Models of species' climatic niche

Jessica J. Hellmann | Director, Institute on the Environment

INSTITUTE ON THE ENVIRONMENT
UNIVERSITY OF MINNESOTA
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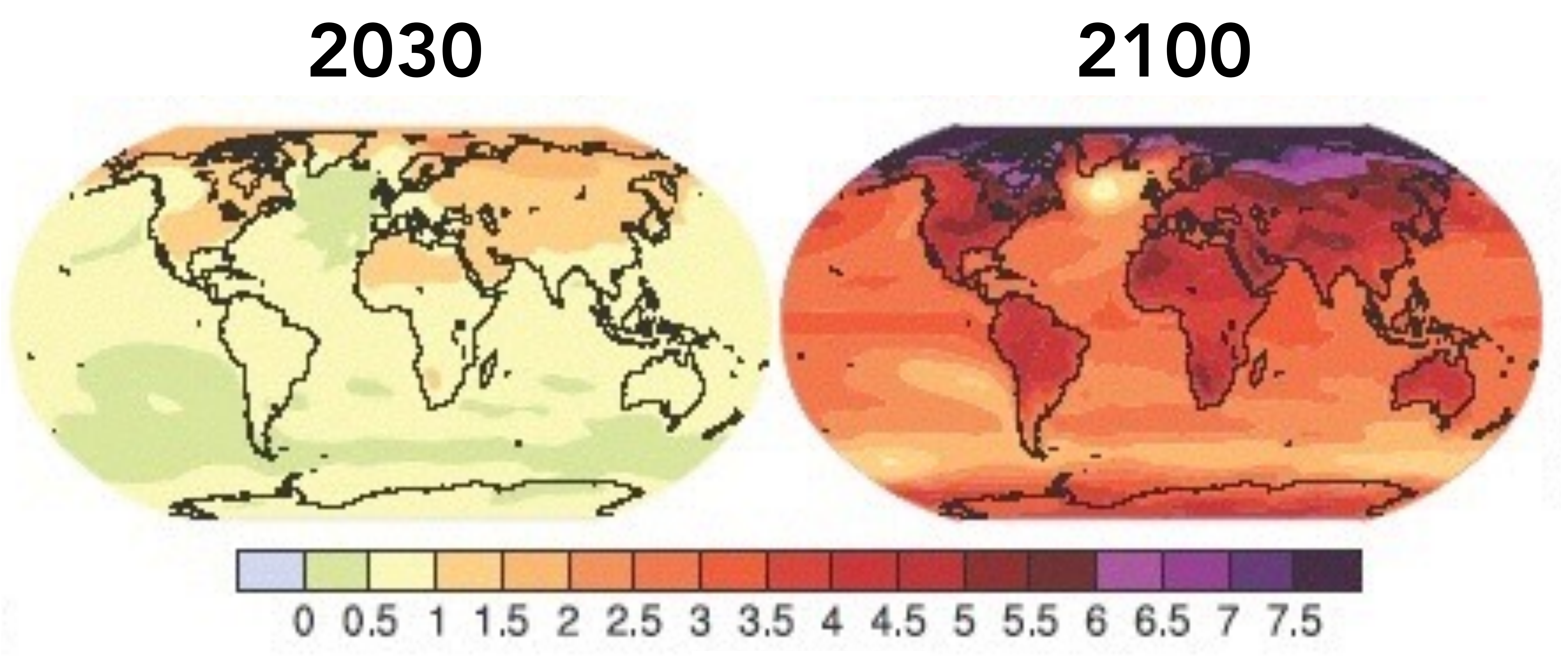
For purposes of basic knowledge and conservation planning, ecologists seek to characterize the climatic conditions that limit where species live on Earth. To do this, they build **statistical models** that describe the climatic niche of individual species based on its geographic occupancy. These models, e.g., MaxEnt, are **classification algorithms** that aim to distinguish occupied from non-occupied points from a set of climatic descriptors. With a description of a species' ecological niche, it is possible to project these conditions forward in time according to global circulation model output and identify locations that might be suitable for the focal species in the future. We will discuss some examples of how these models are used, criticisms that ecologists have leveled at these models, and one particular dilemma having to do with local adaptation of populations within a species' range.

The world is changing...

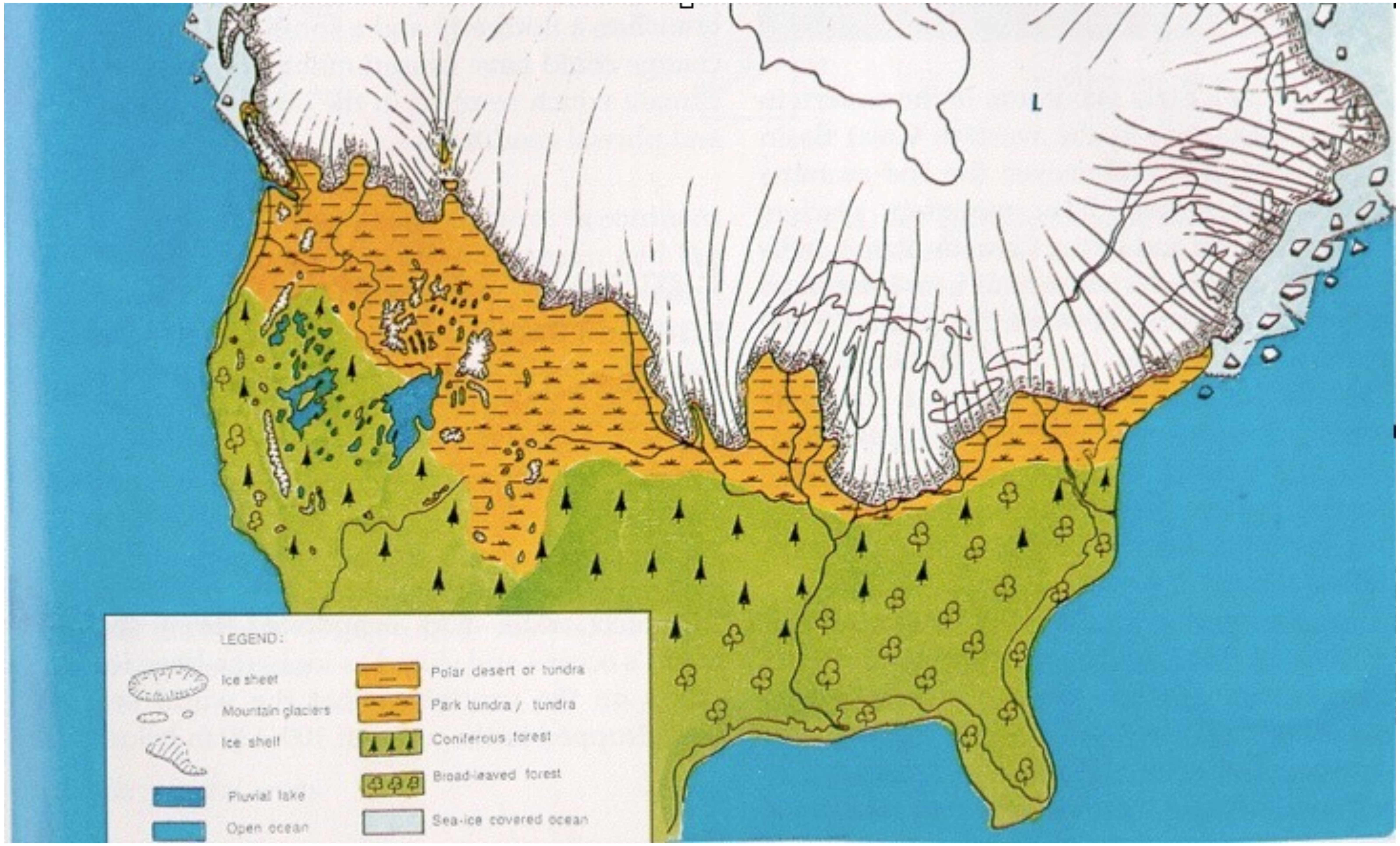


°C increase

IPCC 2007 | National Climate Assessment 2013

The world is changing...

iStockphoto 2630ben | Flickr Mark Land | iStockphoto beckyjenson



Jackson & Weng 1999

Preserving biodiversity under climate change

Species | Genetic Diversity | Ecosystem Function | Ecosystem Services

Questions

1. What factors most limit the distribution of a species?

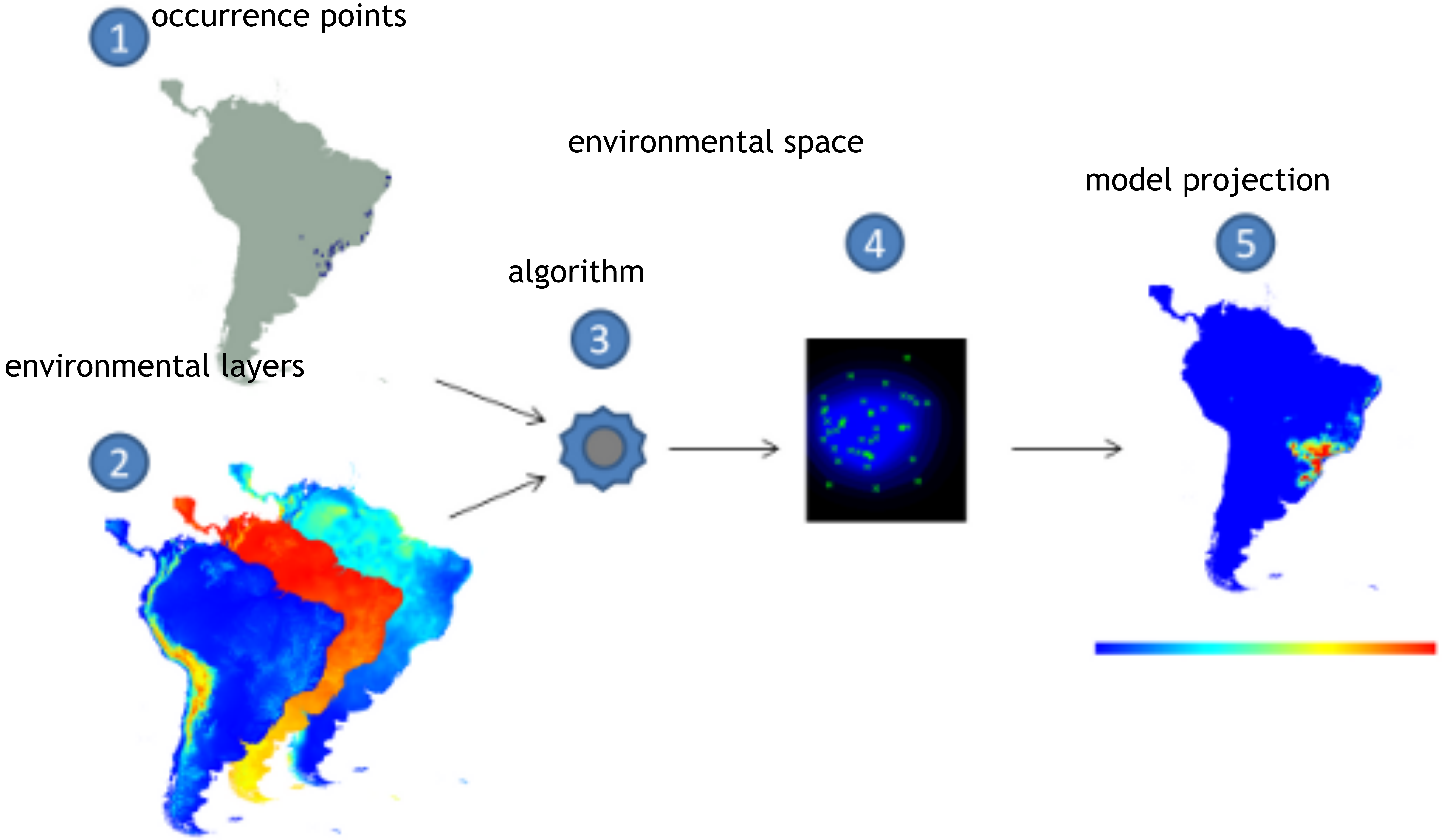
2. Where might a species live under future climate?

3. How far might an invasive species spread?

Management implications

Ecological Niche Modeling

- Also called species distribution modeling, environmental niche modeling, and bioclimatic envelope modeling
- Predict the distribution of species
- Can use to make future projections



http://openmodeller.sourceforge.net/img/enm_diagram_small.png

Multinomial logistic regression

They all have in common a **dependent variable to be predicted** that comes from one of a limited set of items which cannot be meaningfully ordered, as well as a set of independent variables (also known as features, explanators, etc.), which are used to predict the dependent variable. Multinomial logit regression is a particular solution to the **classification problem that assumes that a linear combination of the observed features** and some problem-specific parameters can be used to determine the probability of each particular outcome of the dependent variable.

finds a model that can best differentiate presences from background locations

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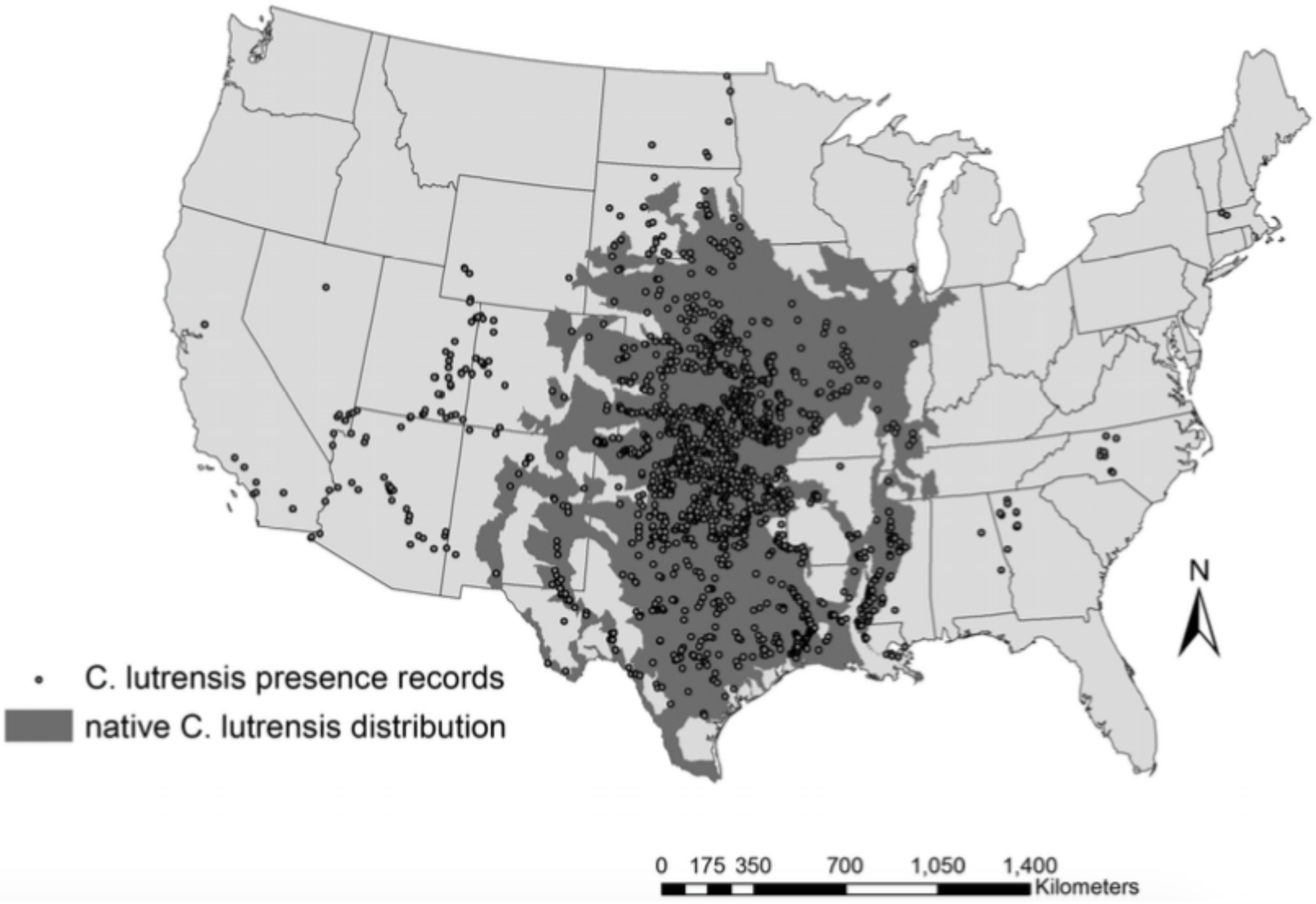
Maxent modeling

Red shiner

Figure 1. Map of Red Shiner presence locations used in the Maxent model. The native distribution of Red Shiner (NatureServe 2010) is shown in dark gray.



Poulos et al. 2012 Aquatic Invasions

Table 1. Environmental predictor variables evaluated for inclusion in the red shiner species distribution models, their native spatial resolution, and data sources. Variables marked with asterisks were those that were included in the final Maxent model.

Predictor variables	Description	Native spatial resolution	Source
Ppt*	mean precipitation 1980-1997	1 km	Daymet[1]
Tmax	mean maximum air temperature 1980-1997	1 km	Daymet[1]
Tmin*	mean minimum air temperature 1980-1997	1 km	Daymet[1]
Jantmin	mean minimum air temperature of the coldest month	1 km	Daymet[1]
Augtmax*	mean maximum air temperature of the hottest month	1 km	Daymet[1]
Sumprecip	average summer precipitation	1 km	Daymet[1]
Summheat*	summer heat: (mean warmest month temperature)/(mean summer precipitation/1000)	1 km	Daymet[1]
RH	relative humidity	1 km	Daymet[1]
Frostdays	number of frost days	1 km	Daymet[1]
Upstream flow	flow length toolbox in ArcGIS	30 m	National Hydrography Dataset[2]
Downstream flow*	flow length toolbox in ArcGIS	30 m	National Hydrography Dataset[2]
Flow accumulation*	flow accumulation from ArcHydro extension of ArcGIS	30 m	National Hydrography Dataset[2]
Watershed slope*	slope of the watershed in degrees	30 m	National Hydrography Dataset[2]
Downslope elevation change*	calculated as the difference between a cell's elevation in meters and the lowest elevation	30 m	National Hydrography Dataset[2]
Stream power index	erosive power of overland flow measured as the area of the catchment area multiplied by the tangent of the slope calculated using Whitebox Geospatial Analysis Tools (Lindsay 2009)	30 m	National Hydrography Dataset[2]
Upslope neigh	number of upslope neighbors	30 m	National Hydrography Dataset[2]
Sed trans	sediment transport capacity index (Burrough and McDonnell 1998)	30 m	National Hydrography Dataset[2]
Impervious	% impervious surfaces	30 m	USGS[3]
Baseflow*	baseflow index grid from USGS stream guages, expressed as percentage of baseflow relative to total flow	30 m	USGS[3]
Saturation overland flow*	estimated by TOPMODEL (Beven and Kirkby 1979)	Vector dataset	USGS[3]

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Figure 2. Maxent results for red shiner including **A**) the habitat prediction map, and **B**) the standard deviation among the 25 model iterations using different subsets of point data to test for model sensitivity to presence locations, and **C**) the presence-absence habitat prediction map for each hydrologic unit (USGS 6-digit HUC) in the United States. The threshold for conversion to binary predictions was derived using the maximum sensitivity plus specificity criterion. The native distribution of *C. lutrensis* is shown in gray.

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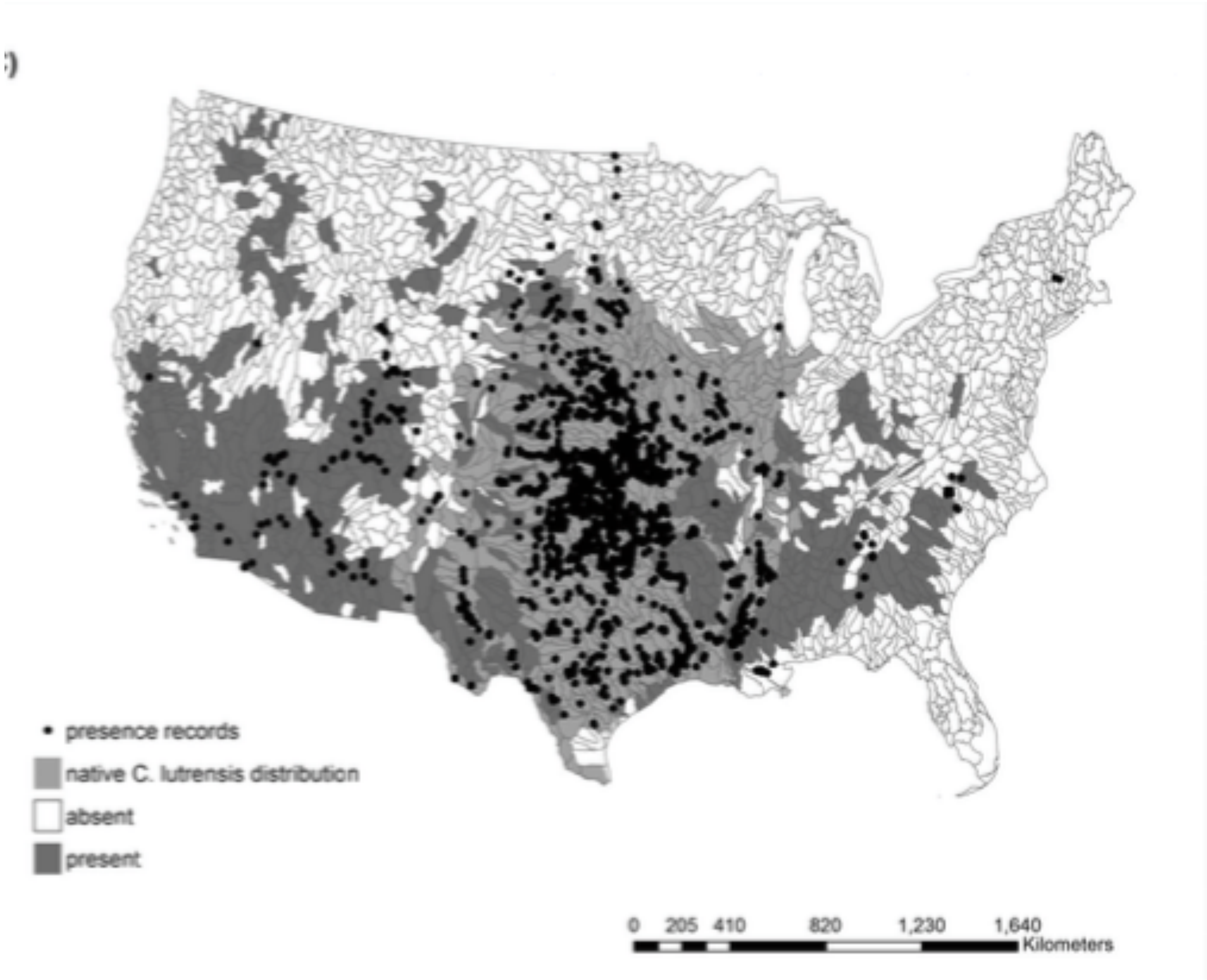

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Random forest modeling

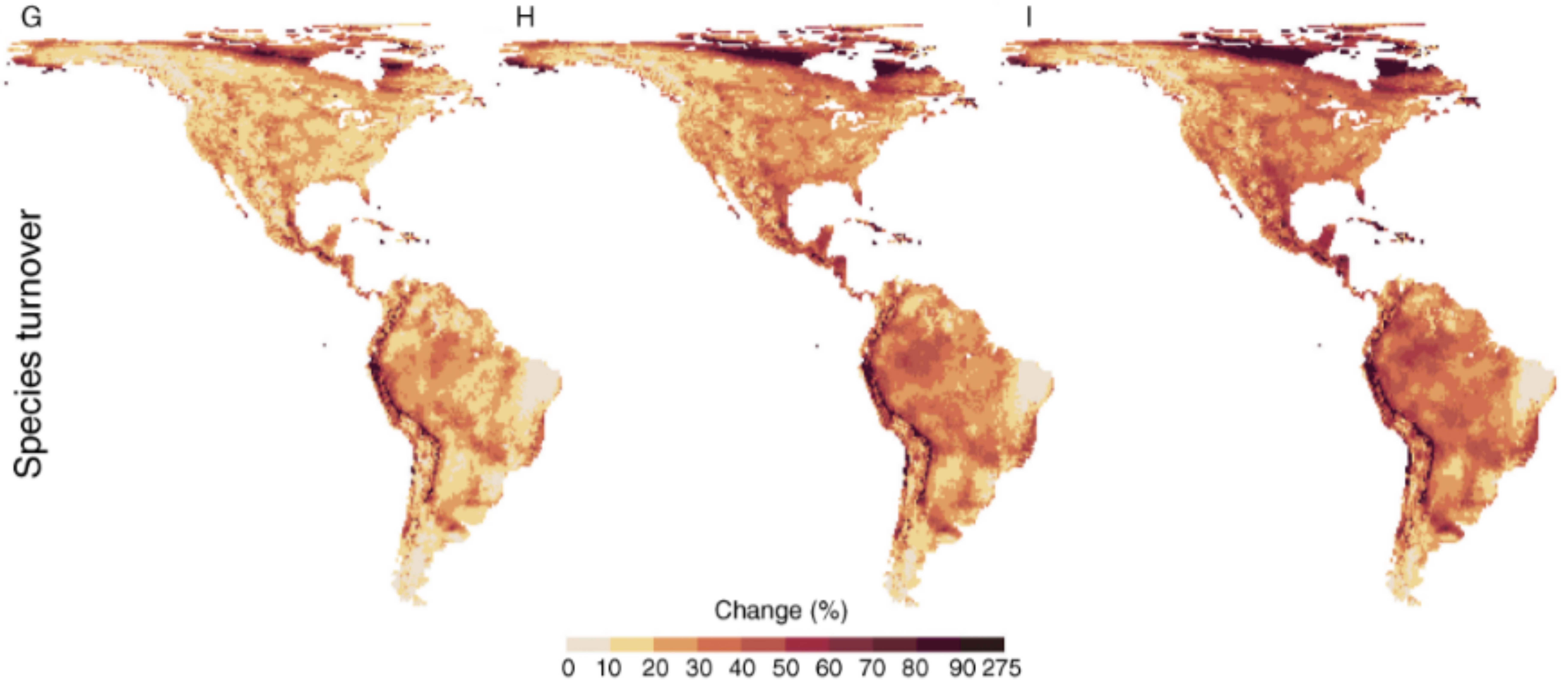


FIG. 1. Consistent predictions of climate-induced (A–C) species range losses, (D–F) expansions, and (G–I) species turnover for lower B1 (A, D, G), mid A1B (B, E, H), and mid-high A2 (C, F, I) greenhouse-gas emissions scenarios. Each map was created using predictions of faunal change (as a percentage) based on 10 different climate-change projections. Species-loss values assume no dispersal of individuals to newly created suitable climatic environments whereas both expansion and turnover values assume that species will be able to move into expanding ranges. Eighty percent of the climate projections (eight of the 10) resulted in losses, gains, and turnover values greater than the values represented in the maps.

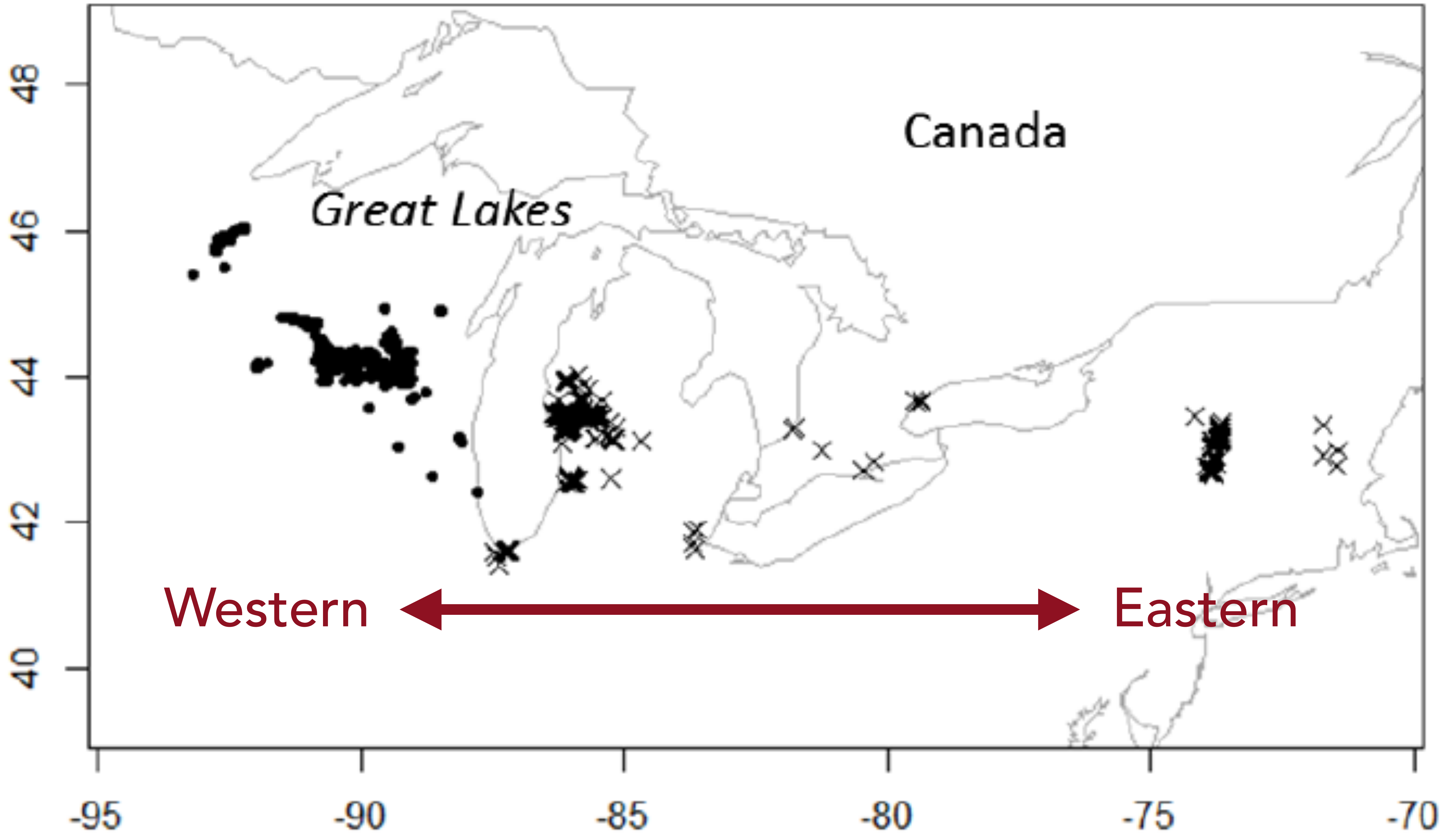
Lawler et al. 2009 Ecology

Critiques

1. assumes climate limits geographic distribution
2. does not include ecology, eg, species interactions
3. junk in, junk out & rigorous assumptions about sampling
4. does not account for local adaptation

Karner Blue Butterfly

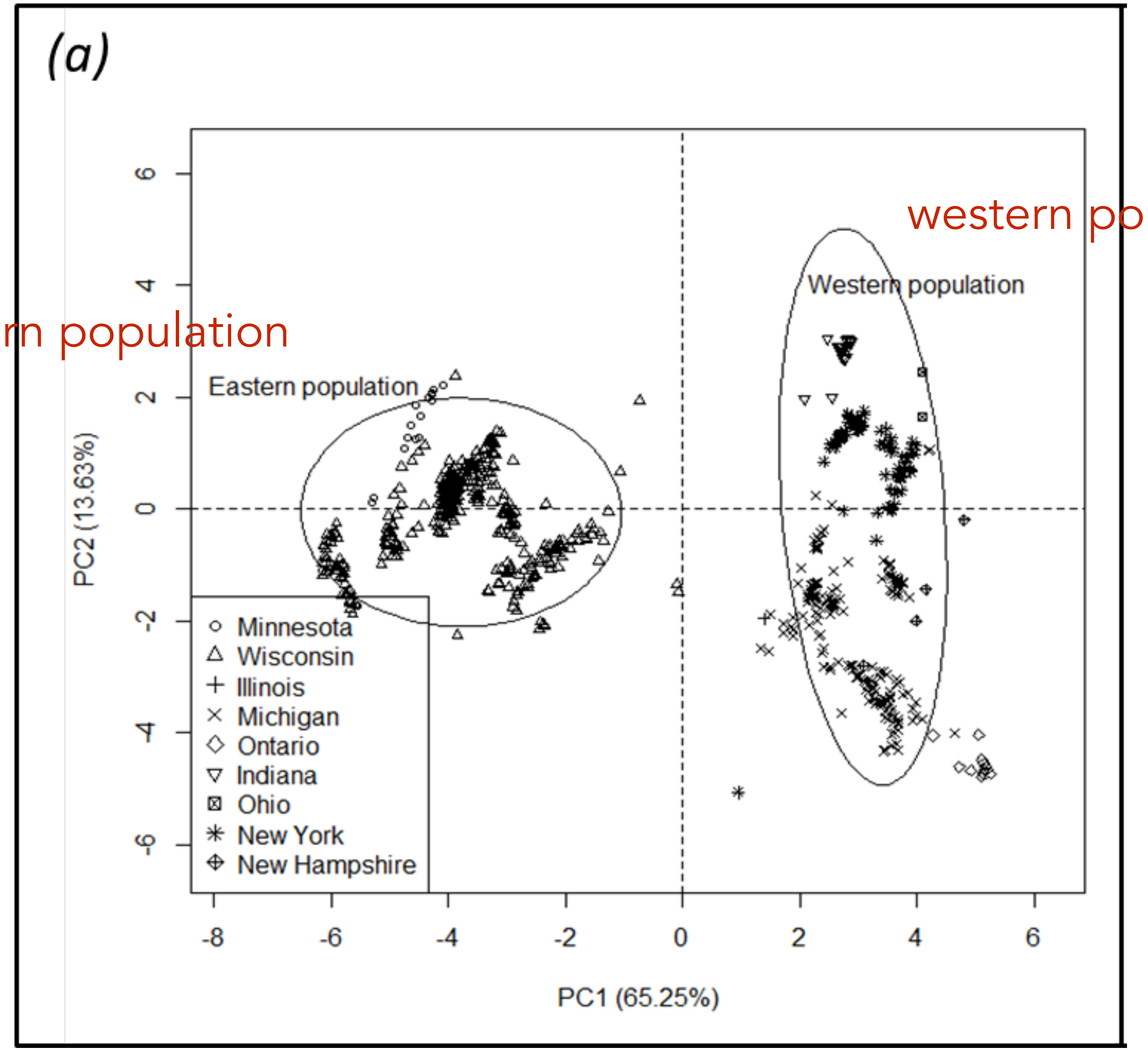
(Lycaeides melissa san)

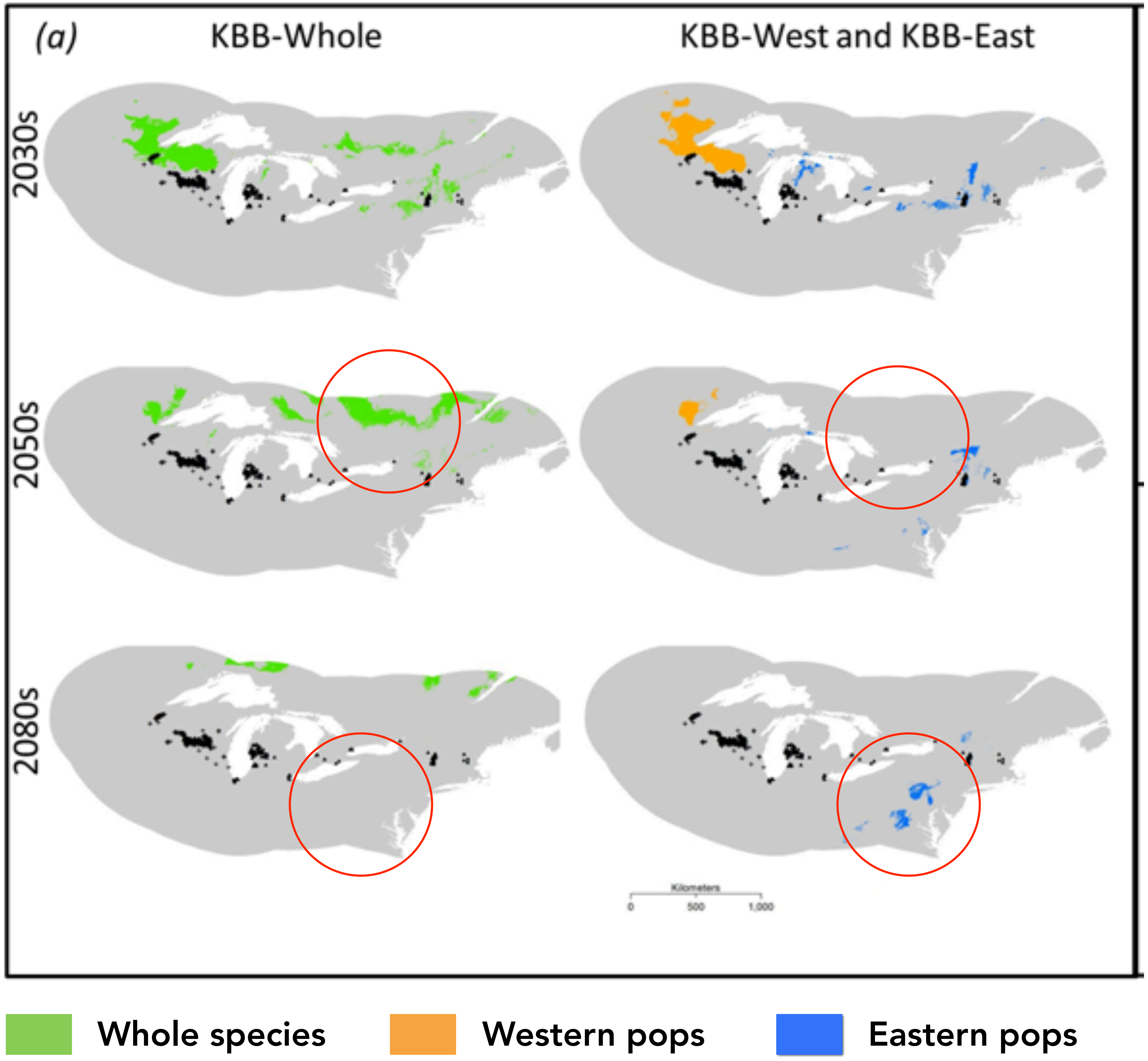


Hällfors et al. In press. *Ecological Applications*. Photo Flickr Justin Meissen

eastern population

western population




(a)
KBB-Whole
KBB-West and KBB-East
2030s
2050s
2080s
Kilometers
0
500
1,000
Whole species
Western pops
Eastern pops

Questions

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Management implications

Managed relocation

Intervention technique aimed at reducing negative effects of climate change on biological units, involving the intentional movement of these units from areas of current occupancy to locations where the probability of future persistence if predicted to be higher.

Richardson et al. 2009. PNAS 106: 9721. Cartoon by Boston Globe 2008.

New York Times | Tues., Nov. 10, 2009

Pros

Prevent extinction

Enhance ecosystem goods

Enhance ecosystem functions

Cons

Create pests

Endanger source populations

Incur opportunity costs

A Hunt for Seeds to Save Species, Perhaps by Helping Them Move

By ANNE RAVER

CHICAGO — Pitcher's thistle, whose fuzzy leaves and creamy pink puffs once thrived in the sand dunes along several of the Great Lakes, was driven by development, drought and weevils into virtual extinction from the shores of Lake Michigan decades ago.

But in the 1990s, seeds collected from different parts of the thistle's range were grown at the Chicago Botanic Garden and planted with the help of the Morton Arboretum along the shore in Illinois State Beach Park, north of Chicago near the Wisconsin state line. The plants from Indiana and the south are doing well; the plants that had come from the north are failing.

With those mixed results in mind, scientists from the botanic garden are sending teams out across the Midwest and West to the Rocky Mountains and Great Basin to collect seeds from different populations of 1,500 prairie species by 2010, and from 3,000 species by 2020. The goal is to preserve the species and, depending on changes in climate, perhaps even help species that generally grow near one another to migrate to a new range.

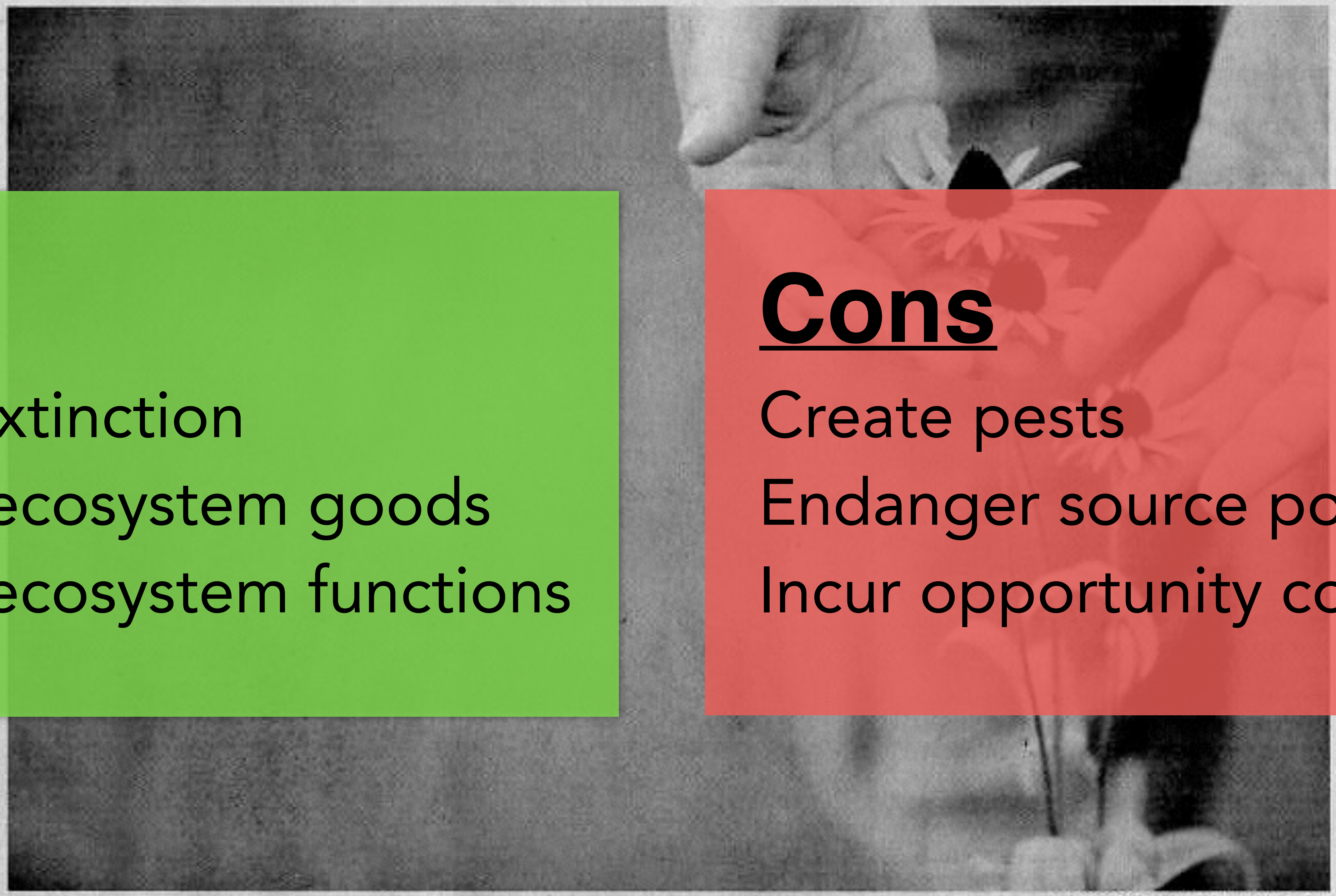
"In 50 to 100 years, because habitats or climates are so altered, we might end up trying to move species in a restoration context, in assemblages of species," said Pati Vitt, a conservation scientist and curator of the Dixon National Tallgrass Prairie Seed Bank at the botanic garden.

The garden is seeking permits to test the concept with the thistle, by pushing it into new, colder territory along the shores of Lake Ontario. "It may be the best test case for moving an individual species outside its range," Dr. Vitt said.

But assisted migration, as it is called, is a hotly debated issue. On one side are those like the botanic garden scientists, who argue that the risks are better than doing nothing.

"We recognize that climate change is likely to be very rapid and that seeds only disperse a few hundred yards, half a mile at most, naturally," said Kayri Havens, the botanic garden's director of plant science and conservation. "They'll need our help if we want to keep those species alive."

Other scientists argue that tinkering with the complexity of habitats is court-



SALLY RYAN FOR THE NEW YORK TIMES

FLOWERING Native plants like black-eyed Susans are growing in what had been a vacant Chicago lot.

change."

The American beech, for example, was so rare during the ice age that it is rarely found in fossils. "It may have been one of those rare and unusual species we think about saving with approaches like assisted migration," Dr. McLachlan said. Now, the beech is so abundant in Eastern forests, he said, it is shading out "almost all other species."

Dr. McLachlan and other scientists have formed a working group on managed relocation, financed by the National Science Foundation and the Cedar Tree Foundation, to open up the discussion to citizens, economists, natural resource managers and policy makers.

While the debate proceeds, scientists at the botanic garden are building the seed collection and assessing the adaptability of different populations of spe-

of September, they moved collections of 800 Midwestern species — some made up of 300,000 seeds — from their old home in four large freezers, hardly different from the kind a large family might use to store home-grown produce and a side of beef.

"The first time I walked in here, I started to cry," Dr. Vitt said. "I know what having this will allow us to do in the

Is it wise or foolish to assist with the migration of plants?

future. It's the most important conservation work the garden can be doing."

The prairie effort is part of a Bureau

Seeds of Success, started in 2001 in response to a Congressional mandate to plant native seed in restoring public lands destroyed by wildfire, began its far more ambitious initiative in June 2008.

A consortium of botanic gardens and other institutions have sent 65 teams across the country, which so far have collected groupings of 3,200 species.

"We hope to collect 20 populations across the species' range so we can get 95 percent of the genetic diversity of the species," said Peggy Orwell, the plant conservation program manager at the bureau. "Because frankly, we don't know what it is we're going to need when we're talking restoration in light of climate change. It's going to be one big experiment."

Seeds of Success sends one collection of every species to the Millennium Seed

The Dixon seed bank at the Chicago Botanic Garden houses not only species from the tallgrass prairie, but also natives of the bogs, dunes and other ecosystems in the prairie region. It also includes the working collections of species singled out for restoration.

"In the Midwest, we have about 200 that are going to be very important," Dr. Havens said. "These are the matrix species, the bread-and-butter species that can be used in restorations after disturbance to really stabilize the community."

Climate models all show temperatures rising, but they do not agree on the prairie's future climate.

"Some models show us with more Virginia-like ecosystem, some say more like Texas," Dr. Havens said.

In a paper published in the journal Biology Conservation and available now online, Dr. Vitt, Dr. Havens and the other scientists at the botanic garden outline a framework for assisted migration, calling first for a globally unified seed banking strategy, which involves collecting genetically diverse populations of each species, accompanied by provenance data like GPS coordinates, soil type and the structure of the surrounding plant community.

They also propose how to predict where species can be relocated. The scientists are just beginning to test their theories in seven climate change gardens planted this fall across the country. Each contains genetically identical clones of plants grown from seed collected in four hardiness zones (4, 5, 6 and 7). Three sites are in the Chicago area, with the others in Boston; Chapel Hill, N.C.; Seattle; and Washington.

Students and volunteers will collect data on the species, and can compare their gardens with others through a webcam system. "If plants grown from seed collected in Zone 4, 5 or 6 can't withstand Texas conditions," Dr. Havens said, "that's a good sign they're going to become extinct here, if there's no way for them to migrate on their own or human-assisted."

Collecting all the native species in the United States, as well as developing restoration techniques and growing huge amounts of seed will take about 10 years and cost about $500 million, Dr. Havens said — a cost that she argues is well worth it.

Future research

1. process-based models
2. algorithm improvements
3. better sampling
4. experimental transplants

THANK YOU

@JessicaHellmann | Director, Institute on the Environment

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