Wetland quality

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# Status and Trends of Wetlands in Minnesota: Minnesota Wetland Condition Assessment (2011/12–2016)

MINNESOTA POLLUTION CONTROL AGENCY

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# Executive summary

The Minnesota Wetland Condition Assessment (MWCA) is a probabilistic survey initiated to broadly measure wetland quality trends in the state and help determine if we are achieving our state and federal goal of no net loss in the quantity, quality, and biological diversity of our wetlands. Vegetation quality (i.e., the deviation of wetland plant communities from a natural or minimally impacted state) can integrate and reflect cumulative wetland impacts and is the primary MWCA indicator. The MWCA includes virtually all of Minnesota's wetland types and is repeated on a five-year cycle with sampling for the first iteration completed in 2011/12 that established the following baseline conditions:

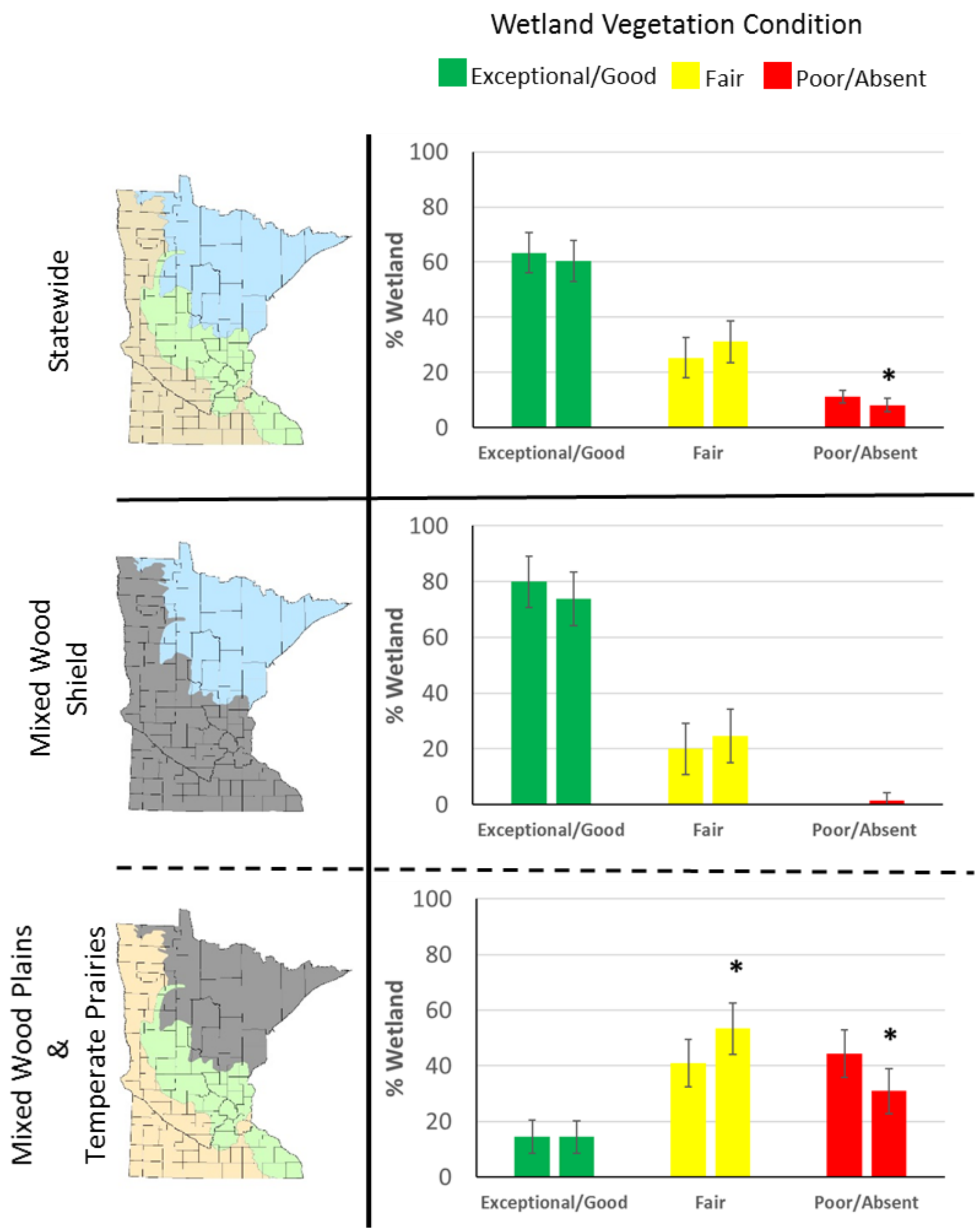
- Minnesota's wetland vegetation quality is high overall
- Wetland vegetation quality, however, varies greatly in different parts of the state. In northern Minnesota, wetlands have predominantly exceptional to good vegetation quality. Conversely, wetlands in the former hardwood forest region of the state are largely degraded—with roughly equal shares of wetland in fair and poor condition. The remaining wetland extent in the former prairie region of the state—where on average 95% of the pre-settlement wetland acreage by county has been drained—has predominantly poor vegetation quality.
- As the majority of Minnesota's wetlands are in the northern region of the state, the large extent of exceptional/good condition wetland occurring there drives the statewide results
- This regional pattern of wetland vegetation quality corresponds to a similar pattern of regional human caused stressors. Stressors are localized in northern Minnesota, with most wetlands being minimally impacted. Conversely, stressors are widespread at severe levels in both of the hardwood forest and former prairie regions in the state, where the landscape is dominated by agricultural development and where most of Minnesota's cities are located.
- There are often multiple stressors at degraded wetlands, but it is the non-native invasive plants—by increasing in abundance and ultimately replacing native species—that appear to be the primary drivers of vegetation community change.
- Emergent wetlands with herbaceous grasses, sedges, and forb vegetation are the most affected wetland type in Minnesota.
- Problems with increased abundance of non-native invasives typically are not self-correcting. Direct management of the vegetation itself is often required—in addition to correcting external stressors—to reestablish native plant communities.
- Ultimately, a greater emphasis on protecting wetlands from human caused stressors would be an appropriate strategy to further promote the no-net-loss of wetland quality and biological diversity of Minnesota's wetlands

This report presents the results from the 2016 ($2^{nd}$) MWCA iteration and provides the first estimates of wetland quality change over time for virtually all of Minnesota's wetland types.

**Minnesota's overall wetland vegetation quality continues to be high (*see figure on next page*).** An estimated 60% of the state's wetland extent is in exceptional/good condition (i.e., natural plant communities), with 32% in fair condition, and only 8% in poor/absent condition (i.e., large changes in plant community composition and structure) in 2016. These estimates are very similar with 2011/12 results (though a small but statistically significant 3% decrease of poor condition wetland was detected).

**Wetland vegetation quality also continues to vary greatly in different parts of the state (*see figure on next page*).** An estimated 74% of the wetland extent in northern Minnesota is in exceptional/good condition in 2016. Condition estimates in this region are indistinguishable between the two iterations, and as the vast majority of Minnesota's wetlands occur here, they continue to drive the statewide quality results. Conversely, over 80% of the wetland extent in the former hardwood forest and prairie regions—which have largely been developed for agriculture—is in either fair or poor/absent condition.

**Change in wetland condition proportion estimates from 2011/12 (left side of each category pair) and 2016 (right side of each category pair) at statewide and ecoregion scales. Error bars are 95% confidence intervals and (*) indicates a significant difference ($P < 0.05$).**




**Wetland quality may have improved in the former hardwood forest and prairie regions of the state (*see figure*).** 2016 estimates show a significant increase in the extent of fair quality wetland and a corresponding decrease in the extent of poor quality wetland in these two regions combined. These changes were unexpected and appear to be associated with an overall decrease in non-native invasive species abundance. However, the most widespread non-native invasives—invasive *Typha* (cattails) and *Phalaris arundinacea* (reed canary grass) are perennial taxa and once they become established would not be expected to decrease in abundance without widespread natural disturbance, changes in human impacts, and/or direct management. None of these appear to have happened. A combination of random sampling variability and measurement error at the site scale are the most likely drivers of the change. The actual proportion of fair and poor/absent quality wetland in these regions are likely somewhere in between the 2011/12 and 2016 estimates.

**The overall picture for Minnesota's wetland vegetation quality, however, largely remains the same and more survey iterations will be required to determine if quality is changing over time.** This is only the second iteration of the survey and the sampling approach and indicator are relatively new and will continue to need refinement. The next MWCA iteration is scheduled for 2021. Continued design and procedural improvements will be a focus of the 2021 effort.

# Introduction

Wetlands are a vital component of Minnesota's water resources that provide a number of beneficial ecosystem services. At an estimated 10.6 million acres (Kloiber 2010), wetlands are also the most abundant water feature in the state—dwarfing the acreage of lakes and streams combined. Concerns stemming from over a century of systematic wetland drainage has led to the adoption of a broad policy goal to achieve no-net-loss (and promote increases) in the quantity, quality, and biological diversity of wetlands at both the state and federal level.

No-net-loss is advanced through a number of regulatory and non-regulatory programs administered at the local, state, and federal levels of government. While programmatic actions can be tracked—exempt activities, privately-funded restorations, natural processes, and other indirect influences (e.g., climate change) can cause losses or gains in wetland quantity outside of a regulatory or conservation program. Furthermore, wetland quality and biological diversity can be impacted by a variety of human activities such as changes in hydrology or excess nutrient loading (Adamus et al. 2001) that have until somewhat recently gone largely unrecognized.

Given the programmatic accounting challenges and the large scope and variety of Minnesota's wetland resource, random (or probabilistic) surveys—where a limited number of random samples can be used to represent the larger resource and track changes over time—are the most scientifically defensible and cost effect way to determine whether or not we are meeting no-net-loss (Gernes and Norris 2006). Since 2006, the Minnesota Department of Natural Resources (DNR) and the Minnesota Pollution Control Agency (MPCA) have initiated a series of random surveys with the goal of tracking the status and trends of both wetland quantity and quality in Minnesota.

The DNR is responsible for the wetland quantity survey consisting of repeated aerial photo-interpretation and wetland mapping of approximately 5,000 randomly selected 1 $mi^2$ plots on a three-year basis that provide wetland extent estimates at state and regional scales (Kloiber et al. 2012). Three survey iterations have been completed between 2006 and 2014—establishing our current baseline wetland statewide acreage estimate and showing very small (but statistically significant) wetland gains over time (Kloiber 2010, Kloiber and Norris 2013, Kloiber and Norris 2017).

The MPCA is responsible for wetland quality status and trends monitoring for the state and has established two random surveys.

The Depressional Wetland Quality Assessment (DWQA) focuses on tracking vegetation, macroinvertebrate, and water quality at depressional wetlands (wetlands occurring in a distinct basin, typically with marsh type vegetation and open water; Genet 2007). DWQA iterations have been completed for 2007/09 (Genet 2012) and 2012 (Genet 2015) and have shown that all three indicators vary regionally in the state—with higher quality in northern Minnesota. In addition, a greater share of depressional wetlands have macroinvertebrates in good condition compared to vegetation in the more developed regions of the state and all three indicators have been stable between the two time periods. Sampling for a third iteration of the DWQA was completed in 2017 with results reported in Genet et al. (2019).

The Minnesota Wetland Condition Assessment (MWCA) is a broader effort with the overall goal to track the status and trends of wetland vegetation quality (and the potential stressors associated with degraded quality) in virtually all of Minnesota's wetland types (Bourdaghs et al. 2015). Initiated in 2011 and 2012, the MWCA is done in conjunction with the larger National Wetland Condition Assessment conducted by the U.S. Environmental Protection Agency (EPA) and is repeated on a five-year cycle.

The 2011 /2012, MWCA established baseline wetland vegetation quality extent estimates at statewide and regional scales (Bourdaghs et al. 2015, Appendix A) and the following conclusions were drawn:

- Minnesota's wetland vegetation quality is high overall.
- Wetland vegetation quality, however, varies greatly in different parts of the state. In northern Minnesota, wetlands have predominantly exceptional to good vegetation quality. Conversely, wetlands in the former hardwood forest region of the state are largely degraded—with roughly equal shares of wetland area in fair and poor condition. The remaining wetland extent in the former prairie region of the state—where an average estimated 95% of the pre-settlement wetland acreage by county has been drained—has predominantly poor vegetation quality.
- As the majority of Minnesota's wetlands are in the northern region of the state, the large extent of exceptional/good condition wetland occurring there drives the statewide results.
- This regional pattern of wetland vegetation quality corresponds to a similar pattern of regional human caused stressors. Stressors are localized in northern Minnesota, with most wetlands being minimally impacted. Conversely, stressors are widespread at severe levels in both of the hardwood forest and former prairie regions in the state, where the landscape is dominated by agricultural development and where most of Minnesota's cities are located.
- Non-native invasive plants is the most widespread type of wetland stressor. Increased abundance of non-native invasives is also strongly associated with all other stressor types.
- Stressors tend to co-occur at degraded wetlands, but it is the non-native invasive plants—by increasing in abundance and ultimately replacing native species—that appear to be the primary drivers of vegetation community change.
- Emergent wetlands are the most affected wetland type (and shallow marshes and fresh meadows the most affected wetland plant communities) in Minnesota, having the largest extent of poor condition wetland.
- Invasive *Typha* (Cattails) and *Phalaris arundinacea* (Reed canary grass) are the non-native invasive taxa that are having the greatest impact to wetland vegetation quality.
- Problems with increased abundance of non-native invasives (which occur when wetlands are exposed to virtually any variety of impact) typically are not self-correcting. Direct management of the vegetation itself is often required—in addition to correcting external stressors—to reestablish native plant communities and wetland ecological integrity.
- Ultimately, a greater emphasis on protection would be an appropriate strategy to further promote the no net loss of wetland quality and biological diversity of Minnesota's wetlands.
- This report presents the results from the 2016 (2$^{nd}$) MWCA iteration and provides the first estimates of wetland quality change over time for virtually all of Minnesota's wetlands.

# Methods

A brief summary of MWCA methods is provided here. The detailed survey methods including: survey design, site-evaluation, vegetation sampling, the Floristic Quality Assessment approach, data analysis, and the MWCA limitations—are provided in Appendix B.

Vegetation condition (the deviation of wetland plant species composition and/or abundance distribution from expected conditions in a minimally impacted state) is the primary MWCA indicator and is expressed through an approach called the Floristic Quality Assessment (FQA). The MPCA has fully developed the FQA for wetland monitoring and assessment in Minnesota (Bourdaghs 2012, MPCA 2014). FQA is based on a numerical rating (0-10) of an individual plant species' fidelity to specific habitats and disturbance tolerance called the Coefficient of Conservatism (*C*) (Swink and Wilhelm 1994, Taft et al. 1997, Milburn et al. 2007). FQA metrics are derived from vegetation data and the *C*-values, and have been found to be the most responsive and frequently used class of metrics to assess wetland vegetation condition (Mack and Kentula 2010). The MPCA relies on a weighted average Coefficient of Conservatism (*wC*) metric that incorporates the relative abundance of all species identified in a plant community into a single score. *wC* scores have been calibrated to defined wetland vegetation condition categories that describe conditions ranging from those thought to be prevalent prior to European settlement, to conditions found at sites known to be severely impacted by human activities (Table 1). MWCA vegetation quality results are primarily expressed in terms of the proportion of the estimated statewide or regional total wetland acreage by condition category.

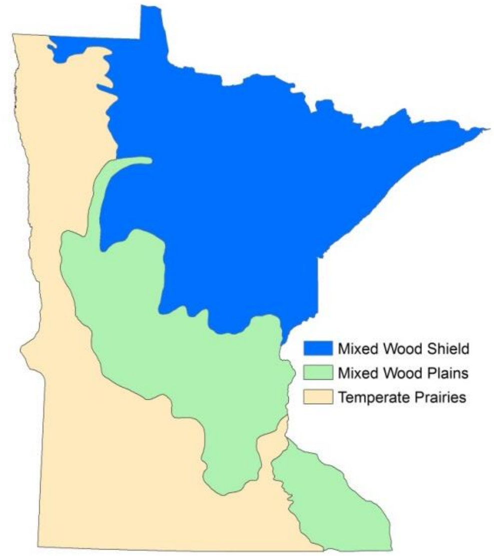
**Table 1. Wetland vegetation condition category descriptions.**

| 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. |
| **Absent** | Plant life only marginally supported or soil/substrate largely devoid of hydrophytic vegetation due to ongoing severe anthropogenic impacts |

The MWCA target population is defined as all wetlands with < 1 meter (m) depth of surface water that are not in active cultivation. This represents virtually all wetlands in Minnesota, essentially capturing wetlands that can safely be sampled on foot and are not currently being farmed.

Three widely recognized ecoregions occur in Minnesota. The MWCA utilizes Omernik's level II ecoregions as a geographic framework to characterize these ecologically distinct regions of the state (Figure 1). The ecoregions are described as the Mixed Wood Shield (northern forest), Mixed Wood Plains (hardwood forest), and the Temperate Prairies (former prairie).

**Figure 1. Omernik level II ecoregions.**




DNR wetland status and trends wetland mapping data is utilized as the sample frame (i.e., wetland map) to randomly locate sampling sites. The total MWCA target sample is 150, allocated equally by ecoregion (i.e., 50 sites/ecoregion) with a 50% revisit rate of sites established in 2011/12 (i.e., 75 revisit sites and 75 new sites). Unequal probability weighting is used (as opposed to pre-stratification) to allocate sites by ecoregion.

The MWCA sample design is integrated with EPA's National Wetland Condition Assessment with 26 sites of the 150 MWCA sample designated as national sites. The sample draw of revisit, new, and overdraw site point locations is provided by the EPA National Health and Environmental Effects Research Laboratory (Corvallis, OR).

Drawn points are then evaluated to determine whether 1) they are actually located on target wetland, 2) a sampling site can be effectively established, and 3) if access permission can be obtained. The standard sampling site is a 0.5 hectare (ha) circle centered on a drawn point. A drawn point can be shifted up to 60 m and alternative site layouts can be employed if field conditions do not permit establishing a standard site layout. Points are rejected if they fail to meet any of the above criteria. Overdraw points are then evaluated and selected in design order to maintain the integrity of the random design when replacing rejected points.

A total of 153 sites were successfully established and sampled for the 2016 MWCA (Table 2). The revisit/new site allocation was as expected, but the ecoregion allocation resulted in a greater number of sites established in the Mixed Wood Shield ecoregion compared to the Temperate Prairies. Complete site evaluation results and discussion is provided in Appendix C.

**Table 2. Number of revisit and new target sampled sites by ecoregion.**

| Ecoregion | Revisit Sites | New Sites | Total |
|---|---|---|---|
| Mixed Wood Shield | 31 | 34 | 65 |
| Mixed Wood Plains | 25 | 22 | 47 |
| Temperate Prairies | 21 | 20 | 41 |
| **Total** | 77 | 76 | 153 |

Two sampling approaches are used to collect MWCA vegetation data as a result of the integrated design with the NWCA. At the 127 MWCA only sites, vegetation community types (e.g., fresh meadow, open bog, hardwood swamp, etc.) are first determined and mapped at a site. A site may have more than one plant community type. A meander sampling approach is then used to collect vegetation data—where the observer walks through the site recording plant taxa in each plant community as they go. Once the meander is complete (i.e., have walked the entire 0.5 ha sampling site), aerial cover estimates are made for each recorded taxa by community type. At the 26 national sites, the National Wetland Condition Assessment vegetation protocol is used (US EPA 2016b) and consists of identifying taxa and making cover estimations within five regularly placed 10 x 10 m sampling plots at a site. National sites were sampled by EPA contract crews in 2016. Data from these sites were then reviewed by the MPCA, plant communities were mapped, and individual sample plots within a site were assigned to a plant community. Plot taxa data were then aggregated by averaging the cover estimates for observed taxa over the plots assigned to each community in a site. This was done to create a corresponding data structure to the MWCA data collected using the MPCA meander sampling approach. In a paired trial from the 2011/12 iteration, both approaches were found to produce overall consistent results (Bourdaghs et al. 2015).

The *wC* metric is then computed at the plant community level and scores are compared to established thresholds to determine vegetation condition categories (Table 1). Plant community level condition category is then aggregated to the site level by calculating the weighted average condition category based on the relative extent of each community within a site.

The potential stressors occurring at each site are also characterized using a best professional judgement approach called the Human Disturbance Assessment (HDA; Appendix D). The HDA incorporates five well-documented types of stressors (i.e., stressor factors) that have been associated with degraded wetland vegetation including: landscape alteration, immediate upland alteration, physical alteration, hydrologic alteration, and invasive species. Each factor is rated qualitatively to one of four levels of severity according to standard narrative criteria. An overall HDA rating of minimally, moderately, or severely impacted is then derived from the combinations of the various factors that broadly characterizes the cumulative stressors at a site. Complete documentation of the HDA is provided in Appendix D.

Finally, wetland extent, wetland condition, and HDA stressor estimates (with 95% confidence intervals) are generated at statewide and ecoregion scales from the site results. Percentage results are based on area (e.g., acres of good condition wetland divided by total wetland acres) as opposed to the number of individual wetlands—which are essentially uncountable given the extent and variety of wetlands that exist in Minnesota. Extent and condition estimates are also generated by general wetland classes and plant community types at the statewide scale (small sample sizes prohibited estimates of wetland class condition at the ecoregion scale). 2016 MWCA analyses were performed in R (version 3.4.2) using the spatial survey design and analysis package (spsurvey; Kincaid et al. 2018).

# Results and discussion

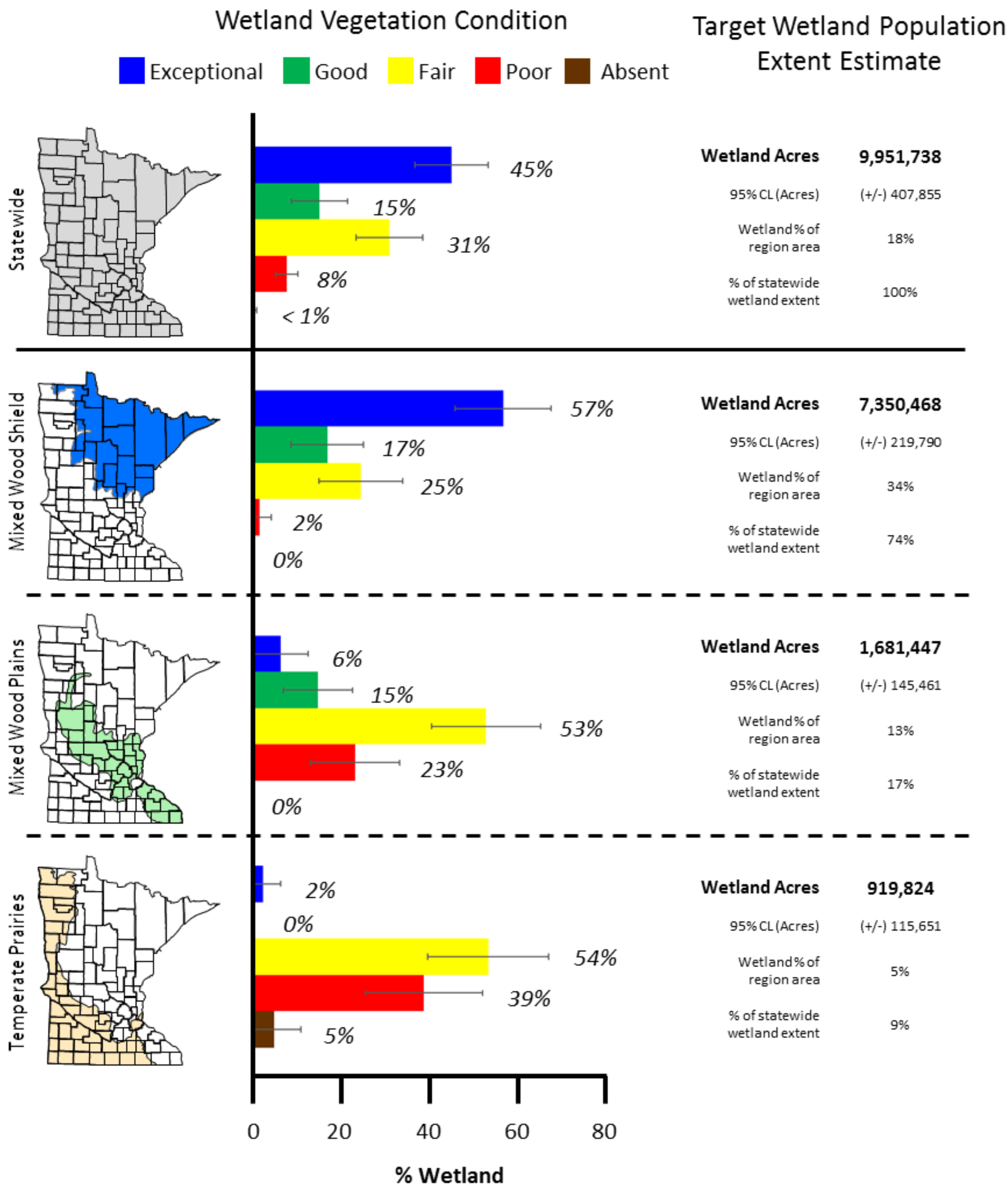
## Statewide and regional wetland vegetation condition

### Statewide

The majority of Minnesota’s wetlands continued to have high quality vegetation in 2016, with a modest share at fair condition, and a relatively small proportion at poor or absent condition (Figure 2, Figure 3).

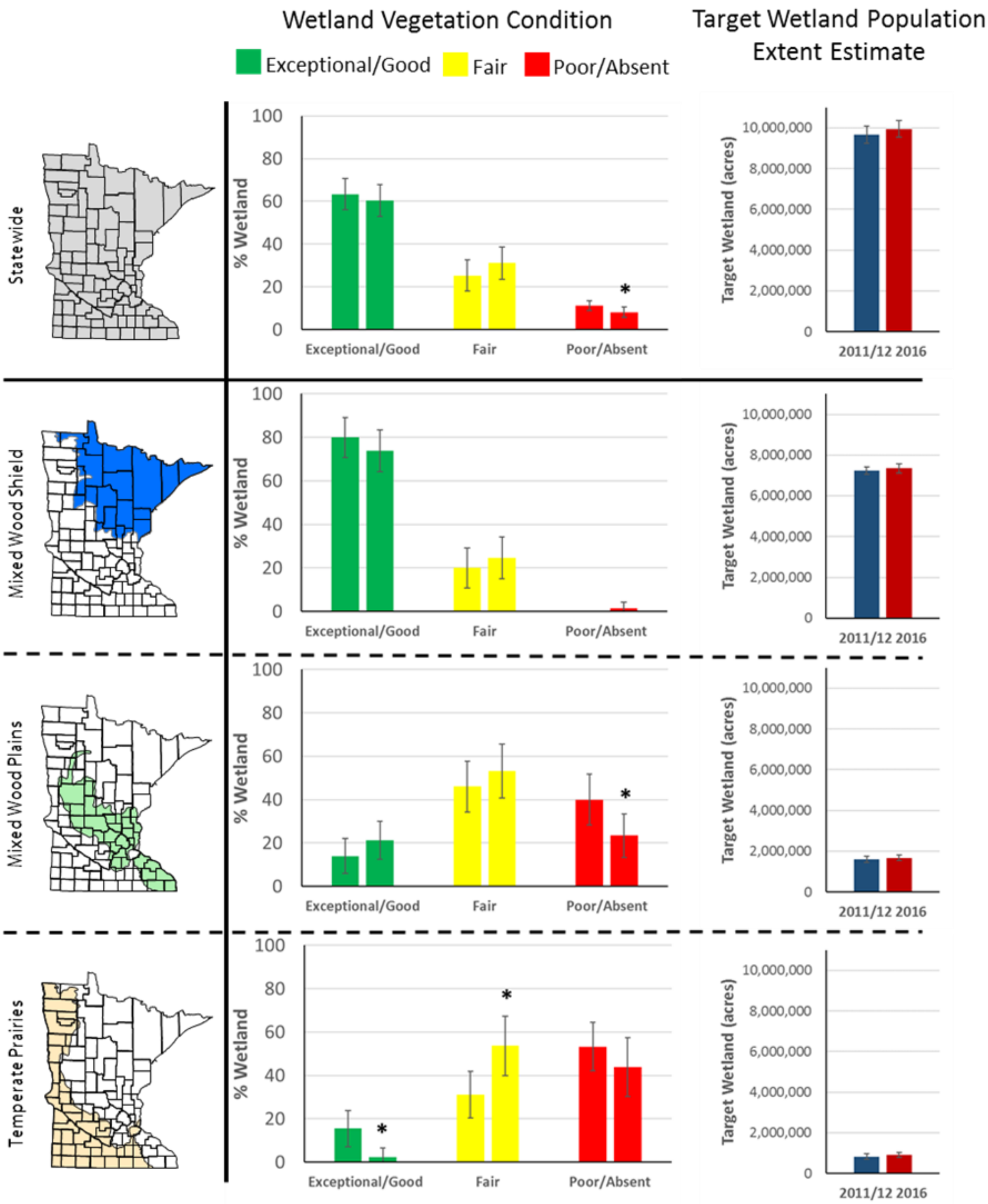
- An estimated 45% of Minnesota’s wetlands had exceptional vegetation condition, where there are no measurable effects of impacts (Figure 2, Table 1). An additional 15% of the state’s wetland extent was in good vegetation condition, where vegetation composition and structure is similar to natural communities.
- The combined percentage of exceptional/good condition wetlands in 2016 (60%) was statistically indistinguishable from 2011/12 (63%; Figure 3).

**Figure 2. 2016 wetland vegetation condition category proportion and extent estimates statewide and by ecoregion.**




- Approximately a third of Minnesota's wetlands had fair vegetation condition in 2016 (Figure 2). Fair condition represents a degree of degradation where plant species composition and/or structure have deviated somewhat from expected natural communities (Table 1).
- The estimated 6% increase in fair condition wetland extent at the statewide scale in 2016 from 2011/12 was not statistically significant (Figure 3).
- Minnesota's wetlands in poor vegetation condition—where there have been large changes in species composition and/or community structure (including wholesale conversion of plant community types and/or the replacement of expected native species by non-native invasive species)—was estimated at 8% (Figure 2).

**Figure 3. Change in wetland condition categories and target wetland population from 2011/12 to 2016 statewide and by ecoregion. The exceptional/good and poor/absent condition categories respectively have been combined to simplify the change analysis. * = significant difference at *P* < 0.05.**




- Wetland that is essentially devoid of any hydrophytic vegetation due to a severe human impact (described as absent condition; Table 1) was detected for the first time in 2016 by the MWCA at 0.4% (Figure 2).
- The extent of poor/absent condition wetland combined in Minnesota decreased by 3% from 2011/12 to 2016 (Figure 3). While the decrease was small, given that it occurred at the low range where confidence intervals tend to also be small, the difference was statistically significant (*P* < 0.05).

- The 2016 MWCA target wetland population was estimated at 9.95 (±0.408) million wetland acres (Figure 2)—an increase of approximately 270,000 from the 2011/12 target wetland estimate (Figure 3). The difference (while seemingly large) was not statistically significant (Figure 3). There was a modest increase of mapped wetlands in the sample frame from 2011/12 to 2016 (Appendix B, Table B-1) which would translate to the statewide estimates, but any differences were more likely due to improved application of the target wetland definition during site evaluation and more accurate inclusion of target wetland.

## Regional wetland condition

The 2011/12 MWCA established that wetland vegetation quality varies widely by ecoregion in Minnesota, with the majority of wetlands in the Mixed Wood Shield ecoregion having high quality vegetation and predominately degraded vegetation in the Mixed Wood Plains and Temperate Prairies (Bourdaghs et al. 2015, Appendix A). The 2016 MWCA results partially correspond to these previously established general regional patterns (Figure 2, Figure 3, Figure 4).

- Approximately 57% of the estimated 7.4-million wetland acres in the Mixed Wood Shield ecoregion had exceptional vegetation condition, with an additional 17% in good condition. Fair vegetation was an estimated 25 % of the wetland extent and poor was limited to approximately 2% (Figure 2, Figure 4).
- There were no significant differences in the percentages of any of the condition categories between the two time periods in the Mixed Wood Shield ecoregion (Figure 3).
- Wetlands in the Mixed Wood Plains ecoregion again had predominately degraded vegetation quality in 2016. An estimated 53% was in fair condition with an additional 23% in poor condition (Figure 2, Figure 4). Wetland in exceptional (6%) and good (15%) condition was correspondingly limited.
- Poor condition wetland significantly decreased ($P < 0.05$) by 17% in the Mixed Wood Plains ecoregion, with what appeared to be corresponding increases in fair and exceptional/good condition wetland (though these differences were not statistically significant).
- Similarly, wetlands in the Temperate Prairies ecoregion had predominately degraded vegetation quality in 2016 (Figure 2, Figure 4). An estimated 54% of the wetland extent was in fair condition while 39% was poor. Absent condition (Table 1) was present at two sites in the Temperate Prairies ecoregion and represented approximately 5% of the ecoregion wetland extent. Exceptional vegetation condition was estimated at 2% and good condition wetland was not detected in the ecoregion in 2016.
- In terms of change in the Temperate Prairies ecoregion, the extent of fair condition wetland increased significantly ($P < 0.05$) by approximately 23% in 2016 compared to 2011/12. There was a corresponding decrease in the extent of poor/absent condition (though the difference was not significant) and a significant decrease of exceptional/good condition wetland by 14% ($P < 0.05$).

**Figure 4. Site locations by vegetation condition category.**

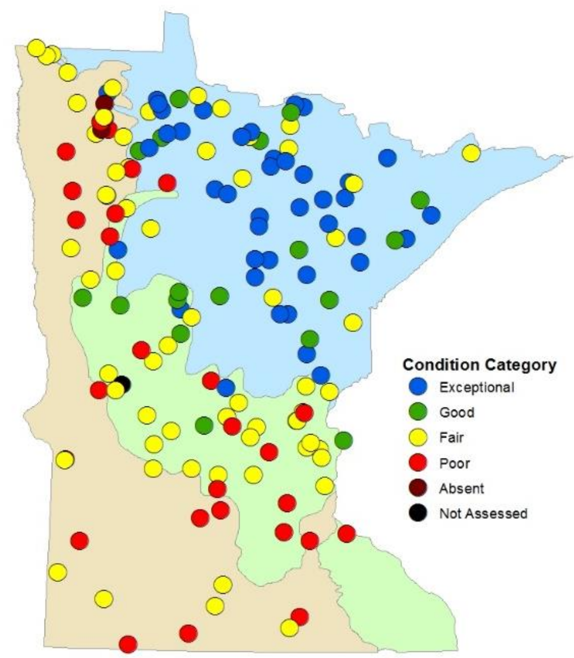
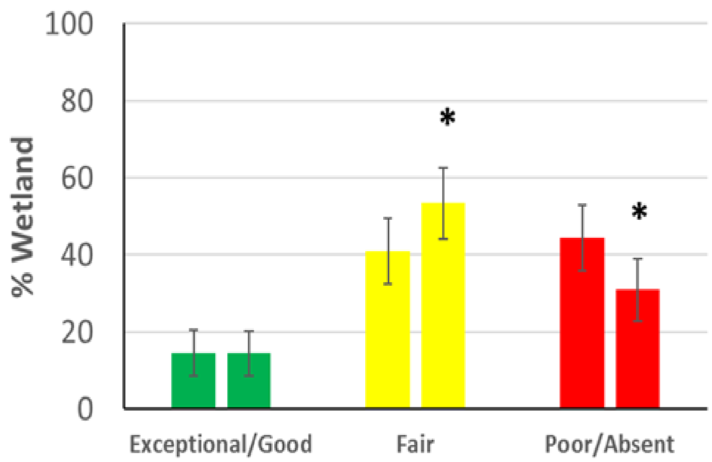


**Figure 5. Change in wetland condition categories from 2011/12 to 2016 for the Mixed Wood Plains and Temperate Prairies ecoregions combined. * = significant difference at *P* < 0.05.**




- Condition estimates for the Mixed Wood Plains and Temperate Prairies ecoregions combined (Figure 5) show no change between 2011/12 and 2016 in the extent of exceptional/good condition wetland, a significant ($P < 0.05$) increase of fair wetland by 12% and corresponding significant ($P < 0.05$) decrease in poor/absent wetland by 14%.
- The Depressional Wetland Quality Assessment (DWQA) employed the FQA approach to measure vegetation quality for the first time in 2017 (Genet et al. 2019). Depressional wetland vegetation condition in the Mixed Wood Plains and Temperate Prairies ecoregions combined had the following percentages by extent: 9% good/ 57% fair/ 27% poor/ 5% absent. Confidence intervals for all of the condition category estimates for depressional wetlands broadly overlap with the corresponding MWCA estimates, indicating that vegetation quality for depressional wetlands was essentially the same compared to all wetlands over the two ecoregions.

In summary, the overall regional wetland vegetation quality pattern in 2016 is similar to 2011/12. The large majority of wetlands in the Mixed Wood Shield ecoregion are in exceptional/good condition and they are driving the statewide results. Conversely, the large majority of wetlands in western, central, and southern Minnesota continue to be degraded. Unlike 2011/12, the majority of wetlands in both the Mixed Wood Plains and Temperate Prairies ecoregions are now in fair condition and the extent of poor condition has decreased correspondingly.

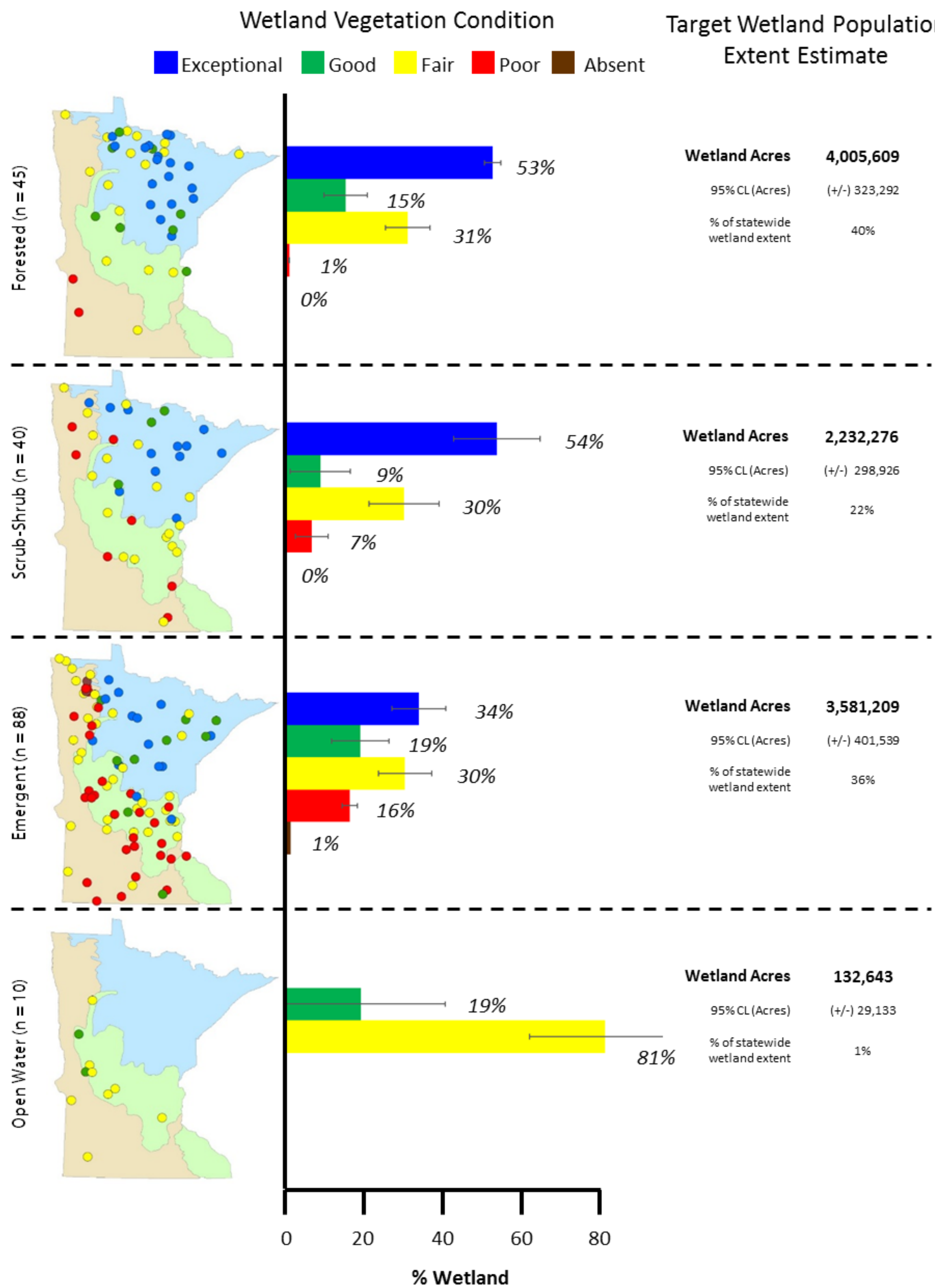
# Condition by general wetland classes and plant communities

## Wetland classes

The 2011 /2012, MWCA also established that wetland vegetation quality varies by the different kinds of wetlands (Bourdaghs et al. 2015). Forested wetlands (swamps, bogs, and floodplain forests with mature tree canopies) are the most abundant general class of wetlands in Minnesota and are predominately in exceptional/good condition. Scrub-shrub wetlands (willow dominated shrub-carrs, alder thickets, and open bogs dominated by ericaceous shrubs)—the third most abundant wetland class—have similarly high percentages of exceptional/good condition. Emergent wetlands (a broad class of wetlands dominated by grasses, sedges and/or forbs) is the second largest class of wetlands in Minnesota but has the highest extent of poor condition. Open-water wetlands are the least extensive wetland class in the state and are under-represented in the survey.

The 2016 MWCA results largely follow the same pattern as 2011/12 (Figure 6).

**Figure 6. Site location maps, condition category proportion estimates, and target population estimates by general wetland classes.**



- Statewide extent estimates of the general wetland classes were very similar to 2011/12 estimates (Figure 6, Bourdaghs et al. 2015). Forested wetland again occupied the greatest share at 40%, with 36% in emergent, and scrub-shrub wetlands at 22%. There were no significant changes in extent for these classes.
- The statewide open water wetland extent estimate increased from approximately 95,000 acres to 132,000 acres (though the increase was not significant) and was likely due to improved application of the target population definition during site evaluation. The open water class, however, continued to be under-represented in the MWCA (Figure 6). Only 10 of the 2016 sample sites had open water wetland present. For context, DNR status and trends has estimated open water wetland at approximately 560,000 acres (Kloiber 2010). Condition estimates were presented for the open water class for completeness (Figure 6), but provide little insight given the low sample size.
- In terms of vegetation quality, the condition category estimates for both the forested and scrub-shrub classes were largely the same from 2011/12 to 2016 (Figure 6). Both are estimated to have > 60% extent in exceptional/good condition, approximately 30% in fair condition, and a generally low percentage in poor condition. The scrub-shrub class did have a higher rate of poor wetland compared to forested wetland in 2016, but the overall rate remained low (7%) at the statewide scale.
- The high percentage of exceptional/good condition wetland for the forested and scrub-shrub class was likely due to the regional variation in wetland vegetation quality (Figure 2, Figure 4). Forested and scrub-shrub wetlands make up roughly 2/3's of the wetland extent in the Mixed Wood Shield ecoregion where vegetation quality is largely intact (Bourdaghs et al. 2015).
- The emergent wetland class again had an elevated percentage of poor condition and a depressed percentage of exceptional condition compared to the forested and scrub-shrub classes in 2016 (Figure 6). An additional 1% of emergent wetland was estimated to be in absent condition (i.e., these sites had been emergent wetland).
- Emergent wetland made up an estimated 76% of the approximately 814,000-wetland acres in Minnesota in poor/absent vegetation condition.
- Similar to forested and scrub-shrub wetlands, the overall pattern of vegetation quality in emergent wetlands was likely a reflection of the regional pattern. Emergent wetlands occur throughout Minnesota, but are the predominant class in both the Mixed Wood Plains and Temperate Prairies ecoregions (Bourdaghs et al. 2015), where wetland condition is more degraded (Figure 2, Figure 6).
- There was, however, a significant decrease of 10% of poor/absent wetland extent in the emergent wetland class from 2011/12 to 2016. As emergent wetland made up the large majority of poor/absent condition wetland in the state, this decrease contributed greatly to the decreased percentage of poor/absent condition wetland of all types at the statewide scale (Figure 2).

## Plant communities

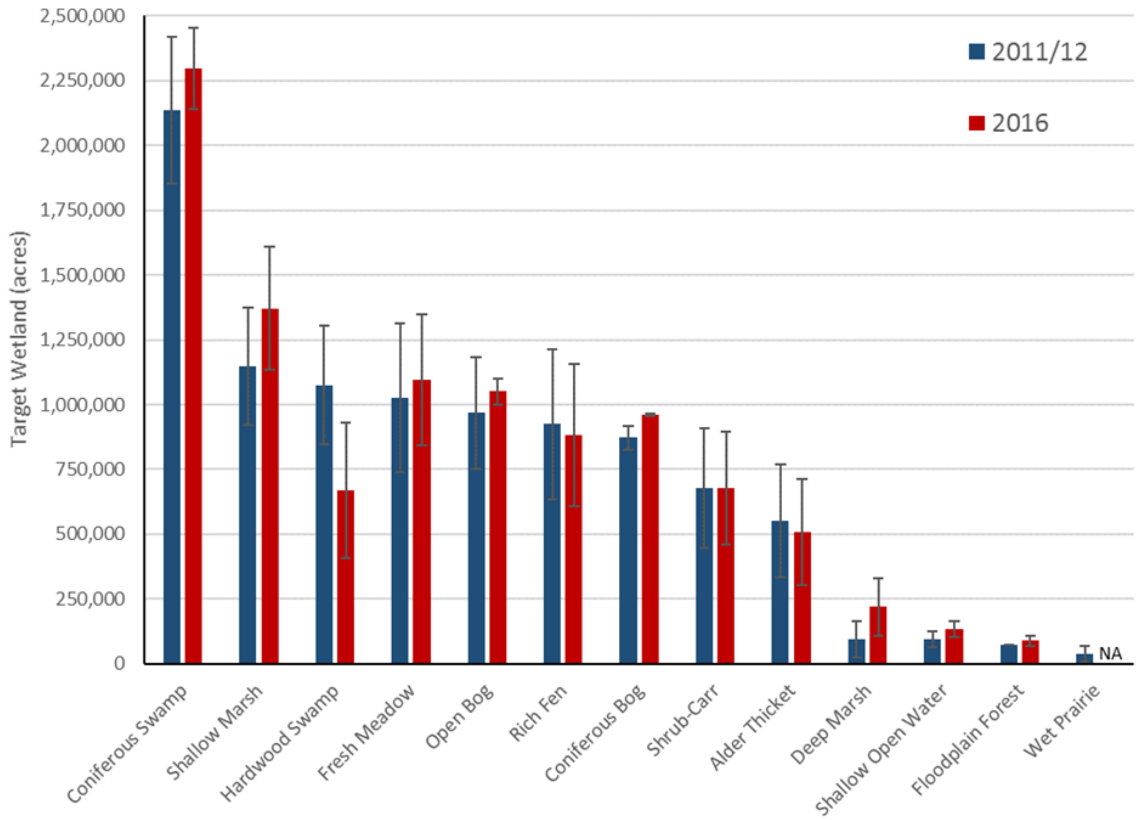
MWCA field data were collected by plant community (Appendix B), which allows for extent and limited condition estimates at the statewide scale for this detailed level of wetland classification.

As with the general wetland classes, the overall patterns in the wetland plant communities is largely the same from 2011/12 to 2016.

- There was very little change in terms of statewide extent of the different plant communities in 2016 (Figure 7).

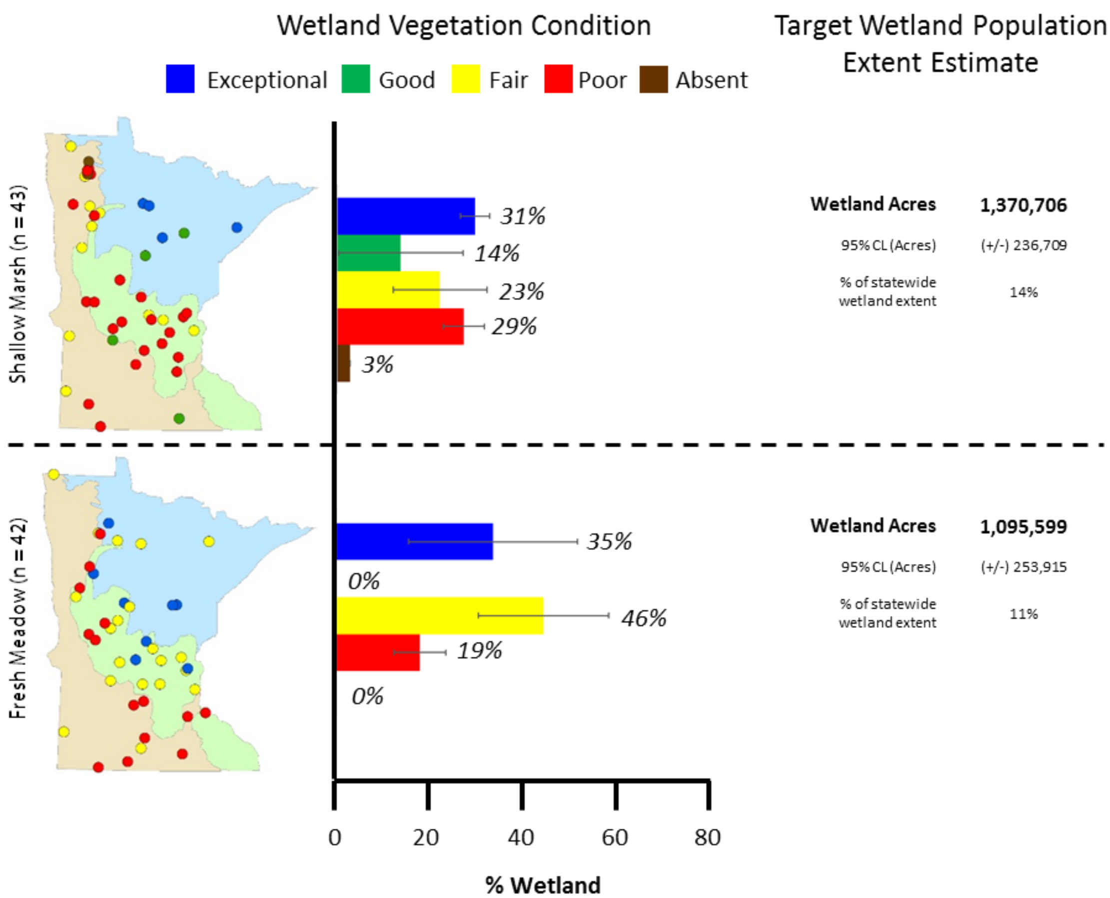
- Coniferous swamp was again the most prevalent wetland plant community type by far at almost 2.3 million acres and comprising 23% of Minnesota's wetlands (Figure 7).

**Figure 7. Plant community type extent estimates for 2011/12 and 2016.**



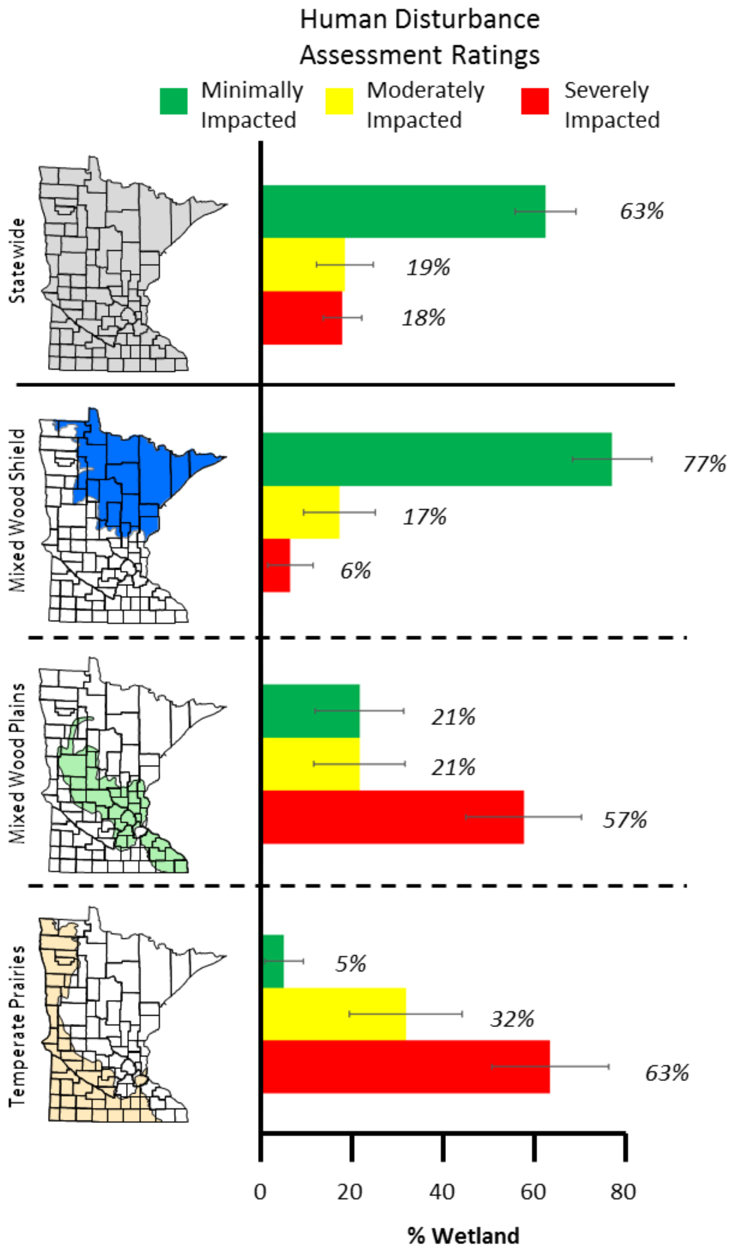

- Shallow marsh, fresh meadow, and open bog (Figure 7) were estimated at over 1 million acres constituting > 10% of Minnesota's wetlands each.
- There were five plant community types with an estimated statewide extent between 500,000 to 1 million acres (i.e., approximately 5 – 10% of Minnesota's wetlands): hardwood swamp, rich fen, coniferous bog, shrub-car, and alder thicket (Figure 7).
- Three community types were estimated at < 250,000 acres: deep marsh, shallow open water (which were under-represented in the MWCA) and floodplain forest (Figure 7).
- Two community types (wet prairie and seasonally flooded wetland) were each sampled only a single time during 2016 sampling, which prohibited making community level extent estimates. The seasonally flooded sample was also excluded from the regional/statewide analyses, as the MPCA does not have FQA assessment criteria for this community type. The calcareous fen plant community—a well-documented but rare wetland type in Minnesota—was not observed during 2016 MWCA sampling.
- Significant differences in extent from 2011/12 to 2016 occurred in only two of the twelve communities that had extent estimates for both time periods. Hardwood swamps decreased from an estimated 1,075,942 acres (± 229k) to 669,772 acres (± 260k) and coniferous bogs increased from an estimated 871,754 (± 45k) acres to 960,674 (± 3k) acres. In both cases, the extent differences were likely due to random chance as there was no field evidence of conversions for these systems over multiple sites noted during field sampling (e.g., dead standing trees or stumps for converted hardwood swamps

**Figure 8. Site location maps, condition category estimates and target population extent estimates for the shallow marsh and fresh meadow community.**




- Plant community condition estimates are only being reported for the shallow marsh and fresh meadow plant communities (Figure 8) as they make up approximately 69% of the emergent wetlands—the wetland class with largest extent of poor condition (Figure 6)—and they each had a relatively high number of samples (≥ 30).
- Shallow marsh had a greater extent of poor condition wetland compared to the emergent class as a whole (Figure 6). In addition, the two sites that were observed to be in the absent condition category were shallow marshes. Both sites had recently been dominated by invasive *Typha* and subsequently treated with herbicide (and in one case mowing). The combined extent of shallow marsh poor/absent condition (32%) was the highest percentage for any community type.
- Fresh meadow had approximately the same proportion of poor condition (Figure 8) compared to the broader emergent class (Figure 6), but had significantly less wetland in good condition. The lack of good condition may be due to narrow scoring criteria for fresh meadow at the good condition level
(Table B-8).
- Compared to 2011/12, both communities had increases of fair condition (though not significant) and significant decreases in poor condition (Bourdaghs et al. 2015, Figure 8). As with the emergent class as whole, this was likely a reflection of the regional condition pattern (Figure 2) as both communities make up a large share of the wetland in the Mixed Wood Plains and Temperate Prairies ecoregions.

**Figure 9. HDA rating estimates statewide and by ecoregion. The HDA describes the potential cumulative stressors occurring at wetlands over three broad levels of severity.**




# Wetland stressors

## Statewide

- As was observed in 2011/12, most of Minnesota's wetlands continue to be exposed to few if any stressors in 2016 as expressed by the HDA (Figure 9). Similarly, the overall pattern of the component HDA stressor factor estimates (Figure 10) largely remained the same for 2016 at the statewide scale. The Invasive Species HDA factor is again the most important type of stressor in terms of extent.

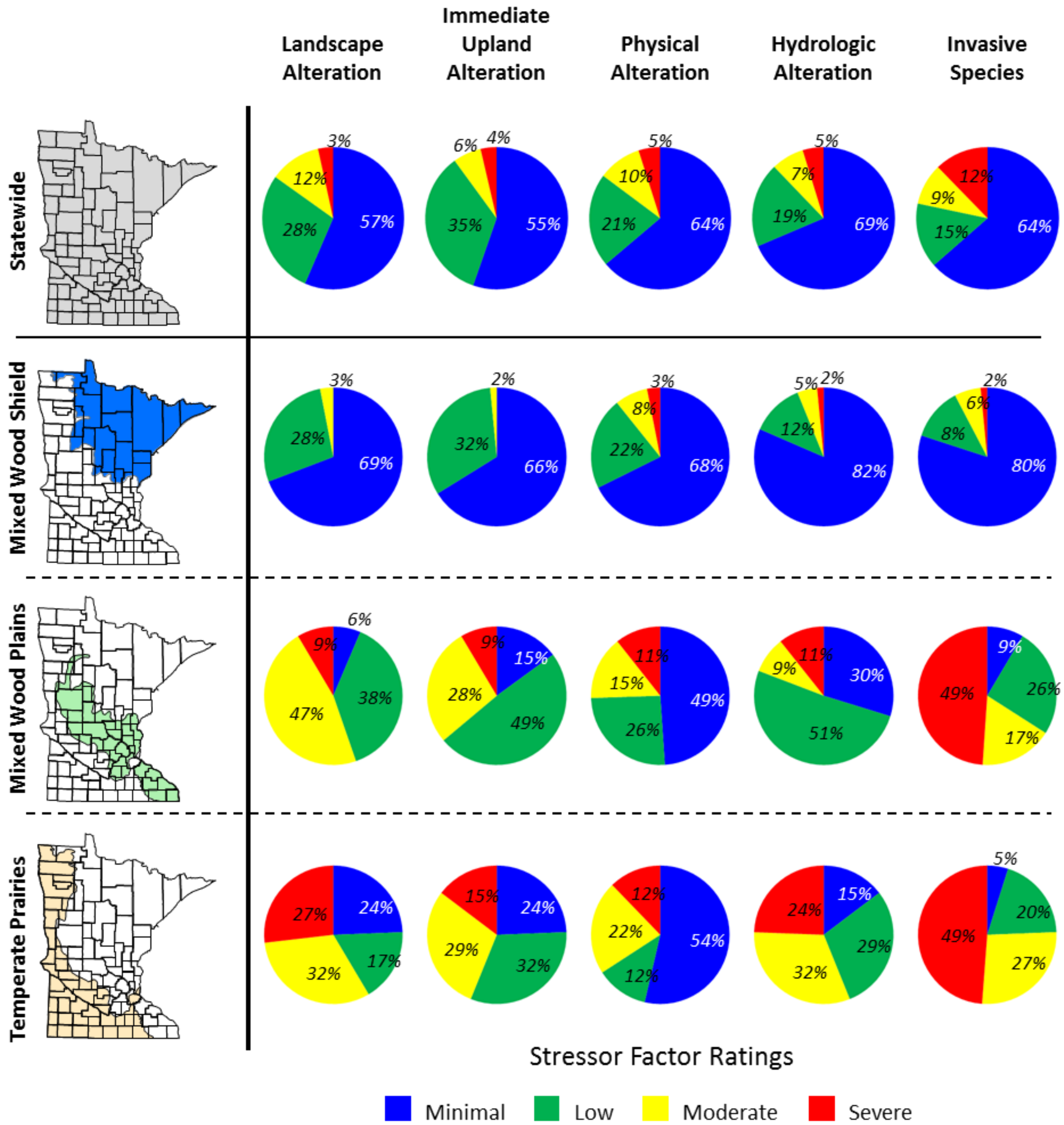
- In 2016, an estimated 63% of the statewide wetland extent was rated as minimally impacted according to the HDA. Moderately and severely HDA impacted wetland extent was limited to 19% and 18%, respectively (Figure 9).
- The 2016 minimally impacted HDA estimates (Figure 9) corresponded well with the extent of exceptional/good vegetation condition (60%) at the statewide scale (Figure 2). The moderately and severely HDA extent estimates (Figure 9), however, did not correspond as well to respective fair (31%) and poor/absent (8%) estimates (Figure 2).
- Statewide 2016 estimates for all three HDA categories were nearly identical to 2011/12 estimates (Bourdaghs et al. 2015)—indicating no changes in overall impacts to Minnesota wetlands over the five-year time period.
- The Landscape Alteration and Immediate Upland Alteration HDA factors—which attempt to account for broader land use that may be a source of stressors not readily observable on-site—had relatively similar estimates of minimal/low/moderate/severe categories statewide (Figure 10). Both had small but significant ($P < 0.05$) decreases of severely impacted wetland compared to 2011/12 (Bourdaghs et al. 2015).
- The direct Physical and Hydrologic Alteration HDA factors also had similar category estimates relative to each other (Figure 10) at the statewide scale. There were no significant differences in Physical Alteration rating estimates from 2011/12 and a modest (but significant) increase in the extent of minimally hydrologically impacted wetland (Bourdaghs et al. 2015).
- As was the case in 2011/12, the Invasive Species HDA factor had the largest estimate of severely impacted extent statewide in 2016 (Figure 10), making Invasive Species again the most widespread stressor of those considered in the survey. Between 2011/12 and 2016, however, there was a small (3%) but significant ($P < 0.05$) decrease in the extent of wetland that was rated as severely impacted for Invasive Species.

## Regional wetland stressors

The 2016 results again show large regional stressor variation that generally corresponds with the regional pattern of vegetation condition (Figure 9, Figure 10). The large majority of wetlands in the northern Mixed Wood Shield ecoregion were exposed to few if any observable impacts, whereas most of the wetlands in the Mixed Wood Plains and Temperate Prairies ecoregions had at least one or more stressors at the severe level. There was some variation in the regional estimates of individual HDA factors over time, but the overall pattern remained essentially the same between 2011/12 and 2016. In 2016 non-native invasive species were again the most widespread and important type of stressor. In addition, the estimated extent of prior plowed wetland in the Mixed Wood Plains and Temperate Prairies remained constant between 2011/12 and 2016.

- An estimated 77% of the wetland extent in the Mixed Wood Shield ecoregion was rated as minimally impacted according to the HDA in 2016 (Figure 9). Correspondingly, the wetland extent HDA rated as moderately (17%) and severely impacted (6%) was limited in the ecoregion.
- In contrast, the majority of wetlands in both the Mixed Wood Plains (57%) and Temperate Prairies (63%) ecoregions had a severe HDA rating with corresponding low rates of moderately and minimally impacted ratings (Figure 9). These two ecoregions combined had an estimated extent of 15% minimally/25% moderately/59% severely impacted according to the HDA.
- This regional pattern of aggregated wetland vegetation impacts is not surprising as both the Mixed Wood Plains and Temperate Prairies ecoregions have largely been developed for agricultural production and urban areas, whereas the Mixed Wood Shield ecoregion is largely undeveloped outside of rotational logging and localized impacts.

**Figure 10. Individual HDA stressor factor rating estimates statewide and by ecoregion. Individual HDA factor ratings are completed at a greater degree of specificity compared to the resulting overall HDA and are expressed over four levels of severity (minimal/low/moderate/severe).**




- The regional HDA category patterns generally corresponded with wetland vegetation condition estimates in 2016 (Figure 2). Wetland condition was predominately exceptional/good and few stressors detected in the Mixed Wood Shield ecoregion, whereas wetland condition was predominately fair/poor and stressors detected at the severe level in the Mixed Wood Plains and Temperate Prairies ecoregions. There was a significant deviation however between the wetland extent in poor/absent condition and severely impacted HDA rating in both the Mixed Wood Plains and Temperate Prairies ecoregions (Figure 2, Figure 9). In both cases, the percentage of poor/absent wetland was lower than the HDA severely impacted wetland. The HDA is a best professional judgement stressor rating approach built upon assumptions on how wetland vegetation responds to stress supported by previous work. This apparent over-estimation of severely impacted wetland by the HDA suggests that a re-examination of the rating guidance is warranted.

- In terms of the extent of the HDA categories, there was no change between 2011/12 (Bourdaghs et al. 2015) and 2016 estimates (Figure 9) in the Mixed Wood Shield and Temperate Prairies ecoregions. The percent of minimally impacted wetland, however, significantly increased ($P <$ 0.05) between the two time periods in the Mixed Wood Plains ecoregion.
- As established with the overall HDA results (Figure 9), the component HDA factors further illustrate the regional differences between the Mixed Wood Plains and Temperate Prairies compared to the Mixed Wood Shield in terms of stressor exposure (Figure 10). Each HDA factor had a larger share of wetland extent at the moderate and severe levels in the Mixed Wood Plains and Temperate Prairies compared to the Mixed Wood Shield. Aside from the greater extent of moderate-severe Hydrologic Alteration in the Temperate Prairies, there were few differences in extent estimates of the various HDA factors between the two ecoregions (Figure 10).
- The Invasive Species HDA category was again clearly the most widespread type of stressor at the severe level (Figure 10). An estimated 49% of the wetland extent in both the Mixed Wood Plains and Temperate Prairies ecoregions was rated at the severe level for Invasive Species.
- The extent of wetland at the severe level for the HDA Invasive Species factor, however, decreased significantly ($P < 0.05$) from 2011/12 to 2016 in Mixed Wood Plains and Temperate Prairies ecoregions combined by roughly 10%.
- In addition to the HDA, we were also able to make estimates of the wetland extent that had at one time been plowed for agricultural production, but has been abandoned or restored and allowed to re-populate with hydrophytic vegetation. Site level determinations were based from aerial photography interpretation, field observations (e.g., regular plow furrow micro-topography present), and/or landowner accounts. In 2016, an estimated 5% of Minnesota's wetlands (or 471,249 ± 243k acres) were at one time plowed.
- Not surprisingly, most of the prior plowed wetland extent occurred in the Mixed Wood Plains and Temperate Prairies ecoregions where agriculture is predominate and approximately 16% of the wetland was prior plowed in the ecoregions combined.
- There was no statistical difference in prior plowed wetland extent between 2011/12 and 2016.

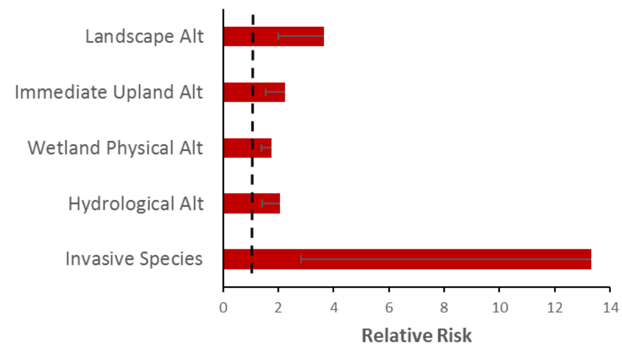
## Relative risk

A relative risk analysis (the probability of having a poor/absent condition at a high level of stress divided by the probability of having a poor condition at a low level of stress) for the HDA factors was completed for the Mixed Wood Plains and Temperate Prairies combined (i.e., where wetland vegetation stressors occur) to assess the relative effect stressors may have on condition.

- All of the HDA factors had a significant risk (i.e., relative risk > 1) of being associated to poor/absent wetland vegetation condition relative to other factors (Figure 11). The Invasive Species HDA factor, however, had a much greater relative risk (albeit with a large degree of uncertainty) compared to the other factors where the relative risk of poor condition was 13.3 times greater when non-native invasive plant species were rated at the severe level.
- This overall pattern of all of the various stressor factors being associated with poor condition and the relative risk of the Invasive Species factor being many times greater than all of the others was similar to what was observed in 2011/12 (Bourdaghs et al. 2015).

- For all factors, the probability of poor/absent condition at the severe level (which is the relative risk numerator) was > 0.94. All factors except for Invasive Species also had moderate probabilities (0.27 – 0.57) of poor vegetation condition when a stressor was at a low level (the relative risk denominator) producing relative risk in the 1-3 times range. Only Invasive Species had a low probability of poor/absent vegetation condition at the low level (0.07), thus producing the high relative risk.
- In other words, all stressor types were associated with poor condition when severe, but they were also (other than Invasive Species) moderately associated with poor condition at low levels, and it was the non-native invasive species that was the common denominator at poor condition wetlands in 2016, as it was in 2011/12.
- Non-native invasives play a unique role in wetland stressor-response relationships. On one hand, increases non-native invasive species abundance are typically conceptualized as being a response to human impacts. On the other hand, they may also act as stressors independently by becoming established in wetlands through natural disturbance and then increasing in abundance in the absence of other stressors (Galatowitsch 2012). This was observed in the MWCA, where in 2016 approximately 6% of the wetland in the Mixed Wood Plains and Temperate Prairies ecoregions had high relative cover of non-native species (> 35%) and low stress as expressed by the HDA (i.e., all independent HDA factors rated as minimal or low). Given the apparent response of non-native invasives to stressors, the observations of high invasive cover at sites with few observable impacts, and that the replacement of native plant communities by non-native species clearly fits within the goals of the MWCA as well as the larger construct of the Biological Condition Gradient (Bourdaghs 2012, US EPA 2016c)—having non-native invasives directly influence assessments while simultaneously be treated as a stressor is warranted.

**Figure 11. Relative risk of poor/absent condition for HDA factors at the severe level in the Mixed Wood Plains and Temperate Prairies ecoregions combined. A line has been added at relative risk equal to 1 for reference.**




## Non-native invasive species

The 2011/12 MWCA established that a high abundance of non-native invasive species is the common denominator in virtually all of the vegetation-degraded wetland in Minnesota (Bourdaghs et al. 2015). Non-native invasive species were again the most important type of stressor affecting wetland vegetation quality in 2016—both in terms of extent (Figure 10) and strength of association with poor condition (Figure 11).

- *Phalaris arundinacea* (Reed canary grass) and invasive *Typha*—*Typha angustifolia* (Narrow-leaved cattail) and *Typha* x. *glauca* (Hybrid cattail) combined—were again the most widespread non-native taxa in the Mixed Wood Plains and Temperate Prairies ecoregions (Table 3, Bourdaghs et al. 2015). They were also the non-native taxa occurring at high cover (relative cover ≥ 35% at a sample site, Bourdaghs et al. 2015).

**Table 3. Percent wetland estimates of selected taxa when present and occurring at high relative cover (≥ 0.35).**

| | % Wetland | | | |
|---|---|---|---|---|
| | Mixed Wood Plains | | Temperate Prairies | |
| **Taxa** | **Present** | **High Cover** | **Present** | **High Cover** |
| *Phalaris arundinacea* | 83% | 6% | 68% | 17% |
| Invasive *Typha* | 45% | 15% | 59% | 24% |

- 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).
- The mean relative non-native cover for all wetland types in the Mixed Wood Plains and Temperate Prairies, however, decreased significantly ($P < 0.05$) from 38% to 31% between 2011/12 and 2016. This roughly corresponds with the decrease in poor condition wetland (Figure 5) and the decrease of the rate of the Invasive Species HDA factor at the severe level (Figure 10) in these two ecoregions.

## Sampling precision

The 2016 regional results show that there has been a significant increase in fair condition wetland and a corresponding decrease in poor quality wetland in the Mixed Wood Plains and Temperate Prairies ecoregions (Figure 5). Most of the changes occurred in emergent wetlands (Figure 6, Figure 8). There were also apparent decreases in invasive species cover in the two ecoregions (Figure 10, Table 3).

These changes were unexpected as virtually all of the wetland plant communities occurring in Minnesota are predominately composed of perennial species that return year after year. In addition, the most widespread non-native invasives—invasive *Typha* (cattails) and *Phalaris arundinacea* (reed canary grass) are also perennial taxa and once they become established would not be expected to decrease in abundance at a wetland without a natural disturbance, human impact, and/or direct management. There was no evidence that any of these possible drivers occurred at a widespread scale between 2011/12 and 2016.

As part of the MWCA QA/QC measures, the revisit data (i.e., sites sampled in 2011/12 and 2016) were examined to explore sampling repeatability (Appendix E). In the Mixed Wood Plains and Temperate Prairies ecoregions, the variation in total cover (i.e., the summed midpoint cover of all taxa observed in a community) appeared to be random, with a similar number of large increases and large decreases at revisit sites (Table E-3). The variation in non-native species cover (i.e., the summed midpoint cover of all non-native taxa observed in a community), however, indicates systematic decreases in 2016 relative to 2011/12 at the revisit sites. There were twice as many large non-native cover decreases as non-native cover increases (Table E-3). The relative decreases may be due to high non-native species cover estimation bias in 2011/12, or low cover estimation bias in 2016, or a combination of both.

Regardless, the relative decrease in non-native cover estimates—in addition to random error (e.g., sampling a greater number of sites in 2016 with lower non-native abundance due to random chance)—most likely explains the apparent changes in non-native invasives as a stressor and subsequently the change in wetland condition in the Mixed Wood Plains and Temperate Prairies ecoregions.

# Conclusions

The overall picture for Minnesota's wetland vegetation quality largely remains the same between 2011/12 and 2016. At the statewide scale, the majority of Minnesota's wetlands are in exceptional/good quality with roughly a third in fair quality and poor/absent quality limited to approximately 10% (Figure 2, Figure 3). This is being driven by the large share of wetlands in the northern part of the state, where human impacts are generally low and wetlands are predominately intact. Wetlands in the rest of the state, however, have predominately degraded vegetation quality largely driven by high abundance of non-native invasive species. High non-native species abundance is associated with a broad spectrum of human impacts and are most prevalent in the shallow marsh and fresh meadow community types where invasive *Typha* (cattails) and *Phalaris arundinacea* (reed canary grass) are widespread.

The increase in fair and the corresponding decrease in poor/absent quality wetland extent in the central and former prairie regions of the state (Figure 5) was, however, unexpected. These changes appear to be associated with an overall decrease in non-native invasive abundance. The most widespread non-native invasive taxa are perennial and once they become established would not be expected to decrease in abundance without widespread natural disturbance, changes in human impacts, and/or direct management. There is no evidence that any of these possible drivers have occurred between 2011/12 and 2016. It does appear, however, that a systematic decreased cover estimation bias occurred during field sampling that roughly corresponds with the changes in vegetation quality (Appendix E). Unfortunately, a combination of random error and this measurement error is the likely driver of the apparent change as opposed to an actual increase in wetland vegetation quality in the region. The actual extent and proportions of fair and poor/absent quality wetland in the region are likely somewhere in between the 2011/12 and 2016 estimates.

Ultimately, the purpose of the MWCA is to track wetland quality over the long term and more survey iterations will be required to determine if Minnesota's wetland quality is changing over time. It is important to keep in mind that only two iterations of the survey have been completed and that the sampling and Floristic Quality Assessment approach are relatively new and will continue to be refined. The MPCA intends to continue the MWCA in conjunction with EPA's National Wetland Condition Assessment on a five-year rotation with the next sampling iteration scheduled for 2021. Continued design and procedural improvements will be a focus of the 2021 effort.

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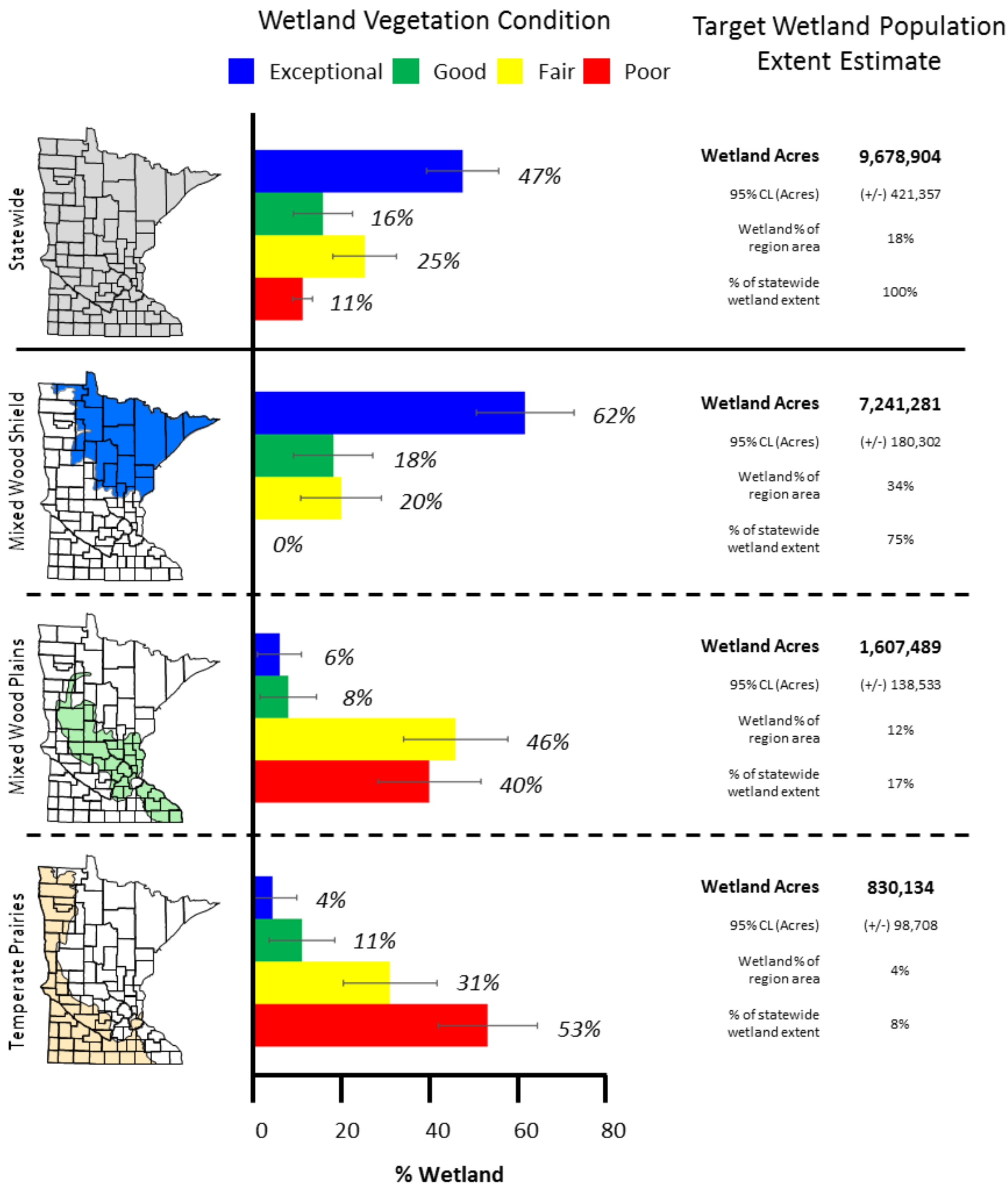
# Appendix A – 2011/12 estimate corrections

**Figure A- 1. Corrected 2011/12 wetland vegetation condition category proportion and extent estimates statewide and by ecoregion.**




Over the course of reviewing paired 2011/12 and 2016 iteration results from the revisit sites, it became apparent that some errors were present in the 2011/12 data. These consisted of data entry, plant community mapping, and a handful of assessment category errors due to incorrect rounding. The entire 2011/12 data set was then reviewed to find and correct the errors and the baseline extent and proportion estimates were then redone (Figure A-1).

Almost all of the corrected vegetation condition estimates at statewide and regional scales and for the different wetland classes and plant community types deviated slightly but were statistically indistinguishable from the previously reported 2011/12 baseline MWCA estimates (Bourdaghs et al. 2015). At the statewide scale, all of the corrected 2011/12 condition estimates (Figure A-1) were within 2% of the previously reported estimates. Similarly, corrected 2011/12 condition estimates for the Mixed Wood Shield and Mixed Wood Plains ecoregions were within 4% of the previous estimates.

There is one notable exception – the Temperate Prairies ecoregion estimates. It was previously reported that 40% of the wetland extent in the Temperate Prairies ecoregion is in fair vegetation condition and 42% is in poor condition (Bourdaghs et al. 2015). These were essentially the same fair/poor extent proportions compared to the Mixed Wood Plains ecoregion and it was concluded that wetland vegetation quality between the two ecoregions was qualitatively the same. The corrected estimates for the Temperate Prairies ecoregion (Figure A-1) have a significantly lower proportion of fair condition wetland extent (31%) and significantly greater proportion of poor condition (53%). This subsequently changes the overall conclusion. The corrected estimates now indicate that the Temperate Prairies ecoregion has a greater share of wetlands in poor vegetation condition compared to the Mixed Wood Plains ecoregion.

The 2011/12 corrected estimates will be used for analyzing wetland changes over time. It is also anticipated that sampling methods, analytical approaches, metrics, and assessment criteria may change in future survey iterations and it will be necessary to similarly to make corrections to previous MWCA iterations as was done here.

# Appendix B – Survey methods

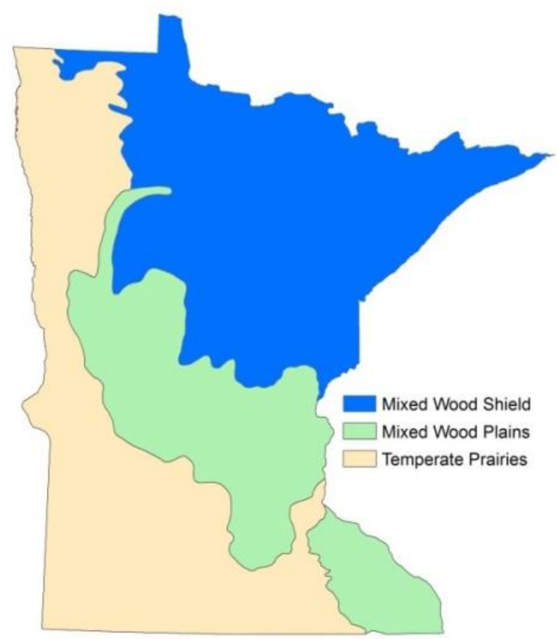
## Scope of survey, target wetland population, and sample frame

The primary goal of the MWCA is to describe wetland vegetation conditions statewide and by major ecoregions using a probabilistic sampling design and begin to determine if condition is changing over time. 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 overall population of wetlands, similar to an opinion or political poll. Secondary goals include: describing wetland condition by different wetland types; and quantifying the potential human impacts that may be associated with degraded condition. The MWCA is repeated on a five-year schedule in conjunction with EPA's National Wetland Condition Survey, with sampling iterations in 2011/12 and 2016.

Three widely recognized ecoregions (i.e., broad regions that contain geographically characteristic/distinct assemblages of natural plant communities) occur in Minnesota. They are generally described as: northern forest, hardwood forest, and former prairie. Both wetland quantity (Kloiber 2010, Kloiber 2013, Kloiber and Norris 2017) and quality (Genet 2012, Genet 2015, Bourdaghs et al. 2015) 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 B-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 sparse in the region 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).

**Figure B- 1. Level II Omernik ecoregions**




***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 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 reduced 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 retaining approximately 5% of pre-settlement wetland acres on average in the ecoregion.

The MWCA target population was defined as: all wetlands with < 1 meter (m) depth of surface water that are not in active cultivation. 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 (US EPA 2016a).

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. The MWCA utilized wetland maps produced from the DNR wetland quantity survey as the sample frame. The DNR survey consists of using aerial photo-interpretation to map wetlands within randomly located 1-mi$^2$ plots (Figure B-2) repeated on a three-year cycle to detect changes. The 2011 /2012, MWCA sample frame was generated from 2006-08 imagery (Kloiber 2010) and the 2016 MWCA iteration sample frame was from 2009-11 imagery (Kloiber 2013). The MWCA utilized the 4,740 "panel" DNR survey plots for the sample frame—excluding the 250 "common plots" where images were acquired and interpreted all three years of a quantity survey iteration 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" DNR class even though actively 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. The mapped sample frame target wetland totals close to 600,000 acres over the 4,740 DNR survey plots (Table B-1)

**Figure B- 2. DNR quantity survey plot locations and a close-up of an individual 1-mi$^2$ plot with mapped wetlands.**

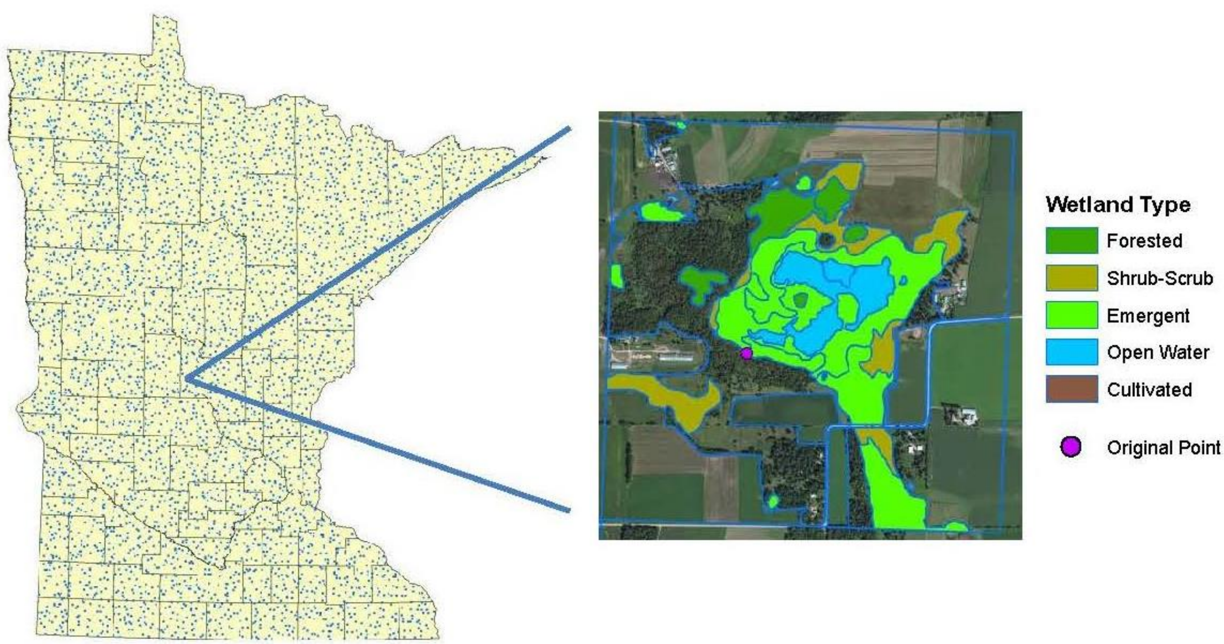


**Table B- 1. Sample frame target wetland totals in acres (ac) for 2011/12 and 2016 MWCA survey iterations.**

| | Sample frame target wetland area (ac) | |
|---|---|---|
| **Ecoregion** | **2011/12** | **2016** |
| Mixed Wood Shield | 416,556 | 416,430 |
| Mixed Wood Plains | 104,398 | 104,502 |
| Temperate Prairies | 65,481 | 65,708 |
| Statewide Total | 586,435 | 586,640 |

# Survey design

The MWCA survey design relied on a number of well-established natural resource survey principles. As the DNR 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 DNR 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 desired 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 in the survey design 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, Genet 2015). Unequal probability weighting was used to allocate sample points by ecoregion, as opposed to a pre-stratification of the sample. 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. In both of the 2011/12 and 2016 MWCA iterations, the total statewide sampling target number of sites was 150, with 50 allocated to each of the three ecoregions (Figure B-1). Finally, as resampling sites that were sampled in the previous survey iteration greatly improves the statistical power to detect trends in natural resource survey results (Larsen et al. 2004), 50% of the target number of sites were revisits of sites. In other words, the design targeted 75 revisit sites and 75 new sites.

This survey design was integrated with the EPA's NWCA sample design (e.g., two-phase design, extensive resource, GRTS, unequal probability weighting), where a subset of the statewide MWCA sample is designated as the NWCA site allocation for Minnesota. In 2011/12, the first 22 target sampled sites were the NWCA sites. For 2016, the design called for 7 revisit sites from the set sampled in 2011/12 and 19 new—for a total of 26 NWCA sites in Minnesota. The survey design and sample draw was provided by the EPA National Health and Environmental Effects Research Laboratory, Corvallis, Oregon.

# Site-evaluation and boundary establishment

Prior to field sampling, potential site locations from the sample draw had to be evaluated to determine whether: 1) they were located within target wetland, 2) a survey site (referred to the Assessment Area according to NWCA protocols) could be effectively established, and 3) access permission could be obtained. The NWCA site-evaluation protocols (US EPA 2016a) were followed and are briefly described here.

Site-evaluation broadly consisted of two phases: desktop and field evaluation. During desktop site-evaluation aerial photography, the sample frame, National Wetlands Inventory, topographic, and soil survey maps were reviewed in a Geographic Information System (GIS) to evaluate whether a drawn point (potential site locations were provided as point coordinates) was 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 site establishment. The standard site consisted of a 0.5 ha circle with a 40 m radius, centered on the point (Table B-2, Figure B-3A). In cases where points were located too close to non-target boundaries (e.g., upland, deep-water habitat, or non-target wetland) or the target wetland area present did not otherwise allow for establishing a standard site layout, alternate site layouts were employed (Table B-2, Figure B-3B-D). Preliminary sites were established using a GIS for points that had not been rejected during desktop site-evaluation. Preliminary center coordinates for use in field Global Positioning System (GPS) units were then derived from the GIS coverage to aid field site-evaluation.

**Table B- 2. Site types and descriptions.**

| Site Type | Description |
|---|---|
| Standard Site | 0.5 ha circular plot (40 m radius) centered on the Point |
| Standard Site-Shifted | 0.5 ha circular plot (40 m radius) but the Point is not the site Center–used when a 0.5 ha circular plot can be established but the Point is < 40 m away from non-target area (e.g., upland, deepwater habitat, non-target wetland) |
| Polygon Site | Established when sampleable area is > 0.5 ha but has dimensions < 80 m in at least one direction |
| Wetland Boundary Site | Site boundary coincides with the wetland boundary–established when sampleable area is 0.1-0.5 ha |

Land ownership information was also obtained and access permission requests were initiated during desktop site-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 residence or office while in the area field sampling. Points were rejected if we were unable to make contact after the in-person request or access permission was denied at any stage/mode of communication.

The final field site-evaluations largely consisted of verifying desktop site-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 site and center was verified. In cases where actual conditions were different than what was interpreted during the desktop site-evaluation, point shifting and/or site layout adjustment (Figure B-3 A-D) was completed in the field to conform to NWCA site establishment protocols (US EPA 2016a). In cases where shifting/adjusting could not be made (e.g., target wetland was > 60 m from the point or a site layout could not be established) the points were rejected. 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 site-evaluation, each point was designated a final evaluation status (Table B-3). Site evaluation results are provided in Bourdaghs et al. 2015 for the 2011/12 survey iteration and in Appendix C for the 2016 survey iteration.

**Figure B- 3. Example site layouts with points (blue circles), site centers (red circles), site boundaries (purple line work), and plant community mapping (yellow line work). A) Standard site layout—there is sufficient target wetland to establish the 0.5 circular plot and the point is the center. B) Standard site-shifted—the point is located close to upland but there is sufficient target wetland to shift the 0.5 ha circle to the northwest. C) Polygon site—a 0.5 ha circle cannot fit within the target wetland in the vicinity of the point, so the boundary is modified to a 0.5 ha rectangle. D) Basin site—point is located within a wetland basin that is < 0.5 ha.**

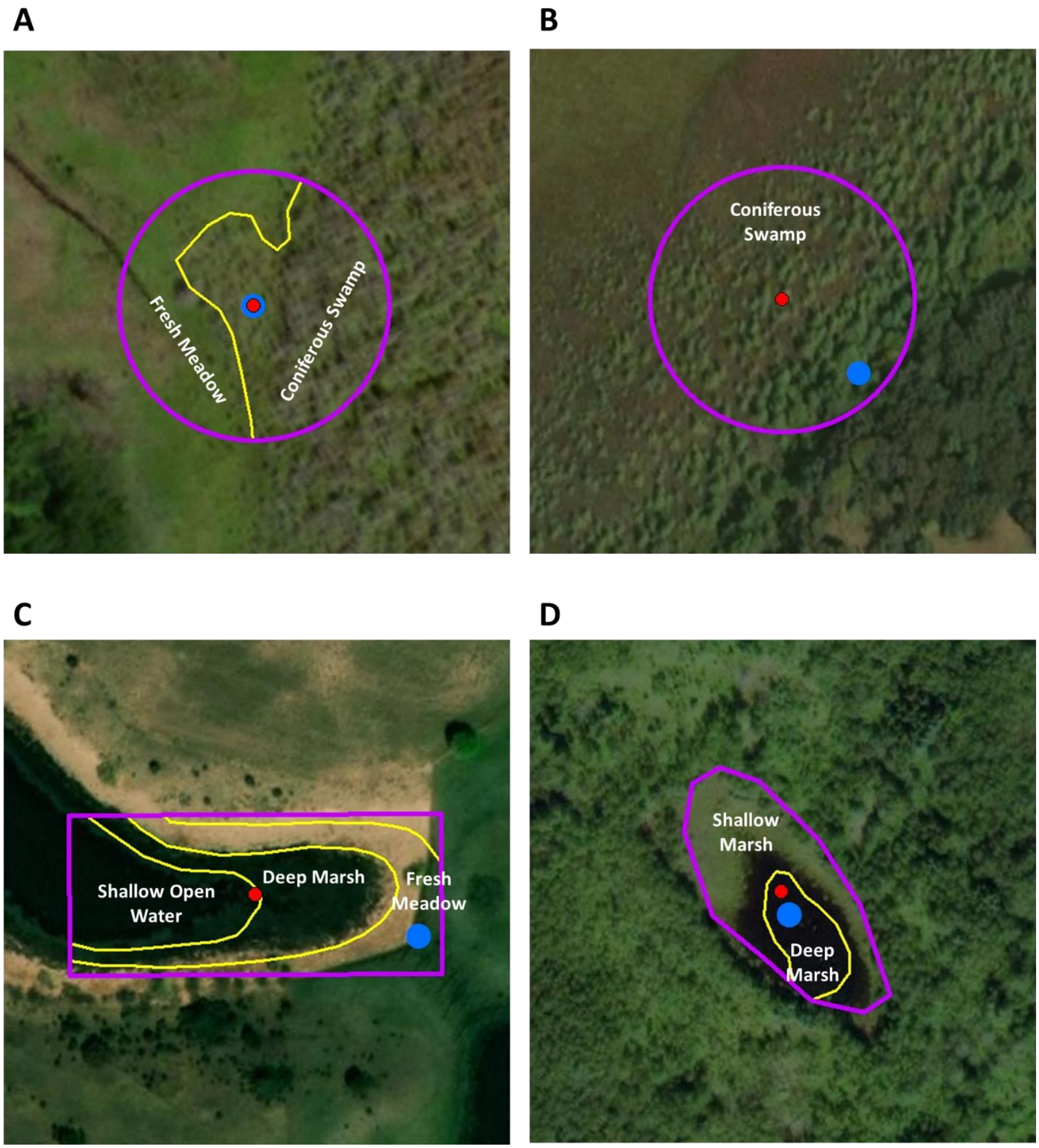


**Table B- 3. Final evaluation status for MWCA points.**

| Category | Description |
|---|---|
| Target Sampled | Point located in (or within 60 m of) target wetland of sufficient size/shape to establish a sampling site 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 |
| Inundated 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 taxa composition and abundance were characterized according to wetland plant community types at each survey site. Two different sampling approaches were used depending on whether a site was part of the NWCA set of sites in Minnesota or was a MWCA site only. In the 2016 survey iteration, NWCA sites were sampled by an EPA contractor according to NWCA protocols (US EPA 2016b). MWCA only sites were sampled by MPCA crews using a MPCA developed protocol that could be completed more rapidly. Both approaches were compared in a paired trial during the 2011/12 MWCA iteration and it was determined that both typically produce comparable vegetation data and that data from both approaches can be used in the survey (Bourdaghs et al. 2015).

At the MWCA only sites, the plant communities present within each site were first determined and their extent was mapped on printed aerial photos (Figure B-3). A modified Eggers and Reed (2011) classification of wetland plant communities of Minnesota and Wisconsin was followed (Table B-4). A meander sampling approach was used to collect vegetation data—where the observer walked through the site and recorded observed plant taxa by community type as taxa were encountered. Taxa were identified to the lowest taxonomic level possible in the field. When taxa could not be identified to the species level in the field—specimens were collected, pressed, and dried for lab identification. Tree species observations were further sub-divided according to vertical height classes (Table B-5). Aerial cover for each taxa by community type was then estimated according to cover classes (Table B-6). In this way, the entire (typically) 0.5 ha site was essentially treated as a large sampling plot.

The NWCA vegetation protocol (US EPA 2016b) was based on collecting taxa composition and cover data within five regularly placed 10 x 10 m sampling plots within a survey site. At each plot, observed taxa were recorded and percent cover estimates were made. No effort was made during vegetation plot establishment to sample according to wetland type within a survey site as EPA does not recognize this as a significant source of natural variation. Following sampling, NWCA plot data were then reviewed by the MPCA. Each plot was designated to one of the plant communities used in the MWCA (Table B-4) and data were aggregated by averaging the cover for each taxa by number of plots for a given community sampled at the site. Community-scale taxa cover averages were then converted to MPCA cover class (Table B-6) prior to metric calculations.

All field sampling was completed between June and mid-September 2016. Ten percent (n = 15) of the sites were re-sampled (Appendix E) and voucher plant specimens were collected and identified (Appendix F) as Quality Assurance/Quality Control (QA/QC) measures.

**Table B- 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 and forbs |
| 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 |
| Rich Fen | 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*) |
| Open Bog | Scrub-Shrub | Low shrub or graminoid 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 |

**Table B- 5. Tree height classes and ranges in meters (m).**

| 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 |

**Table B- 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% |

## Data analysis

Following field sampling, site and plant community mapping was completed using GIS based on field GPS data, the hand drawn maps, and aerial photo interpretation (Figure B-3). A general Human Disturbance Assessment (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 individually as minimal/low/moderate/severe using best professional judgment according to standard narrative criteria for all sampled sites. 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 that a site was located in (as opposed to just conditions immediately within the site boundary) including: landscape and immediate upland alteration as well as hydrologic alterations. The potential stressors that are captured by these categories typically occur at larger scales than a MWCA sampling site or its immediate vicinity. As water chemistry was not collected 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 D.

The MPCA utilizes an approach called the Floristic Quality Assessment (FQA) for wetland vegetation 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).

The primary FQA metric used to quantify vegetation condition from the raw vegetation 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 B-6). *wC* incorporates both species composition and abundance, is not affected by sampling area or effort, 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; US EPA 2016d). 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 five-level BCG model specific to wetland vegetation has been developed to serve as the assessment framework (Table B-7). 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 (DNR 2009), and establishing thresholds at the $10^{th}$ percentile values for the pre-settlement and minimally impacted groups and the $90^{th}$ percentile value of the severely impacted group (Figure B-4). *wC* assessment criteria were developed for each plant community (Table B-8) as both the expected natural and impact response ranges differ by type (Bourdaghs 2012).

**Table B- 7. Wetland vegetation condition category descriptions.**

| Condition Category | Description |
|---|---|
| Exceptional (1) | 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 (2) | 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 (3) | 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 (4) | 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. |
| Absent (5) | Plant life only marginally supported or soil/substrate largely devoid of hydrophytic vegetation due to ongoing severe anthropogenic impacts |

**Figure B- 4. FQA assessment criteria threshold conceptual diagram. Plant community samples were assigned to data analysis groups based on the degree of exposure to human impacts (pre-settlement, minimally impacted, or severely impacted). Metric thresholds were determined at designated percentiles of metric score distributions for each data analysis group that correspond to the condition categories. An additional narrative criterion (< 1% non-native taxa cover) was required to further specify the Exceptional condition threshold.**

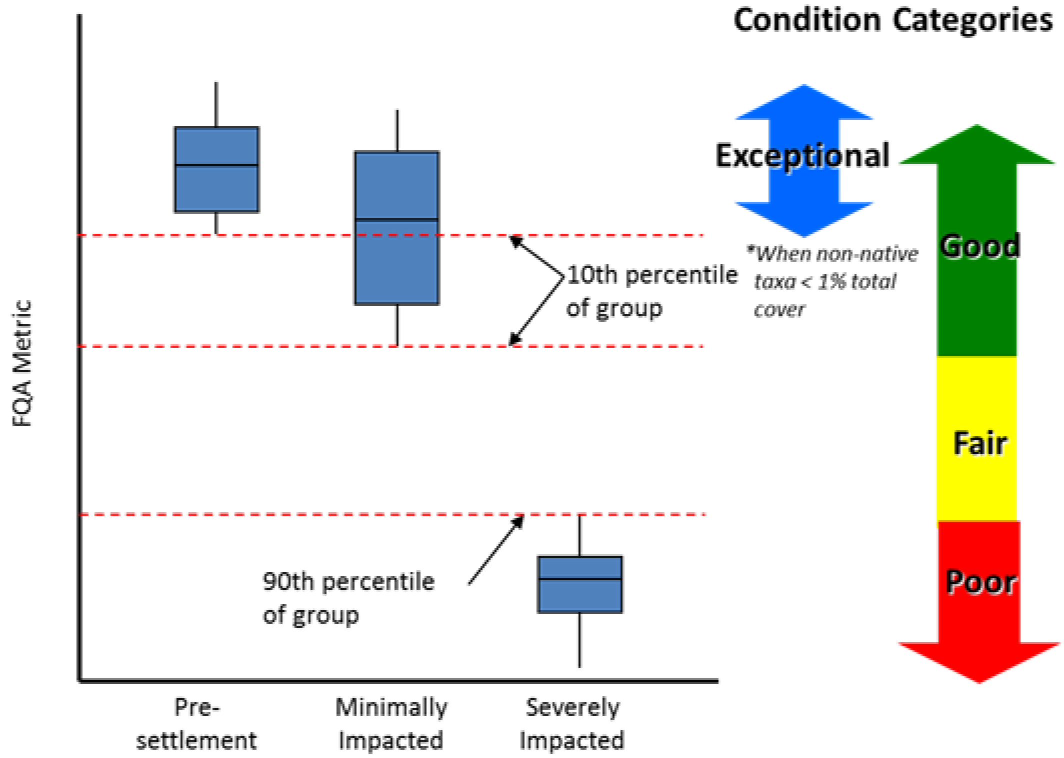
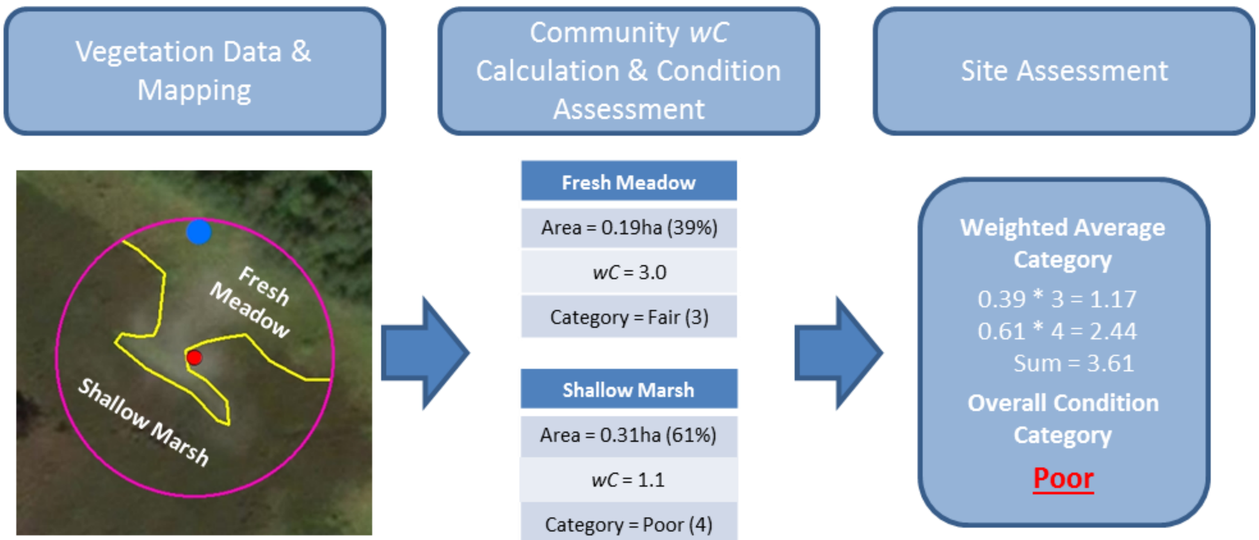



**Table B- 8. *wC* condition category assessment criteria for all community types. An additional criterion of < 1% non-native taxa cover is required to meet exceptional condition (i.e., a community must score above the *wC* threshold and have < 1% non-native taxa cover to be considered in exceptional condition).**

| | Community | | | | | | |
|---|---|---|---|---|---|---|---|
| **Condition Category** | **Shallow Open Water** | **Deep Marsh** | **Shallow Marsh** | **Fresh Meadow** | **Wet Prairie** | **Calcareous Fen** | **Rich Fen** |
| 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 | 5.9 - 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 | 5.6 - 3.8 | 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 percent | | | | | | | |

Because the data were gathered by (and assessment criteria were specific to) plant community type, completing a final assessment for an entire site was a multi-step process (Figure B-5). *wC* scores were first calculated for each community present in a site 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 B-8). Community condition results were then aggregated to the site scale by taking the weighted average condition category based on the relative extent of each community present derived from the community mapping (Figure B-5).

**Figure B- 5. Process to complete a site level assessment: 1) vegetation data are gathered by community type and plant community extent is mapped; 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 numeric condition based on the relative extent of each community type in the site and rounded to the nearest whole number which corresponds to the descriptive condition category.**




Target wetland extent and condition estimates were then made at ecoregion and statewide scales from the site 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 B-3) and to compensate for regional differences in the site allocation. 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 the target wetland extent estimates. A subset of evaluated 2011/12 non-target sites (which were assumed to be the same non-target status in 2016) was included in the weight adjustment to correct for increased Target Sampled rates of revisit sites.

Extent and condition estimates were also generated by NWCA wetland classes (Table B-9) and plant community types (Table B-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 B-10). NWCA class and community type estimates were made using sub-site level data at the community level (Figure B-5)—where results from the mapped/sampled portions of sites that were the same class/type were aggregated to the statewide scale. Small sample sizes prohibited making estimates of classes/types at ecoregion scales.

Stressor estimates were also generated in parallel to the condition estimates. HDA and HDA factor (Appendix D) 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).

**Table B- 9. General NWCA wetland classes (US EPA 2016b) and corresponding Cowardin et al. (1979) and DNR survey (Kloiber et al. 2012) classes.**

| NWCA Class | Cowardin Class | MN DNR 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 vegetation growing above surface water |
| Open Water | Palustrine Unconsolidated Bottom & Aquatic Bed | Unconsolidated Bottom & Aquatic Bed | Open water with plants growing at or below the surface of the water, or no plants present |

Estimate differences from the 2011/12 and the 2016 MWCA survey iterations were then tested to determine if there has been any detectable changes in wetland condition or stressors over the five year time period.

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 3.4.2) using the spatial survey design and analysis package (spsurvey; Kincaid et al. 2018). Extent and proportion estimates were calculated using the Horvitz-Thompson estimator, variance estimates were calculated using the local mean variance estimator, and normal distribution tests of significance were used to evaluate changes (Kincaid et al. 2018).

# 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 the effort presented here is only the second iteration of the survey 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, identify plant species, and make cover estimations. Incorrect plant identification and differences in community interpretation and cover estimates between site visits 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 E, Appendix F). As the survey continues we will continue to refine procedures and training to further minimize observer effects.

***Limited 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 B-8). 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 can artificially influence aggregated site level 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. Metrics and assessments can then be re-run prior to any type of trend analysis.

***Ability to address concerns raised from the DNR quantity survey:*** Two primary concerns have been raised from the DNR wetland quantity survey: 1) there has been a significant conversion of emergent to cultivated wetland 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 or a more specific survey that specifically treats these as part of the target population, 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 B-7). 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 (DNR 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. To date, vegetation has been the most broadly developed type of wetland condition indicator. As other indicators show potential, they may be added in future survey iterations. 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 predominant 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.

# Appendix C – Site evaluation results

**Table C- 1. 2016 MWCA site evaluation results statewide and by ecoregion for all sites. Evaluation category descriptions are provided in Table B-3.**

| | Statewide | | Mixed Wood Shield | | Mixed Wood Plains | | Temperate Prairies | |
|---|---|---|---|---|---|---|---|---|
| **Category** | **Number** | **%** | **Number** | **%** | **Number** | **%** | **Number** | **%** |
| Target Sampled | 153 | 82 | 65 | 98 | 47 | 72 | 41 | 73 |
| Access Permission Denied | 21 | 11 | 1 | 2 | 13 | 20 | 7 | 13 |
| Physically Inaccessible | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Map Error | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Active Crop Production | 8 | 4 | 0 | 0 | 2 | 3 | 6 | 11 |
| Inundated by Water > 1m in Depth | 5 | 3 | 0 | 0 | 3 | 5 | 2 | 4 |
| Industrial/Agricultural/Aquacultural Purpose | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sampleable Area Too Small | 1 | <1 | 0 | 0 | 0 | 0 | 1 | 2 |
| Total Points Evaluated (% of Statewide total) | 187 (100%) | | 66 (35%) | | 65 (35%) | | 56 (30%) | |

**Table C- 2. 2016 MWCA site evaluation results for new sites. Evaluation category descriptions are provided in Table B-3.**

| | Statewide | | Mixed Wood Shield | | Mixed Wood Plains | | Temperate Prairies | |
|---|---|---|---|---|---|---|---|---|
| **Category** | **Number** | **%** | **Number** | **%** | **Number** | **%** | **Number** | **%** |
| Target Sampled | 76 | 71 | 34 | 97 | 22 | 56 | 20 | 61 |
| Access Permission Denied | 18 | 17 | 1 | 3 | 12 | 30 | 5 | 15 |
| Physically Inaccessible | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Map Error | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Active Crop Production | 8 | 7 | 0 | 0 | 2 | 5 | 6 | 18 |
| Inundated by Water > 1m in Depth | 5 | 5 | 0 | 0 | 3 | 8 | 2 | 6 |
| Industrial/Agricultural/Aquacultural Purpose | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sampleable Area Too Small | 1 | <1 | 0 | 0 | 0 | 0 | 1 | 3 |
| Total Points Evaluated (% of Statewide total) | 107 (100%) | | 35 (33%) | | 39 (36%) | | 33 (31%) | |

- The MWCA target design goal is 150 total sample sites allocated equally by ecoregion at a 50% revisit rate. A total of 153 sites were established and sampled for the 2016 MWCA (Table C-1). Three additional sites were sampled where a field crew happened to be in the vicinity of a site just outside of the 150 target mid-sample season and the area was far from headquarters (St. Paul) making it more convenient to sample the site as opposed to returning if needed.
- The revisit/new site allocation was approximately 50% as expected (Table C-2), but the ecoregion site-evaluation resulted in a greater number of sites established in the Mixed Wood Shield ecoregion compared to the Temperate Prairies (Table C-1, Table C-2). The drivers appear to be higher rates of rejection in the Mixed Wood Plains and Temperate Prairies ecoregions due to crop production, open water >1 m in depth, and permission denials.
- Higher rejection for crop production and deep water in these two ecoregions makes sense given that row crop agriculture is the pre-dominant landuse and that open water wetlands make up a larger share of the wetlands in these two ecoregions. Landowner denial rates varying greatly by

ecoregion and over approximately 15% (as was observed for the new sites in the Mixed Wood Plains Table C-2) is out of the ordinary for either MWCA or DWQA. When paired with the very low denial rates in the Mixed Wood Shield (Table C-2), this certainly had to contribute to sites being shifted to that ecoregion.

- This regional shifting of sites due to unequal rejection rates occurred in 2011/12 as well. As the design calls for 50% revisit rate for every sampling cycle it appears that this geographic site allocation problem will likely continue to compound. Currently, the shifting numbers of sites from one ecoregion to another likely has minimal effect on the estimates as the sample size continues to be > 40 other than to increase the size of the confidence intervals. Design modifications to correct this issue will be explored for future MWCA iterations.
- The original locations of random points were on target wetland most of the time (Table C-3). Point relocation rates (i.e., when original point was not on target wetland, but target wetland was present within 60 m) appear to be higher in the Mixed Wood Plains and Temperate Prairies ecoregions. This is likely due to wetlands having smaller size with greater edge effects and higher rates of cultivated wetland that would require point shifting.

**Table C- 3. 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 | 138 | 90 | 62 | 95 | 43 | 91 | 33 | 80 |
| Point Re-located | 15 | 10 | 3 | 5 | 4 | 9 | 8 | 20 |

- The majority of the sites were established using the standard site layout (0.5 ha circle centered on the point), though there was regional variation (Table C-4). The standard site layout was used in nearly 80% of the sites in the Mixed Wood Shield, whereas, alternative layouts were needed much more often in the Mixed Wood Plains and Temperate Prairies. Again, this was likely due to the prevalence of smaller wetlands with greater edge requiring greater shifting and use of polygon layouts.

**Table C- 4. Site layout results. Layout descriptions are provided in Table B-2.**

| | Statewide | | Mixed Wood Shield | | Mixed Wood Plains | | Temperate Prairies | |
|---|---|---|---|---|---|---|---|---|
| **Site Type** | **Number** | **%** | **Number** | **%** | **Number** | **%** | **Number** | **%** |
| Standard Site | 90 | 59 | 51 | 78 | 16 | 34 | 23 | 56 |
| Standard Site-Shifted | 43 | 28 | 10 | 15 | 21 | 45 | 12 | 29 |
| Polygon Site | 14 | 9 | 1 | 2 | 7 | 15 | 6 | 15 |
| Wetland Boundary Site | 6 | 4 | 3 | 5 | 3 | 7 | 0 | 0 |

- The use of the standard site layout, however, increased by approximately 10% at the statewide scale compared to 2011/12 (Bourdaghs et al. 2015). The polygon site layout decreased by a corresponding amount. This may be due to improved application of the site-layout procedures as site establishment was a focus of increased training heading into 2016.
- Finally, the vast majority of MWCA sample sites at the statewide scale (70%) have a single community present, with an additional 27% with two communities (Table C-5). The number of communities per site again varies by ecoregion, with a higher rate of single community sites in the Mixed Wood Plains and more complex 2+ community sites in the Mixed Wood Plains and Temperate Prairies. Again, this is likely due to wetland size and edge effects in the different regions.

**Table C- 5. Plant community per site distribution statewide and by ecoregion.**

| Number of communities per site | Statewide | | Mixed Wood Shield | | Mixed Wood Plains | | Temperate Prairies | |
|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % |
| 1 | 107 | 70 | 52 | 80 | 27 | 57 | 28 | 68 |
| 2 | 42 | 27 | 13 | 20 | 17 | 36 | 12 | 29 |
| 3 | 4 | 3 | 0 | 0 | 3 | 6 | 1 | 2 |

# Appendix D – 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 in the site 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.

# Appendix E – Site level QA/QC results

Ten percent of the target number of sites (n = 15) were re-sampled using the full sampling protocol as a QA/QC measure. Replicate sites were chosen from the revisit sites (i.e., sites previously sampled in 2011/12) by the random order of the design. 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. Thirteen of the replicate sites were MWCA only sites sampled using the meander approach and two were national sites sampled using the national plot sampling protocol. Replicate sampling occurred at least 2 weeks after the primary sample and were often completed by a different sampling crew (n = 10).

The 2011/12 site level QA/QC identified the following issues of concern:

- Inconsistencies between crews establishing sites
- Interpreting and mapping plant communities within sites
- Large cover estimate variability

Leading up to the 2016 sampling, these concerns were addressed through revised protocols and increased training. Sample site establishment procedures were revised in an effort to clarify the decision rules on shifting and alternative site layouts and plant community minimum mapping units were established to increase interpretation consistency. An in-field total cover check was also established where the crew leader was required to sum the midpoint percent cover for a community and compare against the interquartile range for that wetland class. If the total midpoint cover deviated from the interquartile range, cover estimates were reviewed and revised if warranted or the deviation was explained in the field comments.

2016 site level QA/QC results:

- There were zero site-establishment or layout procedural errors between the primary and replicate samples at the QA/QC sites. In addition, all of the QA/QC sites had consistent plant community type interpretation (i.e., the same community types were interpreted to be present each time). There was only one instance where there was a plant community mapping extent inconsistency where the boundary between two communities within a site was determined differently between samples.
- Primary and replicate condition category outcomes at the site level were the same at 11 of the 15 QA/QC sites (73%). The condition category differences appeared to be random—there were two cases where condition category increased from primary to replicate sample (e.g., fair to good) and two cases where condition category decreased (e.g., good to fair)—though sample size was small.
- At the plant community level, there was paired condition category agreement at 13 of the 18 communities (72%) with two condition category increases and three decreases. The average absolute *wC* paired score difference was 0.4 and the median absolute *wC* difference was 0.3.
- Large differences in *wC* scores (≥ 0.6) often coincide with large differences in the total non-native species midpoint cover as non-native species have a *C*-value equal to 0 (Bourdaghs 2012). Four of the 18 communities (22%) had large *wC* score differences and all four had total non-native species cover differences > 20%.

- The two largest community *wC* score differences occurred at the site where there was the disagreement on the extent of the two communities present between the primary and replicate sample observers. The site occurs on a seepage fresh meadow that grades into a shallow marsh. The natural community boundary is obscured by dense invasive *Typha* such that differing placement of the community boundary can produce large differences in non-native species cover in each community, which subsequently has a large effect on *wC* scores.

In addition to the QA/QC data, the revisit data—where sites were sampled in 2011/12 and 2016—may also be a useful data set to explore sample repeatability. Almost all of the wetland plant communities sampled in the MWCA are overwhelmingly composed of perennial plant species that grow year after year. In the absence of widespread natural disturbance, increased human impacts, or widespread management to improve wetland condition—the composition and/or abundance distribution of most wetland plant communities in a large data set would be expected to be stable or only show minor changes over a five-year time period.

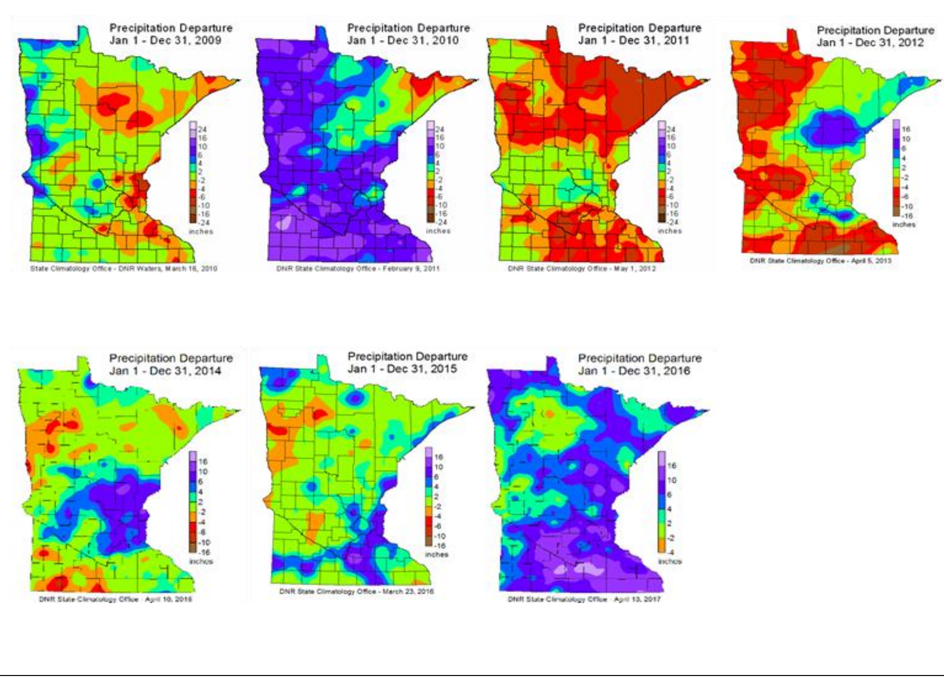
While the vegetation at some of the revisit sites has actually changed over time, it does not readily appear that any of the factors that may cause plant community change were widespread between 2011/12 and 2016, making the revisit data as a whole a reasonable proxy for replicate data.

- Annual precipitation departure from normal maps for the MWCA sampling years (and the two years prior) perhaps indicate some spatially broad qualitative between 2011/12 and 2016 (Figure E-1). Much of the state was dryer than normal in 2011/12 and vice versa in 2016. Preceding years for each time period, however, show variable total precipitation prior to both sampling iterations. It is likely that either dry or wet conditions would have to persist for a number of years over broad regions to cause large shifts in wetland plant communities that could affect wetland vegetation condition. There was very little change in wetland plant community extent (Figure 7) suggesting that if there was a broad change in precipitation patterns over the five-year time period, any changes in wetland plant communities were not detected.

**Figure E- 1. Statewide annual precipitation departure from normal maps for MWCA sampling years and the two years prior (A: 2009-12, B: 2014-16).**

A

B



- Human impacts to Minnesota's wetlands (as measured by the HDA) were largely the same from 2011/12 to 2016 (Figure 9). This was reflected in the paired HDA ratings at the revisit sites where four sites improved and HDA category (e.g., rating increased from poor to fair) and three sites had decreased ratings.
- In addition, there were no widespread accounts from natural resource managers or landowners of non-native invasive species reduction between 2011/12 and 2016, which could potentially boost regional vegetation condition estimates.
- In terms of vegetation condition at the site level, condition category changes at the revisit sites (Table E-1) correspond to the overall regional condition estimates between 2011/12 and 2016 (Figure 5). In the Mixed Wood Shield ecoregion, the revisit sites had approximately the same number of category increases and decreases, whereas there were a greater number of category increases (e.g., poor condition in 2011/12 and fair in 2016) in the Mixed Wood Plains and Temperate Prairies ecoregions combined.

**Table E- 1. Site level revisit condition category change results from 2011/12 to 2016 for the Mixed Wood Shield and combined Mixed Wood Plains and Temperate Prairies ecoregions.**

| Ecoregion | Total Sites | #/(%) Increase Condition Category | #/(%) Decrease Condition Category |
|---|---|---|---|
| Mixed Wood Shield | 31 | 5 (16%) | 6 (19%) |
| Mixed Wood Plains & Temperate Prairies | 46 | 9 (20%) | 3 (7%) |

- A similar regional pattern is present in the *wC* score differences at the plant community level (Table E-2). The median absolute paired difference was approximately the same as the QAQC data. The number of large (≥ 0.6) *wC* increases and decreases (where there is an increased likelihood that the score change will translate into a condition category change) was the same in the Mixed Wood Shield ecoregion, whereas there were twice as many large *wC* increases as decreases in the Mixed Wood Plains and Temperate Prairies ecoregions combined.

**Table E- 2. Community level revisit wC differences results from 2011/12 to 2016 for the Mixed Wood Shield and combined Mixed Wood Plains and Temperate Prairies ecoregions.**

| Ecoregion | Total Paired Communities | Median Absolute Difference | #/(%) of Large (≥ 0.6) *wC* Increases | #/(%) of Large (≥ 0.6) *wC* Decreases |
|---|---|---|---|---|
| Mixed Wood Shield | 37 | 0.5 | 6 (16%) | 6 (16%) |
| Mixed Wood Plains & Temperate Prairies | 62 | 0.4 | 16 (26%) | 8 (13%) |

- As *wC* is weighted by relative cover estimates of the species present at a sampled community, scores often vary by differences in non-native species cover as non-native species have *C* = 0 which largely influences scores (Bourdaghs 2012). In terms of total cover, the number of large increases and decreases was more or less the same in both the Mixed Wood Shield and the Mixed Wood Plains and Temperate Prairies ecoregions combined (Table E-3). The number of large non-native cover decreases, however, was approximately double the number of large non-native cover increases in the Mixed Wood Plains and Temperate Prairies ecoregions (Table E-3).

**Table E- 3. Community level large total cover and large non-native cover differences results from 2011/12 to 2016 for the Mixed Wood Shield and combined Mixed Wood Plains and Temperate Prairies ecoregions.**

| Ecoregion | Total Communities | #/(%) of Large Total Cover Increases (≥ 20%) | #/(%) of Large Total Cover Decreases (≥ 20%) | #/(%) of Large Non-Native Cover Increases (≥ 20%) | #/(%) of Large Non-Native Cover Decreases (≥ 20%) |
|---|---|---|---|---|---|
| Mixed Wood Shield | 37 | 13 (35%) | 12 (32%) | 2 (5%) | 0 (0%) |
| Mixed Wood Plains & Temperate Prairies | 62 | 14 (23%) | 17 (27%) | 6 (10%) | 13 (21%) |

- In other words, the variation in total cover at revisit sites appears to be (more or less) random. The variation in non-native species cover estimates, however, in the Mixed Wood Plains and Temperate Prairies ecoregions indicates systematic decreases in 2016 relative to 2011/12. This may be due to high cover estimation bias in 2011/12 or low cover estimation bias in 2016 or a combination of both.
- Regardless, the relative decrease in non-native cover estimations in these ecoregions may explain the unexpected significant increase of fair condition wetland and the corresponding significant decrease poor condition wetland (Figure 5), as well as the decreased extent of the invasive species HDA factor at the severe level (Figure 10) in the Mixed Wood Plains and Temperate Prairie ecoregions.

In conclusion, compared to 2011/12 (Bourdaghs et al. 2015), the site and community level QA/QC outcomes were improved in 2016. Site establishment errors and plant community interpretation differences were reduced substantially. This translated into improved *wC* score and condition category consistency. The differences that were found did not appear to be biased in either direction.

Improvement was expected given that 2011/12 was the first MWCA iteration and the entire approach was new to the MPCA. The revisit results, however, show that there continues to be room for improvement, where minor but systematic relative differences in non-native species cover estimates between iterations may have obscured the true vegetation quality condition in the Mixed Wood Plains and Temperate Prairies ecoregion. Increased training on making consistent cover estimations will be a priority for future MWCA iterations.

# Appendix F – 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 (US EPA 2016c) 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 specimen collection 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 F- 1. Field voucher specimen results.**

| Sampling Visits | Target # of QA Specimens | QA Specimens Collected | QA Specimen Completeness Rate (%) | # of Visits w/Incomplete Collection | Visit Collection Completion Rate (%) | # of Specimen Taxonomic Agreements | Percent Taxonomic Disagreements (%) |
|---|---|---|---|---|---|---|---|
| 140 | 700 | 682 | 97 | 7 | 95 | 633 | 7% |

- 682 voucher specimens were collected over the 140 sampling visits the MPCA conducted for the 2016 MWCA (127 primary site vegetation samples plus 13 replicate samples, voucher specimen results from EPA contract crews were unavailable) with overall and visit level specimen collection completion rates of > 90%.
- The taxonomic disagreement rate was 7%.
- Both of the completeness and taxonomic disagreement rates were similar to 2011/12 and they met the QA/QC goals.

**Table F- 2. Unknown specimen collection results.**

| Sampling Visits | Total Visit Level Taxa | Total Un-Identifiable Taxa | # Taxa/Visit | # Identifiable Taxa/Visit |
|---|---|---|---|---|
| 140 | 6427 | 315 | 45.9 | 43.7 |
| | | | | |
| **# Un-Identifiable Taxa/Visit** | **Unknown Specimens Collected** | **Unknown Specimens/Visit** | **# of Unknown Specimen Positive ID's** | **Unknown Specimen Positive ID Rate (%)** |
| 2.2 | 532 | 3.8 | 458 | 86% |

- 6,427 unique taxa were observed over the 140 MPCA sampling visits for approximately 46 taxa observations per visit (Table F-2). The overall rate of unidentifiable taxa (i.e., taxa recorded at the family or genus level that lack the flower/fruit characteristics to allow for identification that are typically not collected as they can't be readily identified), was low at approximately 2 per visit. The overall rate of unknown specimens collected per site was also low at approximately four per visit.
- The low un-identifiable and unknown collection rates illustrate that lead botanists on were identifying the vast majority of taxa in the field (i.e., overall rate of 40 out of 46 taxa) and the voucher QA/QC results (Table F-1) indicate that these field identifications are correct over 90% of the time.
- When lead botanists did collect unknown specimens to identify in the lab, they were able to improve the identification to the species level at an 86% rate (Table F-2).
- Compared to 2011/12, the overall number of taxa per visit was down from approximately 53 (Bourdaghs et al. 2015) to 46 and the unknown specimen collection rate also decreased from 16 per visit to four.

**Table F- 3. Lab identification voucher specimen results.**

| Unknown Specimens | Total # of Unknown-QA specimens | # of Taxonomic Agreements | Percent Taxonomic Disagreements (%) |
|---|---|---|---|
| 532 | 54 | 51 | 6% |

- The lab voucher taxonomic disagreement rate was 6% (Table F-3), well below the 15% goal and a large improvement from the 15% disagreement rate from 2011/12 (Bourdaghs et al. 2015).
- Unknown specimens are by definition difficult to identify and the higher disagreement rate in 2011/12 was likely due to MPCA botanists being prone to declare a species level identification when there continued to be uncertainty. More attention was given to the uncertainty of identification in 2016, only naming specimens to the species level when there was a high degree of confidence. This resulted in improved taxonomic disagreements.