INVASION RISK OF AIS NOT IN THE GREAT LAKES UNDER FUTURE CLIMATE SCENARIOS

An Overview and Status

Phyllis Higman, MNFI
Michael Notaro, UW-Mad, CCR
Anne Garwood, MDEQ
Chris Hoving, MDNR
Sarah LeSage, MDEQ
Sue Tangora, MDNR
Yu Man Lee, MNFI
Pete Badra, MNFI
Ed Schools, MNFI
Helen Enander, MNFI
Daria Hyde, MNFI

Michigan Natural Features Inventory

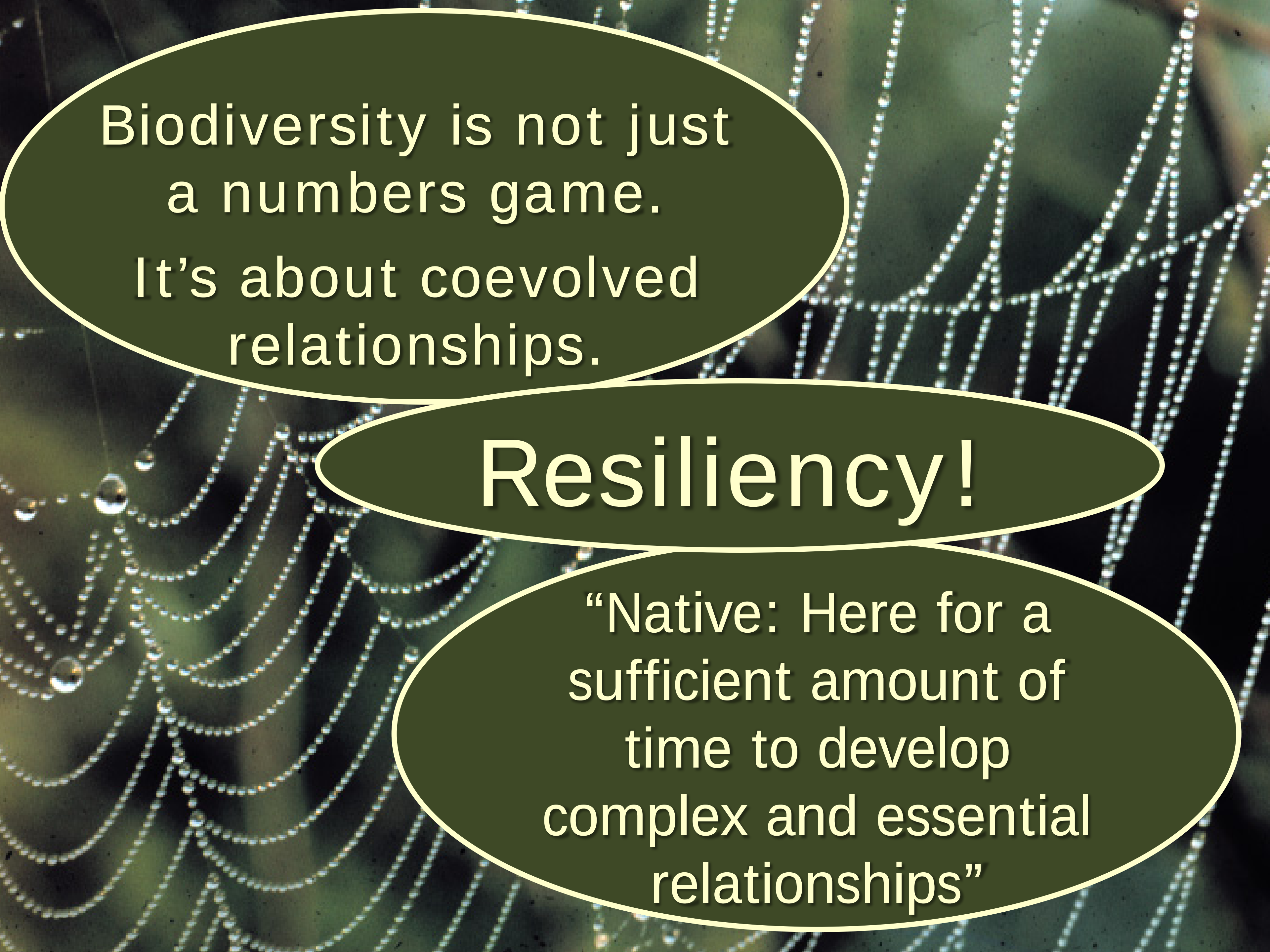
Maintains GIS-based database on Michigan's most vulnerable elements of biodiversity

Endangered, threatened, special concern spp. and high quality native ecosystems

~420 plants

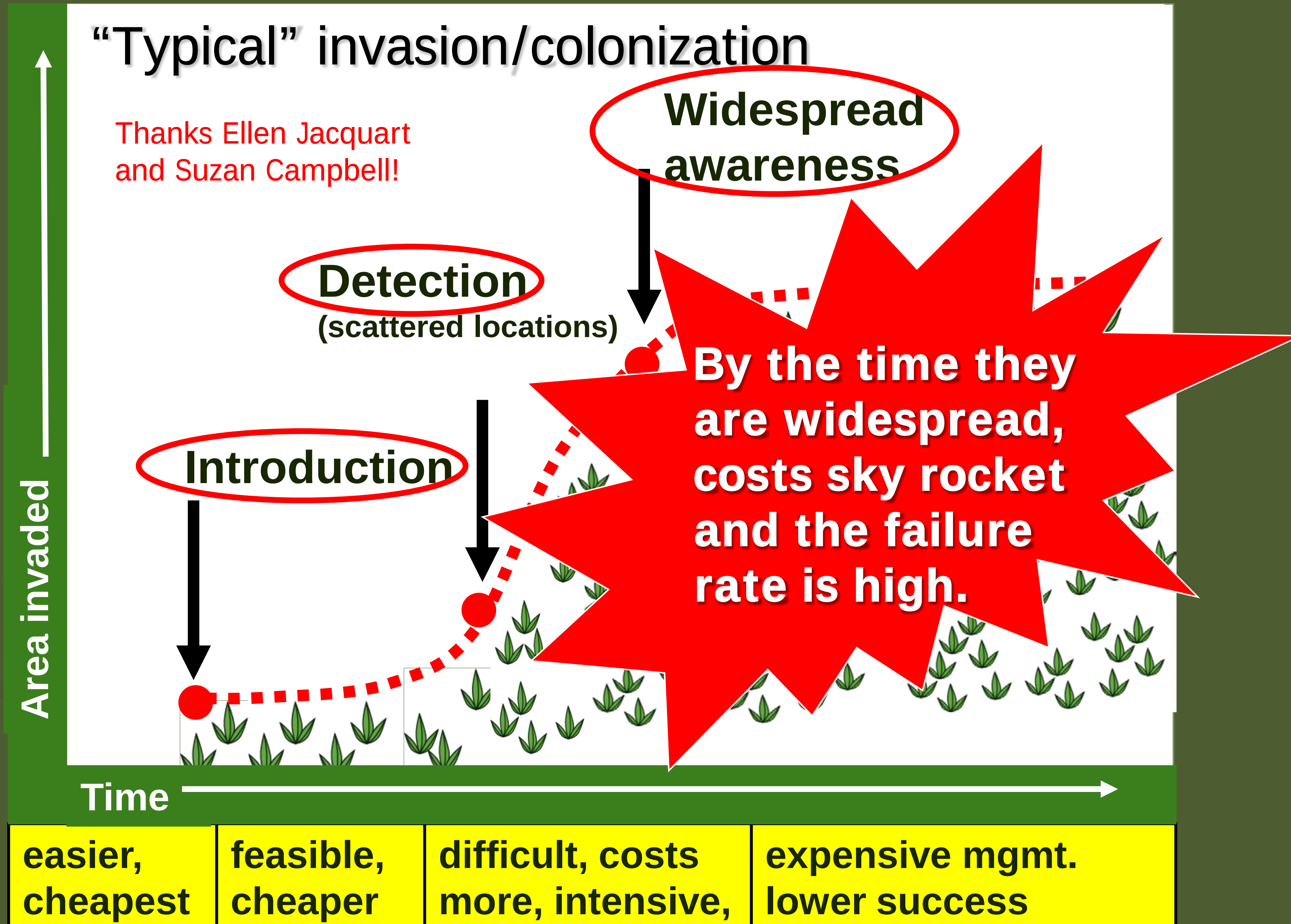
~300 animals

77 natural communities


Biodiversity is not just a numbers game.
It's about coevolved relationships.
Resiliency!
"Native: Here for a sufficient amount of time to develop complex and essential relationships"


Invasive phragmites
Garlic mustard
INVASIVE SPECIES: Eroding native diversity at a seemingly rapid pace.
Glossy buckthorn
Spotted knapweed

Thanks Suzan!



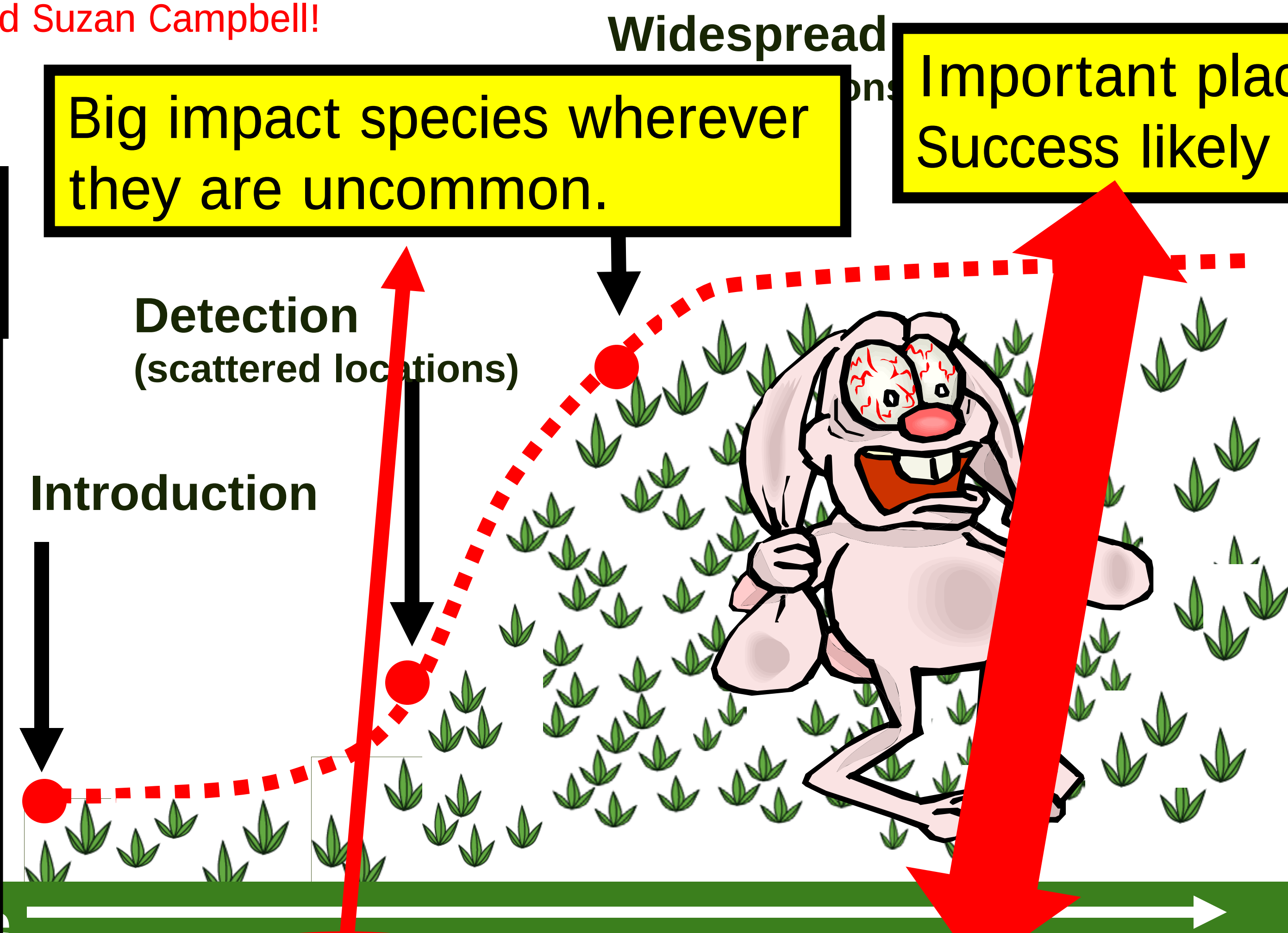
Our challenge is to pick the right battles.

Thanks Ellen Jacquart
and Suzan Campbell!

Risk
Assess...

Big impact species wherever
they are uncommon.

Important places
Success likely



Prevention

Early detection-
and response

Prioritizing winnable battles.
Control, contain, restore.

To use this framework effectively, it is crucial to know:

- What are you trying to protect?
- Do the “invaders” pose a real threat?
- Where are they and how much is there?
- How can we best mitigate their impacts?
  - Eradicate/Contain/Control?
  - Available/best techniques?
  - Resources?

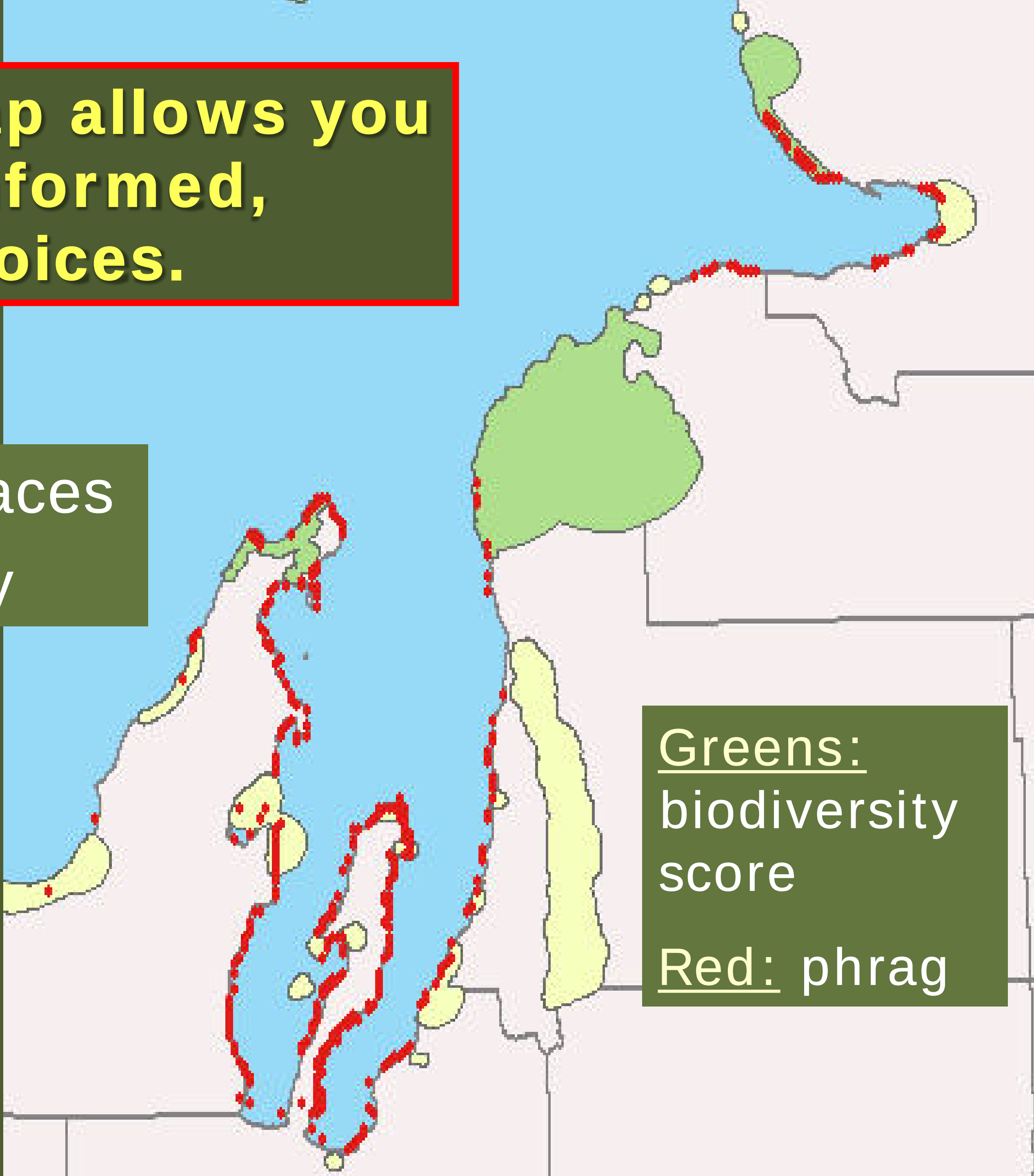
What?, Why?, Where?, How?

Thanks Ellen Jacquart!

A good map allows you to make informed, explicit choices.

- Important places
- Success likely

- Outliers
- Sources
- Pathways



Invasive species meets Climate Change

- Some existing native and invasive species ranges will shrink, expand and/or shift.
- Will native species moving beyond their current range become invasive in the new environment?
- New invasive species that cannot persist here now, are likely to arrive.

Project Objectives
Exploratory!

- Investigate modeling of potential invasion risk of 40-50 AIS species not currently climate matched, in future climate projections

- Using downscaled climate data for the Great Lakes Basin (Michael Notaro, UW-Madison-CCR)
  - Fine enough scale to capture lake effect differences
  - Species distribution modeling/niche modeling
    - Physiological tolerances and potentially other life cycle factors
    - Georeferenced occurrence data for focal species

Methodology: Stage 1 (Selection of AIS to model)

Criteria:

- Not currently climate-matched to Great Lakes
- Clearly invasive outside of normal range
- Likely to cause the big impacts
- Likely to come through known vectors
- Non-native to North America – we had to relax this!
- A diversity of taxa

Lots of information out there!

- Focus has been on species already climate matched
- Challenge was finding species:
  - clearly NOT climate matched

    AND

  - enough info on ecological tolerances
  - enough verified occurrence (persistence) data to be able to model suitable habitat well

SUMMARY OF 15 AQUATIC INVASIVE SPECIES, PREFERRED HABITAT, AND TEMPERATURE CONTROLS

Species	Habitat	Temp	Referen.
	Habitat	Temperature Control	References
Golden mussel	Rivers, lakes, marshes, swamps, estuaries, wetland , rice fields	Climatological water T between 8°C and 35°C	Cataldo and Boltovskoy (2000), de Oliveira et al. (2006), Crosie et al. (2007)
Red-rimmed melania	Rivers, lakes, marshes, estuaries, streams, ponds	Climatological water T between 18°C and 33°C	Muray (1971), Duggan (2002), deKock and Wolmarans (2009)
Rose bitterling	Rivers, marshes, wetlands, ponds	Climatological water T between 16°C and 32°C	Asahina and Hanyu (1983), Baensch and Riehl (1985), Baensch and Fischer (1998), Yuma et al. (1998), Froese and Pauly (2010)
Asian swamp eel	Marshes, swamps, wetland , agricultural areas, move on land	Climatological water T of 8°C and higher	Starnes et al. (1998), Collins et al. (2002), Shafland et al. (2009 2010)
Northern snakehead	Rivers, lakes, swamps, wetlands, streams, ponds, move on land	Climatological water T between 0°C and 30°C	Okada (1960), Dukravets and Machulin (1978), Courtenay an Williams (2004), ISSG (2004), Cudmore and Mandrak (2006); Herborg et al. (2007); Invasive Species Compendium
Red swamp crayfish	Rivers, lakes, marshes, swamps, wetlands, rice fiel s, streams, ponds, move on la d	Climatological water T between 4°C and 35°C	Ackefors (1999), Powell and Watts (2006), Invasive Species Compendium
Australian red claw crayfish	Lakes, wetlands, streams, move on land	Climatological water T between 8°C and 36°C	King (1994), Masser and Rouse (1997), Meade et al. (2002), Prymaczok et al. (2012), Garcia Guerrero et al. (2013)
Malaysian painted frog	Wetlands, rice fields, forest , ponds, agricultural areas, residential areas, move on land	Not enough information	
Yellow anaconda	Rivers, marshes, swamps, caves, move on land	Daily air T extremes: Min T>-7°C and max T<45°C	Waller et al. (2007), Reed and Rodda (2009)
Brazilian waterweed	Lakes, streams, ponds	Climatological water T between 3°C and 30°C	Barko and Smart (1981), Getsinger and Dillon (1984), Haramoto and Ikusima (1988), Carrillo et al. (2006), Yarrow et al. (2009), Curt et al. (2010), Matthews et al. (2014)
Brazilian pepper tree	Wetlands, agricultural area forests, grasslands	Daily air T extremes: Min T>-6°C	Orwa et al. (2009)
Water hyacinth	Lakes, marshes, wetlands, streams, ponds	Climatological water T between 10°C and 40°C	Francois (1970), Urbanc-Bercic and Gaberscik (1989), Madsen al. (1993), Owens and Madsen (1995), Tellez et al. (2008), Koutika and Rainey (2015)
Water lettuce	Lakes, swamps, wetlands, ponds	Climatological water T between 15°C and 35°C	EPPO (2007-2013)
Nutria	Lakes, marshes, swamps, wetlands, streams, ponds, move on land	Daily mean air T extremes between -10°C and 35°C	Aliev (1965, 1973), Norris (1967), Evans (1970), Gosling al. (1983), Doncaster and Micol (1990), Doncaster et al. (1990), Baroch et al. (2002), NEMESIS
Cane toad	Rivers, lakes, swamps, wetlands, agricultural areas streams, ponds, forests, grasslands, move on land	Daily air T extremes: Min T>-14°C and Max T<42°C	Zug and Zug (1979), Muller (1982), Floyd (1985), Sutherst al. (1996), Urban et al. (2007), Kolbe (2010)

Feathered mosquito fern (*Azolla pinnata*)

Native: Africa, Madagascar, India, SE Asia, China Japan, Maylaya, Philippines, New Guinea, Australia

Introduced: Papua New Guinea, Australia, Japan, New Zealand, Vietnam, Florida

Malaysian Painted Frog (*Kaloula pulchra)*

Native: Bangladesh, Cambodia, China, Hong Kong, India, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Nepal, Sri Lanka, Singapore, Thailand, and Vietnam

Introduced: Taiwan, Guam, Singapore, Borneo and Sulawesi; specimens noted in Australia New Zealand

Alligatorweed (*Alternanthera philoxeroides*)

Native to South America

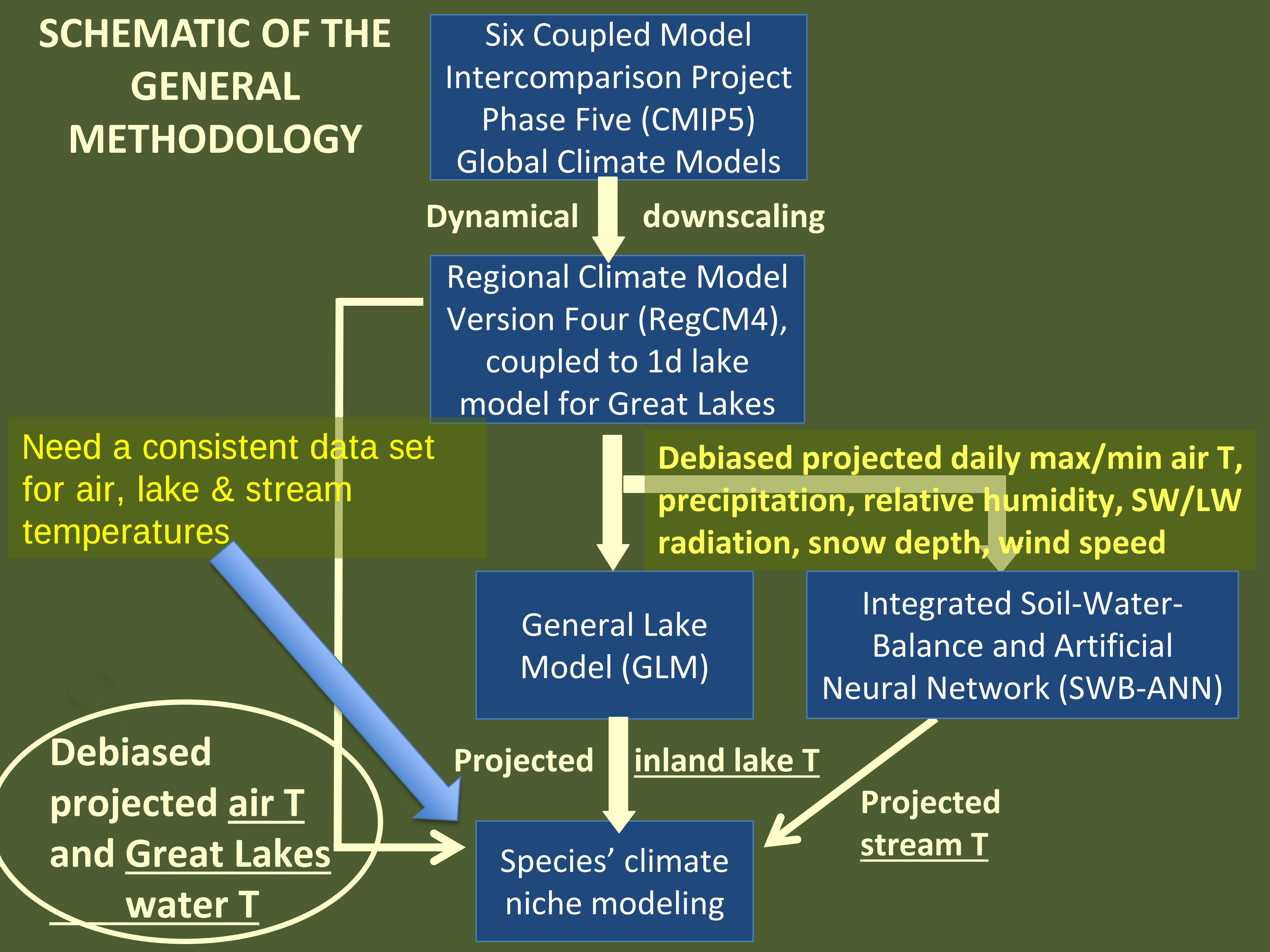
Introduced: Asia, Australasia-Pacific, Europe, N. Amer.

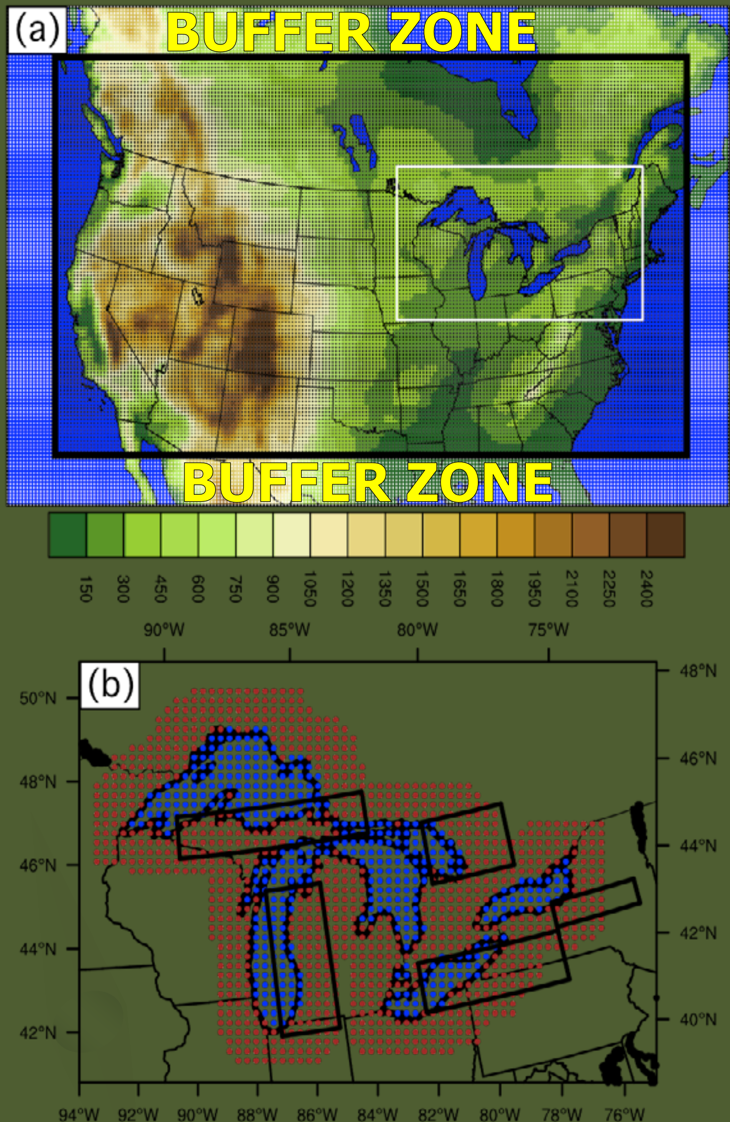
Climate Modeling Synopsis

- 6 downscaled climate models for Great Lakes (CMIP5)
  - Regional Climate Model Version Four (RegCM4)
- 1 emission scenario - representative concentration pathway 8.5 (RCP8.5)
- conduct species distribution modeling using occurrence data
- map suitable habitat for focal species under predicted climate change in late 20th, mid-21st, and late 21st centuries
- BUT: previous work did not include projected inland lake and stream temperatures & occurrence data not adequate

Climate Modeling with New Consistent Data Set

- 6 downscaled climate models for Great Lakes (CMIP5)
  - Regional Climate Model Version Four (RegCM4)
- 1 emission scenario - representative concentration pathway 8.5 (RCP8.5)
- a new, consistent dataset of projected air, lake, and stream temperatures
- conduct species distribution modeling using occurrence data ⟶ climate niche using air, lake and stream T tolerances
- map suitable habitat for focal species under predicted climate change in late 20th, mid-21st, and late 21st centuries


SCHEMATIC OF THE GENERAL METHODOLOGY
Six Coupled Model Intercomparison Project Phase Five (CMIP5) Global Climate Models
Dynamical downscaling
Regional Climate Model Version Four (RegCM4), coupled to 1d lake model for Great Lakes
Need a consistent data set for air, lake & stream temperatures
Debiased projected daily max/min air T, precipitation, relative humidity, SW/LW radiation, snow depth, wind speed
General Lake Model (GLM)
Integrated Soil-Water-Balance and Artificial Neural Network (SWB-ANN)
Projected inland lake T
Projected stream T
Debiased projected air T and Great Lakes water T
Species' climate niche modeling



(a) Model domain with shading for elevation (m). (b) Zoomed-in map with blue dots for lake grid cells and brown dots for land grid cells within the 100-km lake-effect zone.

Methodology: Stage 2 (Downscaling)

Six global climate models (GCMs) from the Coupled Model Intercomparison Project Phase Five (CMIP5), representing a range of climate projections for the Great Lakes Basin, were dynamically downscaled across the U.S. and southern Canada.

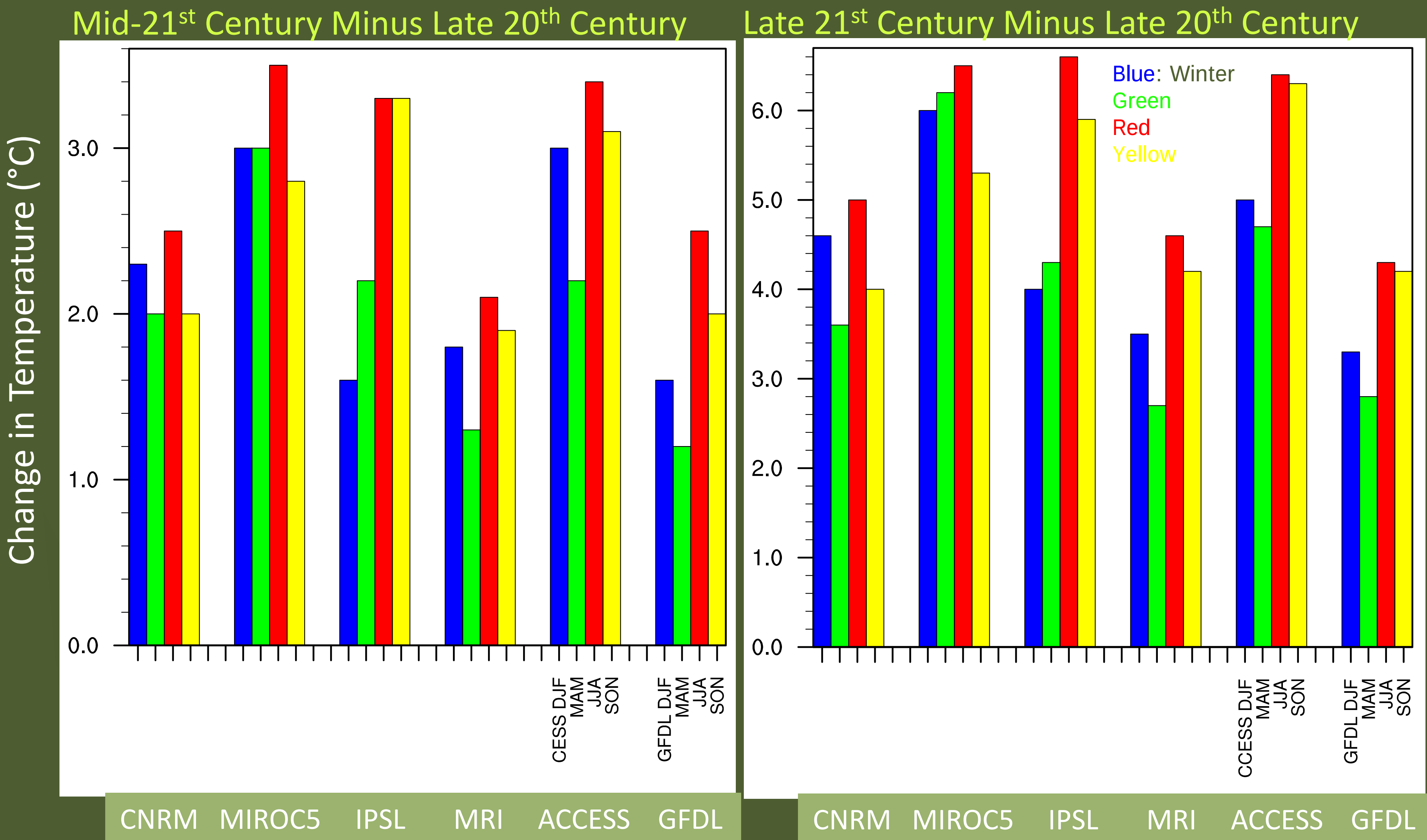
The GCMs include CNRM, MIROC5, IPSL, MRI, ACCESS, and GFDL. Output from the GCMs served as lateral boundary conditions to a high-resolution regional climate model.

The downscaling was performed using the International Centre for Theoretical Physics (ICTP) Regional Climate Model Version Four (RegCM4), interactively coupled to a one-dimensional lake model, representing the Great Lakes. This coupling is critical to assess future changes in Great Lakes' water temperatures, ice cover, evaporation, and lake-effect snowfall.

The GCMs were downscaled from approximately 150 x 150 km to 25 x 25 km.

Simulations covered the late 20^{th} (1981-2000), mid-21^{st} (2040-2059), and late 21^{st} (2081-2100) centuries, according to the representative concentration pathway 8.5 (RCP8.5).

Projected Change in Air Temperature (°C) Within the Great Lakes Region (40-50°N, 95-70°W, Over-Land) by the Mid- and Late 21st Century

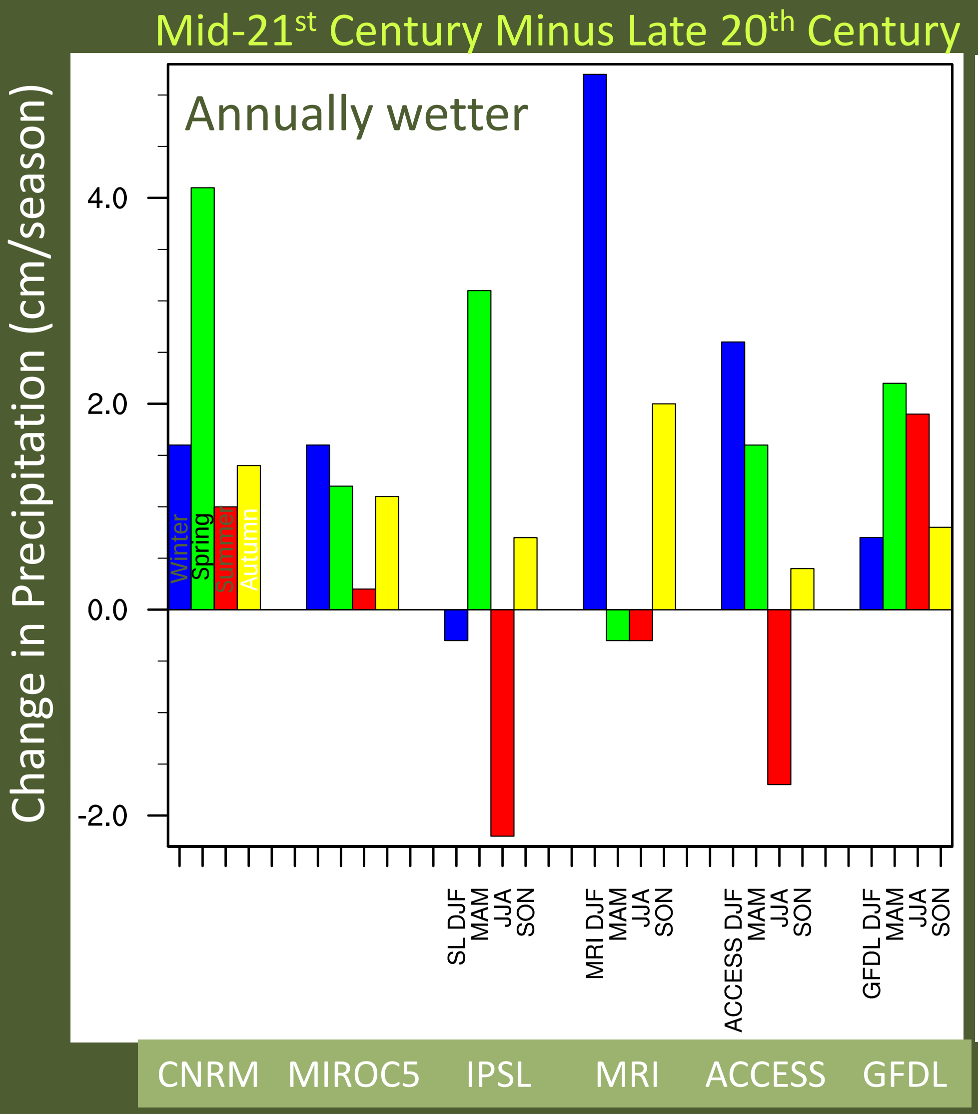


MIROC5: Greatest annual warming, +3.1°C
MRI: Least annual warming, +1.8°C

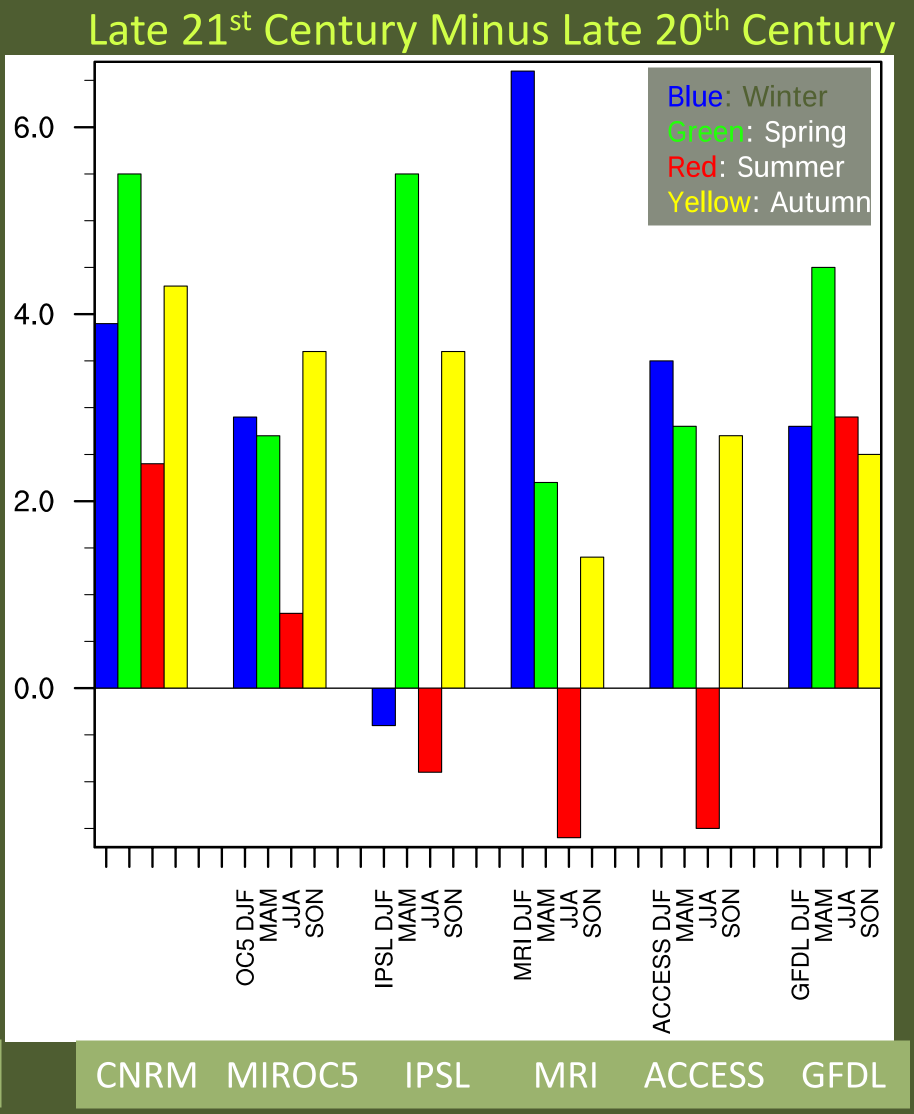
MIROC5: Greatest annual warming, +6.0°C
GFDL: Least annual warming, +3.7°C

The six model projections generally show greatest warming in summer and least warming in spring.

Projected Change in Precipitation (cm/season) Within the Great Lakes Region by the Mid- and Late 21st Century



CNRM: Greatest annual increase, +8.1 cm
IPSL: Least annual increase, +1.3 cm



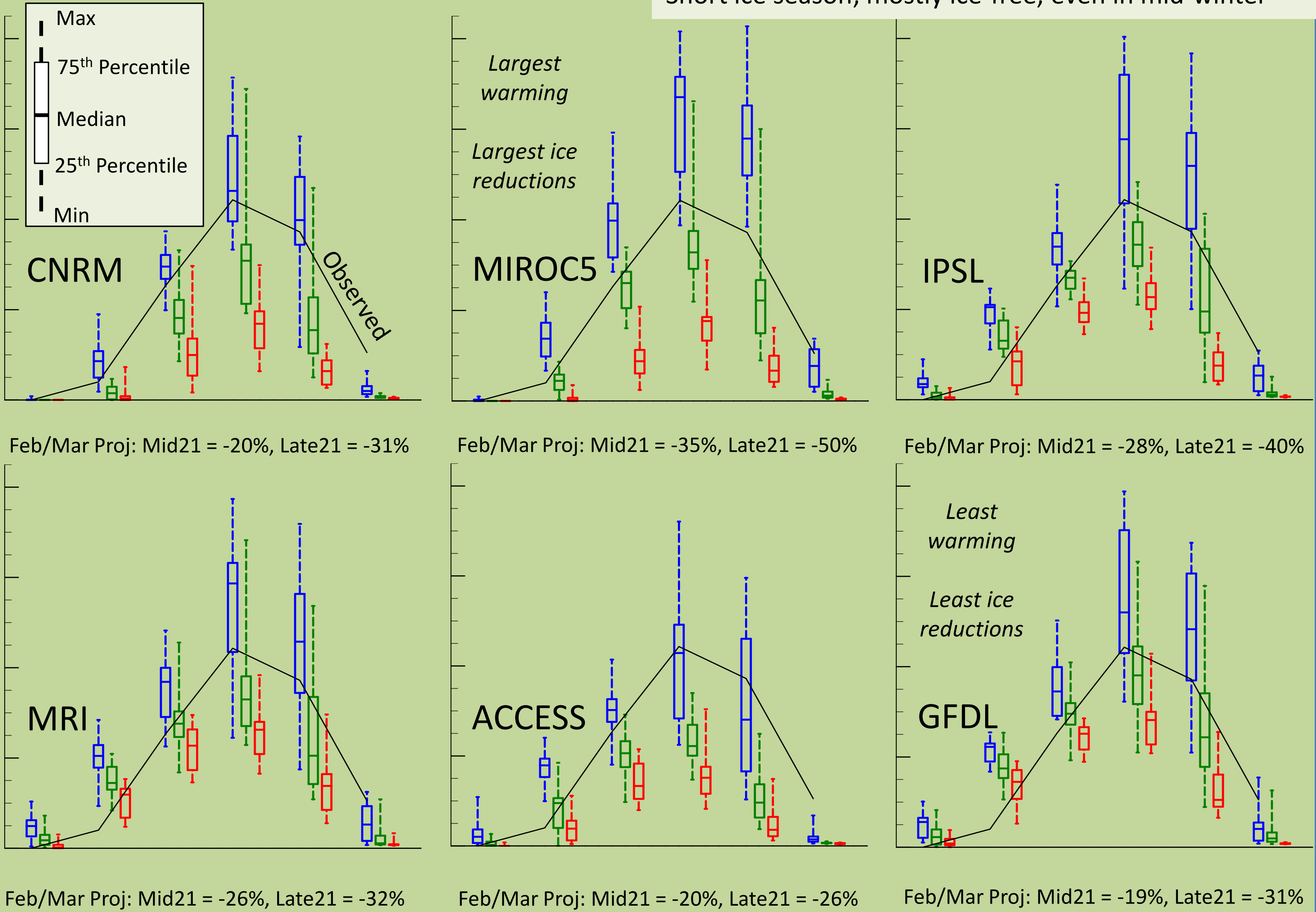
CNRM: Greatest annual increase, +16.1 cm
ACCESS: Least annual increase, +7.5 cm

The 6 model projections generally show greatest ppt increases in spring & large uncertainty in summer (3 wetter, 3 drier).

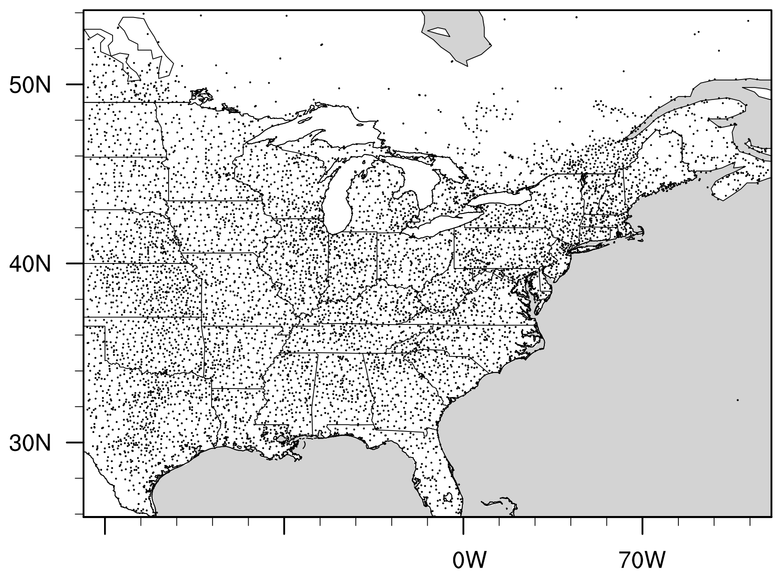
Projected Great Lakes' % Ice Cover

Blue: Late 20th, Green: Mid-21st, Red: Late 21st

Model bias: Significant positive bias (+10%) in DJFM.
Projections: Large reductions in February-March.
Short ice season; mostly ice-free, even in mid-winter



Methodology: Stage 3 (Debiasing)



Distribution of 7360 stations providing snow depth data from the Global Historical Climate Network.

The output from the regional climate model, RegCM4, was debiased against observations, both in terms of the daily mean and interannual variability.

Simulated daily shortwave and longwave radiation and wind speed were debiased against the Global Land Data Assimilation System (GLDAS, Rodell et al. 2004).

Simulated daily maximum and minimum air temperature, relative humidity, and precipitation were debiased against Daymet (Thornton et al. 1997).

Simulated daily snow depth was debiased against a gridded observational product, which we developed based on data from 7360 stations from the Global Historical Climate Network.

The debiased model output is currently being used as input to the lake and stream models by the United States Geological Survey (USGS) and Wisconsin Department of Natural Resources (WI DNR) (Jordan Rea, Steve Westenbroek, Gretchen Hansen).

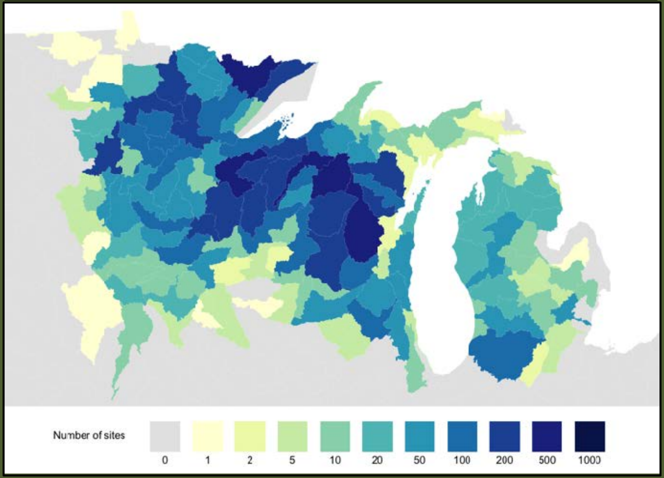
Methodology: Stage 4 (Lake and Stream Modeling, in progress)

Previously, Stewart et al. (2015) developed future projections of summertime stream temperatures in Wisconsin and their thermal classes using 0.1° statistically downscaled climate projections from 10 GCMs in the Coupled Model Intercomparison Project Phase Three (CMIP3), for the A1B emission scenario, driving an artificial neural network model integrated with a soil-water-balance model (SWB-ANN).

USGS and WI DNR have used the General Lake Model (GLM), forced by 50-km dynamically downscaled climate projections from RegCM3 based on three CMIP3 GCMs for the A2 emission scenario (Hostetler et al. 2011), to develop projected changes in water temperatures for 2400 Wisconsin lakes.

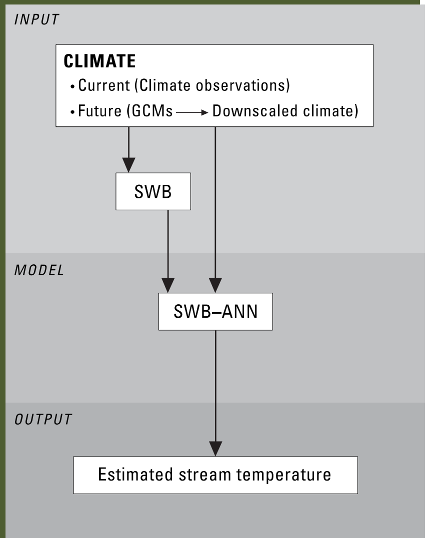
There is a major issue of available data inconsistency that is being addressed in our current project on aquatic invasive species for Minnesota, Wisconsin, and Michigan. UW-Madison Center for Climatic Research (CCR) has developed 25-km dynamically downscaled climate projections using RegCM4 according to six CMIP5 GCMs and the RCP8.5 scenario. The existing lake and stream temperature projections are for different GCM forcings, different emission scenarios, and the older CMIP phase and do not cover all three states. **We need a consistent dataset of future changes in air, lake, and stream temperatures to assess** the potential future risk of invasion of specific species into the Upper Midwest United States.

Distribution of 8,903 lakes being modeled in the 3 states



As a result, Jordan Read and Steve Westenbroek are currently running GLM and SWB-ANN, forced by CCR's RegCM4 dynamical downscaling to create a consistent dataset for niche modeling.

Modeling Approach from Stewart et al. (2015)



EXPLANATION

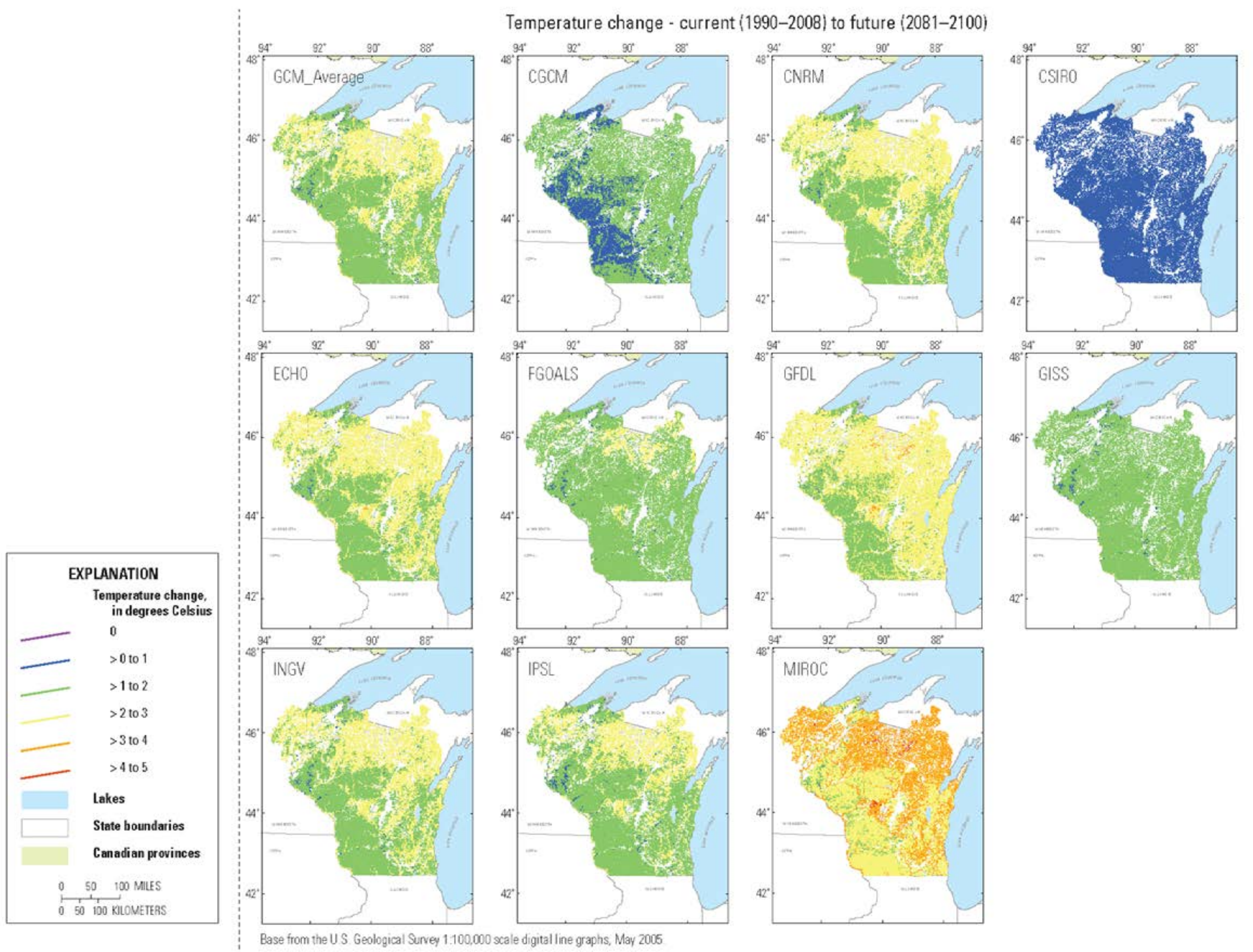
GCMs = General Circulation Models

SWB = Soil-Water-Balance Model

ANN = Artificial Neural Network Model

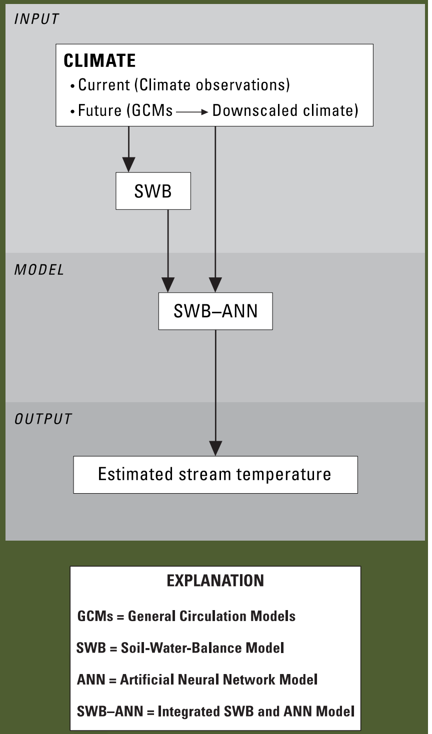
SWB–ANN = Integrated SWB and ANN Model

Projected Change in Summertime Stream Temperature (°C) by the Late 21st Century from Stewart et al. (2015)

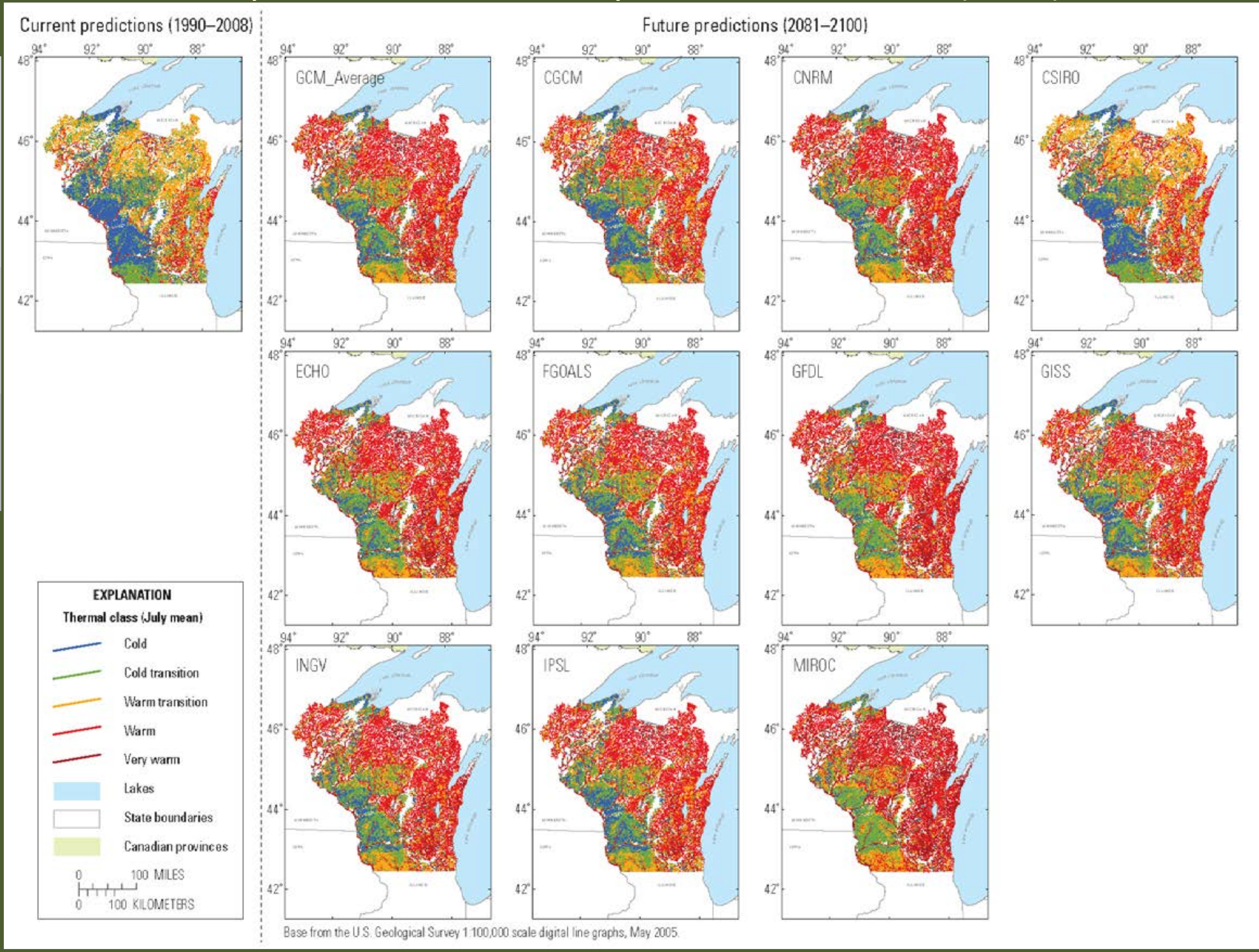


Stewart et al. (2015) simulated a projected warming of 1-2°C for about 80% of stream kilometers by the mid-21st century and 1-3°C of warming for about 99% of stream kilometers by the late 21st century.

Modeling Approach from Stewart et al. (2015)



Projected Change in Summertime Stream Temperature Thermal Classes by the Late 21st Century from Stewart et al. (2015)



Stewart et al. (2015) simulated a loss of cold-water, cold-transition, and warm-transition thermal habitat in Wisconsin, with a gain in warm-water and very warm thermal habitat.

Limitations of geo-referenced location data

Species distribution modeling requires good data

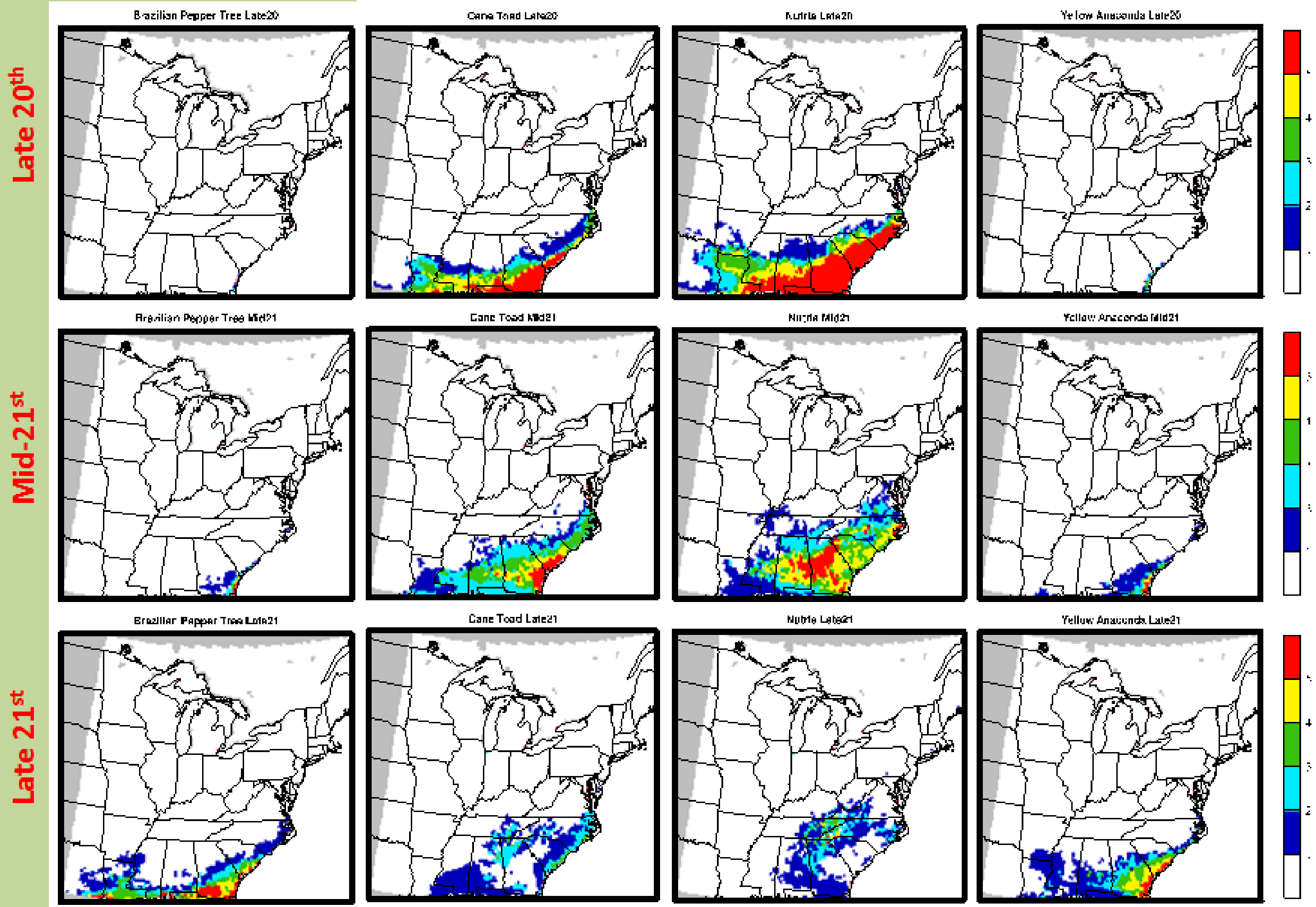
- Systematic surveys for location data are rarely available
- Geo-referenced occurrence data does not always indicate self-perpetuating populations
- Invasives are often generalists with wide tolerances; what are the limiting factors?
- Is habitat not suitable where there is no occurrence data or have they just not gotten there yet?

Methodology: Stage 5 - Climate Niche Modeling (in progress)

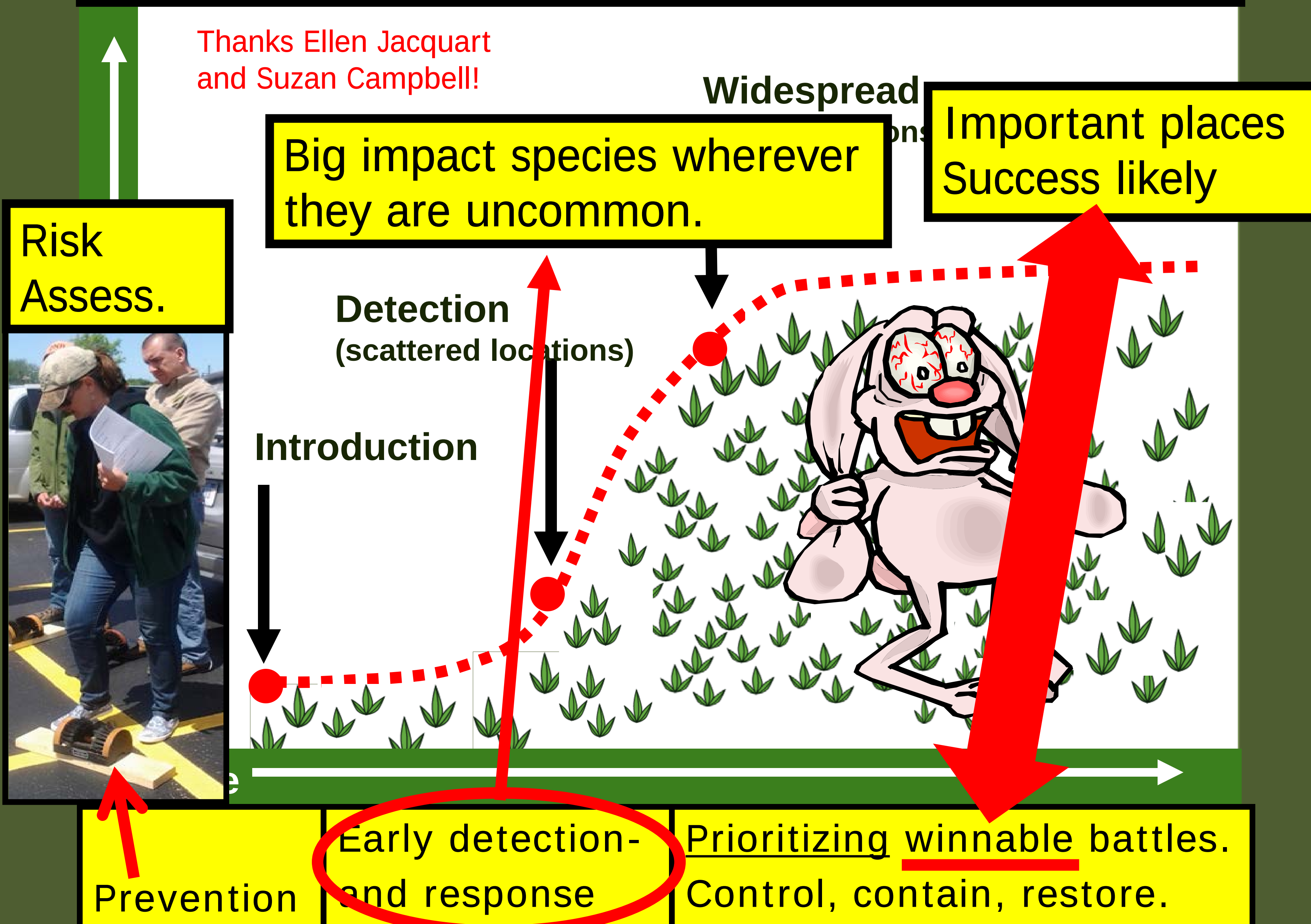
- Thorough lit review and discussion w/ experts:
  - key environmental regulators of AIS species
  - little data for many species
    - presence/absence
    - sensitivity to climatic variables
- Initially examining
  - projected changes in air, lake, and stream temperatures
  - impacts on the distribution of 15 aquatic invasive species

Projected Change in Climate Space Based on Air Temperature (# Models w/Satisfactory Climate)

Brazilian Pepper Tree | **Cane Toad** | **Nutria** | **Yellow Anaconda**



Our challenge is to pick the right battles.



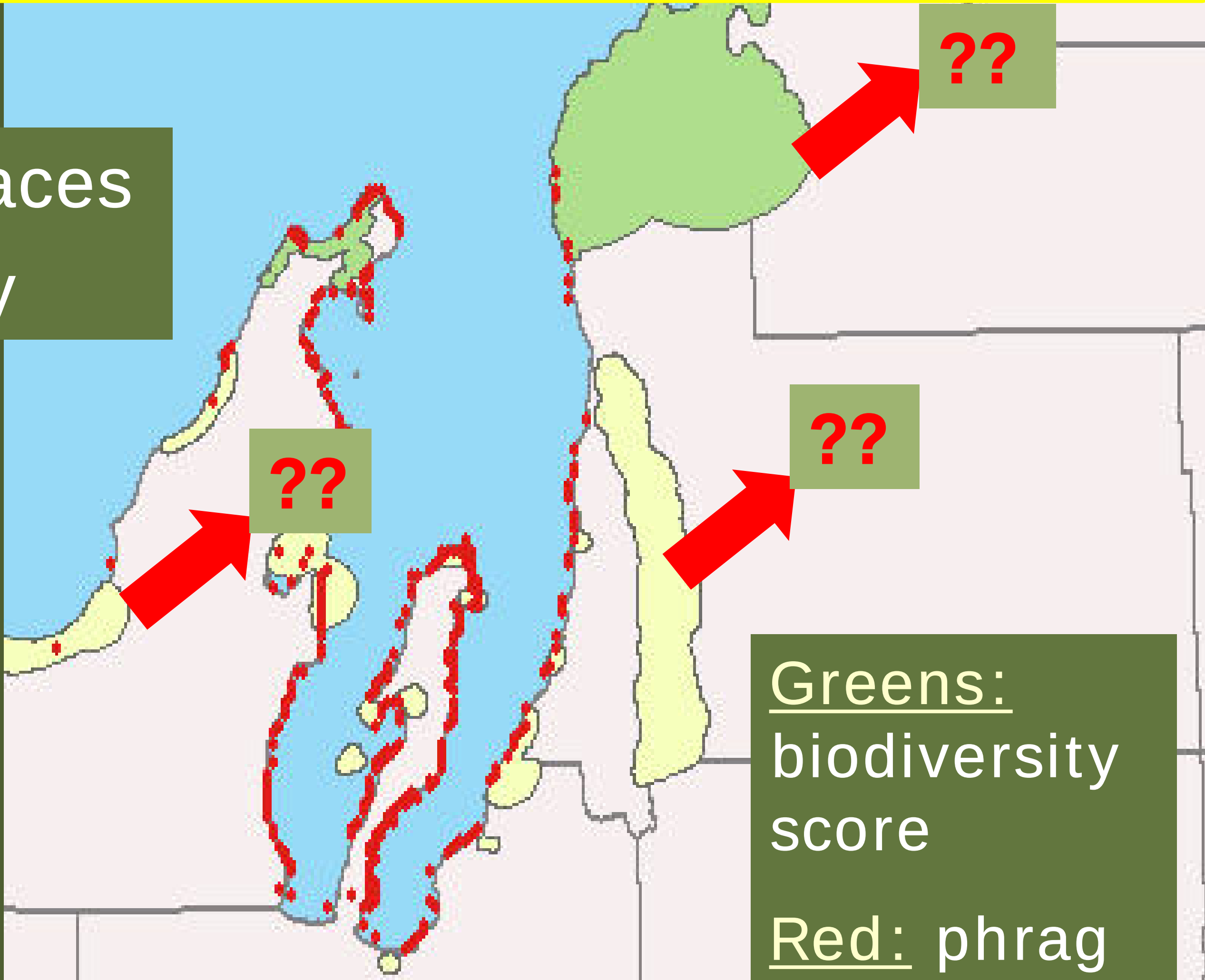
It is crucial to know:

- What are you trying to protect?
  - New climate spaces?
  - Climate refugia?
- Do the “invaders” pose a real threat?
- Where are they and how much is there?
  - What pathways will they move along?
- How can we best mitigate their impacts?
  - Eradicate/Contain/Control?
  - Available/best techniques?
  - Resources?

We need better maps for biodiversity conservation planning under climate change scenarios!

- Important places
- Success likely

- Outliers
- Sources
- Pathways

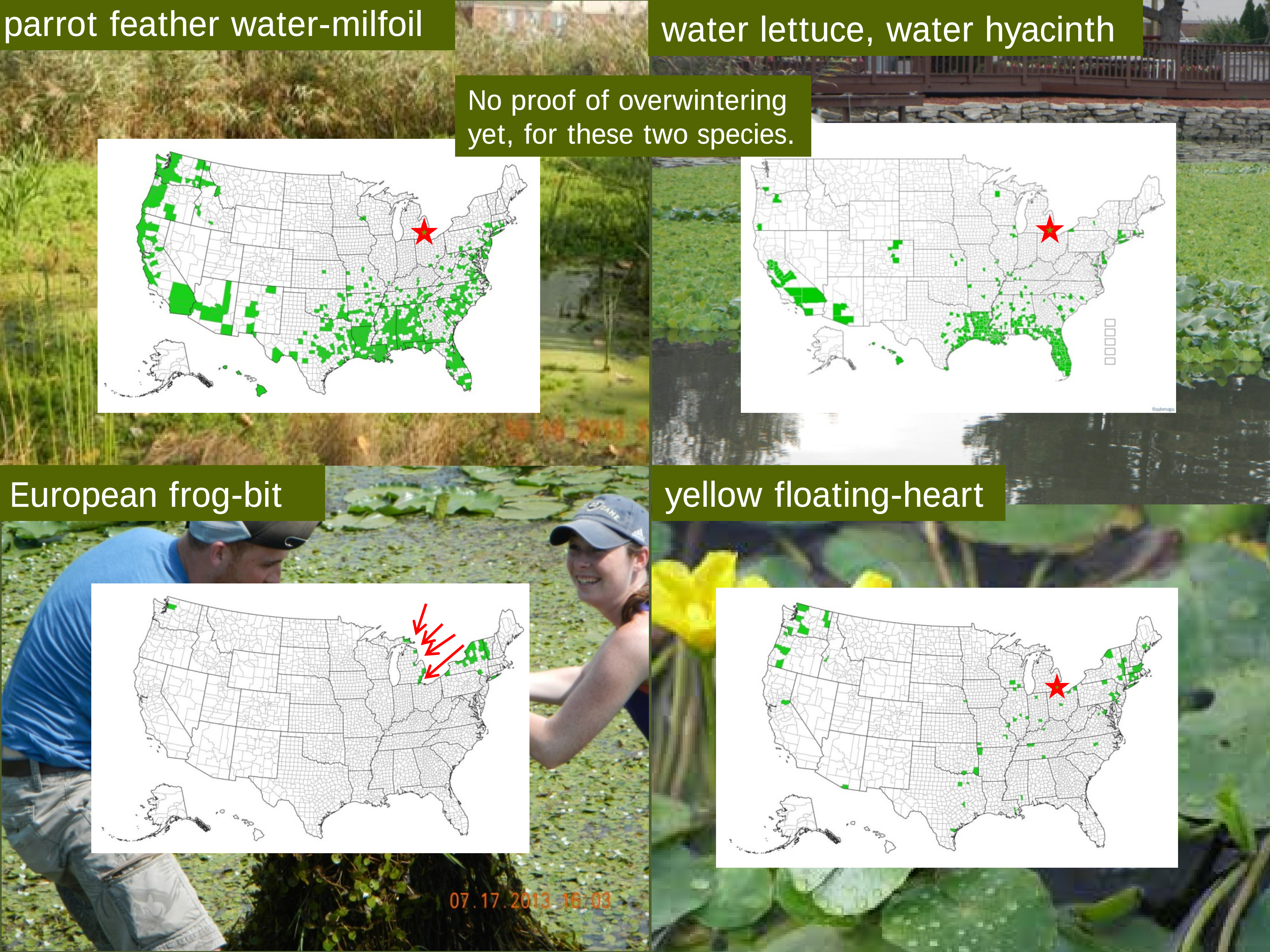



parrot feather
water-milfoil


water lettuce
water hyacinth


European frog-bit
07.17.2013 16:03
UGA5272031


yellow floating-heart


parrot feather water-milfoil
water lettuce, water hyacinth
No proof of overwintering
yet, for these two species.
European frog-bit
yellow floating-heart
07.17.2013 16:03

Concerted efforts needed:

- Infrastructure and field staff capable and ready to jump into action, especially EDRR!
- Where are important new climate spaces and refugia?
- What pathways will invasives follow?
- Improve knowledge of control techniques
  - don’t re-invent the wheel
  - innovate – are there new alternatives?




The sum is greater than it’s parts!