ECOLOGICAL INSIGHTS
A NON-PROFIT 501(c) (3) CORPORATION
501 6TH Ave NE, Mandan, ND 58554

February 28, 2016

Karlene Fine
Outdoor Heritage Fund
Bismarck, ND

Dear Karlene,

We respectfully submit our Outdoor Heritage Fund grant application due March 1, 2016. Please also find the separate attachment file with qualifications and previous work leading to the development of this proposal.

Please advise if you need any additional information. We appreciate your assistance and look forward to working with you.

Sincerely,

Rebecca Phillips
Executive Director

Outdoor Heritage Fund Grant Application

The purpose of the North Dakota Outdoor Heritage Fund is to provide funding to state agencies, tribal governments, political subdivisions, and nonprofit organizations, with higher priority given to projects that enhance conservation practices in this state by:

Directive A. Providing access to private and public lands for sportsmen, including projects that create fish and wildlife habitat and provide access for sportsmen;

Directive B. Improving, maintaining and restoring water quality, soil conditions, plant diversity, animal systems and by supporting other practices of stewardship to enhance farming and ranching;

Directive C. Developing, enhancing, conserving and restoring wildlife and fish habitat on private and public lands; and

Directive D. Conserving natural areas and creating other areas for recreation through the establishment and development of parks and other recreation areas.

Exemptions

Outdoor Heritage Fund grants may not be used to finance the following:

A. Litigation;
B. Lobbying activities;
C. Any activity that would interfere, disrupt, or prevent activities associated with surface coal mining operations; sand, gravel, or scoria extraction activities; oil and gas operations; or other energy facility or infrastructure development;
D. The acquisition of land or to encumber any land for a term longer than twenty years; or
E. Projects outside this state or projects that are beyond the scope of defined activities that fulfill the purposes of Chapter 54-17.8 of the North Dakota Century Code.

NO CONSIDERATION:

In addition to those specific items in law that are ineligible for funding, in the absence of a finding of exceptional circumstances by the Industrial Commission, the following projects will NOT receive consideration for funding:

- A completed project or project commenced before the grant application is submitted;
- A feasibility or research study;
- Maintenance costs;
- A paving project for a road or parking lot;
- A swimming pool or aquatic park;
- Personal property that is not affixed to the land;
- Playground equipment, except that grant funds may be provided for up to 25% of the cost of the equipment not exceeding $10,000 per project and all playground equipment grants may not exceed 5% of the total grants per year (see Budget Form for how this will be calculated);
- Staffing or outside consultants except for costs for staffing or an outside consultant to design and implement an approved project based on the documented need of the applicant and the expenditures may not exceed 5% of the grant to a grantee if the grant exceeds $250,000 and

expenditures may not exceed 10% of the grant to a grantee if the grant is $250,000 or less (see Budget Form for how this will be calculated);

- A building except for a building that is included as part of a comprehensive conservation plan for a new or expanded recreational project (see Budget Form for definition of comprehensive conservation plan and new or expanded recreational project); or
- A project in which the applicant is not directly involved in the execution and completion of the project.

Application Deadline

Applications for this grant round cycle are due on **March 1, 2016 at 5:00 p.m. CT**. All information, including attachments, must be submitted by that date. See instructions below for submission information.

Instructions

Please download this Word document (available on the Industrial Commission/Outdoor Heritage Fund Program website at http://www.nd.gov/ndic/outdoor-infopage.htm) to your computer and provide the information as requested. You are not limited to the spacing provided except in those instances where there is a limit on the number of words. After completing the application, save it and attach it to an e-mail and send it to outdoorheritage@nd.gov or print it and mail it to the address noted in the next paragraph.

Attachments in support of your application may be sent by mail to North Dakota Industrial Commission, ATTN: Outdoor Heritage Fund Program, State Capitol – Fourteenth Floor, 600 East Boulevard Ave. Dept. 405, Bismarck, ND 58505 or by e-mail to outdoorheritage@nd.gov. The application and all attachments must be received or postmarked by the application deadline. You will be sent a confirmation by e-mail of receipt of your application.

You may submit your application at any time prior to the application deadline. Early submission is appreciated and encouraged to allow adequate time to review your application and ensure that all required information has been included. Incomplete applications may not be considered for funding.

Oral Presentation. Please note that you will be given an opportunity to make a ten-minute Oral Presentation at a meeting of the Outdoor Heritage Fund Advisory Board. These presentations are strongly encouraged.

Open Record. Please note that your application and any attachments will be open records as defined by law and will be posted on the Industrial Commission/Outdoor Heritage Fund website.

Name of Organization: Ecological Insights Corporation

Federal Tax ID#: 462111011; DUNS#015285561

Contact Person/Title: Dr. Rebecca Phillips, Executive Director

Address: 501 6th Ave NE

City: Mandan

State: ND

Zip Code: 58554

E-mail Address: rebecca.phillips@ecologicalinsights.org

Web Site Address: www.ecologicalinsights.org

Phone: (701)321-3040

MAJOR Directive:
Choose only one response

O **Directive A**. Providing access to private and public lands for sportsmen, including projects that create fish and wildlife habitat and provide access for sportsmen;

X **Directive B**. Improving, maintaining and restoring water quality, soil conditions, plant diversity, animal systems and by supporting other practices of stewardship to enhance farming and ranching;

O **Directive C**. Developing, enhancing, conserving and restoring wildlife and fish habitat on private and public lands; and

O **Directive D**. Conserving natural areas and creating other areas for recreation through the establishment and development of parks and other recreation areas.

Additional Directive:
Choose all that apply

X **Directive A**. Providing access to private and public lands for sportsmen, including projects that create fish and wildlife habitat and provide access for sportsmen;

X **Directive B**. Improving, maintaining and restoring water quality, soil conditions, plant diversity, animal systems and by supporting other practices of stewardship to enhance farming and ranching;

X **Directive C**. Developing, enhancing, conserving and restoring wildlife and fish habitat on private and public lands; and

O **Directive D**. Conserving natural areas and creating other areas for recreation through the establishment and development of parks and other recreation areas.

Type of organization:

O State Agency

O Political Subdivision

O Tribal Entity

X Tax-exempt, nonprofit corporation.

Project Name and Summary

PRECISION RESTORATION FOR GREATER SOIL, WATER AND HABITAT QUALITY BENEFITS: A DEMONSTRATION PROJECT IN CENTRAL NORTH DAKOTA

Wetland restoration is important as it affects wildlife habitat, water and soil quality, and flood control. These ecosystem services are valuable to sportsmen, wildlife conservationists, farmers, and those interested in wetland mitigation and clean water issues. New precision agriculture tools can be applied to improve restoration design decisions and, ultimately, effectiveness (Phillips et al. 2016). Tools developed by Ecological Insights indicate important surface water networks several miles upstream need to be considered for effective restoration. Now, there is a need to transfer these techniques to field applications, so as to serve North Dakota conservation, ranching and sportsman communities. We will build on our previous successful wetland restoration projects in Sheridan County by employing our precision approach to multiple-use grassland stewardship in central ND. Restorations will focus on enhancement of hydroperiod, grassland nesting cover, and soil and water quality. These benefits will be assessed in the field and by image analyses pre and post restoration (Phillips et al. 2012; 2016). We will work with Northern Plains Sustainable Ag and ND Grazing Lands Coalition leaders to demonstrate how freely available watershed and grassland mapping tools (http://www.arcgis.com/apps/PanelsLegend/index.html?appid=a02f6a0b788e4eac8ad05f75990df8f a) can be applied to ND grassland stewardship and habitat restoration. We will work with collaborators at the ND Natural Resources Trust and ranchers to illustrate new approaches to habitat enhancement that include complex interactions with multiple potholes and surface water flows. We will build consensus around restoration plans that enhance grazing and habitat goals. This 2-yr project will be implemented using funds by OHF, and success will be tracked over the next 20 years using funds by other federal and state agencies. Success will be measured by restoration effectiveness as it pertains to sportsman access, wildlife habitat and environmental quality.

Short Summary: Funds will be used to demonstrate how water, soil and habitat quality can be enhanced using new tools and approaches derived from precision agriculture. OHF will provide funds for implementation and demonstration of precision restoration techniques to achieve the overall goal of enhancing grassland stewardship, habitat and sportsman access.

Phillips, R.L., Eken, M.R., Rundquist, B.C. 2016. A framework for estimating spatial variation in grassland structure for hill country landscapes. New Zealand Grassland Assoc., Hill Country Symposium.

Phillips, R.L., M. Ngugi, J. Hendrickson, E. Smith, M. West. 2012. Mixed-grass prairie canopy structure and spectral reflectance vary with topographic position. Environmental Management 50:914–928.

Phillips, R.L., O. Beeri, E. Scholljegerdes, D. Bjergaard, J. Hendrickson. 2009. Integration of geospatial and cattle nutrition information to estimate paddock grazing capacity in Northern US prairie. Agricultural Systems 100:72–79.

Project Duration: Spring 2016 – 2018

Amount of Grant request: $71,626

Total Project Costs: $94,875
(Note that in-kind and indirect costs can be used for matching funds)

A minimum of 25% Match Funding is required. Amount of Matching Funds
$3,899 of cash match share, $7,000 of in-kind match, and $12,350 of indirect match for a total of $23,249 of matching funds

Source(s) of Matching Funds*
Please provide verification that these matching funds are available for your project. Note that effective as of July 1, 2015 no State General Fund dollars can be used for a match unless funding was legislatively appropriated for that purpose.

The matching funds are available for this project

Certifications *

X I certify that this application has been made with the support of the governing body and chief executive of my organization.

X I certify that if awarded grant funding none of the funding will be used for any of the exemptions noted on Page 1 of this application.

Narrative

Ecological Insights is a ND non-profit, 501(c)(3) corporation that applies sound science and technology to advance stewardship of natural resources, including soil (Phillips et al. 2015) and water conservation (Phillips et al. 2016). This is a public service organization. The founder and executive director of Ecological Insights has been developing on-farm wetland conservation and grassland management tools for ND since 2003. Previous and current collaborators include the ND Natural

Resources Trust, Ducks Unlimited, Landcare Research (New Zealand), US Forest Service, US EPA, North Dakota State University, and the University of North Dakota. The organization includes a scientist, a technician and project coordinator, and temporary labor in summer. Successful projects include development of new precision agriculture tools for grasslands (Phillips et al. 2012, 2013), and new application of radar technology to improve wetland restoration in Sheridan County (Phillips et al. 2016). Our work has wide acceptance in the scientific literature, but more demonstration projects and on-farm applications are needed to advance ND conservation and habitat enhancement.

Phillips, R.L., Ficken, C., Eken, M.R., Hendrickson, J., Beeri, O., 2016. Wetland carbon in a watershed context for the Prairie Pothole Region. Journal of Environmental Quality 45:368-375.

Phillips, R.L., Eken, M.R., West, M., 2015. Soil organic carbon beneath croplands and re-established grasslands in the North Dakota Prairie Pothole region. Environmental Management 55:1191-1199.

Phillips, R.L., West, M., Saliendra, N., Rundquist, B., Pool, D. 2013. Prediction of senescent rangeland canopy structural attributes with airborne hyperspectral imagery. GIScience & Remote Sensing 50:133–153.

Phillips, R.L., Ngugi, M., Hendrickson, J., Smith, E., West, M.. 2012. Mixed-grass prairie canopy structure and spectral reflectance vary with topographic position. Environmental Management 50:914–928.

Purpose of Grant

This project will meet the OHF Directives A, B and C: providing access to private and public lands for sportsmen, including projects that create fish and wildlife habitat and provide access for sportsmen; improving, maintaining and restoring water quality, soil conditions, plant diversity, animal systems and supporting other practices of stewardship to enhance farming and ranching; and developing, enhancing, conserving and restoring wildlife and fish habitat on private and public lands. The economic and soil conservation benefits of precision agriculture have been demonstrated in US croplands. Application in grasslands worldwide has been impeded by the heterogeneity of grassland terrain, and the lack of validation and techniques. Recent advancements can now be applied to assess not only forage quality but also habitat in a watershed context. Application to ND grassland landscapes is urgently needed as grassland acreage declines. We will work with ranchers and sportsmen to show how multiple grassland uses (grazing, habitat) may be optimized to enhance soil and water quality and wildlife habitat.

The project will be outcome-based, with the overall goal of demonstrating to the public how grassland wildlife habitat and forage can both be optimized in the context of wetland restoration. We have identified those wetlands in the landscape that, with restoration, could be enhanced for greater water and soil quality functions (see attachment). In summer 2016, we will set up demonstrations in central North Dakota (see Figure 1). Rancher and sportsmen evaluation and restoration planning meetings will occur winter 2017. Restoration demonstration will be performed in summer 2017. Results from soil, water and habitat surveys will be reported to the ranching and wildlife communities will occur in winter 2017-2018 at annual society meetings. Final report to OHF will be submitted in spring 2018.

Goals will be achieved through on-farm demonstration indicating how forage and wildlife habitat can be enhanced or maintained through precision restoration. In cooperation with wildlife conservationists, we will design metrics for evaluating wildlife habitat and water quality that can be used to measure success. We will inform ND communities about potential stewardship enhancement options with application of these tools. Producers from the Northern Plains Conservation Network, and the ND Grazing Lands Coalition will be among the participants. This demonstration service will be performed using funds from the OHF, so that land managers have an opportunity to participate in the restoration activities. Success will be determined by evaluating how our efforts restored wetland habitat, grassland nesting cover, and water and soil quality. Informational articles will be placed in AgWeek and the Badlands Conservation Alliance newsletter, as well as links in applicable websites.

Management of Project

Management of the project will be conducted by Rebecca Phillips, who has over 30 years of experience as a project manager in both private industry and government organizations. Milestones will be outlined for each objective at the beginning of the project, and these will be evaluated on a monthly basis to ensure all activities are on schedule. Weekly communication with cooperators and collaborators during the summer months will occur to ensure field and imagery goals are met. Data will be carefully organized, archived and backed up weekly. A page of the Ecological Insights website will be created to track activities and data for easy access by OHF managers and project participants. Our aim is to continue monitoring habitat and soil and water quality metrics beyond the life of the OHF grant with funds provided by EPA Region 8 Wetlands Development Program.

Evaluation

As mentioned above, a website link will be created to document progress and post results. The project success will be measured by evaluating restoration success, as it pertains to habitat, soil and water quality before and after restoration. Rancher and sportsman participants will be surveyed to determine their assessment of the project and how precision restoration techniques can best be applied to meet their specific needs.

Financial Information

ATTACHMENT: **Project Budget – Using the standard project budget format that is available on the website at http://www.nd.gov/ndic/outdoor-infopage.htm , please include a detailed total project budget that specifically outlines all the funds you are requesting. Note that a minimum of 25% match funding is required.***

X I certify that a project budget will be sent to the Commission*

Sustainability

We will continue to work with stakeholders to maintain this site beyond the life of the OHF project to ensure habitat, soil and water quality benefits are preserved. We have been supported through competitive bidding for the last 13 years, which led to the development of tools required for this project. Federal agencies have been the primary source of support, yet these agencies do not provide funding for application and demonstration, as we are proposing here. We believe these agencies are currently considering the value of work with stakeholders grasslands gain international attention as key ecosystems. We are actively pursuing funds to sustain this project by 2018. However, we need this grant application funded to bridge the gap between research and applications to better serve ND conservation goals.

Partial Funding

Partial funding would limit the scope of the project and the potential benefits to ranchers, wildlife conservationists and sportsmen.

Partnership Recognition

The ND OHF will be given recognition in all presentations, articles, pamphlets, posters, website, and news media outlets.

Scoring of Grants

All applications will be scored by the Outdoor Heritage Fund Advisory Board after your ten-minute oral presentation. The ranking sheet(s) that will be used by the Board is available on the website at http://www.nd.gov/ndic/outdoor-infopage.htm .

Awarding of Grants*

All decisions on requests will be reported to applicants no later than 30 days after Industrial Commission consideration. The Commission can set a limit on duration of an offer on each application or if there isn't a specific date indicated in the application for implementation of the project, then the applicant has until the next Outdoor Heritage Fund Advisory Board regular meeting to sign the contract and get the project underway or the commitment for funding will be terminated and the applicant may resubmit for funding. Applicants whose proposals have been approved will receive a contract outlining the terms and conditions of the grant. Please note the appropriate sample contract for your organization on the website at http://www.nd.gov/ndic/outdoor-infopage.htm that set forth the general provisions that will be included in any contract issued by the North Dakota Industrial Commission. Please indicate if you can meet all the provisions of the sample contract. If there are provisions in that contract that your organization is unable to meet, please indicate below what those provisions would be. *

Responsibility of Recipient

The recipient of any grant from the Industrial Commission must use the funds awarded for the specific purpose described in the grant application and in accordance with the contract. The recipient cannot use any of the funds for the purposes stated under Exemptions on the first page of this application.

If you have any questions about the application or have trouble submitting the application, please contact Karlene Fine at 701-328-3722 or kfine@nd.gov

Revised: December 16, 2015

Budget Standard Form

Please use the table below to provide a detailed total project budget that specifically outlines all the funds you are requesting and the matching funds being utilized to fund this project. Please note if the matching funds are in the form of cash, indirect costs or in-kind services. The budget should identify all other committed funding sources and the amount of funding from each source. Match can come from any source (i.e. private sources, State and Federal funding, Tribal funding, etc.) Effective as of July 1, 2015 no State General Fund dollars can be used for a match unless funding was legislatively appropriated for that purpose. Note a minimum of 25% match funding is required. An application will be scored higher the greater the amount of match funding provided. (See Scoring Form.)

Please feel free to insert columns and rows as needed. Please include narrative to fully explain the proposed budget.

Note that NO INDIRECT COSTS will be funded from the Outdoor Heritage Fund. Also by law several items are ineligible for funding -- see Exemptions in the Application Form. Effective June 10, 2015 the following guidelines were approved by the Industrial Commission:

NO CONSIDERATION:

In addition to those specific items in law that are ineligible for funding, in the absence of a finding of exceptional circumstances by the Industrial Commission, the following projects will NOT receive consideration for funding:

- A completed project or project commenced before the grant application is submitted;
- A feasibility or research study;
- Maintenance costs;
- A paving project for a road or parking lot;
- A swimming pool or aquatic park;
- Personal property that is not affixed to the land;
- Playground equipment, except that grant funds may be provided for up to 25% of the cost of the equipment not exceeding $10,000 per project and all playground equipment grants may not exceed 5% of the total grants per year; (See Definitions/Clarifications below)
- Staffing or outside consultants except for costs for staffing or an outside consultant to design and implement an approved project based on the documented need of the applicant and the expenditures may not exceed 5% of the grant to a grantee if the grant exceeds $250,000 and expenditures may not exceed 10% of the grant to a grantee if the grant is $250,000 or less; (See Definitions/Clarifications below)
- A building except for a building that is included as part of a comprehensive conservation plan for a new or expanded recreational project; (See Definitions/Clarifications below)
- A project in which the applicant is not directly involved in the execution and completion of the project.

Project Expense	OHF Request	Applicant's Match Share (Cash)	Applicant's Match Share (In-Kind)	Applicant's Match Share (Indirect)	Other Sponsor's Share	Total Each Project Expense
Habitat enhancement (1)	$31,500.00	$0.00	$0.00	$0.00	$0.00	$31,500.00
Water and soil testing (2)	$6,000.00					$6,000.00
Survey Equipment (3)	$0.00	$3,899.00	$0.00	$0.00	$0.00	$3,899.00
Data Processing (4)	$9,500.00	$0.00	$0.00	$0.00	$0.00	$9,500.00
Staff (5)	$9,600.00	$0.00	$7,000.00	$0.00	$0.00	$16,600.00
Operating (6)	$0.00	$0.00	$0.00	$12,350.00	$0.00	$12,350.00
Travel (7)	$15,026.00	$0.00	$0.00	$0.00	$0.00	$15,026.00
Total Costs	$71,626.00	$3,899.00	$7,000.00	$12,350.00	$0.00	$94,875.00

(1) Restoration/habitat enhancement activities estimated based on previous restoration projects (Phillips et al. 2016).
(2) Testing to monitor soil and water quality improvements following restoration
(3) Equipment required for field surveys
(4) Contracted processing fees, included imagery correction, calibration, mapping and modelling acquired pre and post restoration
(5) Temporary summer help needed for field surveys and restoration implementation and monitoring. Temporary help cost estimated as 320 hours per year at 15.00 per hour; also time required to train and supervise summer help estimated at 230 hours per year at 15.00 per hour.
(5) Administrative costs for communications, purchases, printing, accounting, reporting, and computing. Discounted indirect cost (13% of project total cost)
(6) Travel to demonstration sites, collaborator meetings, rancher and public land manager symposia, annual wildlife society and rancher conferences

In-kind services used to match the request for Outdoor Heritage Fund dollars shall be valued as follows:

- Labor costs — $15.00 an hour
- Land costs — Average rent costs for the county as shown in the most recent publication of the USDA, National Agricultural Statistics Services, North Dakota Field Office
- Permanent Equipment — Any equipment purchased must be listed separately with documentation showing actual cost. (For example: playground equipment)
- Equipment usage — Actual documentation
- Seed & Seedlings — Actual documentation
- Transportation — Mileage at federal rate
- Supplies & materials — Actual documentation

More categories will be added as we better understand the types of applications that will be submitted. We will use as our basis for these standards other State and Federal programs that have established rates. For example the North Dakota Nonpoint Source Pollution Management Program has established rates. If your project includes work that has an established rate under another State Program please use those rates and note your source.

Definitions/Clarifications:

Building - Defined as "A structure with a roof either with walls or without walls and is attached to the ground in a permanent nature."

Comprehensive Conservation Plan - Defined as "A detailed plan that has been formally adopted by the governing board which includes goals and objectives--both short and long term, must show how this building will enhance the overall conservation goals of the project and the protection or preservation of wildlife and fish habitat or natural areas." This does not need to be a complex multi-page document. It could be included as a part of the application or be an attachment.

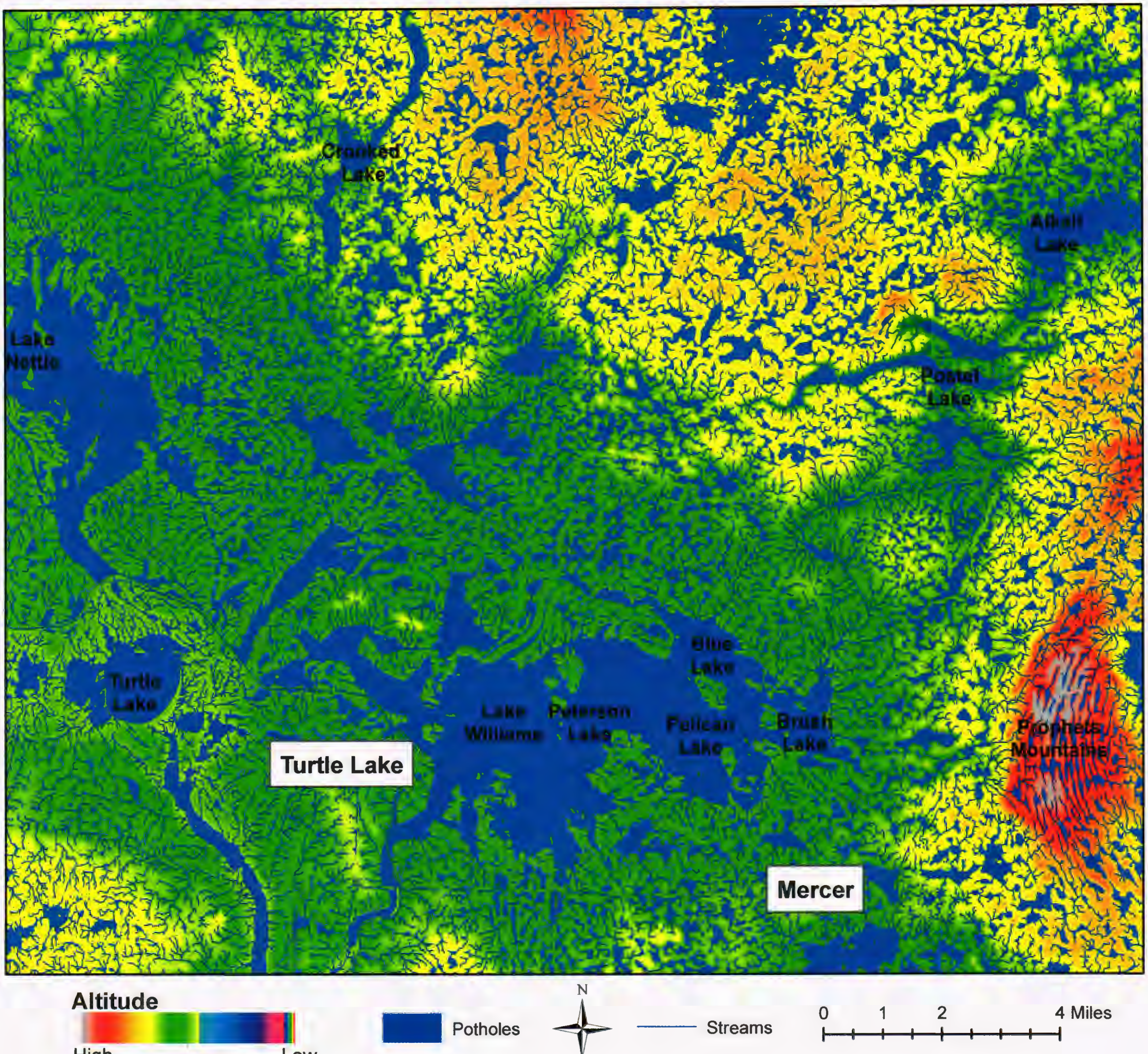
New and Expanded Recreational Project means that the proposed building cannot be a replacement of a current building. The proposed building must also be related to either a new or expanded recreational project--either an expansion in land or an expansion of an existing building or in the opportunities for recreation at the project site.

Playground equipment calculation - Only the actual costs of the playground equipment (a bid or invoice showing the amount of the equipment costs must be provided) - cannot include freight or installation or surface materials or removal of old equipment, etc.

Staffing/Outside Consultants Costs - If you are requesting OHF funding for staffing or for an outside consultant, you must provide information in your application on the need for OHF funding to cover these costs. For example, if you are an entity that has engineering staff you must explain why you don't have sufficient staff to do the work or if specific expertise is needed or whatever the reason is for your entity to retain an outside consultant. If it is a request for reimbursement for staff time then a written explanation is required in the application of why OHF funding is needed to pay for the costs of that staff member(s)' time. **The budget form must reflect on a separate line item the specific amount that is being requested for staffing and/or the hiring of an outside consultant.** This separate line item will then be used to make the calculation of 5% or 10% as outlined in the law. Note that the calculation will be made on the grant less the costs for the consultant or staff.

Recommended by OHF Advisory Board: October 17, 2013
Approved by Industrial Commission: October 22, 2013
Revisions recommended by OHF Advisory Board: January 22, 2014
Approved by Industrial Commission: January 29, 2014
Revisions recommended by OHF Advisory Board: May 13, 2014
Approved by Industrial Commission: May 27, 2014
Revisions recommended by OHF Advisory Board: June 3, 2015
Approved by Industrial Commission: June 10, 2015

Figure 1



Precision restoration map illustrating stream networks intersecting prairie potholes near Turtle Lake, ND. Area is 300 square miles, and elevation gradients are in color where red areas drain toward blue areas. These networks can guide wetland restoration designs (See application text).

Published January 11, 2016

Journal of Environmental Quality | TECHNICAL REPORTS

WETLANDS AND AQUATIC PROCESSES

Wetland Soil Carbon in a Watershed Context for the Prairie Pothole Region

Rebecca L. Phillips,* Cari Ficken, Mikki Eken, John Hendrickson, and Ofer Beeri

Abstract

Wetland restoration in the Prairie Pothole Region (PPR) often involves soil removal to enhance water storage volume and/or remove seedbanks of invasive species. Consequences of soil removal could include loss of soil organic carbon (SOC), which is important to ecosystem functions such as water-holding capacity and nutrient retention needed for plant re-establishment. We used watershed position and surface flow pathways to classify wetlands into headwater or network systems to address two questions relevant to carbon (C) cycling and wetland restoration practices: (i) Do SOC stocks and C mineralization rates vary with landscape position in the watershed (headwater vs. network systems) and land use (restored vs. native prairie grasslands)? (ii) How might soil removal affect plant emergence? We addressed these questions using wetlands at three large (~200 ha) study areas in the central North Dakota PPR. We found the cumulative amount of C mineralization over 90 d was 100% greater for network than headwater systems, but SOC stocks were similar, suggesting greater C inputs beneath wetlands connected by higher-order drainage lines are balanced by greater rates of C turnover. Land use significantly affected SOC, with greater stocks beneath native prairie than restored grasslands for both watershed positions. Removal of mineral soil negatively affected plant emergence. This watershed-based framework can be applied to guide restoration designs by (i) weighting wetlands based on surface flow connectivity and contributing area and (ii) mapping the effects of soil removal on plant and soil properties for network and headwater wetland systems in the PPR.

Core Ideas

- Wetland soil carbon varies with upland land use but not landscape position.
- Carbon mineralization rates vary with landscape position.
- Soil removal for wetland restoration may affect plant re-establishment.

J. Environ. Qual. 45:368–375 (2016)
doi:10.2134/jeq2015.06.0310
Supplemental material is available online for this article.
Freely available online through the author-supported open-access option.
Received 25 June 2015.
Accepted 2 Dec. 2015.
*Corresponding author (PhillipsR@landcareresearch.co.nz).

The Prairie Pothole Region (PPR) is populated by a high density of shallow, glaciated wetlands (van der Valk, 1989) and represents one of the most important regions in North America for breeding, nesting, and migrating grassland birds and waterfowl (Igl and Johnson, 1997; Beyersbergen et al., 2004; Niemuth et al., 2006). Nearly 1 million ha of wetlands are found in the North Dakota PPR (Stewart and Kantrud, 1973; Tiner, 1999), where spatiotemporal variation in wetland hydroperiod (Beeri and Phillips, 2007) is prominent and critical to waterfowl habitat. Wetland hydroperiod varies with topographic position (Zhang et al., 2007) and drives soil carbon (C) dynamics by altering redox potential (Mitsch and Gosselink, 2007). Historical land use of the areas surrounding these wetlands is also known to influence soil C (Gleason et al., 2011). However, a lack of knowledge regarding surface and groundwater drainage networks for these depressional wetlands has hindered understanding of potential surface water connections among wetlands in a watershed (Winter, 2003) and how these might affect the C cycle. Understanding the role of landscape position with respect to surface water flows and soil C dynamics is needed to support managers and mitigation banking teams interested in maintaining C sequestration or minimizing C losses (Cahill et al., 2009).

The hydrology and biogeochemical cycling for PPR wetland networks is largely dependent on interactions among watershed position, climate, and surface and groundwater flows (Winter, 2003). Understanding surface water interactions among wetlands in the PPR is problematic, however, because the region is geologically young and lacks strong changes in elevation and deeply eroded drainage networks (Bluemle, 1981). Visual observations or coarse-resolution elevation data cannot discern watershed boundaries or multiple pathways for surface drainage networks among wetlands (USEPA, 2015). High-resolution digital elevation model (DEM) data (<1 m vertical resolution) have now been modeled to map drainage lines, catchment areas, and other watershed characteristics (McCauley and Anteau, 2014) at

R.L. Phillips, Landcare Research, Gerald Street, Lincoln, New Zealand, and Ecological Insights Corporation, 501 6th Ave NE, Mandan, ND 58554; C. Ficken, Duke University, Box 90338, Durham, NC 27708; M. Eken, Ecological Insights Corporation, 501 6th Ave NE, Mandan, ND 58554; J. Hendrickson, USDA-ARS, Northern Great Plains Research Laboratory, PO Box 459, Mandan, ND 58554; O. Beeri, c/o Bruce Smith, University of North Dakota, Box 9007, Grand Forks, ND 58202. Assigned to Associate Editor Curtis Dell.

Abbreviations: AOI, area of interest; CRP, Conservation Reserve Program; DEM, digital elevation model; NWI, National Wetlands Inventory; PPR, Prairie Pothole Region; SOC, soil organic carbon; TauDEM, Terrain Analysis Using Digital Elevation Model.

scales relevant to the geomorphology of the PPR. For example, these data can now be applied to map headwater (Gomi et al., 2002), or geographically isolated (Tiner, 2003), wetland systems separately from wetlands connected by higher-order drainage lines at lower reaches of the watershed (Strahler, 1957; Gomi et al., 2002). Mapping and understanding potential wetland connectivity through surface flow networks will likely have important implications for wetland restoration, soil C dynamics, and processes influencing soil organic carbon (SOC) sequestration.

Hypoxic or anoxic wetland soil conditions generally slow SOC turnover rates and enhance SOC sequestration. However, mineralization of available SOC to CO_2 is stimulated when wetlands are drained and the C buried beneath them is exposed to oxygen (Mitsch and Gosselink, 2007). Release of SOC to CO_2 is also stimulated by disturbance, such as plowing native prairie grasslands during conversion to annual crop production (Reicosky et al., 1997; Paustian et al., 1997). Carbon mineralization rates have been measured across large landscapes and provide an indication of the potential effects of disturbance on SOC (Ahn et al., 2009). These incubation studies indicate that the effects of land use on C mineralization may persist long after the initial disturbance (Ahn et al., 2009; McLaughlan and Hobbie, 2004). Thus, an understanding of C losses through mineralization may be more informative than SOC inventory data alone. Overall, both land use and position in the landscape are expected to influence wetland C cycling in PPR landscapes but, to the best of our knowledge, have not been explicitly tested.

Soil removal in the PPR is commonly prescribed for wetland mitigation/restoration projects by state Interagency Review Teams in an effort to enhance the hydroperiod by increasing catchment volume (US Department of Defense and USEPA, 2008). Increasing catchment volume can provide benefits to water quality (Jordan et al., 2003) and waterfowl (Johnson et al., 2005), and there is a need to understand restoration effects and to measure restoration success (Fennessy and Craft, 2011). In the PPR, restoration typically involves removal of shallow marsh soils near wetland edges (Stewart and Kantrud, 1971), where hydric vegetation might trap eroded soil from upland crop fields (Luo et al., 1997). Soil removal is intended to expose previously buried seed banks and high-quality soil (Doran et al., 1998; Harris, 2003). However, removal of soil near the surface may actually stimulate C mineralization (Paustian et al., 1997; Reicosky et al., 1997) and reduce water holding capacity, root penetration, C stocks, nutrient availability, and the establishment of desired plant species (Bruland and Richardson, 2005; Bantilan-Smith et al., 2009; Ahn and Dee, 2011). It remains unclear if plant emergence in the shallow marsh zone will be affected by removal of organic and mineral soil horizons in the PPR.

We hypothesized that SOC stocks and cumulative C mineralized (conversion of C to CO_2) during laboratory incubations would be greater for wetland systems connected by multiple drainage lines in the lower reaches of the watershed ("network wetlands") than for headwater wetland systems (Gomi et al., 2002). We also hypothesized that plant emergence would be compromised after removal of organic and/or mineral soil horizons. To address these hypotheses, we evaluated wetlands at three large (~200 ha) sites in central North Dakota, which we refer to as focus areas. Each focus area was comprised of more than 20 emergent wetlands surrounding by either re-established or native prairie grasslands. We used field, greenhouse, and laboratory studies to evaluate SOC and plant emergence after soil removal (Marton et al., 2014; Fennessy and Craft, 2011). With this work, our goal was to better understand the importance of landscape position and land use with respect to soil C cycling in the context of wetland restoration and to examine potential impacts of soil removal on plant emergence and C sequestration.

Materials and Methods

Area of Interest

The total area of the PPR is 77.8 million ha, and 12.8 million ha of the PPR is located in North Dakota. Nested inside the PPR are the Missouri Coteau and Northern Glaciated Plains ecoregions (Omernik, 1987), where the density of water bodies is high and spatiotemporally variable (Beeri and Phillips, 2007). Physiography and land use for this region are described by Bluemle (1981), Strong et al. (2005), Beeri and Phillips (2007), and Phillips et al. (2015). We delineated a 1.2 million ha area of interest (AOI) with a center point near Max, ND (Fig. 1). Most wetlands listed for this region in the National Wetlands Inventory (NWI) are classified as palustrine, emergent seasonal or palustrine, emergent temporary (US Fish and Wildlife Service, 2015). These terms are designated for wetlands that remain dry most of the year and fill with water only after spring rains, substantive snowmelt, or groundwater discharge (Stewart and Kantrud, 1971). When precipitation is below average, most temporary wetlands will remain dry all year. Average (30-yr)

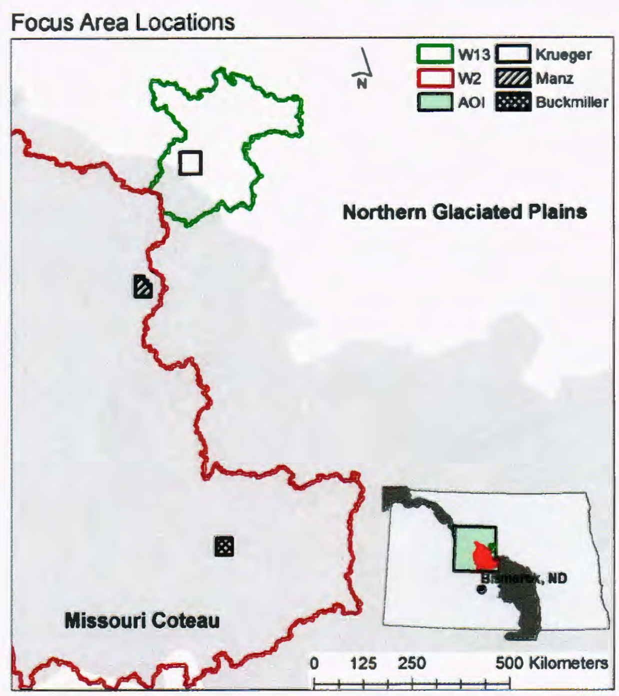


Fig. 1. Focus areas (Buckmiller, Krueger and Manz) were located within the Missouri Coteau and Northern Great Plains ecoregions. Denoted in the legend are watershed identification numbers that correspond with mapped watersheds outlined in red (W2) and green (W13). The intersection of W2 and W13 watersheds is the edge of the Missouri Coteau where elevation drops and slopes toward the Northern Glaciated Plains. The area of interest (AOI) depicted in the map inset represents the entire area where digital elevation model data were obtained on 20 Apr. 2007. The inset also shows the scale of the W2 and W13 watersheds relative to the AOI.

annual rainfall within our AOI is 450 mm, and average annual temperature is 6°C (Menne et al., 2015).

Since the 1980s, large tracts of land previously used for annual crop production were enrolled in the Conservation Reserve Program (CRP), although many of these lands have recently been converted back to crop production (USDA–FSA, 2012). Conservation Reserve Program enrollment requires "resting" lands for a period of time by seeding fields previously used for crop production to perennial grasses. In the central North Dakota PPR, these are typically mixtures of smooth brome [*Bromus inermis* (Leyss.)], crested wheatgrass [*Agropyron cristatum* (L.)], western wheatgrass [*Pascopyrum smithii* (Rybd.) Á. Löve], needle-and-thread [*Hesperostipa comata* (Trin. & Rupr.) Barkworth], and alfalfa (*Medicago*) species (USDA–FSA, 2012). We identified three privately owned, central North Dakota focus areas for this study (Fig. 1), where multiple wetlands were surrounded by either grasslands enrolled in the CRP for over 10 yr or native prairie. Two focus areas were located on the west side of the PPR in the Missouri Coteau ecoregion, and one focus area was located on the east side of the PPR in the Northern Glaciated Plains ecoregion (Fig. 1).

Digital Elevation Data

Evaluation of PPR wetlands in a watershed context required that we first acquire and model high-resolution DEM, similar to McCauley and Anteau (2014), for a landscape that extended well beyond sites where field data were collected. Spatially expansive data would ensure that there would be a high probability that all areas potentially contributing surface flows to specific depressions would be included. High-resolution DEMs were acquired over the AOI the week of 20 Apr. 2007 by Intermap Technology shortly after snow melt and before green-up (Fig. 1). The southeast corner of the data (47°14′48″ N, 100°14′1″W) was near Wing, ND, and the northwest corner (48°15′9″ N, 101°45′40″ W) was near Fort Berthold, ND. Precipitation in 2006 through spring 2007 was 45% below the 30-yr average (Menne et al., 2015), so many seasonal and temporary wetlands did not contain water when the DEM data were collected, which is common during dry years (Beeri and Phillips, 2007). Data were acquired using an on-board Twin Otter aircraft equipped with an interferomic synthetic aperture radar sensor (Intermap, 2012). Data were geometrically corrected according to National Geodesic Survey benchmarks and geographic position system field points collected within 1 wk of the flyover. The bare earth model provided by Intermap Technologies was produced using algorithms to remove buildings, vegetation, roads, and other elevated features (Intermap, 2015). Data vertical accuracy is reportedly <1 m (Mooney et al., 2006), and this was validated using ground control point captured during image acquisition.

The data were first processed using the open source ArcGIS extension Terrain Analysis Using Digital Elevation Models (TauDEM) by Tarboton (2005). Eighteen major pour points, or outlets, were identified that drain into the major central North Dakota river systems (the Missouri, Souris, and Cheyenne Rivers). Watersheds were built around each of the 18 pour points using TauDEM analysis tools (Tarboton et al., 1991). Two of the three focus areas used in this study (named Manz and Buckmiller) were located in the W2 watershed, and one focus area (named Krueger) was located in the W13 watershed (Fig. 1). Drainage networks were mapped in the Arc Hydro module of ArcGIS (version 9.2) using a minimum flow accumulation of 0.008 km, and streams were classified according to the Strahler stream order (Strahler, 1957). The water routing algorithm used in Arc Hydro is such that water is routed from one 5-m pixel into neighboring pixels of lower elevation. To identify potential surface water flows and catchment areas where water could pond, we filled all depressions within the DEM and subtracted the unfilled DEM from the filled DEM, which is referred to as a difference grid (McCauley and Anteau, 2014). This grid contains catchment area and depth information. We did not specify a minimum fill depth because this landscape is populated with thousands of shallow pothole wetlands (Beeri and Phillips, 2007). Only catchments >0.0025 ha (a single pixel) were retained in the map output. Culverts, bridges, and roads can affect water flows, and these obstructions were corrected by processing raw DEM to bare earth digital terrain model (Intermap, 2015). Modeled catchments are depressions in the landscape that could hold water, as compared with wetlands, which are delineated by the NWI (US Fish and Wildlife Service, 2015).

We classified each NWI wetland in our focus areas according to landscape position and drainage networks using the Strahler stream order (Strahler, 1957) as outlined by Gomi et al. (2002). Briefly, wetlands were classified as headwater systems when they did not intersect with streams, when they were intersected by stream orders <2, and when they were located at the upper reaches of the watershed, with no wetlands upstream potentially contributing flow (Gomi et al., 2002). Wetlands that were located in a catchment within 50 m of higher-order drainage lines (Strahler stream order >1) were classified as network systems (Gomi et al., 2002). We would expect greater surface flow accumulation and connectivity for those network systems transected by higher stream orders than headwater systems. Headwater systems, however, may be hydrologically connected when they rise and spill over beyond their catchment volume into neighboring wetlands or by way of groundwater flow systems (Winter, 2003).

Focus Area Description

The three focus areas were located within 40 km of each other in rural areas of Sheridan County, ND (Fig. 1). The site furthest to the south was Buckmiller (47°25′18″ N, 100°28′12″ W), followed by Manz (47°39′8″ N, 100°34′41″ W) directly north of Buckmiller and Krueger (47°45′35″ N, 100°30′51″ W) located east of Manz. Each focus area was comprised of >20 palustrine, emergent, NWI wetlands (US Fish and Wildlife Service, 2015). Wetlands in the PPR are characterized by concentric bands of vegetation zones, with plant communities that co-occur and vary predictably with distance from the lowest point in the wetland (Stewart and Kantrud, 1971). We focused on the shallow marsh vegetation zone, which is normally saturated from spring to early summer and is recognized by hydrophytic vegetation of intermediate height (<0.5 m), such as spike rush (*Eleocharis macrostchya* Britt.) and Baltic rush (*Juncus balticus* Willd.) species (Stewart and Kantrud, 1971). Surrounding these hydric vegetation zones at each of the focus areas were either grasslands managed under the CRP for over 10 yr or native prairie grasslands that were occasionally harvested for hay or lightly grazed by cattle (<0.2 AU ha^{-1}). Grasslands managed under the CRP were dominated by smooth brome, crested wheatgrass, and Kentucky bluegrass [*Poa pretensis* (L.)], whereas native prairie grasslands were dominated by western wheatgrass, needle-and-thread grass, and Kentucky bluegrass. Soils at all three focus areas were dominated by fine, loamy, mixed superactive frigid Typic Argiustolls and Haplustolls (Soil Survey Staff, 2008). Soil particle size was predominantly sand (42–50%), with similar proportions of silt and clay (20–30%), and soil pH ranged from 6.2 to 7.5. All focus areas were managed by the same owner, with an emphasis on minimizing wildlife habitat disturbance. The emergent wetlands in the focus areas were small (average, <1 ha), with hydroperiods that vacillated seasonally and annually (Beeri and Phillips, 2007). Each NWI wetland was designated as either headwater or network systems based on catchment colocation and watershed position classification. Wetlands were also designated according to upland land use as either CRP or prairie grasslands.

Estimates for dry catchment depth, as determined from the modeled DEM, were compared with field estimates of depth at six catchments within each focus area. These catchments did not contain water during the DEM data acquisition, so the remote sensing–based elevation data were not obscured by standing water. Field estimates of depth were determined by first navigating to the lowest point around the perimeter of the catchment (known as the pour point). From this point, height data were collected within the length of each catchment every 5 m using a set of modified Robel poles (Robel et al., 1970) connected by a level line. Depth estimates in the field were matched to each 5 × 5 m pixel from the DEM across the catchment. Observed versus modeled depth was evaluated using the RMSE for the purpose of estimating potential error in modeled catchment depth.

Soil Carbon Experiment

We randomly selected two headwater and two network wetland systems within each focus area (Fig. 1) and land cover class (native prairie vs. CRP grassland) and then randomly selected four points around the perimeter of each wetland in the shallow marsh zone (Phillips et al., 2005). This zone is often excavated during restoration, and our aim was to evaluate the potential effects of soil removal on seedbank, plant emergence, and SOC. Because network wetlands are inundated longer each year than headwater wetlands, we expected more anoxic conditions would increase SOC burial. At each point, duplicate cores (5 × 10 cm depth) were collected within 1 m of each other in plastic sleeves on 12 Sept. 2012. For this initial study, we limited sampling to 10 cm because microbial activity and C inputs are greatest near the surface. Cores were gently saturated with deionized water in the field, allowed to freely drain, stored at 4°C, transported to the laboratory, and processed within 24 h of collection. One set of cores was composited by wetland and used for laboratory incubations, soil moisture determination, and analysis of C. These were well mixed and coarsely (4 mm) sieved (Franzluebbers, 1999). A subsample was removed for determination of gravimetric moisture content and oven-dried at 105°C for 48 h (Marton et al., 2014). Another subsample was dried at 35°C for 3 to 4 d, ground to pass a 0.106-mm sieve, and analyzed for total C by dry combustion (Nelson and Sommers, 1996) using a Carlo Erba NA 1500 Elemental Analyzer (CE Elantech). Using the same fine-ground soil from the C analyses, soil inorganic C was measured by quantifying the amount of CO_2 produced using a volumetric calcimeter after application of dilute HCl stabilized with $FeCl_2$ (Loeppert and Suarez, 1996). Because inorganic C was such a minor fraction of total C, results are reported as SOC. We used these SOC data to estimate percentage of SOC pool mineralized over the course of 90-d incubations (Ahn et al., 2009). The second set of cores was used for bulk density, which was determined as the quotient of oven-dried mass divided by core volume (Marton et al., 2014). Concentration data for SOC (g kg^{-1} dry soil) were multiplied by bulk density and sampling depth (soil layer thickness) to convert SOC to an area basis (Mg ha^{-1}) for the 0- to 10-cm soil depth.

The amount of C mineralized was determined in accordance with previous studies using laboratory incubations in the absence of new organic matter inputs and calculating cumulative CO_2 respired over a 90-d time course (Ahn et al., 2009; McLaughlan and Hobbie, 2004). A total of 12 vials (12-mL exetainer vial, Labco Unlimited) per wetland were prepared, and the equivalent of 3 g dry mass of soil was transferred into each of 10 vials. Two empty vials per wetland were used as the abiotic control. Vials were capped and vented and allowed to incubate in a 22°C water bath. The mass of water in each vial at the beginning and end of the incubation was recorded. Respiration of CO_2 was measured in the headspace of each vial on 11 occasions over the 90-d period. Beginning on Day 1, vials were evacuated and flushed with CO_2–free air for 5 min, and headspace was analyzed on a gas chromatograph (Model 3800 gas chromatograph and Combi-Pal auto-sampler, Agilent Technology). Vials were then transferred to a 22°C water bath, and headspace was analyzed again 24 h later. When vials were not being analyzed, they remained in the 22°C water bath. Gas chromatography details may be found in Phillips et al. (2009). The precision of the gas chromatography analysis, expressed as the coefficient of variation for 10 replicate standards (369, 1748, and 4986 μL L^{-1} CO_2), was consistently <2%. This protocol was repeated on Days 3, 6, 10, 15, 22, 30, 38, 50, 71, and 90. Respiration rates were calculated using the difference in headspace CO_2 determined over each 24-h period and used to determine cumulative CO_2 respired over 90 d (McLaughlan and Hobbie, 2004).

Soil Removal Experiment

Wetlands selected for the soil removal experiment were those network systems targeted for restoration by the North Dakota Interagency Review Teams at the Krueger focus area. The goals of this restoration effort were to enhance water storage capacity and to remove seedbanks of invasive hydric species by removing 0.15 m of soil from the shallow marsh surrounding three wetlands at the Krueger focus area (personal communication, D. Dewald, North Dakota Interagency Review Team, May 2010). Soil cores were collected before commencement of restoration activities and placed in a greenhouse to determine the number of plants emerging from the existing seedbank after soil removal. The restoration plan was to remove sediment in the shallow marsh zone and did not include tillage.

We identified and geo-located three shallow marsh areas surrounding each wetland. At each point, four cores (10 cm diam. × 90 cm depth) were collected using a tractor press on 27 May 2010 and processed the following day. Each core was randomly assigned one of four treatments: O horizon removal, 1/2 of the A horizon plus O horizon removal, full A horizon removal, and control (no removal). The soil removed was reserved for seed bank evaluation. Average (SD) depth of the O horizon was

2.8 cm (0.6), and average depth of the A horizon was 21.6 cm (5.7). Cores were placed at random locations on stands in the greenhouse and regularly watered to maintain soil saturation. The number of plants that emerged was recorded every week for 8 wk. The soil removed for this experiment was evaluated to determine seedbanks for these soil layers (O layer, O plus 1/2A horizon, O plus full A horizon). Soils removed from the cores were mixed and spread into flat trays (30 × 30 × 4 cm). Flats were kept near the cores and under the same conditions. Species emerging from the flats were identified and recorded weekly for 12 wk (Bai et al., 2014; Galatowitsch and van der Valk, 1996). The five species most frequently observed for each layer removed were reported.

Data Analysis

We tested for significant differences in SOC stocks, cumulative C mineralization, and the percentage of the SOC pool mineralized with a mixed ANOVA (Littell et al., 1996). A nested hierarchical model was used with wetland nested inside wetland system class (headwater or network), land use, and focus area (Phillips et al., 2015). For cumulative C mineralization and percent SOC mineralized, we controlled for possible differences in water content by including water content in the model as a covariate. All interactions were tested and retained only if significant. For the greenhouse study, the effect of soil removal treatment on the number of plants that emerged was determined with a mixed ANOVA that included the random effects of sample collection site nested inside wetland. Data were transformed as needed to achieve normality before analysis.

Results

Wetland Mapping

Watersheds designated W2 and W13 (Fig. 1) were populated by a total of 40,235 and 2435 catchments, respectively, and the average number of catchments for both watersheds was 1.5 catchments ha^{-1}. The number of NWI wetlands within W2 and W13 was 37,734 and 1924, respectively, and the average number of wetlands for both watersheds was 1.4 wetlands ha^{-1}. Comparisons between benchmark data and bare earth elevation data for the full AOI (Fig. 1) yielded a RMSE of 0.7 m (Intermap Technologies, unpublished data). The deepest point for those catchments surveyed manually ranged from 0.4 to 1.8 m, with an average of 1.2 m. Root mean square error for manual field estimates of catchment depth, as compared with modeled depth, was 0.4 m.

Figure 2 represents the Krueger focus area and illustrates catchment and NWI classification with drainage lines. The Manz and Buckmiller focus area maps may be found in Supplemental Fig. S1 and S2. At all three focus areas, we mapped a total of 98 NWI wetlands and 221 catchments (Eken and Phillips, 2015). The 123 catchments that were not wetlands were small (0.05–0.1 ha) and shallow (<0.5 m depth). These were below the minimum area criterion for NWI. All NWI wetlands were colocated within catchments (Fig. 2; Supplemental Fig. S1 and S2). Average modeled catchment area and depth for our three focus areas ranged from 0.8 to 5.4 ha and from 0.6 to 3.3 m, respectively. Figure 2 also depicts two drainage lines transected by the road near the north and south edges of the focus area. These lines are connected across the road, indicating the road obstruction was successfully removed by the bare earth model (Intermap, 2015), so modeled flows were not impeded. Headwater wetland systems were noticeably smaller than network systems. At the Krueger focus area, 40 of the 67 wetlands were classified as network and 27 were classified as headwater systems (Fig. 2). At the Manz focus area, 39 of the 83 wetlands were classified as network and 44 were classified as headwater systems (Supplemental Fig. S1). At the Buckmiller focus area, 32 of the 47 wetlands were classified as network and 15 were classified as headwater systems (Supplemental Fig. S2).

Soil Carbon

Average (±SE) SOC stocks for wetlands surrounded by CRP grasslands for network and headwater systems were similar, with 37.8 (3.5) Mg C ha^{-1} for headwater and 37.4 (2.0) Mg C ha^{-1} for network systems at the 0- to 10-cm soil depth increment. Average SOC stocks for wetlands surrounded by prairie grasslands were also similar for both systems, with 64.0 (7.8) Mg C ha^{-1} for headwater and 77.7 (8.3) Mg C ha^{-1} for network systems. However, SOC stocks varied significantly with surrounding land use ($p < 0.01$). Shallow marsh soils surrounded by CRP grasslands were 46% lower, on average, than SOC stocks for shallow marsh soil surrounded by native prairie. Cumulative C respired over 3 mo, on the other hand, varied with wetland system ($p < 0.01$) but not land use. We observed greater cumulative C respired for network systems connected by higher-order drainage lines at lower positions in the watershed (Fig. 3) than for headwater systems ($p < 0.05$). Whereas the average percentage of bulk SOC pool mineralized was 2% for headwater systems, the average percentage of bulk SOC pool mineralized was 4% for the network system. None of the interactions tested was significant.

Soil Removal

Soil removal significantly influenced plant emergence ($p < 0.05$) (Supplemental Fig. S3). The average (±SE) number of plants that emerged 4 wk after removal of O, 1/2 A, and A horizons was 6 (3.3), 0.5 (0.4), and 0.1 (0.1), respectively. The number of plants that emerged from control cores was 15 (4.9). A list of species that emerged for each soil removal treatment may be found in Supplemental Table S4. For the seedbank study, using the soil removed from these cores, we found similar species in O horizon, 1/2A + O horizon, and O + A horizon layers (Supplemental Table S5). Four species were dominant in all seedbank layers. These included *Potentilla norvegica* (L.), *Eleocharis compressa* (Sull.), *Juncus bufonius* (L.), and *Triglochin palustris* (L.). None of these species was listed as invasive (USDA, 2014), but all are common to wetland and/or wet grassland environments in the PPR.

Discussion

Strong differences in SOC stocks between land uses affirm the importance of wetlands surrounded by native prairie with respect to C sequestration in the PPR (Gleason et al., 2011). Soil organic C stocks for wetland soils surrounded by CRP grasslands were 46% greater than wetland soils surrounded by native prairie grasslands, which are similar to SOC differences between natural and restored wetlands reported by Marton et al. (2014) and Fennessy and Craft (2011). Stocks of SOC reported here are in

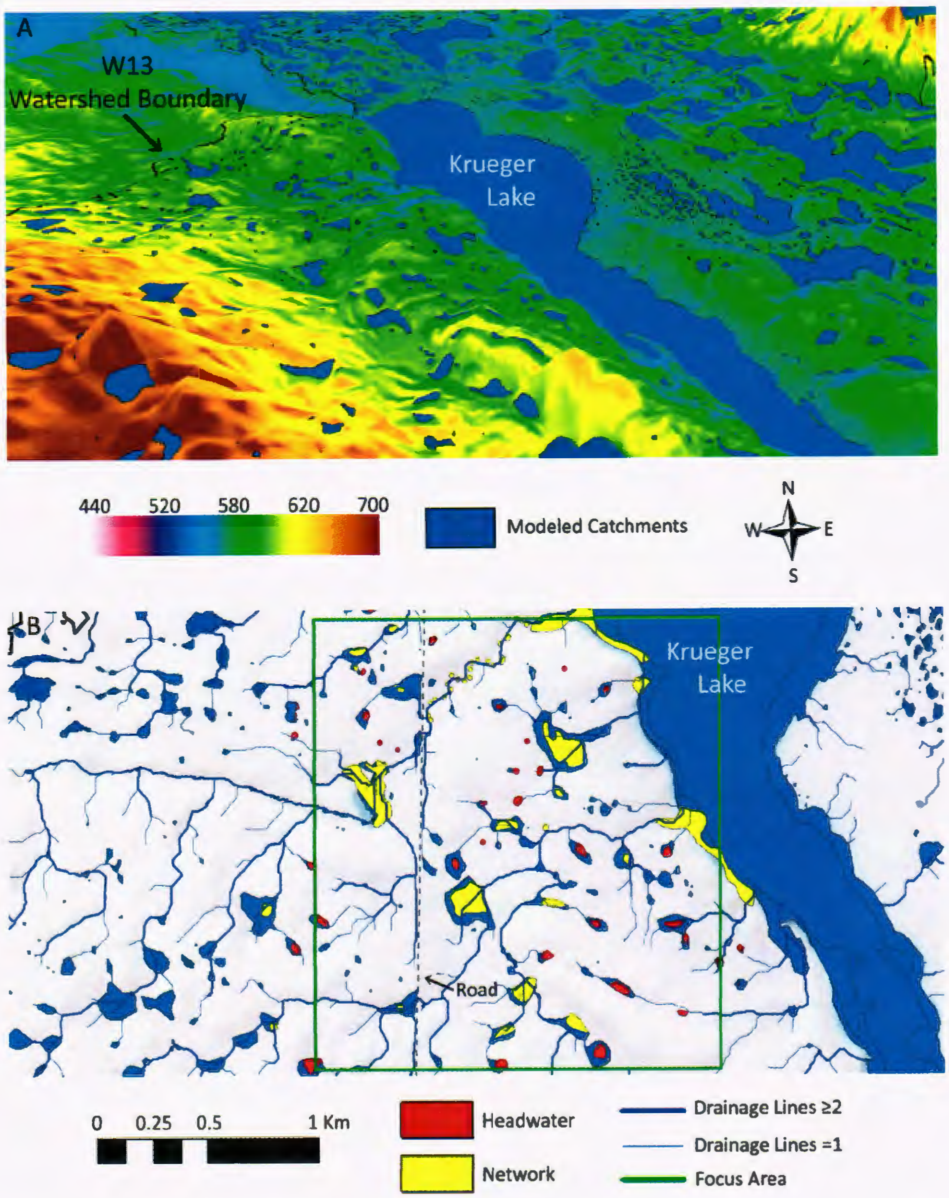


Fig. 2. Krueger focus area model output and classification (A) three dimensional view of topography with respect to modeled catchments and (B) classification of National Wetlands Inventory wetlands into network (yellow) and headwater (red) systems depicted within modeled catchments (blue). Catchments shown in blue only in (B) were not colocated with wetlands.

the range of other wetland SOC reports in the PPR (Phillips and Beeri, 2008; Gleason et al., 2011). Differences in SOC stocks were found despite over 10 yr of conservation grassland management, suggesting that the impacts of agricultural cropping disturbance on SOC stocks may be evident at decadal time scales (Ballantine and Schneider, 2009; Gleason et al., 2011; Marton et al., 2014). Management data before conversion to CRP were not available; however, we suspect tillage of shallow marsh soils in dry years before CRP contributed to differences in SOC.

Soil organic C stocks beneath network systems tend to receive greater inputs of plant organic matter, dissolved organic C, and erosional C than headwater systems (Mitsch and Gosselink, 2007), yet we found SOC stocks to be similar. Carbon mineralization rates, on the other hand, were widely different (Fig. 3). Cumulative C mineralized over 90-d incubation for network systems were twice as high as headwater systems, and this result may help explain why SOC stocks for both wetland systems were similar. Evidence of higher mineralization rates but similar SOC for wetlands connected by higher-order drainage lines suggests greater organic matter inputs lower in the watershed were balanced by higher rates of C turnover (Bedard-Haughn et al., 2006). This would mean that both headwater and network systems might be valued similarly with respect to C sequestration (Brinson, 1993). We found wetlands surrounded by re-established grasslands mineralized a greater fraction of the SOC pool than wetlands surrounded by native grasslands (Ahn et al., 2009). This has important implications for grassland re-establishment and the potential to restore wetland SOC stocks. Because C mineralization rates were similar for wetlands surrounded by both native and re-established grasslands, greater and/or more recalcitrant organic matter inputs would be required to completely restore SOC to native grassland levels. Additional investigations are needed to test this hypothesis. Overall, our results suggest potential controls on PPR wetland C cycling in surface soils may be associated with not only land use but also with position in the watershed and proximity to surface flow networks, defined here as headwater and network systems.

We evaluated plant emergence in the absence of sowing and found soil removal may reduce the number of emergent plants in the short term (Supplemental Fig. S3). Other researchers found

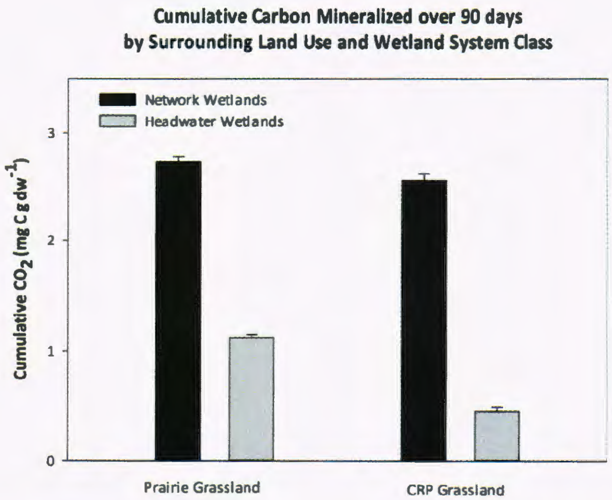


Fig. 3. Average (±SE) cumulative carbon mineralized over 90 d by land use and wetland system class. CRP, Conservation Reserve Program.

soil removal enhanced emergence of desirable hydric species as seedbanks of invasive species were removed (Dalrymple et al., 2003; Hausman et al., 2007; Beas et al., 2013). Here, the seedbank was dominated by native instead of invasive species, with similar species for all three depth layers (Supplemental Table S5). This result suggests removal of soil does not necessarily result in removal of invasive species from the seedbank. This short-term study should be followed up with additional work to determine if soil removal effects are detrimental or beneficial to PPR wetland ecosystems at longer time scales in the field, as suggested by Seabloom and van der Valk (2003).

Watershed characteristics such as catchment areas, drainage lines, and wetland position in the landscape indicate potential surface water connectivity and water retention (Gomi et al., 2002), with implications for water quality and flood control (National Research Council, 1995). Those wetlands with potential connectivity through higher-order drainage networks can easily be delineated from geographically isolated headwater wetlands (Tiner, 2003). Connectivity among network wetlands in the PPR is often intermittent and may only occur during high-rainfall years. However, network systems may be weighted more heavily than headwater systems in restoration projects because these are less limited by contributing area in the watershed. These types of maps (Fig. 2; Supplemental Fig. S1 and S2) can guide practitioners in a manner similar to aerial photographs by supporting more explicit evaluation of potential surface water connectivity and restoration potential in the context of both wetland surface flows and catchment areas. These maps can also be made more available to practitioners and producers using online resources (Eken and Phillips, 2015) to further benefit a wider audience.

This study aimed to broadly and simply address issues salient to practitioners currently involved in restoration projects in the PPR, with a particular emphasis on evaluating wetlands and wetland SOC in a watershed context (National Research Council, 1995). Removal of soil (and SOC) from these geologically young glacial wetlands in the PPR may have a greater impact on soil quality and subsequent plant re-establishment than removal of well-developed, deep soils heavily affected by agricultural tillage (Ahn and Dee, 2011). We did not find evidence that native seedbanks were dominated by weedy species or buried by redistribution of upland sediment into these wetlands. Instead, similar seedbanks were observed in organic and mineral soil horizons. Removal of SOC stocks will affect water holding capacity and nutrient retention (Doran et al., 1998), with unforeseen consequences on additional ecosystem functions. Other factors alter SOC stocks in the PPR that were not addressed here (Johnson et al., 2005; Johnston, 2014). Headwater wetlands were small and often geographically isolated (Tiner, 2003), so excavation could damage ecosystems critical for safeguarding rare and threatened species (Richardson et al., 2015). Results of this study point to the importance of evaluating PPR wetland SOC, SOC turnover, and restoration in a watershed context.

Conclusions

Catchment areas and potential surface flow connections among wetlands within a watershed cannot be reliably discerned at large spatial scales with field observations alone, yet these data are important to understanding the wetland ecosystem C cycle. Therefore, we suggest a framework for evaluating wetlands in a watershed context for large landscapes in the PPR. Maps can be applied to target wetlands with the highest probability of hydrologic restoration within the local watershed using modeled drainage network and catchment information. Data may also be used to weigh potential implications of soil removal during restoration on SOC and plant emergence. Depending on restoration goals, evaluation of seedbanks and watershed tools may improve restoration design to enhance wetland ecosystem services.

Acknowledgments

This work was supported by the USEPA (96814801) and by New Zealand's Program for Ecosystems and Global Change. The authors thank land owner Keith Trego; USEPA managers Cynthia Gonzales, Jim Luey, Jill Minter, and Richard Sumner; anonymous JEQ reviewers and JEQ Associate Editor Curtis Dell; and Moffatt Ngugi, Sarah Waldron, Allen Will, Adam Tollefsrud, Shawn DeKeyser, Mary Kay Tokach, Becky Mann, Rob Monette, and Bruce Smith for technical and administrative support.

References

Ahn, C., and S. Dee. 2011. Early development of plant community in a created mitigation wetland as affected by introduced hydrologic design elements. Ecol. Eng. 37:1324–1333. doi:10.1016/j.ecoleng.2011.03.019

Ahn, M., A.R. Zimmerman, N.B. Comerford, J.O. Sickman, and S. Grunwald. 2009. Carbon mineralization and labile organic carbon pools in the sandy soils of a North Florida watershed. Ecosystems 12:672–685 10.1007/s10021-009-9250-8.

Bai, J., L. Huang, Z. Gao, Q. Lu, J. Wang, and Q. Zhao. 2014. Soil seed banks and their germination responses to cadmium and salinity stresses in coastal wetlands affected by reclamation and urbanization based on indoor and outdoor experiments. J. Hazard. Mater. 280:295–303. doi:10.1016/j.jhazmat.2014.07.070

Ballantine, K., and R. Schneider. 2009. Fifty-five years of soil development in restored freshwater depressional wetlands. Ecol. Appl. 19:1467–1480. doi:10.1890/07-0588.1

Bantilan-Smith, M., G.L. Bruland, R.A. MacKenzie, A.R. Henry, and C.R. Ryder. 2009. A comparison of the vegetation and soils of natural, restored, and created coastal lowland wetlands in Hawai'i. Wetlands 29:1023–1035. doi:10.1672/08-127.1

Beas, B.J., L.M. Smith, K.R. Hickman, T.G. LaGrange, and R. Stutheit. 2013. Seed bank responses to wetland restoration: Do restored wetlands resemble reference conditions following sediment removal? Aquat. Bot. 108:7–15. doi:10.1016/j.aquabot.2013.02.002

Bedard-Haughn, A., A.L. Matson, and D.J. Pennock. 2006. Land use effects on gross nitrogen mineralization, nitrification, and N_2O emissions in ephemeral wetlands. Soil Biol. Biochem. 38:3398–3406.

Beeri, O., and R.L. Phillips. 2007. Tracking palustrine water seasonal and annual variability in agricultural wetland landscapes using Landsat from 1997 to 2005. Glob. Change Biol. 13:897–920. doi:10.1111/j.1365-2486.2006.01306.x

Beyersbergen, G., N. Niemuth, and M. Norton. 2004. Northern prairie and parkland waterbird conservation plan. Prairie Pothole Joint Venture, Denver, CO.

Bluemle, J.P. 1981. Geology of Sheridan County, North Dakota. In: North Dakota Geological Survey Bull 75, Part 1. Associated Printers Inc., Grand Forks, ND. p. 64.

Brinson, M. 1993. Changes in the functioning of wetlands along environmental gradients. Wetlands 13:65–74. doi:10.1007/BF03160866

Bruland, G.L., and C.J. Richardson. 2005. Spatial variability of soil properties in created, restored, and paired natural wetlands. Soil Sci. Soc. Am. J. 69:273–284. doi:10.2136/sssaj2005.0273

Cahill, K.N., C.J. Kucharik, and J.A. Foley. 2009. Prairie restoration and carbon sequestration: Difficulties quantifying C sources and sinks using a biometric approach. Ecol. Appl. 19:2185–2201. doi:10.2307/40346321

Dalrymple, G., R. Doren, N. O'Hare, M. Norland, and T.V. Armentano. 2003. Plant colonization after complete and partial removal of disturbed soils for wetland restoration of former agricultural fields in Everglades National Park. Wetlands 23:1015–1029. doi:10.1672/0277-5212(2003)023[1015:PCACAP]2.0.CO;2

Doran, J.W., E.T. Elliott, and K. Paustian. 1998. Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management. Soil Tillage Res. 49:3–18.

Eken, M.R., and R.L. Phillips. 2015. Catchments of the Prairie Pothole Region. Ecological Insights Corporation. www.ecologicalinsights.org/#!wetlands-research/chtx (accessed 19 May 2015).

Fennessy, S., and C. Craft. 2011. Agricultural conservation practices increase wetland ecosystem services in the Glaciated Interior Plains. Ecol. Appl. 21:S49–S64. doi:10.1890/09-0269.1

Franzluebbers, A.J. 1999. Potential C and N mineralization and microbial biomass from intact and increasingly disturbed soils of varying texture. Soil Biol. Biochem. 31:1083–1090.

Galatowitsch, S.M., and A.G. van der Valk. 1996. The vegetation of restored and natural prairie wetlands. Ecol. Appl. 6:102–112.

Gleason, R.A., N.H. Euliss, Jr., B.A. Tangen, M.K. Laubhan, and B.A. Browne. 2011. USDA conservation program and practice effects on wetland ecosystem services in the Prairie Pothole Region. Ecol. Appl. 21:S65–S81.

Gomi, T., R.C. Sidle, and J.S. Richardson. 2002. Understanding processes and downstream linkages of headwater systems. Bioscience 52:905–916.

Harris, J.A. 2003. Measurements of the soil microbial community for estimating the success of restoration. Eur. J. Soil Sci. 54:801–808.

Hausman, C.E., L.H. Fraser, M.W. Kershner, and F.A. De Szalay. 2007. Plant community establishment in a restored wetland: Effects of soil removal. Appl. Veg. Sci. 10:383–390.

Igl, L.D., and D.H. Johnson. 1997. Changes in breeding bird populations in North Dakota: 1967 to 1992-93. Auk 114:74–92.

Intermap. 2012. NEXTMap Americas data sheet. Intermap Technologies. http://cdn2.hubspot.net/hub/395294/file-1093123840-pdf/pdf/brochures/NEXTMap_Americas_Data_Sheet.pdf?t=1410548986322 (accessed 19 May 2015).

Intermap. 2015. NEXTMap digital terrain model. Intermap Technologies. www.intermap.com/hs-fs/hub/395294/file-2403758392-pdf/pdf/brochures/NEXTMap_Data_Sheet.pdf?t=1432050827086 (accessed 19 May 2015).

Johnson, W.C., B.V. Millett, T.G. Gilmanov, R.A. Voldseth, G.R. Guntenspergen, and D.E. Naugle. 2005. Vulnerability of northern prairie wetlands to climate change. Bioscience 55:863–872.

Johnston, C.A. 2014. Beaver pond effects on carbon storage in soils. Geoderma 213:371–378. doi:10.1016/j.geoderma.2013.08.025

Jordan, T.E., D.F. Whigham, K.H. Hofmockel, and M.A. Pittek. 2003. Nutrient and sediment removal by a restored wetland receiving agricultural runoff. J. Environ. Qual. 32:1534–1547. doi:10.2134/jeq2003.1534

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS system for mixed models. SAS Inst., Inc. Cary, NC.

Loeppert, R.H., and D.L. Suarez. 1996. Carbonate and gypsum. In: D.L. Sparks, editor, Methods of soil analysis. Part 3. Chemical methods. SSSA and ASA, Madison, WI. p. 437–474.

Luo, H., L.M. Smith, B.L. Allen, and D.A. Haukos. 1997. Effects of sedimentation on playa wetland volume. Ecol. Appl. 7:247–252. doi:10.1890/1051-0761(1997)007[0247:EOSOPW]2.0.CO;2

Marton, J.M., M.S. Fennessy, and C.B. Craft. 2014. Functional differences between natural and restored wetlands in the Glaciated Interior Plains. J. Environ. Qual. 43:409–417. doi:10.2134/jeq2013.04.0118

McCauley, L.A., and M.J. Anteau. 2014. Generating nested wetland catchments with readily-available digital elevation data may improve evaluations of land-use change on wetlands. Wetlands 34:1123–1132. doi:10.1007/s13157-014-0571-9

McLaughlan, K.K., and S.E. Hobbie. 2004. Comparison of labile soil organic matter fractionation techniques. Soil Sci. Soc. Am. J. 68:1616–1625.

Menne, M.J., C.N.J. Williams, and R.S. Vose. 2015. United States Historical Climatology Network. 2.5 serial monthly dataset edition. Oak Ridge National Laboratory Carbon Dioxide Information Analysis Center, Oakridge, TN. http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn.html (accessed 1 May 2015).

Mitsch, W.J., and J.G. Gosselink. 2007. Wetlands. Wiley, Hoboken, NJ.

Mooney, L., S. Cliffen, and B. Richardson. 2006. Verifying and validating the accuracy and quality of IFSAR-derived elevation models within an independent quality management system. MAPPS/ASPRS 2006 Fall Conference, 6–10 Nov. 2006, San Antonio, TX.

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In: D.L. Sparks, editor, Methods of soil analysis. Part 3. Chemical methods. SSSA, Madison, WI. p. 961–1010.

National Research Council. 1995. Wetlands: Characteristics and boundaries. National Academies Press, Washington, DC.

Niemuth, N., M. Estey, R. Reynolds, C. Loesch, and W. Meeks. 2006. Use of wetlands by spring-migrant shorebirds in agricultural landscapes of North Dakota's drift prairie. Wetlands 26:30–39. doi:10.1672/0277-5212(2006)26[30:UOWBSS]2.0.CO;2

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Ann. Assoc. Am. Geogr. 77:118–125.

Paustian, K., O. Andren, H.H. Janzen, R. Lal, P. Smith, G. Tian, et al. 1997. Agricultural soils as a sink to mitigate CO_2 emissions. Soil Use Manage. 13:230–244.

Phillips, R.L., M.R. Eken, and M.S. West. 2015. Soil organic carbon beneath croplands and re-established grasslands in the North Dakota Prairie Pothole region. Environ. Manage. 55:1191–1199. doi:10.1007/s00267-015-0459-3

Phillips, R.L., and O. Beeri. 2008. The role of hydropedologic vegetation zones in greenhouse gas emissions for agricultural wetland landscapes. Catena 72:386–394.

Phillips, R.L., O. Beeri, and E.S. DeKeyser. 2005. Remote wetland assessment for Missouri Coteau prairie glacial basins. Wetlands 25:325–339.

Phillips, R.L., D.L. Tanaka, D.W. Archer, and J.D. Hanson. 2009. Fertilizer application timing influences greenhouse gas fluxes over a growing season. J. Environ. Qual. 38:1569–1579. doi:10.2134/jeq2008.0483

Reicosky, D.C., W.A. Dugas, and H.A. Torbert. 1997. Tillage-induced soil carbon dioxide loss from different cropping systems. Soil Tillage Res. 41:105–118.

Richardson, S.J., R. Clayton, B.D. Rance, H. Broadbent, M.S. McGlone, and J.M. Wilmshurst. 2015. Small wetlands are critical for safeguarding rare and threatened plant species. Appl. Veg. Sci. 18:230–241. doi:10.1111/avsc.12144

Robel, R.J., J.N. Briggs, A.D. Dayton, and L.C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. J. Range Manage. 23:269–297.

Seabloom, E.W., and A.G. van der Valk. 2003. Plant diversity, composition, and Invasion of restored and natural Prairie Pothole wetlands: Implications for restoration. Wetlands 23:1–12.

Soil Survey Staff. 2008. Official soil series description. USDA, Washington, DC. www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/?cid=nrcs142p2_053587 (accessed 12 Dec. 2015).

Stewart, R.E., and H.A. Kantrud. 1971. Classification of natural ponds and lakes in the glaciated prairie region. Resource Publication No. 92. US Fish and Wildlife Service, Washington, DC.

Stewart, R.E., and H.A. Kantrud. 1973. Ecological distribution of breeding waterfowl populations in North Dakota. J. Wildl. Manage. 37:39–50.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Eos Trans. AGU 38:913–920. doi:10.1029/TR038i006p00913

Strong, L.L., T.H. Skebar, and K.E. Kermes. 2005. North Dakota gap analysis project. Northern Prairie Wildlife Research Center, USGS, Jamestown, ND.

Tarboton, D.G. 2005. Terrain analysis using digital elevation models (TauDEM). Utah State University, Salt Lake City, UT.

Tarboton, D.G., R.L. Bras, and I. Rodriguez-Iturbe. 1991. On the extraction of channel networks from digital elevation data. Hydrol. Processes 5:81–100.

Tiner, R.W. 1999. Wetland indicators: A guide to wetland identification, delineation, and mapping. Lewis, New York.

Tiner, R.W. 2003. Geographically isolated wetlands of the United States. Wetlands 23:494–516. doi:10.1672/0277-5212(2003)023[0494:GIWOTU]2.0.CO;2

US Department of Defense, USEPA. 2008. Compensatory mitigation for losses of aquatic resources: Final rule. Fed. Regist. 73:19593–19705.

USDA–FSA. 2012. Conservation programs. www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp (accessed 12 Dec. 2015).

USDA–NRCS. 2014. The plant database. National Plant Data Center, Baton Rouge, LA. http://plants.usda.gov (accessed 14 May 2015).

USEPA. 2015. Surf your watershed: Painted Woods-Square Butte watershed. http://cfpub.epa.gov/surf/huc.cfm?huc_code=10130101 (accessed 14 May 2015)

US Fish and Wildlife Service. 2015. National wetlands inventory. www.fws.gov/wetlands/NWI/index.html (accessed 14 May 2015).

van der Valk, A.G. 1989. Northern prairie wetlands. Iowa State Univ. Press, Ames, IA.

Winter, T.C., editor. 2003. Hydrological, chemical and biological characteristics of a prairie pothole wetland complex under highly variable climate conditions: The Cottonwood Lake area, East-central North Dakota. USGS, Washington, DC.

Zhang, L., B.K. Wylie, T. Loveland, E. Fosnight, L.L. Tieszen, L. Ji, et al. 2007. Evaluation and comparison of gross primary production estimates for the Northern Great Plains grasslands. Remote Sens. Environ. 106:173–189.

Wetland Soil Carbon in a Watershed Context for the Prairie Pothole Region

[1,3]Rebecca L. Phillips

[2]Cari Ficken

[3]Mikki Eken

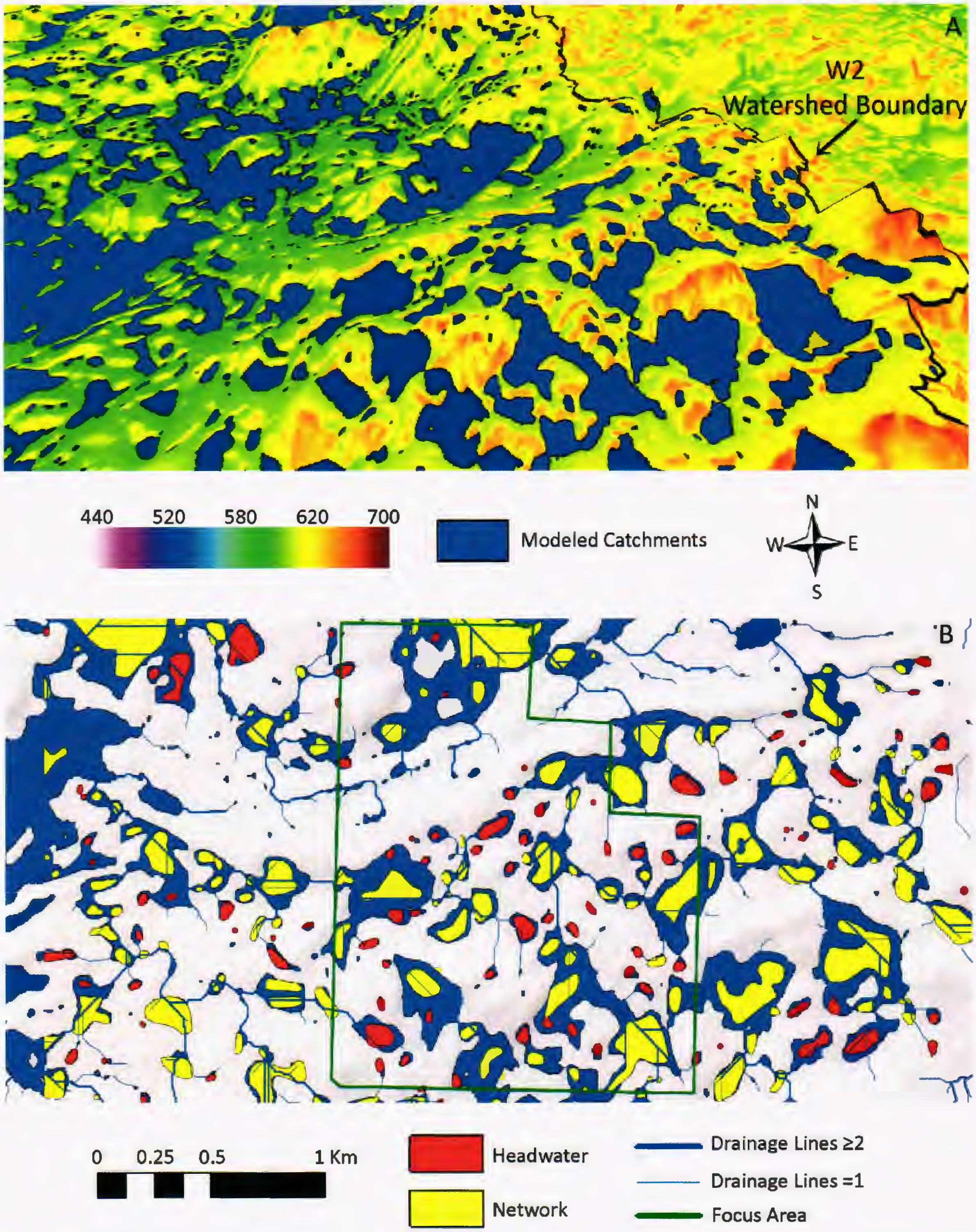
[4]John Hendrickson

[5]Ofer Beeri

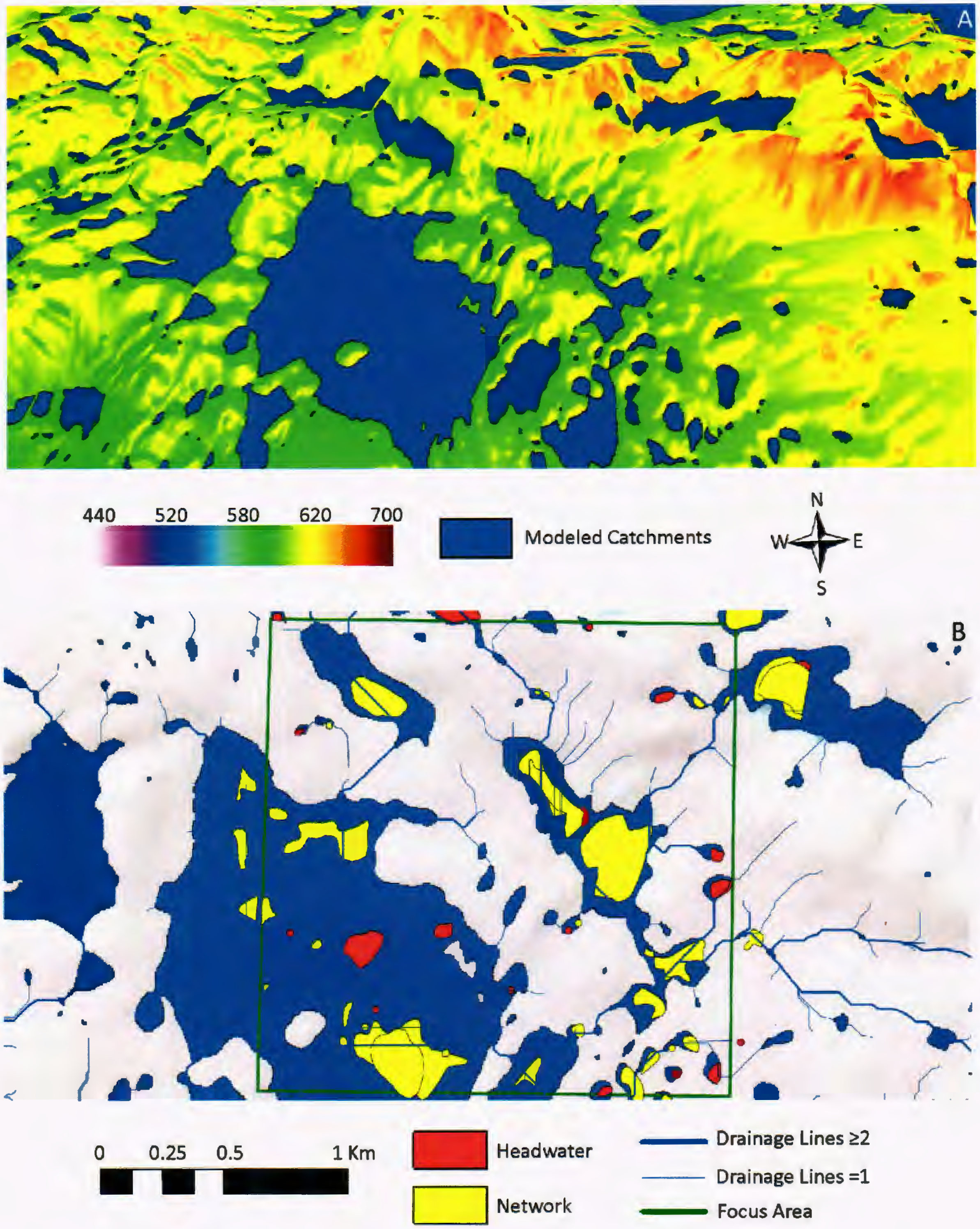
Supplemental Material

(5 pages, 3 figures, 2 tables)

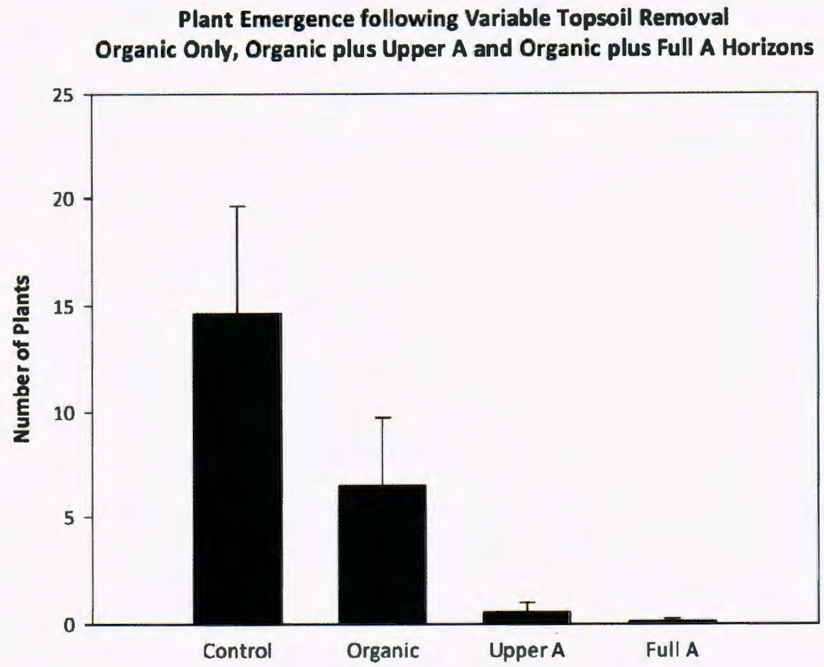
[1] Landcare Research, Gerald Street, Lincoln, New Zealand
[2] Duke University, Durham, North Carolina, USA
[3] Ecological Insights Corporation, Mandan, North Dakota, USA
[4] USDA-ARS, Northern Great Plains Research Laboratory, Mandan, North Dakota, USA
[5] University of North Dakota, Grand Forks, North Dakota, USA



S1. Manz focus area model output and classification (A) three dimensional view of topography with respect to modelled catchments and (B) classification of NWI wetlands into network (yellow) and headwater (red) systems depicted within modeled catchments (blue). Catchments shown in blue only in figure B were not co-located with wetlands.



S2. Buckmiller focus area model output and classification (A) three dimensional view of topography with respect to modelled catchments and (B) classification of NWI wetlands into network (yellow) and headwater (red) systems depicted within modeled catchments (blue). Catchments shown in blue only in figure B were not co-located with wetlands.



S3. Total number of plants that emerged following removal of soil, where O was removal of entire O horizon, ½ A was removal of the O and upper ½ of the A horizon, and A was removal of the entire O and A horizons. Differences among treatment were significant ($p<0.05$).

S4. Species observed following soil removal of intact core mesocosms. Soil horizons removed were: no removal (Control), upper layer including O horizon (O), upper layer including O and one-half of the A horizon (½A + O), and upper layer including entire A and O horizons (A + O).

Species Observed for Intact Cores following Soil Removal		Soil Horizon Removal Treatment			
Latin Name	Common Name	Control	O	½ A + O	A + O
Carex atherodes Spreng.	Wheat sedge	X	X		
Cirsium arvense (L.) Scop.	Canada thistle	X			
Eleocharis compressa Sull.	Flatstem spikerush		X		
Eleocharis obtuse (Willd.) Schult.	Blunt spikerush	X			
Juncus bufonius L.	Toad rush		X		
Poa compressa L.	Canada bluegrass	X	X	X	
Poa pratensis L.	Kentucky bluegrass	X			X
Ranunculus cymbalaria Pursh	Alkali buttercup		X		
Sonchus arvensis L.	Field sowthistle	X			
Triglochin palustris L.	Marsh arrowgrass	X	X		X
Veronica anagallis-aquatica L.	Water speedwell	X			
Artemisia absinthium L.	Absinthe wormwood	X			

S5. The 5 most frequently observed species in the seed bank, using soils removed from intact cores. Soil horizons removed were: O=organic only; ½A + O = O plus upper half of A horizon; A + O = O plus the entire A horizon. Soil removal experiment material was used to here to identify seedbanks. Control cores were not subjected to soil removal but remained intact; consequently, these were not included.

		Soil Horizon Removed		
Latin Name	Common Name	O	½ A + O	A + O
Potentilla norvegica L.	Norwegian cinquefoil	X	X	X
Eleocharis compressa Sull.	Flatstem spikerush	X	X	X
Eleocharis acicularis (L.) Roem. & Schult.	Needle spikerush	X		
Juncus bufonius L.	Toad rush	X	X	X
Triglochin palustris L.	Marsh arrowgrass	X	X	X
Juncus interior Wiegand	Inland Rush		X	X