Status and Trends of Wetlands in Minnesota: Vegetation Quality Baseline

Minnesota Pollution Control Agency

September 2015

Primary author

Michael Bourdaghs

Contributors

John Genet
Mark Gernes
Emily Peters

Acknowledgements

To say that this survey was a large and wide-ranging effort is a bit of an understatement. A multitude of people and organizations contributed to this project.

Many past and present Minnesota Pollution Control Agency personnel (beyond the above co-authors) worked on this. Josh Horky and Sara Wescott served as sampling crew leaders. Matt Summers was our National Wetland Condition Assessment soils technician, buffer team lead, and logistics coordinator. Emma Ziebarth, Andrew Grean, Alida Mau, Mary Jenc, Cody Dieterle and Harold Wiegner provided field sampling assistance. Geographic Information System support was provided by Shawn Nelson and Kris Parson. Finally, Dan Helwig (supervisor of the South Biological Monitoring Unit) provided steady guidance throughout the execution of the project.

Likewise, there were many external contributors. Michael Scozzafava and Gregg Serenbetz from U.S. Environmental Protection Agency (EPA) Water Division, Washington, DC coordinated the NWCA and worked tirelessly to help get our intensification survey off the ground. Tony Olsen from EPA Office of Research Development, Corvallis, OR provided the survey design and statistical analysis assistance. Supplemental soils training and use of a peat auger (aka "big peat") was provided by Michael Whited at the Natural Resources Conservation Service (NRCS) Soil Survey. Trooper Dave Latt, at the Minnesota Department of Public Safety, expertly piloted field crews via helicopter to some of the most remote areas in the state. Helicopter logistics assistance was provided by Matt Nelson. Plant voucher specimens were identified by Dr. Anita Cholewa at the University of Minnesota Bell Museum Herbarium. Rhett Johnson (formerly) from the Nature Conservancy provided field assistance at two sites in the Agassiz National Wildlife Refuge.

Survey sites were located on all manner of public lands, which included: the Chippewa and Superior National Forests; Boundary Waters Canoe Area Wilderness; Upper Mississippi and Agassiz National Wildlife Refuges (thanks to Ashley Hitt for the airboat ride); Lamprecht, Boyer Lake, & Larson Waterfowl Production Areas; Savanna Portage State Park; Red Lake, East Rat Root River, Mulligan Lake, Myrtle Lake, and Gully Fen State Scientific and Natural Areas; Koochiching, Beltrami Island, Savanna, Pine Island, Sturgeon River and Fond Du Lac State Forests; Bejou, Elm Lake, Altona, Carlos Avery, Lac Qui Parle, Expandere, Twin Valley, Eckvoll, and Swan Lake State Wildlife Management Areas; county land in a number of different counties; and the Three Rivers Park District. Thanks to all of the managers that helped facilitate access on these lands.

Minnesota Pollution Control Agency

520 Lafayette Road North | Saint Paul, MN 55155-4194 |

651-296-6300 | 800-657-3864 | Or use your preferred relay service. | Info.pca@state.mn.us

This report is available in alternative formats upon request, and online at www.pca.state.mn.us

Document number: wq-bwm-1-09

Thanks also to the White Earth and Red Lake Nations (special thanks to Kyle Hanson and Vince Graves for the Argo ride) for allowing us to sample wetlands within your boundaries.

Finally, thanks to all of the private landowners that allowed access on their property.

Funding

Primary funding for this project was provided by the U.S. Environmental Protection Agency (EPA) through a section 106 grant (EPA Assistance Number: I 00E78502-2). This report has not been subjected to EPA's peer or administrative review process.

Citation

Minnesota Pollution Control Agency 2015. Status and Trends of Wetlands in Minnesota: Vegetation Quality Baseline.wq-bwm-1-09 Minnesota Pollution Control Agency, St. Paul, MN

Cover photo

A streamlined tree island within an extensive rich fen water-track—Mulligan Lake Peatland Scientific & Natural Area, Lake of the Woods County.

Contents

Figures

Tables

Executive summary

To protect wetlands, both the United States (U.S.) federal government and the state of Minnesota have adopted a broad policy goal to achieve no-net-loss and promote increases in the quantity, quality, and biological diversity of wetlands. As no-net-loss is advanced through a variety of regulatory and non-regulatory programs at many levels of government, targeted monitoring efforts are required to determine whether policy goals are being met. To do so, Minnesota has initiated several random surveys to measure the status and trends of both wetland quantity and quality.

The Minnesota Department of Natural Resources (MDNR) is the lead agency for the quantity survey and currently estimates 10.62 million wetland acres in the state. The Minnesota Pollution Control Agency (MPCA) is responsible for measuring wetland quality, initially focusing on depressional marshes and ponds. Baseline depressional wetland quality for 2007-09 was predominately low based on vegetation but high for macroinvertebrates throughout the state—with better quality for both assemblages in the northern forest region, compared to more degraded quality in the hardwood forest and former prairie regions of Minnesota.

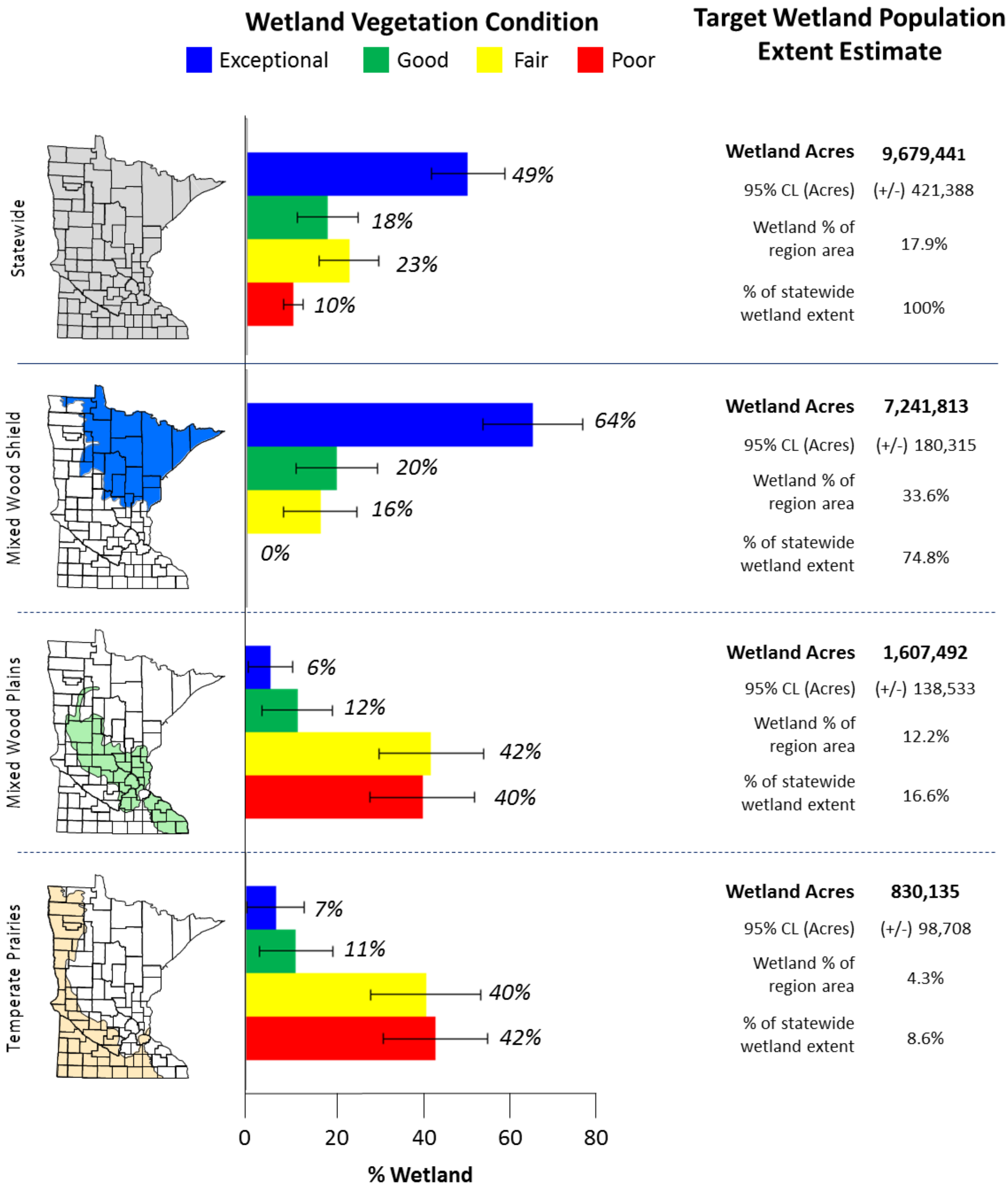
The effort presented here—called the Minnesota Wetland Condition Assessment (MWCA)—was initiated to broaden wetland quality status and trends monitoring beyond depressional wetlands. Our goal was to establish a current baseline quality of virtually all of Minnesota's wetlands at statewide and regional scales, and begin to quantify the potential human impacts that may be associated with degraded conditions.

Our primary indicator was vegetation condition (i.e., the deviation of a plant community from a minimally impacted state). Vegetation surveys were conducted in 2011-12 at 150 randomly selected points that were allocated (more or less) evenly between three major ecoregions: Mixed Wood Shield (northern forest), Mixed Wood Plains (hardwood forest), and Temperate Prairies (former prairie). A Floristic Quality Assessment (FQA) approach, calibrated to four condition categories (exceptional, good, fair, poor), was used to express wetland vegetation condition for each site. A categorical Human Disturbance Assessment (HDA) was also completed at each site to describe the exposure of wetlands to human impacts (i.e., stressors). Vegetation condition and stressor estimates were then made at statewide and ecoregion scales—expressed in terms of the proportion of wetland extent, not the number of wetlands.

Overall, Minnesota's wetland vegetation quality is high (*see figure on next page*). Approximately 49% of Minnesota's wetlands are in exceptional condition. Exceptional condition is considered to have plant species composition and structure consistent with sites where human impacts have had no measurable effect on the vegetation—representing pre-European settlement conditions. An additional 18% are in good condition, where composition and structure is similar to natural communities. The remaining shares of Minnesota's wetlands are at 23% fair and 10% poor condition. Both of these categories characterize degrees of wetland vegetation degradation—with poor representing large to extreme changes in plant composition and structure, including the wholesale conversion of a plant community and/or replacement of native species by non-native invasive species.

However, wetland vegetation quality varies widely in different parts of the state (*see figure*). In the Mixed Wood Shield ecoregion, wetland vegetation is predominantly in exceptional to good condition. The exact opposite is true in both the Mixed Wood Plains and Temperate Prairies ecoregions—where > 80% of the wetland extent is in fair or poor condition.

These regional differences explain (to a large degree) the statewide results**. As approximately 75% of Minnesota's wetlands occur in the Mixed Wood Shield ecoregion, the high levels of good to exceptional condition found there drives the statewide results. This largely masks the smaller wetland extent—but widespread degraded conditions—found in the Mixed Wood Plains and Temperate Prairies.**



Wetland vegetation condition category proportion and extent estimates statewide and by ecoregion.

Minnesota's wetlands are correspondingly exposed to low rates of stressors overall. Sixty-two percent are minimally impacted with 19% moderately impacted and 19% severely impacted as expressed by the aggregated HDA.

As with wetland condition, stressor exposure rates vary widely by ecoregion. In the Mixed Wood Shield, 80% of wetlands are minimally impacted. Stressors are much more widespread in the Mixed Wood Plains and Temperate Prairies, where over 90% of the wetlands are moderately to severely impacted.

Non-native invasive plants is the most widespread type of wetland vegetation stressor—occurring at a severe level at approximately 60% of the wetlands in the Mixed Wood Plains and Temperate Prairies ecoregions. The most damaging non-native invasive species typically can tolerate a broad range of anthropogenic impacts, reproduce clonally, and out-compete native vegetation to form dense monocultures. All of the independent stressors considered in the HDA (surrounding landscape alterations, hydrological alterations, and physical alterations) are strongly associated with high abundance of non-native invasives. Non-native invasive abundance is also high at a modest share of wetlands when other stressors are currently low or absent.

Our findings suggest that stressors tend to co-occur, but that it is the non-native invasive species—by increasing in abundance and ultimately replacing native species—that are the primary drivers of vegetation community change at degraded wetlands.

Emergent wetlands are the most affected wetland type. Approximately 50% of the total vegetative cover of the Shallow Marsh community type in Minnesota (which covers an estimated 1.2 million acres) is comprised of non-native species. Similarly, 35% of the total cover of Fresh Meadows is comprised of non-native species.

Invasive *Typha* (Cattails) and *Phalaris arundinacea* (Reed canary grass) are the non-native invasives that are having the greatest impact. Shallow Marshes are the optimal habitat for invasive *Typha*; whereas, *Phalaris* reaches its greatest abundance in Fresh Meadow communities.

In addition to the non-native invasive species and generalized HDA stressor estimates, we also generated estimates of the wetland extent that had at one time been plowed for agricultural production, but has now been abandoned (or restored) and allowed to re-populate with hydrophytic vegetation. Approximately 14% of the wetland extent in the Mixed Wood Plains and 16% in the Temperate Prairies have been prior plowed. The probability of a poor condition in prior plowed wetlands is 0.84, primarily due to abundant non-native invasive species. **This suggests that if wetlands are converted to agricultural production and are subsequently left to revert back (or passively restored) to hydrophytic vegetation—it is very likely that they will yield poor vegetation quality.** This is a relevant finding given that MDNR has found a significant conversion of emergent wetlands to cultivated wetlands between 2006 and 2011.

Ultimately, a greater emphasis on protection would be an appropriate approach to further promote the no-net-loss of wetland quality and biological diversity of Minnesota's wetlands. The plant community changes that occur (i.e., increased abundance of non-native invasive species) when wetlands are exposed to virtually any variety of impact are typically not self-correcting. Direct management of the vegetation itself is often required—in addition to correcting external impacts—to reestablish native composition and abundance distributions. Enhancing degraded wetland plant communities is typically time consuming and requires a significant financial investment.

The MPCA intends to continue the MWCA survey to monitor wetland quality trends on a 5-year rotation, with the next iteration of field sampling scheduled to begin in 2016.

Introduction

Wetlands are a vital component of Minnesota's water resources that provide a number of beneficial ecosystem services. Wetlands help regulate stream flow in watersheds—supporting source water and baseflow for many of Minnesota's streams, as well as absorbing peak flows and reducing flooding at lower watershed positions (Acerman and Holden 2013). Due to the unique hydrologic conditions present in wetlands, water quality downstream of wetlands is often improved through sediment retention and biogeochemical transformation (Johnston 1991, Mitsch and Gosselink 2000). Numerous plants and animals also depend on wetlands for their habitat.

As Minnesota was settled and developed, approximately half of the historical wetlands and the services they provided were lost to draining and filling (Anderson and Craig 1984). To protect wetlands, both the U.S. federal government and the state of Minnesota have adopted a broad policy goal to achieve no-net-loss and promote increases in the quantity, quality, and biological diversity of wetlands.

No-net-loss is advanced through a number of regulatory and non-regulatory programs administered by a variety of federal and state agencies, as well as local governments. While programmatic outcomes can be tracked, there are many exempt activities, natural processes, and other indirect influences (e.g., climate change) that can lead to losses or gains in wetland acreage. Furthermore, wetland quality and biological diversity can be impacted by a variety of human activities (Adamus et al. 2001) that have—until somewhat recently—gone largely unrecognized. Because of this, it is impossible to determine whether the no-net-loss goal is being met without targeted monitoring efforts.

To begin to address this need, a Comprehensive Wetland Assessment, Monitoring, and Mapping Strategy (CWAMMS) (Gernes and Norris 2006) was developed by state and federal agencies responsible for wetland regulation and management in Minnesota. Primary CWAMMS recommendations included: updating National Wetland Inventory (NWI) maps; improving regulatory and conservation program tracking and reporting; and the development of random (or probabilistic) surveys that could reliably track the overall status and trends of wetland quantity and quality in Minnesota.

In 2006, the MDNR initiated the wetland quantity survey modeled after the U.S. Fish and Wildlife Service's National Wetland Status and Trends Program (Frayer et al. 1983). The quantity survey consists of repeated aerial photo-interpretation and wetland mapping at approximately 5,000 randomly selected 1 mi^2 plots on a 3-year rotation to provide statistically valid wetland extent estimates at statewide and regional scales (Kloiber et al. 2012). The first cycle of the survey (2006-08) established the Minnesota baseline at 10.62 (± 0.363) million wetland acres (Kloiber 2010). A very small (but statistically significant) estimated statewide increase of 2,080 acres was detected during the second iteration of the survey (2009-11; Kloiber and Norris 2013), indicating that the no-net-loss policy goal was met in terms of wetland quantity during this short time period. While these results were encouraging, most of the observed gains in wetland acreage were in the form of open water ponds and an estimated 1,890 acres of emergent wetlands were also converted to cultivated wetlands. Both open water pond and cultivated wetlands have a limited ability to support natural biological communities and, thereby, likely represent a loss of wetland quality (Kloiber and Norris 2013). These observations were consistent with national scale results that show no significant change in wetland acreage during the last reporting cycle (2004-09), but an observable conversion of vegetated wetlands to created ponds (Dahl 2011).

The MPCA is responsible for leading wetland quality status and trends monitoring. The initial focus has been a statewide and regional survey of depressional wetland condition using vegetation and macroinvertebrate Indices of Biological Integrity (IBIs; Genet 2007). The MPCA defines depressional wetlands as wetlands occurring within a distinct basin in the landscape that have marsh type vegetation and an area of permanent to semi-permanent open water present (e.g., prairie potholes). Baseline depressional wetland conditions were established from the first iteration of the survey completed in 2007-09 (Genet 2012). On a statewide basis, the vegetation in almost half (46%) of Minnesota's depressional wetland basins was in poor condition: with 25% in fair and 29% in good condition. Macroinvertebrates were in relatively better condition at the statewide-scale: with 47% of depressional basins in good condition, 33% fair and 20% poor condition. Both vegetation and macroinvertebrate condition varied regionally—with higher proportions of good condition observed in north-central and northeastern Minnesota compared to more degraded conditions in the more developed western and southern portions of the state. A second iteration of the depressional survey was initiated in 2012 and preliminary results indicate that there were few changes from the baseline condition estimates (Genet *in prep*).

While depressional wetlands are an important and iconic part of Minnesota's wetland resource—they represent only a small portion of the total wetland acreage in the state. The MPCA estimates that there are 158,435 (± 19,367) depressional wetland basins in Minnesota, totaling 674,085 (± 73,937) acres (Genet 2012). This comprises roughly 6.3% of the statewide wetland extent.

The effort presented here—called the MWCA—was initiated to broaden wetland quality status and trends monitoring beyond depressional wetlands. The MWCA was modeled after (and done in conjunction with) the U.S. Environmental Protection Agency's (EPA) National Wetland Condition Assessment (Scozzafava et al. 2011). Our overall goal with this initial iteration of the MWCA is to provide an estimate of the current baseline condition of virtually all of Minnesota's wetlands. Future MWCA cycles will be used to detect changes in condition going forward, which will contribute to a more complete determination of whether the no-net-loss policy goal is being met in Minnesota.

Assessing wetland quality

A number of wetland quality assessment approaches have been developed and refined since the adoption of the no-net-loss policy. Two broad divisions have emerged depending on whether quality is assessed based on a functional perspective (i.e., the goods and services wetlands provide) or a condition perspective (i.e., the deviation of a wetland from a minimally human impacted state). Functional assessment grew in response to Clean Water Act (CWA) section 404 requirements applied to regulated filling activities and administered by the U.S. Army Corps of Engineers (USACE). Condition assessment has been developed to meet water quality and biocriteria requirements specified by sections 303, 304, 305(b) and 319 of the CWA, administered by the (EPA). These two approaches have been viewed as being unrelated or competing, but the two often rely on many of the same concepts and are likely complimentary (Stevenson and Hauer 2002). For example, the Hydrogeomorphic (HGM) approach to functional assessment conceptualizes overall wetland function as a hierarchy with ecological integrity (i.e., condition) at the highest level that encompasses the structural components and processes in a wetland ecosystem (Smith et al. 1995). This construct assumes that wetland functions are linked to condition, where a wetland is maintaining its appropriate sustainable level of function when ecological condition is high. Similarly, biological condition assessment approaches assume that when species composition and abundance distributions are similar to reference conditions, functional integrity is also maintained (Karr and Dudley 1981, Stevenson and Hauer 2002).

The primary focus of the MWCA is to assess wetland quality based on vegetation condition. Plant species adapted to the wetland environment are a defining feature of wetlands. In addition, vegetation patterns are obvious features that can be mapped; vegetation sampling methods are well developed and low-tech; and vegetation based assessment approaches are well established (Mack and Kentula 2010). The MPCA has extensive experience developing wetland vegetation condition assessment approaches, beginning with IBIs for depressional wetlands (Gernes and Helgen 2002, Genet and Bourdaghs 2006, Genet and Bourdaghs 2007). More recently, we have focused on an alternative approach called FQA.

The FQA is an ecological condition assessment approach that has increasingly been used for wetland monitoring and assessment. FQA is based on the Coefficient of Conservatism (*C*), which is a numerical rating (0 – 10) of an individual plant species' fidelity to specific habitats and tolerance of disturbance—natural or anthropogenic (Swink and Wilhelm 1994; Taft et al. 1997). Species that have narrow habitat requirements and/or little tolerance to disturbance have high *C*-values and vice versa. *C*-values are typically assigned for state or regional floras by a group of local botanical experts using consistent guidance and relying on best professional judgment, and have been developed for Minnesota's wetland flora (Milburn et al. 2007). FQA metrics are derived from on-site vegetation sampling data and the C-values. They have repeatedly been found to be responsive and reliable wetland condition indicators (Lopez and Fennessy 2002, Cohen et al. 2004, Mack 2004, Bourdaghs et al. 2006, Miller and Wardrop 2006, Rocchio 2007, Milburn et al. 2007, Bourdaghs 2012) and one of the most frequently used class of metrics in wetland vegetation based monitoring and assessment methods (Mack and Kentula 2010). The MPCA has developed the FQA to assess all of Minnesota's wetland types (Bourdaghs 2012).

Methods

Scope of survey, target wetland population, and sample frame

The primary goal of the MWCA is to describe wetland vegetation conditions statewide and by major ecoregions using a probabilistic sampling design. A probabilistic design simply refers to a random selection of a small set of wetlands that can be used to derive unbiased estimates (± a margin of error) of the population of wetlands, similar to an opinion or political poll. Secondary goals include: describing wetland condition by different wetland types; quantifying the potential human impacts that may be associated with degraded condition; and increasing the basic understanding of surface water chemistry in Minnesota's wetlands.

Three widely recognized ecoregions (i.e., broad areas that contain geographically characteristic/distinct assemblages of natural communities and species) occur in Minnesota. They are generally described as: northern forest, hardwood forest, and former prairie. Both wetland quantity (Kloiber 2010) and quality (Genet 2012) are known to vary significantly by ecoregion in the state, so it was important to account for that variability in the MWCA survey design. The MWCA adopted the most recent version of Omernik's level II ecoregions of Minnesota (White and Omernik 2007) as a geographic framework. Three level II ecoregions occur in the state and are described as follows (Figure 1):

- ***Mixed Wood Shield:*** Covering the northeast and north-central areas of the state, the Mixed Wood Shield is characterized by a mix of conifer and hardwood forests. Agricultural and urban development is very low compared to the rest of the state, with forestry and mining as top industries. Wetlands are extensive in the region, with counties retaining an estimated 92% of pre-settlement wetland acreage on average (Anderson and Craig 1984).

  Mixed Wood Plains: This ecoregion occupies a central transitional zone between the drier/warmer prairies to the south and west and the wetter/cooler forests found in the Mixed Wood Shield. Historically, much of the ecoregion was covered by hardwood

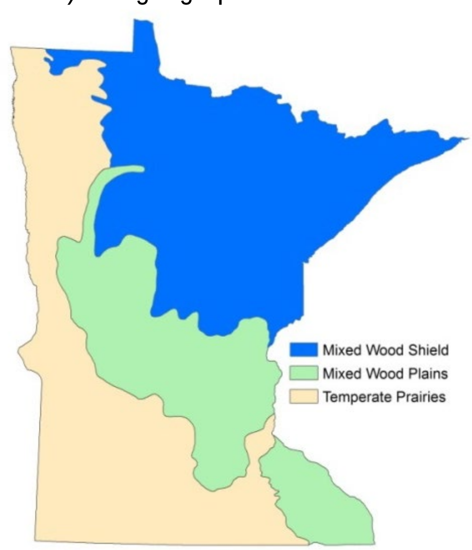


Figure 1. Level II Omernik ecoregions

forests (oak/maple/basswood). Currently, agricultural development is widespread and the majority of Minnesota's population is concentrated here. The remaining pre-settlement wetland acreage is much lower compared to the Mixed Wood Shield, with counties retaining approximately 40% on average.

- ***Temperate Prairies:*** Once covered by tallgrass prairie, oak savanna (southeast), and aspen parkland (northwest)—the Temperate Prairies ecoregion is now predominantly developed for agricultural production. Concomitantly, artificial drainage is widespread with counties averaging approximately 5% of pre-settlement wetland acres in the ecoregion.

The MWCA target population was defined as: all wetlands with < 1 meter (m) depth of surface water that are not actively being cultivated. This includes virtually all wetlands in Minnesota, essentially capturing the wetlands that can be safely sampled on foot that are not currently plowed. Regulatory jurisdictional status (state or federal) did not factor in the target population definition. This definition was consistent with the NWCA target population (EPA 2011a, EPA 2011b).

Probabilistic natural resource surveys require a sample frame that represents the target population (i.e., wetland map) from which to draw the random sampling locations. Due to the inaccuracies of the existing statewide National Wetlands Inventory (NWI; Cowardin et al. 1979) that is outdated for Minnesota, the MWCA utilized the wetland maps produced for the 1st iteration of the MDNR quantity survey (Kloiber 2010) as the sample frame. For the MDNR survey, wetlands were mapped within randomly located 1-mi2 plots using aerial photo-interpretation from images acquired from 2006-08 (Figure 2). The MWCA utilized the 4,740 "panel" MDNR plots for the sample frame, excluding the 250 "common plots" where images were acquired and interpreted all three years of the quantity survey iteration primarily as a quality control measure. Wetland polygons with the "Artificially Flooded-af" modifier—where inundation is artificially manipulated (e.g., treatment/tailings/aquaculture ponds)—were excluded from the sample frame as there is no intention for these to serve as natural waters. The sample frame included the "Cultivated Wetland" class even though cultivated wetlands were not part of the target population. This was done to allow for the possible inclusion of wetlands mapped as cultivated in error or which were not actively being cultivated during the site evaluation.

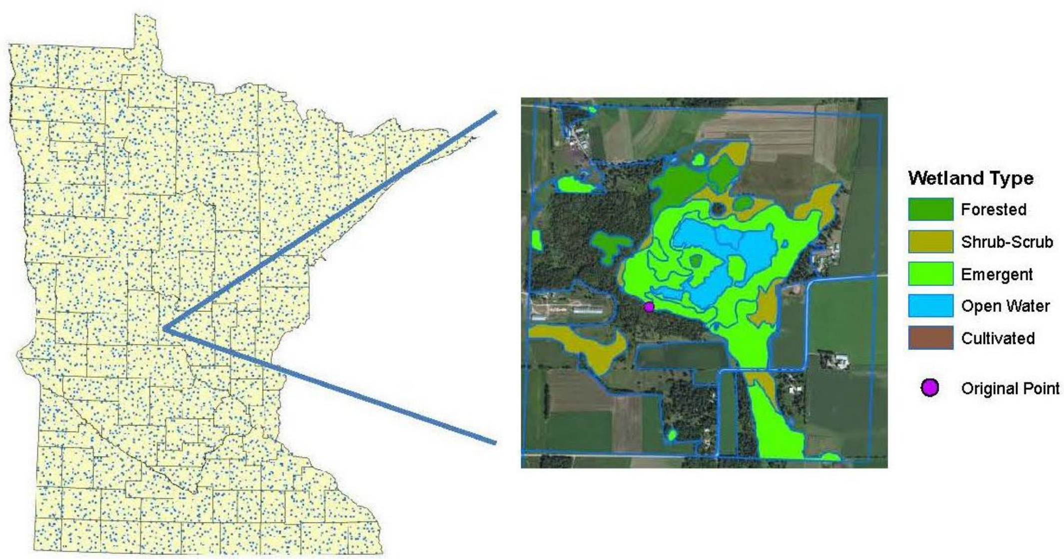


Figure 2. MDNR quantity survey plot locations and a close-up of an individual plot with mapped wetlands.

In this way, the sample frame population was slightly different than both the quantity results reported by the MDNR (Kloiber 2010) and the estimated MWCA target population. The sample frame population was estimated at ecoregion and statewide scales following the same approach as the MDNR (Kloiber 2012). Proportional wetland area was first tabulated for each plot. Plot means, variances, and 95%

confidence intervals were then calculated and multiplied to scale. The statewide estimated extent of the sample frame population was 10.47 (±0.371) million wetland acres (Figure 3). This total was smaller than the MDNR reported total of 10.62 (±0.363) million acres for the same time period (Kloiber 2010) but the difference wasn't significant as the confidence intervals of both estimates overlap. Again, some differences were expected given the exclusion of the common plots and the Artificially Flooded polygons from the MWCA sample frame. There were also differences due to different statewide base maps used for extrapolations (MDNR state area = 84,382 mi2, MPCA state area = 84,448 mi2).

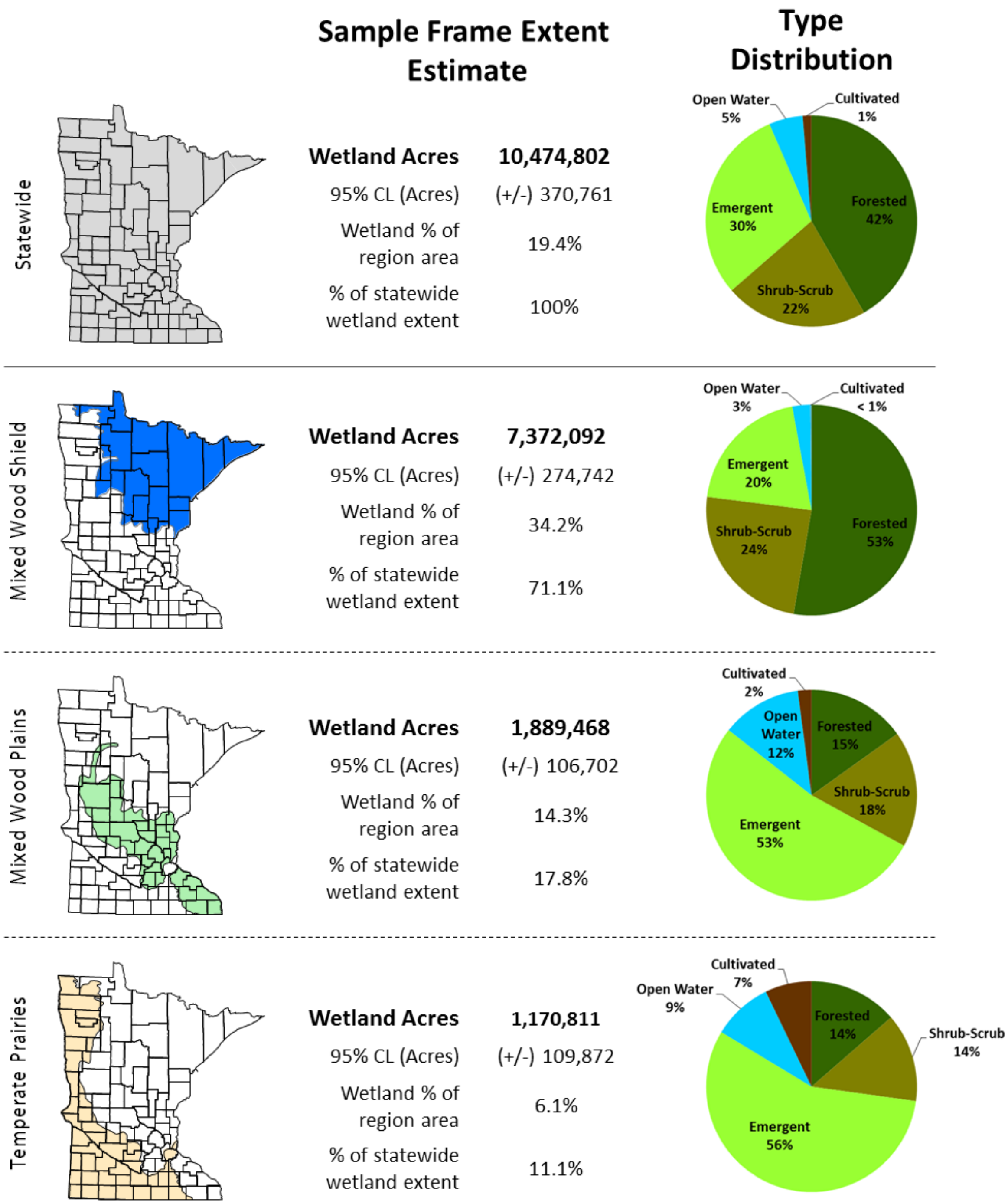


Figure 3. MWCA sample frame extent estimates and wetland type distribution at statewide and regional scales.

The sample frame wetland extent estimates (Figure 3) do provide important context as they are the first estimates reported at the Omernik level II ecoregion scale for Minnesota. Wetlands cover approximately 19.4% of the state. The majority of the wetlands (71.1%) occur in the Mixed Wood Shield ecoregion where much of the landscape is undeveloped. The remainder of the state—where agricultural and urban development are widespread and there have been corresponding wetland losses due to drainage/filling—has a much lower share of the wetland resource with 17.8% in the Mixed Wood Plains and 11.1% in the Temperate Prairies ecoregions. There are also important regional differences in wetland types where the predominant types in the Mixed Wood Shield are Forested (53%) and Scrub-Shrub (24%); whereas, Emergent wetlands are the predominant type in the Mixed Wood Plains (53%) and Temperate Prairies (56%).

Survey design

The MWCA survey design relied on a number of well-established natural resource survey elements. As the MDNR quantity survey mapping served as the sample frame to select random wetland points to measure quality—the MWCA was considered to have a two-phase sample design (i.e., sample of a sample)—where MDNR plots were the phase 1 sample and the random points drawn from the sample frame were phase 2. Both the phase 1 and 2 sample selections employed a Generalized Random Tessellation Stratified (GRTS) design to ensure spatial distribution at statewide and ecoregional scales (Stevens and Olsen 2004). As wetlands have a wide range of sizes and it is often difficult to define them as individual water-bodies, the target population was treated as an extensive (or continuous) resource and results were expressed in terms of the total target population area for a given region. This was in contrast to the depressional wetland quality survey where depressional wetland basins were easier to define and results were primarily reported in terms of numbers of basins (Genet 2012). Unequal probability weighting was used to allocate sample points by ecoregion, as opposed to pre-stratification. The design weights were calculated by taking the inverse of the target number of sample points divided by the measured sample frame wetland area for an ecoregion. The total sampling target was 150 points statewide with 50 in each of the three ecoregions (Figure 1).

This approach was done in conjunction with the EPA's NWCA sample draw (e.g., two-phase design, extensive resource, GRTS, unequal probability weighting) with the first 22 target sampled points serving as Minnesota's allocation of NWCA points. The sample draw (150 targeted base points with 150 oversample points to replace rejected points) was provided by the EPA National Health and Environmental Effects Research Laboratory, Corvallis, Oregon.

Site evaluation and assessment area establishment

Prior to field sampling, drawn points had to be evaluated to determine whether 1) they were located within target wetland; 2) an Assessment Area (AA—the area being characterized by the field sampling) could be effectively established; and 3) access permission could be obtained. NWCA site evaluation protocols (EPA 2011a) were followed and are briefly described here.

The first phase of the process consisted of a desktop evaluation. Aerial photography, sample frame, NWI, topographic, and soil survey maps were reviewed to evaluate the likelihood that the point was actually located on target wetland. Where there was conclusive evidence that points fell on: upland, non-target wetland (e.g., cultivated wetland, steep-narrow ditches), or deep-water habitat and there was no apparent target wetland within 60 m—the points were rejected based solely on the desktop evaluation. Where there was evidence that points were located on or within 60 m of target wetland, the target wetland area surrounding the point was evaluated for AA establishment. The standard AA was a 0.5 ha circle with a 40 m radius (Table 1, Figure 4A). In cases where points were located too close to upland or non-target boundaries (< 40 m) or the target wetland area present did not otherwise allow for establishing a standard AA, alternate AA layouts were employed (Table 1, Figure 4B-D). Preliminary AAs were established using a Geographic Information System (GIS) for points that had not been rejected. Preliminary center and corner GPS coordinates for alternate AA layouts were then derived from the GIS coverage to aid AA establishment in the field.

Table 1. Assessment Area (AA) types and descriptions.

AA Category	Description
Standard AA	0.5 ha circular plot (40 m radius) centered on the Point
Standard AA-Shifted	0.5 ha circular plot (40 m radius) but the Point is not the AA Center–used when a 0.5 ha circular plot can be established but the Point is < 40 m away from unsampleable area
Polygon AA	Established when sampleable area is > 0.5 ha but has dimensions < 80 m in at least one direction
Wetland Boundary AA	AA boundary coincides with the wetland boundary–established when sampleable area is 0.1-0.5 ha

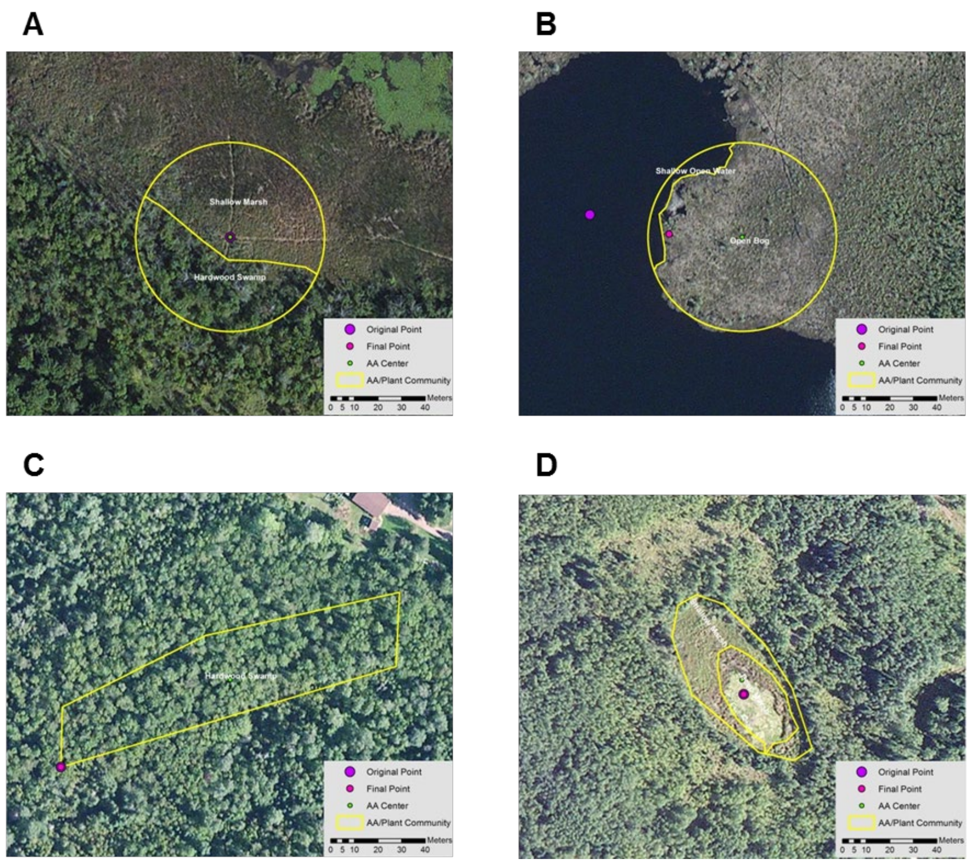


Figure 4. Example AA layouts with Points, AA Centers, and plant community mapping. A) Standard AA: where the Point was the AA Center. B) Standard AA-Shifted: where the original Point was located in non-target wetland (water depth > 1m). The Point was shifted to target wetland, and the AA Center was established to include predominately target wetland in the AA. C) Polygon AA: where the wetland feature was narrow and did not allow for the establishment of a Standard AA. D) Wetland Boundary AA: the size of the wetland basin was < 0.5 ha.

Land ownership information was also obtained and access permission requests were initiated during desktop evaluation. Requests to private landowners and managers of public lands were done by phone, email, and direct mailings. If landowners/managers were un-responsive to these solicitations, a single in-person request was made at their home or office while in the area field sampling. Points were rejected if access permission was not granted.

The final field evaluations largely consisted of verifying desktop evaluations, which in many cases were correct and greatly expedited the process. Potential points were located in the field using a handheld GPS. An on-the-ground determination of the presence of target wetland was made at the point and the preliminary AA was verified. In cases where actual conditions were different than what was interpreted during the desktop evaluation, point shifting and/or AA adjustment (Figure 4A-D) was completed in the field to conform to NWCA AA establishment protocols (EPA 2011a). In cases where shifting/adjusting could not be made (e.g., target wetland > 60 m from point or AA could not be established) the points were rejected.

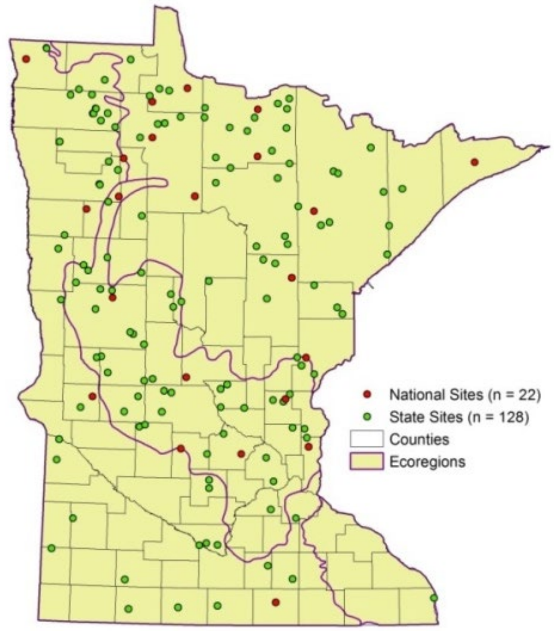


Figure 5. MWCA site locations. Red indicates Minnesota's allocated NWCA sites.

The majority of the field evaluations were completed during the same visit as the field sampling to minimize travel. All points were evaluated according to the order established from the sample point draw to ensure an unbiased sample. Following field evaluation, each point was designated a final evaluation status (Table 2). The final target-sampled sites were distributed throughout the state and ecoregions (Figure 5) with the final regional allocation approaching the target allocation of 50/ecoregion (Table 3). Complete site evaluation results are provided in Appendix 1.

Table 2. Final evaluation status for MWCA sample points.

Category	Description
Target Sampled	Point located in (or within 60 m of) target wetland of sufficient size/shape to establish an AA and access permission was granted
Access Permission Denied	Permission was not granted by the landowner to sample the location
Physically Inaccessible	Location could not be safely accessed and sampled in a single day
Map Error	Map indicates target wetland but no actual target wetland located at (or within 60 m of) the Point
Active Crop Production	Location was being used for active crop production during the index period
Innundated by Water > 1 m	Water > 1 m in depth covers ≥ 90% of the area within 60 m of the Point
Industrial/Agricultural/Aqua-cultural Purpose	Location is being used to treat wastewater or strictly for another industrial/agricultural/aquacultural purpose
Sampleable Area Too Small	Target wetland area is < 0.1 ha or < 20 m wide

Field methods

Vegetation sampling

Vegetation species composition and abundance were characterized according to wetland plant community types at each survey site. Following AA establishment, the plant communities present within the AA were determined and their extent was mapped on printed aerial photos (Figure 4). The Eggers and Reed (2011) classification of wetland plant communities of Minnesota and Wisconsin was followed (Table 4). A meander sampling approach was used to collect vegetation data—where the observer walked through the AA and recorded plant taxa by community type as they were encountered. Taxa were identified to the lowest taxonomic division possible in the field. When taxa could not be identified to the species level—specimens were collected, pressed, and dried for lab identification. Tree species observations were further sub-divided according to vertical height classes (Table 5). Aerial cover for each taxa by community type was then estimated according to cover classes (Table 6). In this way, the AA was essentially treated as a large sampling plot.

Table 3. Number of target sampled sites by ecoregion

Ecoregion	# of Sampled Sites
Mixed Wood Shield	55
Mixed Wood Plains	50
Temperate Prairies	45

Table 4. Eggers & Reed (2011) plant community classes, general NWCA classes, and brief community class descriptions. Two classes have been slightly modified from the original classification (Bourdaghs 2012). Fresh Meadow combines both the Eggers and Reed Sedge Meadow and Fresh (Wet) Meadow classes into a single class.

Community Class	NWCA Class	Community Class Description
Shallow Open Water	Open Water	Open water aquatic communities with submergent and floating leaved aquatic species
Deep Marsh	Emergent	Emergent vegetation rooted within the substrate that is typically inundated with > 6" of water. Submergent and floating leaved aquatic species typically a major component of community
Shallow Marsh	Emergent	Emergent vegetation on saturated soils or inundated with typically < 6" of water. May consist of a floating mat. Submergent and floating leaved aquatic species typically a minor component
Fresh Meadow	Emergent	Graminoid dominated, soils typically saturated
Wet Prairie	Emergent	Similar to Fresh Meadow but dominated by prairie grasses
Calcareous Fen	Emergent	Soils calcareous peat (i.e., organic w/high pH) due to groundwater discharge with high levels of calcium/magnesium bicarbonates. Specialized calcareous indicator species (calciphiles) present-dominant
Sedge Mat	Emergent	Graminoid dominated communities on circumneutral or slightly acidic peat soils. Often occurs as a floating mat and *Carex lasiocarpa* (wiregrass sedge) is often a dominant
Shrub-Carr	Scrub-Shrub	Tall shrub community typically dominated by Willows (*Salix* spp.). Typical understory species composition similar to Fresh Meadow
Alder Thicket	Scrub-Shrub	Tall shrub community typically dominated by Alder (*Alnus incana* ssp. *rugosa*)

Community Class	NWCA Class	Community Class Description
Open Bog	Scrub-Shrub	Low shrub or graminoind dominated community on a mat of *Sphagnum* moss/acidic deep peat. Specialized acid tolerant (indicator) species dominant
Coniferous Bog	Forested	Forested community dominated by coniferous trees on a mat of *Sphagnum* moss/acidic deep peat. Specialized acid tolerant (indicator) species dominant
Coniferous Swamp	Forested	Forested community dominated by coniferous trees on saturated soils. Soils typically circumneutral to acidic
Hardwood Swamp	Forested	Forested community dominated by deciduous hardwood trees on saturated soils
Floodplain Forest	Forested	Forested community dominated by deciduous trees on alluvial soils associated with riverine systems

This sampling approach differed from the NWCA vegetation sampling protocol, which was based on collecting species composition and abundance data within five regularly placed 10 x 10 m sampling plots. The meander sampling approach was done at 18 of the 22 NWCA sites to compare the two methods. At the community scale, FQA metrics varied 5-7% of the effective range on average and the assessment outcomes (i.e., condition category) were the same in 92% of the cases (Appendix 2). Given those results, composite community data from NWCA plots at the 4 sites where only NWCA sampling had been conducted was incorporated into the overall MWCA data set.

Table 5. Height classes and ranges (m) for tree species.

Height Class	Range (m)
6	> 30 m
5	> 15 - 30 m
4	> 5 - 15 m
3	> 2 - 5 m
2	> 0.5 - 2 m
1	> 0 - 0.5 m

MWCA field sampling was completed between June and mid-September in 2011 (n = 99) and 2012 (n = 51). Ten percent (n = 15) of the sites were re-sampled (Appendix 3) and voucher plant specimens were collected and identified (Appendix 4) as Quality Assurance/Quality Control (QA/QC) measures.

Water chemistry sampling

If sufficient standing water (> 15 cm in depth) was present in an AA, water chemistry data were also collected. Sampling stations were established according to the NWCA protocol (EPA 2011b):

- Within the AA and as close to the point as possible
- As close to the middle of the individual water body as practical
- Away from inlets or outlets

Water chemistry parameters were measured in the field using handheld multi-parameter meters and in the lab from surface water grab samples (Table 7). Water samples were taken prior to the vegetation survey to avoid fouling water with foot traffic.

Table 6. Cover classes, percent cover ranges, and midpoints.

Cover Class	Cover Class Range	Midpoint
7	> 95 - 100%	97.5%
6	> 75 - 95%	85%
5	> 50 - 75%	62.5%
4	> 25 - 50%	37.5
3	> 5 -25%	15%
2	> 1 - 5%	3%
1	> 0 - 1%	0.5%

NWCA sampling

The full NWCA sampling protocols (EPA 2011b) were completed at the first 22 sites, which were Minnesota's allotment of national survey sites (Figure 5).

The NWCA field sampling was much more extensive, providing data for the following indicators:

- Vegetation
- Soils
- Physical habitat (in the AA and the surrounding buffer)
- Hydrology
- Water chemistry
- Algae
- USA Rapid Assessment Method

The EPA is currently developing NWCA indicators, metrics, and assessment thresholds from the national dataset. Any reporting of NWCA results for Minnesota is pending this development and will be done separate from this report.

Table 7. Sampled water chemistry parameters.

Parameter	Sample Type	Units
pH	Field Probe	
Conductivity	Field Probe	µS/cm
Dissolved Oxygen (DO)	Field Probe	mg/l
Temperature	Field Probe	C°
Transparency	Field-Secchi Tube	cm
Color	Field-Color Wheel	PCU
Chloride	Grab sample/lab	mg/l
Kjeldahl Nitrogen	Grab sample/lab	mg/l
Nitrate + Nitrite Nitrogen	Grab sample/lab	mg/l
Sulfate	Grab sample/lab	mg/l
Total Phosphorus	Grab sample/lab	mg/l
Total Organic Carbon	Grab sample/lab	mg/l

Data analysis

Following field sampling, AA and plant community mapping was completed using GIS based on field GPS data, the hand drawn maps, and aerial photo interpretation (Figure 4). A general HDA that categorically describes the degree to which wetlands may be exposed to anthropogenic stressors (Bourdaghs 2012) was also completed for each site.

The HDA incorporates six well-documented factors that have been associated with degraded wetland vegetation condition:

- Surrounding landscape alteration (500 m buffer)
- Immediate upland alteration (50 m buffer)
- Within wetland physical alteration (e.g., plowing, logging, etc.)
- Hydrologic alteration (e.g., partial drainage, directed inputs, etc.)
- Chemical pollution (e.g., excess sediment or nutrients, human sources present)
- Non-native invasive species

Each HDA factor was rated separately as minimal/low/moderate/severe using best professional judgment according to standard narrative criteria. Ratings were based on aerial photo interpretation and field observations. Several of the factors were rated based on conditions occurring at the larger wetland body (as opposed to just conditions immediately within the AA boundary) including: landscape and immediate upland alteration as well as hydrologic alterations. As water chemistry was not collected at all sites the Chemical Pollution factor was not rated. An overall HDA rating of minimally/moderately/severely impacted was then determined based on combinations of the individual factor ratings. Complete HDA documentation is provided in Appendix 5.

The primary FQA metric used to quantify vegetation condition from the community data was the weighted Coefficient of Conservatism (*wC*), which is the sum of each species' proportional abundance (*p*) multiplied by its *C*-value:

$$wC = \sum pC$$

In this case, the abundance measure used to calculate *p* was the midpoint percent cover derived from the observed cover classes (Table 6). *wC* incorporates both species composition and abundance, is not affected by sampling area, and has been found to be a more responsive indicator of wetland condition than FQA metrics that rely on species composition alone (Bourdaghs 2012).

The FQA assessment framework for Minnesota wetlands used to translate quantitative *wC* scores into meaningful results was built around a general model of biological response to anthropogenic impacts called the Biological Condition Gradient (BCG); EPA 2005). The BCG describes biological condition according to levels (or condition categories) that range from conditions that are equivalent to those thought to be found prior to European settlement to conditions that are found at sites known to be severely impacted by human activities. A four-level BCG model specific to wetland vegetation has been developed to serve as the assessment framework (Table 8). Numeric *wC* assessment criteria have been established by calibrating *wC* scores to the BCG using a large dataset (Bourdaghs 2012). This was done by assigning targeted data to three analysis groups (pre-settlement, minimally impacted, and severely impacted) based on HDA and Minnesota Biological Survey condition ratings (MDNR 2009), and establishing thresholds at the 10th percentile values for the pre-settlement and minimally impacted groups and the 90th percentile value of the severely impacted group (Figure 6). *wC* assessment criteria were developed for each plant community (Table 9) as both the expected natural and impact response ranges differ by type (Bourdaghs 2012).

Table 8. Wetland vegetation condition category descriptions.

Condition Category	Description
Exceptional	Community composition and structure as they exist (or likely existed) in the absence of measurable effects of anthropogenic stressors representing pre-European settlement conditions. Non-native taxa may be present at very low abundance and not causing displacement of native taxa.
Good	Community structure similar to natural community. Some additional taxa present and/or there are minor changes in the abundance distribution from the expected natural range. Extent of expected native composition for the community type remains largely intact.
Fair	Moderate changes in community structure. Sensitive taxa are replaced as the abundance distribution shifts towards more tolerant taxa. Extent of expected native composition for the community type diminished.
Poor	Large to extreme changes in community structure resulting from large abundance distribution shifts towards more tolerant taxa. Extent of expected native composition for the community type reduced to isolated pockets and/or wholesale changes in composition.

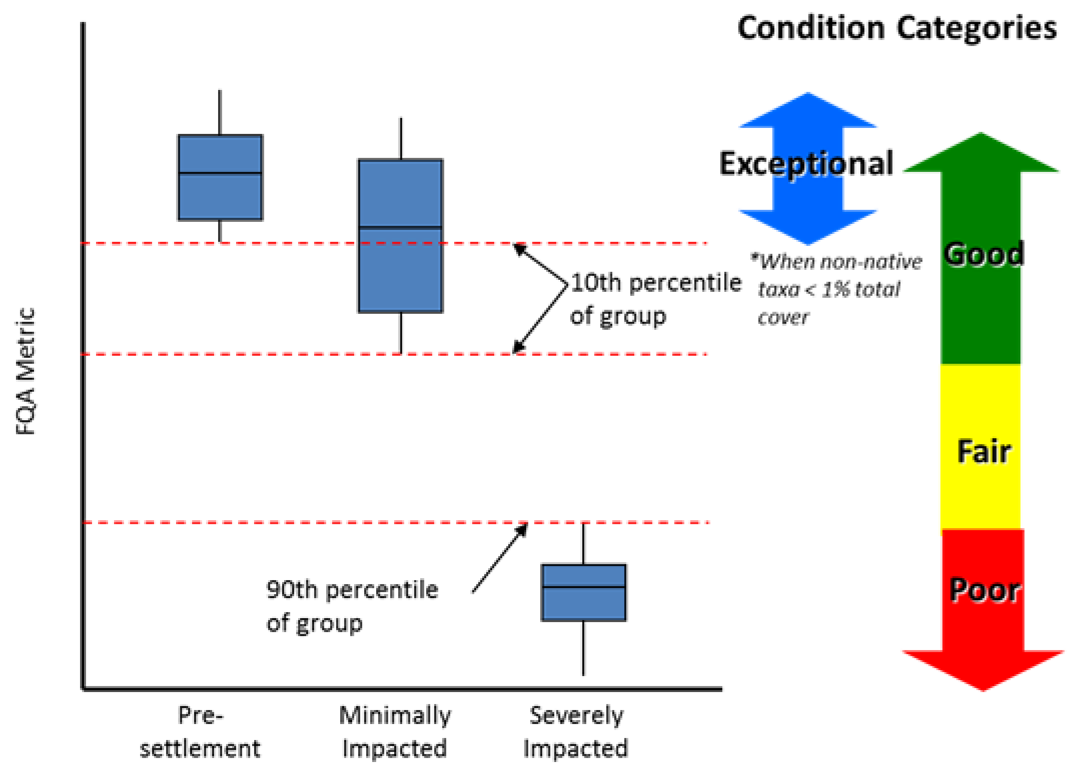


Figure 6. Diagram of FQA assessment criteria threshold development. Community samples were assigned to data analysis groups based on the degree of exposure to human impacts (pre Settlement, minimally impacted, or severely impacted). Thresholds were determined at designated percentiles of the FQA metric distribution for each data analysis group that correspond to the condition categories (Table 8). Separating the exceptional and good threshold required an additional narrative criterion (< 1% non-native taxa cover) to be met.

Table 9. wC Condition category assessment criteria for all community types. An additional narrative criteria (< 1% non-native taxa cover) is required to meet the exceptional condition category (i.e., a community must score above the numeric threshold and meet the narrative requirement to be assessed as exceptional).

	Community						
Condition Category	**Shallow Open Water**	**Deep Marsh**	**Shallow Marsh**	**Fresh Meadow**	**Wet Prairie**	**Calcareous Fen**	**Sedge Mat**
Exceptional			> 4.9*	> 4.2*	> 4.8*	> 7.0*	> 6.4*
Good	> 5.0	> 4.1	> 4.2	> 4.2	> 4.1	> 6.4	> 5.9
Fair	< 5.0	< 4.1	1.9 - 4.2	1.4 - 4.2	1.4 - 4.1	5.2 - 6.4	1.8 - 5.9
Poor			< 1.9	< 1.4	< 1.4	< 5.2	< 1.8

	Community						
Condition Category	**Open Bog**	**Coniferous Bog**	**Shrub-Carr**	**Alder Thicket**	**Hardwood Swamp**	**Coniferous Swamp**	**Floodplain Forest**
Exceptional	> 7.4*	> 7.3*	> 4.5*	> 4.2*	> 4.6*	> 5.8*	> 4.2*
Good	> 7.0	> 7.1	> 4.5	> 3.9	> 4.2	> 5.6	> 2.7
Fair	5.4 - 7.0	5.9 - 7.1	3.2 - 4.5	2.3 - 3.9	2.5 - 4.2	3.8 – 5.6	2.1 - 2.7
Poor	< 5.4	< 5.9	< 3.2	< 2.3	< 2.5	< 3.8	< 2.1

* Total non-native species cover < 1%

Because the data were gathered by (and assessment criteria were specific to) plant community type, completing a final assessment for an AA was a multi-step process (Figure 7). *wC* scores were first calculated for each community present in an AA based on the vegetation data and *C*-values. The condition category for each type was then determined according to the established community assessment thresholds (Table 9). Community condition results were then aggregated to the AA scale by calculating the weighted average condition category based on the relative extent of each community present derived from the community mapping (Figure 7).

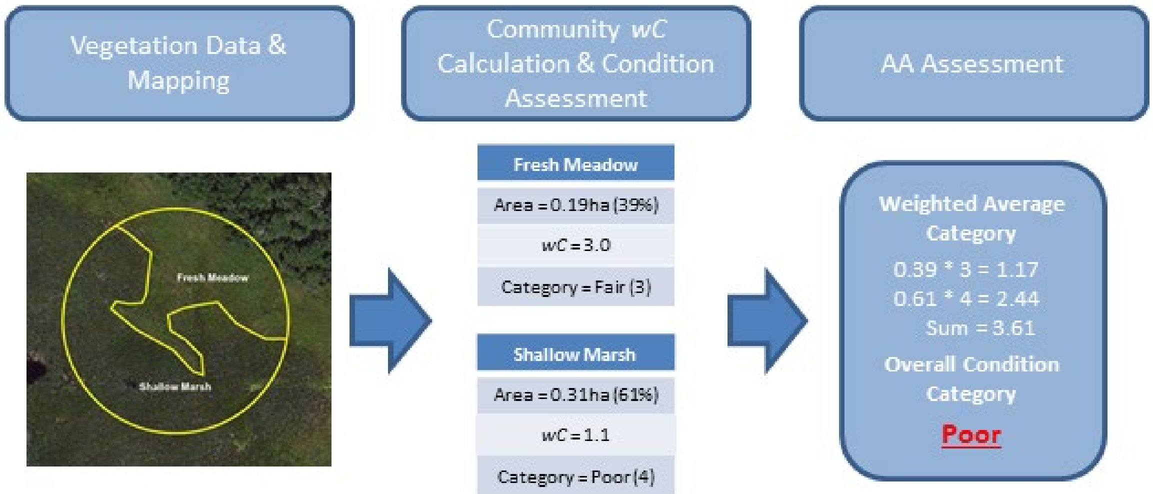


Figure 7. Process to complete an AA level assessment: 1) vegetation data are gathered by community type; 2) *wC* is calculated and the condition category of each community is determined; and 3) community results are aggregated by a weighted average of the extent of each type.

Target wetland extent and condition estimates were then made at ecoregion and statewide scales from the AA condition category results. The design weights were first adjusted based on the exclusion of sites that were confirmed as non-target types during site evaluation (Table 2). Sites that were evaluated as Access Permission Denied or Physically Inaccessible were assumed to be target wetland based on the desktop evaluation and were incorporated into target wetland estimates.

Extent and condition estimates were also generated by NWCA wetland classes (Table 10) and plant community types (Table 4). The NWCA wetland classes generally correspond to US Fish and Wildlife Service's Classification of Wetlands and Deepwater Habitats of the US (Cowardin et al. 1979) at the class level (Table 10). NWCA class and community type estimates were made using sub-AA data at the community level (Figure 7)—where results from the mapped/sampled portions of AAs of the same class/type were aggregated to the statewide scale. Small sample sizes prohibited making estimates of classes/types at ecoregion scales.

Table 10. General NWCA wetland classes (EPA 2011b); corresponding Cowardin (1979) and MDNR S&T classes (Kloiber et al. 2012); with general class descriptions.

NWCA Class	Cowardin Class	MDNR S&T Class	General Description
Forested	Palustrine Forested	Forested Wetland	Trees or tall shrubs > 3m tall with > 30% crown cover
Scrub-Shrub	Palustrine Scrub-Shrub	Shrub Swamp	Shrubs < 3m tall with > 30% crown cover
Emergent	Palustrine Emergent	Emergent Wetlands	Erect rooted herbaceous growing above surface water
Open Water	Palustrine Unconsolidated Bottom and Aquatic Bed	Unconsolidated Bottom & Aquatic Bed	Open water with plants growing at or below the surface of the water, or no plants present

Stressor estimates were also generated in parallel to the condition estimates. HDA and HDA factor (Appendix 5) proportion estimates were generated to provide the wetland extent that may have been exposed to human impacts. A relative risk analysis of the HDA factors was then completed to assess the relative strength of the effect that stressors may have on wetland vegetation condition. Relative risk measures the increased likelihood that a type of human impact may be associated with a poor vegetation condition relative to the other types of impacts. It is calculated as the ratio of two conditional probabilities—the probability of having a poor condition under high stress and the probability of a poor condition under low stress (Van Sickle and Paulsen 2008).

All of the results (e.g., proportion estimates, relative risk, etc) were expressed in terms of target wetland acreage—not in terms of numbers of individual wetlands. Analyses were performed in R (version 3.1.1) using the spatial survey design and analysis package (spsurvey; Kincaid et al. 2014).

Finally, given that sampleable water (surface water depth > 15cm) was not present at all sites and water samples were obtained in a variety of wetland settings when present, it was decided not to make ecoregional and statewide estimates from the water chemistry data. Alternatively, basic descriptive statistics were calculated to begin to understand the variability present in Minnesota wetland surface water chemistry.

Survey limitations

As with any natural resource survey, there are limits to what the MWCA can provide. It is important to keep in mind that this effort is the first attempt to measure the condition of all of Minnesota's wetlands and that the approach to assessing vegetation condition, ability to measure other aspects of wetland quality, and the survey itself will likely evolve as it is continued into the future. As of now, the more relevant limitations include:

- ***The role of interpretation:*** Observer interpretation occurs at a number of stages during the MWCA. In the field, crew leaders must interpret plant community types; delineate their extent in AAs; identify plant species; and make cover estimations. Differences in community interpretation can lead to differences in assessment outcomes (Bourdaghs 2012). In addition, the HDA ratings are interpreted from guidance. While procedures, training, and QA/QC measures are in place to minimize interpretation variability—differences can still occur (Appendix 3, Appendix 4). In future survey iterations, procedure refinements will be made to further minimize observer effects.
- ***Ability to assess some plant community types:*** *wC* assessment criteria have been fully developed for most of the wetland plant community types, but not all (Table 9). Both the Deep Marsh and Shallow Open Water types have a single threshold that defines two condition categories (good/fair) due to a lack of development data. This may artificially influence aggregated results towards the middle of the BCG. Additionally, assessment criteria for several other community types were based on limited data sets (Bourdaghs 2012). The MPCA will continue to revise criteria as more data are gathered. MWCA trend results can then be adjusted as criteria are refined.
- ***Ability to address concerns raised from the DNR quantity survey:*** Two primary concerns have been raised from the second iteration of the DNR wetland quantity survey: 1) there has been a significant conversion of emergent to cultivated wetlands and 2) the majority of the wetland gains have been open water ponds. These changes likely represent a reduction in wetland quality (Kloiber and Norris 2013). As currently designed, the MWCA has a limited ability to directly measure the effect of these changes due to the target population definition, which excludes cultivated and open water wetlands > 1 m in depth. More targeted survey efforts, such as the depressional wetland survey, will be required to assess how these changes are affecting the overall quality of Minnesota's wetlands.

- ***Ability to detect plant community type changes:*** Large changes in plant species composition and abundance distributions that would constitute a change in community type—when due to human impacts—are consistent with our concept of poor condition (Table 8). As currently conceived, our assessment approach allows for (and encourages) assessing current conditions as a former type when evidence of a human cause and former type is present (MPCA 2014). However, it can be difficult to interpret community type changes because wetland plant communities can change due to natural causes (which would not represent a loss of condition) and that evidence of a former type may not always be present (e.g., dead standing trees). Related to this, other significant threats to wetland vegetation condition may be similarly difficult to detect, including: the loss of Tamarack due to swamping and the Eastern Larch Beetle (MDNR 2013); potential impacts to Black Ash swamps due to the Emerald Ash Borer; and changes due to climate change. As future iterations of the MWCA occur, the MPCA will continue to evaluate our ability to detect these kinds of changes.
- ***Vegetation condition is just one measure of wetland "quality":*** While vegetation is a well-established approach to measure wetland condition, other biological assemblages and environmental variables may also be effective condition indicators. In addition, it is not always clear how vegetation condition relates to ecosystem services or function—which is an important component of wetland "quality". As previously discussed, the predominant assumption of wetland quality assessment approaches is that wetlands are supporting a full suite of functions when natural conditions are intact. More recently, there has been a growing acknowledgement of the contextual basis of assessing wetland functions and the concept of realized benefits, where a particular function is only realized when it has been utilized in some way (Maltby 2009, Stelk and Christie 2014). This has brought the predominate assumption into question. The few efforts to explicitly test function-condition relationships—such as evapotranspiration and groundwater exchange that contribute to flood abatement (McLaughlin and Cohen 2013) or nitrogen processing (Jordan et al. 2007)—have shown little connection between vegetation condition and the ability of wetlands to perform some important functions. Given these considerations, caution should be used to infer the status of particular functions (beyond the maintenance of vegetation condition) from the MWCA results.

Results and discussion

Statewide and regional wetland vegetation condition

Statewide

Overall, the vegetation condition in Minnesota's wetlands was high (Figure 8). An estimated 49% (± 8%) of the survey target population was in the exceptional condition category. Exceptional conditions are considered to have plant species composition and structure consistent with sites where human impacts have had no measurable effect on the vegetation—representing pre-European settlement conditions (Table 8). An additional 18% (± 7%) of wetlands statewide were in good condition, where the vegetation composition and structure were similar to natural communities. Combined, wetlands in exceptional and good conditions totaled approximately two-thirds of the statewide wetland extent.

The remaining share of Minnesota's wetlands was estimated at 23% (± 7%) fair and 10% (± 2%) poor conditions (Figure 8). Both of these condition categories represent degrees of wetland vegetation degradation, where plant species composition and/or structure have deviated from observed minimally impacted conditions (Table 8). The fair category describes moderate changes; whereas, poor condition represents large to extreme changes in composition and/or structure—including the wholesale conversion of community types and/or the replacement of expected native species by non-native invasive species.

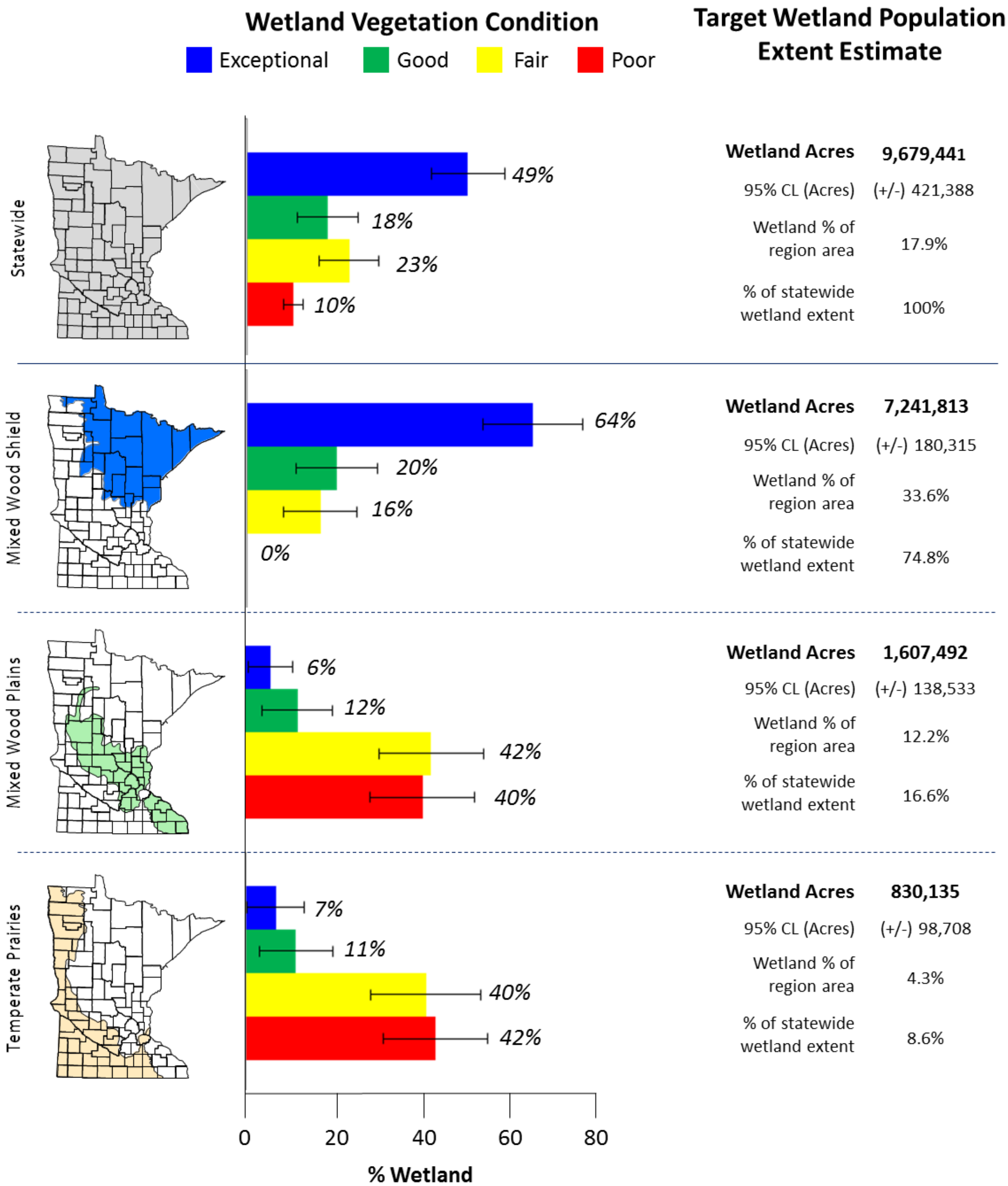


Figure 8. Wetland vegetation condition category proportion and extent estimates statewide and by ecoregion

The MWCA condition proportion estimates apply to the survey target wetland population, which includes virtually all of Minnesota's wetlands. The MWCA statewide wetland target population was estimated at 9.68 (± 0.422) million acres (Figure 8). As expected, this total was less than the estimated statewide sample frame population estimate of 10.47 (±0.371) million acres (Figure 3), though there was a slight overlap of confidence intervals between the two estimates. This was due to the exclusion of cultivated wetlands from the target population and the sampling depth limitation of 1 m which effectively excluded deeper portions of open water wetlands from the target population.

The MWCA statewide condition estimates were also different than the 2007-09 depressional survey vegetation condition estimates for Minnesota (Genet 2012). Statewide, the vegetation condition estimates of depressional wetlands was estimated at: 37% good, 20% fair, and 42% poor. In other words, depressional wetlands had much lower vegetation condition compared to the overall population of Minnesota's wetlands. Considering that the assessment approaches differed somewhat between these two surveys, further explanation here is warranted. The depressional survey relied on multi-metric IBIs developed independently for each ecoregion based on a regional reference assessment approach (Gernes and Helgen 2002, Genet and Bourdaghs 2006, Genet and Bourdaghs 2007). Unlike the BCG approach utilized in the MWCA (which attempts to describe biological condition on an absolute scale; EPA 2005) the regional reference approach assumes that "good" condition exists at sites that are least impacted relative to wetlands in the region—regardless of the absolute range of impacts that occur in the region. This resulted in different criteria to determine assessment categories for each ecoregion and potentially over/under estimating good/poor categories in ecoregions that are heavily (e.g., Temperate Prairies) or minimally (e.g., Mixed Wood Shield) impacted on an absolute basis. While the depressional survey condition estimates were similar in general presentation to the MWCA (i.e., proportion estimates of good/fair/poor condition) the fundamental construct and criteria used to define the categories was somewhat different, making direct quantitative comparisons between the two sets of estimates problematic. However, given the fundamental similarities—a qualitative comparison is reasonable.

Regional wetland condition

While a clear majority of Minnesota's wetlands were in exceptional and good condition, condition varied widely in different parts of the state (Figure 8, Figure 9).

In the Mixed Wood Shield ecoregion, the majority (64% ±11%) of the wetland resource was in exceptional condition with another 20% (± 8%) in good condition (Figure 8). The remaining 16% (± 9%) was in fair condition with no sites observed in poor condition. Wetlands in the Mixed Wood Shield ecoregion tended to be in better condition compared to the statewide estimates, with a potentially higher percentage of wetlands in exceptional condition (overlapping confidence intervals) and lower percentage in poor condition. It should also be noted that the estimate of 0% poor indicates that poor condition occurs at such a low rate that it was not detected in this ecoregion with the MWCA sampling design.

Conversely, a clear majority of wetlands in both the Mixed Wood Plains and Temperate Prairies ecoregions had degraded conditions (Figure 8). Condition category proportion estimates for these two ecoregions were essentially the same with: 6-7% exceptional, 11-12% good, 40-42% fair, and 40-42% poor. The percentage of wetlands with exceptional condition in these two ecoregions was significantly lower than the statewide average, and the percentage of wetlands with poor condition was significantly higher.

These regional patterns explain (to a large degree) the statewide results. As approximately 75% of Minnesota's wetlands occur in the Mixed Wood Shield ecoregion (Figure 8), the high levels of condition found there drives the statewide results. This largely masks the smaller wetland extent—but widespread degraded conditions—that occur in the Mixed Wood Plains and Temperate Prairies.

The depressional wetland survey showed similar regional patterns of vegetation condition. Like the overall wetland resource, depressional wetlands were in better condition in the Mixed Wood Shield (67% good, 13% fair, 20% poor) compared to the Mixed Wood Plains (32% good, 27% fair, 41% poor) and Temperate Prairies (19% good, 9% fair, 69% poor) ecoregions (*unpublished data*). However, unlike the overall wetland resource, the majority of the depressional wetlands (as defined in that survey) occurred in the more developed regions of the state. On an extent basis, 52% of depressional wetlands occurred in the Mixed Wood Plains—with 25% in the Mixed Wood Shield and 23% in the Temperate Prairies (Genet 2012). This explains the qualitative disparity in the statewide condition estimates between the depresssional survey and the MWCA, as a larger percentage of depressional wetlands occurred in the more impacted Mixed Wood Plains and Temperate Prairies ecoregions compared to the total population of wetlands.

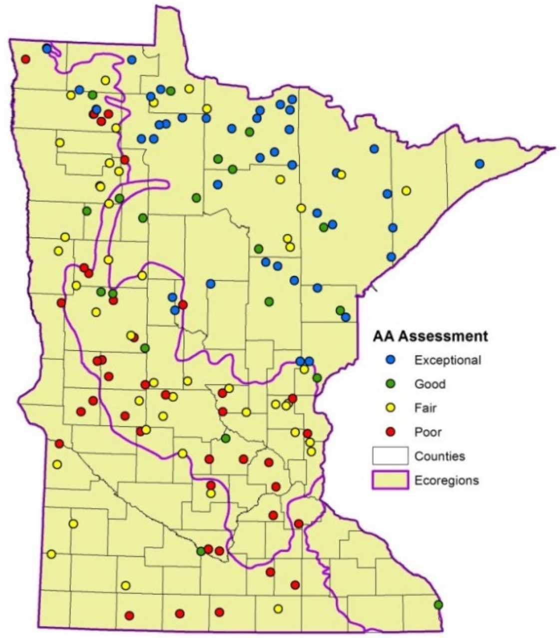


Figure 9. Site locations by condition categories.

In both the Mixed Wood Plains and Temperate Prairies ecoregions, the handful of AAs that were assessed as exceptional (and subsequently generated the 6-7% ecoregion rates) were located near the border with the Mixed Wood Shield (Figure 9). AAs assessed as good in both ecoregions were somewhat more evenly distributed, though some were also located near the Mixed Wood Shield border. This suggests that the exceptional and (to some degree) good conditions in these two ecoregions may be due to a border effect, where the factors that are causing degraded conditions throughout the ecoregions may be locally less intense as the landscape transitions to the Mixed Wood Shield ecoregion. Additionally, in the Temperate Prairies all of the exceptional AAs occurred in a landscape that has been recognized by the MDNR as distinct from the majority of the region called the Tallgrass Aspen Parkland (TAP) Province (MDNR 2005). MDNR classifies most of the remainder of the Omernik Temperate Prairies ecoregion as the Prairie Parkland (PP) Province. Estimates generated according to the MDNR Provinces suggest that wetlands may be somewhat different in these two parts of the overall Temperate Prairies ecoregion—both in terms of extent (11% of the TAP is wetland vs. 4% of the PP) and condition (19% of wetlands in the TAP in poor condition vs. 61% of wetlands in the PP in poor condition). Further geographic classification of the Temperate Prairies ecoregion will be evaluated in future MWCA iterations.

Condition by general wetland classes and plant communities

Wetland classes

In terms of extent, Forested wetlands were the most prevalent general NWCA class (Table 10) of wetlands in Minnesota at 43% (Figure 10), followed by Emergent (36%), Scrub-Shrub (20%), and Open Water wetlands (1%).

These estimates (Figure 10) were similar to the class results from the MDNR Status and Trends quantity survey (Kloiber 2010). The MDNR totals for both the Forested and Emergent classes were within the MWCA confidence intervals, indicating no significant difference. For the Scrub-Shrub class, the MDNR estimate was slightly above the MWCA confidence interval; however, it was presumed that there would be broad over-lap with the MDNR confidence interval (not reported). This helps verify that the MWCA sufficiently captured these wetland types and subsequent condition estimates were representative. The MWCA extent estimates for the Open Water class (94,874 acres); however, were much lower than MDNR estimates (560,400 acres). This was not unexpected due to the limitation in the MWCA target population definition where Open Water wetlands with > 1m of surface were excluded. Given that there was a small sample size in addition to the exclusion of deeper Open Water wetlands, condition estimates for this type should be considered limited.

Condition varied across the general NWCA wetland classes. Both the Forested and Scrub-Shrub class estimates (Figure 10) were similar to the statewide results (Figure 8)—with high percentages of exceptional condition and low percentages of poor condition. Given that Forested and Scrub-Shrub wetlands combined represent roughly 63% of the target wetland population; these two classes strongly influenced the statewide results. Conversely, a lower percentage of Emergent wetlands (Figure 10) were in exceptional condition (though not significant), and a significantly higher percentage were in poor condition, compared to the statewide results. Emergent wetlands represented the highest share of poor condition wetlands by general class and therefore are of greatest conservation concern. Open Water wetlands were approximately split between being in good and fair condition, with a large range of uncertainty (Figure 10).

While the data were too limited to produce quantitative regional condition estimates by class, the class differences were likely related to the overall regional variation in condition. MDNR extent estimates showed that the predominant classes varied by ecoregion (Figure 3). Forested and Scrub-Shrub wetlands comprised the majority of the wetlands in Mixed Wood Shield, where condition was high (Figure 10). Conversely, Emergent wetlands were the predominant general NWCA class in the Mixed Wood Plains and Temperate Prairies ecoregions, where condition was largely degraded (Figure 10).

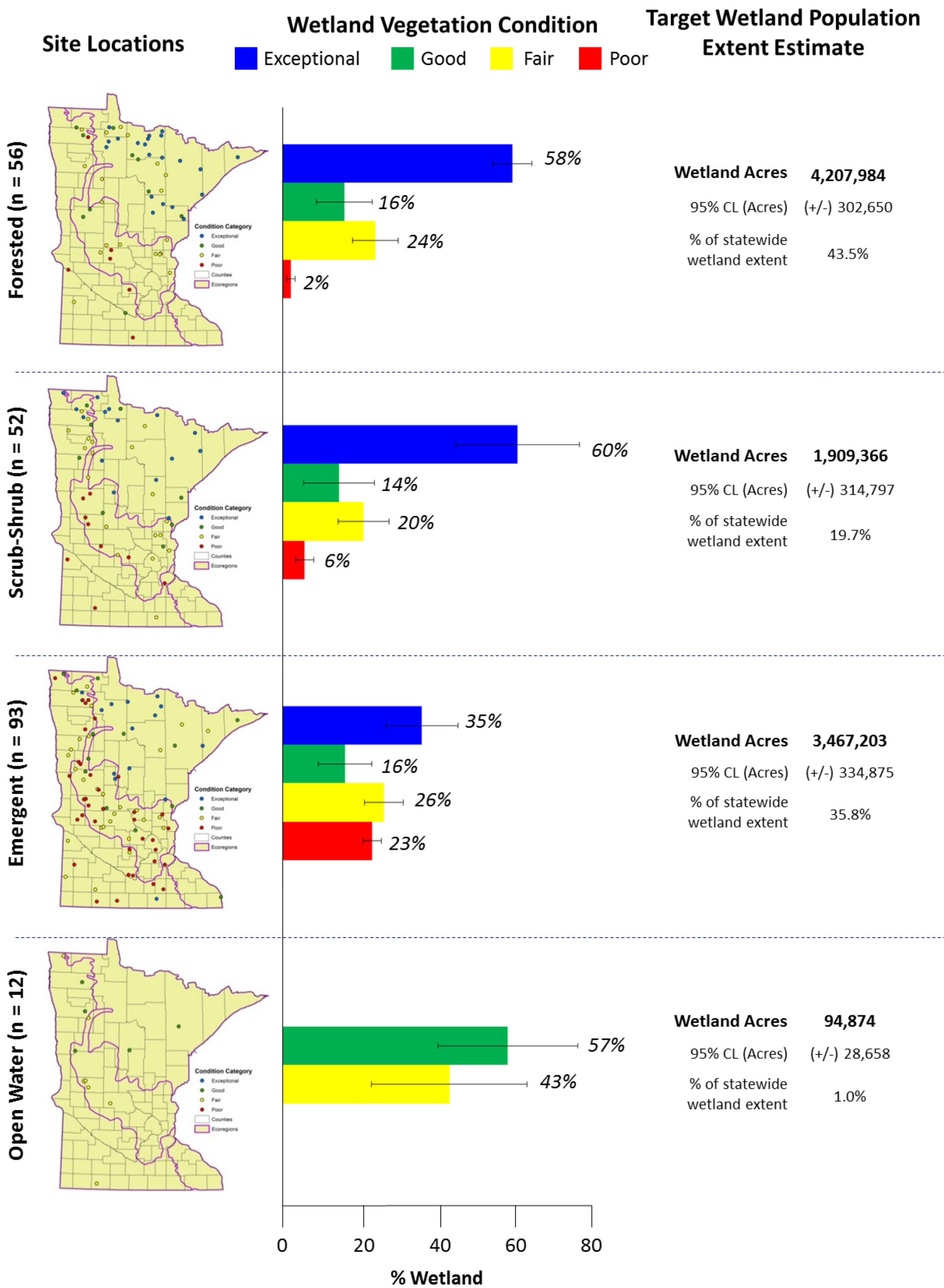


Figure 10. Site location maps, condition category proportion estimates, and target population extent estimates by general NWCA wetland classes.

Plant communities

Collecting field data according to plant communities (Figure 4, Table 4) allowed for the first unbiased extent estimates of Minnesota's wetlands at this detailed level of classification. The Cowardin et al. (1979) classification system used in the NWI has enough fidelity to describe many community types, but not all. Condition estimates were produced for the community types that met a minimal number of samples (n ≥ 10). Any types with < 10 samples were thought to be too unreliable to report condition results given the extremely small sample size.

In terms of extent, Coniferous Swamp was the most prevalent community type—comprising 22% of Minnesota's wetlands (Figure 11). Four additional community types totaled > 10% of the target population each: Shallow Marsh, Hardwood Swamp, Sedge Mat, and Fresh Meadow. Coniferous Bog, Open Bog, Shrub-Carr, and Alder Thicket each amounted to 5-10% of the statewide extent. The four remaining observed community types (Deep Marsh, Shallow Open Water, Floodplain Forest, and Wet Prairie) each comprised < 1% of the statewide target population. As previously discussed, this survey underestimated the Shallow Open Water community. According to MDNR estimates, the Shallow Open Water community represented approximately 5% of Minnesota's wetlands (Figure 3). The Calcareous Fen community—a well-documented rare type of wetland in Minnesota—was not observed in the MWCA.

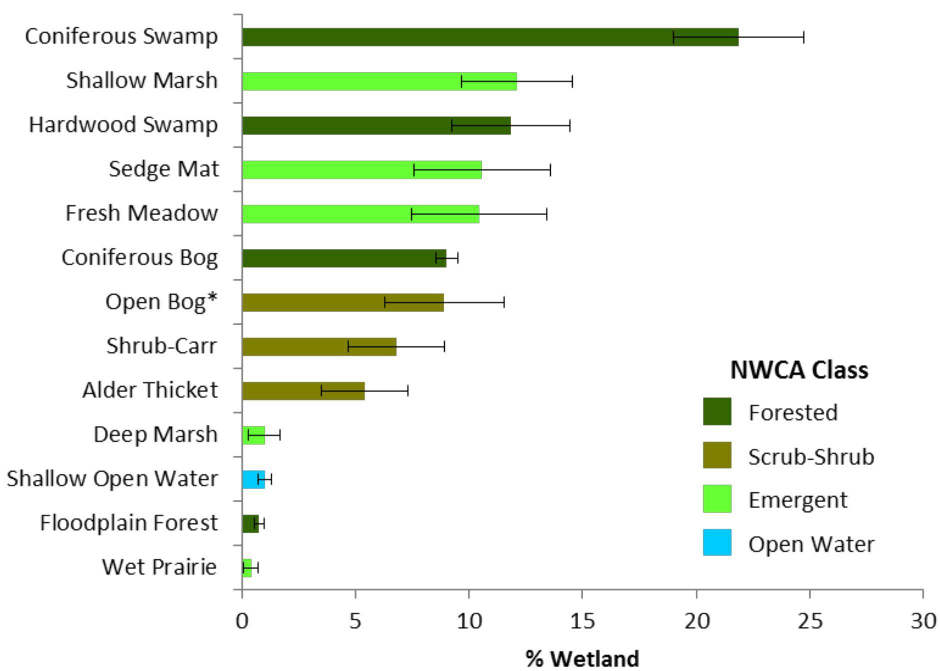


Figure 11. Percent of the statewide wetland extent by plant community type. Bars have been colored according to general NWCA wetland classes. *Open Bog communities can be classed as either Scrub-Shrub or Emergent depending on the total coverage of low-shrub species (typically they are classed as Scrub-Shrub).

Of the Forested wetlands (Table 4), condition estimates were generated for two community types—Coniferous and Hardwood Swamps (Figure 12). Condition estimates for both types were similar to the general Forested class, with high rates of exceptional condition and corresponding low rates of poor condition. These two communities comprised approximately 77% of the Forested wetlands. Coniferous Bogs—which comprised an additional 21% of the Forested wetlands but were not observed frequently enough to generate condition estimates—may have relatively higher rates of exceptional-good condition given that they predominantly occurred in the Mixed Wood Shield ecoregion. Of the seven Coniferous Bog observations in the MWCA, five were assessed as exceptional and one each assessed as good and fair.

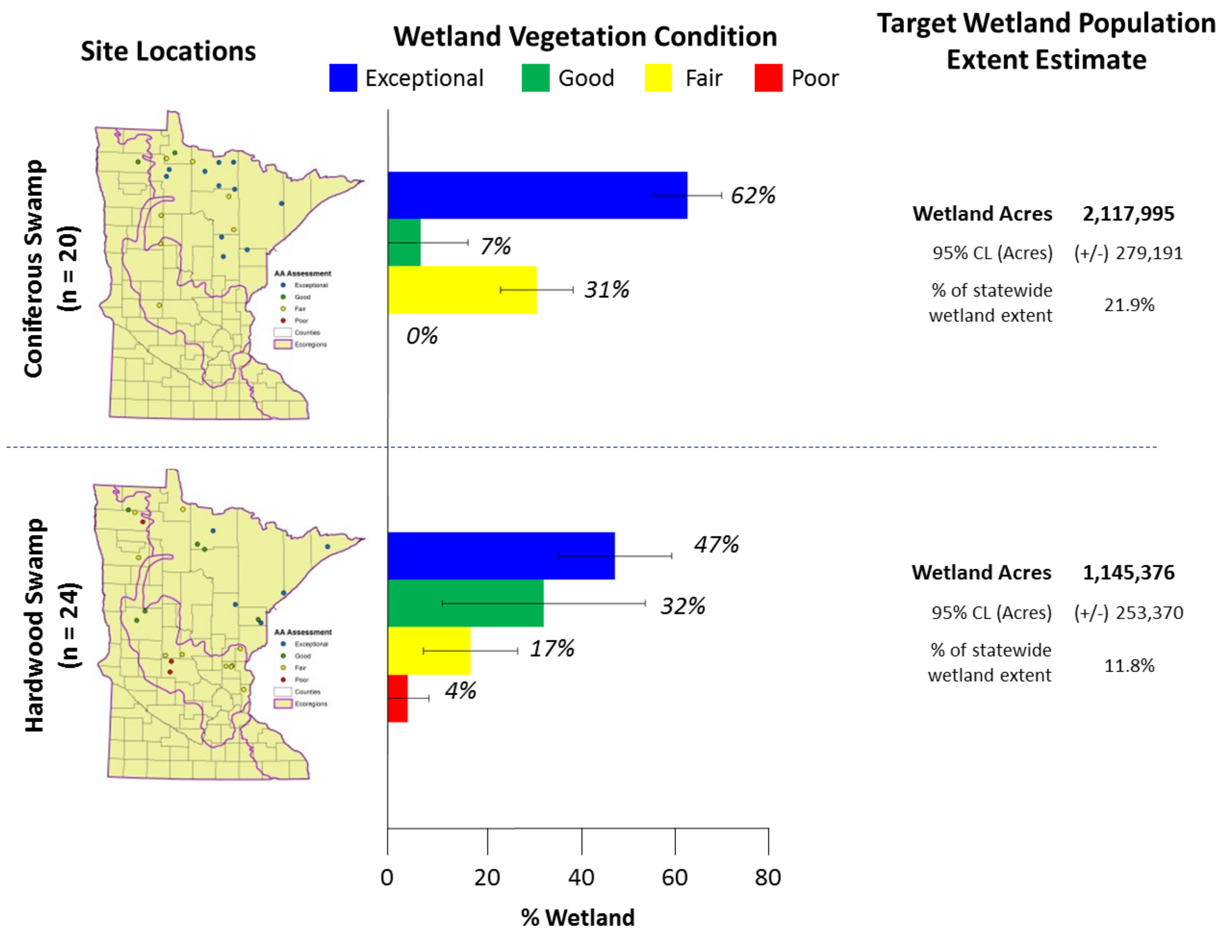


Figure 12. Site location maps, condition category proportion estimates, and target population extent estimates for the Coniferous and Hardwood Swamp community types.

Condition estimates were generated for two of the three Scrub-Shrub communities (Table 4), Shrub-Carr and Alder Thicket (Figure 13). Unlike the forested communities, condition estimates for the Shrub-Carr community differed from the broader Scrub-Shrub class estimates (Figure 10)—with a lower rate of exceptional condition and higher rate of poor condition. The Shrub-Carr community shares similar habitat and many of the same species found in Emergent communities but is differentiated by having a higher abundance of tall shrubs (> 50% cover; Table 4). The condition estimates suggest that Shrub-Carr communities likewise experience similar rates of degraded conditions as the broader Emergent class and is therefore of concern. The condition estimates for the Alder Thicket community was more consistent with the broader Scrub-Shrub class, though the small sample size produced a large confidence interval (Figure 13). The Shrub-Carr and Alder Thicket communities comprised approximately 61% of the Scrub-Shrub wetlands. Open Bogs were actually the most prevalent Scrub-Shrub community by extent at 39%, but were not observed frequently enough to generate condition estimates (n = 9). Open Bogs can be classified as either Scrub-Shrub or Emergent depending on the abundance of low shrubs such as *Chamaedaphne calyculata* (L.) Moench (Leatherleaf) or *Andromeda polifolia* L. var. *glaucophylla* (Link) DC. (Bog rosemary). For this discussion, Open Bog has been lumped into the Scrub-Shrub general class as eight of nine observations had high abundance of low shrubs. All nine of the Open Bog observations were assessed as exceptional, which greatly contributed to the high rates of condition of the overall Scrub-Shrub class (Figure 10).

For Emergent communities (Table 4), condition estimates were generated for three of the five community types: Shallow Marsh, Sedge Mat, and Fresh Meadow (Figure 14). At the plant community scale, both the Shallow Marsh and Fresh Meadow community types were driving the broader Emergent wetland condition estimates. In particular, the Shallow Marsh community had the highest rate of poor condition of any plant community at 45%. Combined, Shallow Marsh and Fresh Meadow communities comprised approximately 63% of the Emergent wetland extent. The Sedge Mat community—a graminoid dominated community that occurs on circumneutral-weakly acidic peat that is often comprised of a floating mat of *Carex lasiocarpa* Ehrh. (Wiregrass sedge) — accounted for the majority of the remainder of the Emergent wetland extent at 30%. Condition estimates for the Sedge Mat type were somewhat different compared to the broader Emergent wetland estimates, with relatively higher shares of good and fair condition. Confidence intervals, however, were large due to small sample size (Figure 14). The Deep Marsh and Wet Prairie community types both comprised small shares of the Emergent wetland extent and had too small of a sample size to generate condition estimates.

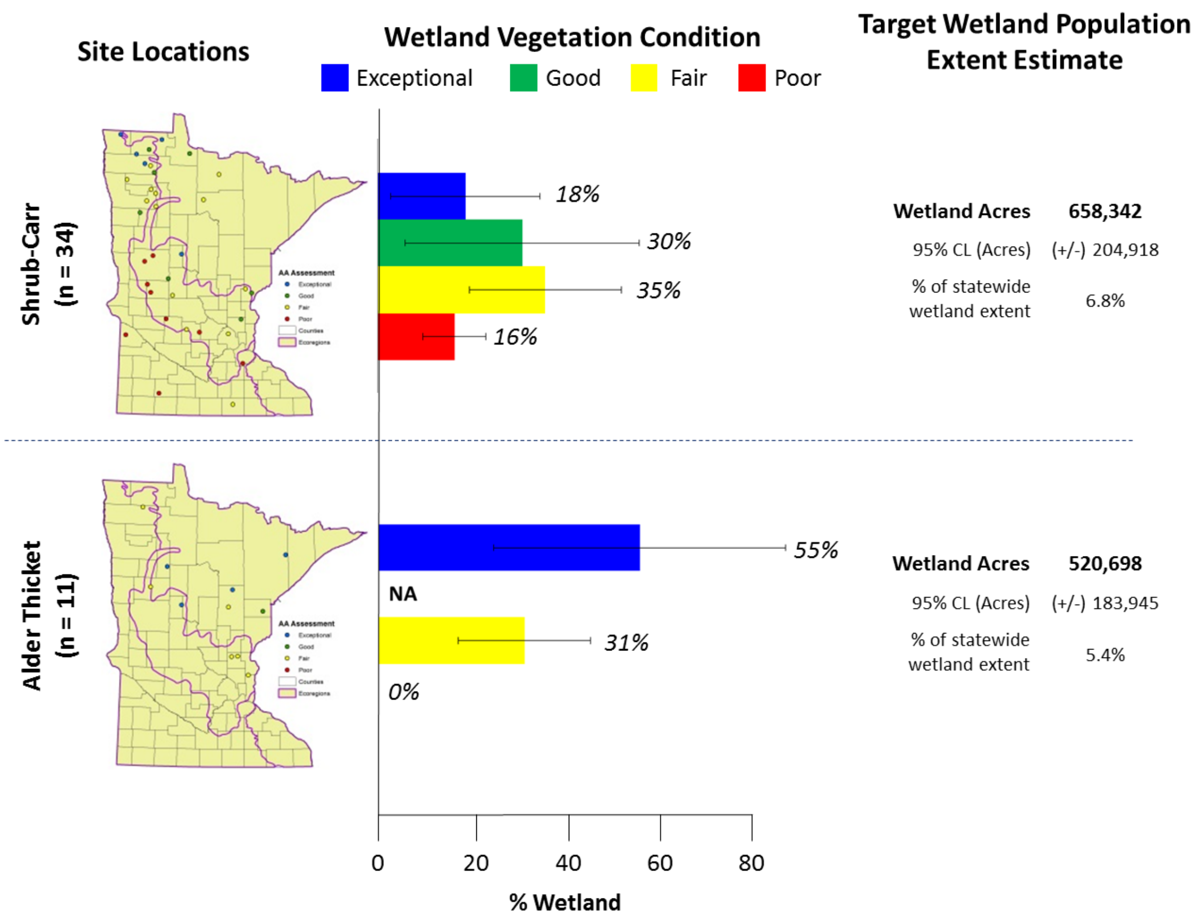


Figure 13. Site location maps, condition category proportion estimates, and target population extent estimates for the Shrub-Carr and Alder Thicket community types.

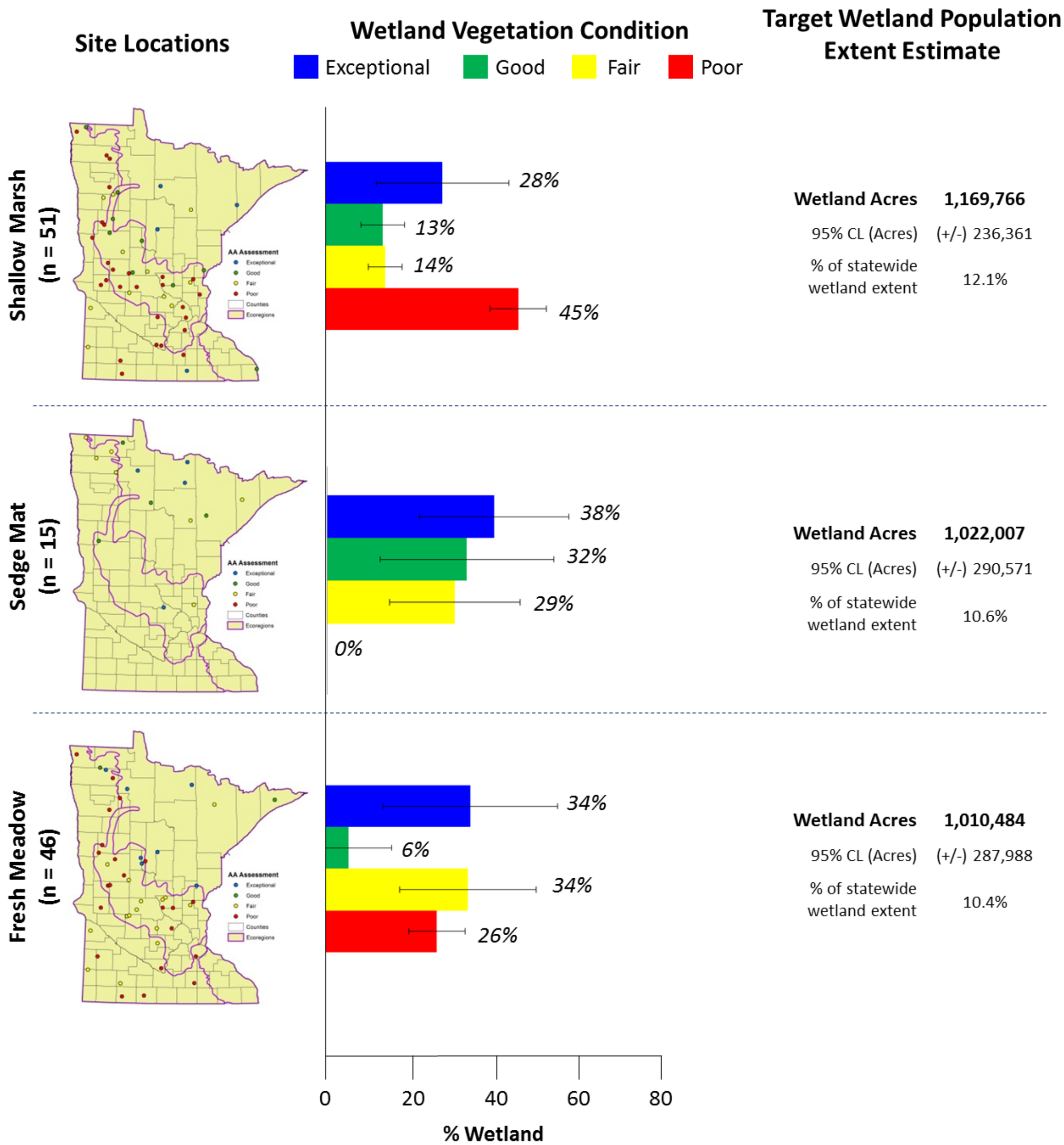


Figure 14. Site location maps, condition category proportion estimates, and target population extent estimates for the Shallow Marsh, Sedge Mat, and Fresh Meadow community types

Wetland stressors

Statewide

Overall, Minnesota's wetlands were exposed to low rates of aggregated stressors, as expressed from the HDA ratings (Figure 15). The MWCA estimated 62% (± 7%) of the survey target population were rated at the minimally impacted level. A minimally impacted rating equates to when all of the individual HDA factors were found to be low or minimal (Appendix 5)—in other words, little apparent exposure to human stressors occurred at an AA. The remainder was estimated at 19% (± 7%) moderately impacted and 19% (± 4%) severely impacted (Figure 15). Severely impacted ratings can result from either cumulative impacts (where a majority of individual HDA factors were rated as moderate-severe) or when a single direct stressor (such as a physical alteration, hydrological alteration, or non-native invasive species) had an overwhelming impact (Appendix 5). Moderately impacted HDA ratings occur in between minimal and severe. The statewide HDA estimates generally corresponded well with the vegetation condition estimates (Figure 8). This was expected due to the fundamental construct of condition assessment and the stressor-response relationship between human impacts and changes in vegetation composition and structure.

Likewise, the extent proportions of the component HDA factors were estimated at generally low levels with only small variation between factors at the statewide scale (Figure 16). The indirect Landscape Alteration and Immediate Upland Alteration factors—which attempt to account for broader land use activities that may be the source of stressors not readily observable on-site—essentially had the same category estimates, indicating that human land use practices surrounding wetlands were more or less the same at these two scales statewide. Two direct stressor factors—Physical and Hydrological Alteration—also had similar estimates at the statewide scale (Figure 16). The severe level of Physical and Hydrological Alteration occurred at lower rates compared to severe levels of the land use factors. The Invasive Species factor occurred at a significantly higher rate at the severe level compared to all other factors. This indicates that the Invasive Species category was the most widespread stressor.

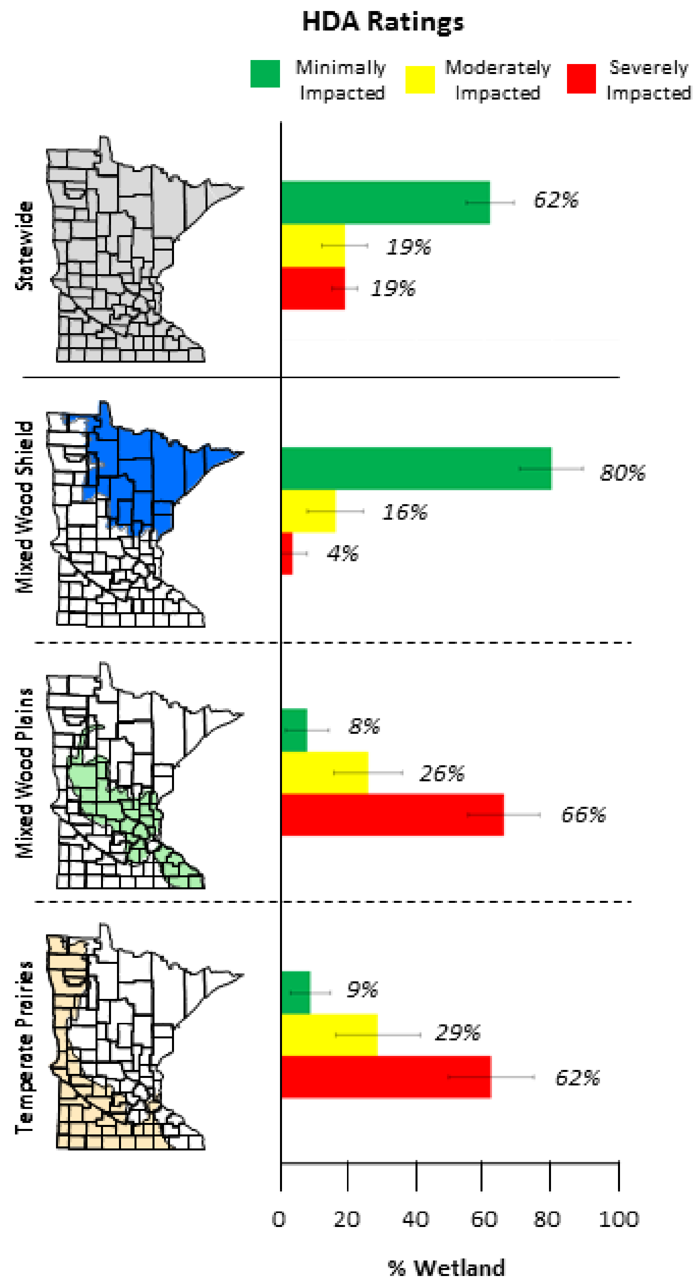


Figure 15. HDA rating proportion estimates statewide and by ecoregion.

Regional wetland stressors

As with wetland condition, there was large regional variation in the extent of wetlands exposed to stressors (Figure 15).

In the Mixed Wood Shield, aggregated stressors were very limited with 80% (± 9%) of the wetland extent rated as minimally impacted according to the HDA (Figure 15). The remainder of the Mixed Wood Shield was rated at 16% (± 8%) moderately impacted and only 4% (± 4%) was rated as severely impacted. Individual stressor factors in the ecoregion at the moderate to severe levels combined occurred at less than 10% each (Figure 16). Again, as the vast majority of Minnesota's wetlands were located in the

Mixed Wood Shield ecoregion (Figure 8) these results dominated the statewide stressor estimates—indicating that the exposure of most of Minnesota's wetlands to human impacts were relatively low. Stressors were much more widespread in the Mixed Wood Plains and Temperate Prairies ecoregions, where the clear majority of the wetland extent (> 60%) had a HDA rating of severely impacted (Figure 15). Similar to the condition results (Figure 8), aggregated HDA stressor estimates were essentially the same between these two ecoregions.

The individual HDA factors further illustrate the differences between the Mixed Wood Plains and Temperate Prairies compared to the Mixed Wood Shield in terms of stressor exposure (Figure 16). Both the Landscape and Immediate Upland Alteration factors were present at moderate to severe levels in over 50% of the wetland extent in the Mixed Wood Plains and Temperate Prairies, compared to less than 10% of the wetland extent in the Mixed Wood Shield. In terms of direct Physical Alteration, moderate to severe levels were present at approximately twice the rate in the Mixed Wood Plains and Temperate Prairies compared to the Mixed Wood Shield. The regional disparity was even greater for the Hydrologic Alteration factor at moderate to severe levels.

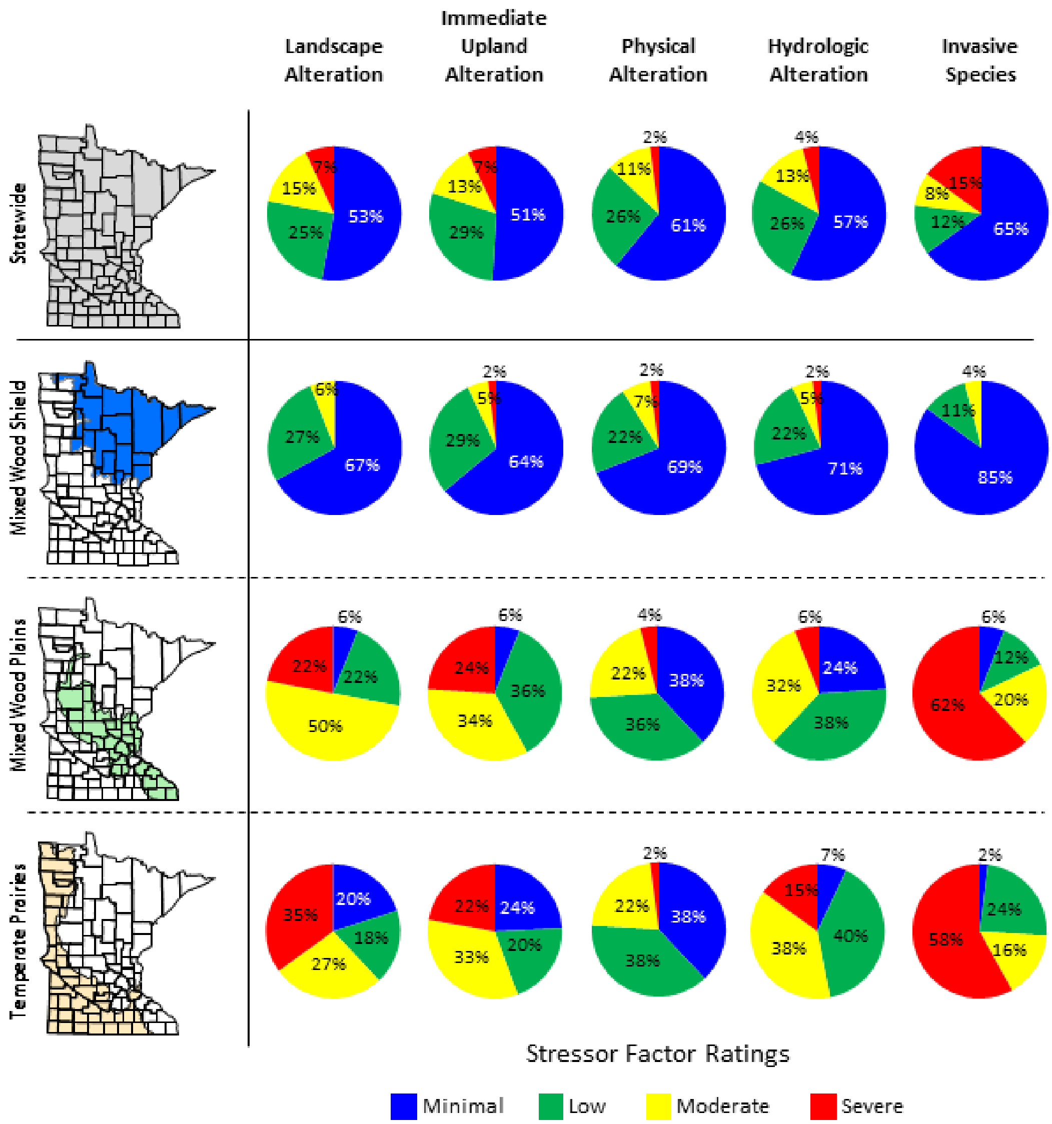


Figure 16. Individual HDA stressor factor rating wetland proportion estimates statewide and by ecoregion.

The largest regional stressor difference, however, was the non-native Invasive Species factor (Figure 16). In the Mixed Wood Plains and Temperate Prairies, the clear majority of the wetland extent had Invasive Species at the severe level. An AA was rated as severe for the factor if non-native invasive species were dominant and there was evidence of significant replacement of the native community. In contrast, none of the AA's in the Mixed Wood Shield ecoregion was rated as severe for Invasive Species. By extent, non-native Invasive Species was clearly the predominant stressor—driving the HDA estimates in these two ecoregions.

While the individual factors help provide a greater degree of detail of the various impacts that may be occurring beyond the aggregated HDA, they are somewhat abstract. They are categorizations of similar impacts that, on one hand, enable the broader analysis of human impacts to wetlands; but on the other, make it difficult to make connections between a direct human activity and wetland quality. One specific activity we were able to estimate was the proportion of wetlands that had once been plowed for agricultural production, but which (at the time of MWCA sampling) had been abandoned (or restored) and allowed to re-populate with hydrophytic vegetation. Prior plowing determinations were made from landowner accounts; direct observations of former plow furrows; and historic aerial photo-interpretation. We estimate that approximately 5% (or 472,411 acres) of Minnesota's current wetlands were at one time plowed—with elevated rates of prior-plowing in the Mixed Wood Plains (14%) and Temperate Prairies (16%). The probability of a poor vegetation condition when the AA had been prior-plowed was 0.84 with the remainder in fair condition. This suggests that if wetlands are converted to agricultural production—either temporarily or intermittently during dry conditions or through artificial drainage—and are subsequently left to revert or are passively restored back to hydrophytic vegetation, it is very likely that they will yield a poor vegetation condition.

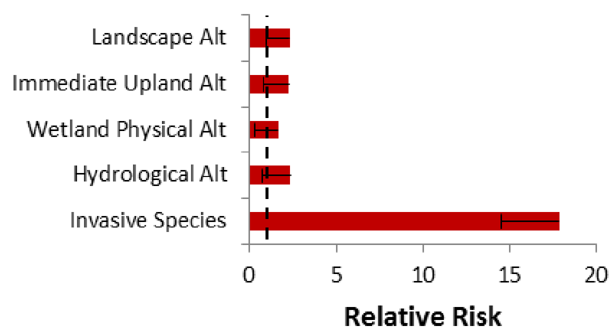


Figure 17. Relative risk of Poor condition for HDA factors in the Mixed Wood Plains and Temperate Prairies ecoregions combined. Error bars represents the lower 95% confidence limit. The dashed line has been added at relative risk equal to 1 for reference.

For the relative risk analysis, it was decided to exclude results from the Mixed Wood Shield as only a handful of severe stressor observations were present. Data from the Mixed Wood Plains and Temperate Prairies were also combined as the stressor extent estimates were so similar between the two ecoregions. Of the individual HDA stressor factors, only Invasive Species posed an elevated risk (i.e., relative risk significantly > 1) of being associated to poor wetland vegetation condition relative to the other factors (Figure 17). The relative risk of poor condition was 17.8 times greater when non-native invasive plant species were rated at the severe level.

It is important to acknowledge that some auto-correlation exists in the relative risk analysis for the Invasive Species factor. Non-native invasive species play a unique role in wetland stressor-response relationships. On one hand, they are typically conceptualized as a response to human impacts. On the other hand, non-native invasive plant species may also act as stressors in and of themselves in wetlands by becoming established through natural disturbances and then increasing in abundance even in the absence of other stressors (Galatowitsch 2012). Recognizing this dual role, during the development of the FQA it was decided to have non-native species factor directly into *wC* scores (non-native species having *C*= 0) and have the Invasive Species HDA factor incorporated FQA criteria development (Bourdaghs 2012). While this presents a certain degree of auto-correlation into the relative risk analysis, the replacement of native communities by non-native invasive species clearly fits within the larger BCG construct (EPA 2005, Bourdaghs 2012).

Secondly, a low or not-significant relative risk does not necessarily mean that a particular stressor is not associated with poor condition. In the relative risk analysis, the probabilities of poor condition when a stressor was rated as severe (which is the mathematical numerator) for all stressor categories was equal to 1 (i.e., the vegetation condition was poor at all of the observed sites when a particular stressor was severe). The reason the land use and direct alteration factors didn't have significant relative risk was due to an occurrence of moderate probabilities of poor condition when a particular stressor was rated as low (which is the denominator). This produces no relative affinity of a poor condition for any of these stressors. In addition, different types of stressors tend to co-occur which further clouds detection of relative affinity.

In summary, the regional differences observed for both wetland vegetation condition and the extent of stressors were not surprising given the landscape changes that have occurred in the Mixed Wood Plains and Temperate Prairies ecoregions. The high rates of exceptional and good wetland conditions found in the Mixed Wood Shield ecoregion were due to the low rates of human impacts that have occurred there. Much of the Mixed Wood Shield landscape is undeveloped outside of rotational logging and many of the large-scale attempts to systematically drain the extensive peatlands that occur there have often largely failed. Conversely, the high rates of fair and poor wetland conditions found in the Mixed Wood Plains and Temperate Prairies were due to stressors associated with the widespread development that has occurred in those two ecoregions.

Non-native invasive species

Given that the Invasive Species HDA factor was the most prevalent stressor in terms of extent (Figure 16) and also posed the greatest relative risk (Figure 17), further investigation of non-native species using the vegetation data was warranted. To do so, the relative non-native species cover (i.e., non-native species cover/total species cover) was calculated at the AA scale and used as a normalized metric. The focus on all non-natives was done to broaden the spectrum of the analysis as opposed to limiting to a pre-defined list of species. Relative non-native species cover distributions by condition category were then examined to determine important ranges (Figure 18). Non-native species typically represented over half of the total vegetation cover in wetlands with poor condition. Wetlands in fair condition typically had relative non-native species cover between 5-35%. The transition from fair to poor condition was approximately at 35% relative non-native species cover.

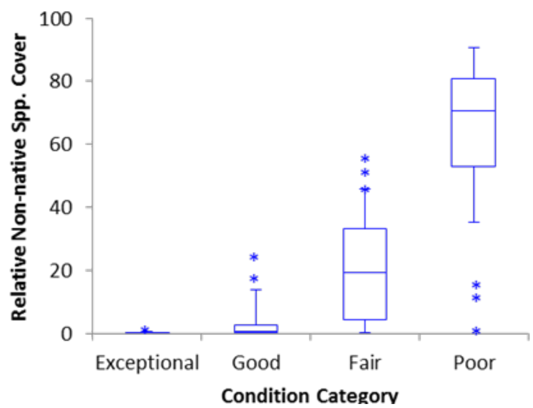


Figure 18. Box and whisker distribution plots of the relative non-native species cover by condition categories from observed results.

Not all of the observed wetlands assessed as poor condition had high non-native species cover (> 35%). There were four AAs in poor condition with < 20% relative non-native species cover (Figure 18).

These were dominated by species (largely) native to Minnesota with low *C*-values such as: *Phragmites australis* (Cav.) Trin. Ex Steud (Common reed, *C* = 1) or *Populus tremuloides* Michx. (Quaking aspen, *C* = 2).

As expected, there were large regional differences in the measured prevalence of non-native species (Figure 19). The majority of the wetland extent (56%) in the Mixed Wood Shield was completely free of non-native plant species with an additional 34% at 0-1% relative non-native species cover. The exact opposite pattern was observed in both the Mixed Wood Plains and Temperate Prairies ecoregions with most wetlands having over 35% relative non-native species cover (Figure 19).

A relative risk analysis of high non-native species cover (≥ 35%) when independent HDA factors were rated as moderate to severe versus when factors were minimal to low, showed that none of the factors posed a significantly increased relative risk of non-native species cover (Figure 20). This result doesn't necessarily indicate that a particular stressor was not associated with high non-native cover, as all factors had moderate to high probabilities of high non-native cover at moderate to severe levels (Figure 21). The non-significant relative risk was because of relatively small differences between the two constituent conditional probabilities. For example, the Landscape Alteration factor had a moderate probability of high relative non-native cover at both moderate to severe levels (0.57) and minimal to low levels (0.35). This suggests that non-native species tend to be highly abundant in wetlands surrounded by developed landscapes, but that high abundance can also occur in the general absence of landscape alterations.

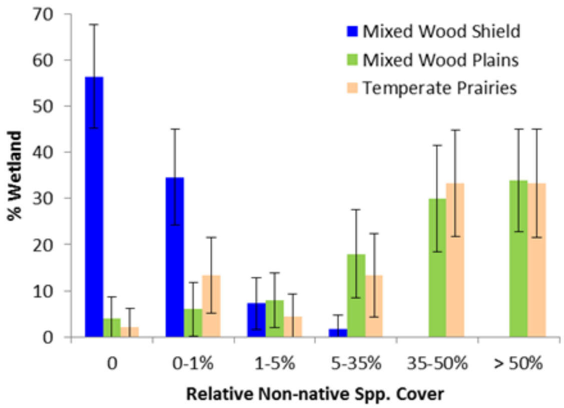


Figure 19. Proportion estimates of relative non-native species cover categories by ecoregion.

These findings suggest that the variety of stressors considered in the MWCA tend to co-occur and all promote increased abundance of non-native plant species and that it is the non-native invasive species—by increasing in abundance and ultimately replacing native species—that are the primary drivers of vegetation community change at degraded wetlands.

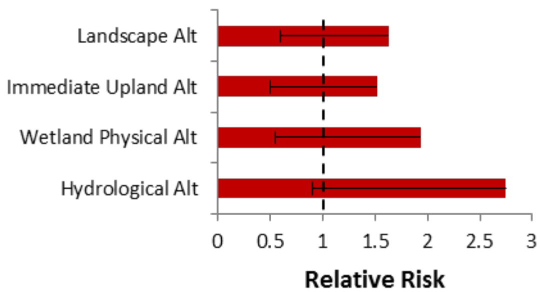


Figure 20. Relative risk of ≥ 35% relative non-native species cover for individual HDA factors in the Mixed Wood Plains and Temperate Prairies ecoregions combined. Error bars represents lower 95% confidence limit. The dashed line has been added at relative risk equal to 1 for reference.

They also tend to support the argument that increases in non-native species abundance is a response to human impacts rather than it being an independent stressor. There were, however, observed cases where non-native species cover was high when all stressors were low or absent—totaling approximately 1% (± 1%) of the statewide extent. There were also cases where non-native cover was at a moderate level (relative non-native species cover ≥ 5%) and stressors were low or absent: 12% (± 8%) of the Mixed Wood Plains and 9% (± 7%) of the Temperate Prairies wetland extent. This may have been due to historical impacts that are no longer observable or non-native invasive species becoming established and subsequently acting as an agent of change in the absence of other types of impacts. As the latter cannot be ruled out, the dual treatment of non-native invasive species as both a response to stress and stressor is supported.

Given that non-native invasive plants were the common denominator in virtually all of the degraded wetland observations, additional analyses were completed to determine which plant community types were most affected by non-native invasive species and which individual species were having the greatest effect. This can help inform natural resource managers more specifically about which wetland community types are most afflicted and/or vulnerable to impacts from non-native invasive species, as well as which species pose the greatest threats.

Estimates of the total relative non-native species cover for each community were generated at the statewide scale by pooling results from community level data (Figure 22). The top three affected communities were all emergent wetland types. Minnesota's Shallow Marshes were the most affected, with 50% of the total cover (over an estimated 1.2 million acres) comprised of non-native cover. Similarly, non-native species comprised a significant portion (35%) of the total cover in Fresh Meadows. The relative non-native species cover estimate for Wet Prairie was in between the Shallow Marsh and Wet Meadow estimates, but unreliable due to a very small sample size. The total relative non-native species cover of Minnesota's Shrub-Carrs and Floodplain Forests, which have similar hydrologic regime and soil conditions as Fresh Meadows and can be impacted by the same non-native species (though they may be light limited under a wooded canopy), was 19% and 11% respectively. The remaining communities had < 10% total relative non-native cover, which was likely due to some combination of geography (e.g., the type was predominantly in the Mixed Wood Shield where impacts and non-native propagule pressure were low) and/or current non-native species not being adapted to the particular habitat (e.g., acidic bog conditions).

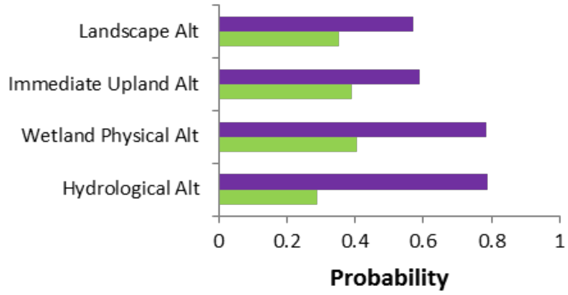


Figure 21. Conditional probabilities of ≥ 35% relative non-native species cover when HDA factors are at Moderate-Severe levels (purple) vs Minimal-Low levels (green) in the Mixed Wood Plains and Temperate Prairies ecoregions combined.

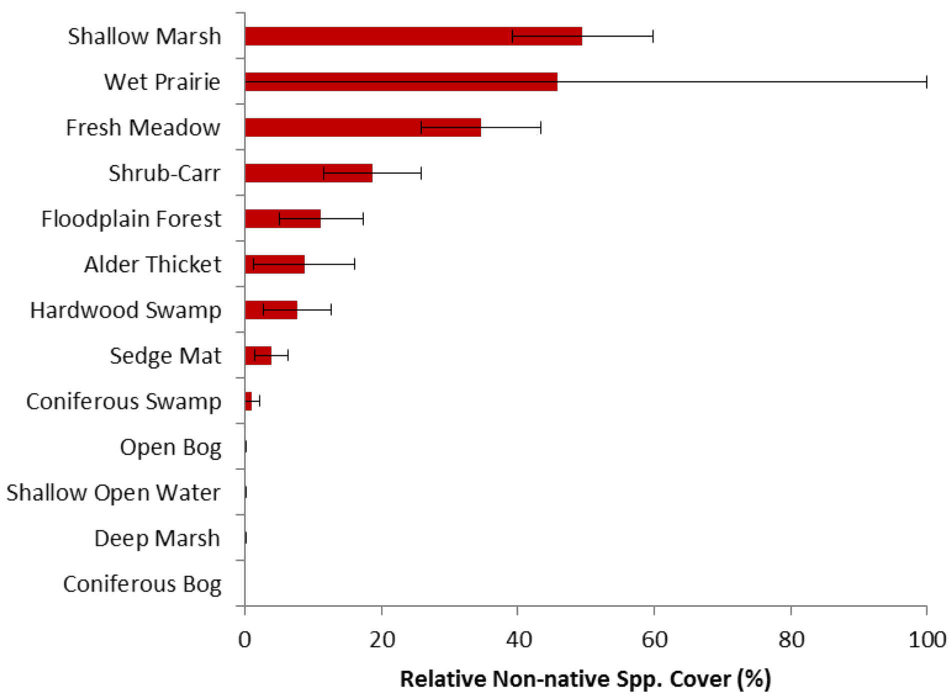


Figure 22. Total relative non-native species cover (%) by community type at the statewide scale.

For the individual species analysis, wetland proportion estimates of selected species were generated at statewide and ecoregion scales based on whether a species was merely present and when a species had high (≥ 35%) relative cover at sampled AA's. This provided the percentage of wetland acres where an individual species was simply found; as well as, the percentage of wetland acres where a species had high abundance and was potentially a primary agent of condition change, regardless of community type (Table 11).

Elevated rates of both presence and high cover for a species suggest that it was both widespread and has often replaced native species composition. In other words, these species would be causing the greatest impact to wetland vegetation condition. One species and a species-hybrid group shared these characteristics. *Phalaris arundinacea* L. (Reed canary grass—historically native to Minnesota but the vast majority of current populations are widely assumed to be Eurasian genotypes and/or cultivars; Czarapata 2005) was the most common non-native species statewide (Table 11). In the Mixed Wood Plains and Temperate Prairies ecoregions, *P. arundinacea* was present in the vast majority of the wetland area, with moderate rates of high relative abundance. Likewise, the combined grouping of *Typha angustifolia* L. (Narrow leaved cattail—which originated from Eurasia) and *Typha* x. *glauca* Godr. (Hybrid cattail—the cross between the non-native *T. angustifolia* and the native *Typha latifolia* or Broad leaved cattail) had elevated rates of presence and high abundance in the two ecoregions (Table 11). Invasive *Typha* were analyzed as a group due to the taxonomic and ecological similarities between the parent and hybrid. Both *P. arundinacea* and invasive *Typha* can tolerate a broad range of anthropogenic impacts, reproduce clonally, out-compete other vegetation to form dense monocultures, and have been well documented threats to wetland vegetation in the upper Midwest (Galatowitsch et al. 1999, Kercher and Zedler 2004, Czarapata 2005, Galatowitsch 2012). *P. arundinacea* prefers moist soil and an open canopy and was the predominant component of the total relative non-native cover in Fresh Meadows; whereas, invasive *Typha* prefers saturated to inundated soil conditions and comprised the majority of the total non-native cover in Shallow Marshes. Fresh Meadow and Shallow Marsh were two of the most affected community types (Figure 22).

Table 11. Proportion estimates of selected species when present and when the species was at high relative cover (≥ 35%) statewide and by ecoregion.

	Statewide % wetland		Mixed Wood Shield % wetland		Mixed Wood Plains % wetland		Temperate Prairies % wetland	
Species	**Present**	**High Cover**	**Present**	**High Cover**	**Present**	**High Cover**	**Present**	**High Cover**
Phalaris arundinacea	35	4	18		88	20	73	11
Cirsium arvense	26		18		42		62	
Invasive *Typha*[*]	14	7			52	26	62	27
Phragmites australis[+]	13	< 1	9		28	2	20	
Rhamnus cathartica	10		2		38		29	
Frangula alnus	3				16			
Lythrum salicaria	2				12			

[*]Data for Typha angustifolia and T. x glauca combined

[+]Only the native genotype was observed during the MWCA

Elevated rates of presence with low occurrence of high cover suggest that a particular species was widespread, but was only rarely replacing native species. *Cirsium arvense* (L.) Scop. (Canada thistle), which was the second most frequently observed non-native species statewide, fits this profile (Table 11). Similarly, *Rhamnus cathartica* L. (Common buckthorn), which was present at 10% of Minnesota's wetlands but with higher rates in the Mixed Wood Plains and Temperate Prairies (Table 11), may also be consistent with this characterization. These species may be emerging threats to wetland vegetation condition, but more likely their ability to reach high abundance in wetlands is limited by soil moisture, as optimal conditions for these two species have been observed to be in upland soil types (Czarapata 2005, Smith 2008). *Phragmites australis* (Common reed) was also similarly widespread and though it can form monocultures, it was rarely observed at high abundance (Table 11). Similar to *P. arundinacea*, native and non-native genotypes of *P. australis* occur in the state; however, *P. australis* genotypes can be reliably field identified. Only the native *P. australis* genotype was observed in the MWCA, suggesting that the non-native genotype has not yet become very well established in Minnesota's wetlands.

Finally, low rates of presence and high cover suggest species that currently are not having much of an overall negative effect on Minnesota's wetland vegetation condition. Both *Frangula alnus* Mill. (Glossy buckthorn) and *Lythrum salicaria* L. (Purple loosestrife) were both observed only at low rates of presence in the Mixed Wood Plains ecoregion. While neither of these species were observed to be widespread in the MWCA, they may pose a future threat to wetland vegetation condition. *Frangula alnus* was likely introduced in the Twin Cities area in the 1930's and is slowly expanding its range from the eastern counties. Unlike *R. cathartica*, *F. alnus* prefers wetland habitats and can displace native wetland vegetation in a variety of community types (Smith 2008). *Lythrum salicaria* is a well-documented invader in upper Midwest wetlands that can form monocultures and displace native vegetation (Czarapata 2005) and is a controlled noxious weed in the state. The DNR Purple Loosestrife Management program has documented that it is widespread geographically in the state (present in 77 of 87 counties). MWCA results, however, suggest that *L. salicaria* has yet to become widely established in the broader wetland population and impacts are likely local in nature or limited to edge habitats (e.g., roadside ditches, shorelines) at this time.

Water chemistry

Water chemistry samples were collected (i.e., sampleable water > 15 cm in depth was present) at 63 of the 150 AA's. These were regionally distributed as follows: Mixed Wood Shield = 12; Mixed Wood Plains = 29; and Temperate Prairies = 22. Statewide and regional subpopulation estimates were not generated for the water chemistry results due to the limited number of samples. Alternatively, box-plot distributions for 5 selected parameters suggest that there may be some regional water chemistry differences (Figure 23).

Median total phosphorus concentrations were greater in the Mixed Wood Plains and Temperate Prairies ecoregions compared to the Mixed Wood Shield (Figure 23A). Both Kjeldahl nitrogen and nitrate-nitrate had similar distributions across ecoregions, with greater variability in the upper range concentrations in the Mixed Wood Plains and Temperate Prairies (Figure 23B-C). Median chloride concentrations increased from the Mixed Wood Shield to Mixed Wood Plains to Temperate Prairies (Figure 23D), which may be partially driven by a natural saline gradient in Minnesota surface waters that corresponds with underlying geology and an evapotranspiration gradient increasing from the northeast to the southwest (Moyle 1956). Similarly, median transparency increased from the Mixed Wood Shield to Mixed Wood Plains to Temperate Prairies (Figure 23E), suggesting increased water clarity in the more developed ecoregions. The transparency tube measurement does not take into account color from dissolved organic matter (DOM). The ecoregion differences in median transparency values may be due to increasing DOM from southwest to northeast Minnesota (where surface waters are often heavily stained). The Temperate Prairies ecoregions showed the largest range and lowest transparency values, followed by the Mixed Wood Plains, and Mixed Wood Shield. This suggests that when turbid water states occurred, they were more severe in the more developed ecoregions.

It should be acknowledged that the water chemistry results were complicated by the fact that samples were taken in a wide variety of settings including: open water features that may be ponded or flowing; under a canopy of herbaceous vegetation with abundant leaf litter; or even in hollows created by fallen trees. The water may have been a permanent feature or only present due to recent rainfall. The ultimate goal in sampling water chemistry would be to detect the deviation of parameters from natural conditions attributable to human impacts. The approach adopted in the MWCA allowed for too much inconsistency making meaningful interpretations problematic.

Future work by the MPCA to characterize wetland water chemistry will focus on semi-permanent to permanent open water wetlands such as was done for the depressional wetland survey (Genet 2012, Genet *in prep*).

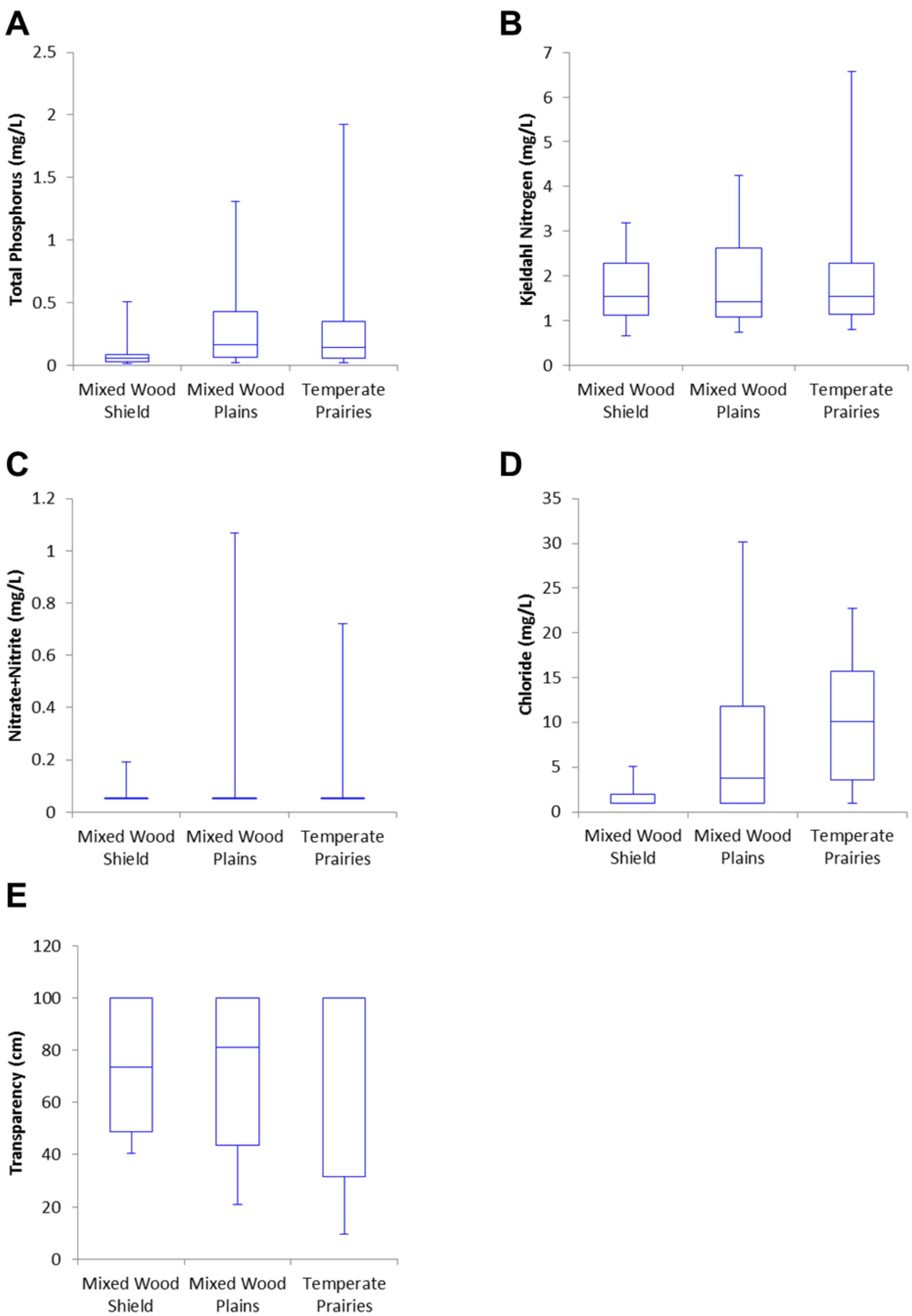


Figure 23. Box and whisker plots of selected water chemistry parameters by ecoregion:
A) Total Phosphorus, B) Kjeldahl Nitrogen, C) Nitrate-Nitrite, D) Chloride, and E) Transparency.

Conclusions

Overall, the current baseline vegetation quality and biological diversity of Minnesota's wetlands is high. This is being driven by the large share of wetlands in the northern part of the state—where human impacts are generally low.

This doesn't mean that there aren't concerns. Wetland vegetation quality and biological diversity outside of the northern forest—roughly two-thirds of the state—is largely degraded. The loss of quality is being driven primarily by increases in non-native invasive plant species abundance that is often associated with a broad spectrum of human impacts. Two emergent wetland communities (Fresh Meadow and Shallow Marsh) and the Shrub-Carr community are the most affected kinds of wetlands. In degraded wetlands, *Phalaris arundinacea* (Reed canary grass) and invasive *Typha* (Cattails) are the predominant non-native plants causing changes.

While this is the first effort to quantify wetland quality in Minnesota at this scale and scope, the regional variation in vegetation quality is not surprising. The differences in regional development in the state are obvious. There is a corresponding history of wetland drainage and filling that has resulted in the most of the wetlands (> 99% in a number of counties) in the former prairie and hardwood forest regions to simply be gone. We also know that the water quality of lakes (Heiskary and Lindon 2010), biological condition of streams (Lueck and Niemela 2014), and the quality of depressional wetlands (Genet 2012) correspond with the broad patterns of development. In addition, the significant threat that non-native invasive plants pose to wetland vegetation quality in the upper Midwest (Galatowitsch et al. 1999, Czarapata 2005) has been recognized for at least several decades.

Even though the regional patterns were predictable, it is important to continue quantifying wetland quality over time (in conjunction with the DNR quantity survey) to assess the implementation of the no-net-loss policy. For example, we estimate that a significant portion of the wetlands in the former prairie and hardwood forest regions of the state have been cultivated at some point in time. Agricultural practices on certain types of wetlands are largely exempt from regulation but are alternatively discouraged through the Swampbuster provisions of the federal farm program. Although actively cultivated wetlands were not directly measured in the MWCA, our observations indicate that when prior plowed wetlands are left to revert to hydrophytic vegetation (or are passively restored) the vegetation quality is predominantly poor. This is a relevant finding given that DNR has found a significant conversion of emergent wetlands to cultivated wetlands between 2006 and 2011 (Kloiber and Norris 2013).

In addition, it is important to recognize that the plant community changes that occur, not only at prior plowed wetlands, but also at wetlands exposed to virtually any variety of impact, are typically not self-correcting (Aronson and Galatowitsch 2008). In other words, when non-native invasive species become abundant in a wetland, direct management of the vegetation itself is often required in addition to correcting external impacts to reestablish native composition and abundance distributions. The enhancement of degraded vegetation including: site preparation, planting, seeding, weed control, and monitoring can take many years, thousands of hours of work, and continued maintenance to achieve results that could approach a good condition (Bohnen and Galatowitsch 2005).

Ultimately, given the expense of restoration and enhancement a greater emphasis on protection would be an appropriate approach to further promote the no-net-loss of wetland quality and biological diversity of Minnesota's wetlands.

The MPCA intends to continue the MWCA and the depressional wetland surveys to monitor trends in wetland quality on a 5-year rotation and in conjunction with EPA's NWCA. Field sampling for the next iteration of the MWCA is scheduled to begin in 2016.

Literature cited

Acerman, M. and J. Holden. 2013. How wetlands affect floods. Wetlands 33:773-786.

Adamus, P., T.J. Danielson, and A. Gonyaw. 2001. Indicators for Monitoring Biological Integrity of Inland, Freshwater Wetlands—A Survey of North American Technical Literature (1990-2000). EPA843-R-01. U.S. Environmental Protection Agency, Office of Water, Wetlands Division. Washington, DC.

Anderson, J.P. and W.J. Craig. 1984. Growing Energy Crops on Minnesota's Wetlands: The Land Use Perspective. University of Minnesota, Minneapolis, MN.

Aronson, M.F. and S.M. Galatowitsch. 2008. Long-term vegetation development of restored prairie pothole wetlands. Wetlands 28:883-895.

Bohnen, J.L. and S.M. Galatowitsch. 2005. Spring Peeper Meadow: Revegetation practices in a seasonal wetland restoration in Minnesota. Ecological Restoration 23:172-181.

Bourdaghs, M. 2012. Development of a Rapid Floristic Quality Assessment. wq-bwm2-02a. Minnesota Pollution Control Agency, St. Paul, MN.

Bourdaghs, M, C.A Johnston, and R.R. Regal. 2006. Properties and performance of the floristic quality index in Great Lakes coastal wetlands. Wetlands 26:718-735.

Cohen, M.J., S. Carstenn, and C.R. Lane. 2004. Floristic quality indices for biotic assessment of depressional marsh condition in Florida. Ecological Applications 14:784-794.

Cowardin L., V. Carter, F. Golet, and E. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Department of the Interior, Fish and Wildlife Service. Washington, DC.

Czarapata, E.J. 2005. Invasive Plants of the Upper Midwest: An Illustrated Guide to their Identification and Control. The University of Wisconsin Press, Madison, WI.

Dahl, T.E. 2011. Status and Trends of Wetlands in the Conterminous United States 2004 to 2009. U.S. Department of Interior, Fish and Wildlife Service. Washington, DC.

Eggers, S.D. and D.M. Reed. 2011. Wetland Plants and Plant Communities of Minnesota and Wisconsin (3rd Ed). US. Army Corps of Engineers, St. Paul District. St. Paul, MN.

Frayer, W.E., T.J. Monahan, D.C. Bowden, and F.A. Graybill. 1983. Status and trends of wetlands and deepwater habitats in the conterminous United States: 1950's to 1970's. Colorado State University. Fort Collins, CO.

Galatowitsch, S.M. 2012. Why invasive species stymie wetland restoration. SWS Research Brief. 2012-0001.

Galatowitsch, S.M., N.O. Anderson, and P.D. Ascher. 1999. Invasiveness in wetland plants in temperate North America. Wetlands 19:733-755.

Genet, J.A. 2007. Minnesota Depressional Wetland Quality Assessment: Survey Design Summary (2007-2009). wq-bwm6-05. Minnesota Pollution Control Agency. St. Paul, MN.

Genet, J.A. 2012. Status and Trends of Wetlands in Minnesota: Depressional Wetland Quality Baseline. wq-bwm1-06. Minnesota Pollution Control Agency. St. Paul, MN.

Genet, J.A. and M. Bourdaghs. 2006. Development and Validation of Indices of Biological Integrity (IBI) for Depressional Wetlands in the Temperate Prairies Ecoregion. Minnesota Pollution Control Agency. Part of Final Report to EPA Assistance # CD-975768-01.

Genet, J.A. and M. Bourdaghs. 2007. Development of Preliminary Plant and Macroinvertebrate Indices of Biological Integrity (IBI) for Depressional Wetlands in the Mixed Wood Shield Ecoregion. Minnesota Pollution Control Agency, Part of Final Report to EPA Assistance # CD-965084-01.

Gernes, M.C. and J.C. Helgen. 2002. Indexes of Biological Integrity (IBI) for Large Depressional Wetlands in Minnesota. Minnesota Pollution Control Agency. Final Report to EPA Assistance # CD-995525-01.

Gernes, M. and D.J. Norris. 2006. A Comprehensive Wetland Assessment, Monitoring, and Mapping Strategy for Minnesota. wq-bwm6-03. Minnesota Pollution Control Agency. St. Paul, MN.

Heiskary, S. and M. Lindon. 2010. Minnesota National Lakes Assessment Project: An overview of water chemistry in Minnesota lakes. wq-nlap1-05. Minnesota Pollution Control Agency. St. Paul, MN.

Johnston, C.A. 1991. Sediment and nutrient retention by freshwater wetlands: effects on surface water quality. Critical Reviews in Environmental Control 21:491-565.

Jordan, T.E., M.P. Andrews, R.P. Szuch, D.F. Whigham, D.E. Weller, and A.D. Jacobs. 2007. Comparing functional assessments of wetlands to measurements of soil characteristics and nitrogen processing. Wetlands 27:479-497.

Karr, J.R. and D.R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Management 5:55-68.

Kercher, S.M. and J.B. Zedler. 2004. Multiple disturbances accelerate invasion of reed canary grass (*Phalaris arundinacea* L.) in a mesocosm study. Oecologia 138:455-464.

Kincaid, T.M., and A.R. Olsen. Spsurvey: Spatial survey design and analysis. R package version 3.1.1.

Kloiber, S.M. 2010. Status and Trends of Wetlands in Minnesota: Wetland Quantity Baseline. Minnesota Department of Natural Resources. St. Paul, MN.

Kloiber, S.M. and Norris, D.J. 2013. Status and Trends of Wetlands in Minnesota: Wetland Quantity Trends from 2006 to 2011. Minnesota Department of Natural Resources. St. Paul, MN.

Kloiber, S.M, M. Gernes, D. Norris, S. Flackey, and G. Carlson. 2012. Technical Procedures for the Minnesota Wetland Status and Trends Program: Wetland Quantity Assessment. Minnesota Department of Natural Resources. St. Paul, MN.

Lopez, R.D. and M.S. Fennessy. 2002. Testing the floristic quality assessment index as an indicator of wetland condition. Ecological Applications 12:487-497.

Lueck, A. and S. Niemela. 2014. The Condition of Rivers and Streams in Minnesota—Based on Probabilistic Surveys, 1995-2011. wq-bsm1-08. Minnesota Pollution Control Agency. St. Paul, MN.

Mack, J.J. 2004. Integrated Wetland Assessment Program Part 4: Vegetation index of biotic integrity (VIBI) and tiered aquatic life uses (TALUs) for Ohio wetlands. Ohio Environmental Protection Agency, Division of Surface Water, Wetland Ecology Group, Columbus, OH, USA. Technical Report WET/2004-4.

Mack, J.J. and M.E. Kentula. 2010. Metric Similarity in Vegetation-Based Wetland Assessment Methods. EPA/600/R-10/140. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Maltby, E. 2009. Functional Assessment of Wetlands—Towards Evaluation of Ecosystem Services. Woodhead Publishing. Sawston, Cambridge, UK.

McLaughlin, D.L. and M.J. Cohen. 2013. Realizing ecosystem services: wetland hydrologic function along a gradient of ecosystem condition. Ecological Applications 23 1619-1631.

Milburn, S.A., M. Bourdaghs, J.J. Husveth. 2007. Floristic Quality Assessment for Minnesota Wetlands. Minnesota Pollution Control Agency, St. Paul, MN.

Miller, S.J. and D.H. Wardrop. 2006. Adapting the floristic quality assessment index to indicate anthropogenic disturbance in central Pennsylvania wetlands. Ecological Indicators 6: 313-326.

Mitsch, W.J. and Gosselink, J.G. 2000. Wetlands (3rd ed). John Wiley and Sons. New York, NY.

Minnesota Department of Natural Resources (MN DNR). 2005. Field Guide to the Native Plant Communities of Minnesota: The Prairie Parkland and Tallgrass Aspen Parklands Provinces. Ecological Land Classification Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program. MNDNR St. Paul, MN.

Minnesota Department of Natural Resources (MN DNR). 2009. Guidelines for Assigning Statewide Biodiversity Significance Ranks to Minnesota County Biological Survey Sites. Minnesota County Biological Survey, Minnesota Department of Natural Resources. St. Paul, MN.

Minnesota Department of Natural Resources (MN DNR). 2013. Tamarack Assessment Project. Division of Forestry, Minnesota Department of Natural Resources. St. Paul, MN.

Minnesota Pollution Control Agency. 2014. Rapid Floristic Quality Assessment Manual. wq-bwm2-02b. Minnesota Pollution Control Agency. St. Paul, MN.

Moyle, J.B. 1956. Relationships between the chemistry of Minnesota surface waters and wildlife management. Journal of Wildlife Management, 20:303-320.

Rocchio, J. 2007. Floristic Quality Indices for Colorado Plant Communities. Colorado Natural Heritage Program, Colorado State University, Fort Collins, CO.

Scozzafava, M. M.E. Kentula, E. Riley, T.K. Magee, G. Serenbetz, R. Sumner, C. Faulkner, and M. Price. 2011. The National Wetland Condition Assessment: National data on wetland quality to inform and improve wetlands protection. National Wetlands Newsletter 33 11:13.

Smith, W.R. 2008. Trees and Shrubs of Minnesota. University of Minnesota Press. Minneapolis, MN.

Smith, R.D., A. Ammann, C. Bartoldus, and M.M. Brinson. 1995. An Approach for Assessing Wetland Functions Using Hydrogeomorphic Classification, Reference Wetlands, and Functional Indices. Wetlands Research Program Technical Report WRP-DE-9. Wetlands Research Program, US Army Corps of Engineers Waterways Experiment Station. Vicksburg, MS.

Stelk, M.J. and J. Christie. 2014. Ecosystem Service Valuation for Wetland Restoration: What is is, How to do it, and Best Practice Recommendations. Association of State Wetland Managers. Windham, ME.

Stevens, D.L. Jr. and A.R. Olsen. 2004. Spatially-balanced sampling of natural resources. Journal of the American Statistical Association. 99:262-277.

Stevenson, R.J. and F.R. Hauer. 2002. Integrating hydrogeomorphic and index of biological integrity approaches for environmental assessment of wetlands. Journal of the North American Benthological Society 21:502-513.

Swink, F.A. and G.S. Wilhelm. 1994. Plants of the Chicago Region, fourth edition. Morton Arboretum, Lisle, IL.

Taft, J.B., G.S. Wilhelm, D.M. Ladd, and L.A. Masters. 1997. Floristic quality assessment for vegetation in Illinois: a method for assessing vegetation integrity. Erigenia 15:3-95.

U.S. Environmental Protection Agency (US EPA). 2005. Use of Biological Information to Better Define Designated Aquatic Life Uses in State and Tribal Water Quality Standards: Tiered Aquatic Life Uses. Office of Science and Technology, U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency (US EPA). 2011a. National Wetland Condition Assessment: Site Evaluation Guidelines. EPA 843-R-10-004. Office of Water, Office of Environmental Information, U.S Environmental Protection Agency. Washington, DC.

U.S. Environmental Protection Agency (US EPA). 2011b. National Wetland Condition Assessment: Field Operations Manual. EPA 843-R-10-001. Office of Water, Office of Environmental Information, U.S Environmental Protection Agency. Washington, DC.

U.S. Environmental Protection Agency (US EPA). 2011c. National Wetland Condition Assessment: Quality Assurance Project Plan. EPA 843-R-10-003. Office of Water, Office of Environmental Information, U.S Environmental Protection Agency. Washington, DC.

Van Sickle, J. and S.G. Paulsen. 2008. Assessing the attributable risks, relative risks, and regional extent of aquatic stressors. Journal of the North American Benthological Society 27:920-931.

White, D. and J.M. Omernik. 2007. Minnesota level III and IV ecoregion map. National Health and Environmental Effects Research Laboratory, Western Ecology Division, U.S. Environmental Protection Agency. Corvallis, OR.

Appendix 1-Site evaluation results

Table 12. Site evaluation results for all points. Evaluation category descriptions are provided in Table 2.

	Statewide		Mixed Wood Shield		Mixed Wood Plains		Temperate Prairies	
Category	**Number**	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**
Target Sampled	150	71	55	83	50	74	45	59
Access Permission Denied	25	12	8	12	8	12	9	12
Physically Inaccessible	2	< 1	2	3	0	0	0	0
Map Error	10	5	0	0	4	6	6	8
Active Crop Production	13	6	0	0	1	2	12	16
Inundated by Water > 1m in Depth	2	< 1	0	0	2	3	0	0
Industrial/Agricultural/Aquacultural Purpose	1	< 1	0	0	0	0	1	1
Sampleable Area Too Small	7	3	1	2	3	4	3	4
Total Points Evaluated (% of Statewide total)	210 (100%)		66 (31%)		68 (32%)		76 (36%)	

- The design goal was to allocate target sampled sites (i.e., actual target wetland was located < 60 m from the original Point; an AA could be established; the site could be physically accessed; and permission was granted) as evenly as possible by ecoregion. In the end, fewer sites met the Target Sampled criteria in the Temperate Prairies (45) and were ultimately replaced by sites in Mixed Wood Shield (55).
- Private landowners hold a relatively greater share of the land in the Mixed Wood Plains and Temperate Prairies, raising concerns that higher rejection rates from private landowners in these ecoregions may be causing the regional shift in target sampled sites. Permission denial rates, however, were essentially the same for all three ecoregions.
- There were slightly higher rates of map errors (i.e., mapped as wetland in the sample frame but not actually wetland) in the Mixed Wood Plains and Temperate Prairies. There was also a higher rate of points located in cultivated wetlands in the Temperate Prairies ecoregion. These account for the shifting of target sampled sites from the Temperate Prairies to the Mixed Wood Shield.
- The unbalanced ecoregion sample numbers likely has only a very minor effect on the statewide confidence intervals as it is the weights primarily derived from the sample frame that are used to aggregate the results.

Table 13. Point category results from the target sampled sites.

	Statewide		Mixed Wood Shield		Mixed Wood Plains		Temperate Prairies	
Category	**Number**	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**
Original Point Sampleable	130	87	50	91	42	84	38	84
Point Re-located	20	13	5	9	8	16	7	16

- Target sampled points were located on target wetland at original locations at high rates.
- Re-location (i.e., when original were not actually located on target wetland, but target wetland was present within 60 m) rates were slightly higher in the Mixed Wood Plains and Temperate Prairies, likely due to wetlands having smaller size with greater edge effects; as well as, higher rates of map errors and cultivated wetlands present that would require point shifting to establish AA's.

Table 14. AA layout results. AA category descriptions are provided in Table 1.

	Statewide		Mixed Wood Shield		Mixed Wood Plains		Temperate Prairies	
AA Category	**Number**	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**
Standard AA	69	46	36	65	17	34	16	36
Standard AA-Shifted	47	31	14	25	19	38	14	31
Polygon AA	28	19	4	7	11	22	13	29
Wetland Boundary AA	6	4	1	2	3	6	2	4
Target Sampled AAs (% of Statewide total)	150 (100%)		55 (37%)		50 (33%)		45 (30%)	

- Standard AA's or shifted circular AA's (which were relatively easier to establish in the field) were established at the vast majority of the Target Sampled sites—77% overall. The rate was highest in the Mixed Wood Shield at 91%.
- Polygon AA's were needed at higher rates in the Mixed Wood Plains and Temperate Prairies. Again this was likely due to the prevalence of smaller wetlands with greater edge requiring greater use of polygon AA layouts.

Appendix 2-National and Minnesota vegetation sampling comparison

Background

The meander vegetation sampling approach employed at the intensification sites—where plant communities were first delineated (Table 4, Figure 4) and the observer then meanders through the AA, recording species and cover estimates by community type—differs from the NWCA approach. The NWCA vegetation sampling protocol calls for making vegetation observations within 5 regularly placed 10 x 10 m plots (Figure 24). Meander vegetation was collected at 18 of the 22 NWCA sites to facilitate a comparison between the two approaches. The goal of the comparison was to determine if the NWCA sampling approach provides sufficient or equivalent data such that NWCA collected data can be directly incorporated into the MWCA dataset.

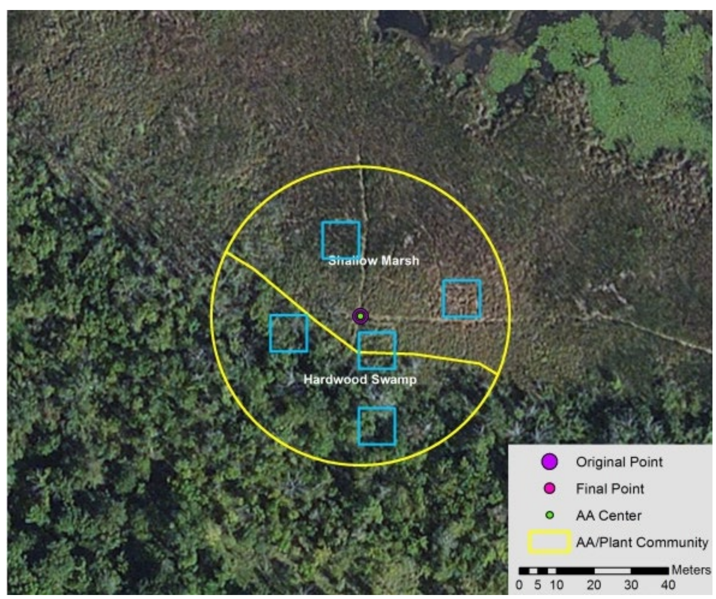


Figure 24.The standard NWCA vegetation plot (10 x 10 m) layout (blue outlines).

To make the comparison, further classification and aggregation of the NWCA data was necessary. Each NWCA plot within an AA was assigned to a community type (Table 4) according to the community mapping (Figure 24). In cases where a plot crossed over the boundary of mapped communities, the data were reviewed and the plot was assigned to the most prevalent community. Data were then aggregated to the AA scale by averaging the midpoint cover of each species over plots, by community. *wC* was then calculated for each community type as described in the methods section. Outcomes from both the NWCA and meander sampling were then compared.

Results and discussion

- 27 plant communities were identified, sampled, and mapped with the meander sampling at the 18 sites.
- While NWCA plots were well distributed in AA's, they failed to detect a community at three of the sites (17%) where a community was identified from the meander sampling. Differing community interpretations (which this is similar to) can lead towards variation in FQA metrics and assessment outcomes (Bourdaghs 2012); however, in each of these cases the condition category generated from the NWCA approach was the same as the meander approach.
- The average *wC* score absolute difference between NWCA and meander sampling in the same community was 0.27. This is about 5-7% of the typical effective range of *wC* scores for a community and is similar to results from repeated FQA samples from the same site (Bourdaghs 2012). The Large *wC* score differences (> 0.6) occurred at three communities (13%)
- In terms of assessment outcomes at the community level, it was expected that the likelihood of producing a different condition category (Table 8) increases as differences in *wC* scores increases (though it is also related to how close scores are to assessment criteria by chance). Only two differences (8%) in condition category were produced between the NWCA and meander sampling. In other words, NWCA sampling produced the same community assessment outcome as meander sampling 92% of the time. One of these assessment outcome differences had a large *wC* score difference (0.8).
- The assessment outcome differences did translate up to the aggregated AA level (Figure 7)—where two AA's had different overall condition categories (11%).

Based on the above results it was concluded that NWCA plot data produces consistent enough results to be incorporated into the MWCA dataset.

Appendix 3-Site level QA/QC results

As a QA/QC measure, 10% of the sites (n = 15) were re-sampled using the full sampling protocol. Replicate sites were primarily chosen based on their random selection order. Exceptions were made for sites that were very difficult to access (e.g., by helicopter), in which case the next site on the list was chosen. Replicate samples occurred at least 2 weeks after the primary sample and were often completed by a different sampling crew (n = 13).

Results and discussion

- AA establishment or layout procedural errors occurred at 2 sites (18%). This happened when the sampling crew that made the primary sample did not follow the correct AA establishment procedure and inappropriately shifted the AA or used an inappropriate layout.
- Primary and replicate crews interpreted the plant communities within AA's consistently (both in terms of type and extent) at 10 sites (67%).
- Agreement of assessment outcomes at the AA level (i.e., the same condition category from primary and replicate samples) occurred at only 8 AA's (53%).

- There were 21 paired plant communities at the 15 sites. Assessment outcome agreement occurred at 14 of the communities (67%). The average absolute *wC* score difference at the paired communities was 0.54. This was twice as large as what was observed in the method comparability trial (Appendix 2) and represents about 11-14% of the effective *wC* range for a community type.

The low (53%) rate of condition category agreement at the AA scale was not expected. This was a result of a number of moderate-large differences in *wC* scores at the community level, which increases the likelihood of a replicate sample producing a different condition category. Chance alone was also a factor, where a particular community may have happened to score near a condition category threshold making it likely to change categories even with a small variation in *wC* scores.

There were clear cases where AA establishment procedural errors or differences in community interpretation caused the variation (n = 3). When this occurred, the end result was essentially the same—the primary and replicate observations were looking at fundamentally different vegetation types. This can cause large variation in *wC* scores and different assessment outcomes (Bourdaghs 2012).

It is important to keep in mind that this effort was the first time employing these types of AA's and applying FQA on interpreted vegetation community types by MPCA wetland monitoring crews was also relatively new (Bourdaghs 2012). Greater effort will be put towards training and periodically auditing field crews during the field season to minimize procedural errors and interpretation inconsistencies in future survey iterations.

Appendix 4-Plant voucher specimen QA/QC results

Accurate plant identification is a key requirement of the MWCA. The MPCA adopted a number of components from EPA's Quality Assurance Project Plan (EPA 2011c) to help ensure that high quality vegetation data were being collected. This included:

- Collecting five randomly selected field voucher specimens from known/identified plant species from each site. Field voucher specimens were submitted to the University of Minnesota Herbarium at the Bell Museum of Natural History for independent identification/verification.
- Collecting plants that could not be not be identified to the species level in the field as unknown specimens and making further attempts to identify them at the MPCA lab.
- Randomly selecting 10% of the lab identified plants as lab vouchers and submitting to the University of Minnesota Herbarium for independent identification/verification

Our goals for plant identification QA/QC were to:

- Minimize collection errors and achieve completeness rates ≥ 90%
- Minimize identification errors in the field and in the lab and achieve taxonomic disagreement rates ≤ 15%
- Generate a greater understanding of how often unknown specimens are being collected, which require lab effort to identify

Table 15. Field voucher results.

Sample Type	Sampling Events	Target # of QA Specimens	QA Specimens Collected	QA Specimen Complete-ness Rate (%)	# of Sites with Incomplete QA Collection	Site Collection Complete-ness Rate (%)	# of QA Specimen Taxonomic Agreements	Percent Taxonomic Disagree-ments (%)
Primary	150	750	732	98	15	90	674	8
Replicate	15	75	75	100	0	100	70	7
Total	165	825	807	98	15	91	744	8

- 807 field voucher specimens were collected over the 165 MWCA sampling events. This translated into a total specimen completeness rate of 98% and a site collection completeness rate of 91%.
- The total field voucher taxonomic disagreement rate was 8%.
- For the field voucher specimens, both of the completeness and taxonomic disagreement goals were met, though the collection errors at the site scale can be improved. This will be addressed during training for future MWCA iterations

Table 16. Lab identification voucher results.

Sample Type	Target # of Unknown-QA Specimens	Total # of Unknown-QA Specimens	Unknown-QA Completeness Rate (%)	# of Taxonomic Agreements	Percent Taxonomic Disagreements (%)
Primary	130	122	94	103	16
Replicate	9	7	78	7	0
Total	139	129	93	110	15

- 129 total lab vouchers were submitted to the Bell Herbarium for a total completeness rate of 93%. The lab vouchers from the replicate sites did not meet the completeness goal, but it was a small sample size.
- The total lab voucher disagreement rate was 15%, which was high but acceptable. Lab voucher specimen taxonomic disagreement rate from primary sites exceeded 15%. Two things were likely occurring: 1) unknown specimens are (by definition) difficult to identify and 2) lab personnel were too prone to give a species level identification when there continued to be uncertainty. MPCA lab operations will be receiving greater oversight from permanent staff in future MWCA iterations.

Table 17. Unknown specimen collection results.

Sample Type	Sampling Events	Total Taxa Observations	Avg Taxa Obs/site	Unknown Specimens Collected	Unknown Specimens Collected/Site	Unknown Specimen Collection Rate (%)
Primary	150	7924	53	1303	9	16
Replicate	15	855	57	92	6	11
Total	165	8779	53	1395	8	16

- 8,779 individual taxa observations were made over the 165 MWCA sampling events for 53 taxa observations per sampling event on average. Unknown specimens were collected at 16% (i.e., taxa were encountered that could not be readily identified to the species level) or 8 per sampling event.
- The moderate-low collection rate indicates that the lead botanists on sampling crews were identifying the majority of plant taxa encountered on the spot and that over 90% of these observations were correct (Table 16).

- In future MWCA iterations, sampling crews will continue to work towards minimizing the collection of unknown taxa and maintaining high a degree of field identification accuracy.

Appendix 5-General human disturbance assessment

Description

The Human Disturbance Assessment (HDA) was adapted from the MPCA Human Disturbance Score (HDS) used to develop depressional wetland Indices of Biological Integrity (Gernes and Helgen 2002) The HDA is generally the same in that key anthropogenic stressor/impact categories are assessed individually and assigned a qualitative/categorical rating. Several modifications, however, have been made. The purpose of the HDA is to assign a site to one of three general stressor/impact categories (minimally, moderately, or severely impacted) according to a consistent and repeatable process. Unlike the HDS, which assigns scores to qualitative ratings and sums over the categories, the output of the HDA is categorical. The stressor/impact categories are similar to HDS categories but have been modified in some cases to increase consistency. All rating narratives are expressed in terms of stressor/impact exposure.

Overall site ratings have also been refined in the HDA. Severe impacts to wetlands can occur either cumulatively or they can occur when a single type of stressor is extremely prevalent. The HDS expresses cumulative impacts in that it is a sum of all the factors but no single factor can trigger an overall severely impacted rating. In the HDA, "Severe" ratings in what are considered direct stressor/impact categories can trigger an overall "Severely Impacted" site rating. In this way the HDA can account for an actual severe impact caused by a single local factor which would otherwise not be accounted for in the HDS. The following factors are considered to be direct stressors/impacts: #3 Within Wetland Physical Alteration; #4 Hydrologic Alteration; #5 Chemical Pollution; #6 Invasive Species. Factors #1 Landscape Alteration and #2 Immediate Upland Alteration are surrogate measures of human stress and are factored into an overall HDA site rating when accounting for cumulative impacts.

General HDA procedure

Rate each of the anthropogenic stressor/impact factor (Landscape Alteration, Immediate Upland Alteration, Within Wetland Physical Alteration, Hydrologic Alteration, Chemical Pollution, and Invasive Species) according to the narrative guidelines provided. Make the overall site HDA rating according to the following guidelines:

- ***Minimally impacted****:* No more than four factors rated as ‘Low’ with no single factor rated greater than ‘Low’ and at least one of factors #3-#6 rated as ‘Minimal’
- ***Moderately impacted****:* Any combination of factor ratings that indicate impacts between the ‘Minimally and ‘Severely Impacted’ criteria
- ***Severely impacted:*** four or more factors rated greater than or equal to ‘Moderate’ or any of factors #3-#6 rated ‘Severe’

HDA factors and rating guidance

1) Landscape alteration (500m buffer)

Human land use in surrounding uplands is a general indicator of exposure to anthropogenic stress, not a direct measure of stress. The purpose of the Landscape Alteration Factor is to capture potential stressors/impacts originating from the broader landscape that may not be accounted for in the other factors. Assess the human land use within a 500 m buffer of the site according to the narrative guidelines below taking into account both extent and intensity.

- Minimal: No or minimal amount of human land-use
  - Examples: mature (> 20 year) forest/prairie; other wetlands; extent of human land-use < 20%
- Low: Predominantly unaltered or recovered land with some human land-use
  - Examples: Old field; Conservation planting; restored prairie (< 10 year); young forest (< 20 year); extent of human land-use 20-50%
- Moderate: Extent of human land use within buffer significant, some of which is intensive
  - Examples: Rural residential; pasture; hay/alfalfa; turf park; extent of human land-use 50-80%
- Severe: Human land use occupies all or nearly all of the buffer area, much of the land use is intensive
  - Examples: Industrial/urban/dense residential development; intensive/row crop agriculture; feedlots; mining/gravel pits; extent of human land-use > 80%

2) Immediate upland alteration (50m buffer)

The Immediate Upland Alteration Factor captures potential stressors/impacts originating from human land use and alterations in the immediate upland area. Assess the human land use and physical alterations within a 50 m buffer of the site according to the narrative guidelines below taking into account both extent and intensity.

- Minimal: No or minimal amount of human land-use
  - Examples: mature (> 20 year) forest/prairie; other wetlands; extent of human land-use < 20%
- Low: Predominantly unaltered or recovered land with some human land-use
  - Examples: Old field; Conservation planting; restored prairie (< 10 year); young forest (< 20 year); extent of human land-use 20-50%
- Moderate: Extent of human land use within buffer significant, some of which is intensive
  - Examples: Rural residential; pasture; hay/alfalfa; turf park; extent of human land-use
  - 50-80%
- Severe: Human land-use occupies all or nearly all of the buffer area, much of the land use is intensive
  - Examples: Industrial/urban/dense residential development; intensive/row crop agriculture; feedlots; mining/gravel pits; extent of human land-use > 80%

3) Within wetland physical alteration

This factor is specifically focused on physical alterations of soil and vegetation within the wetland (or former wetland) boundary. Any subsequent hydrologic impact from a physical alteration is assessed separately in Factor #4 (Hydrologic Alterations). Rate the relative extent, severity, and frequency of physical alterations for a site according to the narrative guidelines below.

- Minimal: No human physical alteration within wetland
- Low: Small extent/historical/low intensity human physical alteration

- Moderate: Significant human physical alteration
- Severe: Extensive/high intensity/high frequency human physical alteration
  - Examples: Grazing; hoof compaction; vegetation removal; grading; bulldozing; plowing; vehicle use; dredging; filling; sedimentation

4) Hydrologic alteration

The Hydrologic Alteration factor deals specifically with the human alteration of a wetland's natural hydrologic regime. Hydrologic alterations are not uni-directional, meaning that increases or decreases to wetland water volume/flow/intensity/frequency/duration/source may represent alterations to the natural hydrologic regime. Rate the relative human hydrologic alterations below.

- Minimal: No evidence of human hydrologic alterations, natural hydrologic regime present
- Low: Low intensity alteration of the hydrologic regime or historical alteration that is not currently affecting the wetland
- Moderate: Significant and ongoing alteration of the hydrologic regime
- Severe: Severe alteration of hydrologic regime, may result in extensive plant community type changes
  - Examples: Ditch/tile/stormwater input; point source; controlled/artificial outlet; within site ditching/dredging; road/railroad/berm constricting flow; unnatural connection to other waters; dewatering in or near wetland; source water changes; and drainage

5) Chemical pollution

The intention of the Chemical Pollution Factor is to assess the broad spectrum of potential human sources of chemical pollution that could impact a wetland including: nutrients, salts, herbicides, etc. A key component for rating this factor is evidence that the chemical pollution is coming from a human source as opposed to concentrations naturally occurring within the expected natural range for the site type. Rate the Chemical Pollution according to the narrative guidelines below. In cases where chemical data is not available omit rating this factor and continue to rate site according to same guidelines.

- Minimal: Chemistry within natural range and no evidence of human sources
- Low: Some deviation of chemistry from natural range and some evidence of human sources
- Moderate: Significant and deviation of chemistry from natural range and clear evidence of human sources
- Severe: Severe chemical pollution from human sources with clear evidence of harm to the biota
  - Examples: High chemical concentrations; point source present; high input potential; herbicide treated area

6) Invasive species

In many cases the presence and/or increase of abundance of invasive species in a wetland is a response to human impacts. There are, however, cases where invasive species can become established and increase in abundance in the absence of any other human impacts. Thus, invasive species can be considered stressors as well as a response to stress. Rate the relative impact of invasive species according to the narrative guidelines below.

- Minimal: No invasive species present or non-native taxa occurring at a very low abundance (< 1% of aerial cover) and not causing displacement of the native community
- Low: Invasive species are established at a low abundance and expansion appears to be limited
- Moderate: Invasive species are established and expanding
- Severe: Invasive species are dominant and there is evidence of significant replacement of the native community
  - Examples: *Phalaris arundinacea* (reed canary grass); *Typha angustifolia* and *Typha* x *glauca* (invasive cattail); *Lythrum salicaria* (purple loosestrife); *Frangula alnus* (glossy buckthorn); Carp; fathead minnow.