Watershed-Scale Wetland Functions Affect Downstream Systems

Charles R. Lane[1], Grey R. Evenson[2,3], Heather E. Golden[1], and Daniel L. McLaughlin[3]

[1] US Environmental Protection Agency, Office of Research and Development

[2] Ohio State University, Department of Food, Agricultural, and Biological Engineering

[3] Virginia Tech, Department of Forest Resources and Environmental Conservation

Presentation Overview

- Wetland Extent
- State of the Science: Habitat/Biogeochemical Functions
- Study: Hydrological and Biogeochemical Functions
- Implications

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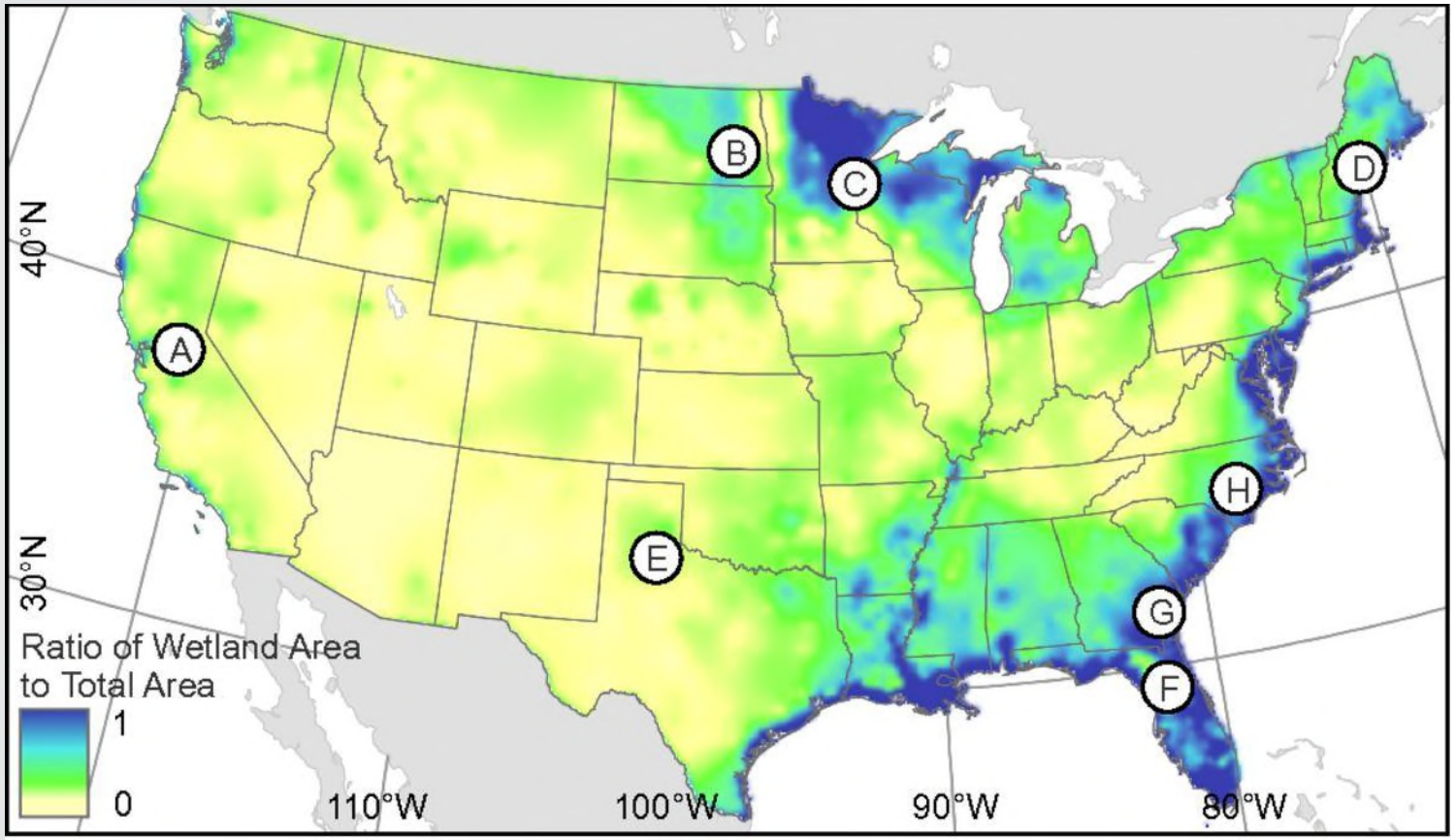
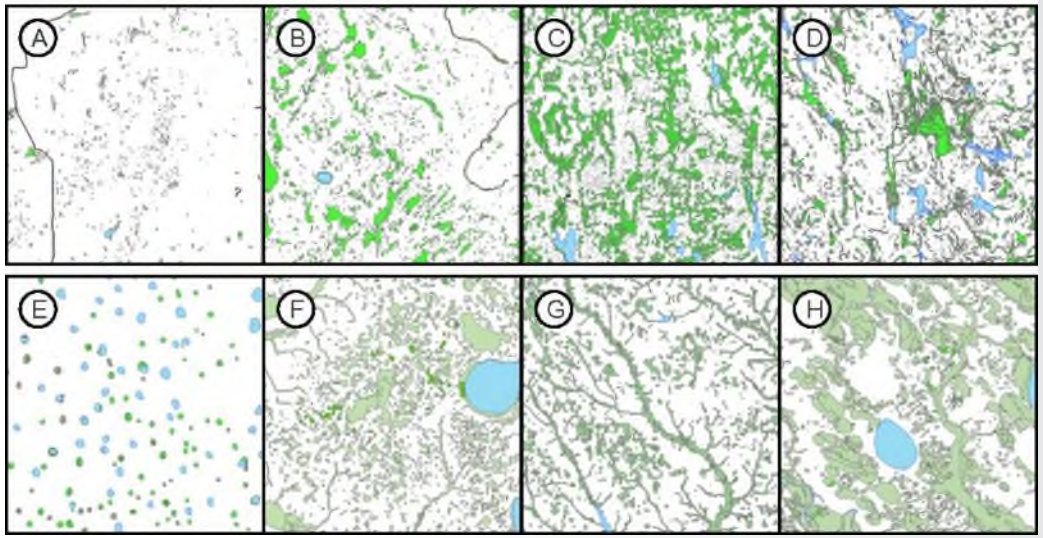
Wetlands Across the CONUS

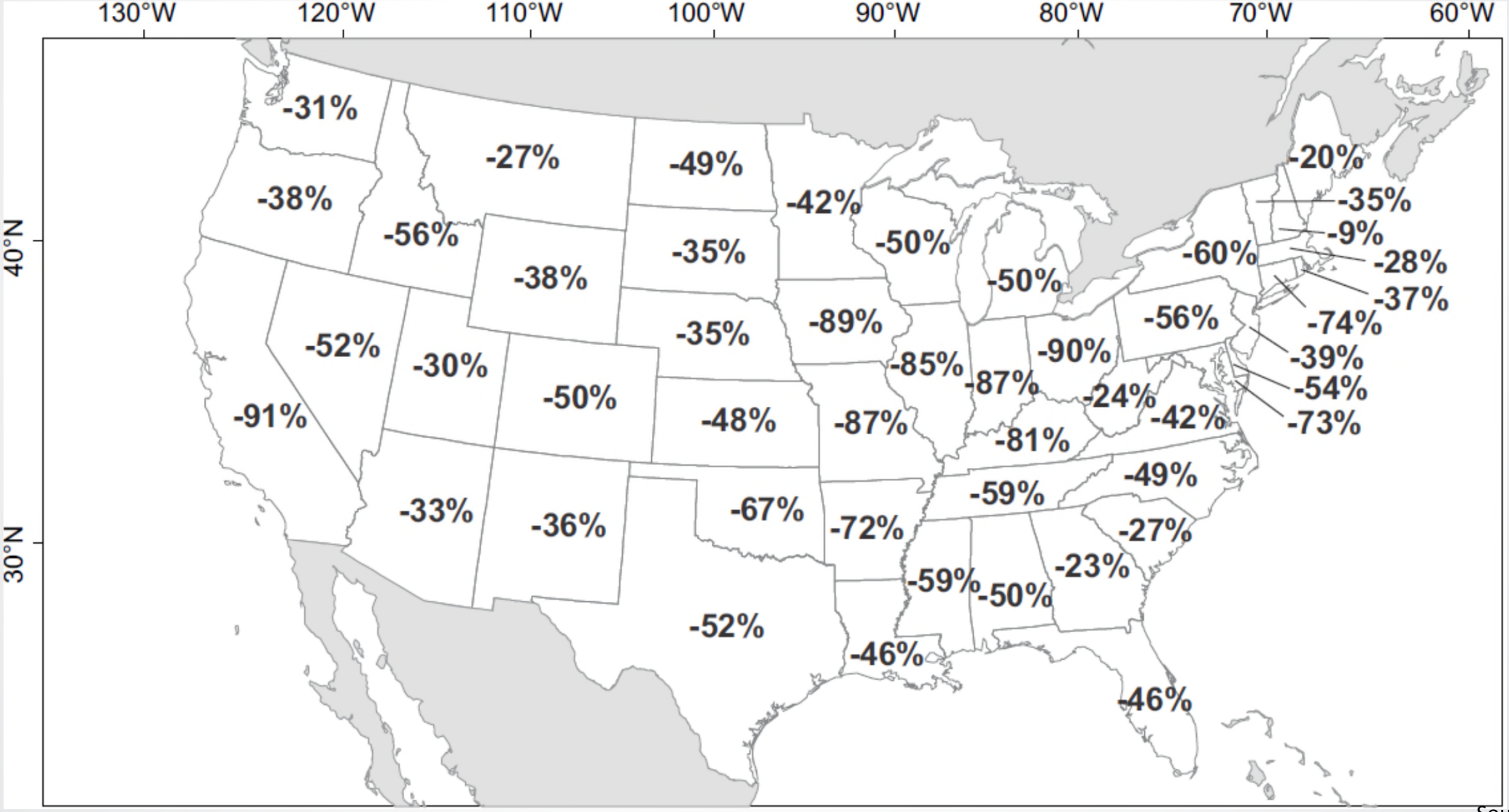




- Current estimates of 45 million ha.
- 95% are freshwater systems
- 16% are non-floodplain wetlands

Cohen et al. PNAS 2016;113:8:1978-1986

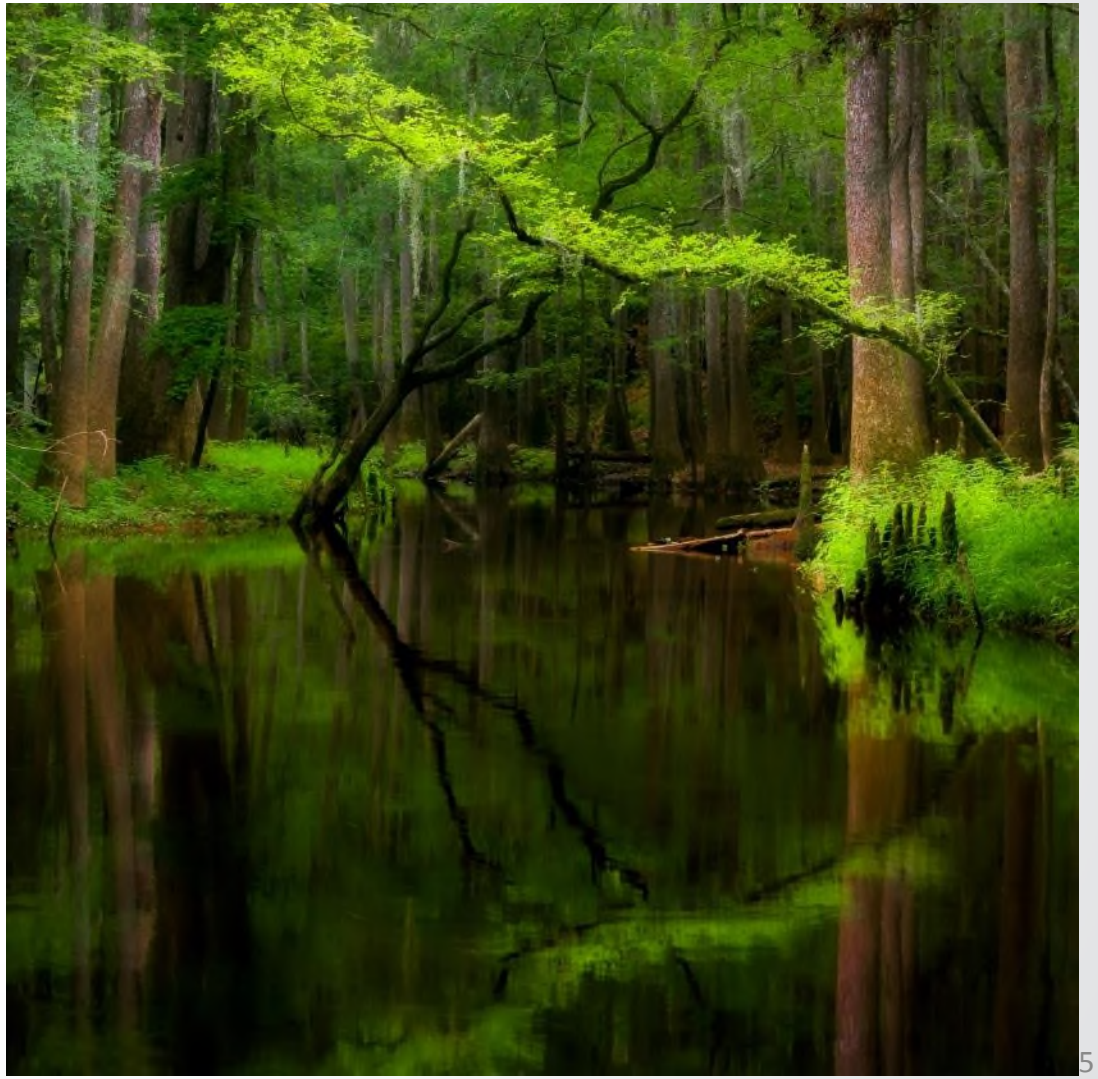
Historical Wetlands Losses: ~ 50%



Source: fws.gov

Wetland Destruction and Modifications

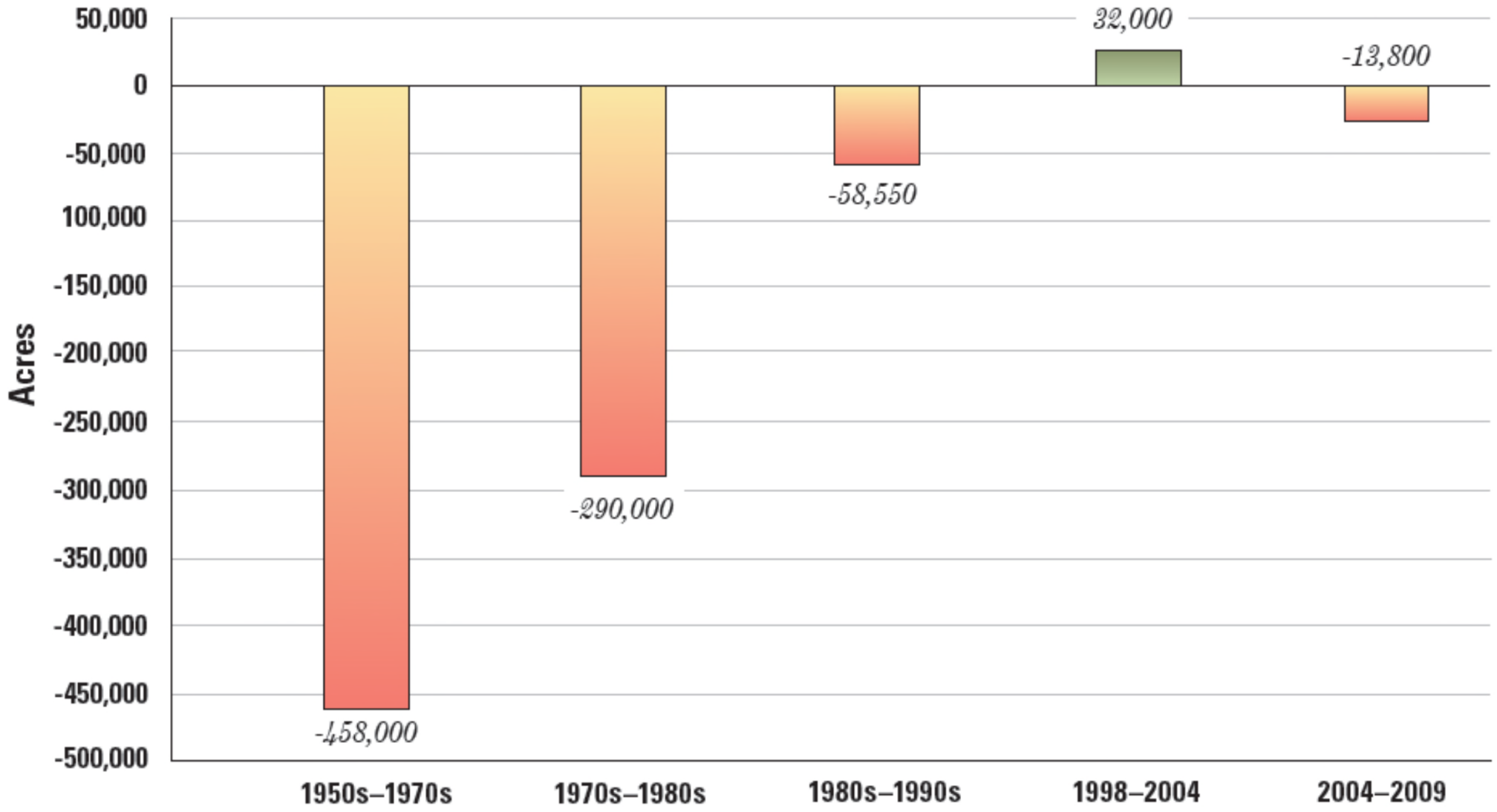
- Ditching and Draining
- Filling and Destruction
- Climate Change
- Invasive Species



Source: FredWasmer.com; Congaree NP

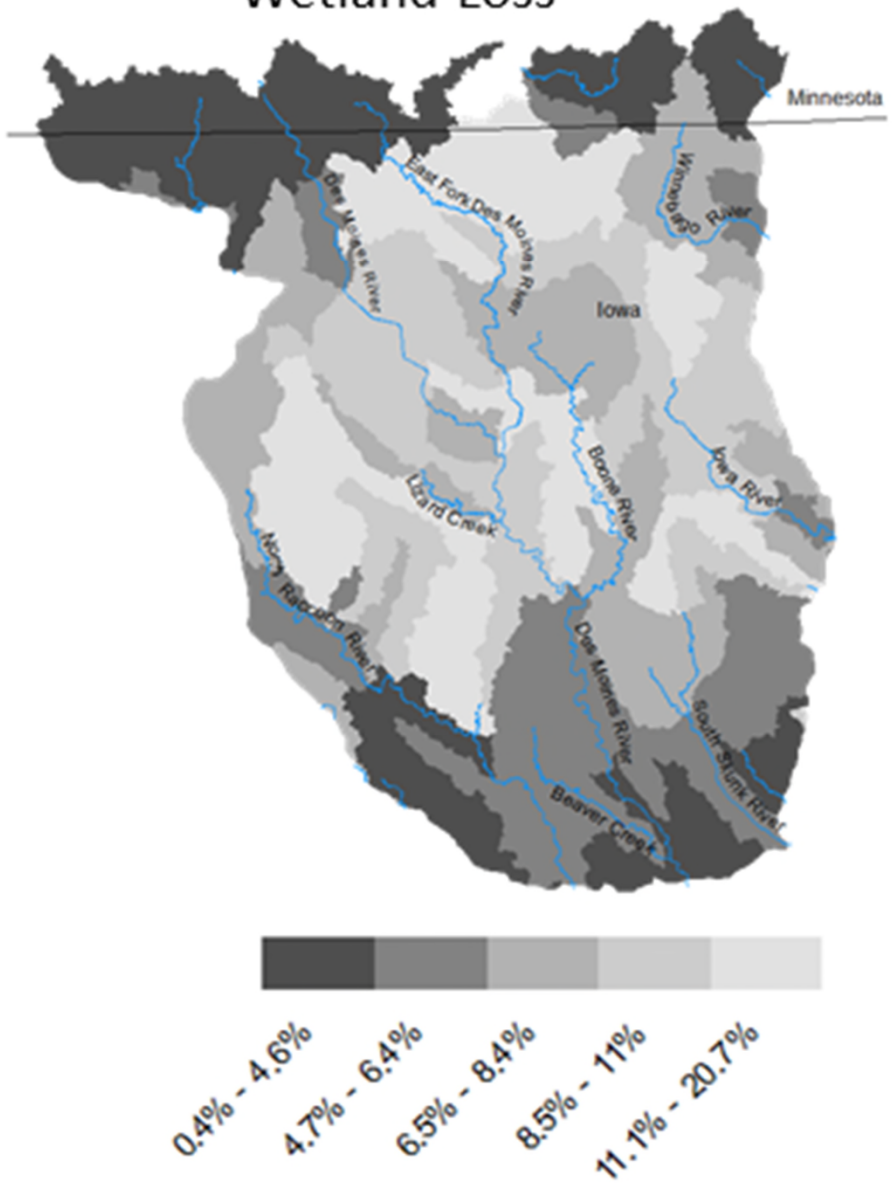
Ditching and Draining

Annual Loss Rate



US FWS – Dahl, T. Status and Trends (2011)

Percent Pre-settlement Wetland Loss

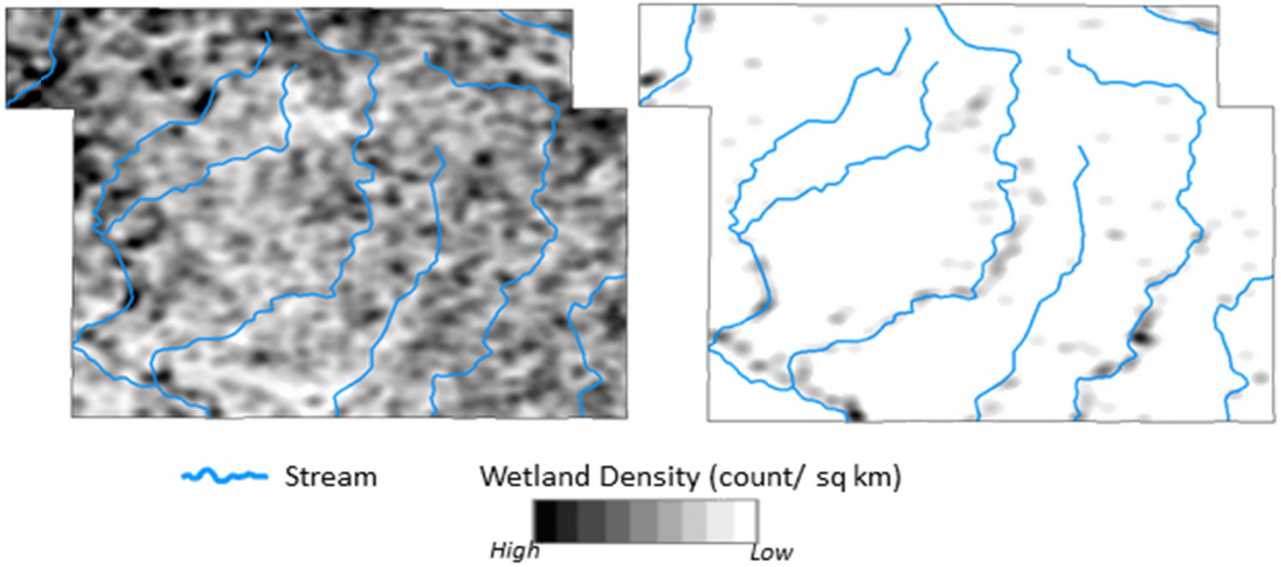


Pre-settlement Wetlands

Calhoun County, IA

Current Wetlands

Calhoun County, IA

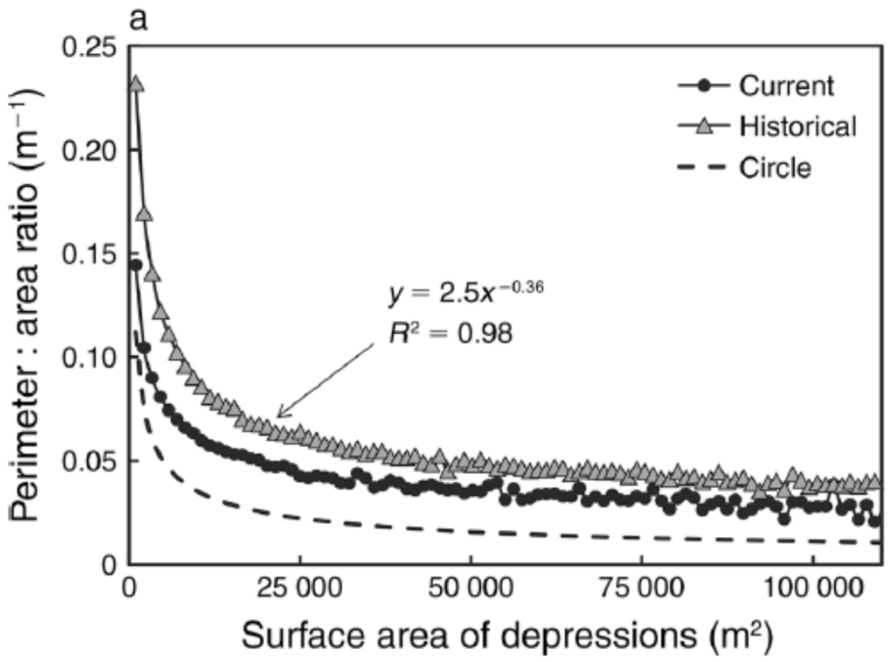


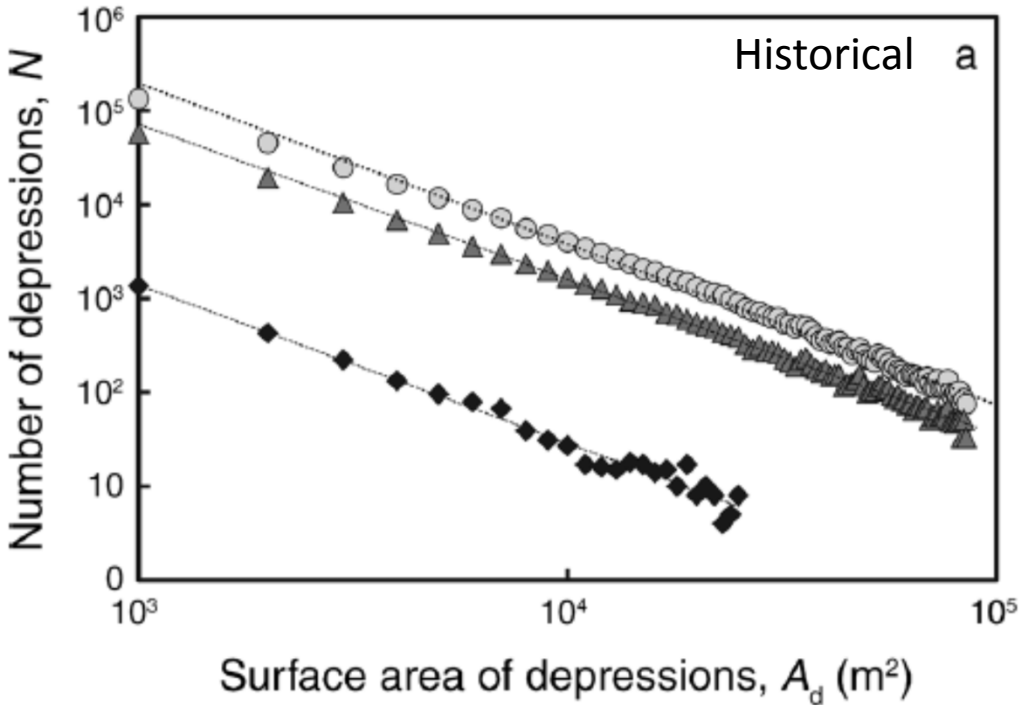
http://www.stateofthebirds.org

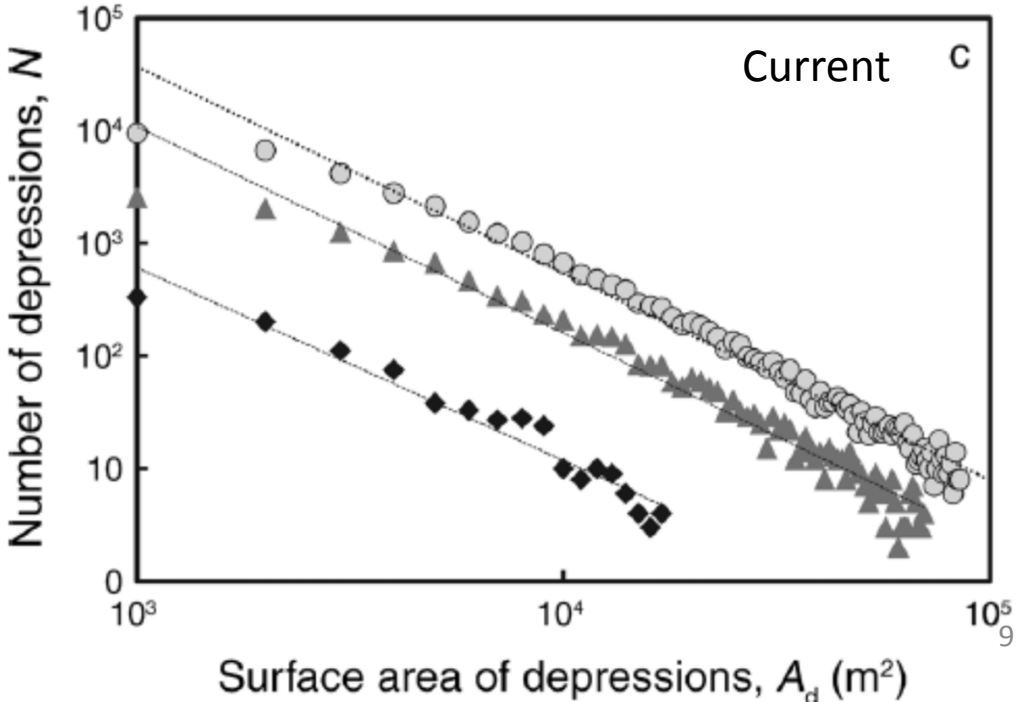
Wetland Losses

- Not all wetlands are “lost the same”
- Existing: circular, ~same size
- Perimeter:Area ratio

Van Meter and Basu (2017) Ecological Applications 25(2):451-465







Wetland Losses Continue

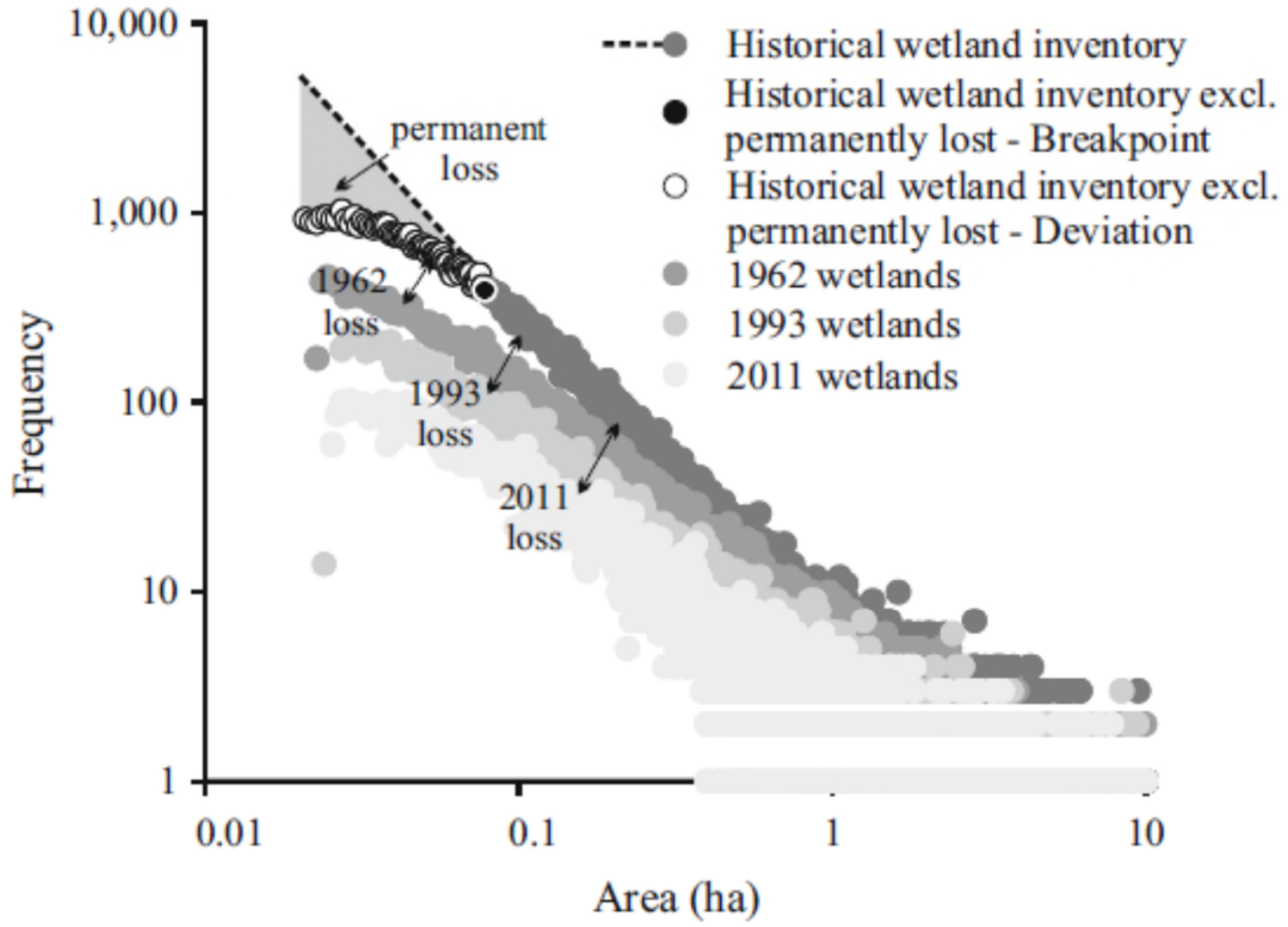
- Serran et al. (2017) Wetlands
- No Net Loss Policy (Alberta, Canada)

Wetlands
https://doi.org/10.1007/s13157-017-0960-y

ORIGINAL RESEARCH

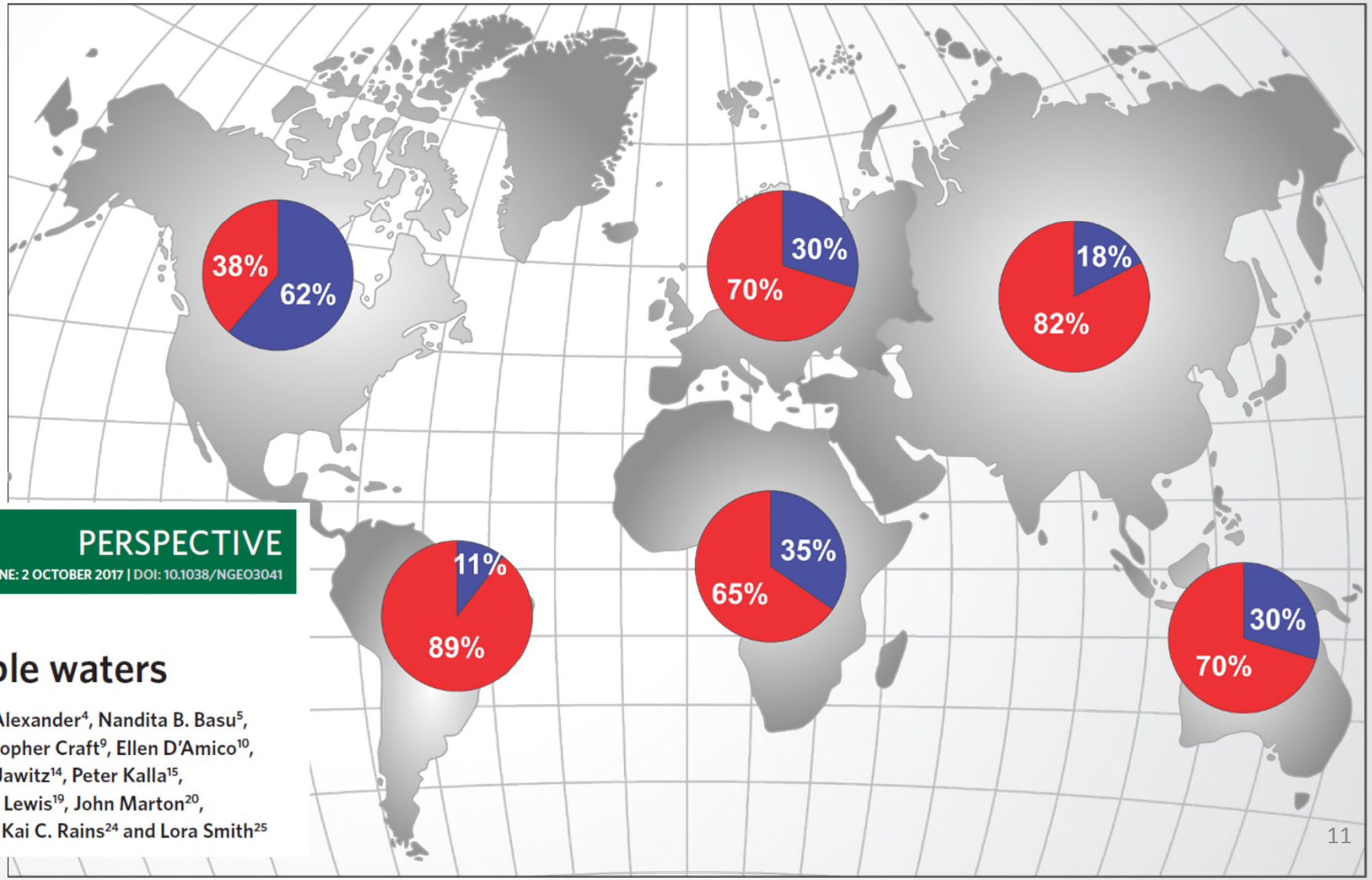
Estimating rates of wetland loss using power-law functions

Jacqueline N. Serran[1] · Irena F. Creed[1] · Ali A. Ameli[1] · David A. Aldred[1]



Worldwide Losses Continue

- Losses (in red) since ~1900
- Creed et al. Nature Geoscience (2017)



nature geoscience
PERSPECTIVE
PUBLISHED ONLINE: 2 OCTOBER 2017 | DOI: 10.1038/NGEO3041

Enhancing protection for vulnerable waters

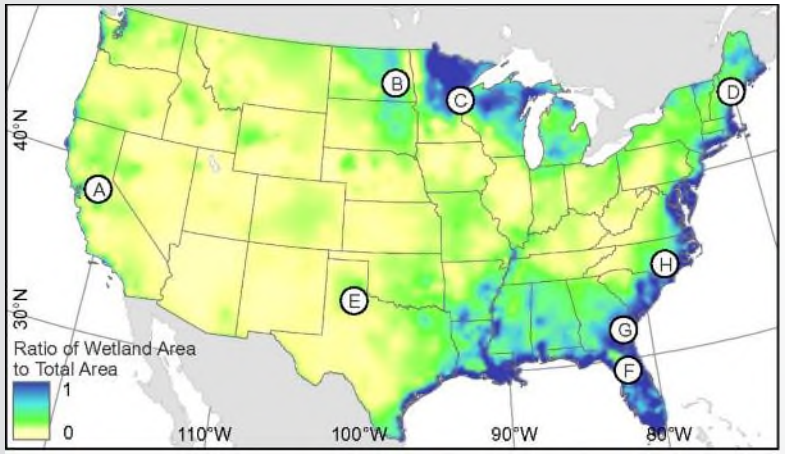
Irena F. Creed[1*†], Charles R. Lane[2], Jacqueline N. Serran[3], Laurie C. Alexander[4], Nandita B. Basu[5], Aram J. K. Calhoun[6], Jay R. Christensen[7], Matthew J. Cohen[8], Christopher Craft[9], Ellen D'Amico[10], Edward DeKeyser[11], Laurie Fowler[12], Heather E. Golden[13], James W. Jawitz[14], Peter Kalla[15], L. Katherine Kirkman[16], Megan Lang[17], Scott G. Leibowitz[18], David B. Lewis[19], John Marton[20], Daniel L. McLaughlin[21], Hadas Raanan-Kiperwas[22], Mark C. Rains[23], Kai C. Rains[24] and Lora Smith[25]

Watershed-Scale Effects of Wetland Losses

- Biodiversity/Habitat Functions
- Biogeochemical Functions
- Hydrological Functions

Biodiversity and Habitat Functions

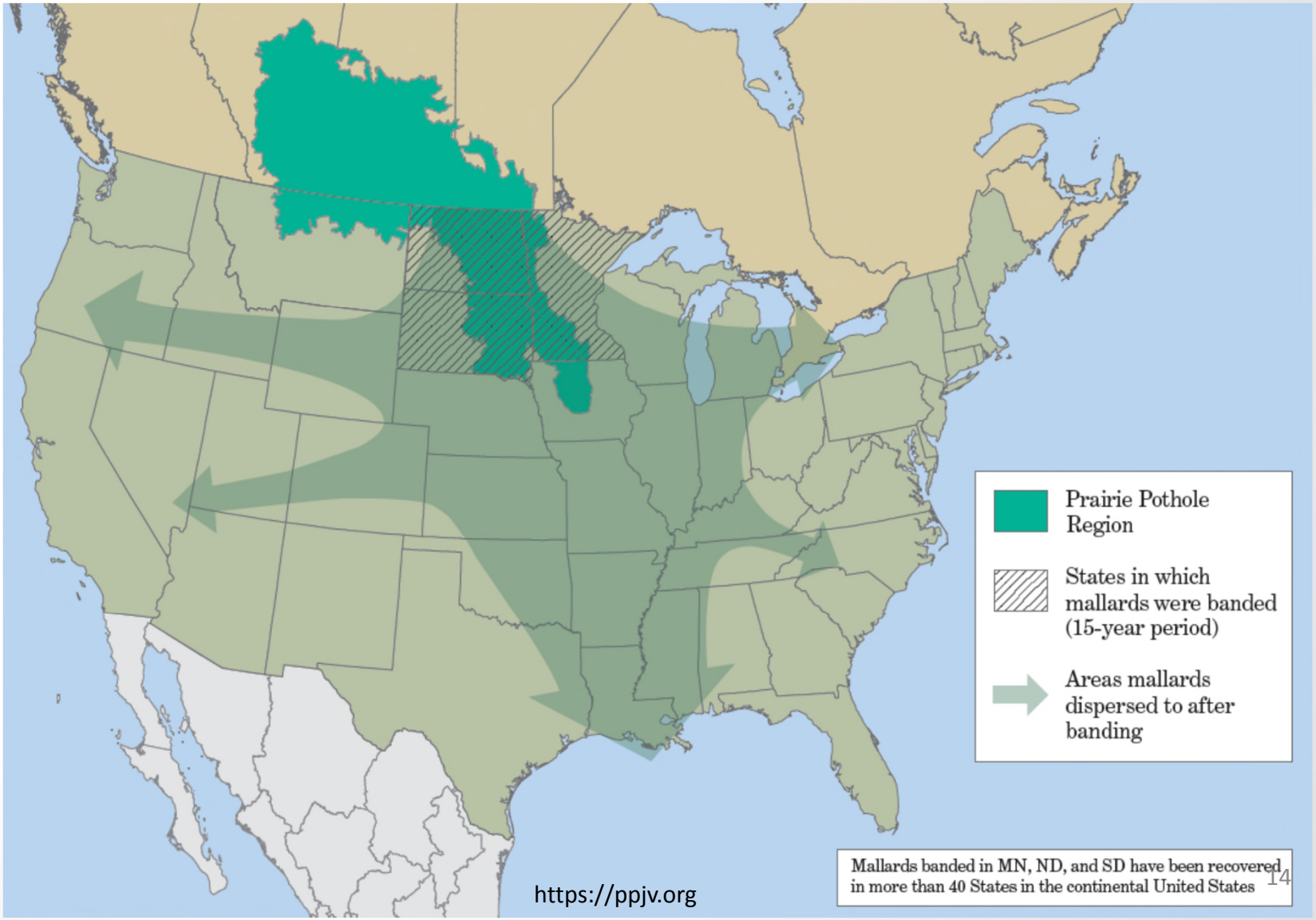
- Prairie Pothole Region
- 715,000 km^2
- US states and Canadian provinces



www.nrcs.usda.gov

Importance of Wetlands: Biodiversity

- North American waterfowl
- 5 million breeding pairs



https://ppjv.org

Wetlands: Habitat

- Landscape element diversity promotes biodiversity
- Deep & shallow (refugia & breeding)
- Streams (drought)
- Panmictic population

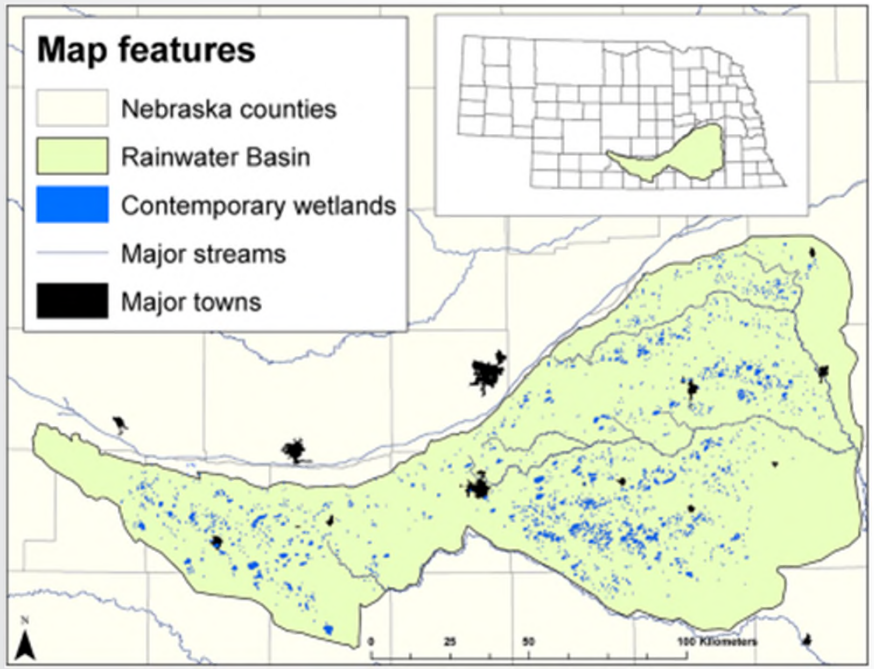
Mushet et al. 2013 Herp. Cons & Bio 8(1):163-175

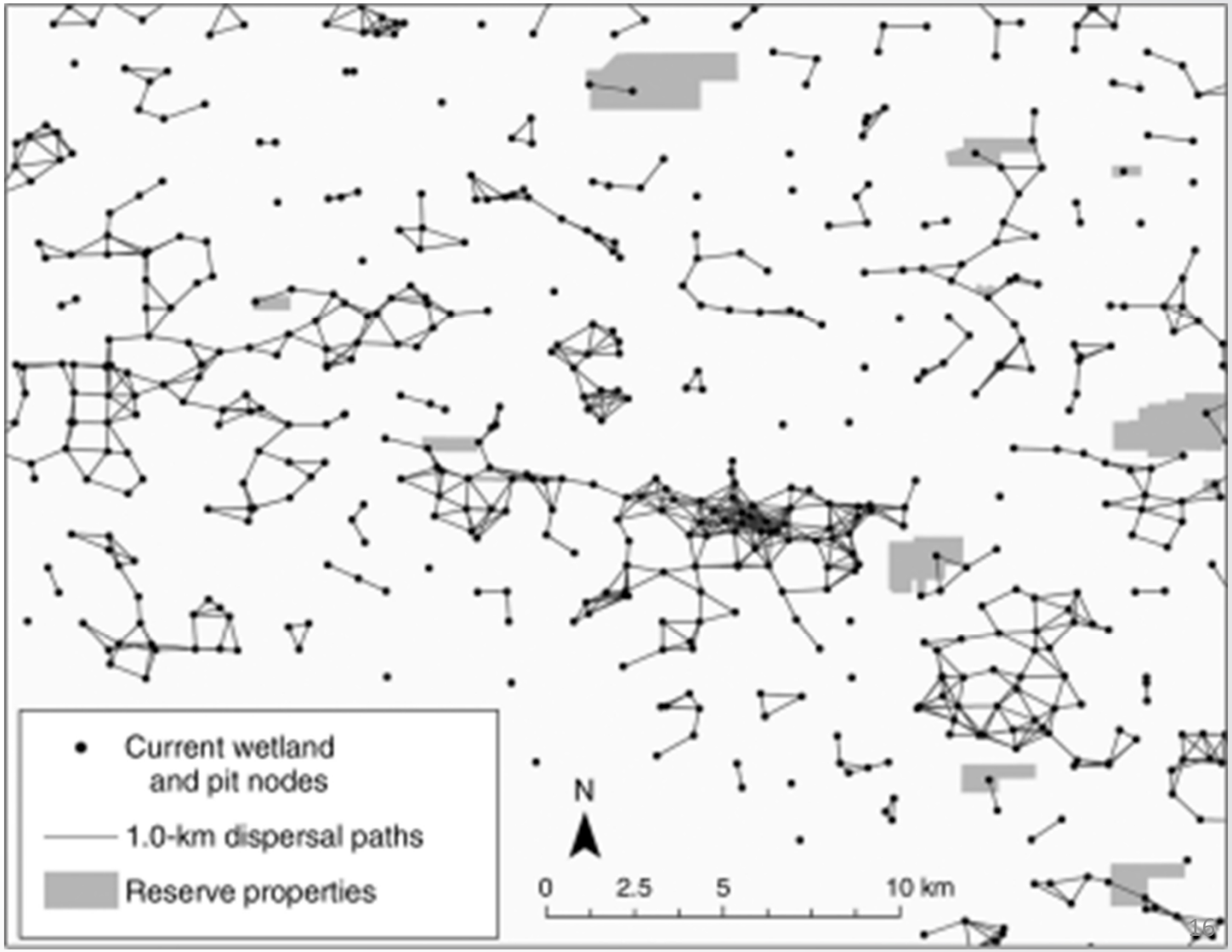
http://www.reptilesofaz.org/Graphics/Turtles-Amphibians/RANPIP-2004c.jpg

Wetlands Affect Anuran Populations

Uden et al. (2014) Ecological Applications 24(7):1569-1582

- Historical: 482 m
- Current: 1083 m

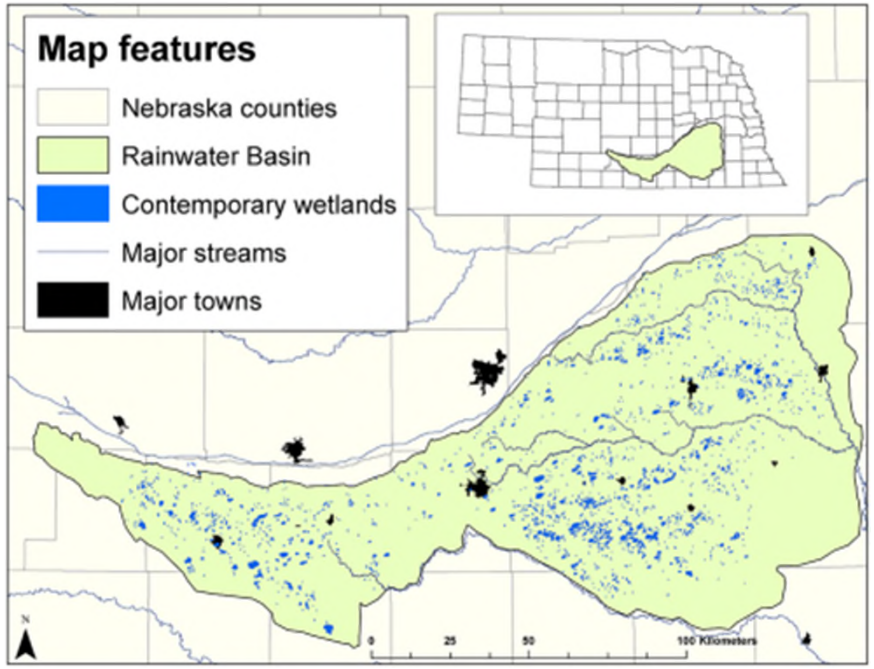


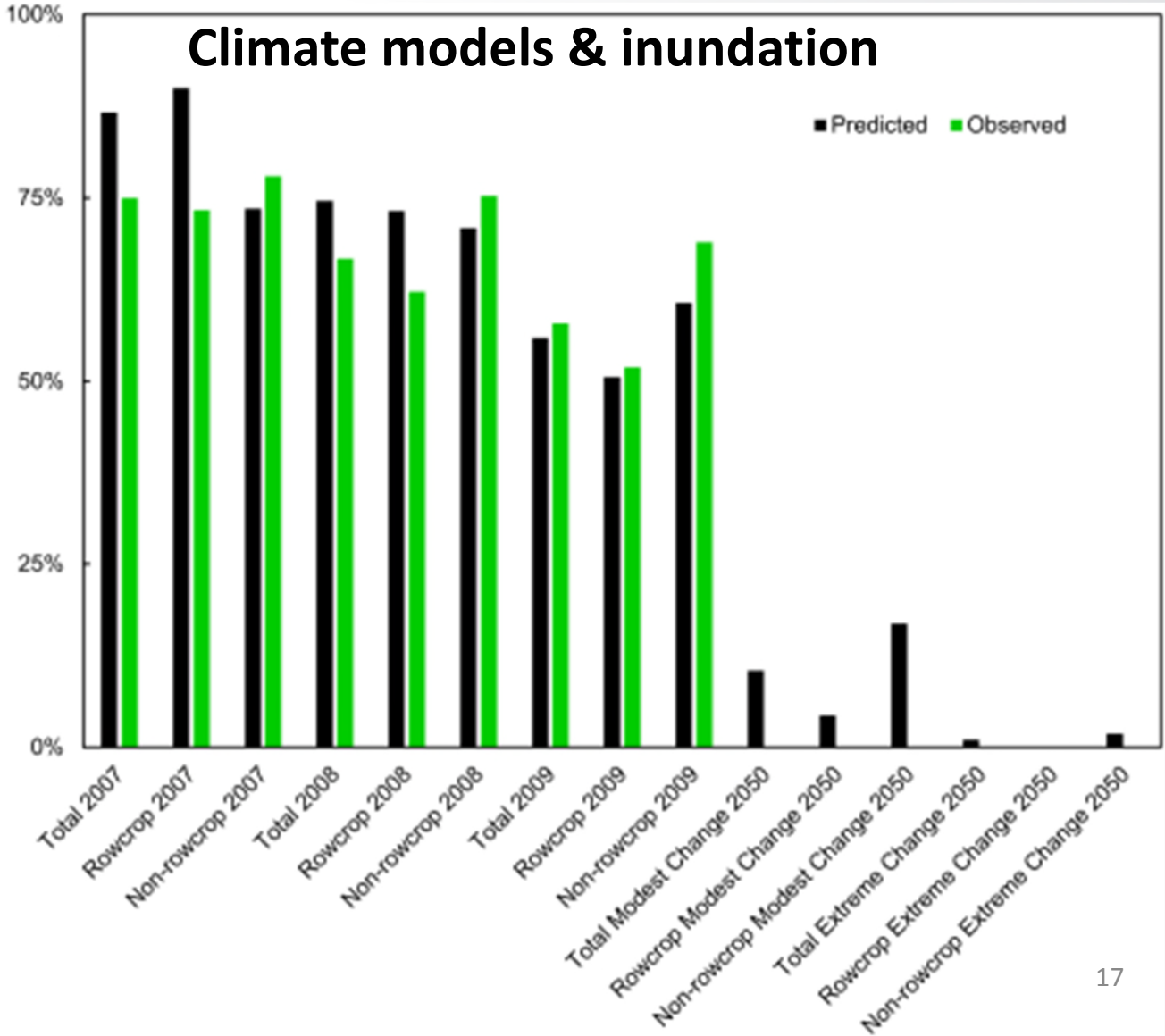


Wetland Inundation: Waterfowl

Uden et al. (2015) Ecosphere 6(11):1-26

7-10 million waterfowl





Wetlands: Habitat is “Easy”

Wetland Biogeochemical Sink & Transformation

- Denitrification, sedimentation, sorption, etc.
- "Biogeochemical reactors" (Marton et al. 2015, Bioscience 65(4):408-415)
  - Sediment: 230-3600 $g/m^2/yr$
  - Carbon: 21-317 $g/m^2/yr$
  - Phosphorus: 0.01 – 5.0 $g/m^2/yr$
  - Nitrogen: 0.8 – 2.0 $g/m^2/yr$
- Cheng and Basu (2017, WRR 53:5038-56)
  - Literature review and metanalysis of 600 studies
  - 50% of N load removed by wetlands <300 m^2 (0.03 ha)

Wetland Biogeochemical/Hydrological Functions

Carbon Storage (Lane and Autrey 2017 Mar. Fresh. Res.)

- Emergent Marsh: 66.1 g Org.C m^{-2} yr^{-1}
- Forested:33.8 g Org.C m^{-2} yr^{-1}

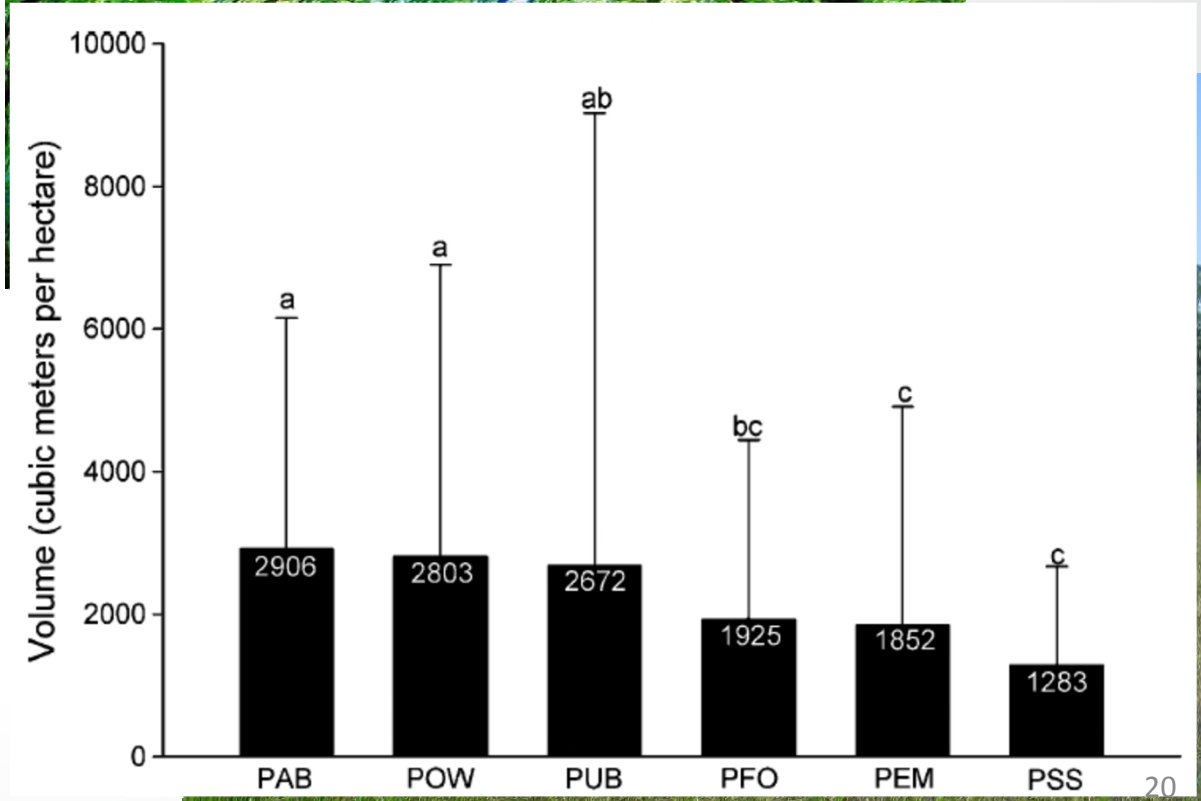
Phosphorus Storage (Lane and Autrey 2015 Wetl. Ecol. & Mgmt. 24:45-60)

- Emergent Marsh: 418 mg P kg^{-1}
- Forested: 1275 mg P kg^{-1}

Denitrification (Lane et al. 2015 Wetlands 35:459-471)

- Emergent Marsh: 8.99 µg N kg DW^{-1} hr^{-1}
- Forested: 3.11 µg N kg DW^{-1} hr^{-1}

Water Storage (Lane and D'Amico 2010 Wetlands 30:967-977)



Congaree NP source: imgur.com/p70SX9F

Watershed-Scale Effects

Watershed-Scale Effects: Literature

Non-floodplain wetlands…

- …are critical habitat
- …affect watershed storage and inundation
- …affect surface runoff dynamics
- …affect nutrient dynamics

JAWRA 2018 54(2) Featured Collection (Lane et al.; Schofield et al.)

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
Vol. 54, No. 2 AMERICAN WATER RESOURCES ASSOCIATION April 2018

BIOTA CONNECT AQUATIC HABITATS THROUGHOUT FRESHWATER ECOSYSTEM MOSAICS[1]

Kate A. Schofield, Laurie C. Alexander, Caroline E. Ridley, Melanie K. Vanderhoof, Ken M. Fritz, Bradley C. Autrey, Julie E. DeMeester, William G. Kepner, Charles R. Lane, Scott G. Leibowitz, and Amina I. Pollard[2]

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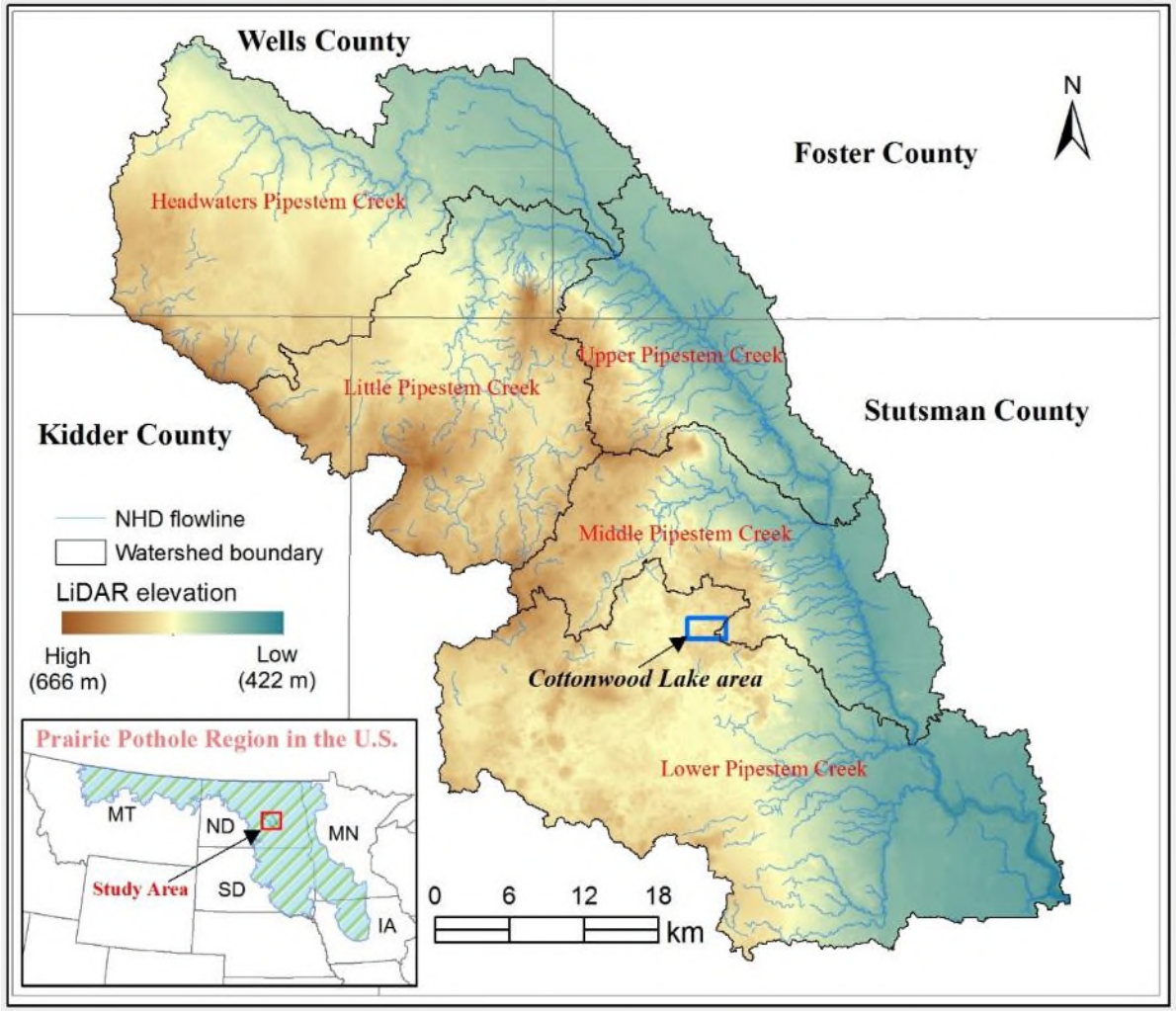
HYDROLOGICAL, PHYSICAL, AND CHEMICAL FUNCTIONS AND CONNECTIVITY OF NON-FLOODPLAIN WETLANDS TO DOWNSTREAM WATERS: A REVIEW[1]

Charles R. Lane, Scott G. Leibowitz, Bradley C. Autrey, Stephen D. LeDuc, and Laurie C. Alexander[2]

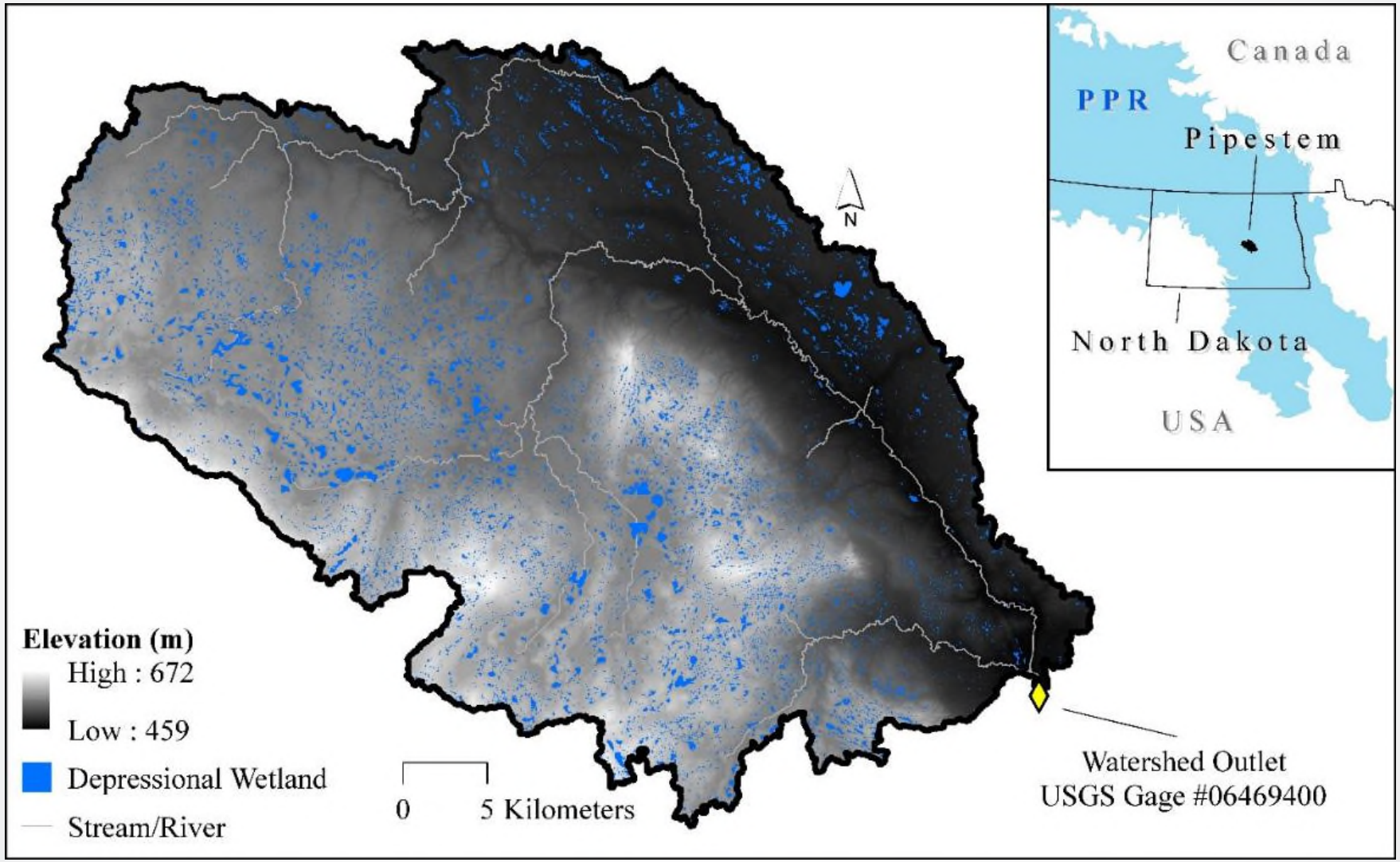
Wetlands and Watershed Functions

- How do wetlands affect watershed functions?
  - Watershed-scale storage
  - Stream-contributing area
  - Streamflow
- Scenario Exploration - Losses
  - Complete loss of non-floodplain wetlands
  - Preferential loss based on area
  - Proximity-based losses or maintenance



(Wu and Lane 2017 Hydrol. Earth Syst. Sci. 21, 3579-3595)

Wetlands and Watershed Functions



(Evenson et al. 2018 Ecological Applications 28(4): 953-966)

Watershed-Scale Effects: Approaches

- DEM from LIDAR-based topography
- NWI input data layer
  - Volumes calculated (ArcGIS v10.x)
  - Min. volume 100 m^3
  - ~13,000 wetlands
- Fill-and-Spill network
- Soil and Water Assessment Tool (SWAT)
- Modified SWAT to focus on non-floodplain wetlands (Evenson et al. 2016 Hydrol. Proc. **30**:4168-4184)

HYDROLOGICAL PROCESSES
Hydrol. Process. (2016)
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.10930

An improved representation of geographically isolated wetlands in a watershed-scale hydrologic model

Grey R. Evenson,[1]* Heather E. Golden,[2] Charles R. Lane[2] and Ellen D'Amico[3]

[1] *Oak Ridge Institute for Science and Education, US Environmental Protection Agency, c/o Office of Research and Development, National Exposure Research Laboratory, Cincinnati, OH, USA*
[2] *US Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Cincinnati, OH, USA*
[3] *CSS-Dynamac Corporation, Cincinnati, OH, USA*

Abstract:

Geographically isolated wetlands (GIWs), defined as wetlands surrounded by uplands, provide an array of ecosystem goods and services. Within the United States, federal regulatory protections for GIWs are contingent, in part, on the quantification of their singular or aggregate effects on the hydrological, biological, or chemical integrity of waterways regulated by the Clean Water Act (CWA). However, limited tools are available to assess the downgradient effects of GIWs. We constructed a Soil and Water Assessment Tool (SWAT) model with improved representations of GIW hydrologic processes for the approximately 1700 km^2 Pipestem Creek watershed in the Prairie Pothole Region of North Dakota, USA. We then executed a series of novel modifications on the Pipestem Creek SWAT model. We (1) redefined the model's hydrologic response unit spatial boundaries to conform to mapped GIWs and associated watershed boundaries, (2) constructed a series of new model input files to direct the simulation of GIW fill–spill hydrology and upland flows to GIWs, and (3) modified the model source code to facilitate use of the new SWAT input files and improve GIW water balance simulations. We then calibrated and verified our modified SWAT model at a daily time step from 2009 through 2013. Simulation results indicated good predictive power (the maximum Nash–Sutcliffe Efficiency statistic was 0.86) and an acceptable range of uncertainty (measured using the Sequential Uncertainty Fitting v.2 uncertainty statistics). Simulation results additionally indicated good model performance with respect to GIW water balance simulations based on literature-based descriptions of regional GIW hydrologic behaviour. Our modified SWAT model represents a critical step in advancing scientific understandings of the watershed-scale hydrologic effects of GIWs and provides a novel method for future assessments in different watersheds and physiographic regions. Copyright © 2016 John Wiley & Sons, Ltd.

KEY WORDS connectivity; fill–spill hydrology; GIW; hydrology; Soil and Water Assessment Tool (SWAT)

(Schematics courtesy Qiusheng Wu, SUNY-Binghamton, wetlands.io)

Watershed-Scale Effects: Approaches

Scenarios Examined

- Complete loss of non-floodplain wetlands
- Preferential loss based on area
- Proximity-based losses or maintenance
- All contrasted versus a 'baseline' model

Ecological Applications, 28(4), 2018, pp. 953–966
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Depressional wetlands affect watershed hydrological, biogeochemical, and ecological functions

Grey R. Evenson,[1,4] Heather E. Golden,[2] Charles R. Lane,[2] Daniel L. McLaughlin,[1] and Ellen D'Amico[3]

[1] *Department of Forest Resources and Environmental Conservation, Virginia Polytechnic Institute and State University, Cheatham Hall, Blacksburg, Virginia 24061 USA*
[2] *US Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Cincinnati, Ohio 45220 USA*
[3] *CSS Corporation, Cincinnati 45220 Ohio USA*

X = loss	Count	Max. Volume ($m^3 \times 10^4$) Median (Std. Dev.)	Surface Area (ha) Median (Std. Dev.)	Distance to Stream (m) Median (Std. Dev.)
Baseline	12921	0.04 (2.4)	0.3 (2.6)	1633 (2760)
ALLWETX	0	NA	NA	NA
WET<3haX	616	2.5 (9.5)	5.0 (9.1)	2430 (2973)
WET>3haX	12305	0.04 (0.3)	0.3 (0.5)	1599 (2742)
WET>30mX	120	0.03 (3.0)	0.2 (6.6)	18.4 (10.0)
WET>457mX	2668	0.04 (1.2)	0.2 (1.8)	219.3 (124)

Watershed-Scale Effects: Results

(Evenson et al. Ecol. App 2018, 28(4):953-966)

Depressional wetlands affect watershed hydrological, biogeochemical, and ecological functions

GREY R. EVENSON,[1,4] HEATHER E. GOLDEN,[2] CHARLES R. LANE,[2] DANIEL L. MCLAUGHLIN,[1] AND ELLEN D'AMICO[3]

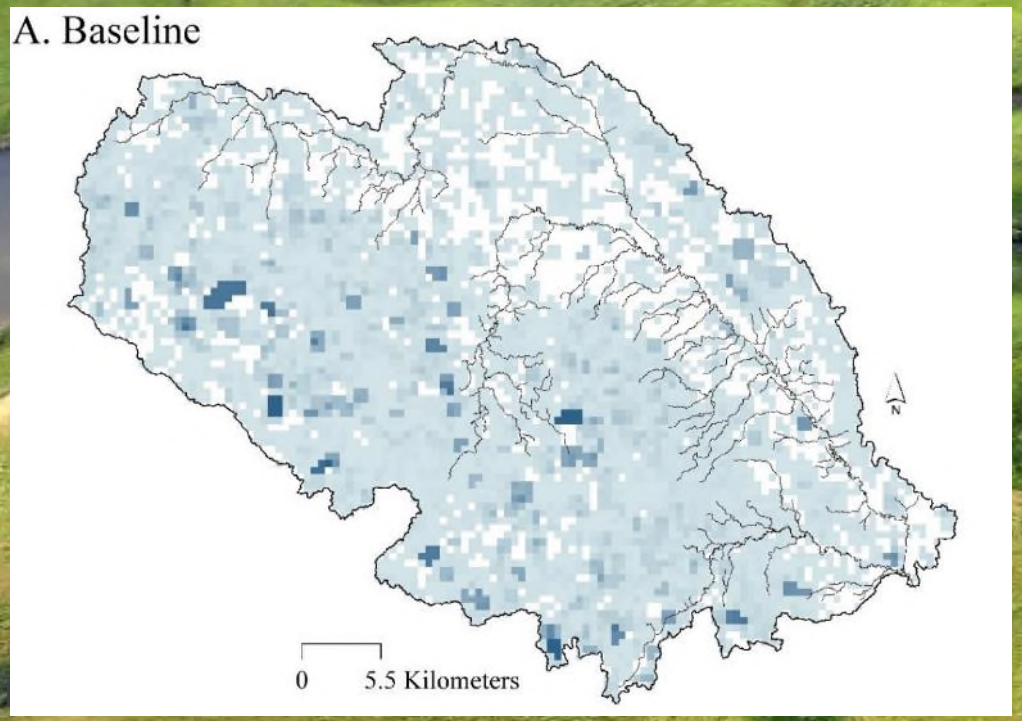
[1] *Department of Forest Resources and Environmental Conservation, Virginia Polytechnic Institute and State University, Cheatham Hall, Blacksburg, Virginia 24061 USA*

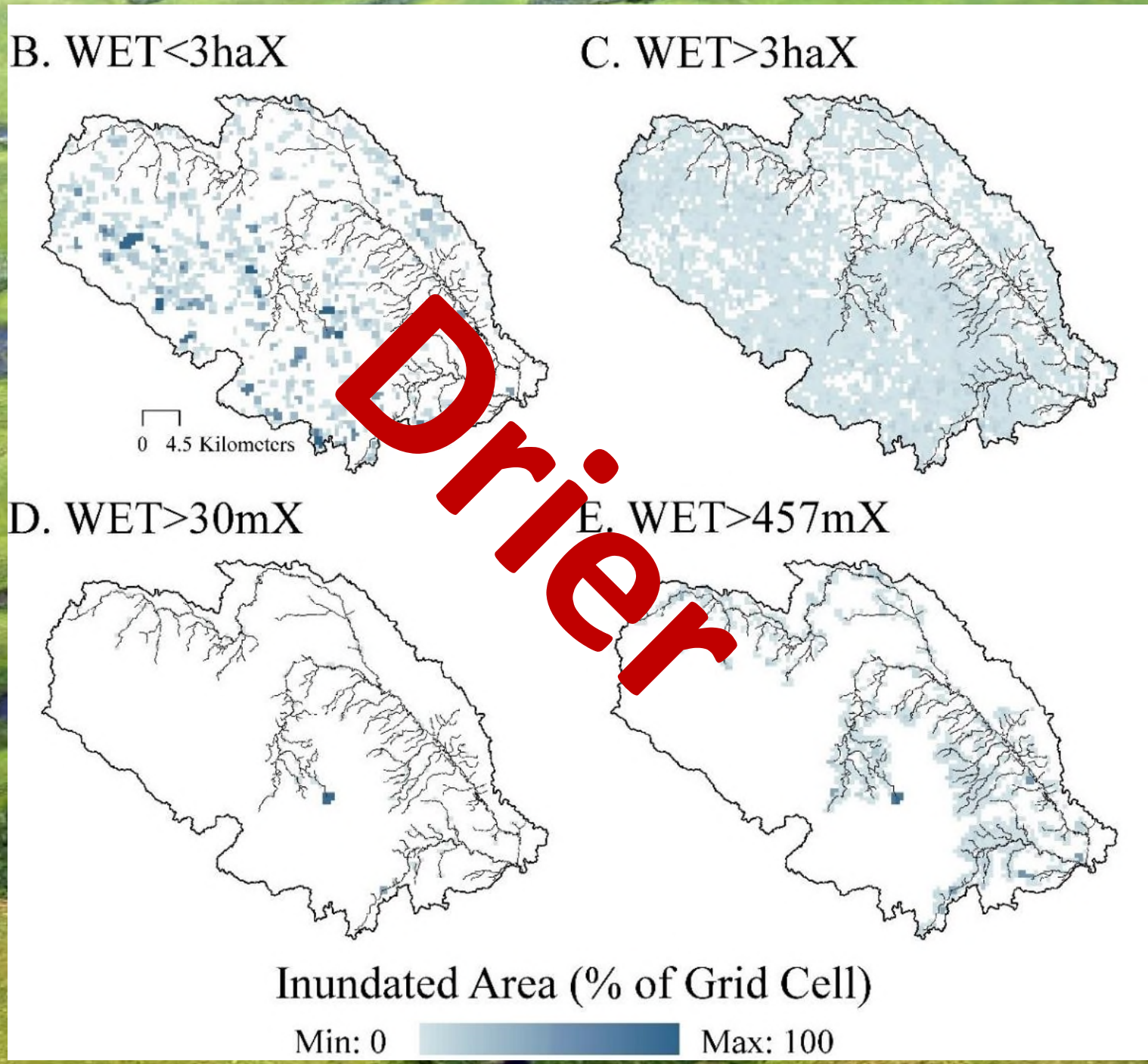
[2] *US Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Cincinnati, Ohio 45220 USA*

[3] *CSS Corporation, Cincinnati 45220 Ohio USA*

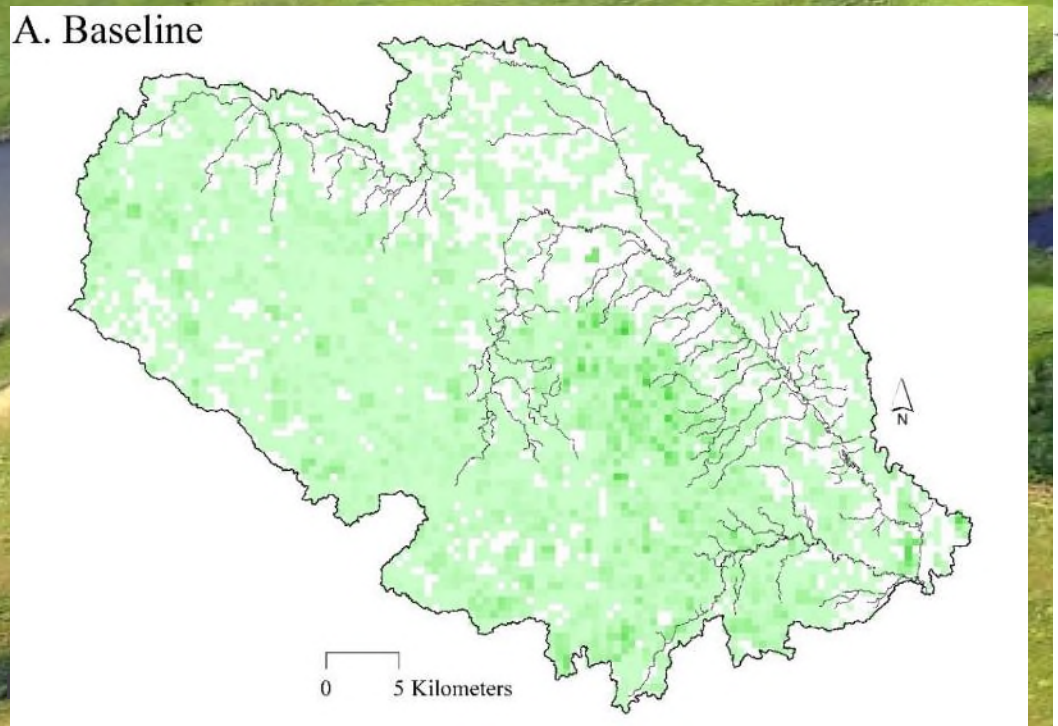
http://www.stateofthebirds.org

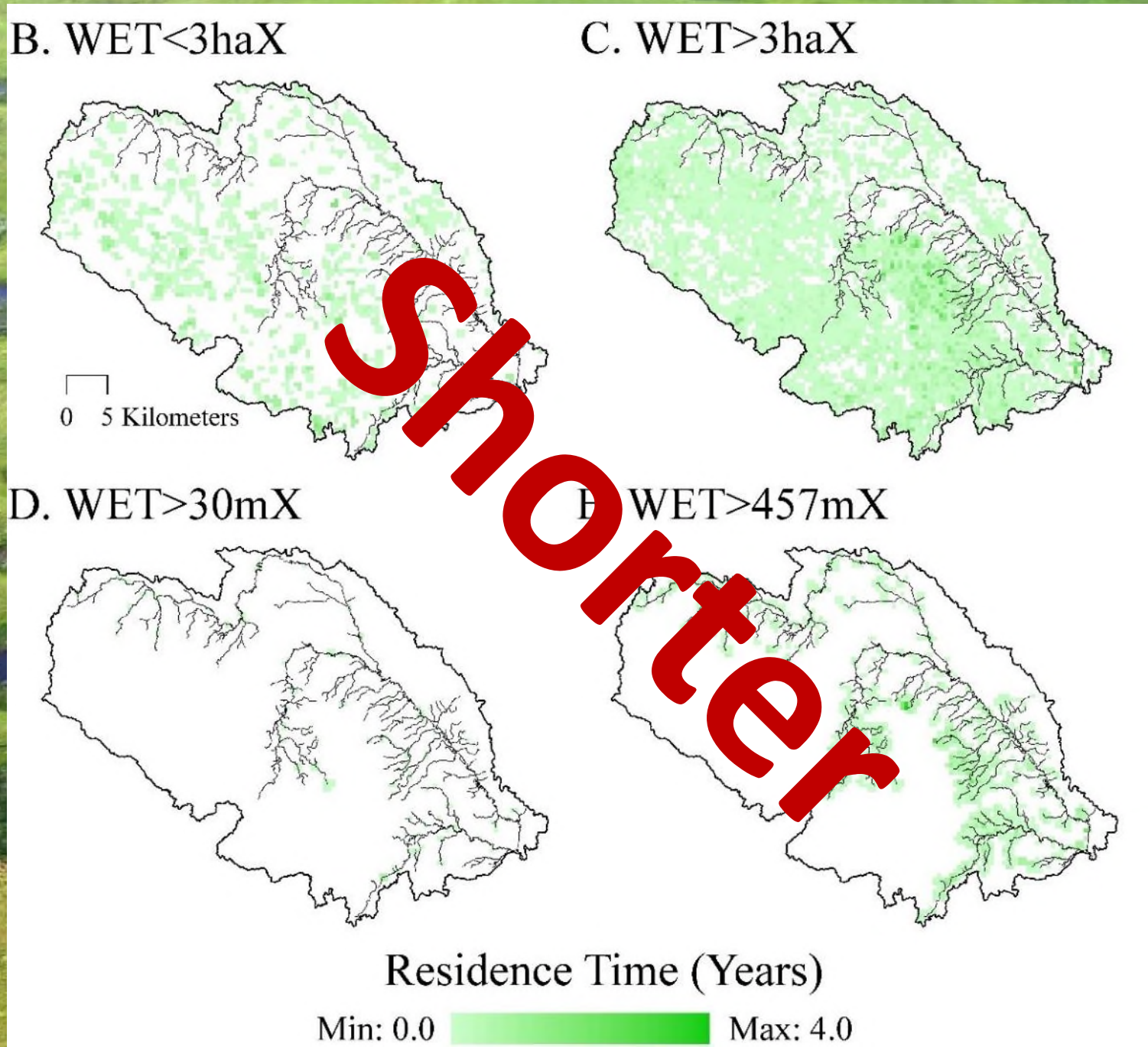
	Inundated Area (ha)	
	Mean*	Std. Dev.*
Baseline	0.26	0.09
WET<3haX	2.98	0.73
WET>3haX	0.14	0.06
WET>30mX	0.43	0.15
WET>457mX	0.19	0.06



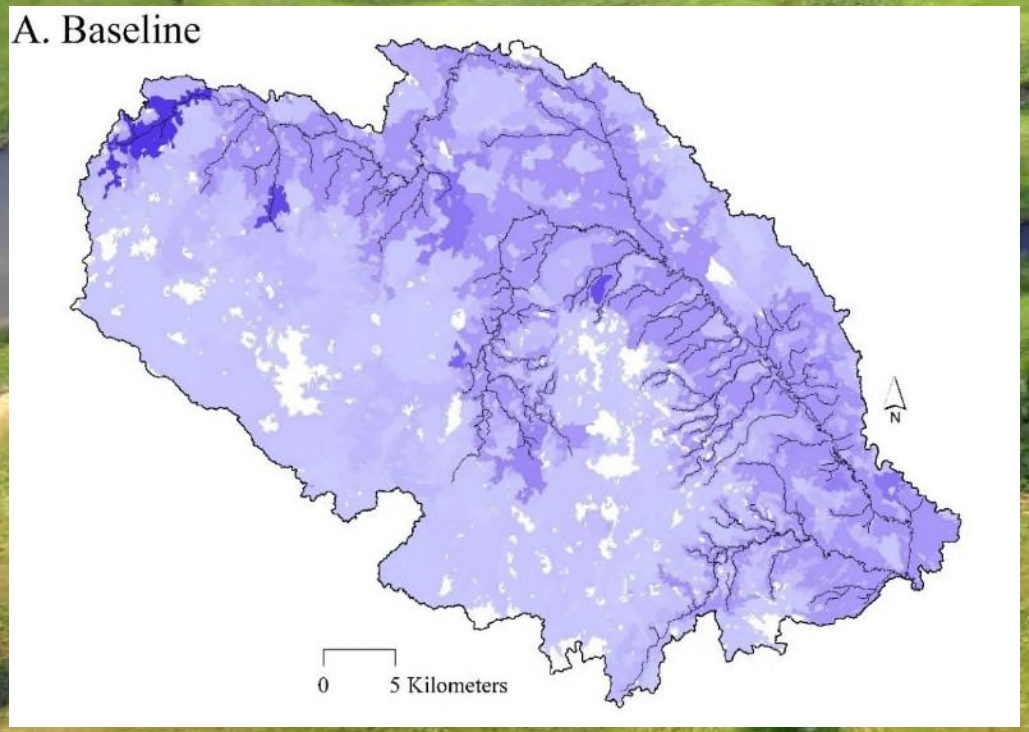


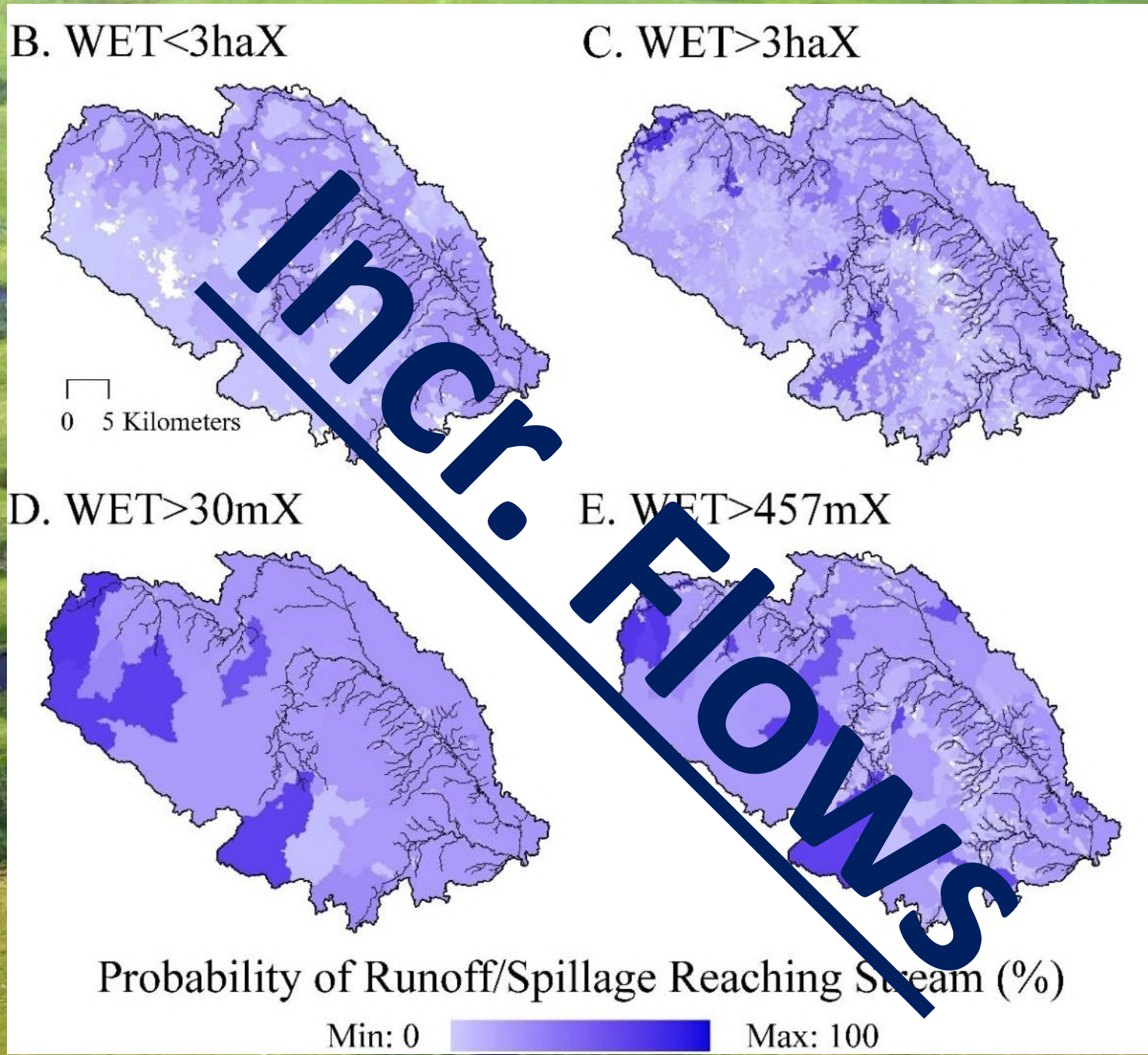
	Residence Time (Days x 10^4)	
	Mean*	Std. Dev.*
Baseline	0.73	2.59
WET<3haX	1.20	4.56
WET>3haX	0.69	2.51
WET>30mX	0.37	1.64
WET>457mX	0.74	2.95



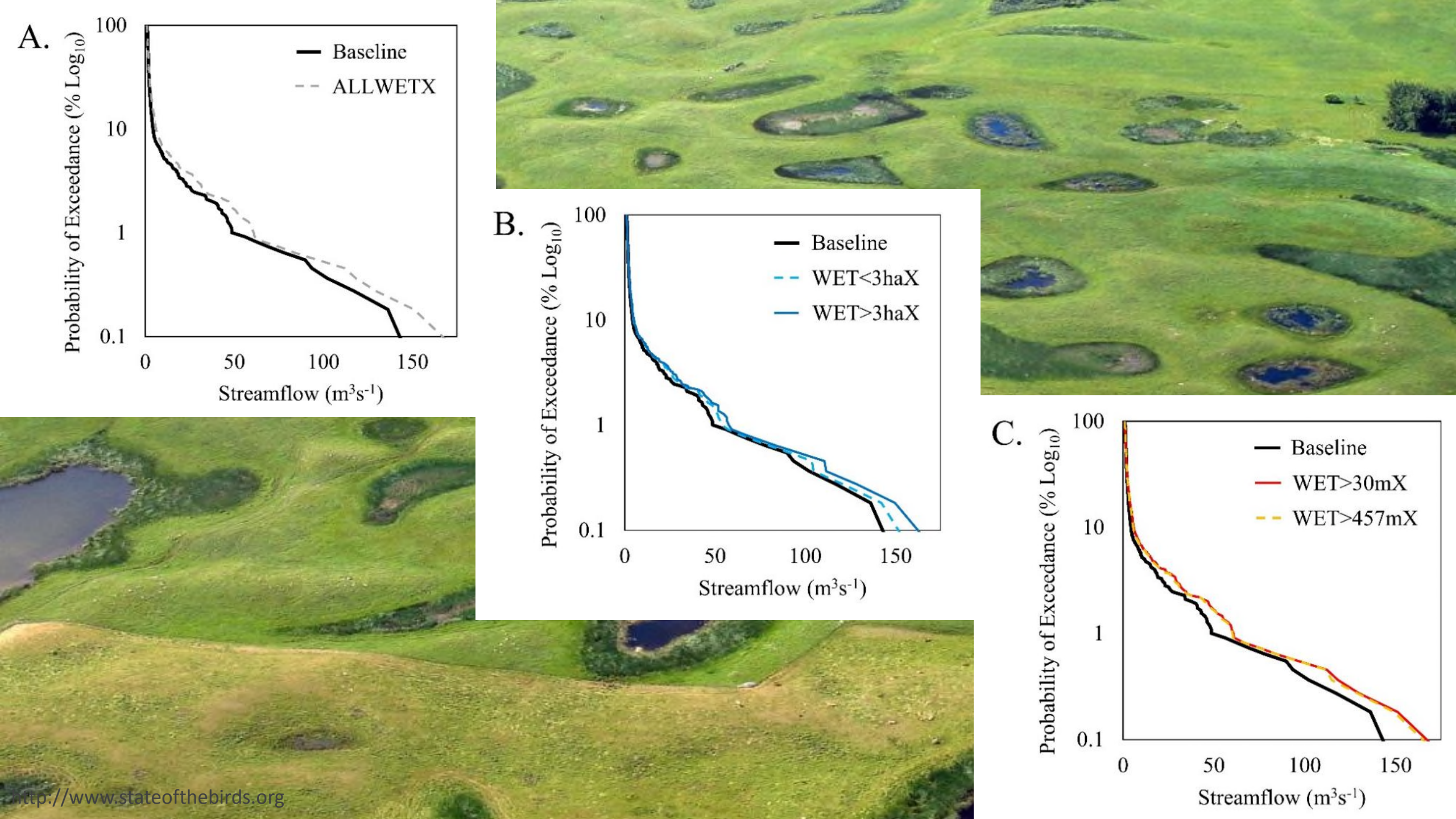


	Runoff Contributing Area (% of Watershed Area)
	Sum†
Baseline	11.1
WET<3haX	14.0
WET>3haX	17.1
WET>30mX	30.5
WET>457mX	25.9





Incr. Flows


A.
Baseline
ALLWETX
Probability of Exceedance (% Log10)
100
10
1
0.1
0
50
100
150
Streamflow (m3s-1)
B.
Baseline
WET<3haX
WET>3haX
Probability of Exceedance (% Log10)
100
10
1
0.1
0
50
100
150
Streamflow (m3s-1)
C.
Baseline
WET>30mX
WET>457mX
Probability of Exceedance (% Log10)
100
10
1
0.1
0
50
100
150
Streamflow (m3s-1)
http://www.stateofthebirds.org

Watershed-Scale Effects: Main Findings

Non-floodplain wetlands…

- …are critical habitat
- …affect watershed storage and inundation
- …affect surface runoff dynamics
- …affect nutrient dynamics

JAWRA 2018 54(2) Featured Collection (Lane et al.; Schofield et al.)

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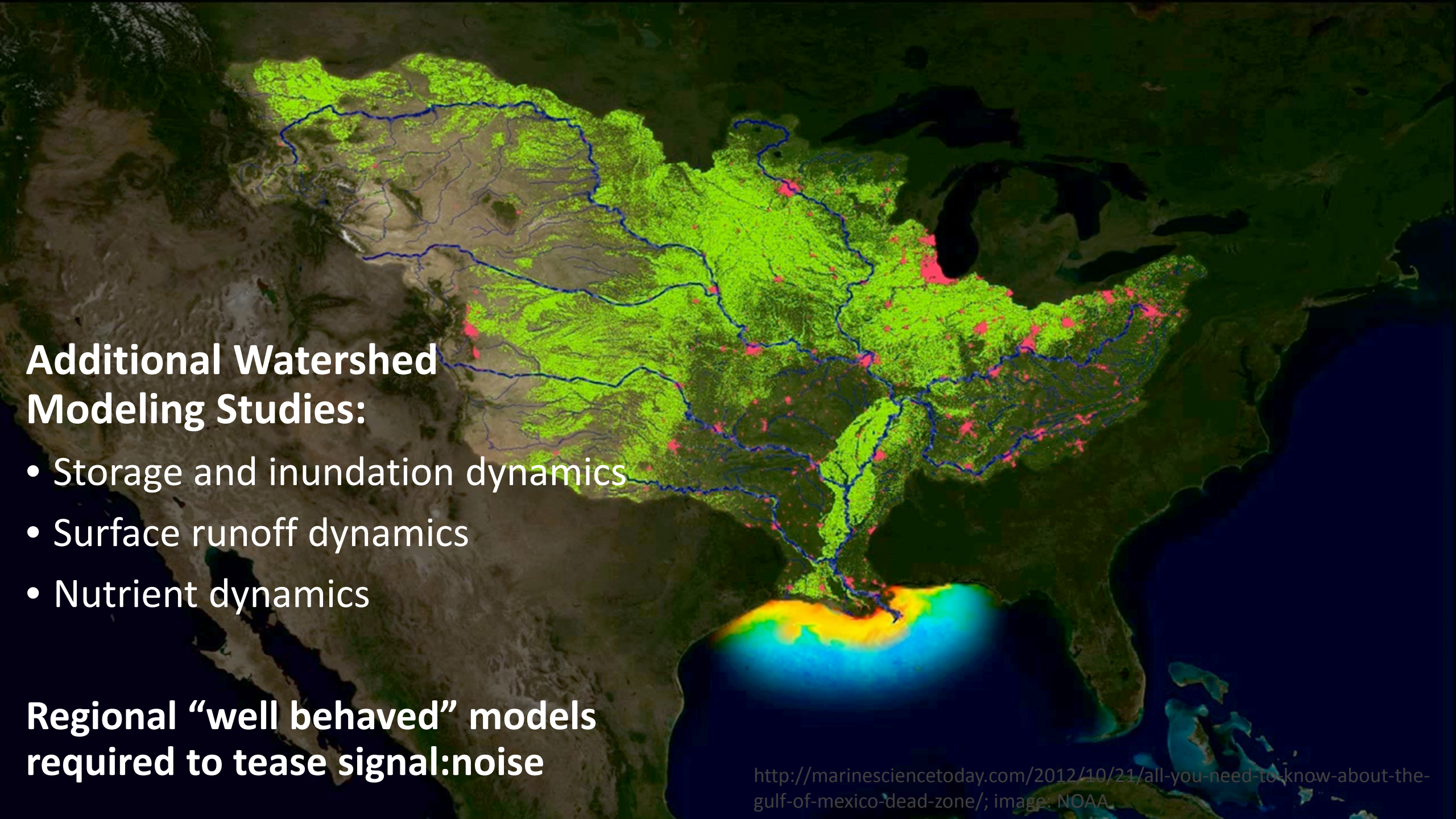


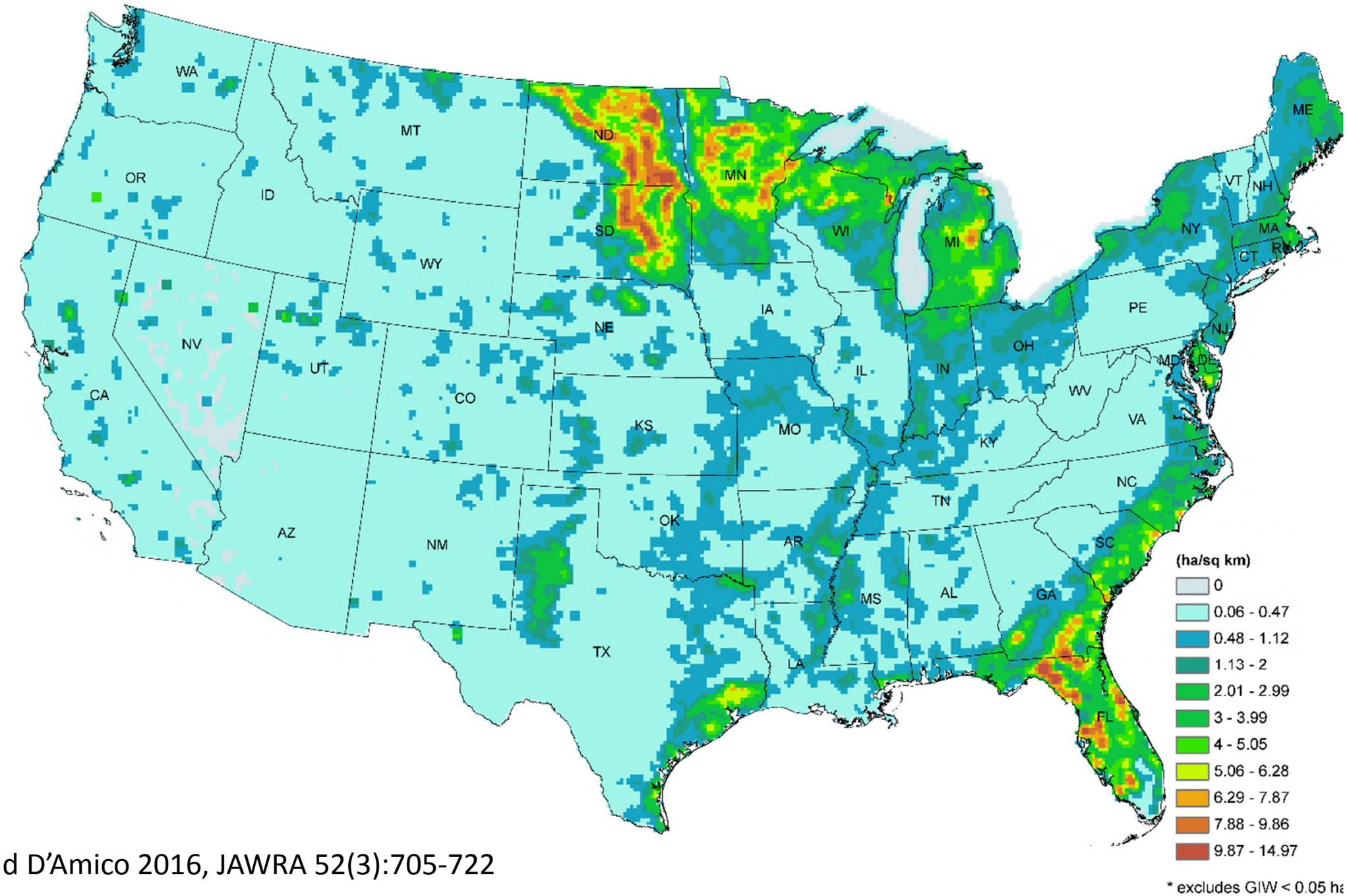
Additional Watershed Modeling Studies:

- Storage and inundation dynamics
- Surface runoff dynamics
- Nutrient dynamics

Regional "well behaved" models required to tease signal:noise

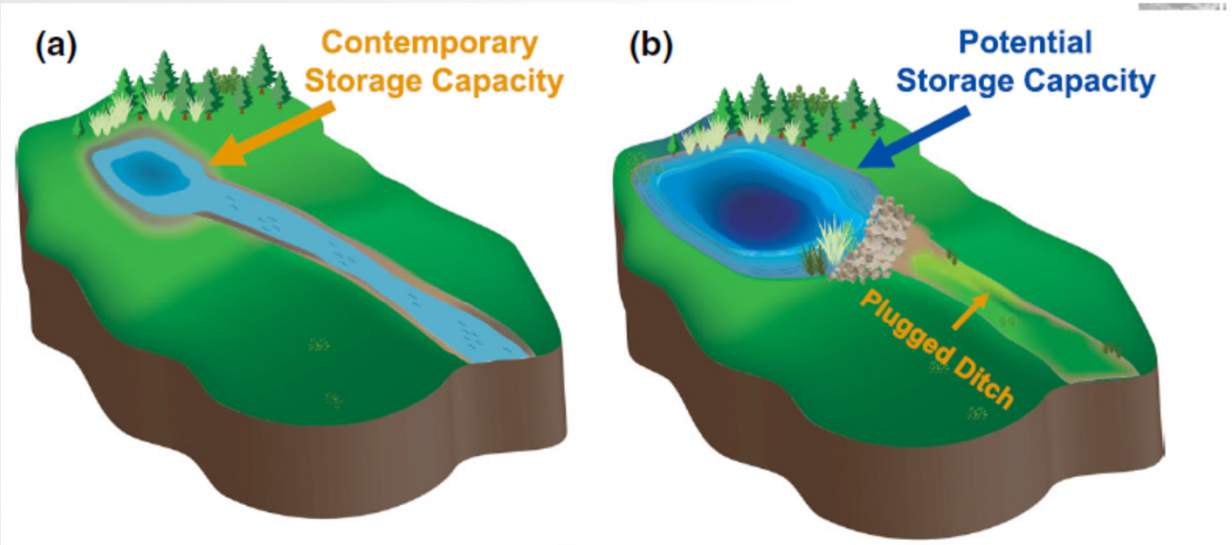
http://marinesciencetoday.com/2012/10/21/all-you-need-to-know-about-the-gulf-of-mexico-dead-zone/; image: NOAA

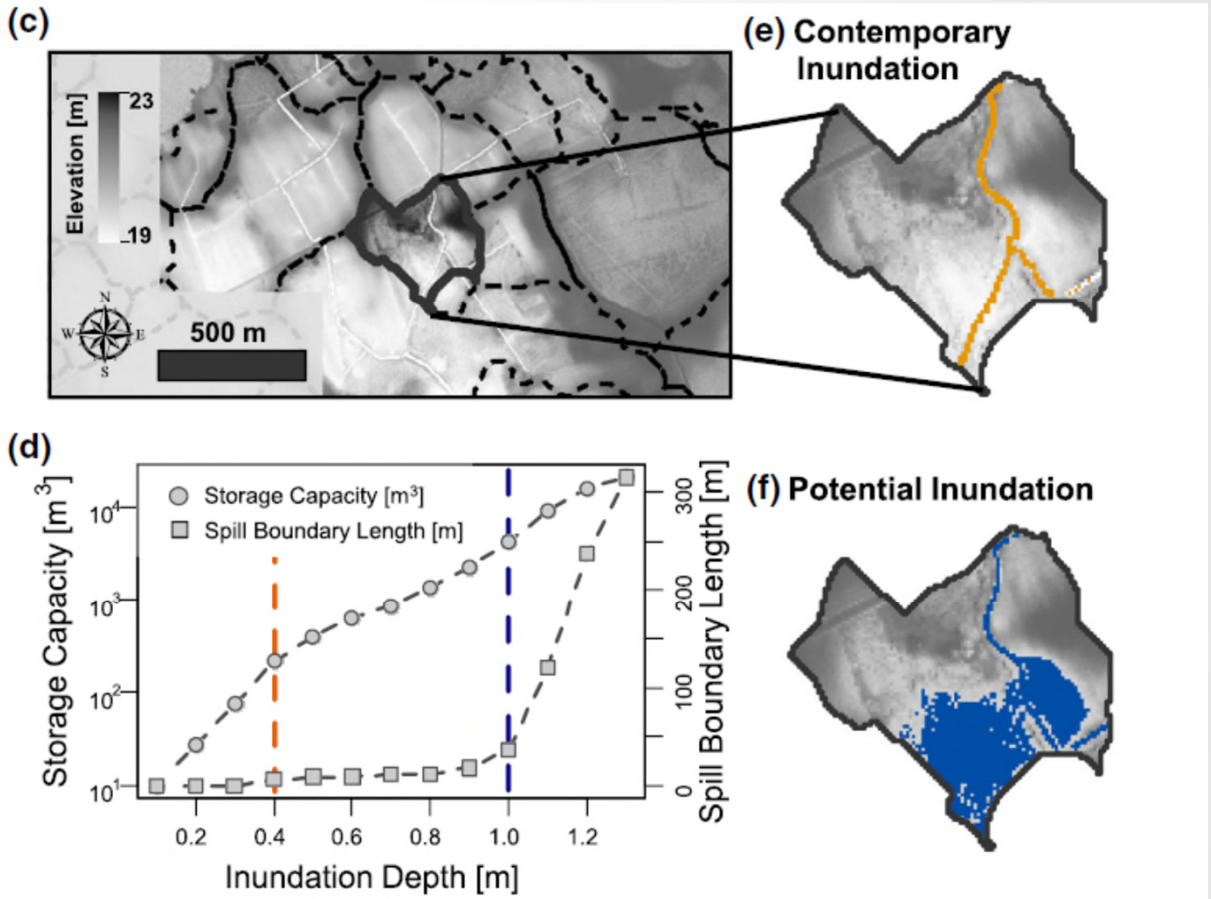
Source: SE Missourian



Lane and D'Amico 2016, JAWRA 52(3):705-722

Restoration Potential?





Estimating restorable wetland water storage at landscape scales

Charles Nathan Jones[1,2] | Grey R. Evenson[2] | Daniel L. McLaughlin[2] | Melanie K. Vanderhoof[3] | Megan W. Lang[4] | Greg W. McCarty[5] | Heather E. Golden[6] | Charles R. Lane[6] | Laurie C. Alexander[7]

Jones et al. 2018, Hydrological Processes; 32:305-313

Non-floodplain wetlands…

- …are critical habitat
- …affect watershed storage and inundation
- …affect surface runoff dynamics
- …affect nutrient dynamics

Additional regional studies needed

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https://i.pinimg.com/originals/8a/14/e9/8a14e9a4c42b71d933ad23ebd1f6de28.jpg