Status and Trends of Wetlands in Minnesota: Depressional Wetland Quality Baseline

Minnesota Pollution Control Agency

March 2012

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Document number: wq-bwm1-06

Contents

Figures

Tables

Abbreviations, acronyms, and symbols

BWSR	Minnesota Board of Water and Soil Resources
cm	centimeter
Ch.	Chapter
CL	Confidence Limit
CWAMMS	Comprehensive Wetland Assessment, Monitoring, and Mapping Strategy
EPA	Environmental Protection Agency
FQA	Floristic Quality Assessment
GIS	geographic information system
ha	hectare
HGM	hydrogeomorphic
IBI	Index of Biological Integrity
m	meter
µg/L	microgram per liter or part per billion
µm	micrometer
mg/L	milligram per liter or part per million
MPCA	Minnesota Pollution Control Agency
MN DNR	Minnesota Department of Natural Resources
MnRAM	Minnesota Routine Assessment Method
WSTMP	Minnesota Wetland Status and Trends Monitoring Program
NPDES	National Pollutant Discharge Elimination System
NWI	National Wetlands Inventory
R.	Rule
SDS	State Disposal System
SE	Standard Error
USFWS	U.S. Fish and Wildlife Service
WCA	Wetlands Conservation Act

Executive Summary

From the prairie potholes in the southwest to the vast expanses of peatlands in the north, the diversity of Minnesota's wetlands is arguably unmatched by any other state. Although roughly half of Minnesota's original wetlands have been lost to draining or filling, beginning in the 1970s public perception began to shift with recognition of the many ecological and societal benefits that wetlands provide. In Minnesota this trend was exemplified by the passage of the Wetlands Conservation Act (WCA) in 1991, which aims to "achieve no-net-loss in the quantity, quality, and biological diversity of Minnesota's existing wetlands" and eventually accomplish gains in these areas. Until recently, existing wetland monitoring programs were unable to accurately evaluate whether the WCA was meeting its stated goals.

In 2006, a statewide wetland monitoring program was initiated to assess status and trends of both wetland quantity and quality. The Minnesota Department of Natural Resources (MDNR) is primarily responsible for the implementation of the wetland quantity monitoring program, while the Minnesota Pollution Control Agency (MPCA) conducts the state's wetland quality monitoring program. The focus of this report is on the design and results of the initial wetland quality survey, which evaluates the function and condition of depressional wetlands (e.g., marshes) and ponds throughout the state.

The wetland quality monitoring program utilizes probabilistic survey techniques to infer function and condition for the entire population of depressional wetlands and ponds based on results obtained from a randomly selected sample of study sites. Sampling was spread out over three years with each year dedicated to one of Minnesota's Level II ecoregions: Mixed Wood Plains (2007), Temperate Prairies (2008), and Mixed Wood Shield (2009). Plant and macroinvertebrate indices of biological integrity (IBIs) developed and calibrated for each ecoregion, were the primary indicators of wetland condition used in this survey. Condition categories of good, fair, and poor were established for each indicator relative to least or minimally disturbed reference sites within each of the three ecoregions. Assessing wetland functions was achieved by conducting the Minnesota Routine Assessment Method (MnRAM) at each study site. In addition, several water quality parameters were measured at each study site to better understand their effect on wetland condition.

Based on the wetland quality survey, an estimated 158,435 depressional wetlands and ponds occur within the state of Minnesota, the majority of which are located on private property. Plant communities are in good condition in 29 percent of Minnesota's depressional wetlands and ponds, while 25 percent are in fair condition and 46 percent are in poor condition. The macroinvertebrate communities (including insects, snails, crustaceans, and leeches) inhabiting these waterbodies are in better condition with estimates of 47 percent good, 33 percent fair, and 20 percent poor. Macroinvertebrate community condition varied depending on whether the wetland or pond was natural or man-made in origin; 57 percent of the natural basins were in good condition compared to only 27 percent of the man-made basins. Plant community condition did not exhibit a substantial difference between these two categories.

The condition of plant and macroinvertebrate communities both varied among the three ecoregions; however a different pattern was exhibited by each community. Both plant and macroinvertebrate IBIs indicated that the Mixed Wood Shield ecoregion has the largest proportion of depressional wetlands in good condition, 54 percent and 60 percent, respectively (Figure 1). Compared to the Mixed Wood Shield, wetland plant communities are significantly worse, almost equally so, in the Mixed Wood Plains and Temperate Prairies ecoregions. Macroinvertebrate communities, on the other hand, demonstrated a pattern of decreasing condition: Mixed Wood Shield > Mixed Wood Plains > Temperate Prairies. Invasive wetland plant species and the differential impact they have on plant and macroinvertebrate communities may partially explain these observed patterns. For instance, invasive plant species have a stronger impact on wetland plant communities and occur more frequently in the Mixed Wood Plains

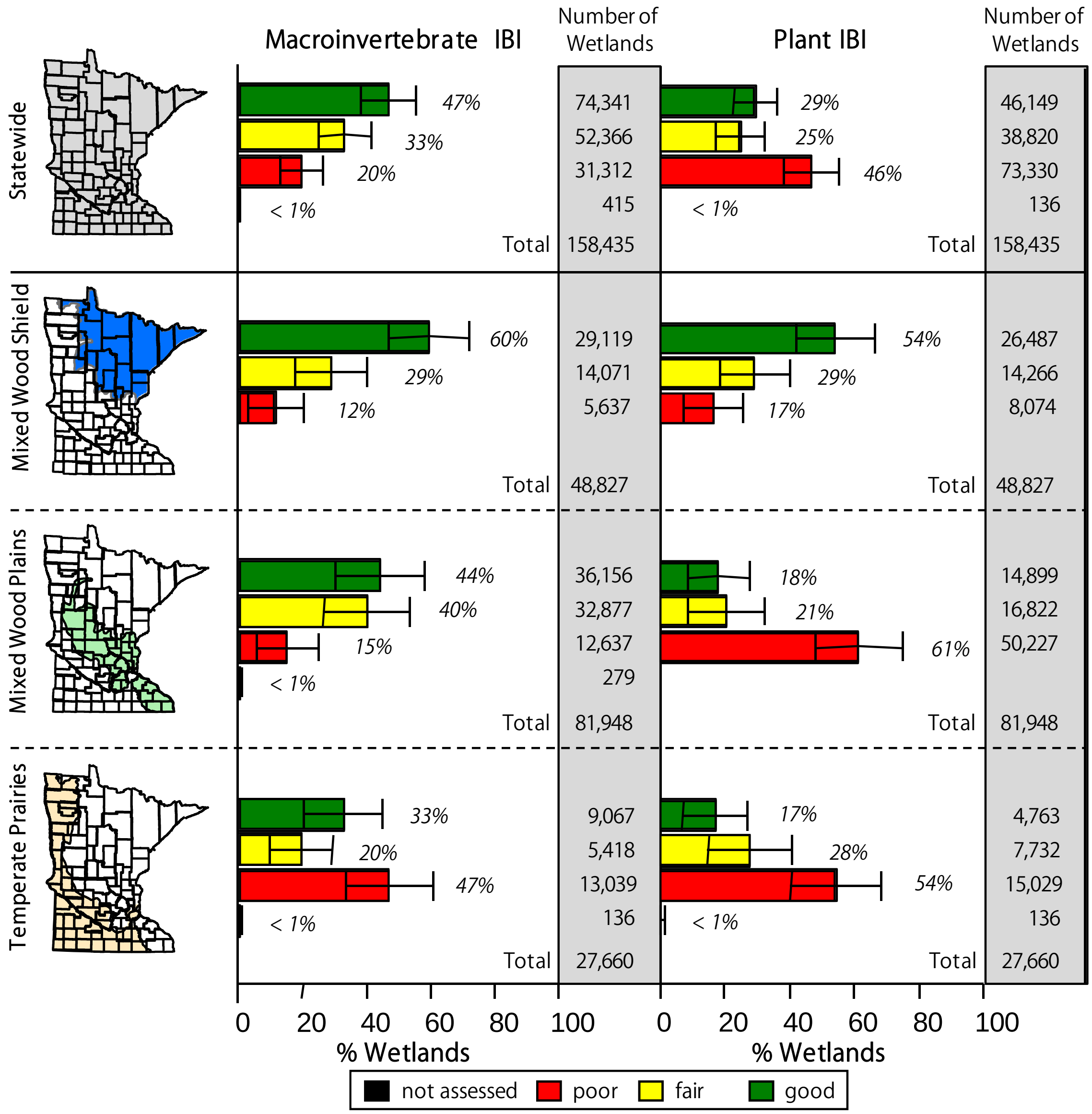


Figure 1. Biological condition of Minnesota's depressional wetlands and ponds according to macroinvertebrate and plant indices of biological integrity (IBIs), including the estimated number of wetlands within each condition category. Bracketed lines represent the width of the 95 percent confidence interval associated with each estimate. Percentages may not add up to 100 percent due to rounding.

and Temperate Prairies ecoregions (see Box 1-1) where depressional wetland plant communities were predominantly in poor condition.

Plant and macroinvertebrate communities in poor condition may be the result of excess pollutant levels in depressional wetlands and ponds. Based on their prevalence as potential stressors (i.e., how often they occur at 'high' concentrations relative to reference sites) and their estimated relative risk to plants and macroinvertebrates, chloride and total phosphorus may represent important pollutants adversely affecting the condition of depressional wetlands and ponds. For example, results from this survey indicate that chloride concentrations are high in 38 percent of depressional wetlands and ponds statewide; and when high concentrations occur, macroinvertebrates are almost four times as likely, and plants are almost twice as likely, to be in poor condition (Figure 2). Total phosphorus had similar impacts on these biological communities, but was found at high concentrations in only 31 percent of the depressional wetlands and ponds statewide. However, water quality parameters measured in this survey represent only a fraction of all the factors that affect the condition of depressional wetlands and ponds. Furthermore, these parameters were measured only one time at each site, providing a snapshot of water quality conditions that may fluctuate on a daily, seasonal, or annual basis. Therefore, these results provide clues to the types of impacts but do not establish cause-and-effect relationships between each parameter and wetland condition.

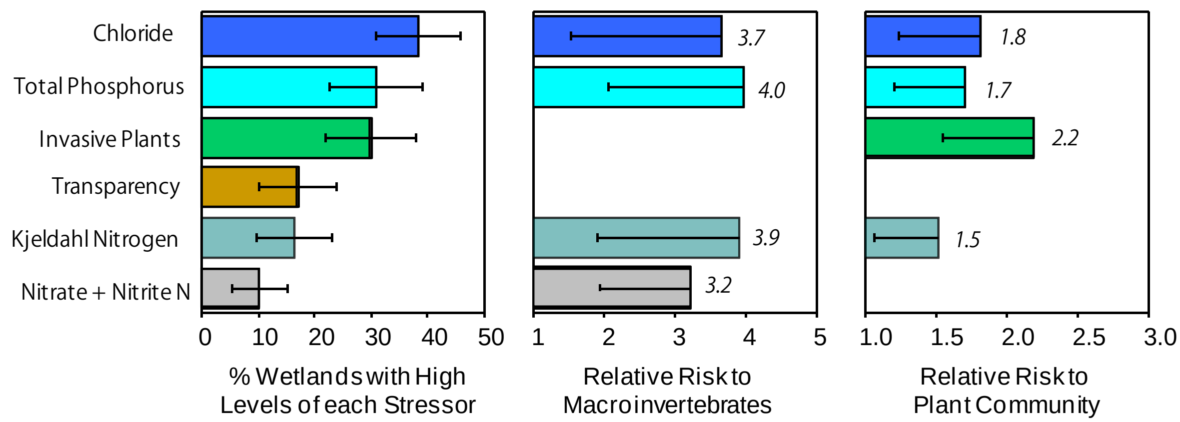


Figure 2. Extent of stressors and their relative risk to plant and macroinvertebrate communities in Minnesota depressional wetlands and ponds. Bracketed lines represent 95 percent confidence intervals (for percent estimates) or lower confidence limits (for relative risk estimates). A stressor without an associated bar on the relative risk graphs indicates that it did not pose an elevated risk to that community.

Depressional wetlands and ponds are providing a variety of ecosystem goods and services (i.e., functions). Among other services, these waterbodies are providing valuable habitat for wildlife and amphibians, filtering out pollutants and sediment for the protection of downstream water quality in lakes and streams, and attenuating the impacts of damaging floods by storing water during intense rain storms. According to MnRAM, the majority of depressional wetlands and ponds are rated high or medium for their ability to provide these services (Figure 3). Of these functions, only the flood attenuation ratings were comparable between natural and man-made wetlands. On average, natural wetlands received higher ratings for the habitat and downstream water quality protection functions. While high functioning wetlands provide ecosystem services that are important for maintaining watershed health, some of these services may be contributing to the degradation of depressional wetlands and ponds, particularly when surrounding landscapes have been significantly altered (e.g., increased impervious surface and/or increased drainage).

The data and results provided by this survey comprise the baseline against which depressional wetland quality can be periodically compared in subsequent years. This will allow the state of Minnesota to begin to understand whether or not policies, regulations, and incentives are achieving stated goals of no-net-loss and eventually net gains in wetland quality and biological diversity. The next round of data collection for the Depressional Wetland Quality Assessment is scheduled for 2012. For a comprehensive assessment of this vital resource, the MPCA initiated the Minnesota Wetland Condition Assessment (MWCA) in 2011, coinciding with the National Wetland Condition Assessment, which encompasses all types of wetlands. Assessing the condition of a diverse array of wetlands can be accomplished using plants as the indicator assemblage since hydrophytic vegetation is present in all wetland types. The Floristic Quality Assessment methodology will be used to estimate the condition of all wetland types found in Minnesota. Therefore, a benchmark for gauging condition gains or losses for a much broader range of wetlands types will be acquired in the first iteration of the MWCA.

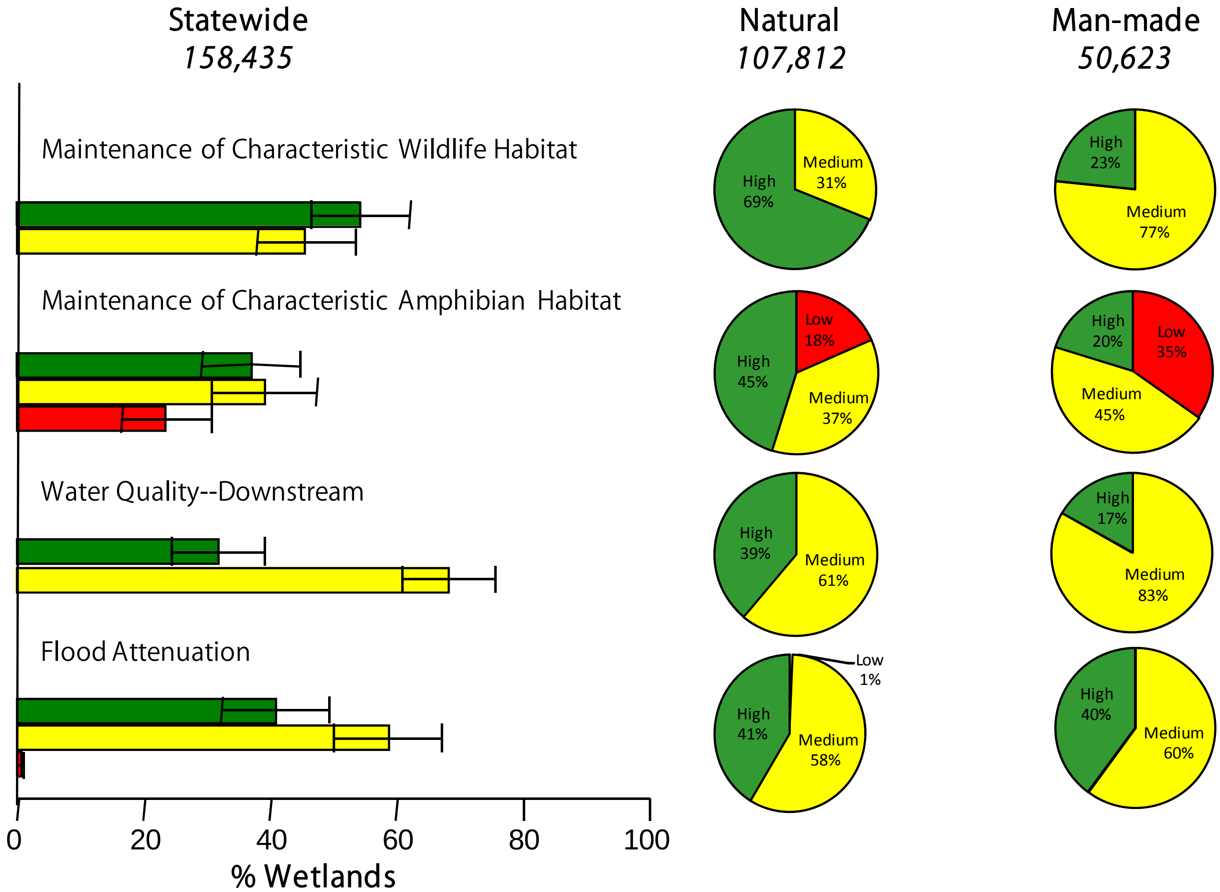


Figure 3. Functional ratings for Minnesota depressional wetlands and ponds. Included for each function is a comparison of estimates for natural vs. man-made wetlands. Lines with brackets represent the width of the 95 percent confidence interval associated with each estimate.

Introduction

Wetlands are an integral part of Minnesota's natural and cultural heritage. Healthy ecosystems rely on a diversity of wetland community types to provide habitat for native vegetation and wildlife, reduce erosion during peak events, maintain stream flow during drier periods, recharge aquifers, and assimilate pollutants derived from upland sources. Globally, wetlands are gaining attention for their ability to trap and store carbon, and thus may be a key component in the strategy to reduce the effects of climate change. Wetlands have also been woven into the fabric of Minnesota's culture, beginning with the customs of Native Americans who harvested wild rice and traditional medicinal plants from wetland habitats. These traditions continue today and have been supplemented by other uses such as waterfowl hunting, bird watching, and outdoor recreation following European settlement of the region. However, the ecological and societal benefits that wetlands provide were not immediately recognized by early European settlers. In fact, it was not until the mid 1980s that the tide began to turn from draining and filling wetlands to their protection and restoration. In Minnesota, this change in how society perceived wetlands was exemplified by the passage of the Wetland Conservation Act (WCA) in 1991.

The overall goal of the WCA is to "achieve no-net-loss in the quantity, quality, and biological diversity of Minnesota's existing wetlands" (Minn. R. ch. 8420.0100). Furthermore, the act seeks to increase wetland quantity, quality, and biological diversity in the state by restoring or enhancing diminished or drained wetlands. Full implementation of the WCA began in 1994 and reporting of wetland gains and losses, focused primarily on quantity, began soon thereafter (BWSR 1996, 1998, 2000, 2001, 2005). However, this reporting system does not account for wetlands lost or degraded by unregulated actions (e.g., WCA exemptions, illegal activities, nonpoint source pollution), deviations from actions proposed in permit applications, temporary losses (i.e., the period before a replacement wetland is mature and fully functioning), mitigation credits for the establishment of upland buffers or wetland preservation, restoration projects that involve multiple organizations, and private restorations (Gernes and Norris 2006). In 2006, a Comprehensive Wetland Assessment, Monitoring, and Mapping Strategy (CWAMMS) were developed by state and federal agencies responsible for wetland protection and regulation in Minnesota to address these existing information gaps.

One of the primary outcomes of the CWAMMS was the development of statewide random surveys to begin assessing the status and trends of wetland quantity and quality in Minnesota. The wetland quantity survey, modeled after the US Fish and Wildlife Service wetland status and trends program (e.g., Dahl 2006, 2011), is being implemented by the Minnesota Department of Natural Resources. The initial "baseline" wetland quantity results of the Minnesota Wetland Status and Trends Monitoring Program (WSTMP) have recently been published in a separate report (Kloiber 2010). The MPCA is responsible for conducting the wetland quality survey, the focus of the current report. This initial report on wetland quality is limited to depressional wetlands (see Scope of Survey for a detailed definition); however, the scope of the survey will broaden to include all wetland types in subsequent cycles. At that time, a comprehensive wetland quality baseline for Minnesota will become established.

Assessing wetland quality

Wetlands are often recognized for their ability to provide functions that support the maintenance of healthy ecosystems and are vital to human welfare. Receiving less attention, however, is a wetland's ability to maintain and support a "...balanced integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to the natural habitat of the region" (Karr and Dudley 1981). The extent to which a wetland deviates from this state of ecological integrity represents a measure of its condition (Fennessy et al. 2004). Rather than focusing on one or the other, this wetland quality survey assessed both wetland function and condition. Assessing both aspects of wetland quality provides a more comprehensive evaluation of the resource because function and condition can behave independently or even have a negative relationship. For example, modifying a wetland to enhance its ability to provide certain functions (e.g., floodwater and nutrient retention) may degrade its ecological condition. To contend with this potentially antagonistic relationship, the wetland quality survey included separate indicators to independently assess wetland function and condition.

Biological monitoring and assessment is one of the most commonly used approaches for measuring the ecological condition of aquatic ecosystems. Aquatic organisms are constantly exposed to their environment and, as a result, are able to integrate the effects of multiple stressors occurring over time and space. Thus, biological monitoring provides a more accurate assessment of ecological condition than traditional water chemistry parameters. Successful implementation of this approach requires the adoption of a classification scheme to reduce natural variability, establishment of regional reference conditions, utilization of standard data collection procedures, and identification of community attributes, called metrics, that reliably respond to human disturbance (Karr and Chu 1999). The index of biological integrity (IBI), a multi-metric indicator originally developed to assess the condition of rivers and streams (Karr 1981), has been successfully adapted to a variety of aquatic and terrestrial habitats, including wetlands.

The MPCA began developing IBIs for wetlands in the early 1990s, focusing on depressional marshes and ponds. During this work, attributes of the aquatic plant and macroinvertebrate (aquatic insects, snails, leeches, and crustaceans) communities were investigated to determine their response pattern along a gradient of human disturbance. These efforts culminated with the development and validation of three separate plant and macroinvertebrate IBIs, one for each of Minnesota's three major ecoregions (Appendix A). Currently, depressional marshes and ponds are the only types of wetlands that have IBIs developed statewide. The wetland quality survey used these plant and macroinvertebrate IBIs as indicators of wetland condition.

Similar to how a medical professional evaluates human health by measuring body temperature, blood sugar, cholesterol and other parameters, the wetland quality survey included measurements of some key parameters that could help explain why some wetlands in the survey were in poor condition. Several water quality parameters were measured at each study site based on their known potential to stress wetland community integrity. By monitoring these stressors, their relationship with the biological communities could be explored through a relative risk analysis. Such an analysis provides an estimate of the likelihood that a biological community will be in poor condition when elevated levels of a stressor are present. For instance, a relative risk estimate of two indicates that the probability of having a poor biological community is twice as likely when stressor levels are elevated compared to when stressor levels are low. Having an estimate of how often a stressor deviates from natural background levels, in addition to the consequent impact on biological communities, provides a better understanding of its relative importance within the population.

In contrast to condition assessment, functional assessments focus on measuring the goods and services provided by wetland ecosystems. Functional assessment is commonly used in regulatory decisions to translate wetland mitigation expectations due to project impacts to wetlands. Wetland professionals in many states around the United States have developed and utilized different approaches to functional assessment (Fennessy et al. 2004). In Minnesota, the Board of Water and Soil Resources (BWSR) recognizes the MnRAM as an approved wetland functional evaluation method for WCA decisions (http://www.bwsr.state.mn.us/wetlands/mnram/index.html). In this wetland quality survey, MnRAM was used to estimate the functional potential of several goods and services that wetlands provide. The MnRAM methodology relies on landscape data and field observation data collected for individual wetlands. Landscape data for individual wetlands were generated using Geographic Information Systems (GIS).

Methods

Wetland classification

In environmental monitoring, the use of ecological indicators to assess human impacts to natural habitats is enhanced by classifying the natural features of interest in a manner that minimizes natural variability associated with factors such as climate, geology, and hydrology. Without classification, it may be difficult to distinguish between natural and human-induced variation in ecological condition. For example, the number of species occupying a given area is a commonly used metric to assess the ecological condition of natural habitats. However, certain habitat types may naturally support fewer species than other habitat types regardless of whether they are disturbed or not. If classification is not utilized to account for natural variability among habitat types, naturally species-poor habitats may appear to be degraded when compared to species-rich habitats.

There are a variety of approaches for classifying wetland habitats, each one focusing on different aspects of these diverse ecosystems. Brinson (1993) developed a hydrogeomorphic (HGM) classification that emphasized a wetland's landscape position, water source, and hydrodynamics. Other classifications have focused on plant communities and/or water regime (i.e., the amount and duration of flooding) to categorize wetlands (e.g., Shaw and Fredine 1956, Cowardin et al. 1979, Eggers and Reed 1997). This survey uses a combination of these existing classification schemes in an attempt to properly calibrate the indicators used to assess the function and condition of wetlands throughout the state. This system is comprised of three main criteria: HGM class, dominant plant community, and water regime (Table 1). The overall classification framework for this survey also includes a geographic component that will be discussed in a following section.

The wetland classification framework outlined in Table 1 is hierarchical with water regime nested within plant community which is nested within HGM class. However, not all potential combinations of the three classification strata are valid. In reality, classification at this stage, without having collected indicator data from all types of wetlands that occur in Minnesota, is an iterative process (U.S. Environmental Protection Agency (US EPA) 2002d). In the future as data are collected and additional indicators are developed the framework presented in Table 1 could be modified to create new classes or combine existing classes. Therefore, the classification framework presented here will serve more as 'building materials' for generating classifications best suited to future indicators as opposed to the completed, definitive 'structure' to be used for all indicators. As an example, the target wetland type for this initial three-year iteration of the wetland quality survey demonstrates how some of the classes were combined to accommodate the applicability of the plant and macroinvertebrate indicators (see page 8.).

Table 1. Wetland quality survey classification system

HGM Class *(from Brinson 1993)*	Plant Community *(from Eggers and Reed 1997)*	Water Regime *(from Cowardin et al. 1979)*
Depressional	Shallow, Open Water	Saturated
	Deep Marsh	Temporarily Flooded
Riverine	Shallow Marsh	Seasonally Flooded
	Sedge Meadow	Semipermanently Flooded
Slopes	Fresh (Wet) Meadow	Permanently Flooded
	Mesic Prairie	Artificially Flooded*
Organic Flats	Calcareous Fen	
	Open Bog	
Mineral Flats	Coniferous Bog	
	Shrub-Carr Swamp	
Lacustrine Fringe	Alder Swamp	
	Hardwood Swamp	
Tidal Fringe	Coniferous Swamp	

* Not included in the wetland quality survey.

Scope of survey

It is intended that the wetland quality survey will eventually be fully complimentary to the wetland quantity survey (i.e., WSTMP) and encompass all wetland types in the state of Minnesota. Furthermore, to distinguish wetlands from other aquatic or terrestrial systems the US Fish and Wildlife Service's definition (Cowardin 1979 et al.) was used and is as follows:

> *Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water... Wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes, (2) the substrate is predominantly undrained hydric soil and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year.*

However, given that wetland condition indicators for Minnesota have only been fully developed for depressional marshes and ponds, the wetland quality survey will initially focus only on these types of wetlands. Utilizing the classification scheme outlined in Table 1 these target wetland types correspond to the following classes:

HGM Class:	Plant Community:	Hydrologic Regime:
Depressional	Shallow, Open Water and/or Shallow Marsh and/or Deep Marsh	Semi-permanently Flooded and/or Permanently Flooded

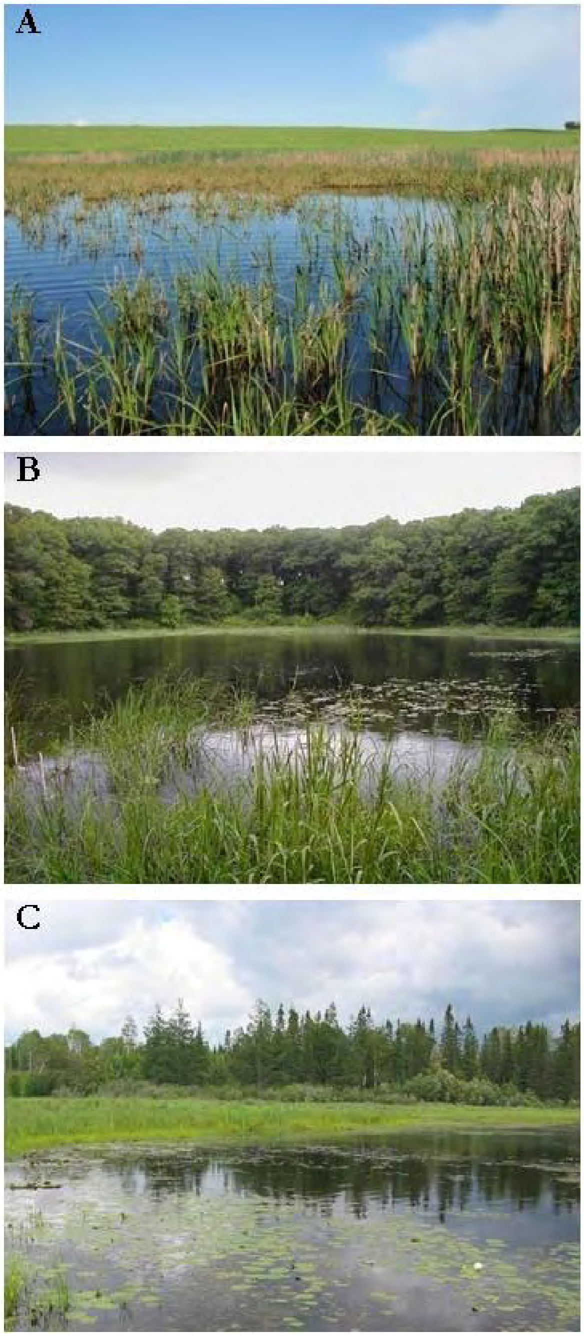


Figure 4. Examples of depressional wetlands found in Minnesota: (A) prairie pothole; (B) glacial kettle in central hardwood forest region; and (C) marsh in northern coniferous forest region.

These wetlands are located within a topographic depression (or basin) and typically have a fringe of emergent, herbaceous vegetation with deeper, permanently flooded areas having submergent aquatic vegetation (Figure 4). Under certain conditions (e.g., natural or human disturbance) or as a result of being man-made, some depressions may not develop emergent or submergent plant communities. Often depressions lacking an emergent fringe or with only a narrow fringe are viewed as ponds (Figure 5). Rather than attempting to draw a distinction based on perception, both vegetated and unvegetated depressions were included in the survey. In addition, all subclasses of depressional wetlands (isolated, inlet, outlet, and flow-through) were included in the survey. Hereafter, for brevity, depressional wetlands and ponds meeting the above mentioned criteria (i.e., the target population) are referred to as 'depressional wetlands'.

Depressional wetlands correspond to three WSTMP wetland classes: aquatic bed, emergent, and unconsolidated bottom. However, these wetland classes also occur within other geomorphic settings and can have different water regimes than those comprising the target population for the wetland quality survey. Therefore, the wetland quality survey results discussed here only pertain to a subset of these three WSTMP wetland classes. Using wetland acres as the common currency between the quantity and quality surveys, estimates of depressional wetland area from the quality survey were compared to WSTMP estimates of aquatic bed, emergent, and unconsolidated bottom area statewide to gain a better understanding of the percentage of these classes represented by depressional wetlands and ponds.

Geographic classification

In addition to the wetland classification system, a geographic framework was utilized to further reduce variability within wetland classes. Three major ecoregions converge in Minnesota with Great Plains occupying the western and southern portions, the Temperate Forests occupying the central and southeastern portions, and the Northern Forests occupying the northeastern portion of the state.

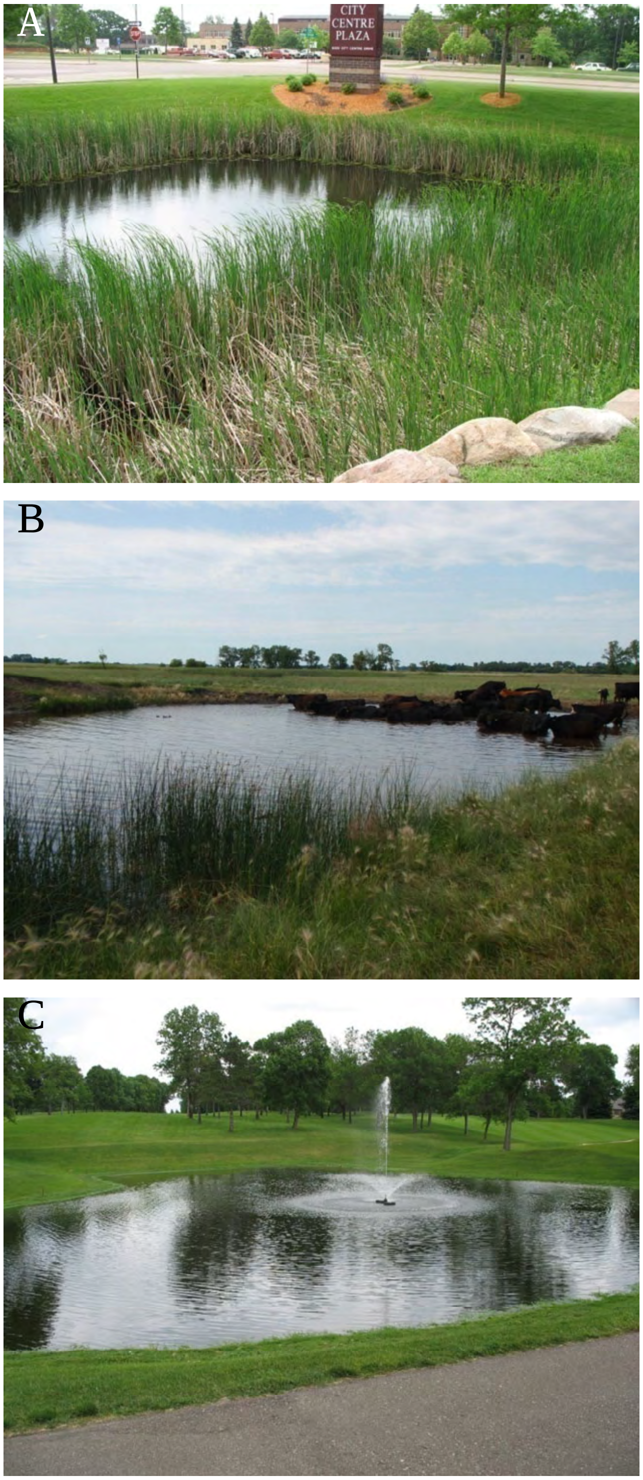


Figure 5. Examples of man-made ponds found in Minnesota: (A) stormwater (wet) pond, (B) livestock pond, and (C) golf course water hazard.

Many different representations of ecoregions have been created for the United States (e.g., Bailey 1976, Omernik 1987) and some continue to be revised. This survey uses the most recent version of Omernik's ecoregion map of Minnesota (White and Omernik 2007). Previous analyses using wetland plant and macroinvertebrate data revealed that level II ecoregions (of Omernik's I-IV hierarchical spatial scale) worked well to reduce within-region variation of these indicators while minimizing the number of regions that would require separate criteria (Genet and Bourdaghs 2006). Three level II ecoregions occur within Minnesota: Temperate Prairies, Mixed Wood Plains, and Mixed Wood Shield (Figure 6). A brief description of each is provided below.

Temperate Prairies – The topography of this ecoregion ranges from gently rolling glacial till plains of the southern part of the state to the nearly level basin of ancient Glacial Lake Agassiz in the northwest. Prior to European settlement the vegetation within this region was primarily tall-grass prairie interspersed with often expansive wet prairie communities. A large portion of this ecoregion coincides with the Prairie Pothole Region, an area characterized by its high density of seasonally to permanently inundate depressional wetlands. Today the dominant land use within the Temperate Prairies is agriculture with both row crop farming (corn, soybeans, grains, sugar beets) and livestock production (cattle, swine, poultry) prevalent in this ecoregion. Large cities in this ecoregion include Albert Lea, Austin, Crookston, Mankato, Marshall, Moorhead, and Willmar. Annual precipitation ranges from 18 inches in the northwest to 34 inches in the southeast[1].

[1] *Source:* Normal Annual Precipitation Map, State Climatology Office, MDNR, July 2003. http://climate.umn.edu/img/normals/precip/precip_norm_annual.htm.

Mixed Wood Plains – A transitional zone between the Great Plains and the Northern Forests, the Mixed Wood Plains ecoregion occupies the central part of the state in a southeast to northwest orientation. The southeast portion of this ecoregion is known as the driftless area, a region that escaped the most recent glacial advance and as a result has a steeply dissected, stream-dominated topography with numerous valleys and bluffs. In the southeast, Maple-Basswood forests are primarily restricted to steep valley walls while agriculture (row crops and cattle) is prevalent on more level terrain. The remainder of this ecoregion, the area to the north and west of the Twin Cities Metropolitan Area, has a gentler topography consisting of nearly level to rolling glacial till plains as well as hilly moraines and beach ridges. Pre-settlement vegetation in this region consisted of maple-basswood forest, oak savanna, and tall-grass prairie. Numerous lakes and depressional wetlands dot the landscape in the western portion of this ecoregion but are virtually nonexistent in the southeast. Wetlands in the southeast driftless area are primarily located within floodplain, riverine, and slope geomorphic settings. Current land use is a combination of agriculture (row crops, cattle, orchards, sod), natural vegetation (forests, grasslands, wetlands), and urban development. In fact, much of Minnesota's population is concentrated within this ecoregion centered on cities such as Minneapolis, St. Paul, Rochester, St. Cloud, and Alexandria. Precipitation ranges from an average annual of 22 inches in the west to 34 inches in the southeast.

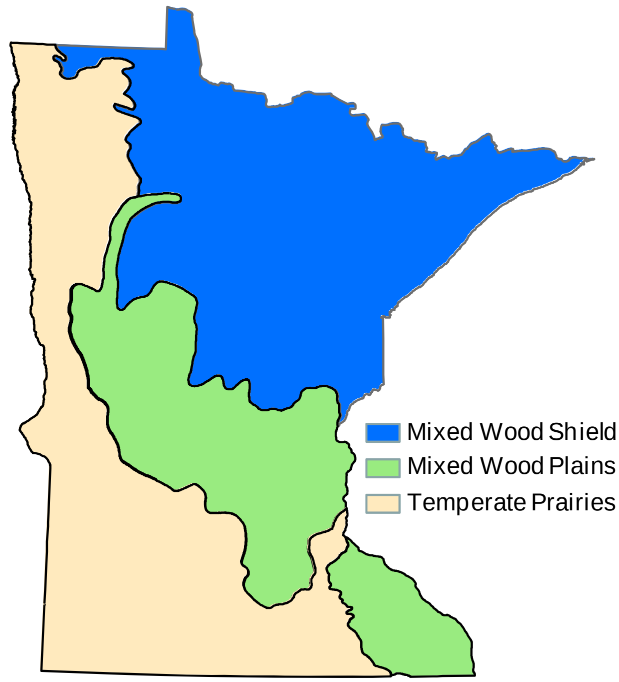


Figure 6. Omernik Level II ecoregions in Minnesota.

Mixed Wood Shield – This ecoregion still retains large contiguous tracts of coniferous and hardwood forests, lakes, and wetlands. Occupying a glacial lake bed, the northwest portion of this ecoregion consists of extensive organic soil flats or peatlands and large lakes. The area to the east and south of the peatlands has a terrain of undulating till plains, hilly moraines, lacustrine basins, and extensive sandy outwash plains. Unlike the other regions of the state, the Mixed Wood Shield does not have much agriculture or urban development. A popular tourist destination, the Boundary Waters Canoe Area lies within this ecoregion along the Canadian border and includes many lakes, streams and wetlands that are in relatively pristine condition. Large cities in this ecoregion include Duluth, Brainerd/Baxter, Bemidji, Hibbing, and Grand Rapids. Apart from tourism, logging and mining are the top two industries in the region. Average annual precipitation ranges from 21 inches in the west to 30 inches in the east.

Survey design

Similar to how an opinion poll gauges public interest on a topic or candidate running for office, the wetland quality survey utilizes techniques that allow it to derive estimates (± margin of error) for the entire population of wetlands by measuring a relatively small subset (i.e., sample) of the population. Wetland study sites were randomly selected to ensure that derived estimates are unbiased. In addition, the selection process was spatially stratified (Stevens and Olsen 2004) to increase the likelihood that the sample represented all regions of the state. To maximize participation in the survey, all landowners were contacted in the weeks prior to sampling to obtain permission and/or the appropriate permits.

Each year a draw of randomly selected wetlands for the quality survey was made from the maps resulting from the wetland quantity survey (Kloiber 2010). Since these maps themselves represent only a sample of the entire state, the wetland quality survey design represents a two-phase sampling approach (i.e., a sample of a sample). Both wetland quantity and quality surveys require three years of sampling to derive statewide estimates. However, the approach to obtaining statewide coverage differs between the two surveys. For the wetland quantity survey, an independent sample is drawn from across the entire state in each of the three years. The quality survey follows a rotating schedule where a sample is drawn from one of the three ecoregions each year. For the first iteration of the quality survey the schedule was: 2007-Mixed Wood Plains, 2008-Temperate Prairies, 2009-Mixed Wood Shield. A total of 60 depressional wetland study sites was the goal for each ecoregion. Site selections for both the quantity and quality surveys were provided by the US EPA National Health and Environmental Effects Research Laboratory, Corvallis, OR. For more details on the design of this survey and its relationship to the quantity survey see design summary paper (http://www.pca.state.mn.us/index.php/view-document.html?gid=6095).

Due to the overwhelming number of small depressional wetlands throughout the state, a simple random selection would have resulted in a sample almost entirely comprised of wetlands less than two acres in size. Therefore, to increase the likelihood of getting a mix of wetland sizes in the sample, the selection process employed unequal probability weighting based on three size categories: < 2.5 acres (< 1 ha), 2.5 – 12.4 acres (1 – 5 ha), and > 12.4 acres (> 5 ha). The goal of the weighting process was to obtain 20 wetland study sites in each size class/ecoregion combination. These weights were also used in data analysis to insure that each study wetland represented its appropriate portion of the population. For example, results from numerically dominant small wetlands carried more weight in analyses that reported based on the number of basins, while results from large wetlands held more weight in the analyses that reported based on acres.

A large number of depressional wetlands and ponds have been created or are being utilized for a variety of purposes including stormwater retention and treatment, crop production (e.g., wild rice, cranberries), aquaculture, aesthetics, and livestock watering. Some would argue that these types of waterbodies should not be included in an assessment of depressional wetlands and ponds. However, while it may not be their primary purpose, these waterbodies are still providing a variety of wetland functions, including wildlife habitat, and a statewide assessment that excludes such waterbodies would be incomplete. Exceptions to this notion are man-made waterbodies that have an artificial hydrology maintained by pumping and/or are lined with geo-textile fabric, concrete, or other such impermeable layers. These types of waterbodies are often associated with wastewater treatment facilities (municipal and industrial), active mining operations, and fish hatcheries and their outflow typically requires National Pollutant Discharge Elimination System and State Disposal System permits. Providing little if any of the functions often associated with wetlands, these waterbodies were not included in the wetland quality survey.

To quantify the current level of human utilization of wetlands and to track changes in this distribution over time, the sample of wetlands was post-stratified into three reporting categories. Category 1 wetlands are either natural in origin or have been created for the purpose of increasing and/or replacing wetland habitat (e.g., compensatory mitigation wetlands). Wetlands assigned to category 2 are waterbodies that have been created or physically altered specifically for treatment, commercial, agricultural, or recreational purposes **and** do not have an artificial hydrology. Henceforth, to better distinguish these two categories, category 1 wetlands will be referred to as **natural** and category 2 as **man-made** throughout the remainder of this report. Category 3 waterbodies have been created or altered for the purposes listed under category 2, but have an artificial hydrology. As mentioned above, category 3 wetlands were excluded from the survey and thus not included in any subsequent analyses of condition or function. Post stratification also allowed the results of the survey to be analyzed and reported both with and without indicator data from man-made waterbodies. By comparing these results, the relative contribution of man-made waterbodies to the overall function and condition of depressional wetlands throughout the state can be ascertained.

Interannual Variability – Since the wetland quality survey employs a rotating ecoregion schedule, there is the potential that interannual variability could result in significant regional differences in wetland condition over the course of the three year survey cycle and beyond. Interannual variability is the extent to which an indicator exhibits either high or low values consistently across an entire population in any given year in response to regional-scale factors such as climate or atmospheric deposition. For example, extremely wet or extremely dry years can have an important effect on the composition of wetland communities (Stewart and Kantrud 1971, van der Valk and Davis 1978, Hershey et al. 1999, Euliss et al. 2004). Shifts in the composition of these communities would most likely be reflected in the biological indicators being used in the survey, and thus could affect condition estimates for a particular ecoregion or iteration of the survey. While it is important to include the influence of regional-scale factors in the estimation of condition, an attempt should be made to determine their relative contribution to any observed differences or changes in condition. In fact, it is vital to do so in order to accomplish the main objective of this survey; to evaluate the effectiveness of policies, regulations, and management activities designed to protect and improve wetland quality. Failing to account for regional interannual variability would greatly diminish the ability of the survey to measure changes in wetland quality associated with activities (e.g., restoration, degradation, mitigation) that are relevant to the regulations and policies governing wetlands in Minnesota.

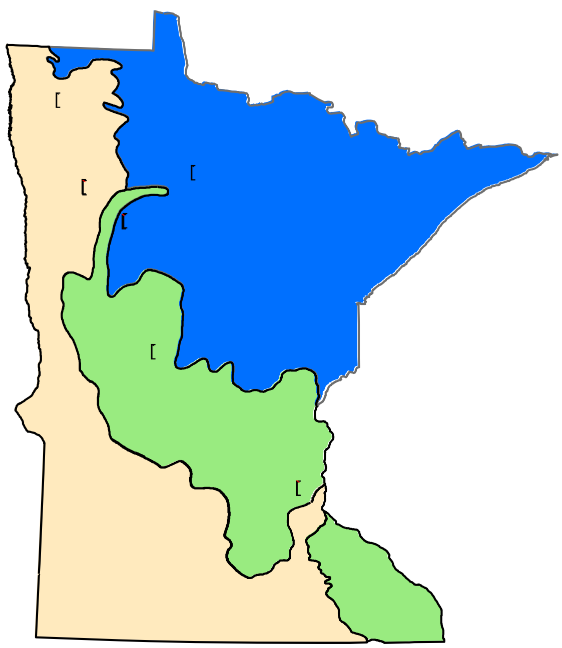


Figure 7. Locations of annual sites across the state. Red stars indicate that two sites are located in close proximity.

To address the issue of potential regional effects resulting from interannual variability, a set of sites was randomly selected from each ecoregion to be sampled every year. Henceforth these sites are referred to as 'annual sites.' Nine sites were selected throughout the state with three occurring within each ecoregion (Figure 7). In a similar manner, it is anticipated that a subset of the study sites sampled in the first iteration of the survey will be repeated in the second iteration to account for any interannual regional-scale fluctuations in wetland quality, thus improving the ability of the survey to detect policy-relevant trends (Urquhart et al. 1998).

Field methods

Prior to sampling, each of the potential study sites was investigated using GIS applications to determine ownership and obtain access permission. If permission was granted, sites were visited in May to evaluate whether they were target wetlands (i.e., depressional wetland) and to determine their reporting category. If sites had to be dropped from the survey for any reason (e.g., access denial, non-target), replacement sites were added in sequential order from the random selection until the desired sample size of 60 sites/ecoregion was reached.

The aquatic macroinvertebrate communities of the study sites were sampled in June using D-frame dip nets with a mesh size of 500 µm. Macroinvertebrates were primarily collected from the emergent vegetation zone in depths ranging from 0.3 – 1 m. If emergent vegetation was not present within the wetland the following zones (listed in decreasing order of preference) were sampled at similar depths: floating-leaved aquatic vegetation, submergent aquatic vegetation, and open water (< 25 percent vegetation cover). Samples were collected by sweeping the net through the water column over a horizontal distance of approximately 1 m. Several sweeps at various locations within the wetland (typically within a 25 m radius) were collected and placed on hardware cloth screen (1.3 x 1.3 cm mesh) overlaying two plastic pans to separate the macroinvertebrates from the vegetation that invariably gets swept into the net. Over a period of ten minutes, vegetation was spread apart on the hardware cloth to allow macroinvertebrates to drop or crawl into the pans below. After ten minutes the vegetation was removed from the hardware cloth and a second series of dip net sweeps were collected and placed on the cleared screen. The ten minute spreading process was repeated, after which the vegetation was discarded and the contents of the plastic pans were consolidated into one 16 ounce plastic jar and preserved with 95 percent ethanol. This dip net method was performed by both members of the sampling crew resulting in the collection of two separate macroinvertebrate samples. Samples were sent to a taxonomy laboratory for identification of macroinvertebrates. More information on the dip net method is available at: http://www.pca.state.mn.us/index.php/view-document.html?gid=6101.

Water chemistry data were collected during the macroinvertebrate sampling visit. A multi-parameter probe (Hach HQ40d18) was used to measure water temperature, dissolved oxygen, specific conductance, and pH. Water samples were collected for laboratory analysis of phosphorus (mg/L), Kjeldahl nitrogen (mg/L), nitrate + nitrite (mg/L), total organic carbon (mg/L), chloride (mg/L), and sulfate (mg/L). All water samples were sent to the Minnesota Department of Health Environmental Laboratory for analysis using standard protocols (see Appendix B). Water column transparency was measured using either a 60 cm or 100 cm transparency tube, depending on the clarity of the site. Details of the water chemistry sampling procedure can be found at: http://www.pca.state.mn.us/index.php/view-document.html?gid=10251.

The composition and structure of the wetland plant community was characterized at each study site in July using releve sampling methodology. Releve sampling is a technique where a field biologist selects a plot (or multiple plots) sampling location that is representative of the overall targeted plant community. Plot placement focused on the emergent community, though the final sampling area typically straddled the emergent/aquatic vegetation interface and the shape of the plot (square or rectangular) depended on the width of the emergent fringe. In the Mixed Wood Plains and Temperate Prairies ecoregions a single large plot was used, while in the Mixed Wood Shield four smaller plots were used to represent the wetland plant community. In all cases the total area examined within a study site was 100 m^2. An inventory of plant species was generated for each plot and the percentage of plot area occupied by each species was estimated using cover classes (Table 2). More information on this method is available at: http://www.pca.state.mn.us/index.php/view-document.html?gid=6111.

Table 2. Cover classes and corresponding ranges of percent cover.

Cover Class	% Cover Range
8	95-100%
7	75-94%
6	50-74%
5	25-49%
4	10-24%
3	5-9%
2	2-4%
1	1%
0.5	0.1-0.9%
0.1	single/few

Wetland functions were also assessed during the July sampling visit using MnRAM version 3.2. MnRAM is a semi-quantitative evaluation requiring the user to document the size, type, and location of the wetland assessment area as well as answer ~60 questions about its vegetation, hydrology, soils, the adjacent upland buffer, habitat characteristics, and ownership status[2]. The majority of the questions in this method were answered based on field observations by wetland scientists within the study sites. Several questions were addressed in the office with the assistance of GIS software and data layers such as the National Wetland Inventory (NWI), National Land Cover Data (NLCD), National Hydrography Dataset, and a Minnesota Natural Heritage Information System data retrieval. For most questions the responses are limited to yes/no or low/medium/high for the particular characteristic in question. Responses to the general information and questions are then quantified in model calculations for the following functions: Vegetative Integrity, Hydrologic Regime, Flood Attenuation, Downstream Water Quality, Wetland Water Quality, Shoreline Protection, Wildlife Habitat, Amphibian Habitat, Fish Habitat, Aesthetics/Recreation/ Education/Cultural, and Commercial Uses. However, some of these functions are not applicable to depressional wetlands (Shoreline Protection and Fish Habitat) or are more representative of human values than wetland quality (Commercial Use and Aesthetics/Recreation/Education/ Cultural), and thus were not included in this report.

Data analysis

A difficult challenge for large-scale resource assessments is the determination of appropriate expectations for interpreting data obtained from the survey. While some indicators used in this survey had pre-defined expectations built into their assessment methodology (e.g., MnRAM), others required careful consideration to determine expectations that were realistic given current social, economic, and climatic factors. For instance, when assessing the ecological condition of a resource should it be compared to conditions that existed prior to European settlement or to the best remaining examples of the resource that exist today? In this assessment of wetland quality the concept of least disturbed condition (Stoddard et al. 2006) was used as the benchmark for making such comparisons. This condition was represented by a set of reference sites comprised of depressional wetlands sampled during previous studies conducted by the MPCA (1999-2006) as well as survey sites (2007-2009) that exhibited little or no evidence of human disturbance. Again acknowledging the influence of natural variability, both wetland and geographic classification schemes were utilized to adjust expectations based on wetland type and ecoregion.

Screening of depressional wetland reference sites was based on previously established qualitative and quantitative criteria (see Genet et al. 2004). An evaluation of the amount of human disturbance

[2] MnRAM was applied only to the IBI community assessment area within individual wetland study sites. Since the functional assessment results were intended for comparison and contrast to the condition assessment results, the 'Special Features' questions of MnRAM were not considered to be congruent with this application. Therefore, elevation of selected functions to exceptional quality did not occur in this nonregulatory application of MnRAM. One exception to this practice, however, was responses to MnRAM question #6:"Does the wetland represent pre-European-settlement conditions?" Wetlands where this question was answered in the affirmative, the Vegetative Integrity function was rated as exceptional.

affecting a site focused on three spatial scales: 1) within the wetland; 2) within 50m of the wetland (i.e., buffer); and 3) within 500m of the wetland (i.e., landscape). Factors that were considered included habitat alterations, hydrologic modifications, water quality, and surrounding land use. These evaluations were made based on a combination of field observations and current aerial photographs of the site and its surroundings. In general, reference depressional wetlands met the following conditions: a largely intact natural buffer of 50m or more; no known history of significant physical alterations (e.g., drainage, filling, and excavation), fish rearing, or fish stocking; receive little or no agricultural runoff; and receive no municipal or industrial wastewater effluent.

Biological and stressor indicator data collected from the reference sites were used to represent the range of expected values for least disturbed conditions within each ecoregion. The distribution of each indicator data set was used to establish thresholds between good/fair/poor condition categories or high/medium/low stressor categories (Figure 8A and B). For example, the 25th percentile of the reference distribution was used to separate the good and fair condition categories. In other words, the condition of study sites with indicator values above this threshold (i.e., good) is comparable to the condition of least disturbed reference sites in the ecoregion (Figure 8A). The 5th percentile was used to separate the fair and poor categories, meaning that wetlands in the poor category are in worse condition than 95 percent of the least disturbed reference sites. Specific values for each of the thresholds used for categorizing condition and stressor levels can be found in Appendix C. To interpret the functional indicator values obtained with MnRAM, the pre-defined thresholds established during the development of this assessment method (Board of Water and Soil Resources 2008) were used as follows:

Functional Rating	Functional Index Score
Exceptional	1.01-2.00
High	0.66-1.00
Medium	0.33-0.65
Low	0.001-0.32
N/A	0.0

Utilizing the criteria above, study sites were categorized or rated based on results from each indicator. The results from this random sample of sites were used in conjunction with the design weights incorporated into the site selection process to estimate the proportion of the population in each category. All analyses were performed in R version 2.8.0 (R Development Core Team 2008) using the spatial survey design and analysis package (spsurvey; Kincaid and Olsen 2008) and script developed by US EPA personnel. This script referenced spsurvey functions for estimating the overall extent of the population, the proportion within each condition category, stressor level or functional rating, and the relative risk posed by each of the measured stressors. Relative risk was estimated using the ratio of the probability of poor condition/high stressor levels (numerator) to the probability of poor condition/low stressor levels (denominator) occurring in the population (Van Sickle and Paulsen 2008). A relative risk estimate statistically greater than one indicates that there is an increased likelihood of poor biological condition when a stressor level is high. The design of the survey allowed indicator data to be analyzed statewide as well as for individual ecoregions and results to be derived in terms of both the number and area of depressional wetlands. Statewide results are provided based on both number and area of depressional wetlands, while ecoregion results are presented using number of depressional wetland basins as the reporting unit.

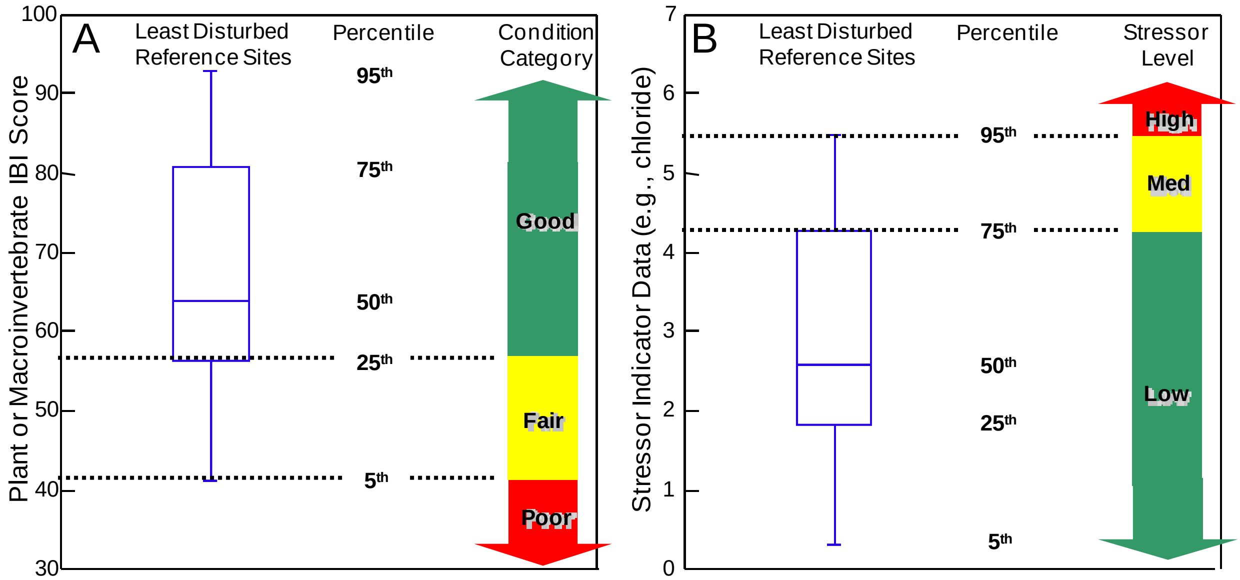


Figure 8. Generalized depiction of the distribution (represented as a boxplots) of indicator values at reference sites and the process for using this information to categorize the (A) condition and (B) stressor levels of each sample site. Sites were categorized independently based on each indicator.

The number of unique dragonfly and damselfly larvae found in a wetland is a component of MPCA's macroinvertebrate IBI. Pictured is the adult stage of a Bluet damselfly

Statewide Results and Discussion

Extent of depressional wetlands

From 2007-2009 a total of 182 depressional wetlands were sampled throughout the state. Based on these results, an estimated 158,435 depressional wetland basins occur within the state of Minnesota with a margin of error (95 percent confidence limit) of ± 19,687 basins. During the initial site evaluation process, 29 potential sites could not be accessed due to failure to obtain permission from landowners or because sites were too remote. If these sites were in fact part of the target population, as suggested by aerial imagery, the estimated number of depressional wetland basins occurring within the state would increase to 178,635 with a margin of error of ± 19,367 basins. Because the analysis procedure for estimating wetland function and condition cannot include information from sites that were not sampled, the estimate of 158,435 basins is used throughout the remainder of this chapter when referencing population size.

The wetland basin estimate represents the first time an attempt has been made to quantify the number of basins (for a specific wetland type) across the entire state. The NWI and Minnesota's WSTMP are only able to estimate the area of wetlands that occur within Minnesota as a whole. In Minnesota, there are some estimates for the number of wetland basins occurring at smaller spatial scales such as watersheds or counties. For instance, in 2003 the MPCA conducted a survey of depressional wetland condition in the Redwood River watershed which lies entirely within the Temperate Prairies ecoregion. In addition to semi-permanent and permanent basins, this survey included seasonally inundated wetlands and estimated that ~900 basins occur within the watershed (Genet and Olsen 2008).

Alternatively, the extent of depressional wetlands that occur within the state can be evaluated in terms of acreage. An estimated 674,085 acres of depressional wetlands occur within Minnesota with a margin of error of ± 73,937 acres. When inaccessible sites are included in the analysis, this estimate increases to 788,689 ± 73,774 acres. As with the statewide basin estimate, the 674,085 acre extent estimate is used throughout the remainder of this chapter when referencing the extent of the population.

According to Minnesota's WSTMP, there currently exist 3,742,800 acres of aquatic bed, emergent, and unconsolidated bottom wetland classes in the state (Kloiber 2010). Based on the population extent estimate of 674,085 acres, depressional wetlands account for approximately 18 percent of the combined area of these three corresponding wetland classes. Though area comparisons with the WSTMP cannot be made regionally, due to the different geographic classification schemes utilized by each survey, it is likely that depressional wetlands account for a larger proportion of these wetland classes in the southern part of the state and a much smaller proportion in the north. Of the three corresponding WSTMP classes, emergent wetlands are by far the most abundant (Kloiber 2010) and have their greatest representation in the northern part of the state where they predominantly occur in organic soil flats (e.g., peatlands) or in association with rivers and lakes.

The majority (~74 percent) of depressional wetland basins in Minnesota are less than 2.5 acres in size (Figure 9). In terms of acreage, however, these small basins account for less than 12 percent of the depressional wetland population. Conversely, depressional wetlands greater than 12.4 acres in size account for ~64 percent of the acreage and ~7 percent of the basins. Depressional wetland extent can also be examined in terms of property ownership. At the state scale, approximately 75 percent of depressional wetland basins, representing ~61 percent of the acreage, occur entirely on private property (Figure 9). Depressional wetlands on public lands account for ~24 percent and ~32 percent of the basins and acreage, respectively, occurring in Minnesota. However, these percentages vary substantially by ecoregion. In the Mixed Wood Shield ecoregion where there are large tracts of federal and state lands, depressional wetland basins occur on public property as often as they occur on private property (see Figure 25). Man-made wetlands represent about a third of the basins that occur in the state and less then 10 percent of the acreage, indicating that the majority of man-made depressional wetlands are relatively small in size (Figure 9). The percentage of man-made basins also varies regionally, accounting for almost half of the depressional wetland basins in the Temperate Prairies ecoregion (see Figure 21).

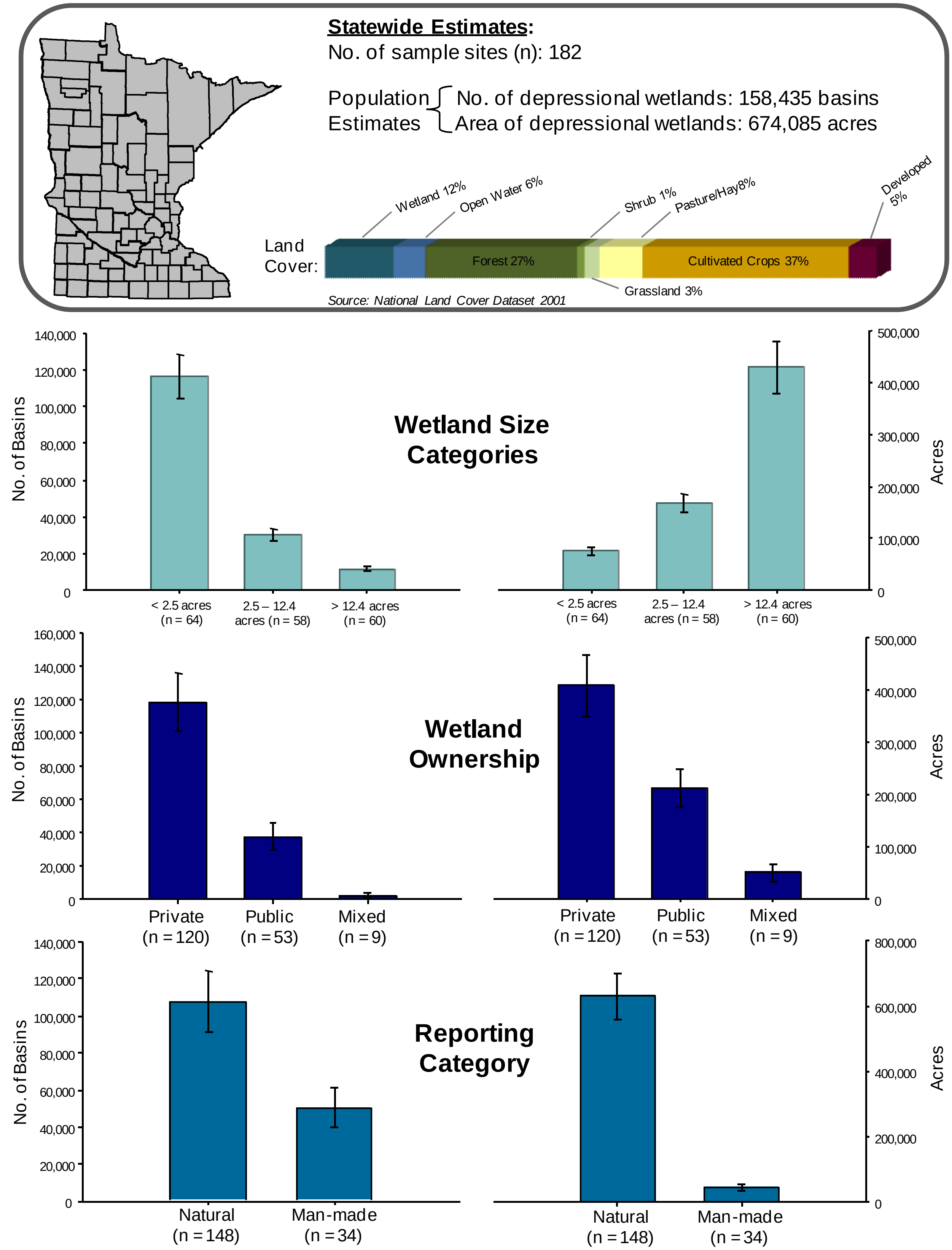


Figure 9. Estimates of the total number and total area of depressional wetlands in Minnesota and these estimates broken down into various subcategories. Bracketed lines represent the width of the 95 percent confidence interval associated with each estimate.

Certainly, there is also significant variation in the distribution of man-made wetlands within ecoregions, typically having the greatest density in urban landscapes (e.g., stormwater ponds, golf course water hazards, etc.).

Wetland condition

As indicated by the plant IBI, 29 percent of Minnesota's depressional wetland basins are in good condition, while 25 percent are in fair condition and 46 percent are in poor condition (Figure 10A). Condition estimates based on the plant IBI varied only slightly between natural and man-made wetland basins. The macroinvertebrate IBI exhibited different results with 47 percent of Minnesota's depressional wetland basins in good condition, 33 percent in fair condition, and 20 percent in poor condition (Figure 10A). Natural depressional wetlands were in better condition than man-made wetlands according to the macroinvertebrate IBI; 57 percent of the natural basins were in good condition compared to only 27 percent of the man-made basins. For each biological indicator a small percentage of depressional wetlands were not assessed due to a failure to collect indicator data at some study sites. This primarily occurred when data for one or more indicators could not be safely and/or effectively collected at a site, while data for the other indicators could be obtained.

In general, results varied slightly when condition estimates were based on wetland acres rather than the number of basins. Using the plant IBI, 37 percent of depressional wetland acres are in good condition, while 20 percent are in fair condition and 42 percent are in poor condition (Figure 10B). Compared to the basin-based results, the macroinvertebrate IBI estimated slightly better wetland conditions when acres were used in the analysis; 55 percent good, 31 percent fair, and 12 percent poor. The overall better conditions estimated in the analysis based on wetland acres was likely driven by the relatively better condition of wetlands in the medium and large size categories (Figure 11). Wetlands in these size categories held more weight in the analysis by wetland acres, while small (< 2.5 acres) wetlands held significantly more weight in the analysis by wetland basins. According to both biological indicators, man-made wetlands were in worse condition than natural wetlands when analyzed using acres as the basis (Figure 10B).

The condition of depressional wetlands varied slightly between the medium and large wetland size categories, irrespective of the biological indicator used or whether the analysis was based on basins or acres (Figure 11). The relatively degraded condition of small wetlands may be explained in part by the proportion of man-made wetlands in this size category. Man-made wetlands comprised 44 percent of the wetlands in the small size category, but represented only 11 percent and 0 percent of medium and large wetlands, respectively. However, the distribution of man-made wetlands among the size categories probably explains the pattern observed in the macroinvertebrate IBI results better than the plant IBI, considering the slight variation in plant community condition observed between natural and man-made wetlands. For instance, in the analyses by plant IBI/basin the magnitude of the difference between percent poor in the natural vs. man-made comparison (three percent; Figure 10A) is less than the observed difference between percent poor in small wetlands and the two larger size categories (9-16 percent; Figure 11). On the other hand, just the opposite is true with the macroinvertebrate IBI results where the difference between percent poor in the natural vs. man-made wetland comparison (27 percent; Figure 10A) surpasses the differences observed between the small and the two larger size categories (12 percent; Figure 11). Thus, it is likely that man-made wetlands and their associated stressors (see next section) account in large part for the degraded macroinvertebrate communities found in small depressional wetlands, but further investigation is required to explain the degraded plant communities in these small wetlands.

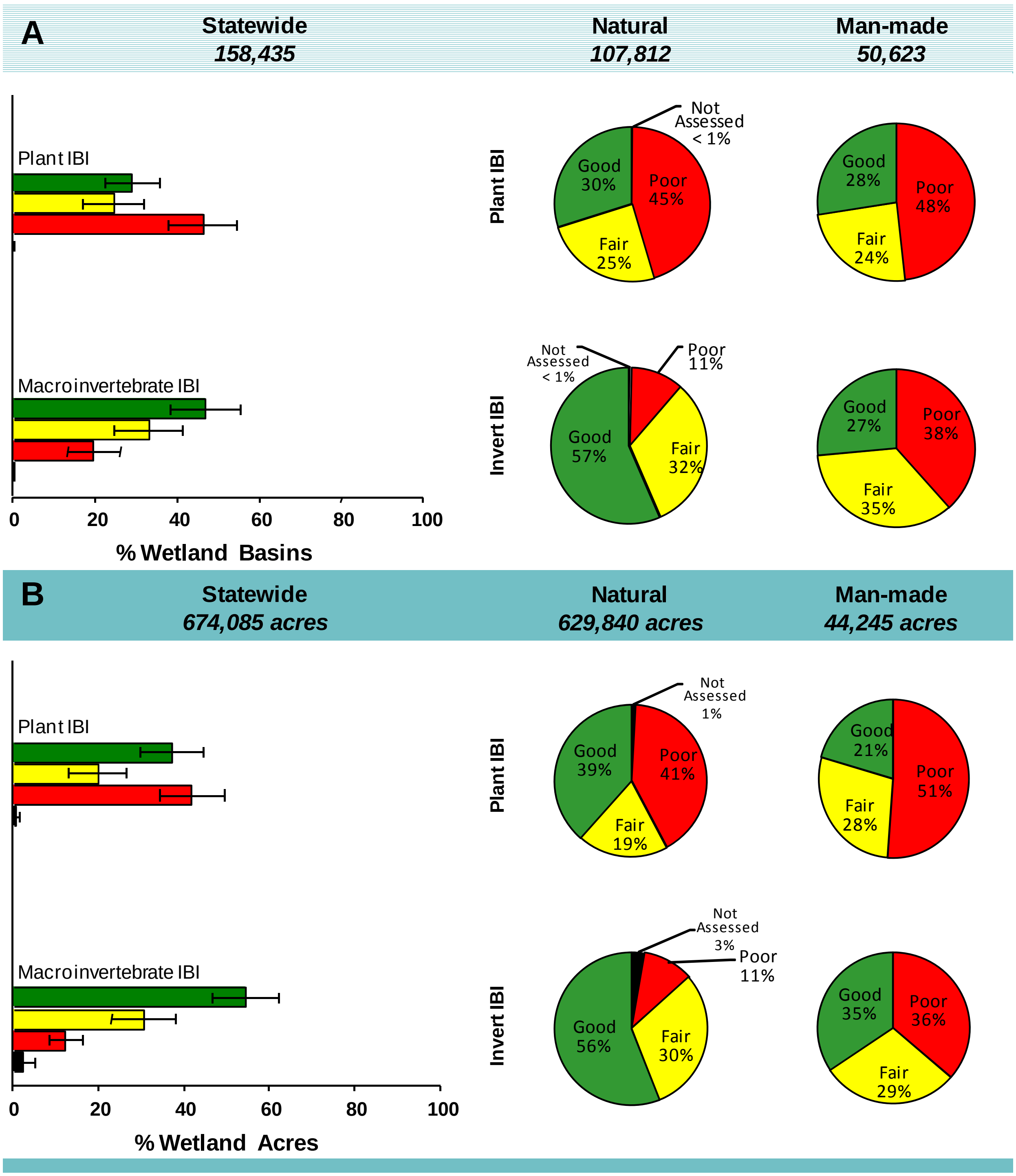


Figure 10. The condition of Minnesota's depressional wetlands based on plant and macroinvertebrate IBIs, reporting according to A) number of depressional wetland basins and B) area of depressional wetlands. Included with each is a comparison of estimates for natural vs. man-made wetlands. Lines with brackets represent the width of the 95 percent confidence interval associated with each estimate.

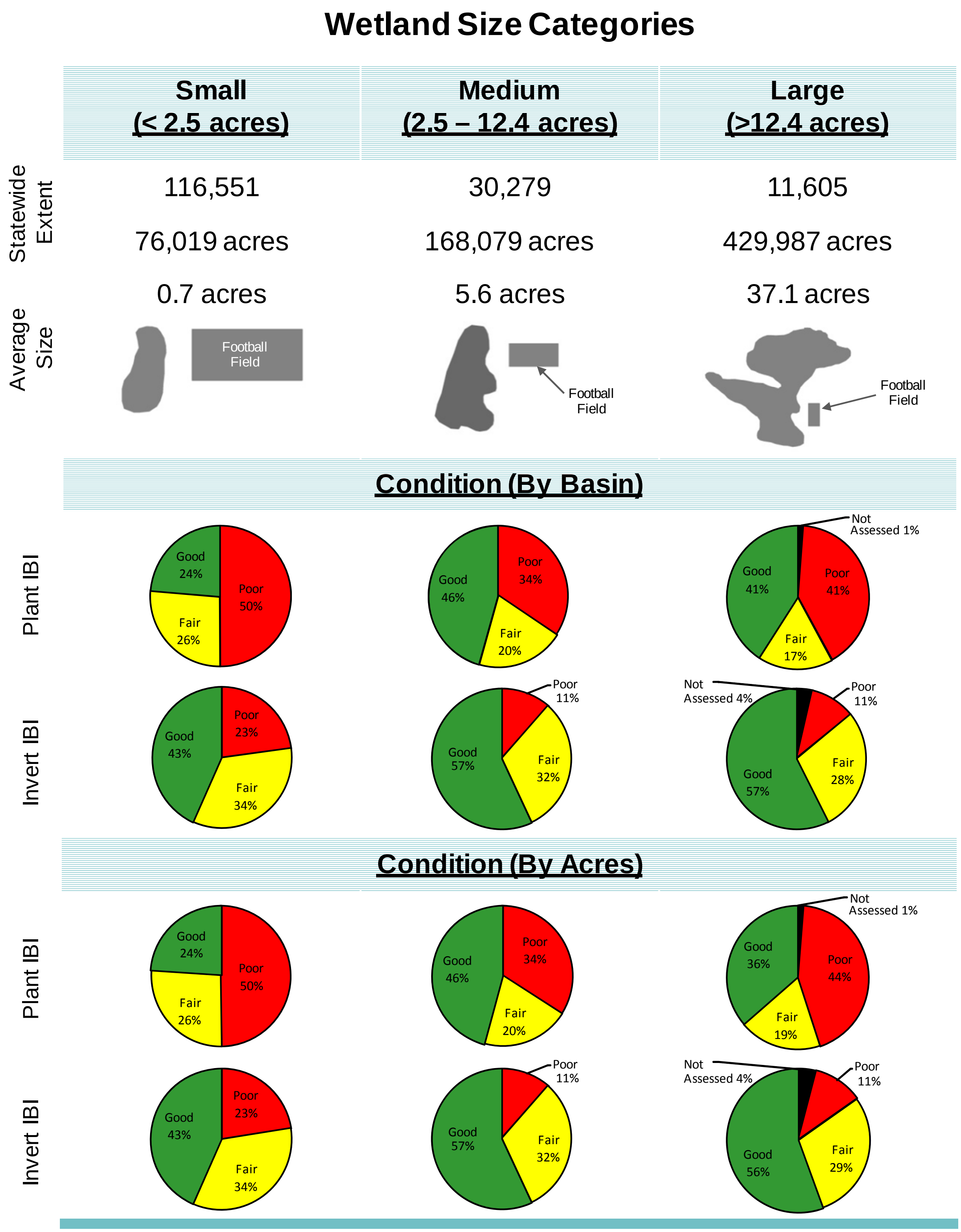


Figure 11. Comparison of condition estimates across wetland size categories, reporting based on the number of depressional wetlands (By Basin) and their area (By Acres). Extent estimates and average wetland size are provided for each category.

Depressional wetlands located on private property, the most prevalent situation in Minnesota, are in slightly poorer condition than those located on public lands, according to both biological indicators (Figure 12). These results suggest that the greatest potential for improving depressional wetland condition relies upon working with individual landowners and companies to restore and/or protect these valuable resources. MDNR Private Lands Program is one example of stewardship consultation that is currently available to citizens. Condition estimates for wetlands categorized as having mixed ownership, partially on public and private property, were highly variable depending on which indicator was used and whether the analysis was based on basins or acres (Figure 12). Due to the relatively low sample size obtained for the mixed ownership category, the condition estimates presented for this category should be interpreted with caution given the large margin of error (not shown) associated with each. As with the other analyses, the macroinvertebrate IBI estimated better wetland condition than did the plant IBI when sites were categorized by ownership.

Obtaining different wetland condition estimates from each biological indicator was not unexpected and in fact highlights one of the main reasons most biological monitoring programs employ multiple indicator assemblages. Environmental perturbations affecting the condition of aquatic systems act over a broad range of spatial and temporal scales and having more than one biological indicator assemblage increases the coverage across this range. For instance, due in part to their relatively short life cycles, macroinvertebrates can respond quickly to environmental variations and thus tend to be more indicative of recent disturbance (Barbour et al. 1999, US EPA 2002a). In comparison, plant communities typically integrate short-term variations with long-term effects and can provide a better indication of disturbances that have occurred in the past (US EPA 2002c). Considering that the plant IBI generally yielded poorer condition estimates than the macroinvertebrate IBI suggests that many depressional wetlands throughout the state are being impacted by disturbances that have occurred in the past (i.e., legacy effects) and have not recovered despite improvements in the quality of their surrounding landscape. Other researchers have drawn similar conclusions regarding wetland plant communities, attributing considerable lag times in the response of these communities following restoration activities to the perennial, and often clonal, life history traits many wetland plants possess (e.g., Galatowitsch et al. 2000).

Overall, condition estimates obtained in this survey indicate that a substantial portion of the depressional wetlands in Minnesota are being negatively impacted by human activities (past and present), resulting in significant deviations in their ecological condition compared to least disturbed, regional reference sites. While the following section attempts to elucidate some of the stressors that may be impacting depressional wetland condition, in reality wetland condition is an expression of multiple, cumulative impacts that may be either episodic or chronic in nature. Thus, it is difficult to gauge the relative contribution of each stressor based on data collected from a single point in time. Furthermore, the indicators of stress measured in this survey represent only a small fraction of all the potential stressors affecting depressional wetland condition in Minnesota. Therefore, results presented in the following section serve more as clues to the types of depressional wetland impacts in Minnesota rather than definitive conclusions regarding the cause-and-effect relationship between stressors and wetland condition.

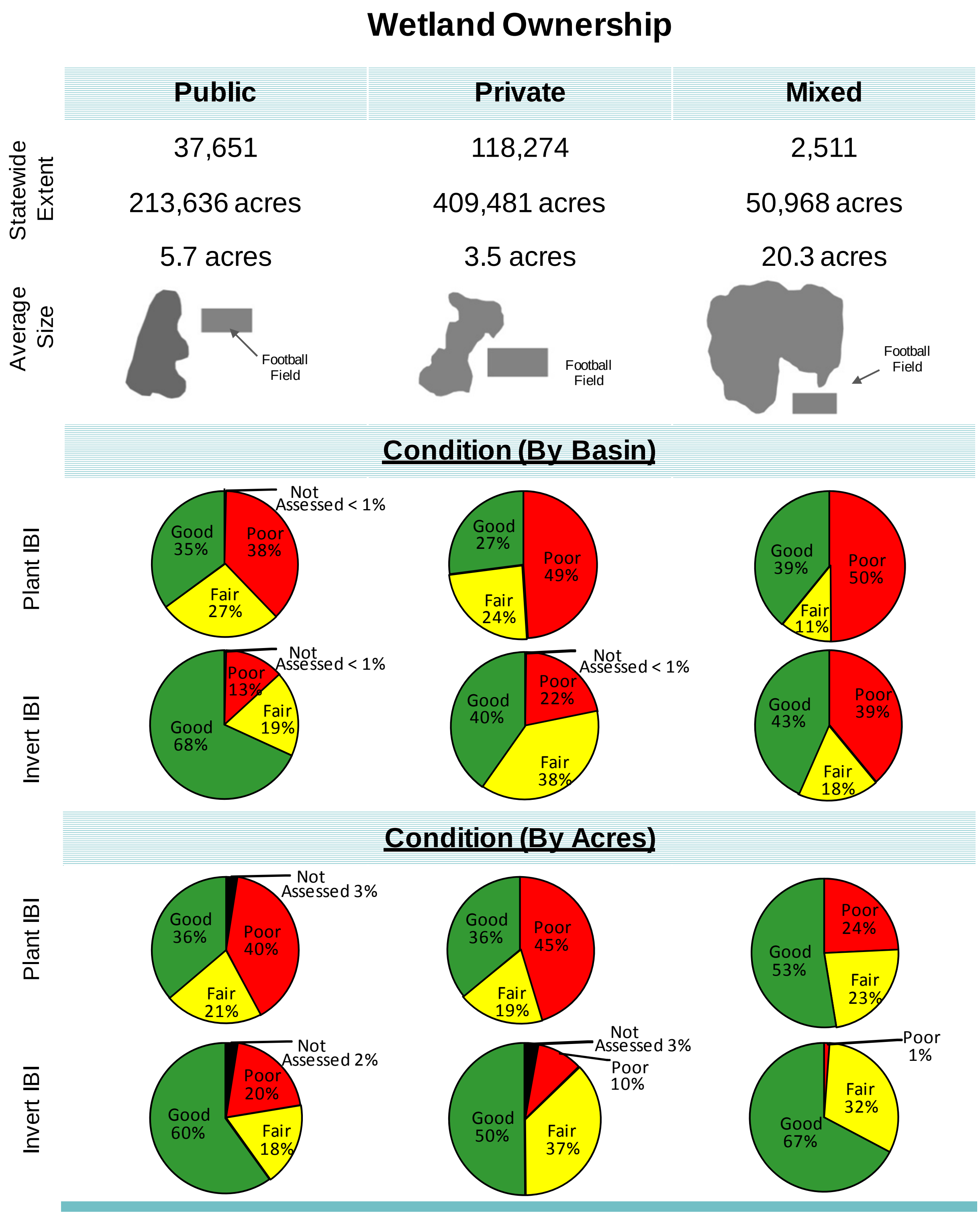


Figure 12. Comparison of condition estimates across wetland landowner categories, reporting based on the number of depressional wetlands (By Basin) and their area (By Acres). Extent estimates and average wetland size are provided for each category.

Wetland stressors

High chloride concentrations, relative to least disturbed reference sites, occur in 38 percent of the depressional wetlands in Minnesota (Figure 13) and pose an elevated risk to both wetland plant and macroinvertebrate communities (Figure 14). Therefore, of the stressors measured in this survey, chloride represents the most serious threat to depressional wetland condition. Not surprisingly, chloride concentrations in man-made wetlands were substantially higher than in natural wetlands (Figure 13). Chloride concentrations varied both regionally, partially to due natural geographic variation (see Appendix C; criteria based on least disturbed reference sites indicate that chloride is highest in the Temperate Prairies, on average the driest region of the state), as well as within regions, often with the highest concentrations occurring in highly developed areas. Increased chloride concentrations in depressional wetlands are presumably due to runoff from adjacent roads and parking areas where de-icing compounds (e.g., NaCl, $MgCl_2$, and KCl) are used during the winter. A study of lakes in the Twin Cities Metropolitan Area determined that the highest chloride concentrations coincided with snowmelt runoff in late winter/early spring (Novotny et al. 2008); a phenomenon that likely applies to urban wetlands as well. In contrast, semi-permanent wetlands, particularly in the western part of the state, may have maximum chloride concentrations in the fall or winter, due to the concentrating effects of summer evapo-transpiration or ice formation, respectively (LaBaugh 1989). Thus, chloride data collected in June, as was done in this survey, likely does not represent the maximum level of exposure being experienced by depressional wetland communities on an annual basis.

The ability of wetlands to sequester nutrients (phosphorus and nitrogen), thus protecting the water quality of downstream waterbodies, is an often cited benefit in the campaign to protect and restore wetlands. However, a wetland's ability to assimilate nutrients is not limitless and once exceeded, its water quality functions will begin to fail (Kadlec and Kadlec 1978, Nichols 1983, Hemond and Benoit 1988, Richardson et al. 1996, Kadlec and Wallace 2009). Even before such a critical threshold is reached, nutrient enrichment may have detrimental effects on the condition of the wetland itself as well as its aesthetic and recreational values (Figure 15). Total phosphorus represents the second largest threat to depressional wetland condition measured in this survey, having elevated concentrations in approximately 31 percent of depressional wetlands statewide and representing a risk to both plant and macroinvertebrate communities (Figures 13 and 14). Both forms of nitrogen measured in the survey, while posing an elevated risk to plant and/or macroinvertebrate communities, exhibit high or detectable concentrations in less than 20 percent of the population. Below average precipitation during the 2007 sampling season may have contributed to the low nitrate+nitrite detection rates (see Mixed Wood Plains chapter). Nutrient enrichment can affect wetland condition through a variety of pathways, including the creation of favorable conditions for invasive plant species and/or nuisance algae, the reduction of habitat heterogeneity, and the alteration of dissolved oxygen regimes. Further discussion of these pathways and their relationship is included in the Temperate Prairies chapter where nutrient enrichment of depressional wetlands occurred most frequently.

Surface water nutrient concentrations were estimated to be high in a larger proportion of man-made wetlands compared to the proportion of natural wetlands (Figure 13). A combination of increased nutrient loadings as well as diminished abilities to remove or assimilate nutrients in man-made systems likely accounts for these differences (Peralta et al. 2010). In fact, a number of the man-made wetlands included in this survey were constructed with the primary intent of collecting runoff and trapping pollutants. Other ponds such as golf course water hazards typically had very little vegetation, potentially limiting the amount of nutrients assimilated via plant uptake and production.

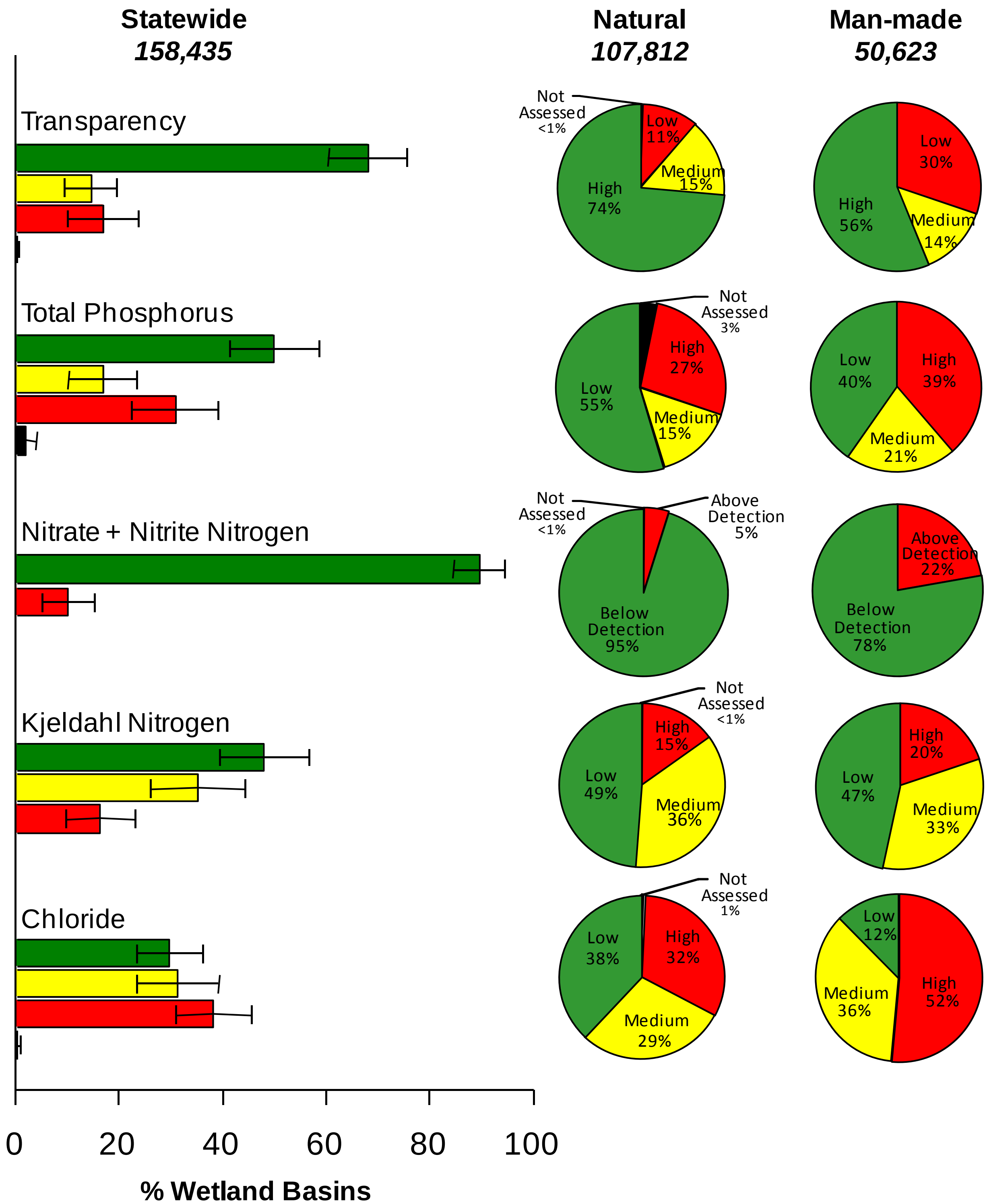


Figure 13. Stressor levels in Minnesota depressional wetlands, reporting based on the number of depressional wetlands. Red bars/pie slices represent the percentage of the population where water quality parameters are deviating from regional reference conditions, and thus may be at levels harmful to aquatic life. Lines with brackets represent the width of the 95 percent confidence interval associated with each estimate.

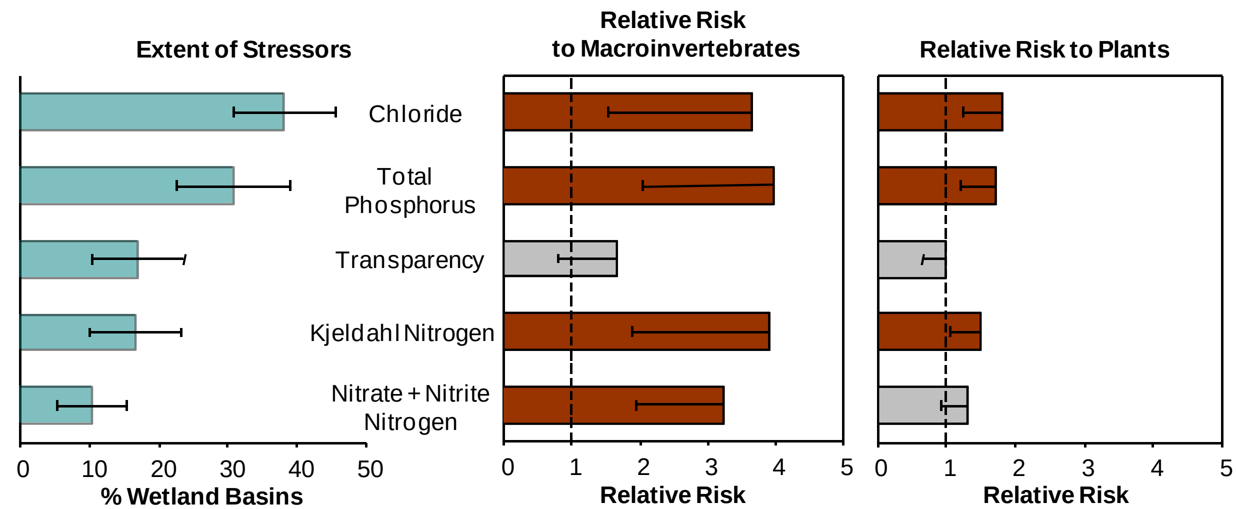


Figure 14. Extent of measured stressors and relative risk estimates for plant and macroinvertebrate communities in Minnesota depressional wetlands. Bracketed lines represent 95 percent confidence intervals. Lower confidence limits (relative risk charts) that do not extend below one represent a significant elevated risk (maroon bars).

Figure 15. Excess nutrients in this wetland have led to extensive growth of filamentous algae.

The transparency or clarity of the water column is low relative to regional reference conditions in approximately 17 percent of depressional wetlands statewide and is substantially lower among man-made wetlands compared to natural (Figure 13). Reduced transparency did not translate into significant elevated risks for either plants or macroinvertebrates (Figure 14). This lack of an observed response by both communities could be due to a number of factors. First, many of the observed water transparency values that were considered 'low' according to the degree of deviation from regional reference conditions may not have been of sufficient magnitude to cause significant impacts to either community. In other words, the criteria used in this survey to categorize transparency values may not have represented ecologically meaningful response thresholds for either community. Secondly, duration of reduced transparency could not be characterized in this survey since only a single reading was made at each site. Whether or not a 'low' transparency reading represents a brief event or a chronic condition is an important consideration when evaluating the impacts on biological communities. And lastly, measurements made in June may not represent the lowest clarity most water bodies experience on a seasonal basis (for further discussion see Mixed Wood Plains chapter). Thus, understanding the relationship between transparency and depressional wetland communities requires an extensive data set that spans the range of conditions these wetlands experience throughout the year.

In general, aquatic macroinvertebrates were more sensitive to chemical pollutants (relative risk estimates between 3 and 4) compared to the sensitivity of emergent and submergent vegetation (relative risks between 1 and 2) (Figure 14). Wetland plant communities may be more vulnerable to other stressors such as invasive species (see Box 1-1), physical alterations, and hydrologic impacts that are either currently affecting the wetland or have done so in the past. Based on the parameters measured, man-made depressional wetlands have poorer water quality than natural wetlands (Figure 13). Thus, the proportion of man-made depressional wetlands will be an important statistic to monitor in future iterations of the survey. At the national scale, this type of waterbody (i.e., ponds) has been increasing in acreage since the 1950s (Dahl 2006, 2011).

Wetland functions

The vegetative diversity/integrity function of MnRAM is a measure of the ecological intactness of a wetland's plant community. In this survey the area of focus for this functional assessment was shallow open water, shallow marsh, and deep marsh community types in depressional wetlands and ponds. Wetland communities with many native plant species that are not dominated by non-native and/or invasive species receive a high rating. A low rating is indicative of a plant community dominated by non-native and/or invasive species. In this survey the exceptional rating was only given to a community when the assessor judged it to be representative of pre-European settlement conditions. Approximately 40 percent of the depressional wetlands throughout the state are rated as having either high or exceptional vegetative diversity/integrity (Figure 16). According to these results, man-made basins do not support healthy wetland plant communities to the extent that natural basins can. Wetlands rated as exceptional for this function were limited to northern Minnesota and all occurred within the Mixed Wood Shield ecoregion.

Painted turtles are common inhabitants of depressional wetlands and ponds in Minnesota.

In addition to plants, wetlands provide habitat for a wide variety of terrestrial, aquatic, and semi-aquatic animal species. The ability to support these various species is estimated by the maintenance of characteristic wildlife habitat function of MnRAM. Since each species has unique habitat requirements, this function provides a rating of habitat quality in a more general sense and is not based on any single species. Characteristics that contribute to a high rating for this function include: a diverse plant community, a surrounding upland buffer, the presence of other nearby wetlands, and a lack of migration barriers. According to this survey, all depressional wetlands and ponds in Minnesota are rated as medium or higher for the wildlife habitat function (Figure 16). While there was a significant decline in the ability of man-made wetlands to provide this function compared to natural basins, it is surprising that no wetlands were rated low for this function considering some of the pond types that were included in the survey. For example, one site in the survey was a golf course water hazard with no emergent plant community, surrounded by manicured turf grass in a heavily urbanized area. The fact that this site and others like it did not get a low wildlife habitat rating, leads the authors of this study to question whether this function is properly calibrated and/or requires clarification in the guidance that observers use when answering associated questions.

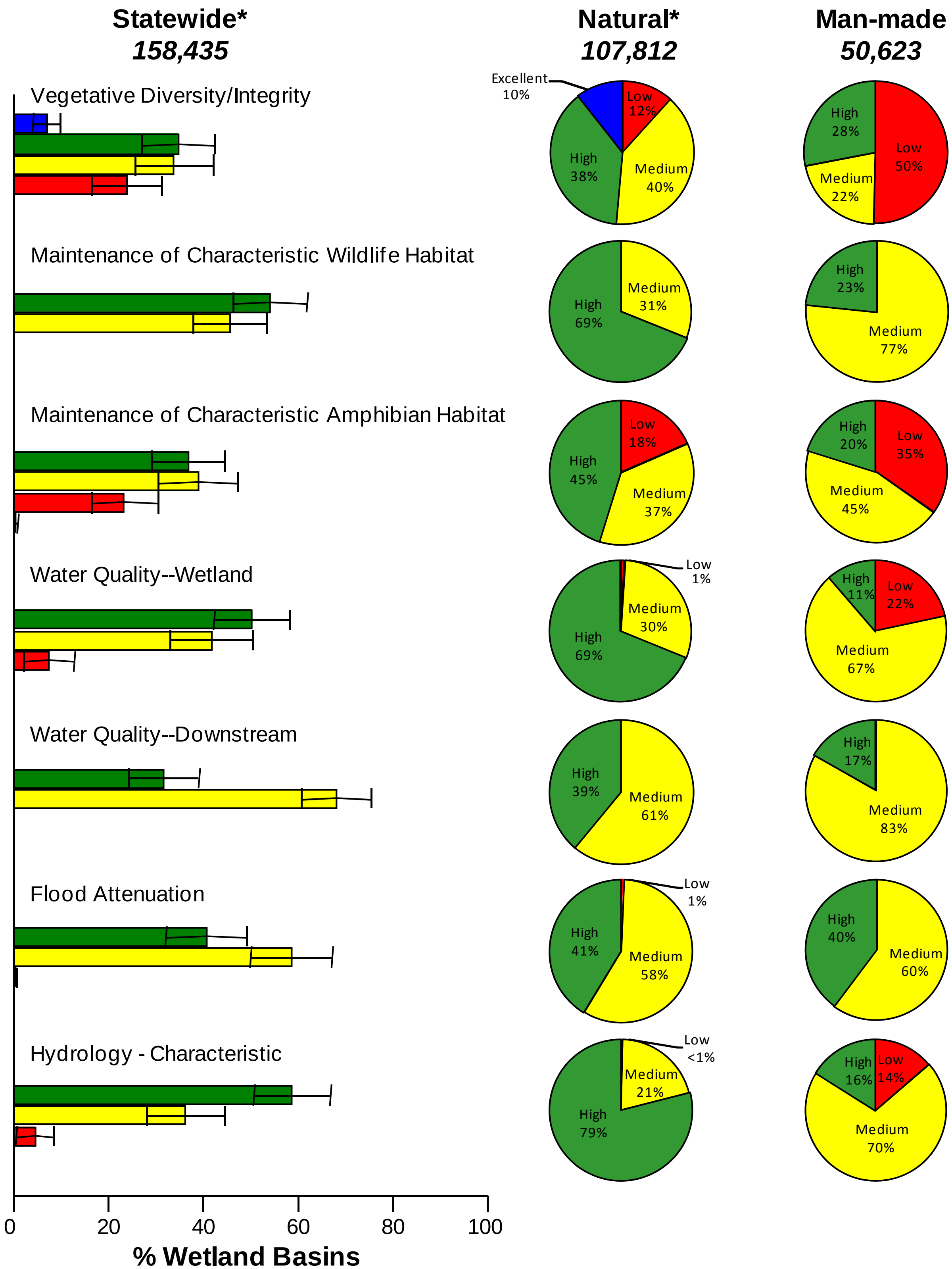


Figure 16. Functional ratings for Minnesota depressional wetlands, reporting based on the number of depressional wetlands. Included for each function is a comparison of estimates for natural vs. man-made wetlands. Lines with brackets represent the width of the 95 percent confidence interval associated with each estimate. * for each function < one percent was not assessed (not represented on pie charts).

Similar to the wildlife habitat function, the maintenance of characteristic amphibian habitat function focuses on the breeding and overwintering requirements of frogs, toads, and salamanders. Still, this function provides a generic rating of the wetland habitat as individual amphibian species have specific requirements that are difficult to ascertain through observation. Characteristics that contribute to a high rating for this function include: an inundation period through early June (to allow metamorphosis of larval stages), absence of predatory fish, a surrounding upland buffer, and a lack of migration barriers. The majority (~75 percent) of depressional wetlands in the state are rated as high or medium for the amphibian habitat function. It is not surprising that so many wetlands in the survey scored well for this function considering that a criterion for including sites in the survey was semi-permanent (or longer) inundation and that many sites were either too shallow or lacked sufficient connections to other waterbodies (e.g., lakes and streams) to harbor predatory fish; two primary factors in the rating calculation. Once again, there is a noticeable decline in the ratings for this habitat function when man-made wetlands are compared to natural wetlands (Figure 16).

Depressional wetlands and ponds provide valuable breeding and overwintering habitat for amphibians.

The wetland water quality function provides a rating of a wetland's ability to sustain its functions and condition in relation to stormwater runoff. This function is based on an evaluation of the contributing watershed area and visual indicators within the wetland itself to characterize the quality and quantity of runoff entering the wetland. Watershed characteristics that affect this functional rating include: surrounding land use; runoff volume, rates, and pre-treatment; and upland buffer extent and condition. Indicators within the wetland include evidence of excess sedimentation and nutrient loading (e.g., Figure 15). Roughly 50 percent of depressional wetlands in Minnesota are rated high for the wetland water quality function with an additional 42 percent rated medium (Figure 16). Based on survey results, the sustainability of wetland characteristics relative to stormwater impacts appears to be higher in natural basins compared to man-made basins.

Most depressional wetlands in Minnesota are rated medium for their ability to protect the water quality of downstream resources (Figure 16). The opportunity to protect downstream resources such as lakes, streams, and potable water supplies is also a consideration in this functional rating. Factors contributing to this function include: land use/soils in the upstream watershed; stormwater and sediment delivery characteristics to the wetland; vegetation within the wetland; outlet characteristics; and proximity to a valuable downstream resource. Natural wetland basins have better ratings for this function than man-made basins (Figure 16), which is no doubt partially attributable to the greater extent of vegetation found in natural wetlands. The ability of a wetland to sequester, transforms, and/or remove nutrients and other pollutants from the water column is primarily dependent on the amount and diversity of its vegetation. Vegetation can sequester pollutants directly, but more importantly, plants provide the structure that fosters many of the microbial and physical transformations that occur in wetlands (Kadlec and Wallace 2009). In flow-through depressional wetlands, vegetation also contributes to a longer retention period for water and gives the wetland greater opportunity to remove sediment, nutrients, and other pollutants from the water column via physical and biological processes.


Stormwater ponds protect the water quality of other waterbodies by capturing pollutants such as sediment and phosphorus.

The vast majority of depressional wetlands throughout the state have a medium or better rating for the flood attenuation function of MnRAM (Figure 16). Unlike other functions evaluated in this survey, there was not a significant decline in the flood attenuation ability of man-made wetlands compared to natural wetlands. The similarity in the ability of natural and man-made wetlands to provide storage of water during storm events may be somewhat related to how this functional rating is quantified. Natural wetlands have site characteristics (e.g., unaltered outlet, undisturbed soils, etc.) that contribute to a higher rating, but often have watershed characteristics (e.g., low amount of impervious surface) that contribute to a lower rating. For man-made wetlands, especially stormwater retention basins, it is the opposite situation. The end result may be that the combination of site and watershed characteristics yields similar flood attenuation results for both natural and man-made wetlands, but the basis for obtaining medium/high ratings in each category is driven by different components of the function.

The hydrologic regime or hydrology of a wetland is the seasonal pattern of water level fluctuations and the sources of water supplying and leaving the wetland. Maintaining a somewhat predictable pattern of water level fluctuations, characteristic of the wetland type (e.g., ephemeral, seasonal, permanent), from one year to the next is important for the long-term sustainability of a wetland’s functions and condition. Disruptions in how water is transported to or from the wetland can seriously alter its characteristic hydrology. Berms, outlet control structures that are either too high or too low, subsurface drainage (e.g., drain tiles), and extensive impervious surface in the surrounding upland are all factors that contribute to a low rating for this function. The expected hydrologic regime for wetlands included in this survey ranged from semi-permanently to permanently flood. Approximately 60 percent of depressional wetlands in Minnesota are able to maintain their characteristic hydrology at a high level, while 36 percent perform this function at a medium level (Figure 16). Man-made wetlands were not able to perform this function as well as natural wetlands; shifting from predominantly high ratings in natural basins to predominantly medium ratings in man-made basins.

Function versus condition

As discussed in the previous section, the majority of depressional wetlands and ponds throughout the state are providing functions at medium to high levels (Figure 16). In general, the results for most of the wetland functions contrast with the wetland condition results provided by the IBIs and water chemistry data. While high functioning wetlands provide ecosystem services that are important for maintaining watershed health, and thus are beneficial to society as a whole, some of these services may be contributing to the degradation of depressional wetlands, particularly when surrounding landscapes have been significantly altered. In the Mixed Wood Shield ecoregion where landscapes are relatively intact, wetlands providing protection of downstream water quality at high levels are in good condition (Invertebrates = 60 percent Good, Plants = 70 percent Good). While in the largely agricultural Temperate Prairies ecoregion where the majority of wetlands have been drained or filled, remaining wetlands that protect downstream water resources at high levels are in relatively poor condition (Invertebrates = 50 percent Good, Plants = 27 percent Good). To be certain, there are a multitude of factors that contribute to wetland degradation in Minnesota. The comparison above merely suggests that in some situations wetland management decisions based on wetland functions can be detrimental to wetland condition.

Considering the percentage of wetlands estimated to be in poor condition by the biological indicators (Figure 10), the percentage of wetlands with elevated levels of pollutants (Figure 13), and the reference site approach used to derive these estimates, MnRAM appears to be overestimating the performance of the wetland water quality function in depressional wetlands. Of the wetland stressors measured in the survey, wetland water quality functional ratings (Figure 16) are most comparable to the results for nitrate + nitrite levels, suggesting that this function may be doing a reasonably good job of detecting nutrient enrichment. However, an examination of the results on a site by site basis reveals that when nitrate + nitrite was detected in the wetland water column, the wetland water quality function was rated low only 17 percent of the time. Furthermore, the correspondence between this function and wetland stressors could not be significantly improved when various combinations of stressors were examined in a similar manner. Based on the relative risk analysis (Figure 14), wetland communities are negatively impacted by degraded water quality, but it appears that those impacts are not being adequately detected by the wetland water quality function. Overall, these results suggest that the visual cues used by MnRAM for detecting water quality impacts may not be evident until the wetland has reached an advanced state of degradation (e.g., Figure 15) and/or characteristics of the upland buffer and surrounding landscape may be imprecise surrogates for estimating this function.

There was better correspondence between two of the habitat-related functions, vegetative diversity/integrity and amphibian habitat, and wetland condition. Even so, compared to the plant IBI results (Figure 10A), the semi-quantitative vegetative diversity/integrity function estimated a larger proportion of healthy (i.e., excellent/high ratings) plant communities in natural wetland basins (Figure 16). Previous comparisons by MPCA of the MnRAM vegetative diversity function and plant IBI results have found similarly poor correspondence. This discrepancy is likely attributable to generous plant community assessment thresholds applied in MnRAM. For example: high quality shallow marsh communities include those which support three or more dominant native aquatic plants and cattails comprise less than 40 percent cover and purple loosestrife comprises less than 20 percent cover. Contrast this to the IBI thresholds which are derived from reference condition results which are typically more conservative toward greater integrity. The authors of this report acknowledge that MnRAM was developed primarily as a tool to guide regulatory decisions particularly related to wetland replacement and not intended to feature prominently in an ambient monitoring context.

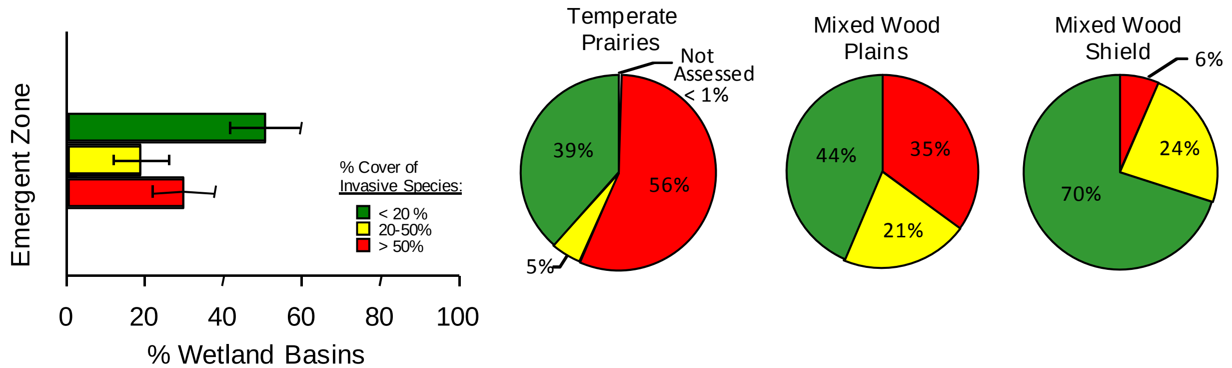
In man-made wetland basins, plant IBI and vegetative diversity categorical estimates were very similar. The amphibian habitat functional ratings and macroinvertebrate IBI condition estimates were also comparable when results were based on the percentage of wetland basins (Figures 10A and 16). This similarity in results was somewhat expected considering both assemblages are negatively impacted, directly and indirectly, by the presence of fish (e.g., Werner and McPeek 1994, Hanson and Riggs 1995, Smith et al. 1999, Schilling et al. 2009) and are sensitive to pollutants and hydrologic disturbance (e.g., Hilsenhoff 1987, Richter and Azous 1995, Helgen and Gernes 2001, US EPA 2002a, 2002b, Genet and Bourdaghs 2006).

Box 1-1 Invasive plant species in Minnesota depressional wetlands

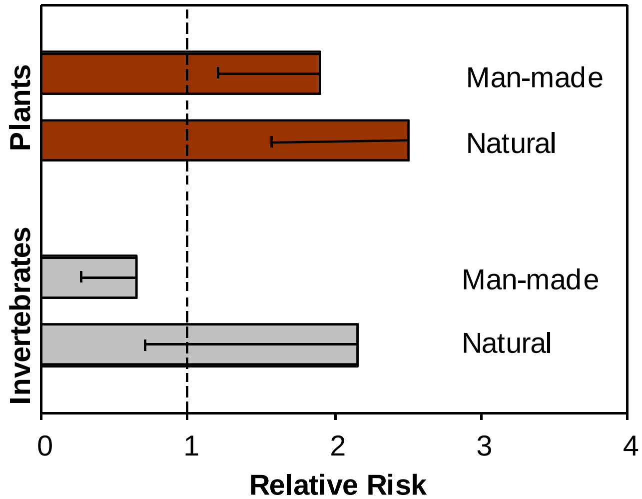
As can occur in most habitats, invasive plant species can colonize and dominate the emergent vegetation zone of wetlands. Once established, these plants can aggressively spread, thereby replacing or dramatically reducing the abundance of native vegetation. In this context, invasive plant species can be considered a biological stressor to depressional wetlands. Alternatively, the spread of an invasive species may be enhanced by anthropogenic impacts (e.g., nutrient enrichment, altered hydrology) that allow them to establish and proliferate in new locations. Therefore, invasive species can also be considered a response to human disturbance. Regardless of the pathway, invasive plant species are a serious threat to the quality and biodiversity of wetlands and thus should be an integral component of any wetland condition assessment.

In Minnesota there are several invasive plant species that can become established in the emergent vegetation zone of depressional wetlands and ponds. These species include Purple loosestrife (*Lythrum salicaria*), Narrowleaf cattail (*Typha angustifolia*), and Hybrid cattail (*Typha X glauca*) which are not native to Minnesota, as well as Reed canary grass (*Phalaris arundinacea*) and Common reed (*Phragmites australis*) which have native and Eurasian ecotypes that are considered to be more aggressive. Agricultural cultivars of Reed canary grass used for erosion control or forage have also been developed. It is thought that the majority of the Reed canary grass observed today in Minnesota is the aggressive Eurasian and agricultural varieties; whereas, the majority of the Common reed is the native variety.

MPCA vegetation sample plots are located in an area of each wetland that the botanist believes to be representative of the submerged aquatic and emergent plant community. Therefore, data from the plots (percent cover, richness) can serve as an approximation of the overall plant community. One of the metrics that can be calculated using data from the plots is the percent cover of invasive plant species in the emergent zone.



Invasive species comprised > 50 percent plant cover of the emergent zone in approximately 30 percent of the depressional wetland basins statewide. Results varied substantially among the ecoregions with the Temperate Prairies exhibiting the greatest proportion of depressional wetland basins dominated by invasive plant species. Invasive species posed an elevated risk to the integrity of wetland plant communities in both man-made and natural depressional wetland systems. Relative to other stressors, however, invasive plant species may not have as significant of an impact on the aquatic macroinvertebrate community.



These results highlight the importance of considering all types of impacts (i.e., chemical, physical, and biological) when assessing potential causes of degradation and restoration strategies. For instance, these results suggest it is unlikely that depressional wetland plant communities would improve in condition if only pollutants were addressed. Macroinvertebrate communities on the other hand would likely respond more to improvements in water quality than to the control of invasive plant species. Still, based on the estimated risk to wetland plant communities, management practices aimed at preventing the spread and reducing the prevalence of invasive plant species will be necessary to restore and protect Minnesota's depressional wetlands.

Wild calla (Calla palustris) is a sensitive plant species that is more common in northern Minnesota wetlands

Mixed Wood Plains

Extent of depressional wetlands

A total of 61 random sites were sampled in the Mixed Wood Plains ecoregion during the summer of 2007. Seventy six potential sites from the random draw were evaluated in order to obtain this sample (see Appendix D).

An estimated 81,948 ± 16,256 (± 95 percent CL) depressional wetland basins occur within the Mixed Wood Plains ecoregion in Minnesota. These basins represent an estimated 352,251 ± 61,345 (± 95 percent CL) acres of wetland area within this ecoregion. Based on these estimates, the average depressional wetland size within this ecoregion is about 4.3 acres.

During the initial phase of site evaluations, a number of potential study sites could not be accessed due to landowner denial and therefore could not be included in the survey (see Appendix D). If these sites were in fact part of the target population, as the aerial imagery suggested, the population estimates presented above would increase slightly. Assuming that all landowner denied sites belonged to the target population, the estimates would increase to 87,479 ± 16,562 (± 95 percent CL) basins and 408,587 ± 56,594 (± 95 percent CL) acres in this ecoregion. However, given the constraints of the analysis procedure for estimating function and condition (i.e., it cannot incorporate data from landowner denied sites), the estimates provided in the previous paragraph are used throughout the remainder of this chapter when referencing the extent of the population.

Approximately 77 percent or 63,000 of the depressional wetlands occurring within this ecoregion are less than 2.5 acres in size (Figure 17). The relatively few large wetlands greater than 12.4 acres in size account for about 67 percent of the depressional wetland acreage in the ecoregion. In terms of both the number of basins and acreage, the majority of depressional wetlands within the Mixed Wood Plains are located on private property (Figure 17). Sample sites on public property were typically located within MDNR Wildlife Management Areas, US FWS Waterfowl Production Areas, or Minnesota Department of Transportation highway right-of-ways. Wetlands owned by both public and private entities (‘Mixed’) tended to be large with ownership divided among local units of government, private citizens, and housing developers. Man-made wetlands account for a substantial percentage of the number of basins within the population, approximately 32 percent, but in terms of associated wetland area only account for about six percent of the population. Based on the population estimates reported in Figure 17 the average size of a natural and man-made wetland is 5.9 and 0.8 acres, respectively. Man-made wetlands sampled in the Mixed Wood Plains included golf course water hazards, livestock watering ponds, ornamental ponds, and stormwater retention ponds.

Wetland condition

- According to the plant IBI, approximately 18 percent of the depressional wetlands in the Mixed Wood Plains ecoregion are in good condition, 21 percent are in fair condition, and 61 percent are in poor condition. Estimates did not change substantially when man-made wetlands were excluded from the analysis (Figure 18).
- Results from the macroinvertebrate IBI show that an estimated 44 percent of the depressional wetlands in the Mixed Wood Plains ecoregion are in good condition, 40 percent are in fair condition, and 15 percent are in poor condition. When man-made wetlands were excluded from the analysis these estimates changed to 52 percent good, 42 percent fair, and six percent poor (Figure 18). In each analysis a small percentage of the population is represented as ‘not assessed’ because at one of the study sites macroinvertebrates could not be effectively sampled.

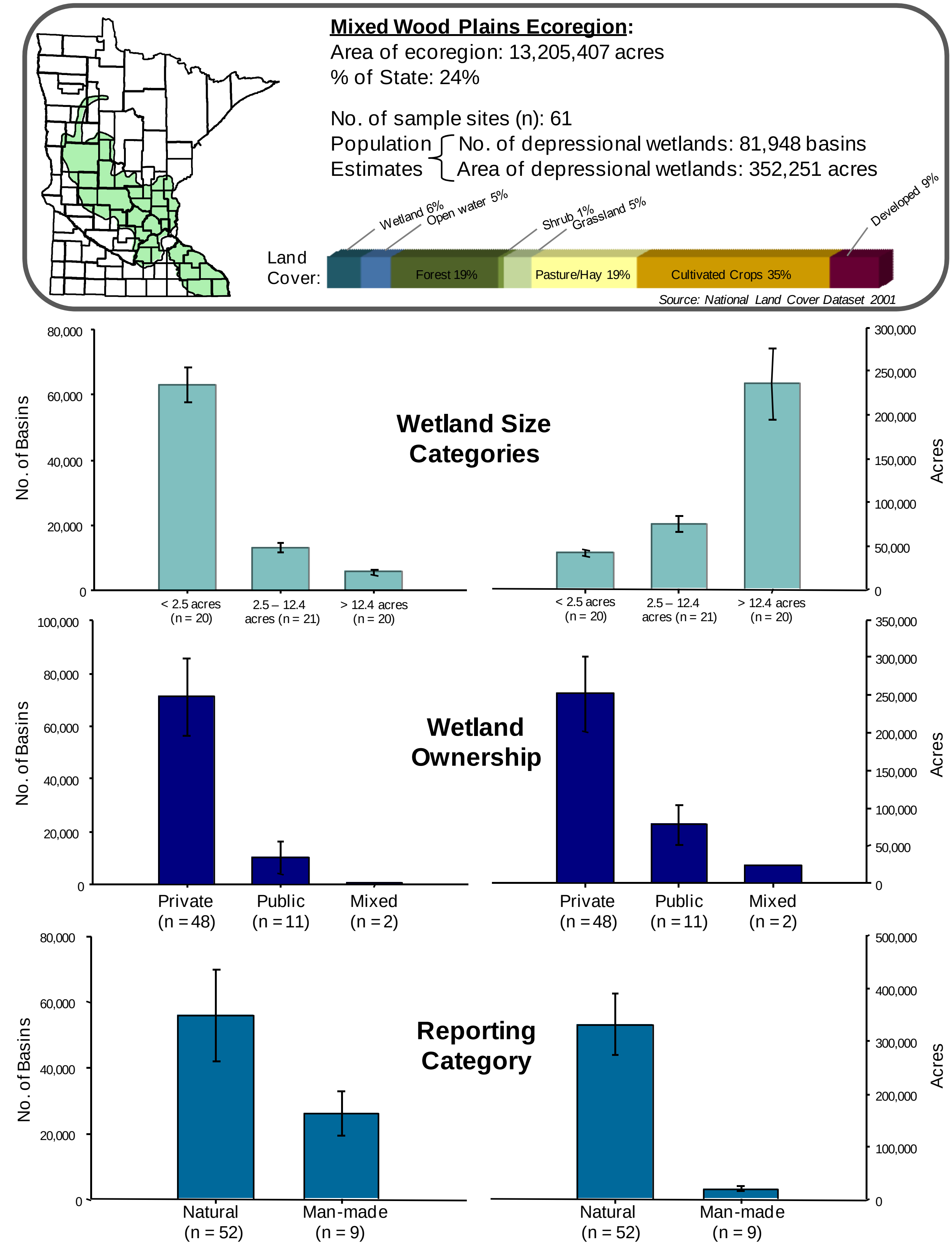


Figure 17. Estimates of the total number and total area of depressional wetlands in the Mixed Wood Plains and these estimates broken down into various subcategories. Bracketed lines represent the width of the 95 percent confidence interval associated with each estimate.

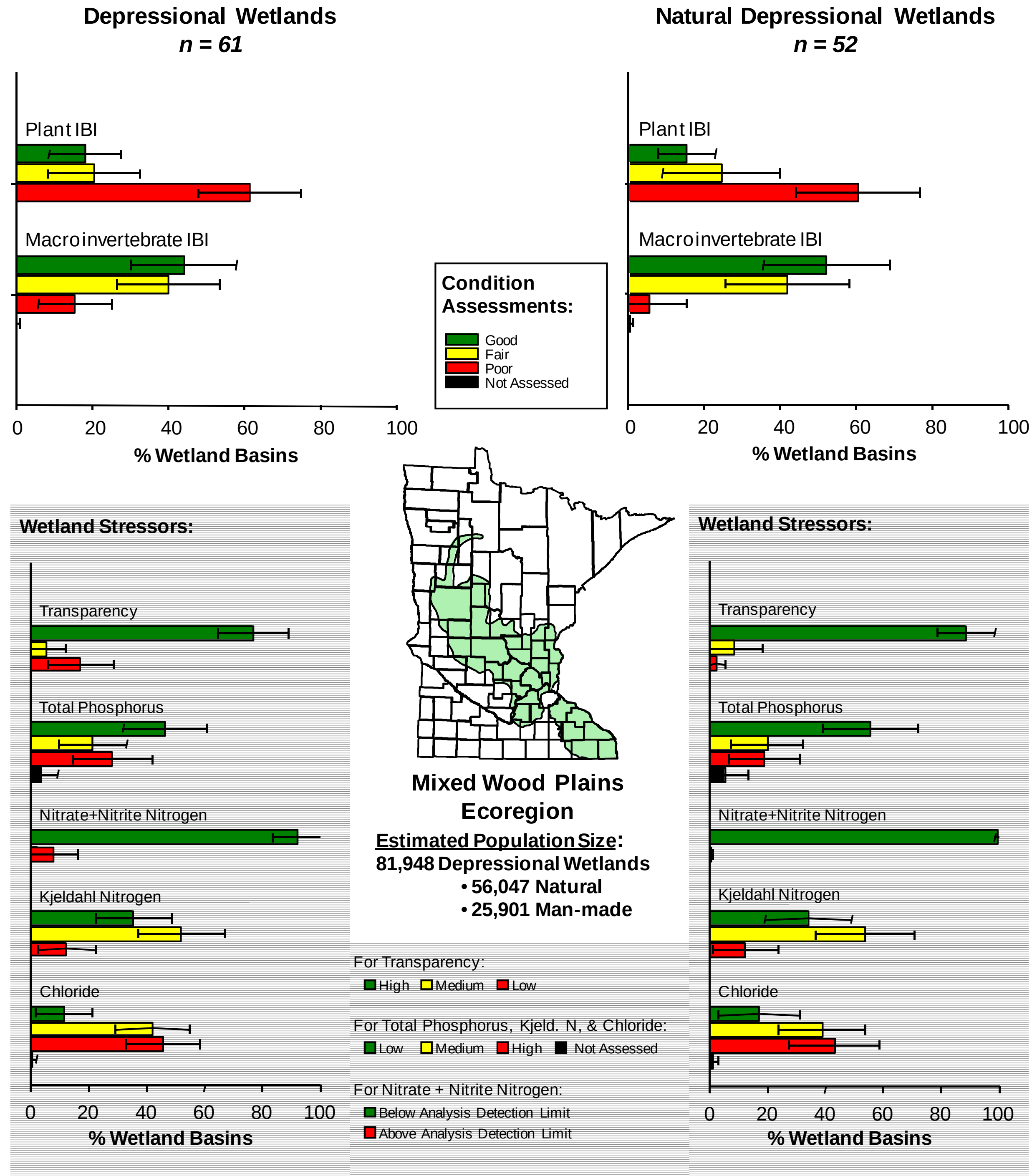


Figure 18. The condition of Mixed Wood Plains depressional wetlands and estimated stressor levels occurring in these wetlands, reporting based on the number of depressional wetland basins. Estimates are presented both for all depressional wetlands within the ecoregion and excluding man-made wetlands. Lines with brackets represent the width of the 95 percent confidence interval associated with each estimate.

The discrepant assessments produced by the plant and macroinvertebrate indicators can likely be attributed to the differential effects on each community resulting from a key stressor plaguing Minnesota wetlands: invasive plant species. Wetland plant communities dominated by invasive species typically have low diversity, a high abundance of plants that produce recalcitrant or persistent litter, and a low abundance of sedges (*Carex* spp.) and other typical native depressional wetland plant species; characteristics that reduce several metric scores in the Mixed Wood Plains plant IBI. On the other hand, macroinvertebrate community composition within depressional wetlands may perhaps be affected more by the habitat structure provided by emergent and submergent vegetation and less so by the individual species comprising this structure. However, there are instances when the type (e.g., floating cattail mats) or density of growth exhibited by invasive plant species results in the reduction of habitat heterogeneity in the emergent zone. Even so, the effects on the macroinvertebrate community are not likely to be as severe as those experienced by the plant community when such situations occur (see Box 1-1).

It was anticipated that when man-made wetlands were excluded from the estimation procedure, the proportion of the population in the poor category would decrease. This pattern occurred in the macroinvertebrate IBI analysis, but not in the plant IBI analysis (Figure 18). These unexpected plant results may have been due to the configuration of the sampling plot in conjunction with the size of the emergent vegetation zone within man-made sites. Physically altered or created "pond" type waterbodies often support only a narrow band of emergent vegetation along the shore. When sampling plots are established within this narrow fringe, they inevitably include portions of the submerged aquatic and emergent plant community as well as communities further inland such as the wet meadow. An unintended consequence of this plot configuration may be an artificially high characterization of condition in man-made wetlands, resulting from the bolster in species richness obtained from the additional, albeit narrow, and plant community type included in the sampling area.

Wetland stressors

- Relative to least disturbed depressional wetlands, approximately 77 percent of the depressional wetlands in the Mixed Wood Plains ecoregion have high transparency, six percent have medium transparency, and 17 percent have low transparency. When man-made wetlands were excluded from the analysis these estimates changed to 89 percent high, eight percent medium, and three percent low (Figure 18).
- Total phosphorus concentrations in the water column are low in approximately 47 percent of Mixed Wood Plains depressional wetlands, medium in 21 percent, and high in 28 percent. Without man-made wetlands in the analysis these estimates changed to 56 percent low, 20 percent medium, and 19 percent high (Figure 18). In each analysis a small percentage of the population is represented as 'not assessed' due to a failure to collect total phosphorus data at one of the study sites.
- Nitrate and/or nitrite nitrogen concentrations are above the analysis detection limit (0.05 mg/L) in an estimated eight percent of the depressional wetlands in the ecoregion. This estimate decreased to less than one percent when man-made wetlands were excluded from the analysis (Figure 18).
- An estimated 36 percent of the depressional wetlands in the Mixed Wood Plains ecoregion have low concentrations of Kjeldahl nitrogen (organic N + ammonia), 52 percent have medium concentrations, and 12 percent have high concentrations compared to least disturbed reference sites. These estimates did not change substantially when man-made wetlands were excluded from the analysis (Figure 18).

- Chloride concentrations in the water column are low in approximately 12 percent of Mixed Wood Plains depressional wetlands, medium in 42 percent, and high in 46 percent. These estimates did not change substantially when man-made wetlands were excluded from the analysis (Figure 18). In each analysis a small percentage of the population is represented as 'not assessed' due to a failure to collect chloride data at one of the study sites.

Chloride levels are elevated in almost 50 percent of the depressional wetlands in this ecoregion. Yet there was no elevated risk to plant communities in depressional wetlands due to increased chloride concentrations (Figure 19) and the risk to macroinvertebrates could not be calculated. The inability to calculate risk for the macroinvertebrates was due to the lack of any instances in the data set where the macroinvertebrate community was in poor condition and chloride concentrations were low, making it impossible to calculate the denominator (or baseline risk) of the relative risk estimate. However, there were many instances where macroinvertebrates were in good condition and chloride concentrations were high, suggesting that chloride levels encountered in the majority of Mixed Wood Plains depressional wetlands do not pose an elevated risk to macroinvertebrate communities either. These results are in contrast to those observed in the statewide analysis where increased chloride concentrations represented a significant risk to both plants and macroinvertebrates. Conceptually, this discrepancy is difficult to explain considering chloride concentrations among the three ecoregions were greatest in the Mixed Wood Plains. However, these differing results may simply represent an artifact of sample size and its influence on the estimation of confidence intervals. For the most part, relative risk estimates for chloride are similar across the three ecoregion and statewide analyses, ranging from 0.9 to 2.3 for plants and 2.3 to 5.1 for macroinvertebrates (Figures 14, 19, 23 and 27). Even though relative risk estimates were not greatest in the statewide analyses, due to the significantly larger sample sizes of these analyses (i.e., sum of all three ecoregions) resulting estimates tended to have smaller confidence limits that did not extend below a value of one, indicating that statistically significant elevated risks existed (Figure 14).

Nutrients (phosphorus, Kjeldahl-N and nitrate+nitrite-N) pose an elevated risk to both the plant and macroinvertebrate communities of Mixed Wood Plains depressional wetlands (Figure 19). Considering how often it occurs at high concentrations within the ecoregion, phosphorus represents the most serious threat (among those measured) to the biological integrity of depressional wetlands. Both forms of nitrogen measured in the survey, while posing an elevated risk to the communities, exhibited high or detectable concentrations in less than 15 percent of the population. However, nitrate+nitrite nitrogen is transient in wetland habitats due to its rapid rate of assimilation by plants and microbes, its mobility in aqueous environments resulting in its loss through groundwater flow, and its conversion to reduced forms of nitrogen under anaerobic conditions (e.g., microbial denitrification). The occurrence of detectable levels of nitrate+nitrite nitrogen in the study sites is thus highly dependent on the timing and magnitude of precipitation events occurring prior to sample collection. Rainfall transports these forms of nitrogen into wetlands and other aquatic habitats via runoff from upland habitats as well as atmospheric deposition. Consequently, the low occurrence (~8 percent) of nitrate+nitrite detections in Mixed Wood Plains depressional wetlands may have been due to the lack of appreciable rainfall that this ecoregion experienced during the 2007 sampling period (http://climate.umn.edu/doc/weekmap.asp: June 2007 maps).

Reduced transparency in Mixed Wood Plains depressional wetlands did not represent an elevated risk to either the plant or macroinvertebrate community (Figure 19). In addition, the majority of depressional wetlands and ponds in this ecoregion were in a 'clear-water' state when transparency was measured during the June sample index period (Figure 18). These results suggest that water clarity is currently not a significant issue for depressional wetlands in the Mixed Wood Plains ecoregion. However, similar to nitrate+nitrite, reduced water clarity may have been encountered more often in the survey had precipitation been greater throughout the ecoregion, which presumably would have increased the amount of sediment-laden runoff entering the water column in a number of study sites (particularly man-made waterbodies). Another important consideration is the effect of phytoplankton abundance on transparency and how measurements in June may not adequately integrate the contribution of this community. In Minnesota the onset and duration of warmer temperatures in the spring can influence the seasonal development of phytoplankton communities in wetland and shallow lake basins. Thus, transparency measured in June, particularly at sites in the northern part of the state, may not accurately characterize the trophic condition (clear- vs. turbid-water state; *sensu* Scheffer et al. 1993) of the basin (M. Hanson and B. Herwig pers. comm.). Overall, the above situation and drier than normal conditions in the ecoregion may have resulted in underestimating the proportion of Mixed Wood Plains depressional wetlands having water clarity issues.

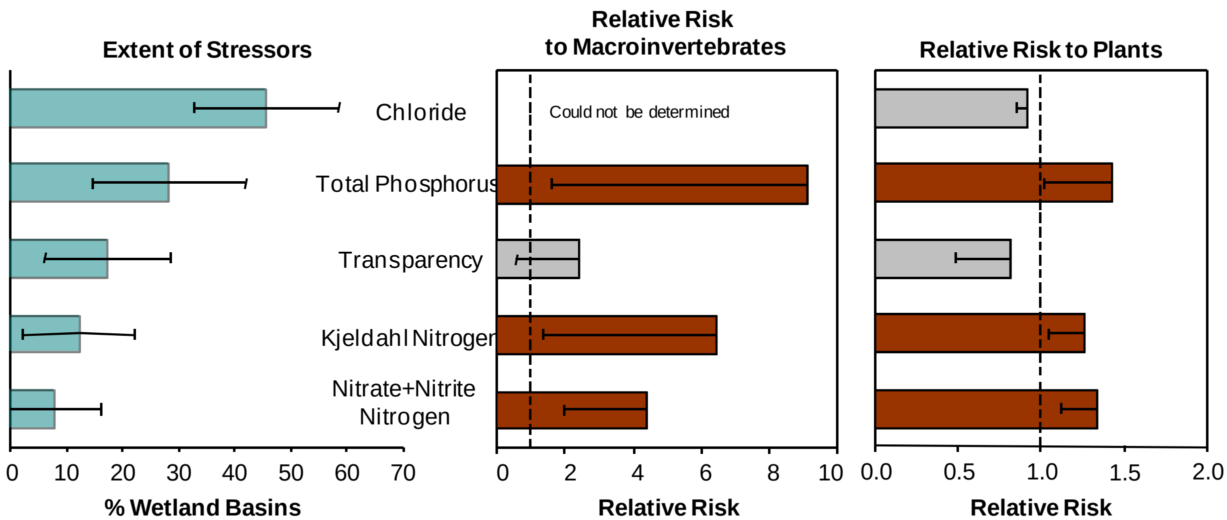


Figure 19. Extent of measured stressors in the Mixed Wood Plains ecoregion and relative risk estimates for plant and macroinvertebrate communities. Bracketed lines represent 95 percent confidence intervals. Lower confidence limits (relative risk charts) that do not extend below one represent a significant elevated risk (maroon bars).

Wetland functions

- An estimated 31 percent of the depressional wetlands in the Mixed Wood Plains are rated high, 39 percent are rated medium, and 30 percent are rated low for their ability to support a diverse wetland plant assemblage (Figure 20). When man-made waterbodies were excluded from the analysis the percentage of wetlands rated medium increased to an estimated 56 percent and low decreased to 10 percent.
- The ability to provide characteristic wildlife habitat is rated high in 43 percent of Mixed Wood Plains depressional wetlands and medium in 57 percent (Figure 20). These estimates exchanged places when man-made sites were excluded, going to 57 percent high and 43 percent medium.
- The ability to provide characteristic amphibian habitat is rated high in 33 percent of Mixed Wood Plains depressional wetlands, medium in 35 percent, low in 31 percent, and was not assessed in less than one percent. These estimates did not change substantially when man-made waterbodies were excluded from the analysis (Figure 20).
- An estimated 40 percent of the depressional wetlands in the Mixed Wood Plains are rated high, 48 percent are rated medium, and 12 percent are rated low for the wetland water quality function (Figure 20). Analysis of the data set without man-made sites yielded estimates of 59 percent high and 41 percent medium for this function.

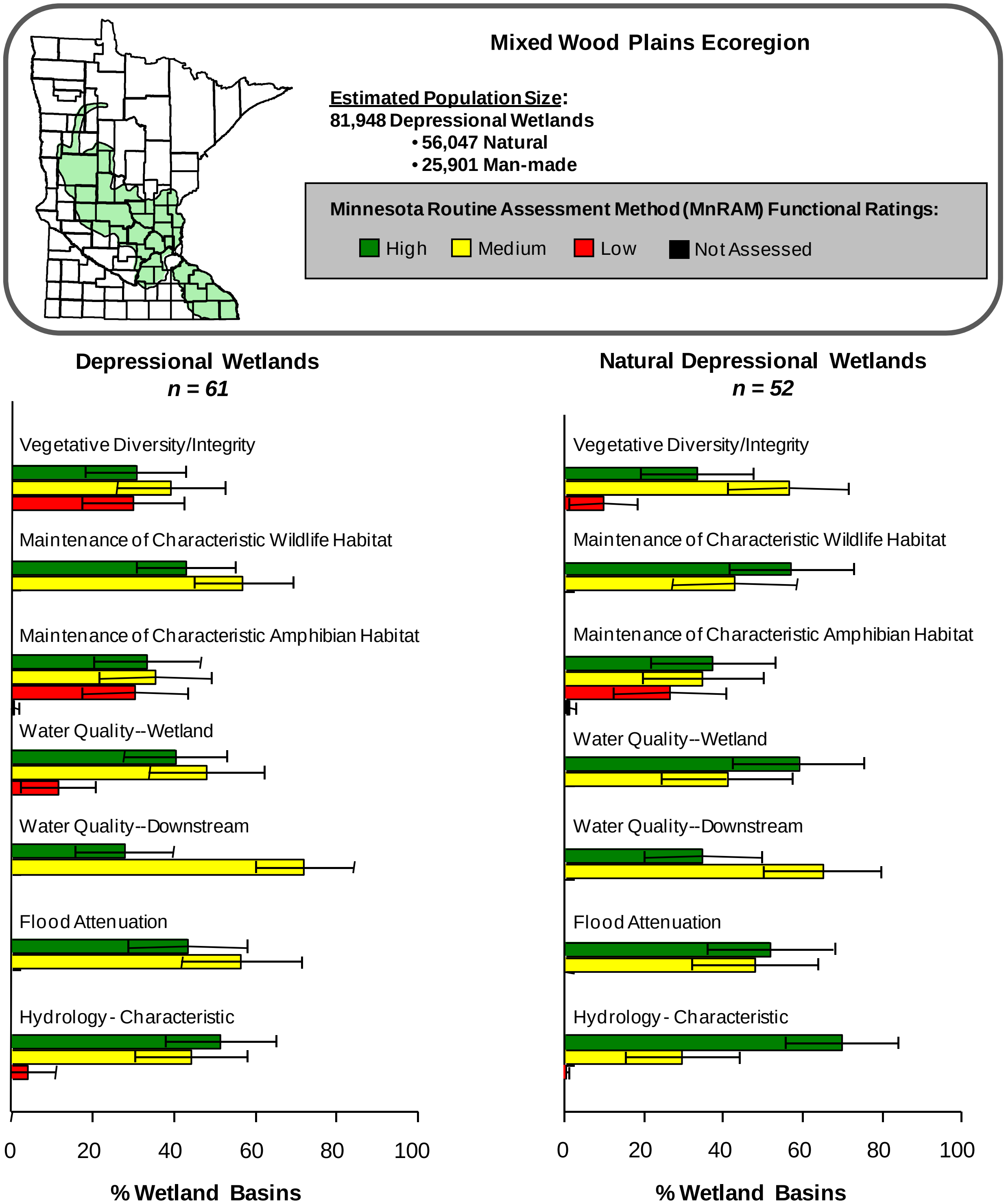


Figure 20. Functional ratings for Mixed Wood Plains depressional wetlands, reporting based on the number of depressional wetlands. Included for comparison are the rating estimates for the subpopulation of natural wetlands. Lines with brackets represent the width of the 95 percent confidence interval associated with each estimate.

- The ability to protect the water quality of downstream waterbodies is rated high in 28 percent of Mixed Wood Plains depressional wetlands and medium in 72 percent (Figure 20). These estimates did not change substantially when man-made waterbodies were excluded from the analysis.
- The ability to provide flood storage has a high rating in 43 percent of Mixed Wood Plains depressional wetlands and a medium rating in 57 percent. Excluding man-made wetlands from the analysis did not alter these estimates substantially (Figure 20).
- An estimated 52 percent of the depressional wetlands in the Mixed Wood Plains are rated high, 44 percent are rated medium, and four percent are rated low for their ability to maintain a characteristic hydrologic regime (Figure 20). When man-made waterbodies were excluded from the analysis the functional rating estimates for depressional wetlands in this ecoregion changed to 70 percent high, 30 percent medium, and less than one percent low.

For each function that was evaluated, the proportion of Mixed Wood Plains depressional wetlands with high functional ratings increased when only the data from natural wetlands were analyzed (Figure 20). Although in most cases the increase would likely not be statistically significant considering the size of the 95 percent confidence limits. Functional ratings for Mixed Wood Plains depressional wetlands largely mirror the results found in the statewide analysis (Figure 16). However, no wetland in this ecoregion received an exceptional rating for the vegetative diversity function based on a rater's supposition of pre-settlement conditions.

Temperate Prairies

Extent of depressional wetlands

The 2008 sample from the Temperate Prairies ecoregion consisted of 62 sites. Ninety five potential sites from the random draw were evaluated in order to obtain this sample (see Appendix D). However, one site was actively being managed for waterfowl (i.e., water level completely drawn down) and was not able to be sampled or assessed for condition.

An estimated 27,660 ± 5,226 (± 95 percent CL) depressional wetland basins occur within the Temperate Prairies ecoregion in Minnesota. These basins represent an estimated 156,791 ± 26,926 (± 95 percent CL) acres of wetland area within this ecoregion. Based on these estimates, the average size of a depressional wetland within this ecoregion is about 5.7 acres.

During the initial phase of site evaluations, a number of potential study sites could not be accessed due to landowner denial and therefore could not be included in the survey (see Appendix D). If these sites were in fact part of the target population, as the aerial imagery suggested, the population estimates presented above would increase slightly. Assuming that all landowner denied sites belong to the target population, estimates would increase to 32,300 ± 5,203 (± 95 percent CL) basins and 190,747 ± 27,278 (± 95 percent CL) acres in this ecoregion. However, given the constraints of the analysis procedure for estimating function and condition (i.e., it cannot incorporate data from landowner denied sites), the estimates provided in the previous paragraph are used throughout the remainder of this chapter when referencing the extent of the population.

Approximately 70 percent or 19,500 of the depressional wetlands occurring within this ecoregion are less than 2.5 acres in size (Figure 21). In contrast, the relatively few large wetlands greater than 12.4 acres in size account for about 75 percent of the depressional wetland acreage in the ecoregion. In terms of both the number of basins and acreage, the majority of depressional wetlands within the Temperate Prairies are located on private property (Figure 21). Sites on public property were typically located within MDNR Wildlife Management Areas, US FWS Waterfowl Production Areas, or county/city administered lands. Wetlands owned by both public and private entities ('Mixed') tended to be large with ownership divided between government agencies and private citizens. Man-made wetlands account for about half of the basins within the population, but in terms of associated wetland area only account for about eight percent of the population. Based on the population estimates reported in Figure 21 the average size of a natural and man-made wetland is 9.7 and 1.0 acres, respectively. Man-made wetlands sampled in the Temperate Prairies included livestock watering ponds, stormwater retention ponds, ornamental ponds, and abandoned gravel pits.

Wetland condition

- Plant IBI assessments indicate that approximately 17 percent of the depressional wetlands in the Temperate Prairies ecoregion are in good condition, 28 percent are in fair condition, and 54 percent are in poor condition. Estimates did not change substantially when man-made wetlands were excluded from the analysis (Figure 22).
- Based on the macroinvertebrate IBI an estimated 33 percent of the depressional wetlands in the Temperate Prairies ecoregion are in good condition, 20 percent are in fair condition, and 47 percent are in poor condition. When man-made wetlands were excluded from the analysis these estimates changed to 41 percent good, 28 percent fair, and 30 percent poor (Figure 22).

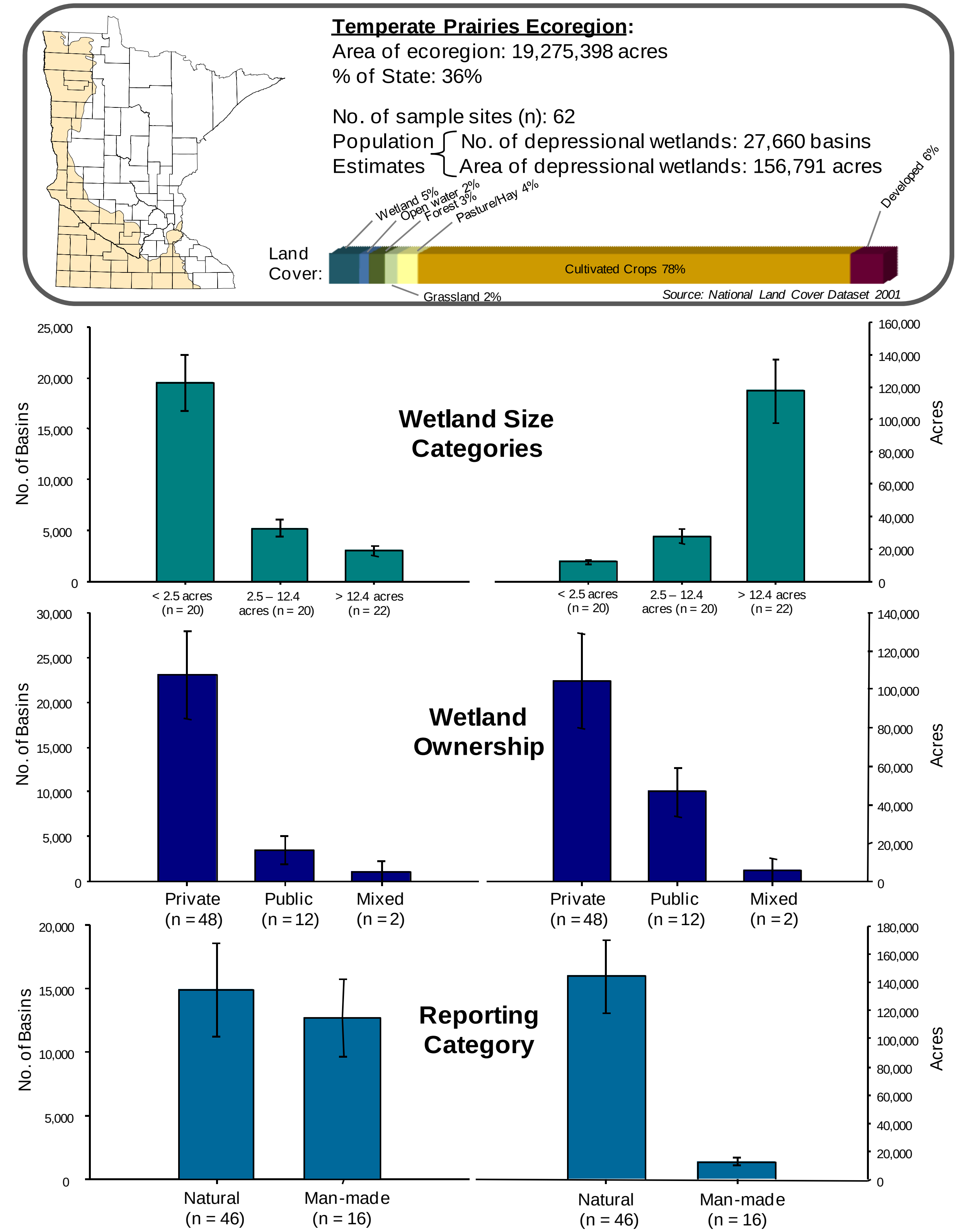


Figure 21. Estimates of the total number and total area of depressional wetlands in the Temperate Prairies and these estimates broken down into various subcategories. Bracketed lines represent the width of the 95 percent confidence interval associated with each estimate.

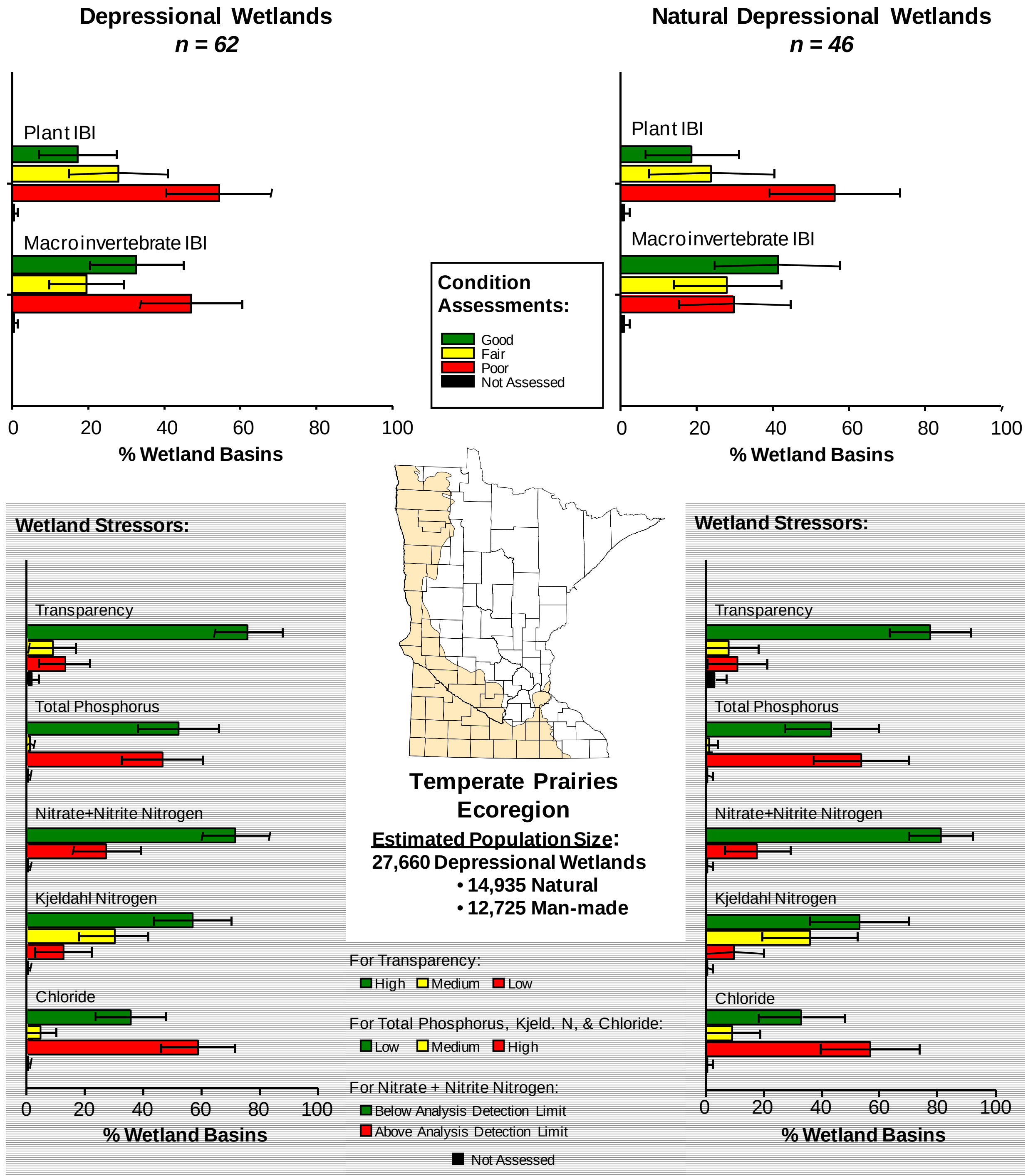


Figure 22. The condition of Temperate Prairies depressional wetlands and estimated stressor levels occurring in these wetlands, reporting based on the number of depressional wetland basins. Estimates are presented both for all depressional wetlands within the ecoregion and excluding man-made wetlands. Lines with brackets represent the width of the 95 percent confidence interval associated with each estimate.

Plant and macroinvertebrate indicators both estimated that approximately 50 percent of the depressional wetlands in this ecoregion are in poor condition. As in the Mixed Wood Plains, macroinvertebrate-based condition estimates improve, while plant-based estimates remain unchanged, when man-made wetlands are excluded from the analysis. Once again, sample plot configuration when only a narrow band of emergent vegetation exists, as is the case with most man-made wetlands, likely explains the unexpectedly high plant IBI scores obtained at these sites. At the same time, an emergent vegetation zone, which is typically interspersed with submerged and/or floating vegetation that is diminished or nonexistent often translates into reduced structural habitat (attachment sites and refuges from predators) and food resources (living and dead plant material) for aquatic macroinvertebrates. In fact, some of the lowest macroinvertebrate IBI scores were from man-made sites where there was virtually no emergent vegetation to sample and crews instead collected macroinvertebrates from submergent or floating-leaved vegetation zones or from open water.

Wetland stressors

- Relative to least disturbed reference conditions, approximately 76 percent of the depressional wetlands in the Temperate Prairies ecoregion have high transparency, nine percent have medium transparency, and 13 percent have low transparency. When man-made wetlands were excluded from the analysis these estimates did not change substantially (Figure 22).
- Water column total phosphorus concentrations are low in approximately 52 percent of Temperate Prairies depressional wetlands, medium in one percent, and high in 47 percent. Without man-made wetlands in the analysis these estimates changed to 44 percent low, two percent medium, and 54 percent high (Figure 22).
- Nitrate and/or nitrite nitrogen concentrations are above the analysis detection limit (0.05 mg/L) in an estimated 28 percent of the depressional wetlands in this ecoregion. This estimate decreased to 18 percent when man-made wetlands were excluded from the analysis (Figure 22).
- An estimated 57 percent of the depressional wetlands in the Temperate Prairies ecoregion have low concentrations of Kjeldahl nitrogen (organic N + ammonia), 30 percent have medium concentrations, and 13 percent have high concentrations compared to least disturbed reference sites. These estimates did not change substantially when man-made wetlands were excluded from the analysis (Figure 22).
- Chloride concentrations in the water column are low in approximately 36 percent of Temperate Prairies depressional wetlands, medium in five percent, and high in 59 percent. These estimates did not change substantially when man-made wetlands were excluded from the analysis (Figure 22).

An evaluation of each stressor based on its occurrence within the ecoregion and the relative risk it poses to biological communities reveals that chloride represents the greatest threat (among those measured) to macroinvertebrate communities of depressional wetlands in the Temperate Prairies (Figure 23). The highest chloride concentration measured in this ecoregion (130 mg/l) was from a stormwater retention pond that received runoff from a shopping mall parking lot. However, elevated chloride concentrations were also found in a number of wetlands that were not located near any roads or parking lots, suggesting that de-icing compounds may not be the only significant source of chloride in this ecoregion. Increased chloride concentrations can adversely affect some freshwater macroinvertebrates by disrupting their ability to maintain a proper balance of salt and water (Sutcliffe 1961). Although, many aquatic macroinvertebrates appear to tolerate chloride concentrations well above those measured in this survey (Blasius and Merritt 2002, Benbow and Merritt 2004). Overall, reduction macroinvertebrate IBI scores could be due to loss of chloride sensitive species, but more likely is due to the cumulative impact of stressors that often occur concurrently with increased chloride concentrations such as increased water level fluctuations, sediment and phosphorus loading, reduced habitat heterogeneity, and decreased transparency (which also poses an elevated risk to macroinvertebrates, Figure 23).

Exposure to increased nutrient concentrations resulted in degraded plant and macroinvertebrate communities within Temperate Prairie depressional wetlands and ponds (Figure 23). Similar to results in the Mixed Wood Plains, phosphorus represents the most significant risk to depressional wetland plant communities in the Temperate Prairies given how often it occurs at high concentrations (47 percent) throughout the ecoregion. Elevated nutrient concentrations can negatively impact emergent and wet meadow plant communities by allowing invasive species such as reed canary grass and hybrid cattail to proliferate and out-compete native species due to their enhanced ability to utilize excess nutrients (Green and Galatowitsch 2002, Woo and Zedler 2002, Kercher and Zedler 2004). Submerged aquatic vegetation as well as the macroinvertebrate community can also be impacted by increased nutrient levels if the wetland becomes hypereutrophic. For instance, increased nutrient concentrations in the water column often lead to dense floating mats of filamentous algae (Figure 15) and/or duckweed (*Lemna* spp.), thereby shading out aquatic macrophytes and reducing habitat complexity for macroinvertebrates. Another expression of elevated nutrients is a shift to a phytoplankton-dominated turbid-water state (*sensu* Scheffer et al. 1993), which can have the same effect as floating mats. The increase in community productivity resulting from nutrient enrichment can also lead to dramatic diel oxygen fluctuations and prolonged periods of hypoxia in the water column that is detrimental to some wetland macroinvertebrates.

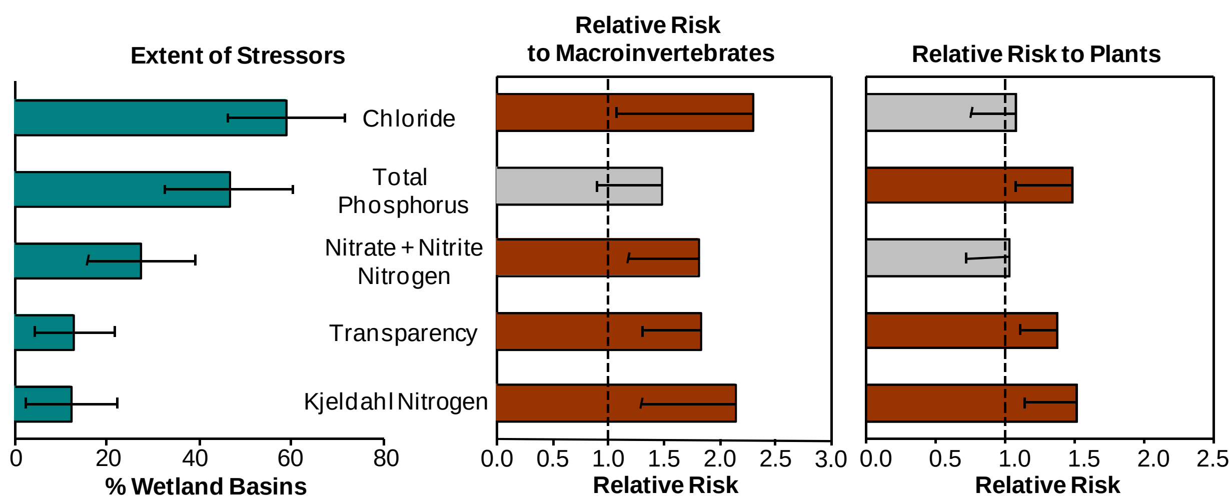


Figure 23. Extent of measured stressors in the Temperate Prairies ecoregion and relative risk estimates for plant and macroinvertebrate communities. Bracketed lines represent 95 percent confidence intervals. Lower confidence limits (relative risk charts) that do not extend below one represent a significant elevated risk (maroon bars).

Unlike results statewide and in the Mixed Wood Plains, decreased transparency did represent a significant threat to both plant and macroinvertebrate communities in the Temperate Prairies. As mentioned previously, this threat may stem from either sediment loading into the wetland or nutrient loading that results in phytoplankton proliferation. However, without accompanying chlorophyll-a data to estimate phytoplankton abundance, the relative contribution of each could not be determined. The percentage of wetland basins in the Temperate Prairies with decreased transparency is relatively low, but this result may underestimate the true occurrence of water clarity problems in the ecoregion if June data collection is too early to accurately characterize the seasonal contribution of phytoplankton and/or June 2008 was a drier than normal period (i.e., reduced sediment loading from surface runoff). While the former cannot be sufficiently addressed without further investigation, it appears that, with the exception of one dry week, the ecoregion experienced considerable precipitation in the month of June (http://climate.umn.edu/doc/weekmap.asp: June 2008 maps).

Wetland functions

- The ability to support a diverse wetland plant assemblage is rated high in an estimated 25 percent of the depressional wetlands in the Temperate Prairies, medium in 34 percent, and low in 41 percent (Figure 24). When man-made waterbodies were excluded from the analysis these estimates did not change.
- An estimated 51 percent of the depressional wetlands in the Temperate Prairies are rated high and 48 percent are rated medium for their ability to provide characteristic wildlife habitat (Figure 24). These estimates did not vary substantially when man-made sites were excluded from the analysis.
- The ability to provide characteristic amphibian habitat is rated high in 24 percent of Temperate Prairie depressional wetlands, medium in 43 percent, and low in 32 percent. These estimates did not change substantially when man-made waterbodies were excluded from the analysis (Figure 24).
- An estimated 34 percent of the depressional wetlands in the Temperate Prairies are rated high, 56 percent are rated medium, and nine percent are rated low for their own sustainability in relation to water quality impacts (Figure 24). Analysis of the data set without man-made sites yielded estimates of 44 percent high, 48 percent medium, and seven percent low for this function.
- The ability to protect the water quality of downstream waterbodies is rated high in 35 percent of Temperate Prairie depressional wetlands and medium in 64 percent (Figure 24). These estimates did not change substantially when man-made waterbodies were excluded from the analysis.
- The ability to provide flood storage has a high rating in 66 percent of the depressional wetlands in the Temperate Prairies and a medium rating in 34 percent. Excluding man-made wetlands from the analysis changed estimates to 76 percent high and 23 percent medium (Figure 24).
- An estimated 47 percent of the depressional wetlands in the Temperate Prairies are rated high, 51 percent are rated medium, and one percent is rated low for their ability to maintain a characteristic hydrologic regime (Figure 24). When man-made waterbodies were excluded from the analysis the functional rating estimates for depressional wetlands in this ecoregion changed to 72 percent high, 26 percent medium, and one percent low.

In general, the percentage of high ratings increased for each function when man-made wetlands were excluded from the analysis (Figure 24). Although, many of these changes would not be statistically significant considering the margin of error (i.e., 95 percent confidence interval) associated with each estimate. Compared to statewide results, the vegetative diversity functional ratings were lower in the Temperate Prairies ecoregion with no wetlands receiving an exceptional rating due to pre-settlement conditions. Similarly, ratings for the maintenance of characteristic amphibian habitat, wetland water quality, and characteristic hydrology functions were all lower in this ecoregion compared to results statewide. Flood attenuation was the only function in this ecoregion that exhibited noticeably higher ratings than the statewide analysis (Figures 16 and 24). When only natural basins are examined, the difference between the Temperate Prairies and statewide ratings for this function becomes even more pronounced. In this ecoregion where row crop agriculture is the dominant land use and greater than 50 percent of its original wetlands have been drained (see map in Minn. R. ch. 8420.0117), wetlands that remain on the landscape today are particularly important for providing flood storage. This concept is integrated into the flood attenuation rating of MnRAM and may partially explain the higher ratings observed for depressional wetlands in the Temperate Prairies.

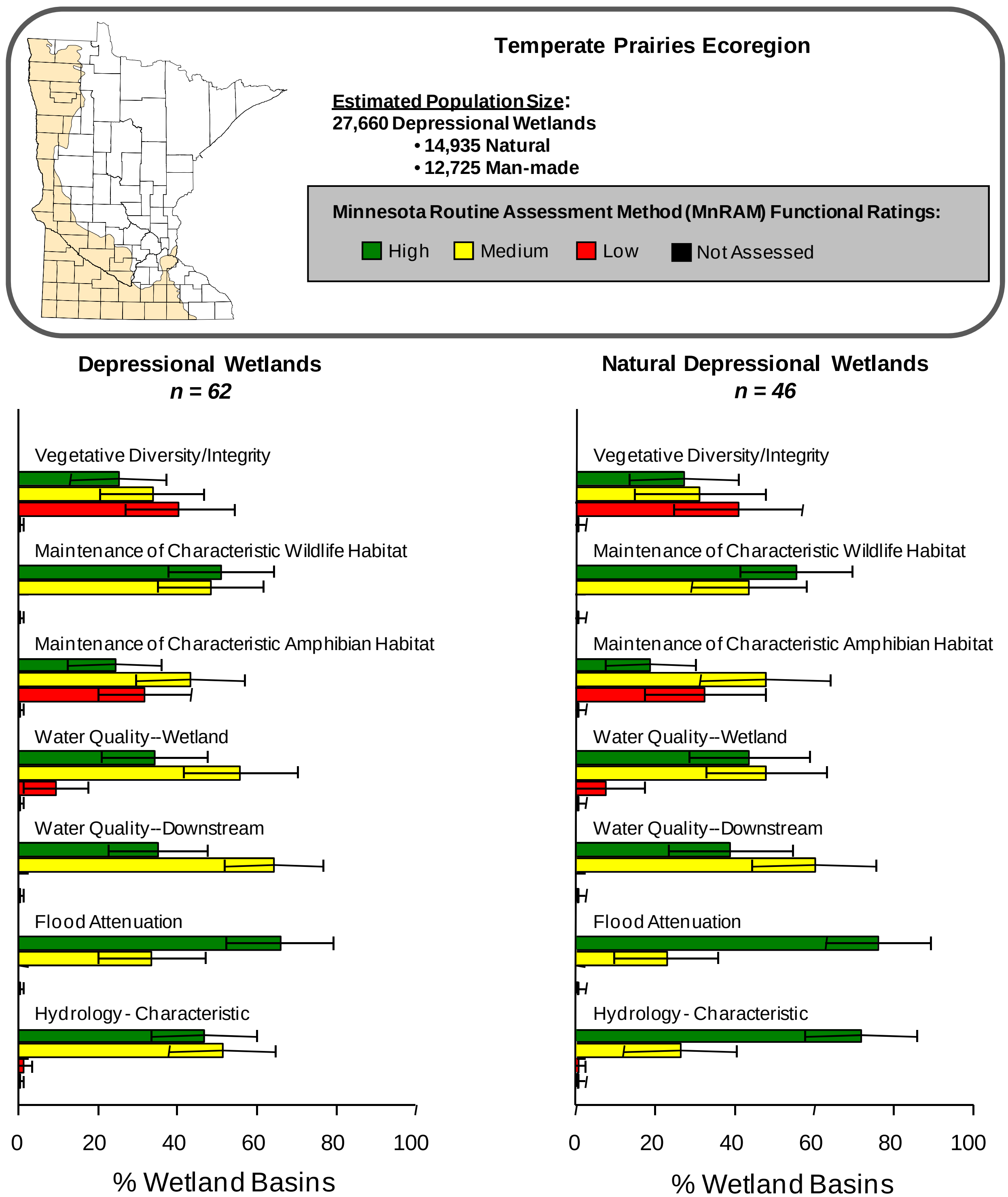


Figure 24. Functional ratings for Temperate Prairies depressional wetlands, reporting based on the number of depressional wetlands. Included for comparison are the rating estimates for the subpopulation of natural wetlands. Lines with brackets represent the width of the 95 percent confidence interval associated with each estimate.

Mixed Wood Shield

Extent of depressional wetlands

The 2009 sample from the Mixed Wood Shield ecoregion consisted of 59 sites. Ninety potential sites from the random draw were evaluated in order to obtain this sample (see Appendix D). Unlike the other two ecoregions, there were three potential wetland sites in the Mixed Wood Shield that were deemed physically inaccessible (remote location in the Boundary Waters Canoe Area) and not evaluated in the field.

An estimated 48,827 ± 8,098 (± 95 percent CL) depressional wetland basins occur within the Mixed Wood Shield ecoregion in Minnesota. These basins represent an estimated 165,044 ± 22,661 (± 95 percent CL) acres of wetland area within this ecoregion. Based on these estimates, the average size of a depressional wetland within this ecoregion is about 3.4 acres.

During the initial phase of site evaluations, a number of potential study sites could not be accessed due to their remote location or because of landowner denial and therefore could not be included in the survey (see Appendix D). If these sites were in fact part of the target population, as the aerial imagery suggested, the population estimates presented above would increase slightly. Assuming that all inaccessible sites belong to the target population, estimates would increase to 58,856 ± 6,999 (± 95 percent CL) basins and 189,354 ± 21,060 (± 95 percent CL) acres in this ecoregion. However, given the constraints of the analysis procedure for estimating function and condition (i.e., it cannot incorporate data from inaccessible sites), the estimates provided in the previous paragraph are used throughout the remainder of this chapter when referencing the extent of the population.

Approximately 70 percent or 33,900 of the depressional wetlands occurring within this ecoregion are less than 2.5 acres in size (Figure 25). The relatively few large wetlands greater than 12.4 acres in size account for about 47 percent of the depressional wetland acreage in the ecoregion. Compared to the other ecoregions, the proportion of depressional wetlands located on public lands was much higher in the Mixed Wood Shield (Figure 25). This was primarily due to large tracts of federally owned and managed lands in this ecoregion such as Superior National Forest (including the Boundary Waters Canoe Area), Chippewa National Forest, and US FWS National Wildlife Refuges. Other publicly owned wetlands were located within State Forests, State Parks, Wildlife Management Areas, or County/City administered lands. Wetlands owned by both public and private entities ('Mixed') tended to be large with ownership divided between government agencies and private citizens. Of the three ecoregions examined, the ratio of natural to man-made wetlands was highest in the Mixed Wood Shield ecoregion at approximately 3:1. Based on the population estimates reported in Figure 25 the average size of a natural and man-made wetland in this ecoregion is 4.2 and 0.9 acres, respectively. Man-made wetlands sampled in the Mixed Wood Shield included livestock watering ponds, stormwater retention ponds, ornamental ponds, and golf course water hazards.

Wetland condition

- Based on plant IBI assessments, approximately 54 percent of the depressional wetlands in the Mixed Wood Shield ecoregion are in good condition, 29 percent are in fair condition, and 17 percent are in poor condition. Estimates did not change substantially when man-made wetlands were excluded from the analysis (Figure 26).

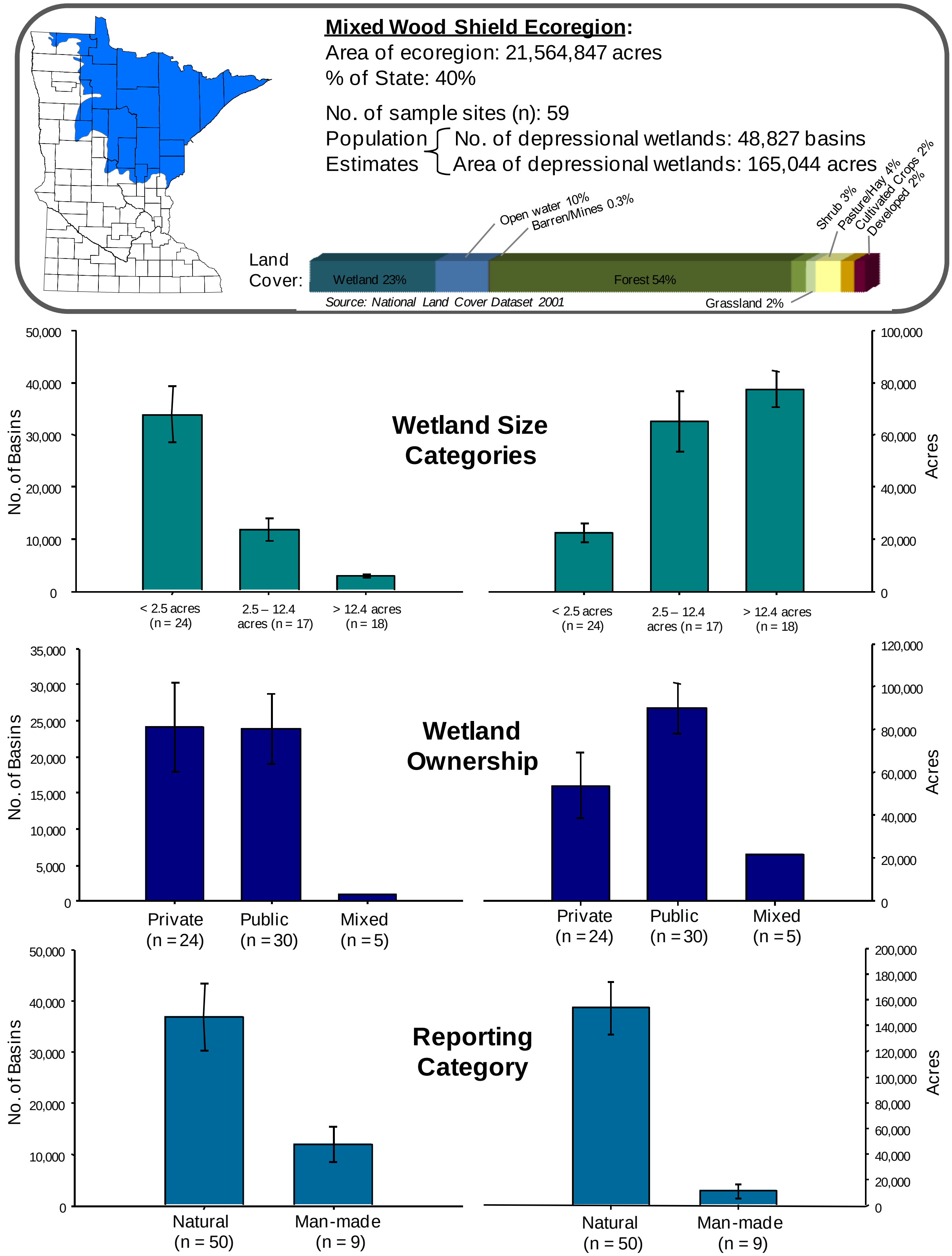


Figure 25. Estimates of the total number and total area of depressional wetlands in the Mixed Wood Shield and these estimates broken down into various subcategories. Bracketed lines represent the width of the 95 percent confidence interval associated with each estimate.

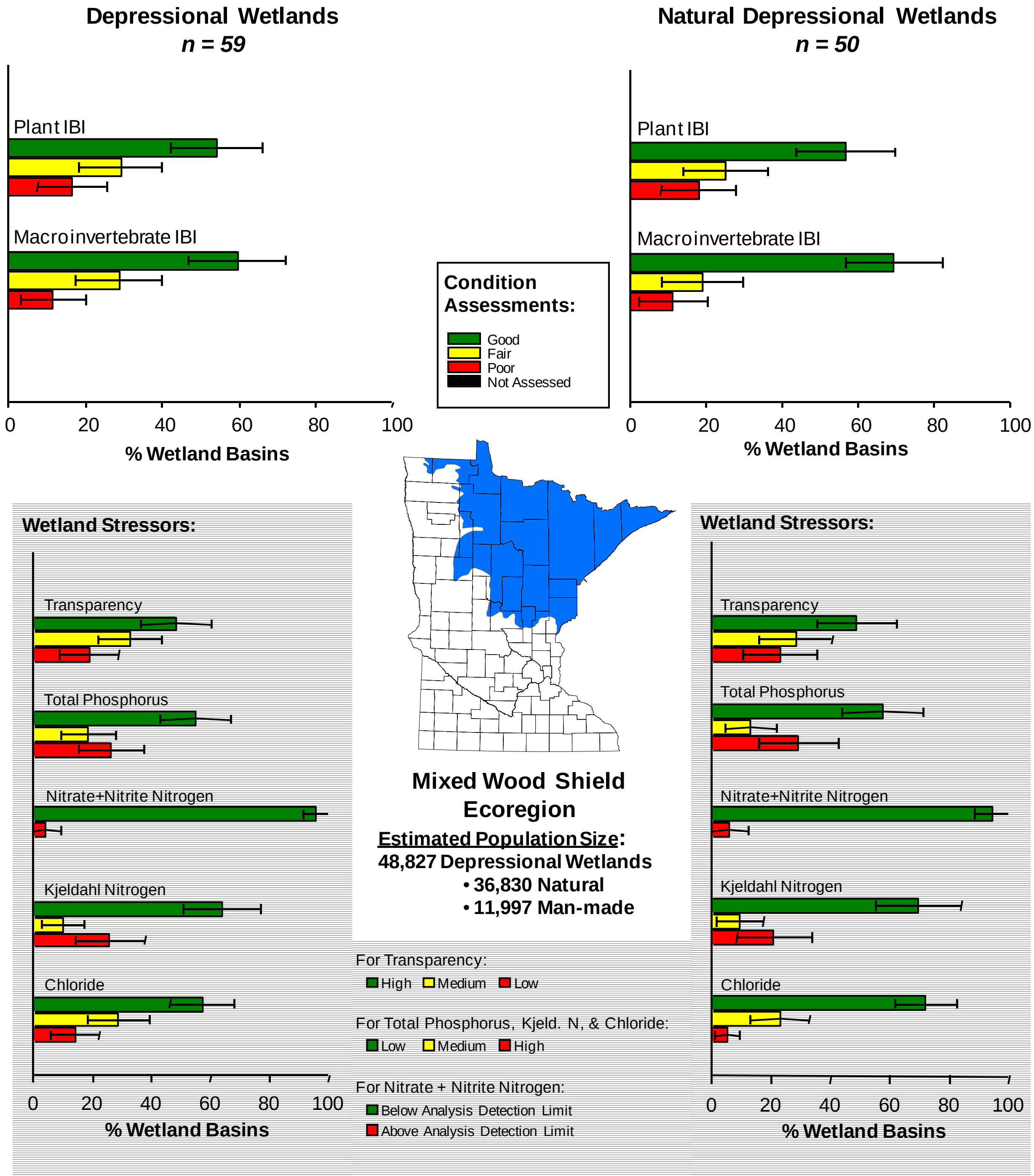


Figure 26. The condition of Mixed Wood Shield depressional wetlands and estimated stressor levels occurring in these wetlands, reporting based on the number of depressional wetland basins. Estimates are presented both for all depressional wetlands within the ecoregion and excluding man-made wetlands. Lines with brackets represent the width of the 95 percent confidence interval associated with each estimate.

- Macroinvertebrate IBI assessments indicated that an estimated 60 percent of the depressional wetlands in the Mixed Wood Shield ecoregion are in good condition, 29 percent are in fair condition, and 12 percent are in poor condition. When man-made wetlands were excluded from the analysis these estimates changed to 69 percent good, 19 percent fair, and 11 percent poor (Figure 26).

Not surprisingly, both biological indicators estimated that the population of depressional wetlands in the Mixed Wood Shield ecoregion is in the best condition (i.e., smallest deviation from reference conditions) compared to the other two ecoregions in the state. Large-scale urban development and agricultural operations are largely restricted to the periphery of this ecoregion, with anthropogenic disturbance predominantly represented by diffuse, less intensive impacts (e.g., logging, historic hydromodification) scattered across the ecoregion or by intensive impacts (e.g., mining operations) restricted to a few localized areas of the ecoregion. Inclusion of man-made wetlands in the analysis procedure had a negative impact on the macroinvertebrate-based condition estimates, but did not seem to affect the plant-based estimates of wetland condition (Figure 26); the same pattern repeated in both the Mixed Wood Plains and Temperate Prairies. There is no evidence to suggest that the proposed explanation for this pattern, put forth in previous chapters, should not apply to the Mixed Wood Shield ecoregion as well.

In contrast to the least disturbed reference conditions of the other two ecoregions, many of the reference wetlands in the Mixed Wood Shield represent minimally disturbed conditions (*sensu* Stoddard et al. 2006). Thus, condition categories (good, fair, poor) across all three ecoregions are not necessarily equivalent. For instance, in the two ecoregions where reference sites represent a least disturbed condition, sites considered to be in good condition may be comparable to 'fair' sites in the Mixed Wood Shield in terms of their relative position along a biological condition gradient (Davies and Jackson 2006). Future iterations of the wetland quality survey may better define the conditions represented by reference sites in each of the ecoregions if a biological condition gradient model is developed for depressional wetlands, a process currently being undertaken for Minnesota's rivers and streams.

Wetland stressors

- Relative to least disturbed reference conditions, approximately 48 percent of the depressional wetlands in the Mixed Wood Shield ecoregion have high transparency, 33 percent have medium transparency, and 19 percent have low transparency. When man-made wetlands were excluded from the analysis these estimates did not change substantially (Figure 26).
- Total phosphorus concentrations in the water column are low in approximately 55 percent of Mixed Wood Shield depressional wetlands, medium in 19 percent, and high in 26 percent compared to least disturbed reference sites. Estimates did not change substantially when man-made wetlands were excluded from the analysis (Figure 26).
- Nitrate and/or nitrite nitrogen concentrations are above the analysis detection limit (0.05 mg/L) in an estimated four percent of the depressional wetlands in this ecoregion. This estimate did not change substantially when man-made wetlands were excluded from the analysis (Figure 26).
- An estimated 64 percent of the depressional wetlands in the Mixed Wood Shield ecoregion have low concentrations of Kjeldahl nitrogen (organic N + ammonia), 10 percent have medium concentrations, and 26 percent have high concentrations compared to least disturbed reference sites. These estimates did not change substantially when man-made wetlands were excluded from the analysis (Figure 26).

- Water column chloride concentrations are low in approximately 57 percent of Mixed Wood Shield depressional wetlands, medium in 29 percent, and high in 14 percent. When man-made wetlands were excluded from the analysis these estimates changed to 72 percent good, 23 percent fair, and five percent poor (Figure 26).

Unlike the other two ecoregions, there are not many stressor-response relationships demonstrated between biological indicators and measured environmental variables in Mixed Wood Shield depressional wetlands (Figure 27). This is likely due to the relatively undisturbed condition of depressional wetlands in the ecoregion (Figure 26) and the method used to establish condition/stressor categories. Category criteria establishment in the Mixed Wood Shield is largely based on data from minimally disturbed reference sites. Therefore, category thresholds in this ecoregion represent comparatively lower levels of human disturbance than thresholds in the Mixed Wood Plains and Temperate Prairies ecoregions that are based on least disturbed reference conditions. For example, the 5th percentile values for Kjeldahl nitrogen, phosphorus, and chloride in Mixed Wood Shield reference sites are all considerably lower compared to the other ecoregions. According to the methodology of the survey, sites that exceed these values are considered to have 'high' stressor levels. However, these concentrations likely fall within the range of natural variability inherent within Mixed Wood Shield depressional wetlands and thus slight exceedances of these threshold values would not be expected to have significant detrimental impacts on resident plant and macroinvertebrate communities.

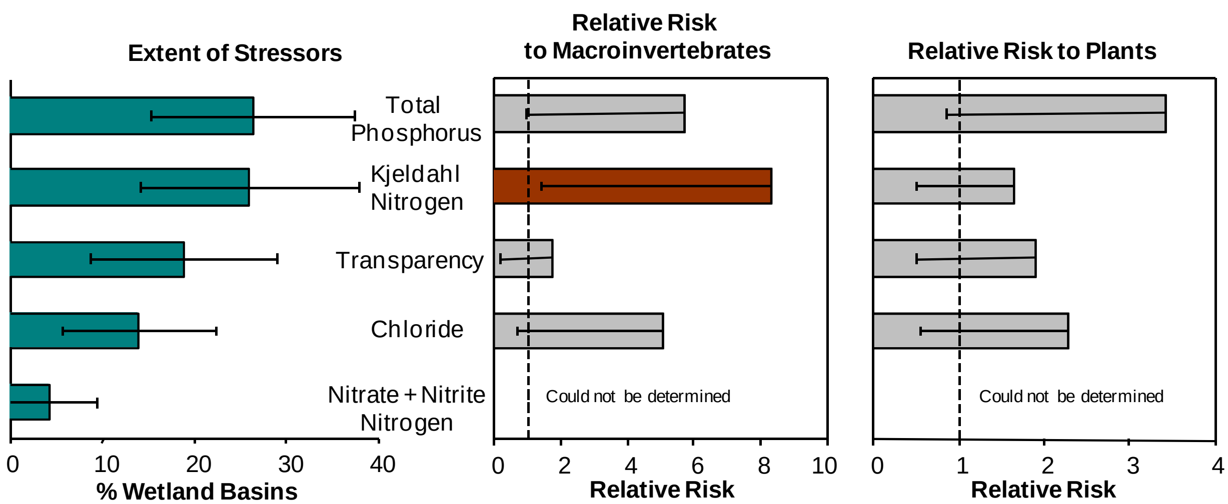


Figure 27. Extent of measured stressors in the Mixed Wood Shield ecoregion and relative risk estimates for plant and macroinvertebrate communities. Bracketed lines represent 95 percent confidence intervals. Lower confidence limits (relative risk charts) that do not extend below one represent a significant elevated risk (maroon bar).

Kjeldahl nitrogen (organic N + ammonia) was the only measured water quality parameter in the Mixed Wood Shield ecoregion that posed an elevated risk to biological communities (Figure 27). Moreover, Kjeldahl nitrogen represented a significant risk to macroinvertebrate communities in all three ecoregions and to plants in two of the ecoregions. These findings are consistent with a review of the literature, supplemented with additional empirical analyses, by Bedford et al. (1999) that found both freshwater marshes and vascular herbaceous wetland species to be predominantly nitrogen limited. Thus, increased nitrogen concentrations within these wetlands may lead to a shift in plant community composition, due to variable responses of individual species, that results in an overall decrease in species diversity. Shifts to a community dominated by a few invasive and/or exotic species, or to an algal-dominated submerged aquatic vegetation zone has obvious impacts on plant community integrity. Elevated nitrogen concentrations may also indirectly impact macroinvertebrates, via shifts in plant community composition, by reducing habitat heterogeneity and/or altering dissolved oxygen regimes (see discussion of nutrient impacts in Temperate Prairies: Wetland Stressor section).

Wetland functions

- The ability to support a diverse wetland plant assemblage is rated exceptional in an estimated 23 percent of the depressional wetlands in the Mixed Wood Shield, high in 48 percent, medium in 25 percent, and low in 5percent (Figure 28). When man-made waterbodies were excluded from the analysis these estimates did not change significantly.
- An estimated 75 percent of the depressional wetlands in the Mixed Wood Shield are rated high and 25 percent are rated medium for their ability to provide characteristic wildlife habitat (Figure 28). Ratings for this function improved to 92 percent high and eight percent medium when man-made sites were excluded from the analysis.
- The ability to provide characteristic amphibian habitat is rated high in 50 percent of Mixed Wood Shield depressional wetlands, medium in 43 percent, and low in seven percent. Ratings for this function improved to 67 percent high and 33 percent medium when man-made sites were excluded from the analysis (Figure 28).
- An estimated 77 percent of the depressional wetlands in the Mixed Wood Shield are rated high and 23 percent are rated medium for their own sustainability in relation to water quality impacts (Figure 28). Analysis of the data set without man-made sites yielded estimates of 94 percent high and 6percent medium for this function.
- The ability to protect the water quality of downstream waterbodies is rated high in 37 percent of Mixed Wood Shield depressional wetlands and medium in 63 percent (Figure 28). These estimates did not change substantially when man-made waterbodies were excluded from the analysis.
- The ability to provide flood storage has a high rating in 22 percent of the depressional wetlands in the Mixed Wood Shield, a medium rating in 76 percent, and a low rating in one percent. Excluding man-made wetlands from the analysis changed estimates to 10 percent high, 88 percent medium, and two percent low (Figure 28).
- Maintaining a characteristic hydrologic regime is rated high in 78 percent of Mixed Wood Shield depressional wetlands, medium in 15 percent, and low in seven percent (Figure 28). Ratings for this function changed to 96 percent high and 4percent medium when man-made sites were excluded from the analysis.

As observed in the other ecoregions, functional ratings were generally higher when man-made wetlands were excluded from the analysis. The exception was flood attenuation that saw a decrease in the ratings when man-made wetlands were excluded (Figures 28). Man-made wetlands typically occurred in the more developed (agricultural and urban) areas of this ecoregion and, with other factors being equal, the elevated importance of such wetlands for storing surface runoff may have contributed to the slightly higher ratings for this type of wetland. With the exception of flood attenuation and protecting downstream water quality, functional ratings in the Mixed Wood Shield were substantially higher compared to results at the state scale (Figures 16 and 28). It is not surprising that flood attenuation and downstream water quality were not rated higher in this ecoregion since these functions partially depend on the opportunity to provide such services. The Mixed Wood Shield is the least developed of Minnesota's ecoregions and thus, there is not as great of a need for any single wetland to provide these services when there are many wetlands in a watershed that can each contribute flood storage and downstream water quality protection. Conversely, wetlands occurring in a relatively intact landscape are able to sustain their natural characteristics and provide habitat for native vegetation, wildlife, and amphibians as reflected in the predominantly high ratings for these functions (Figure 28).

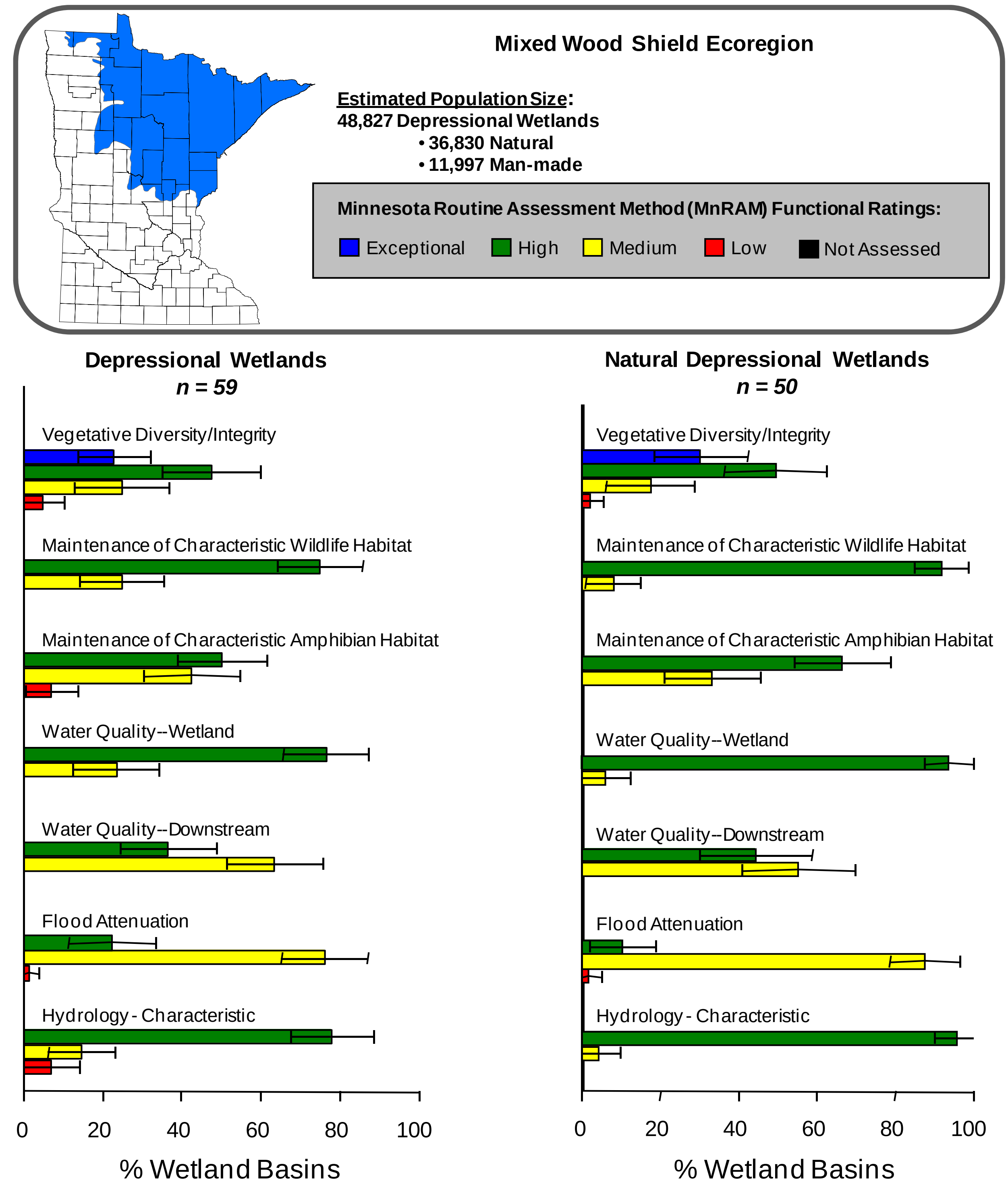


Figure 28. Functional ratings for Mixed Wood Shield depressional wetlands, reporting based on the number of depressional wetlands. Included for comparison are the rating estimates for the subpopulation of natural wetlands. Lines with brackets represent the width of the 95 percent confidence interval associated with each estimate.

Interannual Variability

Wetland community composition and structure is greatly affected by the interplay of natural climatic conditions (i.e., wet vs. dry years) and the relative contribution of ground water to the wetland (Euliss et al. 2004). This concept has obvious implications for a wetland assessment program that employs biological indicators to infer ecological condition with an emphasis on determining the relative impact of human activities. To a large extent the effect of ground water on community composition has been addressed by limiting study sites to semi-permanently or permanently flooded depressional wetlands, which function primarily as ground water flow-through or discharge wetlands. Therefore, the main source of interannual variability that must be ascertained in this study is climate.

To help shed light on the issue of climatic variability and how it may impact survey results spanning a three year time period, indicator data from the nine annual sites were analyzed to look for year-to-year differences. In other words, were climatic conditions in any particular year of the survey responsible for significantly altering depressional wetland condition in any of the three ecoregions? To address this question, a repeated-measure analysis of variance was used to test whether plant or macroinvertebrate IBI scores at the annual sites varied significantly across the three years of the survey. This analysis was done both at the state scale, using data from all the annual sites, and within each individual ecoregion. Neither plant nor macroinvertebrate IBI scores exhibited statistically significant differences among the three years, analyzing the data on a statewide scale (Figure 29A) as well as within each ecoregion (Figure 29B). Based on this limited comparison, in terms of both the number of annual sites and their spatial distribution across the state, it appears that climatic conditions did not significantly affect results in any of the three years/ecoregions.

Annual sites represented a mix of landscape conditions, ranging from sites located within the heart of the Twin Cities Metropolitan Area to sites located off the beaten path in forested landscapes. The three annual sites from the Temperate Prairies ecoregion were all located within an agricultural landscape, but were well buffered from any immediate human impacts. Two of the annual sites representing the Mixed Wood Plains ecoregion were located in a highly developed landscape, while the third was located in a matrix of second growth forest and tree plantations. Sites in the Mixed Wood Shield represented the most diverse group with one site located in a relatively undisturbed forest landscape, one site located in a mixed rural/forested landscape, and the third located in a mixed agricultural/forested landscape. The hydrology of at least two of the nine annual sites was influenced by beaver activity during the three year study period. These two sites were not ideal for gauging potential responses to climatic variability, suggesting that the site selection process for such investigations include additional criteria to evaluate potential sites.

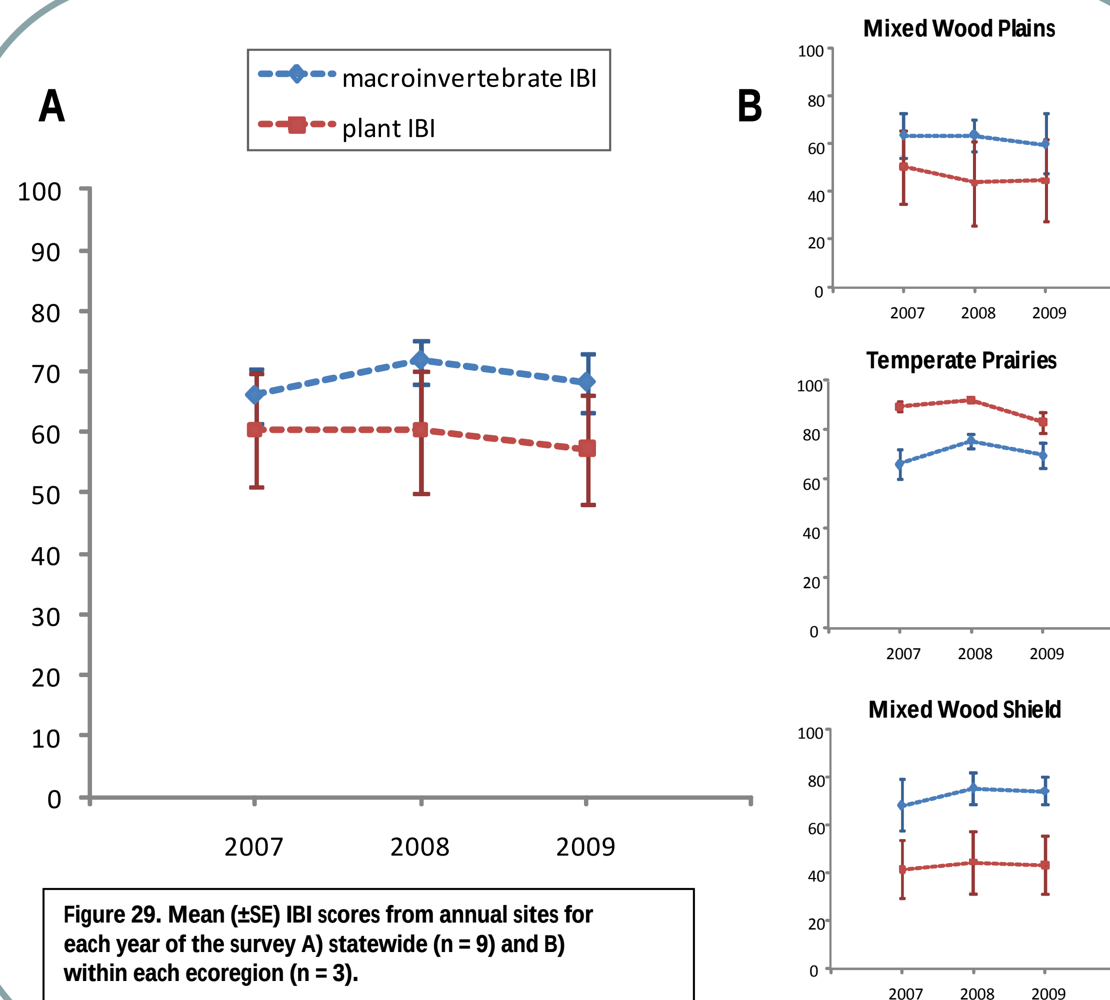


Figure 29. Mean (±SE) IBI scores from annual sites for each year of the survey A) statewide (n = 9) and B) within each ecoregion (n = 3).

Next Steps

The data and results provided by this survey comprise the baseline against which depressional wetland quality can be periodically compared in subsequent years. This will allow the state of Minnesota to begin to understand whether or not policies, regulations, and incentives are achieving stated goals of no-net-loss, and eventually net gains, in wetland quality and biological diversity. For a complete understanding of this issue, the wetland quality survey will need to expand to a broader range of wetland types. The next stage of the survey, data collection planned for 2011 and 2012, will accomplish this objective but will focus on wetland condition. Assessing the condition of a broad range of wetland classes requires the use of a plant-based indicator since hydrophytic vegetation is present in virtually all wetlands. The recently developed Floristic Quality Assessment or FQA (Bourdaghs *in prep*) will be used to estimate the condition of all wetland types found in Minnesota. Therefore, a benchmark for gauging condition gains or losses for a much broader range of wetlands types will be acquired in the first iteration of the Minnesota Wetland Condition Assessment (MWCA).

The current survey which focuses on the quality (function and condition) of depressional wetlands will also continue with the next round of data collection planned for 2012. To distinguish itself from the MWCA, the Depressional Wetland Quality Assessment (DWQA) will henceforth represent an intensification of the broader MWCA since these types of wetlands will be included in both surveys but the amount of information collected at each site in the DWQA will be much greater. For instance, a depressional wetland that meets the criteria for being included in the DWQA (i.e., predominantly emergent vegetation, semi- to permanently inundated, etc.) will be evaluated using plant and macroinvertebrate condition indicators, functional assessments, and water quality measurements. While the same wetland would only be assessed using a plant condition indicator (i.e., FQA) if it was included in the MWCA.

It is the intention of the MPCA to make these two probabilistic wetland surveys as complimentary as possible in order to comprehensively assess the quality of this vast and diverse natural resource. As such, since depressional wetlands of the type included in the present survey represent only a small fraction of the total wetland area occurring in the Mixed Wood Shield, the MWCA will assume sole responsibility for evaluating the condition of depressional wetlands in this ecoregion. Therefore, the next iteration of the DWQA will only represent an assessment of depressional wetlands occurring in the Mixed Wood Plains and Temperate Prairies ecoregions where they represent a much larger proportion of total wetland area. At that time, initial results will be available for ascertaining wetland quality changes in these two ecoregions. Considering these two wetland quality assessments in conjunction with the wetland quantity monitoring program (i.e., WSTMP), Minnesota will soon be well-positioned to comprehensively evaluate the quantity, quality, and biological diversity of its wetlands and be able to track these components over time in a unbiased manner.

Acknowledgments

Considerable assistance with the design of this survey and analysis of the data was provided by Anthony Olsen and Thomas Kincaid. Funding for the development of the plant and macroinvertebrate indicators used in this assessment was provided by US EPA Wetland Program Development Grants. The depressional wetland quality assessment was partially supported through a Wetland Demonstration Pilot Grant (Federal Assistance #WL96576801). We appreciate the support and technical assistance provided by US EPA Project Officer Dertera Collins and project technical contact Sue Elston. Comments and revisions provided by Steve Kloiber greatly improved the quality of this report. Field assistance was provided by Joel Chirhart (crew leader), Harold Wiegner (crew leader), Will Bouchard (crew leader), Caitlin Ward, Patrick Schuett, Kenneth Pasanen, Lee Zettler, Holly Clouse, Joseph Grady, and Elizabeth Spande. Thanks also to the many land owners and land managers whose cooperation and willingness to allow us access to their wetlands made this survey a success.

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Appendix A

Metrics of the plant and macroinvertebrate IBIs used to assess the condition of depressional wetlands and ponds throughout the state. Tables indicate the ecoregions where each metric applies and can be used to construct the six individual IBIs.

Plant IBI Metrics	Response to Disturbance	Ecoregion[1]		
		MWP	TP	MWS
Number of native aquatic plant species.	Decrease	X	X	
Number of native wetland graminoid species.	Decrease	X	X	
Number of native wetland perennial species.	Decrease	X	X	X
Number of vascular genera.	Decrease	X	X	
Number of nonvascular taxa	Decrease	X		
Number of sensitive species	Decrease	X		
Number of disturbance tolerant taxa divided by the total taxa richness	Increase	X		
Number of distinct plant guilds.	Decrease		X	
Number of taxa sensitive to disturbance, defined by Coefficient of Conservatism values ≥ 7	Decrease		X	X
Number of disturbance tolerant taxa divided by the total taxa richness. Tolerant taxa defined by Coefficient of Conservatism values ≤ 3 or is introduced.	Increase		X	
Number of native Cyperaceae (Sedges, bulrushes, etc) species divided by the total emergent taxa richness	Decrease			X
Cover of *Carex* spp.	Decrease	X		
Cover of invasive *Typha* spp. and small floating aquatics (*Lemna*, *Spirodela*, *Wolfia*, *Riccia*, *Ricciocarpos* spp.)	Increase		X	
Cover of small floating aquatics (*Lemna*, *Spirodela*, *Wolfia*, *Riccia*, *Ricciocarpos* spp.) divided by total aquatic cover	Increase			X
Cover of the 3 most dominant species divided by total sample cover	Increase	X		
Cover of the 2 most dominant emergent species divided by total emergent cover	Increase			X
Cover of taxa with persistent litter divided by total sample cover	Increase	X		
Cover of disturbance tolerant taxa. Tolerant taxa defined by Coefficient of Conservatism values ≤ 3 or is introduced.	Increase			X
Shannon Diversity index based only on native species	Decrease			X
	Total number of metrics in IBI:	10	8	7

Macroinvertebrate IBI Metrics	Response to Disturbance	Ecoregion[1]		
		MWP	TP	MWS
Number of Ephemeroptera, Trichoptera, and Odonata genera	Decrease	X	X	X
Number of intolerant genera[2]	Decrease	X	X	
Number of macroinvertebrate taxa (most groups identified to genus, snails and leeches identified to species)	Decrease	X	X	
Number of Chironomidae genera	Decrease	X		X
Number of Diptera genera	Decrease		X	
Number of collector-gatherer genera	Decrease	X		
Number of collector (collector-gatherer & collector-filterer) genera	Decrease			X
Number of scraper genera	Decrease	X		
Abundance of Corixidae divided by total abundance of Hemiptera and Coleoptera	Increase	X	X	
Abundance of tolerant taxa divided by total abundance of sample[2]	Increase	X	X	
Abundance of Ephemeroptera, Trichoptera, and Odonata divided by total abundance of sample	Decrease	X		
Abundance of the most dominant genus divided by total abundance of sample	Increase			X
Abundance of the 3 most dominant genera divided by total abundance of sample	Increase	X		
Abundance of Chironomidae divided by total abundance of sample	Increase		X	
Abundance of Pleidae divided by abundance of Hemiptera	Decrease		X	
Abundance of non-insect individuals divided by total abundance of sample	Increase			X
Total number of metrics in IBI:		10	8	5

[1] Ecoregion abbreviations: MWP - Mixed Wood Plains; TP - Temperate Prairies; MWS - Mixed Wood Shield.

[2] Tolerant/intolerant macroinvertebrate taxa designations determined empirically (see Genet and Bourdaghs 2006).

Appendix B

Water quality parameters analyzed by Minnesota Department of Health and years each method was utilized in the first three years of the survey.

Analyte	Fraction	Report Limits	Units	Method Reference	MDH Code	Year of Survey
Chloride	Total	1.0	mg/L	EPA 325.2	23	2007, 2008
Chloride	Total	1.00	mg/L	EPA 300.0	297	2009
Nitrate + Nitrite Nitrogen	Total	0.05	mg/L as N	EPA 353.2	69	2007-2009
Kjeldahl Nitrogen	Total	0.10	mg/L as N	EPA 351.2	68	2007-2009
Organic Carbon	Total	1.0	mg/L	SM 5310 C	98	2007-2009
Phosphorus	Total	0.003	mg/L as P	EPA 365.1	59	2007-2009
Sulfate	Total	1.00	mg/L	EPA 300.0	293	2007-2009

Appendix C

Criteria used to determine depressional wetland condition and stressor levels relative to regional reference sites (MWS = Mixed Wood Shield; MWP = Mixed Wood Plains; TP = Temperate Prairies).

Parameter/ Ecoregion	Wetland Condition Categories		
	Good	**Fair**	**Poor**
Plant IBI score (0-100):			
MWS	**> 55**	**< 55, > 43**	**< 43**
MWP	**> 56**	**< 56, > 42**	**< 42**
TP	**> 78**	**< 78, > 61**	**< 61**
Macroinvertebrate IBI score (0-100):			
MWS	**> 67**	**< 67, > 49**	**< 49**
MWP	**> 64**	**< 64, > 44**	**< 44**
TP	**> 66**	**< 66, > 56**	**< 56**

Parameter/ Ecoregion	Transparency Categories		
	High	**Medium**	**Low**
Transparency Tube Reading (cm):			
MWS	**> 100**	**< 100, > 57**	**< 57**
MWP	**> 61**	**< 61, > 35**	**< 35**
TP	**> 60**	**< 60, > 41**	**< 41**

Parameter/ Ecoregion	Stressor Level Categories		
	Low	**Medium**	**High**
<u>Nitrate + Nitrite Nitrogen (mg/L):</u>			
MWS,MWP,TP	**no detect**	**n/a**	**detect**
<u>Kjeldahl Nitrogen (mg/L):</u>			
MWS	**< 1.27**	**> 1.27, < 1.47**	**> 1.47**
MWP	**< 1.49**	**> 1.49, < 3.10**	**> 3.10**
TP	**< 1.60**	**> 1.60, < 2.97**	**> 2.97**
<u>Total Phosphorus (mg/L):</u>			
MWS	**< 0.054**	**> 0.054, < 0.081**	**> 0.081**
MWP	**< 0.148**	**> 0.148, < 0.384**	**> 0.384**
TP	**< 0.180**	**> 0.180, < 0.202**	**> 0.202**
<u>Chloride (mg/L):</u>			
MWS	**< 1**	**> 1, < 3.3**	**> 3.3**
MWP	**< 1.4**	**> 1.4, < 7.9**	**> 7.9**
TP	**< 7.6**	**> 7.6, < 8.6**	**> 8.6**

Appendix D

Site evaluation summary and assessing landowner denial rates.

Mixed Wood Plains Ecoregion

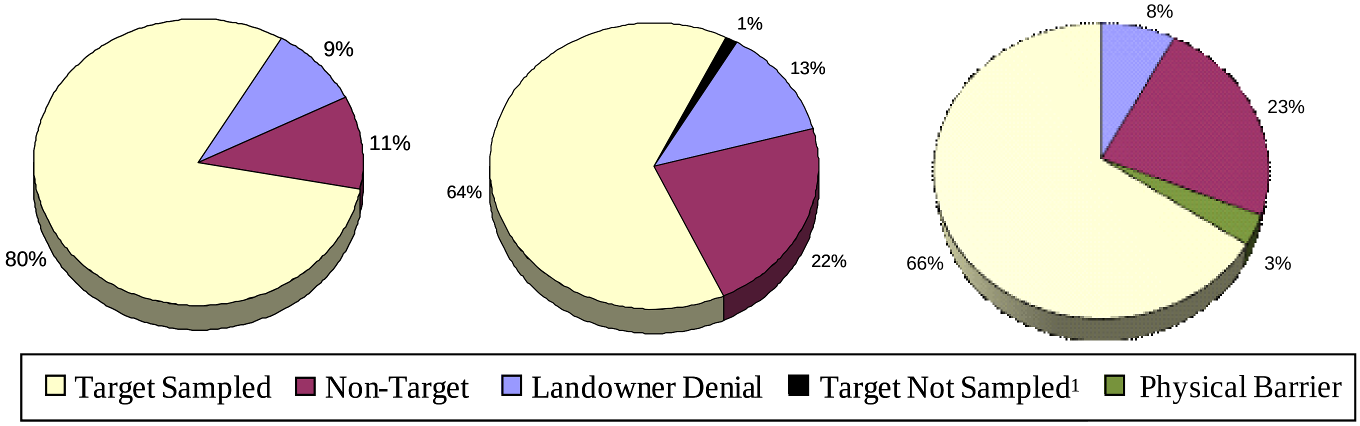
No. of sites evaluated = 76

Temperate Prairies Ecoregion

No. of sites evaluated = 95

Mixed Wood Shield Ecoregion

No. of sites evaluated = 90



Landowner Denial Rates:
No. of denials = 7

Overall = (7/76) x 100 = **9.2 %**

Among Public[2] Landowners = (0/16) x 100 = **0 %**

Among Private Landowners = (7/60) x 100 = **11.7 %**

Landowner Denial Rates:
No. of denials = 12

Overall = (12/95) x 100 =12.6%

Among Public[2] Landowners = (0/20) x 100 = **0 %**

Among Private Landowners = (12/75) x 100 = **16.0 %**

Landowner Denial Rates:
No. of denials = 7

Overall = (7/90) x 100 = **7.8%**

Among Public[2] Landowners = (0/53) x 100 = **0 %**

Among Private Landowners = (7/37) x 100 = **18.9%**

[1] = 'Target Not Sampled' were wetlands that belonged to the target population but could not be sampled during the index period of the survey due to various reasons such as water level draw downs in support of managing wildlife populations.

[2] = Denominator includes wetlands that were owned by both public and private interests; accessed sites via public property.

Assessing the potential for bias within the sample: The process of extrapolating results from the sample to the entire target population relies on the assumption that missing responses (e.g., non-response or denials) are missing completely at random. A violation of this assumption may occur if the survey experiences a large number of landowner denials on private property. Post-stratification can be used to investigate whether response rates differ between categories that represent management practices that presumably have contrasting affects on wetland quality. A common approach is to categorize evaluated sites based on whether they occur on publicly or privately managed lands (Stevens and Jensen 2007). Below are the results for each ecoregion of Pearson's χ^2 test that was used to determine whether there was an association between response rates (i.e., site accessibility) and ownership. If response rates were significantly different ($\alpha = 0.05$), further adjustment of the design weights was required to insure appropriate representation of the strata in the estimation procedure (Lesser 2001, Stevens and Jensen 2007).

Analyses below exclude non-target sites. Contingency tables include both observed and expected (in parentheses) frequencies.

Mixed Wood Plains Ecoregion

	Response		
Ownership	Denial	Access	**Total**
Public	0	13	13
	(1.3)	*(11.7)*	
Private	7	48	55
	(5.7)	*(49.3)*	
Total	*7*	*61*	68

$\chi^2 = \sum (\text{obs.} - \text{exp.})^2/\text{exp}$
$= 1.844$
df = (r -1)(c-1) = (2-1)(2-1) = 1

$\chi^2_{0.05,1} = 3.841$ $P > 0.05$

Response is independent of ownership. Therefore, no adjustments of design weights were needed to account for differential response rates by ownership class.

Temperate Prairies Ecoregion

	Response		
Ownership	Denial[1]	Access	**Total**
Public	1	13	14
	(2.5)	*(11.5)*	
Private	12	48	50
	(10.5)	*(49.5)*	
Total	13	61	74

$\chi^2 = \sum (\text{obs.} - \text{exp.})^2/\text{exp}$
$= 1.296$
df = (r -1)(c-1) = (2-1)(2-1) = 1

$\chi^2_{0.05,1} = 3.841$ $P > 0.05$

Response is independent of ownership. Therefore, no adjustments of design weights were needed to account for differential response rates by ownership class.

[1] Denial on public property actually represents the target not sampled site (i.e., a missing response)

Mixed Wood Shield Ecoregion

	Response		
Ownership	Denial[1]	Access	**Total**
Public	3	35	38
	(5.5)	*(32.5)*	
Private	7	24	31
	(4.5)	*(26.5)*	
Total	10	59	69

$\chi^2 = \sum (\text{obs.} - \text{exp.})^2/\text{exp}$
$= 2.971$
df = (r -1)(c-1) = (2-1)(2-1) = 1

$\chi^2_{0.05,1} = 3.841$ $P > 0.05$

Response is independent of ownership. Therefore, no adjustments of design weights were needed to account for differential response rates by ownership class.

[1] Denials on public property actually represent sites not visited due to physical inaccessibility (i.e., missing responses)

Literature Cited

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