# Implications of Changing Winter Severity for Waterfowl in the Great Lakes Basin

**Ashley Fortune Isham**: Good afternoon or good morning from the US Fish and Wildlife Service's National Conservation Training Center in Shepherdstown, West Virginia. My name is Ashley Fortune Isham.

I would like to welcome you to our webinar series held in partnership with the US Geological Survey's National Climate Change and Wildlife Science Center, or NCCWSC, located in Reston, Virginia.

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

Please remember a recording of this broadcast will be posted on the NCCWSC webinar page. We'll post that link in the chat box. I'd like to introduce Dr. Shawn Carter, senior scientist at NCCWSC, to introduce our speakers for today.

**Dr. Shawn Carter**: Thank you and welcome. It's my privilege to introduce a couple of speakers today that are going to be speaking. First off is Mike Notaro.

He's the associate director and senior scientist for the Nelson Institute for Climatic Research at the University of Wisconsin-Madison, comes to us from State University in New York at Albany. He has expertise in regional and global climate modeling, climate change impacts on terrestrial ecosystems at the Great Lakes, and land-atmosphere interactions.

We also have Michael Schummer. He's a visiting assistant professor of zoology at SUNY-Oswego and Roosevelt waterfowl ecologist at SUNY-ESF, my alma mater. He's a graduate of Paul Smith's College, SUNY-ESF, Southeast Missouri State, and received his PhD from the University of Western Ontario.

His lab focuses on applied wildlife science with emphasis on ecology and management of wetland systems in North American waterfowl. Without further ado, I'll turn it over to our speakers today.

**Dr. Michael Schummer**: Thank you very much. I greatly appreciate the introduction and opportunity to talk to everybody today. This is Mike Schummer. I'm going to start us out and then do a hand-off to my colleague, Michael Notaro. Then I'll come back and talk about actionable science and management implications.

I just noted I have the title wrong here on the slide. Things are changing frequently these days. We can all bear with a few little differences there. Michael and I have been working on this for quite some time together now/ There's some good history here with lots of partners you'll see in the next slide. The webinar's going to have four sections.

That's the, "What was the real need for and development of weather severity indices for waterfowl? What have the long-term changes in that weather severity index been in the eastern portion of North America, the Mississippi, and Atlantic Flyways 1979 to 2013?"

Said another way, "Has the weather become milder for waterfowl giving them the opportunity to winter further north, which is anecdotally what we had been hearing?"

Then Michael Notaro's going to talk about wildlife implications of changing winter severity in the Great Lakes Basin. These are our projections of what the distributions of these birds may be into the future. Then I'm going to end with actionable science and management implications.

We'll start with a little NASCAR slide here, and recognize the coauthors and the support that we've had throughout this process. Michael Notaro's coauthor on this along with Lena Van Den Elsen, who is with the University of Western Ontario, John Coluccy, Mike Mitchell, and Robb Macleod from Ducks Unlimited.

Then prior work that has gotten us to this point was conducted with Judah Cohen of Atmospheric and Environmental Research, Rick Kaminski, Charlie Wax, and Mike Brown at Mississippi State University, and Andrew Raedeke and Dave Graber from the Missouri Department of Conservation.

As you can see, we've had a fair amount of support throughout the years from a diversity of funding agencies and research partners.

The first portion of this is really about the development of these weather severity indices for dabbling ducks in Eastern North America. We focus largely on dabbling ducks because as far as abundance estimates and interest from the waterfowl hunting community, dabbling ducks were at the top of that list.

Those of you that are not really super familiar with waterfowl, they are ducks, geese, and swans. They're ecologically, environmentally, culturally, and economically important.

Ecologically, they number in the millions. They're relatively large-bodied animals with high energy needs that migrate from southern wintering areas to relatively northern breeding areas. They have to fuel that migration as well as nesting.

They do this by feeding on a diversity of plants, seeds, invertebrates, and other animals, dependent upon which species you're working with.

They move these seeds invertebrates on their feathers, on their feet, in their bills, and in their guts. They actually are one of the main mechanisms that genetic diversity in plants and invertebrates occurs among isolated wetlands.

Environmentally, they're important because they're biomonitors of the environment because they range from deep oceans to terrestrial areas, uplands, and forested habitats.

Wetland restoration programs that are focused on conserving waterfowl also benefit a diversity of other species. Economically, they're extremely important for the birding and hunting community, which I refer to as waterfowl enthusiasts.

Each of these groups spend billions of dollars annually with waterfowl hunters having to buy duck stamps or wildlife habitat stamps that go directly back into national wildlife refuges and other federal and private lands programs. As an example, economically in Mississippi alone, the economic impact of waterfowl hunting is estimated to be $86.6 million per year.

Why did we investigate dabbling ducks? This all started when I was working at Mississippi State as a postdoc in 2007. Prior to that, there had been a lot of discussion of where have all the ducks gone.

It seemed to a lot of the waterfowl hunters that spend hours annually in the field that the numbers of birds that they were seeing had declined drastically. They were showing up later into the fall season and winter season.

There was some research that went along with us by Rod Brook looking at black duck winter distribution change, more black ducks wintering in Ontario and Quebec in Canada relative to the States, changes in duck abundance in the Mississippi Alluvial Valley by Reinecke and Kaminski.

The Mississippi Alluvial Valley winters anywhere from, say, two to three million mallards every single winter. Those birds were showing up seemingly later in a lower abundance compared to the past.

What we wanted to answer was has the weather changed as interpreted by a duck? We thought that there would be literature out there that detailed the type of weather that makes ducks migrate. Surprisingly, although there was a lot of anecdotal evidence of what that was, there were not many empirical studies on this.

The first thing we had to do was develop weather severity indices that reasonably predicted autumn winter migration by dabbling ducks. We did this by working mostly with Missouri Department of Conservation data -- we'll talk about that in a little bit -- and mostly with mallards.

That was because mallard are a really common species that are counted quite a bit. That was published in 2010 in "The Journal of Wildlife Management." Once we had that, then we could describe historic changes and weather known to influence duck migration. That was recently published in late 2017 in "The Wildlife Society Bulletin."

Then, because we were getting so many requests for weather severity index data once we produced the 2010 paper, we also wanted to provide an open-access web-based tool to query these data at different spatial and temporal scales. Ducks Unlimited GIS folks helped largely with the development of this program to date.

Then, with the help of Michael Notaro, we wanted to forecast future spatial distributions of dabbling ducks based on climate change. We've gotten through objectives one through four at this point. All of this information is published in some form or another.

The one that we haven't gotten at yet that I think is really the most important one is to estimate how weather severity or changes in weather severity influences waterfowl enthusiasts' participation and satisfaction for use and recruitment, retention, reactivation, decision-making, which is a fairly substantial program that's underway by the US Fish and Wildlife Service.

The first thing we had to do was develop the weather severity indices. We went to the State of Missouri for this because they have well-managed waterfowl conservation areas that have standardized aerial and ground surveys of waterfowl.

What we did was we took a variety of weather metrics, calculated these indices daily, selected the maximum of these between two waterfowl surveys, and looked to correlate weather severity with changes in abundance of these ducks.

What we found that causes ducks to migrate, and this is not anything that we wouldn't be surprised with, but we put some numbers to it. What caused them to decrease in abundance or change their abundance was, "How cold is it on that day?

"What's the snow depth in inches? What are the numbers of days in a row that have been below freezing? What are the numbers of days where there's been measurable snow?"

This makes sense because these are direct impacts on the energy output of that bird at any time and the factors that also affect the energy intake. The snow interferes with these, especially mallards, being able to field feed. They very often fly out to cornfields and eat energy dense corn.

Then the numbers of days below freezing influences the wetland icing that can influence energy intake as well. Combined, these have influences on energy acquisition and expenditure.

This is what the weather severity index looks like. Going from left to right is increasing weather severity. Then on the y-axis, we have the rate of change in relative abundance.

Any points below the x-axis, we would have decreasing abundance between any two waterfowl counts. Any points above, we would have increasing abundance. As you can see, we start to cluster points below that x-axis as we have increasing weather severity.

With this one single number, we were able to explain about 40 percent of the variation in the rate of change in relative abundance of mallards at waterfowl conservation areas in Missouri, which we felt was pretty good, especially given all of the different factors that could potentially affect duck abundance in any location to explain 40 percent of that variation with a single number.

We followed this up. Lena Van Den Elsen at the University of Western Ontario used data from across the Mississippi and Atlantic Flyway from 25 locations in the United States and Canada that had standardized data.

We put out a pretty substantial call for data availability for these birds across the Mississippi and Atlantic Flyways. Came up with 25 locations that had standardized data over an extended period of time.

She reran the mallard weather severity index. The curve is quite similar to what we came up previously, which is nice. Black ducks, which are extremely closely related to mallards, had a very similar curve.

Then the rest of the dabbling duck species fell into the weather severity index range that we thought. Green-winged teal migrate relatively early followed by northern shoveler, wigeon, gadwall, and pintail.

What we knew about the progression of the migration of these species we detected with these weather severity indices and could apply them. All of those weather severity indices had this keynote of a fact that temperature, snow depth, the numbers of days that is was below zero, and had measurable snow on the ground.

Then we were able to use these to determine, "Has the weather changed as interpreted by a duck?" The second portion of this is long-term trends in weather severity indices for dabbling ducks in Eastern North America.

The first thing we did was develop this web application tool using North American Regional Reanalysis data throughout Eastern North America from 1979 to 2013. These data are available at a 32 by 32 kilometer resolution, which is about the home range size of most nonbreeding dabbling ducks. It's applicable to these birds.

It's provided at a broad spatial and temporal scale to develop comparisons between weather severity indices, waterfowl populations, and waterfowl enthusiasts' demographics. Using the web application, we were able to calculate this weather severity index for each species from September, 1979, to April, 2013.

The way we output this so that it was user friendly, and there's the web address below, is there i's three color schemes. The blue area would be the weather severity index estimates decreasing abundance or areas below that x-axis. Increasing abundance in red would be areas above that x-axis.

Then anything that was outside of our survey range of when people would even be collecting data, we estimated or assumed, few to no migrants because the waterfowl biologists probably wouldn't be bothering to count if there weren't any birds showing up yet.

The data are available at the LCC Joint Venture Flyway, or state spatial scales, and can be bounded by a beginning and end date and by selecting a species. What you get as an output from this is the daily square kilometers that are greater than the WSI threshold for your area of interest for how much area is in your area of interest where the weather should be severe enough that it would be causing ducks to decrease in abundance or migrate south.

The output from this from 1979 to 2013 shows that from October, November, and December reducing weather severity, or less area where that weather severity index is great enough to cause migration for American wigeon, green-winged teal, and northern shoveler. Those are early migrants, generally.

November, December, January reduced weather severity for mallards, black ducks, and pintails. Then February, March, and April, although this was a fall/winter index, we think it's probably strongly applicable to the spring as well.

What we found was that mallards, black ducks, gadwall, wigeon, green-winged teal, and northern shoveler, all would be experiencing milder weather from 1979 till present. If you look at those slopes, they don't look really substantial.

When we calculate out, say, for November, December, January for mallards, black ducks, and pintails, these are three of our larger ducks that are sought after by birders and hunters. The amount of area that was available for them to remain at northern latitudes increased by 2,866 square kilometers every single year or, let's say, 97,000 square kilometers in 1979 to 2013.

If we use, for the Upper Mississippi River-Great Lakes Joint Venture, the mean of 1,572.7 duck use days per square kilometer, that is the amount of ducks that can be sustained by the habitat, the food resources that are available in that habitat per square kilometer.

I'm going to go with a whole lot of duck use days, but if we divide that by 92, what this means is that an estimated additional 1.65 million mallards, black ducks, and pintails don't have to migrate out of those mid-latitude and northern regions for the 92-day period from November to January.

Said another way, 1.65 million of these ducks are not available to waterfowl hunters and birders, potentially not available at southern latitudes to them that were once available in the late '70s and early '80s. I'm going to hand it off to Michael at this point to go over part three of the webinar.

[pause]

**Dr. Michael Notaro**: Thank you. I just brought up my slides, so hopefully everyone can see them OK. I'm going to be talking more about the projected changes in weather severity during the 21st century and implications on the dabbling ducks.

As mentioned before, this is a collaboration between UW-Madison, SUNY Oswego, Ducks Unlimited, and Michigan Department of Natural Resources.

The funding's through Climate Sciences and NOAA, Great Lakes Restoration Initiative, and NSF. The three primary questions are,"What changes in air temperature, snow depth, and resulting winter severity are projected for the Great Lakes region by the mid and late 21st century?

"Within the Great Lakes Basin, what changes in lake-effect snow might be expected in response to changes in ice cover and resulting evaporation versus cold surge frequency? How will future changes in winter severity affect the population and migratory behavior of dabbling duck species?"

As you can see, this is clearly an interdisciplinary study. It requires a carefully established collaboration of expertise. This is an outline of some of those experts that we've brought together.

From the UW-Madison side, there's myself who studies lake-effect snow in regional climate modeling, Steve Vavrus, who's an expert on climate extremes, Yi-Fung Sung, who's an expert on climate modeling, and Val Bennington, who's an expert on lake modeling.

We also likewise collaborated with Mike Schummer, both with long point waterfowl and SUNY Oswego, who worked in waterfowl ecology and management.

Also, with Lena Van Den Elsen, an expert in waterfowl conservation related to Ducks Unlimited and long point waterfowl, John Coluccy, Ducks Unlimited, an expert in conservation planning, and Chris Hoving from the Michigan DNR, who works in wildlife adaptation and endangered species protection.

First, I want to get to the background on what downscaling is as it relates to climate change. Downscaling is a method for transforming coarse, biased global climate model output into more reliable, local-scale information that targets the spatial scale necessary for resource managers and adaptation planners.

Another background of the importance of generating downscale data for the Great Lakes region is recognizing any limitations in these global climate models. Here, I'm going to plot 26 of the global climate models from the latest CIMA 5 archive. This is the percent water surface in the Great Lakes region.

First 16 I bring up, you'll see there are no Great Lakes in those 16 models. The next four I put up have some of the Great Lakes in them, represented by a couple of grid cells, but some of the lake's not there. Then finally, you could see six more, which actually capture all the Great Lakes.

Only 10 out of the 26 models even include the Great Lakes. Even those models crudely represent these very critical freshwater bodies. Clearly, just using the CIMA 5 data as is, is not going to suffice.

We're going to need to do some technical downscaling to acknowledge those Great Lakes. Downscaling can be done typically two different ways. The first way is statistical downscaling.

In that case, you establish observed relationships between large-scale atmospheric predictor fields and local-scale meteorological conditions. You apply these observed relationships to simulated large-scale output to estimate what should occur at the local scale.

Now there's two concerns for our particular study, is typically this is usually done only for temperature and precipitation, not snow depth.

The second is statistical downscaling is usually restricted by a stationarity assumption which states that all modern relationships will hold true in the future. Problem with that is, is no consideration of the impacts of changing lake ice cover on evaporation, therefore lake-effect precipitation.

In order for us to make these winter severity assessments, we need reasonable assessments of air temperature and snow depth into the future.

Alternative route, which is the one we went with, is dynamical downscaling, in which you use coarse global climate model output, have it serve as lateral boundary conditions to drive a higher resolution regional climate model which dynamically simulates lake atmosphere coupling.

Further on, we're going to use six of the CIMA 5 global climate models. We're going to apply dynamical downscaling using a regional climate model. We're focusing in RCP 8.5 high-end emissions scenario, which is currently about what we're tracking at this point.

We're using the 25-kilometer red CM4 regional climate model interactively coupled to a 1-D lake model to represent the Great Lakes and examine changes in lake temperature, ice cover, and heat and moisture fluxes. We're going to focus on 20-year periods with the late 20th, mid-21st, and late 21st centuries.

Later on, after we run the models, we use simulated daily air temperature and snow depth. We debias them using daymet and global historical climate observations. On the left, I can show the domain. We're basically running the regional model across most of the United States and southern Canada.

A lot of the analysis we're going to do is going to focus more on the Great Lakes region. The methodology, observed relationships were established between changes into their relative abundance of dabbling duck species during autumn and winter at the mid-latitude migration areas of eastern North America and key [inaudible 24:15] winter severity indices, considering both air temperature and snow depth.

That was my work that Mike just alluded to. These relationships reflect the impact of winter severity on duck energy, expenditure, and food availability. Based on these observed relationships, debiased winter severity projections were used to generate projected changes in the population and migration of seven dabbling ducks species within Mississippi and Atlantic Flyways.

Here's a scatterplot of projected changes in winter to spring, two-meter air temperature in Celsius, and precipitation in millimeters per day across the Great Lakes region over land from the CIMA 5 global climate models. Within the global climate models, they're predicting by the mid-21st century warming of about one to five degrees Celsius in the Great Lakes region.

They're predicting an increase in precipitation during the winter and spring of 0.1 to 0.5 millimeters per day. By the late 21st century, these global climate models are predicting the temperature in the Great Lakes region to increase by about four to nine degrees Celsius and precipitation during the winter and spring to increase 0.1 to 1 millimeter per day.

All the models indicate that it's going to get warmer and wetter. You'll see that by comparing the orange and red dots, that's there minimal overlap between the projections between the two periods, although you'll notice the uncertainty increases over time, particularly by the late 21st century.

By making this kind of scatterplot, it helped us decide which of the 6 global climate models out of those 26 choices that we want to dynamically downscale to create an envelope around future changes.

Now moving ahead, we're going to show the results of some of the dynamical downscaling from the red CM4 of these six models.

This is projected changes in air temperature in the Great Lakes region by the mid and late 21st century based on this dynamical downscaling. The left is changes by the mid-century, and the right is changes by the late century. Blue, green, red, and yellow pertain to changes by winter, spring, summer, and autumn.

You can see in the x-axis the six models that we dynamically downscaled. By the mid-century, the original model's projecting warming of about two to three degrees Celsius. By the late century, it's projecting warming about three to six degrees Celsius with the greatest warming in the summer and the least warming in the spring.

Now as I'm going to be alluding to lake-effect snow, it's important to understand how cold air outbreaks and cold days might change in the future, which are going to determine snow versus rain. This is the frequency of daily mean air temperatures in degrees Celsius during November to March within the Great Lakes region.

You could see on the x-axis, there's different temperature bins of daily temperature. The blue bars show the late-20th century climatology. Most of the time during November to March, we're just below freezing.

Then the green and red lines are showing future changes in the frequency of these different temperature bins, basically showing that warmer days are going to increase in frequency and colder days below freezing are going to decrease in frequency. That would infer that in the future, we're going to have more favorable conditions for rain as opposed to lake-effect snow.

Now from the dynamical downscaling, these are projected changes in precipitation, centimeters per season within the Great Lakes region by the mid-century on the left and the late-century by the right, again for winter, spring, summer, and autumn for the six models.

The six models are showing that by the mid-century that we should be getting anywhere from 1 to 8 centimeters more precipitation. On the right, you can see that they're predicting about 8 to 16 centimeters more annual precipitation by the late 21st century.

The models are very consistent with the increases in precipitation in the spring, although they don't have a sense about what's going to happen in summer.

Likewise, again relevant to winter severity, these are projected dynamically downscaled percent changes in snowfall during October to May within the Great Lakes region by the mid-century on left and the late 21st century on right. They have six lines in each plot, one for each of the models we downscaled.

At the bottom of the x-axis, those numbers are the average percent change in snowfall. You'll find that the October to May snowfall is projected to decrease from 17 to 37 percent by the mid-century and from 39 to 57 percent by the late 21st century. The largest reductions occur in the cold seasons' fringe months.

You'll see big percent declines in October/November or April/May, so the snow season becomes greatly compressed. Now furthermore, mentioning about food supply, here it's projected Great

Lakes ice cover. This is shown for blue, green, and red for the late 20th, mid-21st, and late 21st century and for the six different models.

This is basically showing large reductions are projected in February and March such that by the end of the century, we'd have very short ice seasons, mostly ice-free, even in mid-winter. You could see the percent changes underneath each of the plots, where we're looking at percent changes from about 26 to 50 percent decline.

Visiting their future change in lake-effect snow, there's two possible hypotheses on how it might change. The first says that the observed positive trend in lake-effect snow will persist as lake ice cover continues to decline in response to warming and lake evaporation increasing provides moisture to lake-effect episodes.

Hypothesis two argues instead that this positive trend in lake-effect snowfall will reverse as extreme cold air outbreaks, which are the key triggers of lake-effect snowstorms, become less common in response to anthropogenic climate change.

We could allude to a study by Vavrus 2006 in which extreme cold air outbreaks are projected to decline into North America by 74 percent and 87 percent by the mid and late 21st century. Using the output for the regional climate model, I developed an objective method to identify data grid cells that are experiencing heavy lake-effect snowstorms. It's based on five criteria.

First is location within 100 kilometers of the lakes. Second is that the wind must blow off the lake for, at least, six hours. Third is that the lake needs to be, at least, 30 percent open. Fourth is that you have to have a substantial amount of snowfall near the lake. Fifth, that the snowfall near the lake is greater than away from the lake.

Next, we'll show projected changes in annual frequency of heavy lake-effect snowstorm days by the mid-century. It's showing for the six models and also average across the bottom of the six models. You can see by the mid-century a 1 to 20 percent reduction in the frequency of heavy lake effect snowstorm days by the mid-21st century.

Around Lake Superior where even by the mid-century it's still going to be old than we might actually experience an increase in lake-effect snow days. Now, by the late 21st century, it's a different story across the board. The whole region 17 to 46 percent reduction in the frequency of heavy lake-effect snowstorm days by the late 21st century, declining across the whole basin.

Furthermore, in terms of affecting dabbling duck access to food, these are projected changes in the frequency of days with snow on the ground by the mid-21st century. Top left is showing the simulated results of the frequency of days per year with an inch of snow on the ground.

Depending on where you are in the Great Lakes Basin, that's anywhere from 60 to 140 days per year with snow on the ground.

On the bottom six plots per model is showing the dynamically downscale projected changes in the frequency of days per year with, at least, an inch of snow on the ground by the mid-century. You can see by the mid-century the number of days with snow on the ground may decrease by 11 to 31 days per cold season in the Great Lakes region.

By the late 21st century, it's even more extreme. Now we're talking decreases of 29 to 52 days per cold season in the Great Lakes region as the snow line retreats dramatically northward. This has large implications of warming, reduced snow pack, and diminished lake ice on dabbling duck migration.

Moving on, I'm going to show some of the results that was developed by Mike Schummer and Lena Van Den Elsen. This is observationally based. These are empirical relationships that they derived based on over 10 years of aerial and ground-based survey data across the Atlantic and Mississippi Flyways.

For each of seven different duck species, they developed an equation which represent the change in population of species based on the winter severity to the American black duck. This is a quadratic equation for changes in population such that the onset of negative rates implies southward migration.

That's a function of latitude and that's also a function of a term PC1, which is more of a measure of this winter severity based on a temp which is proportional to the daily mean temperature. Temp days, the number of consecutive days below freezing.

Snow, which is the snow depth at the time and snow days, which is the number of consecutive days with, at least, an inch of snow on the ground.

This kind of formula was established for each of the different species. I'll show on the bottom this American widgeon, which seemed to be more sensitive to temperatures during the last seven days. Gadwall has its own relationship. Green-winged teal, mallards. Finally, two more, northern pintail and northern shoveler.

Based on those observed relationships of winter severity, you get a sense about when migration might be expected. Now I'm going to begin to show a kind of complex figure. I'll walk through on how this can be interpreted. This particular example is focused on northern pintail.

This is the probability of negative population rates and, therefore, southward migration by latitude going from 30 to 50 degrees north across the Midwest, Great Lakes, and Northeast United States, and focusing on a time period from September 1st to March 31st.

Going from left to right, this shows you the change in migratory behavior over time due to climate change. The first three columns show the probability for a late 20th, mid-21st, and late 21st. The last two columns show projected changes in that probability by the mid-century and late century going top to bottom as they cross model uncertainty in these projections.

Now for each one of these panels you can see a date, which is the initial date when there's a 50/50 chance that the population's going to begin to decline within 40 to 50 north, which is the general of the Great Lakes Region.

Now that's a lot of information. I'm going to zoom in on one example to make that point where I got that date from. For the late 20th century, I zoom in and the date was November 5th when they start migrating south on average.

The reason you can conclude that is if you look at 40 to 50 north on the y-axis and you head right, once you hit that light blue color, you can see that there's now about a 50/50 chance at around November fifth. That's where that date comes from.

Now we can examine what changes might occur. For the northern pintail, you can find that the two models with the largest winter and autumn warming of the two that experience the largest delay in migration, northern pintails are projected to experience the smallest impact on migration timing.

For the late 20th century, they typically leave the Great Lakes region in early November. The delay is about 12 to 23 days for the mid and late 21st century. By the late 21st century, they may leave the Great Lakes region around late November to early December on average.

Now with each subsequent species, I show you it gets worse. The gadwall, which is projected to be delayed by 13 days by the mid-century and 24 by the late 21st century. The green-winged teal, delays of 16 and 25 days by the mid and late 21st century. American widgeon, 15 and 27 day delays.

The northern shoveler, you'll notice in the left most columns the extensive blue color. That gives you a sense that these are a species that migrate the earliest of the seven species. They're a wetland obligate foraging species. They skim invertebrates off the top of the water in wetlands. They have to migrate before the wetlands freeze, so they leave early.

Right now, in the late 20th century, they were typically leaving the Great Lakes region in early October. That was projected to change to like mid to late October by the mid-century and late October, early November, up to almost a month later, by the end of the century.

Furthermore, American black duck, they migrate the latest of the seven species now. They're projected to migrate even later. Right now, late 20th century, they were typically migrating out of the Great Lakes region in early to mid-December, by the mid-21st century about 19 days later.

Now you'll see by the late 21st century, depending on which model you examine, they're projected to migrate out of the Great Lakes region, at least, 33 days later, early to mid-January, but in some cases not at all in many years, based on those models. They may remain in that area.

Finally, the mallards. The mallards are a gentler-type species. They're cold tolerant. They can occupy a variety of wetland types. They incorporate waste green into their diet as an option when shallow wetlands freeze. That allows for later migration.

You'll see that the two species that typically migrate latest nowadays, mallards and American black ducks, which are close relatives, they're the ones that get most affected by climate change in terms of migration.

Mallards typically leave in the late 21st century in early December. By the late 21st century, it may become early January, mid-February, if ever, depending on the year and depending on the model that you examine.

The main conclusion here is six global climate models were dynamically downscaled for the mid and late 21st century using high resolution regional climate models interactively coupled to a lake model to represent the Great Lakes.

Observed relationships were established between changes in the abundance of dabbling duck species during autumn and winter and the cumulative winter severity and disease based on air temperature and snow depth.

Using these observed relationships, debiased projections of winter severity were used to assess potential impacts on population rate and migration timing for seven dabbling duck species in the Mississippi and Atlantic Flyways.

In a response to warming and a reduced duration of snow on the ground, substantial delays in southward migration are projected, especially for mallards and American black ducks, on the order of four to five weeks by the end of the century. These are both late migrating species as is.

These projected changes in migration may increase the foraging person in the Great Lakes region and negatively impact hunting and bird watching-based tourism in the southern states.

I'm now going to hand it over to Mike Schummer.

[silence]

**Dr. Schummer**: Thank you, Michael. Really appreciate the detail there. We all see why the partnering and collaboration is extremely important. Michael does a fantastic job of climate modeling and compliments the work that we've done with obtaining waterfall survey data and weather data on the ground.

The really important part here in the end, I believe, is this actionable science and management implications that I'm going to go through to finish this up now. This is a little different way than what Michael showed the changes in migration date. This pulls everything together.

If we look at this first column, that's mean migration date late 21st century or, let's just say, over the last 20 years what we've become accustomed to. These are really typical. Your early migrants are your shovelers. Your late migrants are black ducks and mallards. The other species fall somewhere in between.

Again, we've got about a half a month increase in when these birds are going to migrate, migrating anywhere from 12 to 19 days later by mid-21st century. Then late 21st century, the easy way I say this is, they're about a month later.

Some of them like black ducks and mallards, which are large-bodied birds which will readily feed in agricultural fields, may not have to leave the Great Lakes at all. That's a big area to possibly suck up a lot of birds. There's a lot of wetlands around the Great Lakes that freeze and cause birds to move out.

Now if we think of this in combination with that prior data from 1979 till 2013, by my estimate, and it is a rough estimate because that's not how the data output comes through, but it's quite possible that dabbling duck migration has shifted by about a month already. By late 21st century, we may see an additional month.

That would mean, compared to early '80s, we would be seeing a shift in the timing of migration by about two months. That's a lot of potential foraging pressure at mid and northern latitudes that has not historically been happening.

What are the recommendations here? There's really changing nonbreeding habitat needs by latitude. We should be probably shifting habitat conservation northward for late migrating species like mallards and black ducks.

The good thing is some of these early migrants shovelers, green-winged teal, widgeon, and gadwall are probably still going to make it to southern latitudes. Even in these really mild years, a lot of these birds do show up to provide opportunity for hunting and birding.

In mid to southern latitudes, focus the habitat management on the winter foraging needs of these early migrants. Gadwall and widgeon, which are herbivores, green-winged teal, which are small natural seed specialists, and northern shovelers that are largely carnivorous, feeding on invertebrates, as Michael noted.

How do we calculate the energy needs of these birds? In the waterfall community, we use these daily energy requirements or duck energy days. This is the mean numbers of kilocalories per day needed by a single average size duck is 294.35.

If we say, take those 1.65 million ducks I said that nowadays don't need to migrate, multiply that by 294.35 kcals times the numbers of days those birds will be staying at those more northern latitudes, we can come up with the additional wetland acres that are needed to feed these birds for their longer residency time in these regions.

For instance, in my waterfowl ecology management class that I teach, we usually use about 50 days in the fall for ducks migrating through the central New York region and then 25 days in the spring. Because in the spring, they're really pushing to get as far north as fast as they possibly can. That's 75 days we would usually consider that we have to feed these birds.

For some of them that may not have to leave the region or with a really constricted or reduced winter season where it takes longer to get into a condition where the birds have to leave and then spring becomes milder and they can come back earlier, I have the students calculate additional days that we estimate the birds would stay in the region.

We come up with extra acres that would be needed. This is the type of exercise you can go through to determine acres and the location of them given that web application tool.

The waterfowl enthusiast's portion of this is we wonder how weather severity index data and participation data are related. There's a lot of available user group data out there from the US Fish and Wildlife Service hunting diaries that waterfowl hunters keep.

There's eBird data through the Cornell Lab of Ornithology that could be related to weather severity indices. There's data in the harvest information program that keeps the number and timing of federal duck stamps. There's also state duck stamps by region.

We might be able to relate the timing of a severe weather event with the purchase of duck stamps. This says there's some people that are most certainly identified as duck hunters. They are going no matter what, so they buy early in the year. Then there's a large group of people that partake on and off.

When there's a good push of birds their friend who this person that identifies as a duck hunter may say, "Hey, go get your federal duck stamp or go buy your state duck stamp. Let's go duck hunting tomorrow." These types of things we can determine if participation is linked to this weather severity index which is pushing birds south.

Then a lot of states collect hunt quality surveys directly at wildlife management areas that access the number of ducks seen, the number of ducks harvested, and the number of shooting opportunities. What we want to do is determine not only is this affecting the birds, but is it affecting birder and hunter participation at southern latitudes.

If a relationship exists, we could forecast the potential changes in participation, funding for conservation, revenue for local economies, potentially. We'd, basically, just follow the same methodology that Michael Notaro used for the weather severity index with ducks. We just plug people and people metrics into that equation instead.

However, I want to make a caveat here and just some food for thought at the end of this. I guess, pun intended there. One of the thoughts is that as ducks run out of food at northern latitudes, as they stay in these areas longer and they feed themselves out of house and home, they might migrate south providing opportunities for southern waterfall enthusiasts.

One of the things we have to remember is that ducks need not migrate south when they run out of food. They can also move east and west, possibly following rivers, to find new food resources during winter.

The question and one of the information needs, I think, we also have to know is, what happens in mild winters? This is a great paper by Green and Krementz out of Arkansas a few years back that used the locations of mallard band recoveries.

These are ducks that are banded at northern latitudes in the prairies and in Canada. Then looking at the probability of where those birds are recovered through time. With the idea that, if we saw a strong shift in where these birds were wintering, that we would see a strong shift in where these bands where recovered by hunters.

What you find is that in the big woods White River area and such of Arkansas, the traditional mallard wintering area, that that core area hasn't changed. The one thing you do notice is that in that 95 percent probability kernel density estimate that there's a lot of spread of the other birds there.

If you look at that location on that last map, what it seems to follow is major rivers of the United States. If we overlap the two of those, those areas really seem to follow, say, the Platte River, the Wabash, the Arkansas, the Canadian, the Tennessee River, the Illinois River, and the Upper Miss.

That is these birds when they're coming down the Mississippi and they're staying a little bit north in Illinois and Missouri, that if they do eat themselves out of house and home, they use all of their food resources. To me, it most certainly looks like there is some redistribution occurring east and west.

Even if these birds do run out of food, that doesn't mean that southern waterfowl enthusiasts are most certainly going to end up seeing those birds.

Thanks very much. I really appreciate everybody's time. There's a little bit of information there. The WSI web application that I noted that we used is available to the public.

On our next funding cycle that we get into, funding that we find to investigate the effects of weather severity and [inaudible 50:23] participation, it is our expectation to upgrade that web application. It does run. It just runs relatively slowly right now. You just have to be patient with it, but it does pump out all the data that you need.

If you have any questions about how to get data from that or what those data mean, you can always email me.

Thank you very much.

**Ashley**: Excellent. Thank you to both of our presenters. All right. Well, we'll go ahead. I'd like to just, again, thank both of our presenters. A recording of this broadcast will be posted on the website that I'm posting in the chat box. There we go. I just sent it out. All right. Thanks everyone. I hope you have a great day.

**Dr. Notaro**: Thank you.

**Ashley**: Thanks, Mike.

**Dr. Schummer**: Thank you, Ashley. Thank you, everybody.

**Ashley**: Thanks. Bye-bye.

**Dr. Schummer**: Bye-bye.

**Dr. Notaro**: Bye.

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