of Brent. Brent is with NOAA, Great Lakes Environmental Research Lab. Essentially, what he's trying to do is forecast these variables from 2043 to 2070. Typically, I think ecologists are very guilty of this. We think of this as a simplistic chain of events.

You have some measure of greenhouse gases in the atmosphere. That drives some measure of air temperature. Maybe precipitation. That in turn has some ecological impact, which is sort of a one-way linear relationship. Whereas, in reality, it's a much more complex. There are different exchanges that occur between the surface and up here in the atmosphere.

What Brent has done is develop a model he calls CHARM, which essentially tries to take into account all that complexity I just showed you on that slide before. I'm going to show you some of the highlights here in case there are any physical scientists or climatologists on the line. What you can see here is that the results that Brent is going to be showing you are based on this particular GCM and this scenario of greenhouse gas concentrations.

The other thing I should note is that the model does allow one to take the relationships and derive one-dimensional lake column water temperatures for each 40 kilometer grid cell. Stepping through some of the predictions, first in terms of air temperature. What we're showing you is the difference between 2057, which is the midpoint between 2043 and 2070, and 1985 which is the midpoint between 1978 and 1993.

In the winter, you see a real north-to-south gradient. No real evidence of anything different happening over water versus over land. We find much greater increases in the winter temperatures to the north than the south. It's a little bit flipped in the summer, where we find stronger, larger differences. We do see a modulation of air temperatures over the large Great Lakes, where actually the difference is less over the lakes than it is over the land.

Translating that to water temperatures then between these two time periods, historical in blue, and yellow looking out 2058 to 2070. If we look at July or June out to December, what we see is generally about a two to three degree Celsius increase in water temperatures all the way down through the water column.

A couple of other things Brent wanted to point out is in February, we don't actually see the lake getting all the way to four degrees C, which is what we would expect to see, because water is most dense at four degrees. At the bottom, as the lake cools, we get four degree water in the hypolimneon. It's not even cold enough in the future to reach four degrees, so turnover might be happening at something like six degrees instead.

The other interesting thing is in April, typically we see a reverse stratification with the colder water on top, the warmer, denser four degree water on the bottom. In the future scenario, we actually see a stratification more like we see in summer, where it's the warmer water on top, colder water on the bottom. We think about the water balance, that is the difference between precipitation and evapo-transpiration. This has consequences for lake water levels.

You can see that over land, we expect to see a positive net balance. Over water, we expect evapo-transpiration to win out and have a negative net water balance. If you sum this across the entire Great Lakes watershed, you actually get a small negative net water balance, which would predict a small reduction in lake level. Brent's findings tend to predict a smaller reduction in lake levels than some other studies have found.

In terms of precipitation in the winter, so this would be snow falling, we see evidence of lake effect snow. It's on the lakes, and to the land to the east of the lakes. In the summer we also see more precipitation, but it's a much more patchy distribution. In both of these, I should note that you're seeing mostly grays, gray being increases in precipitation, whether it's winter or summer.

And very, very few areas, like maybe down here where it's more white, where you would actually see reductions in precipitation. Finally, ice thickness. Here, if we look back in time, we see ice occurring in southern Lake Michigan. Also some evidence of ice occurring in the deepest northern part of the lake, also deeper ice occurring in the shallower regions of Lake Michigan. Alternatively, into the future, we see barely, if any, ice occurring in the south.

The only ice occurring is more shallow, and limited to these very shallower regions of the lake. The preliminary forecasts are for two to three degrees increase in water temperature throughout the water column. We also found in February that the deepest waters may actually be warmer than four degrees. In terms of precipitation, it's going to be characterized as wetter, whether it's winter or summer.

In winter, we saw more snow, especially within the lake effect regions. No clear spatial pattern in summer, however. Ice cover is less, in general, with that north to south gradiant, more ice in the north. Our last part for this mini-talk is trying to forecast some effects of fish growth. This work was lead by Yu-Chun Kao, who is a PhD student at University of Michigan, and assisted by Chuck Madenjian at USGS.

He was looking at the response of six fish species in Lakes Michigan and Huron. The first question is how does a warming climate affect fish growth? Certainly, the direct affect would be on the fish physiology itself. Temperature affects how much a fish can consume. It also affects how much is lost in metabolism, or how much is lost to ingestion or excretion.

The temperature's also going to be affecting other components of the food web that are going to affect fish growth, such as how many prey are out there, and what's the quality of those prey. We think about fish responding to a warmer environment. How are they going to do that? First of all, fish are ectothermic. They're unable to regulate their body temperature internally, but rather take on the temperature of their environment.

Fish have to balance choices about the temperature they occupy based on...All things considered, they want to stay within their physiological optimum temperature. That is where their biochemistry allows for the greatest or the most efficient chemical reactions to occur, and for consumption to be highest. They also may have to consider quality of habitat, such as is there enough oxygen there, for example.

They also might think about prey availability, or they might consider predation risk. These are things that could keep them from occupying that optimal temperature. As we look into the literature, we find for fish, there's a lot of evidence of this behavioral thermoregulation.

These are data for lake whitefish, published last year from Clear Lake, Maine, showing that fish occupied, on average, temperatures about 13 degrees C, which is very close to their physiological optimum temperature, even when much warmer water was available, or even colder water was available potentially deeper.

The results, for the sake of time, we're going to show today include those for yellow perch, which is a cool water fish, and for lake trout, which is a cold water fish. Again, building on the forecast that Brent provided, we're going to forecast their growth in 2043 to 2070. We're doing this in Lakes Michigan and Huron. The assumption is that fish are going to behaviorally thermoregulate. They're going to occupy that physiological optimum temperature if it's available.

We're also going to assume different densities of prey. We're going to allow them to essentially have high densities of prey, feed ad libitum. We're going to keep them at baseline densities of prey, that is densities of prey that they're experiencing now. They're allowing them to achieve growth rates in today's climate, and then lower densities of prey.

Effectively, what this looks like is for every part of the lake, we have essentially a future forecast of what that water temperature's going to look like relative to baseline. Here for yellow perch, which has a physiological optimum temperature of 23 degrees, you can see that in the future, it has the potential to occupy 23 degree water for a longer period. That was what we assumed happened in the model.

Same thing for lake trout. It's going to be able to occupy eight degree water longer than it can find that water in today's climate. In terms of the methods, fish growth was predicted using a Wisconsin bioenergetics model, which is a mass balance approach. Ultimately, we know from laboratory studies and from field validation that fish consumption is directly related to temperature.

There is a certain temperature, that is their optimum temperature, at which consumption is highest. That's this black circle. Oftentimes there's a realized consumption, or PC. That is because fish can't always feed because of prey densities or some other reason, can't feed at optimum levels. There's a realized consumption, and then within whatever they're able to consume, some of it goes to metabolism loss. Some of it's lost to waste, digestion, excretion.

Whatever's left over can go towards growth. All the energy is essentially accounted for in this model. Briefly, there were some results that are not at all surprising. When prey availability was highest, we found increases in growth for both species. Concomitant with that, we found increases in consumption. When prey availability was limited, growth was reduced.

Here are what the plots look like. On your left is yellow perch. You can see, relative to baseline, when we allowed higher prey availability, we did see an increase in weight of yellow perch at a given age. Again, they would fall below baseline when prey was more limited. On the bottom here, this just shows the amount of prey that would be needed to allow that greater consumption, which translates to higher growth, to occur.

For lake trout, it's actually an even greater increase relative to baseline, and a somewhat smaller reduction during low prey densities. You can begin to see that some species are going to fare better, potentially, say lake trout than yellow perch, in a changed climate scenario. Why might that be? Especially why might that be, because the number of days over which the optimal temperature is increased actually is more days for yellow perch than it is for lake trout.

If you're just thinking about the net number of days increase, you would predict that yellow perch growth would improve more than lake trout. Once Yu-Chun got into the guts of the model, he found that one of the things that was holding yellow perch back was, first of all, they're going to have higher metabolic costs and waste costs in the future. That lead to less energy available for growth.

The other interesting thing was that lake trout could prey upon alewife and rainbow smelt later into the fall at greater rates of consumption. Because these two particular species have seasonality in their energy density, or in the number of calories they have, and they are highest in the fall, that essentially gave lake trout more bang for their buck in terms of not only were they able to feed longer, but they were able to feed on more energy-rich prey in the fall.

Again, for the sake of time, I'll just let people know that Yu-Chun and Chuck have similar estimates for lake whitefish, for rainbow trout, and for Chinook salmon. In conclusions, unless prey resources concomitantly increase, fish growth will most likely decrease in a warming climate. We've got to know a lot more about how many prey will be out there. That just pushes home the point of how fish respond to climate change will depend on more than just temperature.

Our last slide here is just overall take-home messages. One thing that's clear is that climate change in the Great Lakes region is definitely going to affect key fish habitat variables, whether it's water temperature. Remember, even throughout the water column, we saw consistently higher water temperatures even in the hypolimneon being predicted. Ice cover is going to be reduced. Water levels could potentially be less than they are today.

Today, we saw a record low level for water levels in Lake Michigan earlier this spring. We recommend a mechanistic approach to try to translate these climate-driven effects into fish responses. Those mechanisms should obviously go beyond climate factors. To our surprise, our results revealed that non-climate factors really had an even greater impact.

We saw that with the affect of dreissenid mussels on phytoplankton, or the effect of salmon predation on alewife recruitment, or the importance of knowing what the prey densities were to the ultimate response for fish growth. Now, that certainly doesn't mean that forecasted climate change effects should be ignored, that we don't want to leave that message at all.

Rather, it's just that these changes in aquatic habitat must be considered within a food web or an ecosystem context to best understand the direct and indirect effect of climate on fisheries production. We want to acknowledge many people that have contributed data or technical assistance, and also want to acknowledge the National Climate Change and Wildlife Science Center for funding this work.

I also want to say that over the question and answer period, I may kick it to our co-PI's, especially if your questions get highly technical for certain things. This is also intended to let you know that you can contact these people for more information on their leadership of their specific components. That's it. Thank you very much.

Ashley: Excellent. Thanks, Bo. Very interesting presentation, and I like that picture at the end.

Bo: Thanks.

Ashley: Anybody that has questions, there's two methods of asking your questions. First, you can text-chat it in in the chat box that's located below the participant list. You can also use the raised hand icon that is located between the participant list and the chat box. I'll call on you by name, and then I will ask you to have your question ready. Then just press star six, take off the global mute, and then just ensure that the mute on your own phone is turned off as well.

Bo: That would be the same way for other co-authors to answer questions. If I kick it to them, they need to hit star six beforehand? Is that right, Ashley?

Ashley: Yes, that's correct. Thank you.

Ashley: All right, do we have any questions? I see one from Holly.

Doug Beard: Can you hear, Bo?

Bo: Yes.

Doug: I do have a question. I'm curious about the final part. You showed the species by species predictions. It seems to me that we really need to bottle that distribution, like a population ecosystem model. Because if Chinook go up and bloaters go down, or et cetera, et cetera, it's all interacted.

Is there any plans to do that? Just having the three different prey densities was interesting, but it's not going to be as informative of the interactions that would actually happen between the species? Thanks.

Bo: Yeah, that's a great question. We do now have an Ecopath ecosystem model that Mark Rogers has developed for Lake Michigan. We've thought about ways to try to integrate climate responses. As you said, you can't look at these things in isolation because of the feedbacks that are going on.

We have not operationalized that yet, but that's a great idea. We need to think harder about how to actually run EcoSim to simulate a climate effect. Is it going to affect the production, the P/B ratio, for example? Try to look at the guts of Ecopath, which I have not run, but try to look at the guts of that and try to figure out how can we make Ecopath work to simulate the climate change effects.

Ashley: All right, thank you. Did Holly's group have any more questions?

Holly: No, I think that's it.

Ashley: I'm not seeing any more raised hands, or anything coming in the chat box.

Bo: I see one from Gregor Schuurman. Do you see that, Ashley?

Ashley: I don't, I think he just sent it to you. Could you go ahead and read it into the audio record, please?

Bo: Sure. He says, "How do you think your findings might translate to fishes and fisheries, and streams and rivers? Presumably many of the same principles apply, but what is likely to be different?" That's a tough question for somebody that hasn't worked in those systems since his Master's degree.

I think the same process could be in place to try to think about what are the mechanistic drivers that are happening for a particular salmonid, say brook trout in the eastern United States. I know that a lot of people are doing work on brook trout and potential effects of climate change, and trying to use downscaled models to forecast that. I think Ben Letcher would be somebody.

If he hasn't given a seminar in this particular webinar series, I might invite Greg to reach out to Ben, who's really thought about the effect of climate change on stream fishes and could answer your question a lot better than me. Kind of a lame answer. I have another one, Ashley, that's been sent to me.

Ashley: Yeah, go right ahead. I don't have any.

Bo: This is from Donald Rivard. I apologize if I'm not getting the pronunciation right. "Water levels have been historically low, as I understand. Is the predicted trend to continue downward? How much of this water level drop is attributable to dredging in Lake Huron or in Lake St. Clair?"

I'm just going to briefly answer that, and kick this to our water level expert, Brent Lofgren, who is on the line. Just to revisit what I said, that Brent's models are forecasting a little bit lower water levels, but not as low as has been forecast by other modelers that have essentially used different methods to come up with it. Brent, do you want to address Donald's question, in terms of lake levels? Can people see Brent's response here on the chat?

Brent Lofgren: Hi, this is Brent. Actually, I was busy texting a response regarding the previous question while you were saying what this question is, so could you please repeat it?

Bo: Sure. Donald is interested in water levels. He's saying the predicted trend in water levels is to continue downward and how much of this drop is attributed to dredging in Lake Huron, or Lake St. Claire.

Brent: The attribution to dredging in the St. Claire River is a controversial topic. I would say it's not entirely out of the question. We also have a very difficult time of attributing the low lake levels, even though they have persisted over about 15 years. We have a hard time attributing those to greenhouse gas related causes. They seem to be primarily due to the climate and increased evaporation primarily from the lakes, somewhat from the land and the watershed as well.

Yeah, we have not directly linked those to human-caused climate change, there is definitely a large measure of natural variability involved in what we've seen over the past 15 years.

Bo: OK, thanks Brent.

Ashley: Then do you have anymore Bo? Because I'm not seeing them for some reason.

Bo: I do not.

Ashley: OK. All right. I'm just scanning for anymore hands.

Ashley: All right. I don't see anymore questions and so I'd like to thank Bo for a great presentation. Thank you Bo.

Bo: OK. Thanks for the invitation Ashley.

Ashley: Oh, absolutely. I'd like to thank all the participants for their attendance.

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