FINAL REPORT

ADMINISTRATIVE INFORMATION

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Project title: Development of dynamically-based 21st century projections of snow, lake ice and winter severity for the Great Lakes Basin to guide wildlife-based adaptation planning, with emphasis on deer and waterfowl

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• Funding supported an early-career assistant researcher, Yafang Zhong, at the University of Wisconsin-Madison and two undergraduate students at the State University of New York at Oswego.

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PUBLIC SUMMARY

We developed high-resolution climate projections for the mid- and late 21st century across the Great Lakes region, including the Midwest and Northeast United States and southern Canada. We applied a regional climate model that addresses future changes in Great Lakes’ water temperatures, ice cover, and evaporation, which critically impact lake-effect snowfall. This new dataset is highly valuable, given that most global climate models applied in the reports of the Intergovernmental Panel on Climate Change and National Climate Assessment either completely lack the Great Lakes or largely under-represent their coverage and impacts. After quantifying projected changes in weather severity based on air temperature and snow depth, we examined the impacts on dabbling duck migration and white-tailed deer survival. Future delays in the southward migration of dabbling ducks during the autumn-winter will increase foraging pressures in the Great Lakes region and need for available wetlands, while negatively impacting hunting and bird-watching in the southern states.

PROJECT SUMMARY

The goals of the Northeast Climate Science Center-funded project were to develop dynamically downscaled projections of weather severity for the Great Lakes region, Midwest, and Northeast United States for the mid- and late-21st century and to investigate implications to the migration of dabbling duck species and survival/predation of white-tailed deer. The project brought together a diverse range of partners and collaborators, including academia (University of Wisconsin-Madison, State University of New York at Oswego, University of Illinois at Urbana-Champaign), wildlife and resource agencies (Ducks Unlimited, Long Point Waterfowl, Wisconsin and Michigan Departments of Natural Resources, Department of Environmental Quality), federal agencies (National Oceanic and Atmospheric Administration, Department of Environmental Quality), tribal groups (Great Lakes Indian Fish and Wildlife Commission, Forest County Potawatomi Community), regional networks (Great Lakes Integrative Sciences and Assessments Center, Global Lake Temperature Collaboration), and an energy company (Alliant Energy). Resulting products included 7 publications, 29 presentations/webinars, 26 media releases/interviews, three new websites (weather severity, dynamical downscaling, and lake data), dynamically downscaled ensemble dataset, contributions to the CSC fellows retreat and review focus group, training for students and an early-career researcher, and expanded investigations with new collaborators (e.g. tribal adaptation planning, aquatic invasive species, precipitation extremes, Great Lakes’ water levels, lake-effect snow, lake warming mechanisms, changing subnivium).

REPORT BODY

Purpose and objectives: Anthropogenic climate change is transforming the winter climate of the Great Lakes Basin, with direct implications to regional wildlife. In light of these concerns, our project aimed to (1) develop high-resolution, state-of-the-art projections of snow depth/cover, lake
ice fraction/thickness, and winter severity across the Great Lakes Basin (GLB) for the mid- and late 21st century and (2) assess the impacts of these projected changes in winter conditions on the abundance and distribution of deer and waterfowl. A subset of global climate models (GCMs) from the latest Coupled Model Intercomparison Project Phase Five (CMIP5), representing a range of likely climate change outcomes for the basin, was dynamically downscaled to 25-km using a regional climate model (RCM), interactively coupled to a lake model to represent the Great Lakes. These downscaled projections of snowpack, lake ice, air temperature, and winter severity index were the foundation of projections of mid- and late 21st century distributions of deer and waterfowl and would aid in adaptation planning to manage wildlife and fish populations. The collaboration of academia, government, and non-profit organizations combined the climate modeling experience of the University of Wisconsin-Madison’s Nelson Institute Center for Climatic Research; the wildlife impacts, conservation, and adaptation experience of the Wisconsin and Michigan Department of Natural Resources (DNR), Long Point Waterfowl, and Ducks Unlimited; and the stakeholder-engagement experience of the Wisconsin Initiative on Climate Change Impacts.

Organization and approach: Northeast CSC funding helped facilitate a diverse collaboration among the University of Wisconsin-Madison, State University of New York at Oswego, Long Point Waterfowl, Ducks Unlimited, and Michigan Department of Natural Resources to address climate change impacts on regional wildlife. The project provided the opportunity to expand to new collaborations with the Great Lakes Indian Fish and Wildlife Commission, in which we provided dynamically downscaled climate data to aid in risk and adaptation planning, with the United States Geological Survey and Department of Environmental Quality in which the downscaled data was used to drive lake and stream models to investigate potential spread of aquatic invasive species, and with Alliant Energy, in which we developed a climate risk assessment report. The grant fostered a synergy with additional funding from the National Oceanic and Atmospheric Administration, Environmental Protection Agency, and National Science Foundation to greatly expand our dynamically downscaled climate projection dataset for the Great Lakes region using the RegCM4 regional climate model, interactively coupled to a 1D lake model to represent the Great Lakes. The importance of this data cannot be understated, given that most models applied by the Intergovernmental Panel on Climate Change and National Climate Assessment Reports lack or largely underrepresent the Great Lakes, while statistical downscaling products cannot provide insight into future changes in key environmental variables, such as snow depth, soil moisture, and evapotranspiration.

We dynamically downscaled six state-of-the-art CMIP5 GCMs, using a high-resolution (25-km) RCM, the International Centre for Theoretical Physics (ICTP) Regional Climate Model Version 4 (RegCM4), coupled to a 1D energy-balance lake model (Fig. 1). According to our assessment of projections by the coarse CMIP5 GCMs, we carefully selected 6 GCMs for downscaling to capture the range of potential 21st century climate change in the basin. Downscaled simulations were produced for the late 20th (1981-2000), mid-21st (2046-2065), and late 21st (2081-2100) centuries, following the representative concentration pathway 8.5 (RCP8.5) emission scenario, in which CMIP5 model output served as lateral boundary conditions to the RCM. Simulated regional patterns of temperature, precipitation, and snowfall; the frequency of extreme weather events; and Great Lakes’ water temperatures and ice cover in the late 20th century RCM simulations were evaluated against observations using spatial and temporal correlations, root-mean-square-differences, and mean and absolute biases. Observational data sources included the Great Lakes Surface Environmental Analysis, National Data Buoy Center, Great Lakes Ice Atlas,
University of Delaware gridded observations, U.S. High Resolution Cooperative Dataset, and Environment Canada’s climate archive. We computed projected changes in air and water temperature, snowfall, snow depth, and lake ice cover/thickness across the Great Lakes region by the mid- and late 21st century. We investigated the potential for a reversal in the observed positive trend in lake-effect snowfall. Prior to calculating species-specific weather severity indices, RegCM4-simulated output of daily 2-meter air temperature and snow depth was debiased against observational data, both in terms of the daily mean and interannual standard deviation for each day. The source of observed daily mean air temperature for 1984–2013 was the gridded Daily Surface Weather and Climatological Summaries (Daymet) product. For the purpose of debiasing daily snow depth, a gridded product was created using data from meteorological stations within the Global Historical Climate Network (GHCN) across the area of 26–54°N, 101–63°W.

Observed relationships were established between changes in the relative abundance of dabbling duck species during autumn-winter at mid-latitude migration areas of eastern North America and cumulative winter severity indices, which considered both air temperature and snow depth. The empirical relationships were based on 10 or more years of aerial and ground-based survey data across the Atlantic and Mississippi Flyways. These relationships reflected the impacts 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 duck species across the Mississippi and Atlantic Flyways. We developed statistical models for seven species of dabbling ducks, relating the relative rate of population change to current and cumulative weather severity, with the onset of negative population rates implying southward migration.

In related investigations with collaborators, the RegCM4-based dynamically downscaled climate projections were also used to:
(1) drive lake and stream models for the Upper Midwest to projected future changes in water temperatures and the risk of spread of aquatic invasive species;
(2) develop future projections of Great Lakes’ water levels;

Figure 1. Model domain with elevation (shading, meters). The thick black rectangle indicates the buffer zone. Dots indicate the 25-km grid spacing. The orange, blue, red, and purple polygons identify the Pacific, Central, Mississippi, and Atlantic Flyways, respectively.
(3) guide climate change risk assessment and adaptation planning efforts by the Great Lakes Indian Fish and Wildlife Commission and Forest County Potawatomi Community for ceded territories; 
(4) establish an ensemble of Great Lakes regional projections by the Great Lakes Integrated Sciences and Assessment (GLISA) through serving on its advisory board; 
(5) investigate projected changes in precipitation extremes by the Illinois State Water Survey; 
(6) develop insights in Great Lakes’ warming mechanisms by the Global Lake Temperature Collaboration; and 
(7) study the changing snowpack and underlying subnivium of the Upper Midwest.

Project results, analysis, and findings:

Lake-effect snowfall projections: The downscaled models produce atmospheric warming and increased cold-season precipitation. The Great Lakes’ ice cover is projected to dramatically decline and, by the end of the century, become confined to the northern shallow lakeshores during mid-to-late winter. Projected reductions in ice cover and greater dynamically induced wind fetch lead to enhanced lake evaporation and resulting total lake-effect precipitation, although with increased rainfall at the expense of snowfall (Fig. 2). A general reduction in the frequency of heavy lake-effect snowstorms is simulated during the 21st century, except with increases around Lake Superior by the mid-century when local air temperatures still remained low enough for wintertime precipitation to largely fall in the form of snow.

Duck migration projections: Based on observed relationships and downscaled climate projections of rising air temperatures and reduced snow cover, delayed autumn-winter migration is expected for all species, with the least delays for the Northern Pintail and the greatest delays for the Mallard. The Mallard, the most common and widespread duck in North America, may overwinter in the Great Lakes region by the late 21st century (Fig. 3, Table 1). This highlights the importance of protecting and restoring wetlands across the mid-latitudes of North America, including the Great Lakes Basin, because dabbling ducks are likely to spend more time there, which would impact existing wetlands through increased foraging pressure. Furthermore, inconsistency in the timing and intensity of the traditional autumn-winter migration of dabbling ducks in the Mississippi and

![Figure 2. Projected change in the mean number of days during autumn-winter (September through February) with at least 2.54 cm of snow on the ground by the (a-c) mid-21st and (d-f) late 21st century, compared to the late 20th century. Results are shown for the (a,d) six-model mean, (b,e) the model with the least loss of snowpack, and (c,f) the model with the greatest loss of snowpack.](image)
Atlantic Flyways could have social and economic consequences to communities to the south, where hunting and birdwatching would be affected.

Figure 3. Probability of negative population rates / southward migration by latitude (30-50°N, across the Midwest, Great Lakes, and Northeast United States) and day (1 September to 31 March) for Mallards. Projected changes in these probabilities are shown for the mid- and late 21st century compared to the late 20th century. Result show for CNRM, MIROC5, IPSL, MRI, ACCESS, and GFDL.

Table 1. For each of seven duck species, the following information is provided for the Great Lakes zone of 40-50°N: (a) mean migration date during the late 20th century, (b) earliest and latest mean migration dates during the mid-21st century among the six models, (c) earliest and latest mean migration dates during the late 21st century among the six models, (d) change in the mean migration date by the mid-21st century, compared to the late 20th century, and (e) change in the mean migra
tion date by the late 21st century, compared to the late 20th century.

Duck Species | (a) Mean Migration Date: Late 20th Century | (b) Mean Migration Date: Mid-21st Century, Earliest and Latest Model | (c) Mean Migration Date: Late 21st Century, Earliest and Latest Model | (d) Change: Mid-21st Century Minus Late 20th Century | (e) Change: Late 21st Century Minus Late 20th Century |
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American Black Duck | 10 Dec (Late Migrant) | GFDL: 18 Dec MIROC5: 8 Nov | CNRM: 4 Nov ACCESS: 17 Nov | +19 days | +33 days, if ever |
American Wigeon | 16 Oct | CNRM: 26 Oct MIROC5: 8 Nov | CNRM: 4 Nov ACCESS: 17 Nov | +15 days | +27 days |
Gadwall | 5 Nov | GFDL: 15 Nov MIROC5: 20 Nov | GFDL: 23 Nov ACCESS: 8 Dec | +13 days | +24 days |
Green Winged Teal | 15 Oct | CNRM: 25 Oct MIROC5: 7 Nov | CNRM: 3 Nov MIROC5: 15 Nov | +16 days | +25 days |
Mallard | 9 Dec | GFDL: 18 Dec MIROC5: 5 Jan | GFDL: 5 Jan MIROC5: Never | +19 days | +40 days, if ever |
Northern Pintail | 4 Nov | GFDL: 14 Nov MIROC5: 20 Nov | GFDL: 21 Nov MIROC5: 7 Dec | +12 days | +23 days |
Northern Shoveler | 2 Oct (Early Migrant) | GFDL: 11 Oct MIROC5: 24 Oct | CNRM: 23 Oct MIROC5: 7 Nov | +15 days | +29 days |

Deer projections: White-tailed deer in Michigan’s Upper Peninsula exist on the edge of their climate tolerance for cold temperatures and deep snow, especially in the lake-effect snow zones of the north half of the peninsula. Each year, deer migrate to conifer swamps to escape the deep snow. Many of these swamps are managed by the Michigan Department of Natural Resources as critical deer wintering complexes (DWC), and there has been an effort to acquire and protect
additional acres of DWC as deer habitat. Conifer swamps are also managed for many other values, including timber products, which are difficult or impossible to access during mild winters. Recent warming trends have resulted in a 71% decrease in ice cover on Lake Superior, and a concomitant increase in lake effect snow. As the severity of winters in terms of duration of snow depth has increased, DWC habitat has become more critical to deer over-winter survival. However, regional climate models project a shift from lake effect snow to lake effect rain as temperatures continue to rise. Thus, while DWCs have high wildlife habitat value now, their value to deer is expected to decrease by the end of the 21st century. The economic value of timber products is also expected to decrease as access for harvest becomes more challenging. The projected changes in the ecological and economic values of conifer swamps will complicate long-term conservation of these regionally important resources. Conservation tools other than land acquisition could provide managers the flexibility to meet dynamically shifting values across Michigan’s northern forests.

Conclusions and recommendations: We recommend the following additional areas of exploration and adaptation efforts.

- Expansion of the dynamically downscaled ensemble to include additional regional climate models, parent GCMs, and scenarios
- More advanced regional climate modeling, including non-hydrostatic simulations down to a couple of km’s in grid spacing and the incorporation of 3D lake circulation for the Great Lakes
- Training classes in the use of downscaled climate data by stakeholders and interdisciplinary researchers
- Development of seasonal prediction tools for the Great Lakes region to aid stakeholders
- Expansion of student science learning and citizen science data collection, including through the National Aeronautics and Space Administration Global Learning and Observations to Benefit the Environment Program (GLOBE)
- Economic investigation of impacts of climate/wildlife changes on hunting, bird watching, stamp sales, tourism
- Adaptation should address a greater restoration of Midwestern wetlands and food resources

Outreach and products: The project led to 7 scientific publications, 29 presentations, and 26 media releases or interviews, facilitating effective dissemination of findings to the scientific community, planners and resource managers, schools, and the general public.

Wildlife researchers and conservationists were specifically targeted through presentations at the Wildlife Society Conference, North American Ornithological Conference, North American Congress for Conservation Biology, North American Duck Symposium, Midwest Fish and Wildlife Conference, and Atlantic Flyway Tech Section. Diverse audiences of the general public were addressed through presentations at the Waunakee Public Library, Wisconsin Science Festival, St. Maria Goretti School, and Mount Horeb Gardening Club.

Examples of outreach and engagement:

In response to an invitation by the Northeast CSC program manager, Addie Rose Holland, Dr. Notaro participated in and helped organize a subset of the Northeast Climate Science Center Graduate and Postdoctoral Fellows Retreat in Green Bay in September 2015. Dr. Notaro gave a presentation, with the title, “The path to collaboration sometimes resembles falling dominoes.” He helped coordinate a session in which collaborators, Kim Stone, Hannah Panci, and Esteban Chiriboga from the Great Lakes Indian Fish and Wildlife Commission, shared about the Ojibwe
efforts to assess climate change risk and adaptation and in which Brian Glenzinski of Ducks Unlimited presented a tour of wetland restoration sites.

The Northeast CSC and Gulf Coastal Plains and Ozarks LCC co-sponsored and helped advertise a joint webinar by Drs. Notaro and Schummer in March 2015, with the title, “Application of dynamical downscaling to generate projections of winter severity, with implications for waterfowl migration and deer survival.” The webinar reached a diverse audience of 125 attendees, ranging across academia and stakeholder groups. The invitation list included 206 people from the Landscape Conservation Cooperatives, Climate Science Centers, Audubon, Wisconsin Initiative on Climate Change Impacts, universities, National Oceanic and Atmospheric Administration, Midwest Deer and Wildlife Turkey Study Group, Mississippi and Atlantic Flyways, Upper Mississippi River Great Lakes Joint Venture, Midwest MFWA Climate Change Technical Committee, and other agencies.

Drs. Notaro and Schummer presented a Northeast CSC-sponsored webinar in October 2017, as invited by the Communications and Outreach Manager, Jeanne Brown, with the title, “Wildlife implications of changing winter severity in the Great Lakes Basin: Collaborative investigation to guide regional adaptation planning.”

Dr. Notaro participated in the 2017 Climate Science Center Review Science Producers Focus Group.

Publications: 7

Presentations: 29
Notaro, M., Observed and projected climate change in Wisconsin and its implications, November 2017, Waunakee Public Library, Waunakee, WI.
Notaro, M., Observed and projected climate change and its implications, November 2017, Wisconsin Science Festival, University of Wisconsin-Parkside, Kenosha, WI.
Notaro, M., Wildlife implications of changing winter severity in the Great Lakes Basin:
Collaborative investigation to guide regional adaptation planning, October 2017, Northeast Climate Science Center webinar, Madison, WI.

Notaro, M., Dynamically downscaled hydrological projections for the Great Lakes Basin, October 2017, Navigating the Future of Water Conference, Milwaukee, WI.

Notaro, M., Potential impacts of changing winter conditions during the 21st century on the migratory behavior of dabbling ducks in eastern North America, August 2017, Ecological Society of America Annual Meeting, Portland, OR.

Notaro, M., Projected climatic and limnological changes and their potential implications for the spread of aquatic invasive species in the Upper Midwest United States, March 2017, webinar to Department of Environmental Quality, Department of Natural Resources, and United States Geological Survey, Madison, WI.

Notaro, M., Overview of observed and projected climate change and its implications, March 2017, St. Maria Goretti School, Madison, WI.

Notaro, Climate change projections and implications for the Great Lakes region, October 2016, University of Wisconsin-Madison, Weston Roundtable lecture, Madison, WI.

Notaro, Overview of observed and projected climate change and its implications, October 2016, University of Wisconsin-Madison InterAg 155 class, Madison, WI.


Notaro, Historical and future projected climate change in the Upper Midwest United States, as Relevant to Plant Communities, September 2016, Wisconsin Initiative on Climate Change Impacts (WICCI) Adaptation Workshop: Preparing Wisconsin’s Plant Communities for an Uncertain Future, Madison, WI.


Notaro, Climate change in Wisconsin: Historical trends, projections, impacts, and adaptation, June 2016, Forest County Potawatomi Community (FPCP) Climate Change Adaptation Workshop, Crandon, Wisconsin.

Schummer, Weather severity indices for estimating influences of climate on autumn-winter distributions of waterfowl and hunter opportunity and satisfaction, February 2016, Seventh North American Duck Symposium, Annapolis, Maryland.

Vanden Elsen, Factors influencing autumn-winter distributions of dabbling ducks in the Atlantic and Mississippi Flyways, February 2016, Seventh North American Duck Symposium, Annapolis, Maryland.


Notaro, The path to collaboration sometimes resembles falling dominoes, September 2015, Northeast Climate Science Center Retreat, Green Bay, Wisconsin.

Vanden Elsen, September 2015, Northeast Climate Science Center Retreat, Green Bay, Wisconsin.

Notaro, Climate change in Wisconsin, with gardening implications, September 2015, Mount
Horeb Gardening Club, Mount Horeb, Wisconsin.


Notaro, Dynamically downscaled projections of lake-effect snow in the Great Lakes Basin, May 2015, American Geophysical Union Joint Assembly, Montreal, Canada.


Schummer, A weather severity index for estimating influences of climatic variability on waterfowl populations, waterfowl habitat, and hunter opportunity demographics, March 2015, 2-part webinar co-sponsored by the Northeast Climate Science Center and the Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative, 125 participants on webinar.

Notaro, Application of dynamical downscaling to generate projections of winter severity, with implications for waterfowl migration and deer survival, March 2015, 2-part webinar co-sponsored by the Northeast Climate Science Center and the Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative, 125 participants on webinar.

Hoving, Projections of snow cover, winter severity, and lake ice cover for the Great Lakes Basin with implications to regional wildlife, February 2015, Midwest Fish and Wildlife Conference.


Schummer, Climate envelope models for forecasting and prioritizing conservation needs for migratory waterfowl throughout North America, October 2014, National Workshop on Large Landscape Conservation.

Notaro, MET-606 Historic and projected Wisconsin climate change, impacts, and adaptation, October 2014, University of Wisconsin-Madison, Molecular and Environmental Toxicology (MET-606) class, Madison, Wisconsin.

Media releases/interviews: 26
The Capital Times, “Climate change is here: Wisconsin is seeing earlier springs, later falls, less snow, and more floods,” 2017.
WORT Community Radio 8 O’Clock Buzz, 2017.
Weather Channel website, Climate change could bring more lake-effect snow – for a few decades, 2017.
Wisconsin State Journal, Wisconsin’s climate may need to adapt to Donald Trump, 2017.
Badger Herald, “Warming temperatures in Wisconsin to lead to milder winters”, 2016.
Syracuse Post-Standard, “Study: Less lake effect snow, more rain near Great Lakes as climate changes”, 2014.
Department of Interior press release, “Secretary Jewell announces new research projects at the Northeast Climate Science Center”, 2014.
UW-Madison Nelson Institute news item, “Nelson study on winter severity among new research funded by Northeast Climate Science Center”, 2014.
Wisconsin Center for Academically Talented Youth (WCATY) Summer Transitional Enrichment Program (STEP) Summer Sentinel, “The beginning of the end: Impact of global warming will be felt throughout the 21st century”, 2014.
Gulf Coastal Plains and Ozarks LCC website, “New snow modeling study indicates some waterfowl hunting may have to migrate north”, 2014.
Wisconsin Public Radio, “Despite record lake ice this winter, climate forecasts still say trend is warming,” 2014.
University of Wisconsin Stevens Point news release, “Climate change talk focuses on hunting, fishing,” 2014.
University of Wisconsin Stevens Point The Pointer article, “Panel discusses climate change,” 2014.
Nelson Institute news release, “Climate research shows changes in Midwestern winters,” 2014.
Madison.com, “UW researcher: Good chance for less snow but more rain in winter later this century,” 2014.

Websites/databases
(1) Predicting Mallard Migration (WSI Web Application): http://gisweb.ducks.org/WSI/
- Plot historical weather severity indices for Mallards
(2) Dynamical Downscaling for the Midwest and Great Lakes Basin:
https://nelson.wisc.edu/CCR/resources/dynamical-downscaling/index.php
- Interactively plot dynamically downscaled climate projections for the study region
(3) Data Release: A Large-Scale Database of Modeled Contemporary and Future Water Temperature Data for 10,774 Michigan, Minnesota, and Wisconsin Lakes:
https://www.sciencebase.gov/catalog/item/57c5c793e4b0f2f0cebdaa4d
- Data contains projected changes in lake water temperatures by depth