# Indexes of Biological Integrity (IBI) for Large Depressional Wetlands in Minnesota

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An Invertebrate Index of Biological Integrity (IBI) for Large Depressional Wetlands

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ABSTRACT

This report presents the invertebrate Index of Biological Integrity (IBI) for large depressional wetlands based on work from the 1999 field season in the North Central Hardwood Forest Ecoregion in Minnesota. The study design was based on sampling of 44 wetlands selected to meet *a priori* criteria as either high quality, least impaired reference sites (14 sites), or wetlands receiving various degrees of human disturbance from agriculture (14 sites) or urban influences (16 sites). The invertebrates were sampled within the shallow emergent vegetation zone during the seasonal index period of June. Standardized replicate samples were taken with dipnets, and sets of five pairs of activity trap samplers were used to collect a wide range of invertebrates. Water and sediments were analyzed for several analytes and the data were used in linear regressions against the biological data. In addition, biological data was plotted and regressed against a broader measure of human disturbance to the wetlands that included estimates of disturbances to the buffer and near landscape area around the wetland, and factors that disturb the wetland substrate, vegetation or water and sediment quality. The Human Disturbance Score (HDS) is described in this report. Invertebrates are richly represented in depressional wetlands: there were 203 taxa observed with 187 genera. The invertebrate IBI is composed of ten metrics, each is scored and added into the total IBI score. The metrics include measures of taxa richness, invertebrates that are intolerant of disturbance, and longer-lived invertebrates. Three metrics are based on proportions of certain more tolerant invertebrates that tend to increase under conditions of disturbance. The regressions of the data for each metric against the chemical factors and the Human Disturbance Score are given, and plots of metric data with several disturbance factors are shown. The metrics based on taxa richness tend to show the great significance in relation to human disturbance factors, and the proportion metrics tend to be less significantly related. The overall IBI scores for the 44 wetlands show the most significant relationship with the HDS scores: with $p < .0000005$ and r of .715. Likewise, the IBI shows the greatest significance with other factors, particularly turbidity and concentrations of phosphorus and chloride in the water. This report gives details of the chemical and disturbance measurements. Overall, the mean of HDS scores for the reference wetlands (18.25) was considerably lower than that for the impaired wetlands (65.7 and 77.7 for agricultural and urban sites, respectively). Overall, the urban-influenced wetlands had the highest levels of chloride in the water, and the highest concentrations of copper, lead and zinc in the sediments. Both categories of impaired wetlands had greater concentrations of total nitrogen, phosphorus and chlorophyll a than did the reference sites.

## INTRODUCTION

Wetlands are a resource for sustaining biological diversity that have historically diminished in quantity and quality. Yet little is known about the degree of biological changes in wetlands in response to human disturbances. Dahl (1990) estimates that between 1780 and the 1980s, 53% of the presettlement wetlands in the United States have been lost. Between 1986 and 1997 the wetlands were still being lost, but at a lower rate than previously recorded (US Fish and Wildlife Status and Trends). Work continues using aerial photography and GIS techniques to document changes in the quantity and types of wetlands (USDA NRCS 1997; US EPA Status and Trends). More recently, local inventories are being done on wetland extent and acreage along with assessments of particular wetland functions using functional assessment methods (Bartoldus 1999; Hrby et al 1998; MN BWSR; Smith et al 1995).

Although functional assessment methods include a function for support of wildlife habitat, they usually do not measure directly the biological communities in wetlands, and cannot substitute for a biological assessment method. Some functional methods assess vegetation, but none routinely assess the invertebrates. In a review of compensatory mitigation projects, almost none of the projects had restoration designs with criteria for evaluating the animals, including invertebrates, in the new wetland (NRC 2001). In one design in the Chicago area, the presence of species that were restricted to the least disturbed wetlands was considered a good indicator of achieving the natural condition in a restoration. More often, the biota are not measured to set goals for restorations or to estimate human impacts to wetlands. The US Army Corps Nationwide General Permit (July 2001) also points out that "there is no documentation of the quality of the affected wetland" during the mitigation process.

The result is we have little information about the ecological condition, or the integrity of biological communities in wetlands, either in relation to human-caused disturbances, or in connection with the mitigation replacement process. We assume that if the hydrology and other functions are there, then the biology will come, and it will be healthy. Without this knowledge, a progressive deterioration of wetland ecosystem health may occur, even if a no net loss of wetland acreage is achieved. In the future, biological assessment of wetlands condition may be necessary to document trends in wetlands health, and to determine which improvements in the landscape contribute most to a restoration of biologically functioning wetlands.

To date, biological assessments of wetlands are rare on any large scale, although considerable work has been done in Ohio (Mack 2001) and Montana (Apfelbeck 1999), and several biological assessment methods have been developed by the EPA sponsored Biological Assessment Working Group for Wetlands (US EPA BAWWG web site). Biological assessments provide the information necessary for determining the degree to which biological richness and integrity are being degraded or restored in wetlands, and for determining if the water quality of wetlands meets goals of aquatic life use protection (see Yoder and Rankin 1998; Davies et al 1999). Protection goals in statutes may elevate the maintenance of biological diversity of existing or restored wetlands, in reality, it is rarely measured. To meet such a goal, a biological evaluation is needed.

This paper presents one approach to monitoring the condition of wetlands using the aquatic invertebrates as an indicator of the ecological health. A separate paper will present the use of wetland vegetation to assess wetland condition (Gernes 2002). Aquatic invertebrates respond to a wide array of damage to wetlands that originates from chemical and sediment pollution, from alterations of the vegetation, or from physical disturbances in the landscape. As in streams, the invertebrates of wetlands are sensitive to toxicants and other kinds of pollution (Barbour et al 1999; Beck 1977; Cairns and Niederlehner 1995; deFur et al 1999; Lewis et al 1999; Servos 1999; Warwick 1980). Diverse ecological niches within wetlands, such as diverse vegetation and differing hydroperiods, provide invertebrates with a variety of subhabitats (Wissinger 1999). Wetland vegetation types can support different communities of invertebrates (Burton et al 1999; Gathman et al 1999).

Various attributes of invertebrates are used to develop appropriate measures of the biological health of wetlands. These include attributes based on losses of species that are directly sensitive to pollutants, presence of species that are long-lived and more impacted by longer term disturbances, the presence of predators reflecting the presence of prey species, the increase in individuals of species that are tolerant of pollution, or increases in numbers of prey taxa when key predators have been lost.

The assessment of wetlands health using invertebrates is based on a biological index score that is quantitatively derived from direct, standardized sampling of the wetland. This is in contrast to some of the rapid assessment methods that lack procedures for direct sampling and quantitation of impacts to wetlands. Several measures of the invertebrate community, called metrics, compose the Index of Biological Integrity (IBI) score. Each metric should show a significant response to some of the factors of disturbance. The composite scores summed in the IBI score should also show a strong response to the degree of disturbance to the wetland (Helgen 2002). It is the IBI score, based on sufficient data sets, that can be used to set criteria for meeting aquatic life use goals in water quality rules (Yoder and Rankin 1998; Davies et al 1999). To establish scoring criteria for the individual metrics that compose the IBI, the metric data is plotted and related statistically to several measured factors of disturbance to wetlands. The IBI reported here uses ten different measures of the invertebrate community that show statistically significant relationships to different kinds of disturbances.

This paper explains the sampling methods and study design used to develop the invertebrate IBI for large depressional wetlands. It gives details and rationale for the ten metrics and their scores, and it shows the relationships of metric data and the IBI total scores to factors of disturbance to the wetlands. Also, a new method for scoring the gradient of human disturbance using landscape, hydrological and chemical factors is outlined in the paper. In a separate report, the vegetation IBI is described for the same large depressional wetlands in Minnesota (Gernes 2002). The vegetation IBI has been developed using a similar study design and approach to that used for the invertebrate IBI. The work has been funded by US EPA Grant No. CD985879-01-1 from U.S. Environmental Protection Agency Region V.

## METHODS

### Study design and site selection

To develop the IBI in any kind of wetland or waterbody type, it is necessary to analyze biological data from a full range of sites from the least disturbed, hereafter referred to as reference sites, to the most degraded or impaired sites. These include several wetlands located in predominantly agricultural or urban landscapes. Wetlands were selected in a targeted manner to assure there would be a full range of impairment from most disturbed to the highest quality, least impaired sites available in the region. Having a full range of wetland disturbance was necessary to assure there would be a range of biological data for each metric for deriving the metric scoring criteria.

In this project, 44 large depressional wetlands were sampled for invertebrates, vegetation, water and sediment chemistry. An additional set of replicate samples were taken using the invertebrate sampling methods on six of the wetlands, two reference, two agricultural and two urban affected sites. Replicate sampling was done in a different location starting approximately 30 m or more along the shore from one edge of the original sampling location. All the invertebrate sampling was done in June, the established seasonal index period for depressional wetlands in Minnesota.

*A priori site selection process*

Natural resource managers in MN were given a description of the kinds of wetlands needed for the project. In brief, we sought large depressions that were of the highest quality and lacking several kinds of human disturbances, plus other sites that were influenced by a range of agricultural activities from pasture to direct inflow from an agricultural ditch. Urban wetlands were sought with a wide range of storm water input and other urban influences. Additionally, an effort was made to find high quality wetlands within or close to the urban area of Minneapolis St. Paul. From the pool of candidate sites, 44 wetlands were selected so that there was a similar range of sizes among the groups of reference, agricultural and urban wetlands. A reconnaissance of all the sites was carried out ahead of the field season as part of the final site selection process. The site names, locations, and sizes are given in Appendix 1, and their locations are shown in Figure 1.

*Physical analysis of the study wetlands*

During the season of field analysis in 1999, water and sediment chemistry samples were taken from the study sites in locations where the biological samples were collected. Surface water grab samples were collected in June from three to four representative locations in the emergent vegetation zone and pooled for the analysis of total phosphorus, total Kjedahl nitrogen, chloride, chlorophyll a, phaeophytin a, turbidity, Mg $CaCO_3$, conductivity, pH and field temperatures. The water samples were analyzed by the MN Department of Health Analytical Laboratory using standard protocols (Gernes and Helgen 1999; MPCA 1999). During August, three sediment cores were taken and the top 5 cm of sediment were extruded and pooled for analysis of nitrogen, Olsen phosphorus, chloride, % moisture, pH, total organic carbon, CCE % $CO_3$, heavy metals (Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Rb, S, Si, Sr, Ti, V, Zn) by the University of Minnesota Soils Analytical Laboratory. Samples were air dried at the laboratory. Metals were analyzed by ICP after $HNO_3$ digestion.

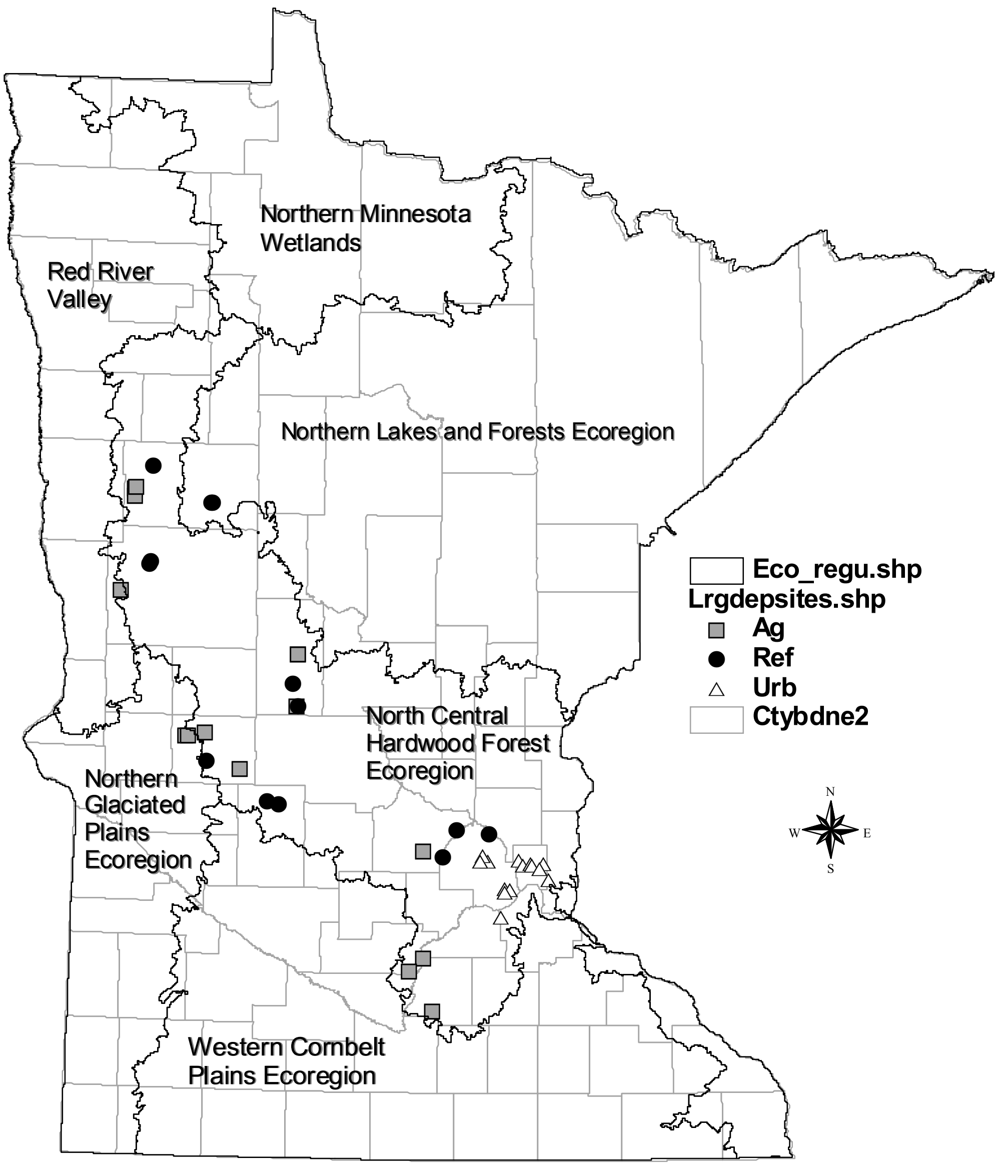



Figure 1. Map showing the locations of the 44 large depressional wetlands in the North Central Hardwood Forest Ecoregion in Minnesota. Ag, agriculture-influenced; Ref, reference wetlands selected to have the least amount of human disturbance; Urb, urban-influenced wetlands. Outlines of counties are shown, and the other ecoregions in the state.

GPS locations of the wetlands were taken using a Trimble Navigation (Sunnyvale, CA) Pathfinder Basic Plus GPS unit. All GPS files were post-processed at MPCA using Trimble Pathfinder software and a Trimble Community Base Station maintained by the Minnesota Department of Transportation.

In the summer of 1999, low altitude aerial photographs were taken of each wetland by MN DNR Forestry staff in Grand Rapids, MN. The scale of the photographs varied with the altitude that was needed to include the wetland and its immediate surrounding landscape in the image. Full color prints were made and the images were digitized for use in the GIS analysis of the landscape and the wetlands.

**Human disturbance gradient score (HDS)**

In previous development of wetland IBIs in MN (Gernes and Helgen 1999), we have related the biological data to measures of water and sediment chemistry to show responses to stressors in wetlands. Using this approach, significant relationships have been shown between the IBI scores and the log of concentrations of phosphorus, chloride and some sediment metals. We felt that an indicator of the broader range of human disturbances to the wetlands was needed to try to capture the full range of sources of stress to wetland health. We have developed a method for assessing the degree of disturbance to wetlands from landscape, physical and chemical stressors.

To analyze the landscape level disturbances, fifty meter buffer lines were drawn digitally around the digitized aerial photographs taken in 1999. GIS layers used included statewide landuse from the mid 1990s, digital aerial photographs (DOQs) from 1992, statewide roads from 1996, stream traces from 1998, and digital elevation models (DEM). The sources for these layers are given in Appendix 2.

A human disturbance gradient score was derived from the several sources of data described above and scored as five factors, each factor was judged and scored in one of four categories from best to poor. For example, the narrative scoring criterion for best buffer area was: "as expected for undisturbed reference wetland, no evidence of disturbance;" the criterion for poor was: "nearly all or all of the buffer is in intensive human use." The total points ranged from zero, for the least disturbed site, to 100, for the most disturbed site. The scoring sheets are in Appendix 3. The five factors are briefly summarized as follows: Factor One assesses the degree of disturbances within the 50 meter buffer area around the wetland edge; Factor Two assesses the degree of disturbances within the near wetland landscape generally within less than 500 meters; Factor Three assesses habitat, substrate and vegetation disturbances; Factor Four assesses hydrologic alteration; Factor Five assesses the degree of chemical pollution from chloride, phosphorus and nitrogen in water and sediment copper and zinc. An additional four points were reserved for features of disturbance not included in factors one to five.

**Invertebrate analysis methods**

*Seasonal index period, stratified sampling*

A seasonal index period of June to early July for sampling was used to allow some of the invertebrates, such as the dragonfly nymphs, to be mature enough to identify and to sample before there might be excessive vegetation growth, immigration of other invertebrates, or possible increases in fish populations through the summer. The

samples were collected in the near shore emergent vegetation zone, from the water's edge into water no deeper than one meter.

Both dipnetting and activity trap methods were used: the standardized dipnetting method captures the greatest richness of invertebrates, while the activity traps capture more active swimmers, and the night-active predators. Data from two standardized dipnet samples were used for all of the metrics except for the Corixidae Proportion metric. Data from activity trap samples were used for all metrics except for the Tolerant Taxa, Dominant 3 Taxa Proportion and the Chironomid Taxa metrics. These were derived solely from dipnet data. Table 1 summarizes the metrics and the sampling data used for each metric.

Table 1. Sampling methods used for each invertebrate metric with explanation.

| Proportion metrics | | Explanation |
|---|---|---|
| Corixidae Proportion | AT only | Activity traps capture active swimmers especially leeches, beetles and bugs |
| Dominant 3 Proportion | DN only | DN collects the greatest richness of taxa; time saved not counting entire AT samples |
| Tolerants Proportion | DN only | DN collects the greatest richness of taxa; time saved not counting entire AT samples |
| Taxa richness metrics | | |
| Chironomid genera | DN only | DN collects the greatest richness of taxa; time saved not counting entire AT samples |
| Leech genera | DN and AT | Both methods sample leeches, more active swimming leeches are in AT samples |
| Odonata genera | DN and AT | Both methods sample odonates, although most taxa are captured in DN samples |
| Snail taxa | DN and AT | Both methods sample snails, although most taxa are captured in DN samples |
| Total taxa | DN and AT | Chironomid taxa from DN only |
| Sensitivity metrics | | |
| ETSD metric | DN and AT | Both methods sample mayflies, caddisflies, dragonflies and Sphaeriidae |
| # Intolerant Taxa | DN and AT | Intolerant taxa include some Odonata, caddisflies, Sphaeriidae. Chironomid taxa are from DN samples only. |

*Dipnetting procedure*

Two samples were taken in different areas of the emergent zone of each wetland using the standardized dipnetting procedure below. The sampling method reduces the work effort required to pick the samples from vegetation by using a ½" hardware cloth screen fixed to a 12" x 16" wood frame, which sits over a tray containing sieved water set within a larger, floatable pan. The invertebrates drop down or are pushed through the screen from the vegetation for a period of ten minutes following each sweeping effort. For each sample, two separate dipnet samples of 4-5 sweeps each are taken within the shallow water and the emergent vegetation zone in representative areas up to approximately one

meter in depth with a D-frame aquatic dipnet, 600 micron mesh, Wildlife Supply Co. The organisms from the two sampling efforts are sieved, combined and preserved in 70-80% alcohol. For details see Gernes and Helgen (1999); see also Helgen (2002) for a summary of other wetlands methods.

*Activity trap sampling*

The activity traps work as funnel traps designed to collect organisms that swim through the funnel into clear two-liter plastic bottles. They collect the active swimmers such as leeches, beetles and bugs. Ten activity traps were deployed in pairs in representative areas of the shallow near shore emergent vegetation zone from wetland edge to water less than one meter deep. The bottles were filled to exclude air and placed approximately 10 cm under the surface for two overnights. Contents of each pair of traps were pooled to one sample through a 200 micron sieve and preserved in 80% alcohol. Activity trap samples were picked and counted for all taxa except chironomids and amphipods. For reasons of efficiency, small immature snails and pigmy backswimmers (Neopleia) were counted in a gridded tray over the lightbox, but not picked out of the samples.

Identifications were made to genus level for most taxa except snails and leeches which were recorded at species level where possible. Identifications of Chironomidae were done by Leonard C. Ferrington (University of Minnesota). Sphaeriidae were identified only to family, for reasons of efficiency.

Data were entered into MPCA's ACCESS database and plotted in EXCEL. Linear regression analysis was used to relate biological data to physical and chemical factors and the disturbance gradient. To evaluate metrics for their responses to chemical factors or human disturbance scores, they were plotted as scatter plots and the metric data, e.g., total number of taxa, were regressed against the disturbance measures. To score each metric, the 95th percentile range of the metric data was trisected and scored 5 (excellent), 3 (moderate) or 1 (poor). The data values above the 95th percentile were included in the range for the score of 5. The overall IBI score consists of the summation of the scores for the ten invertebrate metrics. The assessment of the ranges of the overall IBI score as excellent, moderate or poor was done by trisecting the 95th percentile range of the IBI scores. The data was rank ordered by percentile in EXCEL.

## RESULTS

**Physical-chemical gradients**

The goal of the *a priori* site selection process was to choose wetlands that together showed a gradient of disturbance from the least impaired to the most disturbed condition. Based on the scoring with the HDS criteria, there is a broad range of impairment within the set of 44 wetlands. The mean scores for each of the 44 wetlands for the human disturbance gradient are shown by site category type (reference, agricultural, urban) in Table 2. Detailed scores are given in Appendix 4 and Appendix 5.

Overall, the Human Disturbance Scores ranged from three, for the least disturbed wetlands, to 100 for the most disturbed sites. As expected, most of the wetlands that were selected *a priori* to be reference sites had low HDS scores: 12 of the reference sites scored between three and 33 (mean HDS 18.25), the two other reference sites scored

Table 2. Human disturbance scores (HDS)for 44 large depressional wetlands in Minnesota. Summary data are given for the categories of reference (Ref), agricultural (ag) and urban (urb)-influenced wetlands. In reality there is some overlap in site categories (some ref sites are in urban areas, some ag sites were less impaired than expected during the a priori site selection process). SD = standard

| Site type | HDS Mean | HDS Median | SD | HDS Min | HDS Max | n |
|---|---|---|---|---|---|---|
| Ref | 18.25 | 17.5 | 10.9 | 3 | 39.5 | 14 |
| Ag | 65.7 | 64.5 | 15.7 | 27.5 | 90 | 14 |
| Urb | 77.7 | 78.5 | 15.3 | 45 | 100 | 16 |

less than 40 points. Of the impaired wetlands, 11 scored between 33 and 67 for the HDS, and 18 were in the range of > 67 – 100 points. Within the set of urban-influenced wetlands, 11 sites scored in the upper range of disturbance (> 67-100), and only three urban sites scored in the mid range (>33-67). The mean HDS for urban wetlands was 78.5. Agriculture-influenced wetlands had a mean HDS of 65.7 points, with one of the sites scored within the lowest HDS range (27.5) with the reference sites. Eight agriculture sites scoring in the mid disturbance range (>33-67), seven were in the most disturbed range (> 67 – 100).

Chemical analysis shows a wide range of concentrations in water and sediment factors, with the reference sites tending to have the lowest measurements. These analyses are summarized as mean values in Tables 3 and 4 by category of site type, Appendix 6 and 7 show the chemical means arranged by chemical. Detailed lab and field water and sediment chemistry data are given in Appendices 8 - 10.

Table 3. Water chemistry in 44 large depressional wetlands in Minnesota 1999. Data for 14 reference, 14 agricultural and 16 urban wetlands in mg/L. Chl a, chlorophyll a; N, Kjedahl nitrogen; P, total phosphorus. Mean, median and standard deviation (S

| | Reference | | | | Agricultural | | | | Urban | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Chl a | Chloride | N | P | Chl a | Chloride | N | P | Chl a | Chloride | N | P |
| Mean | 12.05 | 4.75 | 1.22 | 0.076 | 29.3 | 19.5 | 2.01 | 0.236 | 32 | 56.9 | 1.56 | 0.154 |
| Median | 6 | 3.8 | 1.01 | 0.034 | 11.22 | 14 | 1.86 | 0.124 | 19.3 | 56 | 1.3 | 0.154 |
| SD | 23.4 | 4.54 | 0.475 | 0.108 | 57.5 | 15.8 | 1.21 | 0.333 | 34.3 | 23.4 | 0.692 | 0.049 |
| min | 2.26 | 1 | 0.68 | 0.015 | 1.35 | 1 | 0.9 | 0.023 | 1.15 | 27 | 0.53 | 0.077 |
| max | 92.9 | 16 | 2.29 | 0.429 | 238 | 50 | 5.81 | 1.38 | 107 | 110 | 2.99 | 0.251 |

The urban-influenced wetlands had the highest levels of chloride in the water, ranging from 27 - 110 mg/L, with a mean of 56.9 mg/L, compared with the reference sites (mean 12.05 mg/L) and agriculture-influenced (19.5 mg/L) wetlands. Heavy metals (copper, lead and zinc) were also considerably higher in the sediments of urban wetlands, with respective means of 50.8, 67.4 and 95.9 mg/kg air-dried

Table 4. Sediment chemistry and water turbidity in 44 large depressional wetlands in Minnesota 1999. Data for 14 reference, agricultural and 16 urban wetlands for copper, nickel, lead and zinc in mg/kg air dried weight wetland soil, turbidity (turb) in

| | Reference | | | | | Agricultural | | | | | Urban | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cu | Ni | Pb | Zn | Turb | Cu | Ni | Pb | Zn | Turb | Cu | Ni | Pb | Zn | Turb |
| Mean | 11 | 11.9 | 13.5 | 40.3 | 2.8 | 14.3 | 14.9 | 14.3 | 50 | 9.35 | 50.8 | 17.1 | 67.4 | 95.9 | 10.6 |
| Median | 11 | 10.7 | 10.1 | 38.1 | 2.65 | 14.3 | 15 | 11.8 | 54 | 3.2 | 26.3 | 15.8 | 39.7 | 71.8 | 5.9 |
| SD | 4.8 | 5.78 | 8.59 | 19.4 | 1.36 | 6.77 | 7.28 | 11.7 | 23 | 19.4 | 98.3 | 7.46 | 68.1 | 51.2 | 9.24 |
| min | 3.3 | 4.64 | 6.72 | 14.1 | 1.1 | 2.4 | 3.84 | 6.72 | 11 | 0.96 | 10.6 | 7.32 | 13.3 | 53 | 2.5 |
| max | 18 | 24.2 | 39.4 | 75.8 | 5.8 | 24.3 | 25.7 | 56.1 | 85 | 81 | 390 | 32.9 | 272 | 190 | 28 |

weight of sediment compared with copper, lead and zinc in the reference wetlands (10.8, 13.5 and 40.3 mg/kg), and copper, lead and zinc in the agriculture wetlands (14.3, 14.3, 49.8). Both categories of impaired wetlands had higher concentrations of total nitrogen, phosphorus, and chlorophyll a. Both the agricultural and urban wetlands had greater turbidity than did the reference wetlands.

**Richness of invertebrates**

The large depressional wetlands are very rich in invertebrate taxa, with 203 taxa recorded (Table 5). There were 187 taxa at the genus level, with 15 taxa of snails and leeches at the species level, plus the fingernail clams at family level. At the order level, the greatest richness of genera was in the Diptera, with 56 genera of true flies, followed by the Coleoptera, with 45 genera identified beetles. Within the order Diptera, 36 of the 56 genera were in the family Chironomidae. Aquatic bugs, or Hemiptera, were represented by 18 genera, followed by 17 genera of Odonata, or dragonflies and damselflies, 15 genera of the caddisflies, or Trichoptera, 14 genera of snails, or Gastropoda, and 12 genera of leeches, or class Hirudinea. Just three genera of mayflies, or Ephemeroptera, were found. Three genera of macrocrustaceans in the orders Amphipoda and Isopoda were recorded, not including crayfish, which were not sampled by our methods. The aquatic insects clearly dominate the diversity of wetlands invertebrates, with 158 of the 187 genera recorded (84.5%), but non-insect taxa are also common in wetlands and may contribute to biomass (Fairchild et al 1999) and potentially serve important roles in the food chain of wildlife (Swanson et al 1985; Swanson et al 1977).

**Metrics analysis**

A list of the ten metrics and the criteria used for scoring each metric's data are shown in Table 6. The individual metric scores for each metric for the 44 wetlands are shown in Table 7 and plotted against the human disturbance gradient scores in Figures 2, 3, and 4. The metrics varied in the degree of response to the specific measures of disturbance (see Appendix 11). The metrics that showed the most significant relationships with the human disturbance gradient and with some of the chemical factors are the Intolerant Taxa and the Chironomid Taxa metrics, followed by the

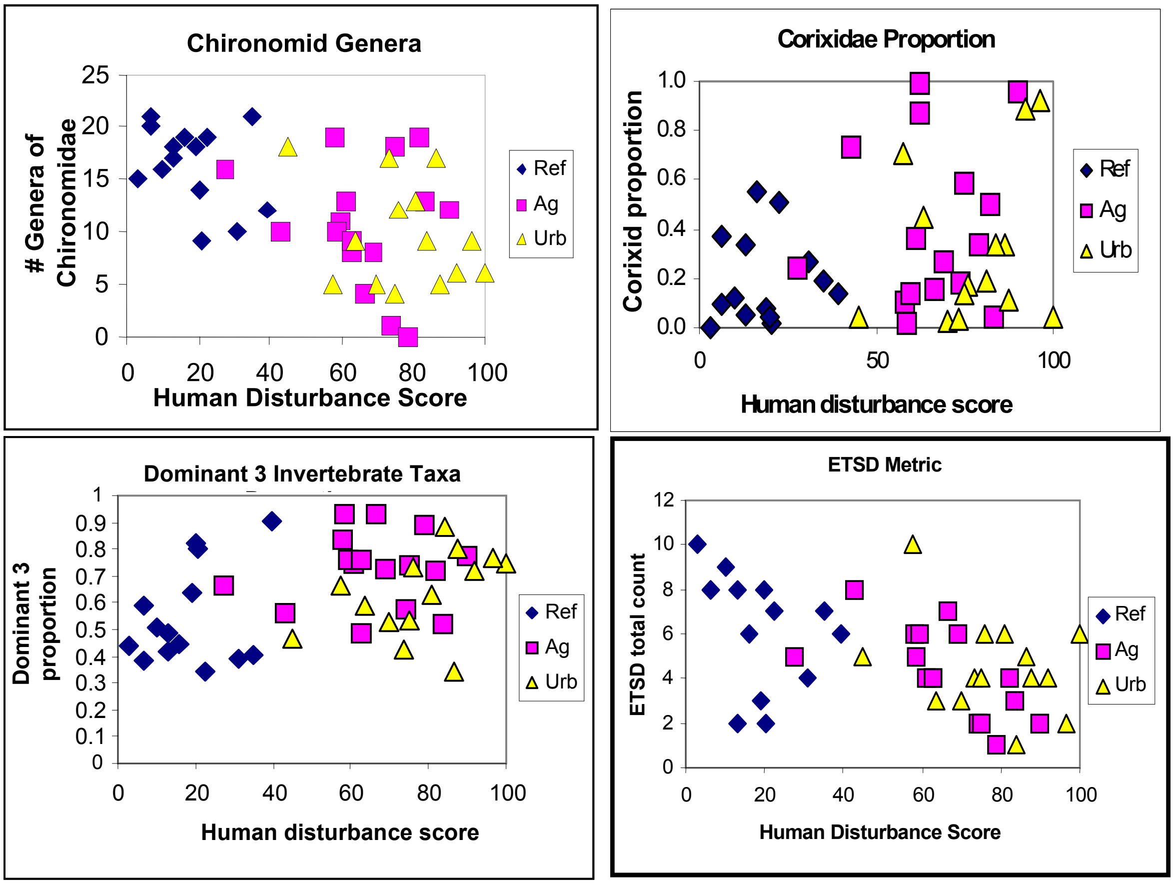



Figure 2. Invertebrate metrics plotted against the human disturbance scores for 44 large depressional wetlands in Minnesota: Chironomid Genera, Corixidae Proportion, Dominant Three Taxa and ESTD Metrics. ESTD counts mayfly and caddisfly genera, plus presence of dragonfly larvae and fingernail clams.

Table 5. Summary of invertebrate taxa found in 44 large depressional wetlands in Minnesota by major taxonomic groups. Taxa are genera in most groups, but species in leeches and snails.

| Order | Family | Common name | Taxa in family | Taxa in order |
|---|---|---|---|---|
| Amphipoda | | Scuds or sideswimmers (crustaceans) | | 2 |
| Coleoptera | | Beetles | | 45 |
| | Carabidae | Predaceous ground beetles | 1 | |
| | Chrysomelidae | Leaf beetles | 4 | |
| | Curculonidae | Weevils | 4 | |
| | Dytiscidae | Predaceous diving beetles | 23 | |
| | Haliplidae | Crawling water beetles | 2 | |
| | Helodidae | | 2 | |
| | Hydrophilidae | Water scavenger beetles | 10 | |
| Diptera | | True flies | | 56 |
| | Ceratopogonidae | Biting midges, midges | 9 | |

| | | | |
|---|---|---|---|
| Chaoboridae | Phantom midge | 1 | |
| Chironomidae | Midges | 36 | |
| Culicidae | Mosquitoes | 2 | |
| Dixidae | Dixid midges | 2 | |
| Sciomyzidae | Marsh flies | 2 | |
| Stratuinyidae | Soldier flies | 2 | |
| Tipulidae | Crane flies | 2 | |
| Ephemeroptera | Mayflie s | | 3 |
| Baetidae | | 1 | |
| Caenidae | | 1 | |
| Siphlonuridae | | 1 | |
| Gastropoda | Snails (limpet not counted) | | 21 |
| Ancylidae | Limpets | 1 | |
| Hydrobiidae | Lunged snail | 1 | |
| Lymnaeidae | Lunged snail | 8 | |
| Physidae | Lunged snail | 3 | |
| Planorbidae | Lunged snail | 6 | |
| Valvatidae | Gillled snail | 1 | |
| Viviparidae | Gilled snail | 2 | |
| Hemiptera | Bugs | | 18 |
| Belostomatidae | Giant water bugs | 2 | |
| Corixidae | Water boatman | 4 | |
| Gerridae | Water strider | 5 | |
| Hydrometridae | Water measurers | 1 | |
| Mesoveliidae | Water treaders | 1 | |
| Nepidae | Water scorpion | 1 | |
| Notonectidae | Back swimmers | 2 | |
| Pleidae | Pigmy back swimmer | 1 | |
| Veliidae | Broad-shouldered water strider | 1 | |
| Hirudinea (class) | Leeches | | 20 |
| Glossiphonidae | Creeping leeches | 15 | |
| | Swimming leeches | 5 | |
| Isopoda | Aquatic sow bug | | 1 |
| Lepidoptera | Aquatic moths | | 2 |
| Megaloptera | Alderflies | | 2 |
| Odonata Anisoptera | Dragonflies | | 12 |
| Odonata Zygoptera | Damselflies | | 5 |
| Trichoptera | Caddisflies | | 15 |
| Hydroptilidae | | 2 | |
| Leptoceridae | | 6 | |
| Limnephilidae | | 2 | |
| Phryganeidae | | 3 | |
| Polycentropodidae | | 2 | |
| Sphaeriidae (family only) | Fingernail clams | | 1 |
| | | Total invertebrate taxa | 203 |

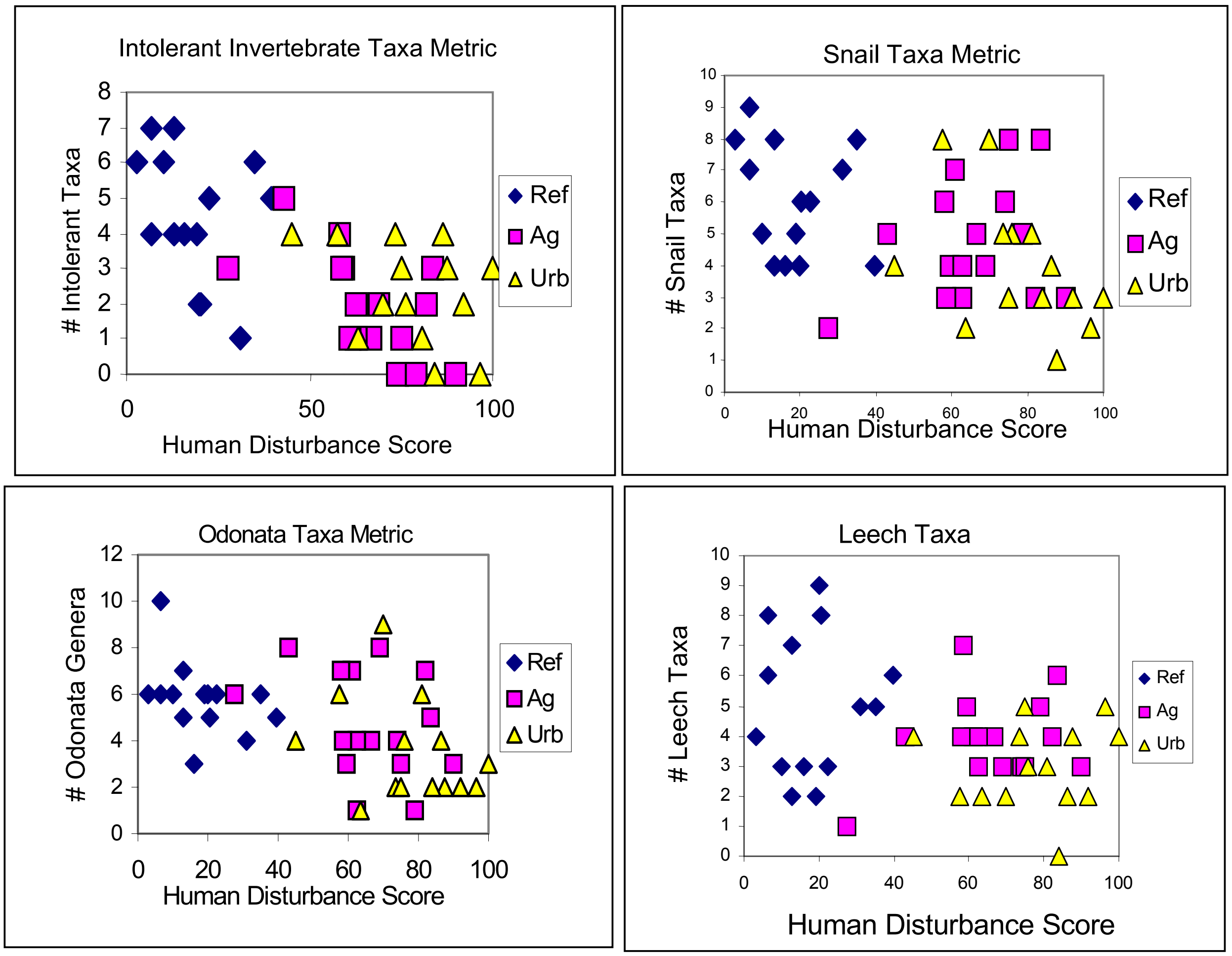


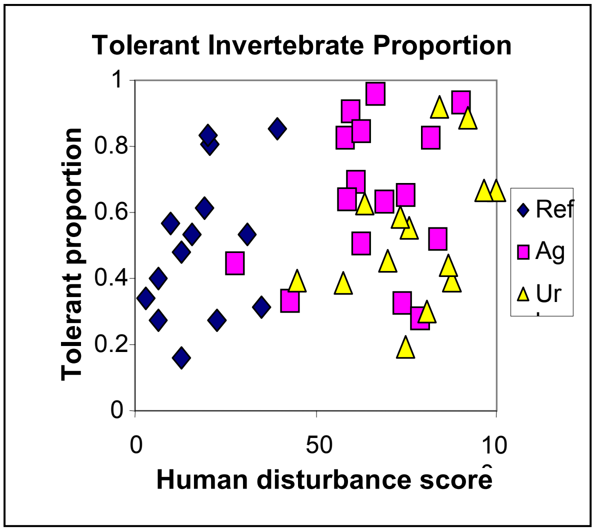

Figure 3. Invertebrate metrics plotted against the human disturbance gradient scores for 44 large depressional wetlands in Minnesota: Intolerant Taxa, Snail Taxa, Odonata Taxa and Leech Taxa metrics.

Total Invertebrate Taxa metric and the ETSD and Odonata metrics. These metrics are based on species richness, particularly of the more sensitive species: the chironomids, dragonflies and some damselflies, mayflies, caddisflies and the fingernail clams.

For the Intolerant Taxa metric, the taxa were determined to be sensitive to disturbance in a previous project (Gernes and Helgen 1999). The sensitive taxa derived from the data as the taxa that tended to be present in high quality reference wetlands and to disappear from disturbed sites. These same taxa are also sensitive in the large depressional wetlands reported here. The intolerant taxa include two genera of dragonflies, Leucorrhinia and Libellula, two genera of chironomids, Procladius and Tanytarsus, two caddisflies, Triaenodes and Oecetis, and the presence of fingernail clams, Sphaeriidae. The number of intolerant taxa was very significantly related to the HDS scores ($p < .000002$, r .649), and very significant with chloride, phosphorus and nitrogen concentrations. The number of Chironomid taxa was strongly significant

with the HDS scores (p. 000014), and also with chloride and phosphorus in the water.

The weakest of all ten metrics is the leech taxa metric, which was only weakly



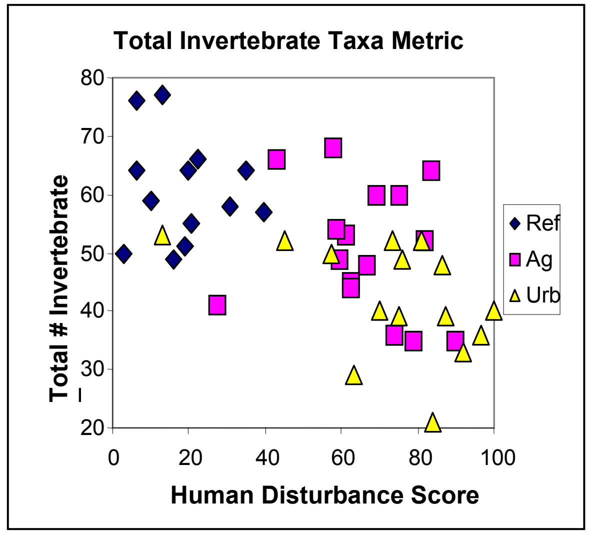




Figure 4. Invertebrate metrics plotted against the human disturbance gradient scores for 44 large depressional wetlands in Minnesota: Tolerant Invertebrate Proportion and Total Invertebrate Taxa

significant with the human disturbance scores.

The ETSD metric is the number of genera of Ephemeroptera (mayflies), and of Trichoptera (caddisflies) plus the presence of Sphaeriidae (fingernail clams) and dragonflies. ETSD is a substitute for the EPT metric used in streams, for mayflies, caddisflies and stoneflies (Plecoptera). In spite of the lower richness of mayflies and caddisflies in these wetlands compared with streams, with only three taxa of mayflies, and up to 15 taxa of caddisflies found, the ETSD metric is a sensitive metric. This was seen in the previous work on depressional wetlands by MPCA (Gernes and Helgen 1999). ETSD was very significantly related to the human disturbance score (p .00044) and significant with phosphorus, nitrogen and TSS and other factors

The Odonata metric, the number of genera of dragonflies and damselflies, was also a sensitive metric. While there were a total of 17 genera of Odonata observed in the 44 wetlands, no one wetland had more than 10 genera. The greatest significance for this metric was with the turbidity (p .00013), and significance was seen with phosphorus, HDS and other factors. Both the dragonflies and the damselflies are predators in their larval stages, they are dependent on other aquatic invertebrates as prey. The dragonfly larvae may develop in the wetland for months before emerging to the adult stage. Additionally, their method of anal respiration exposes them to contaminants and silt in the water.

The Total Invertebrate Taxa metric showed very significant relationships to the human disturbance scores (p .000022, r .594), and to chloride and turbidity, and significant to other chemical factors. Total invertebrate

Table 6. Scoring criteria for invertebrate metrics for large depressional wetlands. Criteria based on trisection of data ranges below 95th percentile. The numbers of reference sites (ref) and agriculture- (ag) and urban storm water-influenced (urb) site

| Metric with data range | Criteria | Score | Ref | Ag | Urb | n |
|---|---|---|---|---|---|---|
| 1. Total invertebrate taxa | Criteria | Score | Ref | Ag | Urb | n |
| Range 21 - 77 taxa | > 51 - 77 | 5 | 11 | 8 | 3 | 22 |
| | > 36 - 51 | 3 | 3 | 5 | 7 | 15 |
| | < 21 - 36 | 1 | 0 | 3 | 4 | 7 |
| 2. Odonata taxa metric ** | Criteria | Score | Ref | Ag | Urb | n |
| Range 0 - 10 | 6 - 10 | 5 | 9 | 6 | 3 | 18 |
| | 4 - 5 | 3 | 5 | 8 | 4 | 17 |
| | 0 - 3 | 1 | 0 | 2 | 7 | 9 |
| 3. Chironomid genera metric | Criteria | Score | Ref | Ag | Urb | n |
| Range 0 - 21 | 14 - >21 | 5 | 11 | 4 | 3 | 18 |
| | 7 - 13 | 3 | 3 | 9 | 5 | 17 |
| | 0 - 6 | 1 | 0 | 3 | 6 | 9 |
| 4. Leech taxa metric | Criteria | Score | Ref | Ag | Urb | n |
| Range 0 - 9 | 5 - 9 | 5 | 8 | 4 | 2 | 14 |
| | 3 - 4 | 3 | 4 | 11 | 6 | 21 |
| | 0 - 2 | 1 | 2 | 1 | 6 | 9 |
| 5. Snail taxa metric | Criteria | Score | Ref | Ag | Urb | n |
| Range 1 - 9 | 7 - 9 | 5 | 6 | 3 | 2 | 11 |
| | 4 - 6 | 3 | 8 | 8 | 5 | 21 |
| | 0 - 3 | 1 | 0 | 5 | 7 | 12 |
| 6. ETSD metric: # genera mayflies, caddisflies | Criteria | Score | Ref | Ag | Urb | n |
| presence of fingernail clams, dragonflies | > 6 - 10 | 5 | 8 | 2 | 1 | 11 |
| | > 3 - 6 | 3 | 3 | 9 | 9 | 21 |
| Range 1 - 10 | 0 - 3 | 1 | 3 | 5 | 4 | 12 |
| 7. Number of intolerant taxa | Criteria | Score | Ref | Ag | Urb | n |
| Range 0 - 7 taxa | 5 - 7 | 5 | 7 | 1 | 0 | 8 |
| | 3 - 4 | 3 | 4 | 5 | 7 | 16 |
| | 0 - 2 | 1 | 3 | 10 | 7 | 20 |
| 8. Tolerant taxa proportion of sample count | Criteria | Score | Ref | Ag | Urb | n |
| Range 16% - 96% | 16 - 42% | 5 | 6 | 3 | 5 | 14 |
| | > 42 - 69% | 3 | 5 | 6 | 7 | 18 |
| | > 69% | 1 | 3 | 7 | 2 | 12 |
| 9. Dominant 3 taxa as proportion of sample | Criteria | Score | Ref | Ag | Urb | n |
| count | < 34 - 54% | 5 | 9 | 2 | 3 | 14 |
| Range 34% - 94% | > 54 - 74% | 3 | 2 | 5 | 5 | 12 |
| | > 74 - 94% | 1 | 3 | 9 | 4 | 16 |
| 10. Corixidae proportion of beetles and | Criteria | Score | Ref | Ag | Urb | n |
| bugs in activity traps | < 33% | 5 | 10 | 8 | 8 | 26 |
| | 33 - 67% | 3 | 4 | 4 | 3 | 11 |
| Range 0 - 99% | > 67% | 1 | 0 | 4 | 3 | 7 |

** Please see metric addendum on page 24A

Table 7. Invertebrate metric and IBI (index of biological integrity) scores for 44 large depressional wetlands in Minnesota. Three wetland condition categories: excellent, moderate and poor, were made by trisecting the range of IBI scores below the 95th percentile. Metrics in order: Chironomid Taxa, Corixidae Prop., Dominant 3 Prop., ETSD, Intolerant Taxa, Leech Taxa, Odonata Taxa, Snail Taxa, Total Taxa.

| Site Name | A priori class | Chiro Taxa | Corix Prop | Dom3 Prop | ETSD | Intol Taxa | Leech | Odonata | Snail | Toler Prop | Total Taxa | Invert IBI | Condition |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lasher | Ref | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 50 | |
| Field | Ref | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 48 | |
| Bloom | Ref | 5 | 5 | 5 | 5 | 5 | 3 | 5 | 5 | 5 | 3 | 46 | |
| Glacial | Ref | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 5 | 46 | |
| Minnow N | Ref | 5 | 3 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 46 | Excellent |
| Overby N. | Ref | 5 | 3 | 5 | 5 | 5 | 3 | 5 | 3 | 5 | 5 | 44 | Condition |
| Prairie | Ref | 5 | 5 | 5 | 5 | 5 | 3 | 5 | 3 | 3 | 5 | 44 | |
| Mud | Urb | 5 | 5 | 5 | 3 | 3 | 3 | 3 | 3 | 5 | 5 | 40 | |
| Sheets Big | Ag | 5 | 1 | 3 | 5 | 5 | 3 | 5 | 3 | 5 | 5 | 40 | |
| Donley Lg. N | Ref | 3 | 5 | 5 | 3 | 1 | 5 | 3 | 5 | 3 | 5 | 38 | |
| Malardi | Ag | 3 | 5 | 5 | 1 | 3 | 5 | 3 | 5 | 3 | 5 | 38 | |
| Legion | Urb | 3 | 5 | 3 | 3 | 1 | 3 | 5 | 3 | 5 | 5 | 36 | |
| Leman's | Ref | 5 | 5 | 1 | 5 | 1 | 5 | 5 | 3 | 1 | 5 | 36 | |
| Turtle | Urb | 5 | 5 | 5 | 3 | 3 | 3 | 1 | 3 | 3 | 5 | 36 | |
| Zager | Ref | 5 | 5 | 5 | 1 | 3 | 1 | 3 | 3 | 5 | 5 | 36 | |
| Kasma | Ref | 3 | 5 | 1 | 3 | 5 | 5 | 3 | 3 | 1 | 5 | 34 | |
| New London | Ref | 5 | 3 | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 34 | |
| Seter | Ag | 3 | 5 | 3 | 3 | 1 | 3 | 5 | 3 | 3 | 5 | 34 | |
| Sheets Small | Ag | 5 | 5 | 1 | 3 | 3 | 3 | 5 | 3 | 1 | 5 | 34 | |
| Battle | Urb | 1 | 1 | 3 | 5 | 3 | 1 | 5 | 5 | 5 | 3 | 32 | |
| Bunker | Ag | 5 | 5 | 3 | 3 | 3 | 1 | 5 | 1 | 3 | 3 | 32 | |
| Lake 21 | Ref | 5 | 5 | 3 | 1 | 3 | 1 | 5 | 3 | 3 | 3 | 32 | |
| Savage | Urb | 5 | 3 | 5 | 3 | 3 | 1 | 3 | 3 | 3 | 3 | 32 | |
| Tyrone Bean | Ag | 3 | 5 | 1 | 3 | 3 | 5 | 3 | 1 | 3 | 5 | 32 | Moderate |
| Wood Lake | Urb | 1 | 5 | 5 | 3 | 3 | 5 | 1 | 1 | 5 | 3 | 32 | Condition |
| Lake Park | Ag | 5 | 3 | 1 | 1 | 1 | 3 | 3 | 5 | 3 | 5 | 30 | |
| Round | Urb | 3 | 5 | 3 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 30 | |
| Sethre | Ag | 3 | 3 | 1 | 3 | 1 | 3 | 5 | 5 | 1 | 5 | 30 | |
| Skarpness E | Ag | 3 | 5 | 1 | 3 | 3 | 5 | 3 | 3 | 1 | 3 | 30 | |
| Sunset | Urb | 1 | 5 | 5 | 1 | 1 | 1 | 5 | 5 | 3 | 3 | 30 | |
| Cataract | Ref | 3 | 5 | 1 | 1 | 1 | 5 | 3 | 3 | 1 | 5 | 28 | |
| Sigler | Ag | 3 | 3 | 3 | 3 | 1 | 3 | 5 | 1 | 1 | 5 | 28 | |
| Breen | Ag | 1 | 5 | 3 | 1 | 1 | 3 | 3 | 3 | 5 | 1 | 26 | |
| Jones | Urb | 1 | 5 | 1 | 3 | 3 | 3 | 1 | 1 | 5 | 3 | 26 | |
| New Prairie | Ag | 1 | 5 | 1 | 5 | 1 | 3 | 3 | 3 | 1 | 3 | 26 | |
| Ney | Ag | 3 | 1 | 5 | 3 | 1 | 3 | 3 | 1 | 3 | 3 | 26 | |
| Grass | Urb | 1 | 5 | 1 | 3 | 3 | 3 | 3 | 1 | 1 | 3 | 24 | |
| Davis | Ag | 1 | 3 | 1 | 1 | 1 | 5 | 1 | 3 | 5 | 1 | 22 | |
| Trappers | Ag | 3 | 1 | 1 | 3 | 1 | 3 | 1 | 3 | 1 | 3 | 20 | |
| Casey | Urb | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 18 | Poor |
| Lost1 | Urb | 3 | 1 | 1 | 1 | 1 | 5 | 1 | 1 | 1 | 1 | 16 | Condition |
| Sucker N | Ag | 3 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 1 | 16 | |
| Rose Golf | Urb | 1 | 1 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 14 | |
| Wakefield | Urb | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 14 | |

taxa was a count of the number of genera of Amphipoda, Coleoptera, and Diptera including the chironomids, Ephemeroptera, Hemiptera, Odonata and Trichoptera. Gastropoda and Hirudinea were counted at species level where possible, and Sphaeriidae at family level. While there were 203 taxa recorded overall for the 44 wetlands, the highest quality wetlands had the species level, rather than genus level, there would be many more taxa recorded in these sites.

Overall, the total number of invertebrate taxa did increase significantly with the size of the wetland (log of acres, p<.004, r .422). The large depressions were selected to have

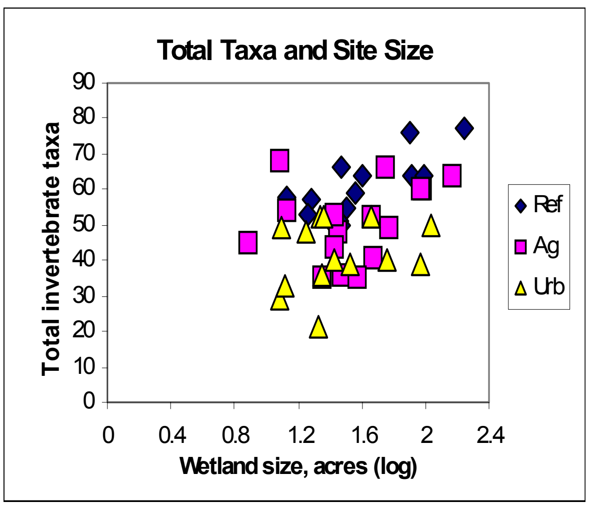



Figure 5. Total number of invertebrate taxa plotted against the log of the size in acres of 44 wetlands in Minnesota. The best fit line is drawn through the points. Reference sites lie mostly above the best fit line.

a range of sizes within each category of reference, agricultural and urban-influenced wetlands (see Appendix 1). There is no significant relation of the numbers of taxa within the categories of reference, agricultural or urban against site size. Figure 5 shows a plot of total invertebrate taxa against wetland size, with a definite trend of increasing numbers of taxa in all the wetlands as the size increases. When the fitted line for the regression is drawn through the data points, one can see that all of the reference sites are positioned on or above the fitted line, whereas many, but not all of the agricultural and urban influenced wetlands lie below the best fit regression line. As size increases, the number of taxa increases in both the reference and disturbed wetlands. There are more taxa in many of the reference wetlands of any size when

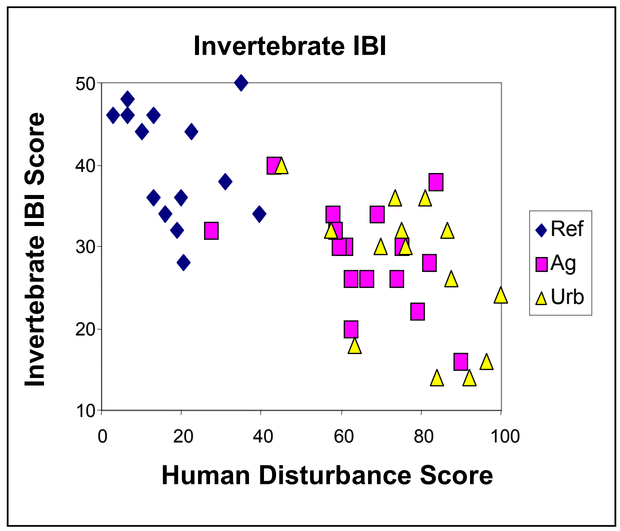



Figure 6. Invertebrate Index of Biological Integrity (IBI) plotted against the human disturbance scores for 44 large depressional wetlands in Minnesota.

compared with the impaired sites.

The proportion metrics, Dominant 3 Taxa, Corixidae Proportion, Tolerants Proportion, tend to show less significance than most of the taxa-based metrics when related to the human disturbance scores and to the chemical factors. The Dominant 3 Taxa metric was significantly related to HDS and three chemical factors. The greatest significance (p .0009) was in relation to phosphorus in the water. The Tolerants Proportion metric was significant with four

chemical factors, but not with the HDS scores. Its greatest significance (p.0017) was with nitrogen in the water. Corixidae proportion was weakly significant with HDS and turbidity in the water. These metrics are more vulnerable to variations in overall abundances and to low sample counts that can occur in highly impaired wetlands. Richness metrics usually show lower variances or coefficients of variability. For the Tolerant Proportion metric, a ratio of the count of individuals of the tolerant taxa

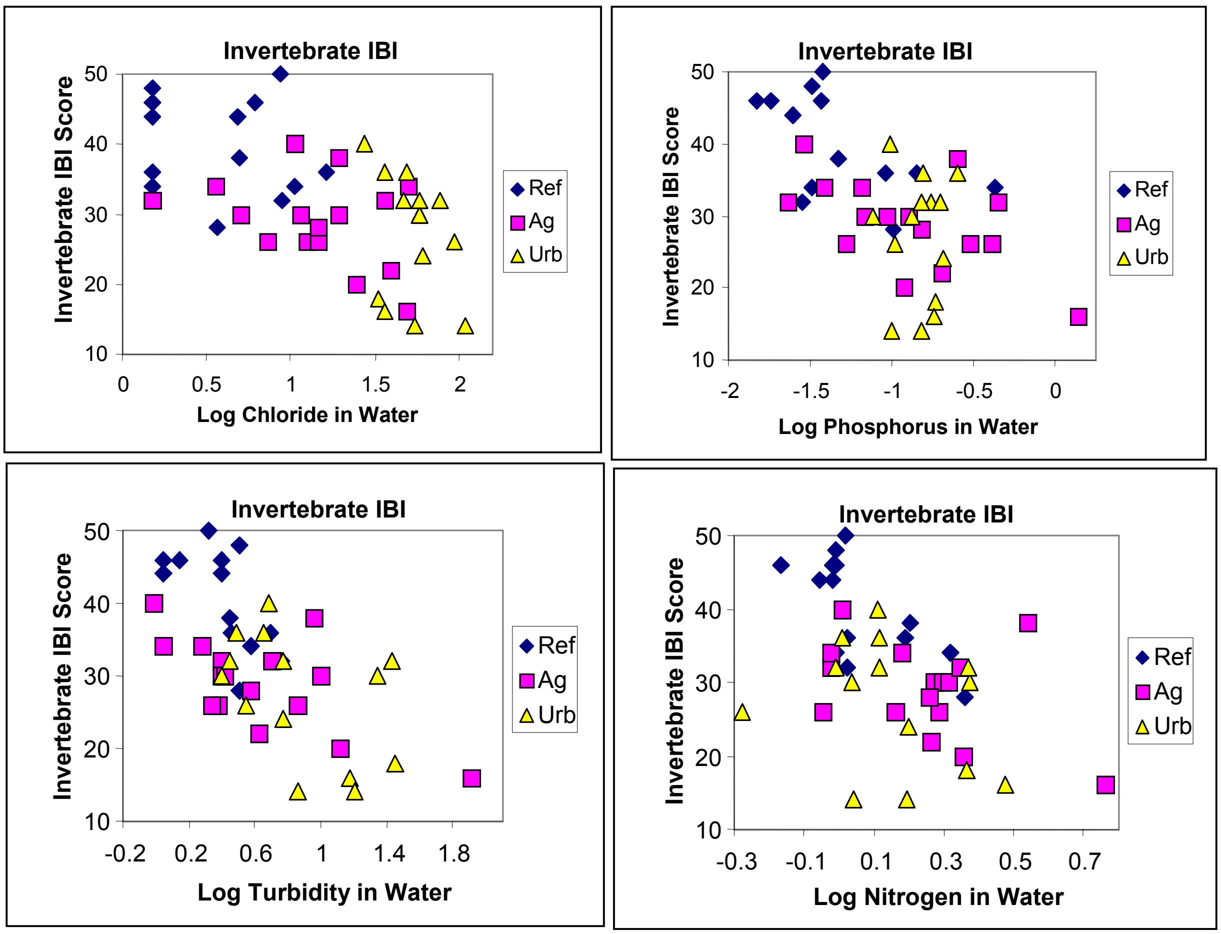



Figure 7. Invertebrate Index of Biological Integrity (IBI) scores plotted against chloride, phosphorus and nitrogen in the water (log of concentration in mg/L) and turbidity (in ntu).

is made to the total sample count. The tolerant taxa were the amphipods, the corixid Trichocorixa, the damselfly Enallagma, the leech Erpobdella, the snail Physa, and five genera of chironomids: Cricotopus, Dicrotendipes, Endochironomus, Glypotendipes, and Paratanytarsus. These taxa were selected because they tended to increase in the more disturbed sites, or are thought to be more tolerant of pollution. This metric is substituting for the previously used Erpobdella Proportion metric, which did not show a good response in the large depressions, partly because the leech Erpobdella was present in a very small proportion to total sample count in these wetlands.

## Invertebrate IBI

The invertebrate IBI scores showed the strongest relationship with the human disturbance scores ($p < .0000005$, r .715; Figure 6), but turbidity, phosphorus and chloride were also highly significantly related to the IBI scores (Table 8). Other factors, chlorophyll a, total nitrogen, TSS, and sediment copper, were significant, but showed low r values. Sediment zinc and nickel were very weakly significant with the invertebrate IBI scores. But see the plots which suggest stronger relationships (Figures 7 and 8). IBI scores are shown plotted against the human disturbance scores in Figure 6. IBI scores are plotted against several chemical factors in Figures 7 and 8. The statistical relationships of the individual metrics as p values and r values are given in Appendix 11.

Table 8. Invertebrate IBI regressions with Human Disturbance Score (HDS), turbidity, phosphorus, chloride, chlorophyll a, nitrogen and TSS in water and copper, zinc and nickel in sediments. p values, r and $r^2$ are shown.

| Factor | p value | r | $r^2$ |
|---|---|---|---|
| HDS score | < .0000005 | .715 | .511 |
| Turbidity | < .0000043 | .631 | .398 |
| Phosphorus | < .000017 | .599 | .359 |
| Chloride | < .0007 | .587 | .344 |
| Chlorophyll | < .0007 | .492 | .242 |
| Nitrogen | < .0007 | .492 | .242 |
| TSS | < .0008 | .487 | .237 |
| Sediment Cu | < .0067 | .403 | .162 |
| Sediment Zn | < .04 | .311 | .096 |
| Sediment Ni | < .05 | .304 | .092 |

The IBI total scores are shown in Table 7 with the metric scores. Trisection of the 95th percentile of the scoring range assigned the scores of 35 – 50 as in excellent condition, 23 – 34 as moderate, and 10 – 22 as poor condition. Using these criteria, 10 reference wetlands, 3 urban sites and 1 agriculture-influenced site would be excellent; while 4 reference, 7 urban and 11 agriculture sites are moderate; and no reference, 4 urban and 3 agriculture wetlands are assessed to be in poor condition.

## Replicate sampling results

Six wetlands were sampled a second time in a different location not far from the original sample on the same day (see Appendix 12). Four of the wetlands had replicate IBI scores that were close in value and gave the same assessments (18, 18, poor; 46, 50, excellent; 34, 34, moderate; 28, 30, moderate). For two of the wetlands, Donley Large (a reference site) and Wood Lake (an urban site), the IBI scores varied enough in the two replicates that the assessments of condition differed by one level. The Donley Large

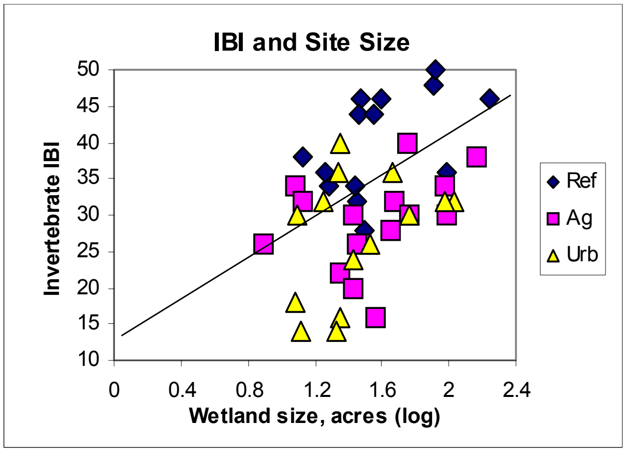



Figure 8. Invertebrate IBI scores plotted against the log of size in acres of 44 wetlands in Minnesota. The best fit line is drawn through the points.

replicates had IBIs that differed by 6 points (32, 38; moderate, excellent). They were similar in having 56 and 58 invertebrate taxa. Where the replicates differed the most was in the Dominant 3 Proportion metric and the number of snail taxa. This difference is unexplained, the wetland had a history of farming, and had an old berm near the sampling area, but its impact is unknown.

The IBI scores for the replicates at Wood Lake differed by twelve points (32, 44; moderate, excellent). The replicates differed widely in invertebrate taxa richness (39, 56), especially in the number of Odonata taxa (2, 6) and chironomid taxa (4, 14). Wood Lake, also an urban wetland, one with a very popular nature center, moved up to the moderate/excellent IBI range in 1999 from the poor IBI range when it was analyzed in 1995. The impact of the major dredging and removal of deep storm water silt deposits from this wetland in 1996 - 1998 on the invertebrates may have been a factor. Two other large depressional wetlands were analyzed in both 1999 and 1995. The reference site, Prairie, scored in the excellent range for the invertebrate IBI scores in both 1995 and 1999. Legion, an urban wetland, scored in the moderate IBI range in both 1995 and 1999.

The vegetation IBI (Gernes 2002) and the invertebrate IBI both provide good measures of impairment to, or improvements in, the condition of wetlands. Together they are significantly co-related (p .00004, r .58). But the two IBIs give different assessments in several of the large depressions (Figure 9).

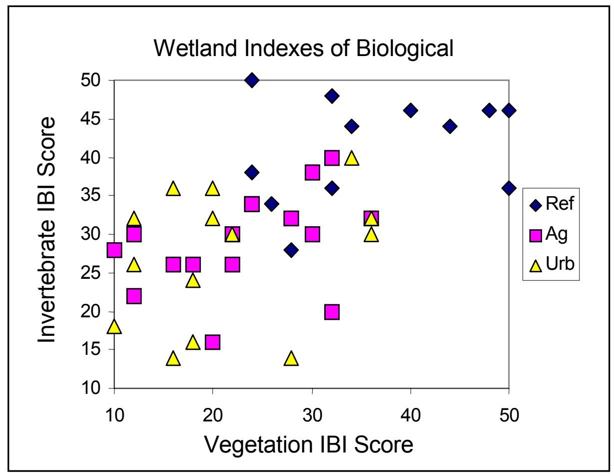



Figure 9. Invertebrate IBI scores plotted against the vegetation IBI scores from 44 large depressional wetlands in Minnesota.

## DISCUSSION

The aquatic invertebrates in wetlands are significantly affected by degrees of disturbances to large depressional wetlands. The IBI scores and the data for many of the individual metrics show very significant impairment as measured by the human disturbance scores and in relationship to some of the specific water and sediment quality factors, especially turbidity, phosphorus and chloride with lesser significance with chlorophyll, nitrogen, TSS and sediment copper.

The measure of disturbance, the human disturbance gradient (HDS), provides a useful x axis for gauging the response of the biota to stressors that are summarized in the HDS scores. HDS provides a broad, more comprehensive measure of disturbance than just using the specific chemical measures. But there are advantages to measuring standard water quality factors in pointing to some of the disturbance sources. Many of the urban wetlands have very high concentrations of chloride in the water and heavy metals in their sediments. The agricultural wetlands, on average, have higher phosphorus and nitrogen. The subtotal for the HDS scores that relate to landscape disturbances (factors 1-3), has a very significant relation (p < .0000013, r .657) to the invertebrate IBI. Likewise, the subtotal for the combined hydrologic alteration and chemistry scores (factors 4-5) is also very significantly related to the IBI (p .00000004, r .718). It appears that all the factors can contribute to the observed impacts.

The study design in which a range of disturbance to wetlands is selected is valuable in developing the IBI. It is not possible to find a pristine set of highest quality reference wetlands. Some of the selected reference sites scored in the moderate range of IBI scores. The approach to scoring metrics used here is based on analyzing the entire gradient of data for a particular metric. This method of using the gradient of sites and data is preferable to the older method used in the Rapid Bioassessment Protocol for Rivers (RBP) and Streams (Pflakin et al 1989). In RBP, the metric, such as taxa richness, was scored in relation to its proportion to the mean taxa richness expected for a set of reference sites. In that case, it was critically important that the chosen reference sites all be in the highest condition. In the gradient approach used for the IBI development, it is acceptable if some of the *a priori* selected reference sites ended up actually somewhat moderately disturbed, and if some of the *a priori* selected disturbed sites ended up showing less disturbance when the field data are analyzed than expected during the site selection process. In fact, this might be anticipated, because the *a priori* selection process does not actually measure the levels of disturbance to wetlands. The disturbance factors were measured as the wetlands were sampled during the field season. What does matter is how the measured biological metrics respond to the measured degrees of disturbance. The biological response is evident, a gradient of impairment results in greater reductions and impacts to the biological integrity of large depressional wetlands.

In this overall project two biological indexes were tested, one based on invertebrates and one based on plants. More reference sites scored in the excellent range with the invertebrate IBI (10) than with the vegetation IBI (5). Neither the invertebrate IBI nor the vegetation IBI scored any reference sites in the poor range. The vegetation IBI scored more urban and agricultural sites (13) in the poor range that did the invertebrate IBI (7). Often there was not agreement on sites that were assessed to be poor, although of the four urban wetlands rated poor with the invertebrate IBI, three were also rated poor with vegetation. If anything, the invertebrate IBI may tend to rate sites somewhat higher than the vegetation IBI, but this needs to be further analyzed. In addition, in the future, an analysis of the impact of site size on the invertebrate IBI needs to be further explored.

There is utility in having more than one measuring tool in one's toolbox, because the

two IBIs may respond to different stressors. The vegetation IBI may be more responsive to certain disturbances such as hydrologic alterations, herbicides or grazing, it will be useful in dryer wetlands, and the data is acquired more efficiently than the invertebrate data. The invertebrates will be expected to be more directly responsive to shorter term changes in the wetland water quality and to losses of wetland vegetation or vegetation types. Overall, both IBIs show significant reductions when wetlands are chemically or physically impaired.

MPCA will report to EPA in the future the results from a statistical evaluation of three replicates done in nine large depressional wetlands in 2001. The goal of this next analysis will be to determine how many replicates are needed to permit at least three levels for assessments of condition (excellent, moderate, poor).

## SUMMARY AND CONCLUSIONS

The invertebrate Index of Biological Integrity (IBI) provides a scientifically sound measure of the response of invertebrates to the degree of human disturbances to depressional wetlands. It shows highly significant relations to the Human Disturbance Scores for 44 large depressions in Minnesota, and to several water quality factors such as turbidity, chloride and phosphorus. The human disturbance scores are very low on average in the reference wetlands and higher in the urban and agriculture influenced wetlands. The sub scores for the landscape-related factors contained within the HDS scores are significantly related to the IBI scores, as are the sub scores for the hydrologic alteration plus chemical factors.

Ten metrics compose the invertebrate IBI. The metrics that are most significantly related to human disturbance scores and to chemical factors are the Intolerant Taxa, the Chironomid Taxa, the Odonata Taxa, the ETSD metric and the Snail Taxa. The metrics that show significant, but weaker relations to measures of disturbance are the Leech Taxa and the proportion metrics: Dominant 3 Taxa, Tolerant Proportion metric, and Corixidae Proportion metric.

The advantages of a biological index are that it provides a direct, measurable indication of the health of a wetland, a measure that reflects the ultimate goal of protection of wetlands as surface waters and life support systems. We need to ask, what are we trying to protect by conserving wetlands? These large depressional wetlands host 187 invertebrate taxa at only the genus level, and many more species may be present within each genus. The unimpaired wetlands are a reserve for this biological richness. They provide organisms to colonize other wetlands and a food web for many species including waterfowl, song birds and amphibians. A biologically healthy wetland is providing other ecosystem services through basic biological processes. When we can demonstrate that a wetland, or a complex of wetlands, has the biological integrity expected for one of its class and ecogeographic region, then we know there has been restoration or protection of wetlands as living ecosystems.

We conclude that the invertebrate IBI provides one way to measure the health of the biological community of wetlands, and by extrapolation, the health of the wetland ecosystem. The measures are quantifiable, based on standardized methods, repeatable, and made from the wetland itself. The IBI provides a direct and valid measure of wetland condition, a measure that can be

used to document trends over time in the quality of wetlands. Compared with the major efforts in measuring IBIs with fish and invertebrates to assess stream condition (Niemela and Feist 2000; Ohio EPA 1988), there is very little information at the present time that assesses the biological integrity of wetlands except in Ohio and Montana (Apfelbeck 1999; Mack 2001; see also Helgen 2002). This is a direction for the future, to document that existing wetlands within landscapes, while being restored or maintained in numbers and acres, are not diminishing in the ecological quality that supports diverse living systems.

## ACKNOWLEDGEMENTS

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## Addendum

As this report was going to press an error was detected in how one of the metrics was being calculated in the database. The query that calculated the 'Odonata Taxa Richness' metric in the Access database was lacking the criteria to prevent a family or suborder level taxon (e.g., a specimen that couldn't be identified to genus) from being included in the taxa count when genera belonging to that taxon were identified in the sample. As a result, the range of Odonata taxa richness (0-10) presented in the report represents an overestimate, and after the metric calculation was corrected the range decreased to 0-7 taxa. Therefore, determining the scoring criteria (trisection of data ranges below 95$^{th}$ percentile) for this new range of data results in the following:

| Odonata taxa metric | Criteria | Score | Ref | Ag | Urb | n |
|---|---|---|---|---|---|---|
| | >4 | 5 | 8 | 6 | 3 | 17 |
| Range 0 – 7 | 3-4 | 3 | 6 | 7 | 4 | 17 |
| | 0-2 | 1 | 0 | 3 | 7 | 10 |

The above scoring criteria represents a return to the original scoring criteria developed for this metric in (Gernes & Helgen 1999). The incorporation of the changed metric calculation and the above scoring criteria results in changes to the metric scores at seven sites. The metric score decreased by 2 at three reference sites (Leman's, Minnow, Prairie), one ag-impacted site (Sucker N), and one urban-impacted site (Wood Lake), and increased by 2 at two reference sites (Kasma, Zager). These changes result in changes to the condition status for two reference sites: Leman's (changed from Exc to Mod) and Kasma (changed from Mod to Exc).

The above changes also affect a number of figures and statistical analyses throughout the invertebrate portion of the report. However, the statistical significance of the dose response relationships (see Appendix 11) for Odonata taxa richness are essentially unaffected by these changes.

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for DEMs:

http://deli.dnr.state.mn.us/metadata/full/dem
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# Plant-based Index of Biological Integrity for Large Depressional Wetlands in Central Minnesota

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May, 2002

## ABSTRACT

Aquatic plant field sampling results in 44 large depressional wetlands including small shallow lakes in the North Central Hardwood Forest Ecoregion of Central Minnesota were related to measures of human disturbance. In total, 189 plant taxa representing 58 plant families occurred in the field samples and were included in the analysis. Ten previously proposed plant metrics were validated and correlated against a qualitative human disturbance index. The plant metrics were based on (1) species richness of vascular and nonvascular taxa; (2) community composition including *Carex* cover, aquatic species, perennial species and grasslike guilds; (3) tolerance and sensitivity measures; and (4) ecological process attributes based on dominance and persistent litter taxa. Depending whether the metric relationship with disturbance was linear or logarithmic, metric scoring criteria were respectively developed by trisecting below the $95^{th}$ percentile or scoring metrics directly from simple plots. Metrics were strongly correlated with chloride and phosphorus in the water column and copper, nickel, and zinc in the sediments. The metrics were combined and presented to form a plant-based multimetric index of biological integrity (IBI) for depressional wetlands. Individual metrics and the multimetric wetland plant index are clearly able to distinguish impaired agricultural and urban sites from the reference sites. The vegetation IBI would be suitable for assessing wetland quality for status and trends analysis.

## INTRODUCTION

In Minnesota, as in the North Central Plains region of North America, once vast reaches of prairie potholes and other wetland types have been drained and filled. It is estimated that in pre-Columbian times Minnesota supported approximately 18.6 million acres of wetland (Anderson and Craig 1984). Of this original wetland resource an estimated 10.6 million acres remain (Jaschke et al 2000). Various state and federal wetland protection efforts have been successful at slowing the tide of wetland loss due to draining and filling actions. Even though it appears the loss of wetland acres has been significantly slowed, there is very little data or information concerning the relative condition or quality of wetlands at any scale. There has been some use of professional judgment based functional assessment tools (Wells 1988; Ammann and Lindley 1991; Smith et al 1995; MIWG 1996) within the context of local comprehensive wetland plans. A difficult to resolve inherent problem with these best professional judgment approaches are evaluator bias. Wetlands are recognized as being waters of the nation and therefore subject to the provisions of the Federal Clean Water Act (33 USC Chapter 26). One of the often quoted goals of the Federal Clean Water Act is to protect the physical, chemical and biological integrity of the Nations waters. Several states within the United States have passed wetland protection laws or rules. Minnesota has codified wetland narrative water quality standards (Minnesota Rules, Ch. 7050).

Minnesota has also enacted legislation known as the Wetland Conservation Act of 1991 (MN Laws, chapter 354, as amended by Laws 1993, chapter 175; Laws 1994, chapter 627; Laws 1996, chapter 462; and Laws 2000, chapter 382) and the supporting administrative rules (Minnesota Rules, Ch. 8420). The purpose of the Wetland Conservation Act is to: (A) achieve no net loss in the quantity, quality, and biological diversity of Minnesota's existing wetlands; (B) increase the quantity, quality, and biological diversity of Minnesota's wetlands by restoring or enhancing diminished or drained wetlands; (C) avoid direct or indirect impacts from activities that destroy or diminish the quantity, quality, and biological diversity of wetlands; and (D) replace wetland values where avoidance of activity is not feasible and prudent.

Ten years after this landmark legislation was enacted we are only beginning to develop a process to assess the diminishment of wetland biological quality and diversity. Currently estimates of wetland quality are derived from best professional based wetland functional assessment methods. Better tools and approaches to directly measure wetland biological quality and diversity are needed. The wetland index of biological integrity (IBI) is a robust multimetric wetland assessment method which can be used to prioritize wetlands for protection, management or restoration efforts. The term metric refers to an attribute of the biological community, in this case plant based, which shows a predictable response to human disturbance (Karr and Chu 1999). A multimetric index removes investigator bias to provide assessments of biological community stability (Simon et al 2001). Multimetric indexes have been very useful in assessing condition in other surface water types,

especially streams (Karr et al 1986, Simon and Davis 1995).

Several investigators have proposed promising plant-based metrics or multimetric indexes for wetlands suitable for use in the Upper Great Lakes Region (Galatowitsch 1999; Simon et al 2001). Plant-based wetland mulitmetric indexes have also been developed and tested in Ohio (Mack 2001). Though not a multimetric index, the Floristic Quality Assessment Index (FQAI) has been shown to be a very strong indicator of human disturbance in wetlands (Lopez and Fennessy 2002). The FQAI requires the assignment of coefficients of conservatism (CC) to all plant species within a local or regional flora. Coefficients of conservatism have not been developed or validated in Minnesota, though some Minnesota investigators have effectively used CCs (Donna Perleberg, personal communication) developed for lakes in WI (Nichols 1999).

Under Section 305b of the Clean Water Act, states are responsible for reporting on the status and condition of waters within their jurisdiction including wetlands (USEPA 1997). Ideally results from 305(b) reports would be used by state and local wetland managers, enabling them to set clear and consistent goals and objectives which can be implemented in their local comprehensive water plans. State water resource managers are also required to publish lists of impaired waters within their jurisdiction whereby appropriate targets and pollutant (TMDL, Section 303d) loads can be reduced and remediation plans can be developed. The IBI assessment approach is particularly well suited to providing an assessment structure which can be useful in 305(b) and 303(d) processes.

The IBI approach provides a direct measure of aquatic life represented by diverse natural flora and faunal communities. Indexes of biological integrity can be effectively used to define stress response thresholds and increase confidence of management decisions (Karr 1986; Simon and Davis 1995). Index of biological integrity results are intuitive and resonate with citizen advocates and other people who lack professional environmental training yet want to see wetlands be protected.

The primary goal of this project was to validate wetland metrics based on the plant community. The metrics to be validated were proposed (Gernes and Helgen 1999) for depressional wetlands in the North Central Hardwood Forest Ecoregion of Central Minnesota. In this paper we discuss the response of the ten metric IBI in an independent data set of 44 large depressional wetlands, to confirm the IBI as being suitable for use in the North Central Hardwood Forest Ecoregion of North America (Omernik 1987).

## METHODS

Forty-four large depressional wetlands were selected for study through a process of contacting local area resource managers and other persons familiar with the wetland resource in their local region. Each of the contacts was asked to recommend wetlands which were known or believed to have been influenced by human activities. Numerous recommendations or site nominations were received from local area resource managers and field reconnaissance visits were made to

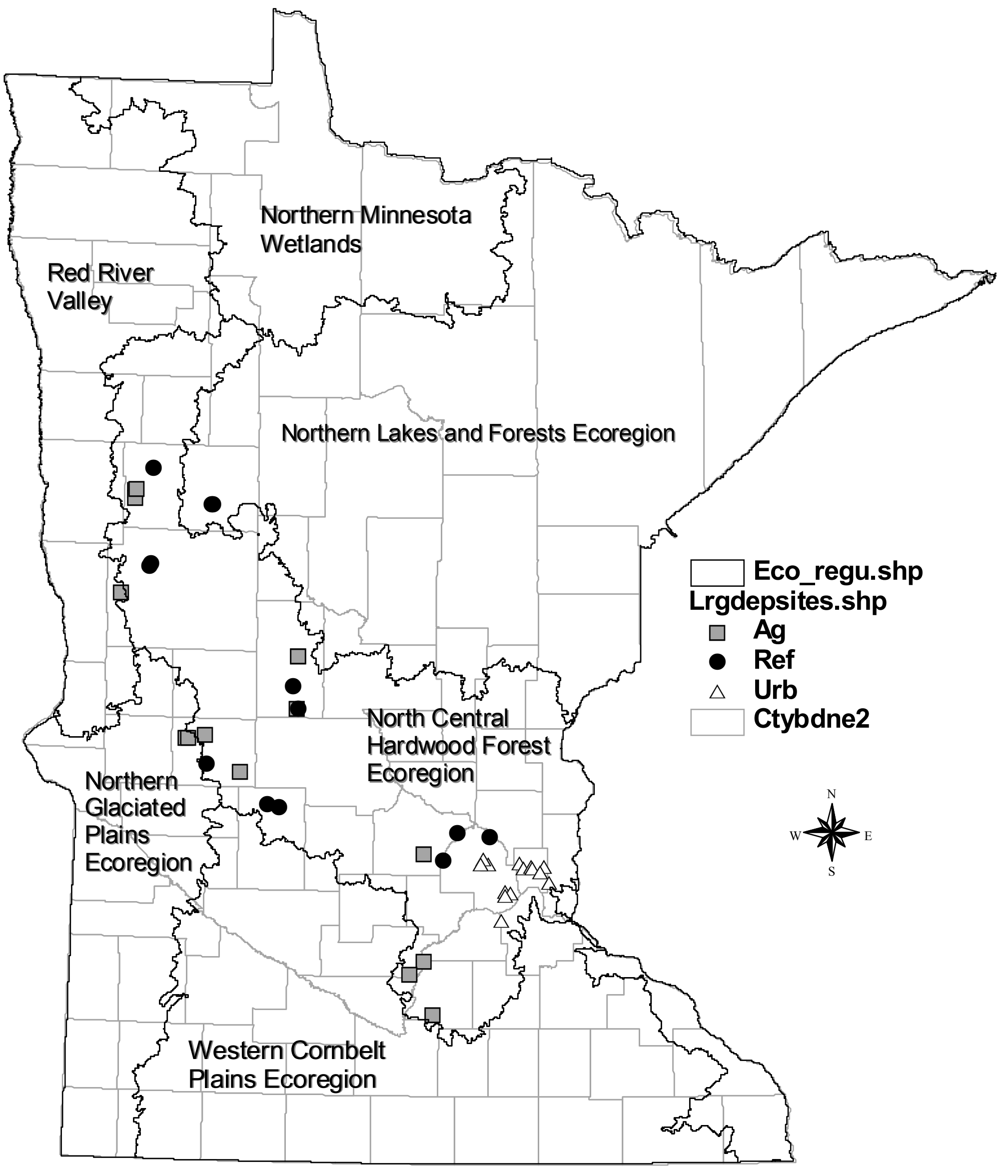


Figure 1. Map showing the locations of the 44 large depressional wetlands in the North Central Hardwood Forest Ecoregion in Minnesota. Ag, agriculture-influenced; Ref, reference wetlands selected to have the least amount of human disturbance; Urb, urban-influenced wetlands. Outlines of counties are shown, and the other ecoregions in the state.

assess the suitability of their recommendations as study sites. Study sites were intentionally chosen to represent a gradient of environmental impact within each primary land use type which resulted in 14 agricultural sites, 16 urban wetlands and 14 least disturbed reference condition wetlands totaling 44 large depressional wetlands being selected for inclusion in the project. Figure 1 illustrates the location of the final large depressional study sites. Sites were distributed through the ecoregion and were representative of the agricultural and urban landuse influences typically found in this region of Minnesota. Supporting site information and disturbance factors are included in Appendix 1.

Large depressional wetlands were defined as being semi-permanently to permanently inundated palustrine wetlands (Cowardin et al 1979). They were typically 10 to 100+ acres in size, though some were 180 acres in size. They typically have an average depth of two meters and a maximum depth of about 3 meters, and typically support a well developed emergent fringe plant community. Large depressional wetlands typically do not support game fish, though other native fish species tolerant to periodic low oxygen conditions were often present.

The emergent plant community was sampled in July 1999 using plot based releve methods as described in Gernes and Helgen (1999) and in accordance with the project quality assurance program plan (MPCA 1999). An inventory of species was completed within each sample plot and coverclass values were estimated for each plant taxon (species) occurring in the plot.

All vascular plant species were identified to species whenever possible. Vascular plant nomenclature followed Ownby and Morley (1991). Plant identification was aided by the following general keys and taxonomic aids: Gleason and Cronquist 1991; Eggers and Reed 1997; Wheeler 1983; Voss 1972; Carlson and Moyle 1968; and Fassett 1957. Only a few vascular plants were not able to be identified to species. Nonvascular taxa were noted and identifiable only to lowest commonly recognized taxonomic level.

Water chemistry samples were collected using an integrated grab sampling technique in accordance with the project quality assurance program plan (MPCA 1999). All water chemistry sampling was completed in June as part of the invertebrate field work associated with another part of this project. Temperature, pH, conductivity, and dissolved oxygen were measured directly in the field. Chloride, total phosphorus, Kjeldahl nitrogen, chlorophyll a, total suspended solids, turbidity, and calcium were analyzed under contract with the Minnesota Department of Health Analytical Chemistry Laboratory, St. Paul, MN. Sediment samples were collected in accordance with the project quality assurance program plan (MPCA 1999). Sediment sample analysis was completed under contract with the Soils Research Analytical Laboratory, within the Agronomy Dept. at the University of Minnesota, St. Paul, MN. More detailed discussion of the chemical sample collection methods and results are discussed by Helgen (2002). Water and sediment chemistry raw data are provided in Appendices 8, 9, and 10. Water and sediment chemistry summary

tables are provided in Appendices 6 and 7.

All biological and chemical data for this project and related MPCA wetland biological criteria development work are managed and able to be queried from a series of Microsoft Access 97® databases. Plant taxa included in these databases were related to taxonomic serial numbers available from the Integrated Taxonomic Information System (ITIS) database. This database is available online for standardized queries or database downloads at http://www.itis.usda.gov/index.html. Statistical analysis was completed using Systat ® 8.0 for Windows. Statistical applications and interpretation were aided by the following references (Gilbert 1981; Kleinbaum and Kupper 1978). Plots were created using Microsoft Office Excel® 97.

### Human Disturbance Rating

Human disturbance at each study site was scored using a qualitative scoring approach of five primary influence factors: (1) condition and intactness of the immediate 50 meter buffer around the wetland; (2) extent and intensity of human landuse disturbance within the immediate landscape; (3) habitat alterations and human activities within the immediate landscape; (4) degree of wetland hydrology alterations, if any; (5) relative concentration of chemical pollution indicators [CL, N, and P in water and Cu and Zn in the sediments] in the wetland; and a minor adjustment factor. Potential scoring values ranged from 0 to 100. Actual values range from 3 to 100 and had a mean of 54.43 and a median of 61.75. See Helgen (2002) for more detailed description and discussion of the HDR scoring procedures.

Appendix 3 includes the human disturbance score (HDS) rating form. Appendix 2 includes online sources of landuse information used in evaluating the HDS factors for each wetland. Appendix 5 provides final HDS individual factor scores and the final HDS result for each wetland.

### Metric Scoring

Metric scoring followed the Karr et al (1986) convention of 5, 3 and 1 with 5 being assigned to the highest biological quality sites. As each metric was developed the results were rank ordered to observe if the vegetation community attribute effectively separated the high quality from the low quality sites. Ideally the reference sites separated from the human-influenced sites at one end of the sorted attribute data. Attributes which achieved a good separation were retained and scoring criteria were developed.

Two approaches were used to develop scoring criteria. The first approach used was to trisect the rank ordered results below the 95$^{th}$ percentile of the maximum result. Metrics having a linear trend relationship with human disturbance were scored using this method. The second scoring approach was to score the metric directly from the plot of the metric attribute results against the human disturbance score. Deriving scoring criteria from the plot was used for metrics having a logarithmic trend relationship with the human disturbance score. Table 1 provides the name and a brief description of each plant metric. Table 1 also provides the final metric scoring criteria, gives the scoring

Table 1. Scoring criteria for 10 wetland vegetation metrics obtained within a 100 $m^2$ releve plot set in the emergent zone of large depressional wetlands

| Metric Name | Description of the Metric | Scoring Criteria | Score method | Score | Ref | Ag | Urb |
|---|---|---|---|---|---|---|---|
| Vas. Genera | Number of vascular genera in the sample | ≥ 14 | Fit to 1999 data | 5 | 5 | 1 | 3 |
| | | 8 - 14 | curve | 3 | 9 | 7 | 1 |
| | | ≤ 7 | | 1 | 0 | 8 | 10 |
| Nonvas Taxa | Number of nonvascular taxa in the sample | ≥2 | Fit to 1999 | 5 | 6 | 2 | 0 |
| | | 1 | curve | 3 | 5 | 2 | 6 |
| | | 0 | | 1 | 3 | 12 | 8 |
| Carex cover | Sum of all Carex species combined cover | > 2 | Fit to 1999 data | 5 | 6 | 2 | 1 |
| | | 0.5 - 2 | curve | 3 | 6 | 3 | 1 |
| | | ≤ 0.4 | | 1 | 2 | 11 | 12 |
| Sensitive Species | Taxa whose presence decreased with disturbance | ≥ 5 | Fit to 1999 data | 5 | 6 | 0 | 1 |
| | | 2 – 4 | curve | 3 | 5 | 7 | 5 |
| | | ≤ 1 | | 1 | 3 | 9 | 8 |
| Tolerant Taxa | Proportion of tolerant taxa to total taxa | ≤ 25.97 | Trisect data | 5 | 5 | 3 | 3 |
| | | 25.98. - 44.8 | below the 95% | 3 | 7 | 8 | 5 |
| | | ≥44.9 | rank | 1 | 2 | 5 | 6 |
| Grasslike | Number of grass, sedge and rush species | ≥ 7 | Trisect data | 5 | 4 | 1 | 2 |
| | | 3 – 6 | below the 95% | 3 | 6 | 8 | 2 |
| | | ≤ 2 | rank | 1 | 4 | 7 | 10 |
| Perennials | Count of all perennial species in the sample | ≥ 18 | Fit to 1999 data | 5 | 7 | 1 | 4 |
| | | 6 - 17 | curve | 3 | 6 | 4 | 5 |
| | | ≤ 5 | | 1 | 1 | 11 | 5 |
| Aquatic Guild | Number of aquatic guild species | ≥ 9 | Trisect data | 5 | 5 | 0 | 2 |
| | | 5 – 8 | below the 95% | 3 | 8 | 6 | 4 |
| | | ≤ 4 | rank | 1 | 1 | 10 | 8 |
| Proportion of dominant 3 taxa cover class | Equitability of perennial plant cover within the sample | ≤ 0.36 | Trisect data | 5 | 5 | 3 | 4 |
| | | 0.35 -.68 | below the 95% | 3 | 8 | 8 | 4 |
| | | ≥ 0.67 | rank | 1 | 1 | 5 | 6 |
| Persistent Litter | Relative cover class (sum of individual cc/total sample cc) taxa with persistentlitter | ≤ 17.4 % | Trisect data | 5 | 5 | 6 | 4 |
| | | 17.3% – 34.6% | below the 95% | 3 | 6 | 4 | 5 |
| | | ≥ 34.7% | 95% rank | 1 | 3 | 6 | 5 |

method for each of the ten metrics and shows the number of sites scoring a 5, 3, and 1 in each a priori landscape setting class.

## RESULTS

One of the goals of the current work was to validate in a new dataset the metrics Gernes and Helgen (1999) proposed. In this study of 44 large depressional wetlands, the original metrics were correlated to the human disturbance score ($r = -0656$, $P < 0.0001$) and were statistically significant. Refinements in the scoring methodology and criteria presented here were believed to be more objective. In these current results the scoring criteria for the nonvascular species metric remained the same as originally proposed. Based on the current standardized scoring methods the scoring criteria changed for seven of the original ten metrics and two new metrics replaced two of the original metrics presented in (Gernes and Helgen 1999).

Detailed descriptions and rationale for the eight original metrics included in the current multimetric index are provided in (Gernes and Helgen 1999). Two new metrics presented here; perennial species count and proportion of dominant 3 taxa cover class were not included in the original proposed IBI. Justification and discussion are provided here for these two new metrics. These two new metrics were substitutions for the previously proposed monocarpic taxa metric and the dominance metric respectively.

Figure 2 illustrates plots of the ten plant metrics plotted against the human disturbance score. Though the pattern varies for each of the metrics all ten of these plots show the expected trend in biological response due to increasing human disturbance. Data points in all the plots are depicted according to the appropriate a priori categories for each site landuse setting; reference (refer), agricultural (agri) and urban. Several of the metric plots have a priori reference sites scoring outside the expected range for a minimally impacted study site. This was not unexpected since the study design and site selection process clearly included a gradient in reference site quality. We found the biological data and the human disturbance score data to be continuous and to have normal distributions; therefore we used parametric regression and Pearson correlation statistics for data analysis.

Plot 2-A illustrates the vascular genera metric. This metric was correlated to the human disturbance score, and the data best fit a logarithmic model ($y = 4.5282 Ln(x) + 26.649$, $R^2 = 0.4585$). Three urban sites Battle Creek (57.5, 20) Mud Lake (45, 20) and Sunset (70, 15) had higher than expected genera counts for their respective human disturbance ratings. Battle Creek and Mud Lake were relatively well buffered by adjacent city parklands and moderate density housing developments. Sunset was a large wetland surrounded by an urban park whose wetland fringe and adjacent upland was planted with wet prairie and upland prairie plants. This planting likely benefited Sunset’s score. Trappers is the one agricultural site outlier (62.5, 17). Though Trappers supported a very narrow emergent fringe community it was rich in sedge and grass species suggesting a ground water discharge helped to buffer the agricultural influences. Scoring criteria for the vascular genera metric changed

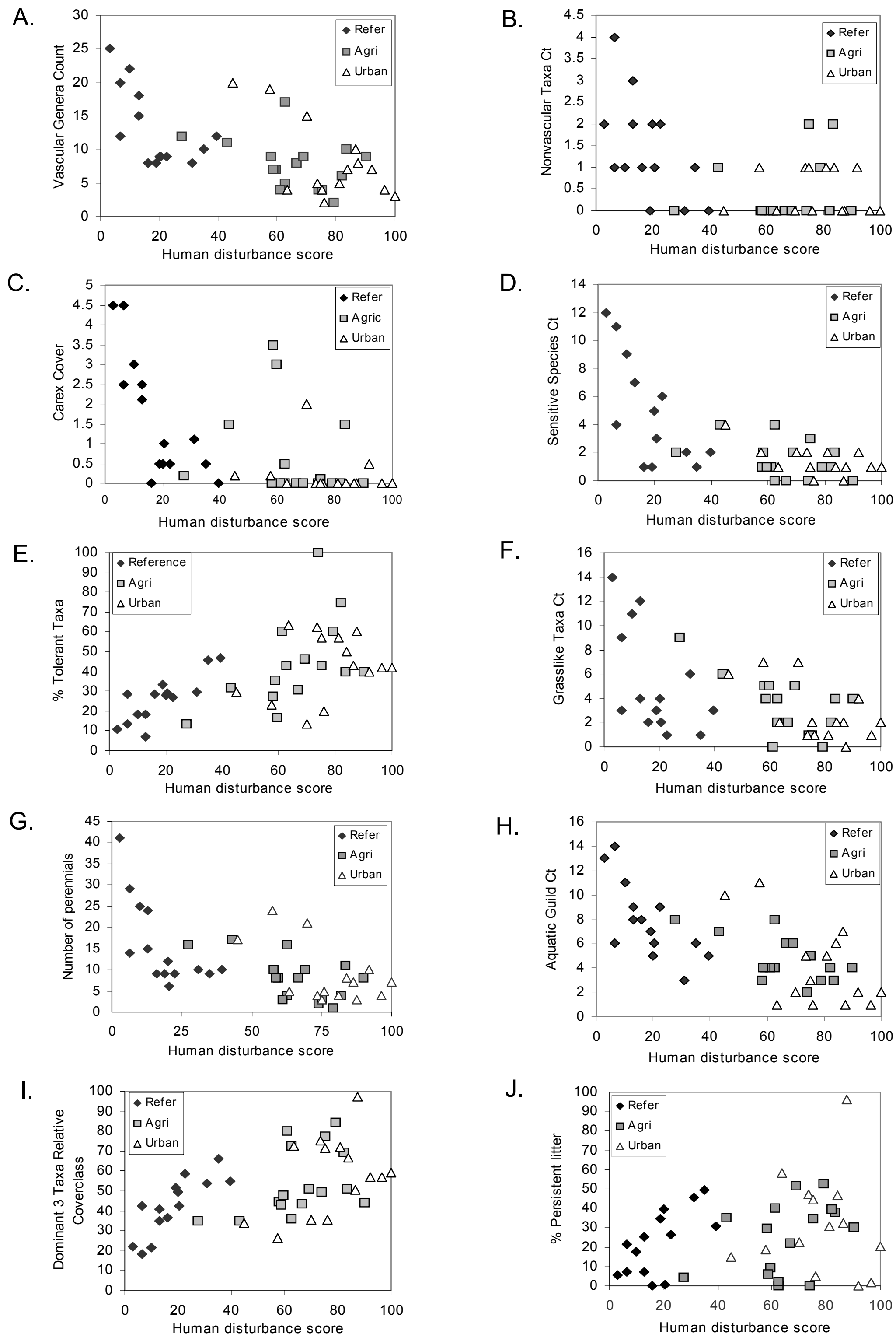


Figure 2. Scatterplots A-J present wetland plant metric data for large depressional wetlands from central Minnesota against Human disturbance score. Site symbols relate to a priori landuse class: reference = Refer; agricultural = Agri; and Urban.

slightly from the metric proposed by Gernes and Helgen (1999).

Figure 2-B illustrates the number of nonvascular taxa relationship with the Human disturbance score (HDS). As expected, this metric has a negative trend with respect to the HDS. The metric score was developed from the plot since a logarithmic model provided the best fit. $y = -0.8452Ln(x) + 3.71$ $R^2 = 0.2779$. Two of the agricultural sites, Lake Park (75, 2) and Malardi (83.5, 2) appeared to be outliers. We acknowledge that this metric has a very narrow range from zero to typically two nonvascular taxa. The human disturbance score suggested that zero or one nonvascular taxa would occur at these two sites. We don't have an explanation why these two sites were able to support two nonvascular taxa. This metric was scored from the plot and resulted in the criteria being the same as originally proposed.

The *Carex* cover plot (2-C) was best fit by a logarithmic equation ($y = -1.0266Ln(x) + 4.6739$, $R^2 = 0.474$). Tyrone Bean (58.5, 3.5) and Skarpness (59.5, 3) both agricultural landscape sites were outliers in this plot. These two sites benefited from intact shorelines and relatively unaltered hydrology compared to many of the other agricultural sites. Sunset (70, 2) was an urban site outlier. As mentioned previously, this site's *Carex* cover result likely benefited from adjacent landscaping efforts. Scoring criteria for the *Carex* cover metric are developed from the plot. These criteria were lowered at the upper end and increased slightly at the lower end of the scale in comparison to the original scoring criteria.

Figure 2-D illustrates the number of sensitive species relationship with the HDS. As expected this metric has a negative trend with respect to the HDS. Scoring criteria were developed from the plots since a logarithmic model fitted the data best $y = -4.0599Ln(x) + 16.029$ $R^2 = 0.6177$. Scoring criteria for this metric increased by one species at all three scoring levels. The sensitive species metric was the strongest metric in this dataset. A list of the species considered to be "sensitive", for purposes of this metric is provided in Appendix 13.

The relationship between the tolerant taxa abundance, measured by coverclass estimates, and the HDS is illustrated in Figure 2-E. As expected they were positively correlated ($y = 0.3764x + 17.075$, $R^2 = 0.3327$). Breen was the one agricultural site outlier (74, 100). Though this site was cropped to near the edge on two sides and it appeared to have significant agricultural influence. Breen's hydrology was relatively natural except for a road bisecting the wetland. In addition the HDS evaluation gave habitat credit to the site being a wildlife management area. Since tolerant taxa data was best fit by a linear model the scoring criteria were derived by trisecting the range of values below the $95^{th}$ percentile, resulting in a much lower criterion between the 3 and 1 level than was used in the original metric.

The grasslike metric related to the HDR is plotted in 2-F. This plot exhibits significant scatter in the metric result, but as expected it was negatively correlated ($y = -0.0612x + 7.1261$, $R^2 = 0.2968$). Several of the a priori wetland sites had fewer than expected grasslike taxa. These sites tended to be marsh

communities dominated by cattails (*Typha* sp.) or wildrice (*Zizinnia palustris*). These types of communities typically are not rich in grasslike species. Scoring for the grasslike taxa was developed by trisecting below the 95th percentile, which resulted in only minor shifts in the scoring criteria compared to the original metric.

Perennial species count is a substitution for the monocarpic species metric used in the proposed IBI. Monocarpic species had been one of the weakest metrics in the previous plant IBI, though it did exhibit a predictable response to human disturbance. A count of perennial species derived from a similar plant life history concept as had been used in the previous monocarpic species metric. Plot 2-G illustrates the perennial count metric against the Human disturbance score (HDS). The response was a negatively correlated logarithmic relationship ($y = -6.7914Ln(x) + 36.198$, $R^2 = 0.5033$). Scoring criteria for this metric were developed from the scatterplot. Two urban sites supported greater numbers of perennial species than expected, Battle Creek (57.5, 24) and Sunset (70, 21). Battle Creek is an important shallow recreational lake in the East Twin Cities Metropolitan area that supports diverse emergent and submergent plant communities. The lake was well buffered on three sides, the fourth side being occupied by an interstate highway, yet five stormwater inlets discharged to the lake and were likely at least partly responsible for conveying seeds of purple loosestrife (*Lythrum salicaria*) which was common along much of the shoreline. Battle Creek Lake has been one of the beetle release sites the local watershed district is sponsoring in an effort to control this problem plant. As mentioned previously, Sunset is another urban wetland situated in a park surrounded by mostly commercial property. It receives significant stormwater discharges, yet its plant community benefited from native plantings along the edge and in the adjacent upland.

The count of aquatic guild plants plotted against the HDS is illustrated in Figure 2-H. This relationship had a fair amount of scatter, though a negative correlation was readily apparent and the high quality sites were clearly separated from the low quality sites. The regression equation was $y = -0.0766x + 9.6692$ and the $R^2$ value of 0.48 was considered significant. Scoring criteria for this metric were lowered at the upper end and remained essentially the same at the lower end of the scale in comparison to the original scoring criteria.

In the original proposed plant IBI an ecological dominance metric based on coverclass estimate results was used as a measure of species equitability. Though this metric showed an apparent predicable response to human disturbance other authors (Kerans and Karr 1994; Fennessy et al 2001) have developed or proposed metrics based on the top one, two or three dominant taxa abundance for invertebrate data or when using vegetation coverclass estimates. In this work the concept of dominance is presented as the coverclass values of the three dominant species in proportion with the sum of coverclass estimates from all the species by site. Figure 2-I is a plot of the dominant 3 species plotted against the HDS. Though there was a wide degree of scatter in this plot, overall it exhibited a positive linear correlation ($y = 0.3416x + 32.948$, $R^2$ =

0.3002). Scoring criteria for this metric were developed by trisecting the range of the values below the 95th percentile.

In the proposed plant IBI (Gernes and Helgen 1999) the persistent standing litter metric showed a strong relationship between human disturbance and the sum of cover values for taxa which produce recalcitrant litter. Taxa recognized as producing persistent litter included: *Lythrum salicaria*, *Polygonum* sp., *Phragmites* sp., *Scirpus* sp., *Sparganium* sp. and *Typha* sp. This metric was not as strongly related to human disturbance in this dataset. While validating this metric, we found a stronger relationship between the sum of coverclasses of taxa with persistent litter in proportion with the sum of coverclasses of all taxa in the sample. The metric has been redeveloped to express this stronger relationship. Figure 2-J illustrates the proportion of persistent standing litter metric plotted against the HDS. Though the plot exhibits a linear trend with a positive correlation ($y = 0.1833x + 16.063$, $R^2 = 0.0674$) it was a very weak statistical relationship. Even though this relationship is statistically weak the attribute was still able to distinguish between the highest quality reference sites and the most severely impaired sites and it exhibited a predictable response to human disturbance. By meeting these two criteria this metric is retained in this work. This metric attempts to get at the biogeochemical cycling, particularly carbon cycling which has been reported to be an important process in wetlands (Davis and van der Valk 1978; Mitsch and Gosselink 1993; Cronk and Fennessy 2001).

Exclusions or data filters were included in several of the metric queries to strengthen their response to human disturbance. The vascular genera metric, the *Carex* Cover metric, the sensitive species metric, the Grasslike metric and the Perennial Count metric included only native taxa and only wetland plant species having moderate to high affinity requirements for saturated or inundated habitats [obl, fac+, fac-, facw, fac, facw+ or facw-]. These terms represent accepted hydrologic affinities as assigned by the U.S. Fish and Wildlife Service as regional wetland plant indicators (Reed 1988).

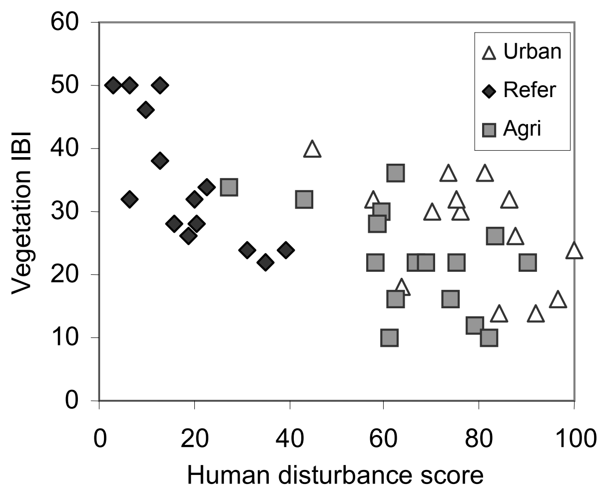


Figure 3. Plot of wetland plant index of biological integrity (IBI) for 44 large depressional wetlands from Central Minnesota against Human disturbance score. Site symbols relate to a priori landuse class: reference = Refer; agricultural = Agri; and Urban.

When all the metric results were scored for each site and aggregated together into the index of biological integrity (IBI) score we observed a nice separation of the most disturbed sites from the high quality reference sites. Figure 3 showed a positive correlation between the plant index of biological integrity scores for the 44 large

depressional sites and the human disturbance score (y = -0.2677x + 40.706, $R^2$ = 0.4982). There was a clear biological response gradient and a human disturbance gradient represented by the sites in the study. Several of the a priori reference sites scored lower than expected based on the HDS. The reference site Zager (13, 50) had a similar HDS score as the New London reference site (16, 28). Both sites were mostly surrounded by oak forest, both were within wildlife management areas and both had a history of agricultural grazing practices. The respective plant communities were however different.

New London supported a mudflat shoreline with few grasses and sedges and an interrupted band of wildrice (*Zizinna palustris*). Zager supported a narrow emergent plant community rich in grasses and sedges along the shoreline. Detailed data on water budgets of these two sites was not available, though the conductivity of Zager was 1620 microsiemens compared with 706 uS at New London which could suggest ground water inputs were greater at Zager. There was no apparent human caused explanation for the difference in plant communities at these two sites. Thus in making a final assessment, other data in addition to the plant IBI results may be necessary to accurately determine the degree of human influence. Table 2 presents the scoring value for each metric for each of the 44 study sites. Study sites are sorted in descending order of IBI score. Three assessment classes of wetland biological condition; excellent, good and poor are presented. Thresholds for these assessment classes were derived by trisecting the rank ordered sites below the $95^{th}$ percentile. All of the a priori reference sites occurred in either the excellent or good assessment class. Three urban sites and one agricultural site were in the excellent class. In this same project the invertebrate IBI results (Helgen 2002) for the urban site Mud Lake is in near exact agreement with the plant data (45, 38). The invertebrate results are somewhat lower for the urban site Battle Creek compared with the plant results (57.5, 40). The urban site Sunset also had a somewhat lower invertebrate IBI score (30) compared with the plant results for this site (70, 36). Trappers, the one agricultural site scoring in the excellent class for the plants (62.5, 36) scored much lower based on the invertebrate IBI score of 20. Trappers was a large open water wetland with only a narrow fringe of emergent plants, mostly grasses and sedges, growing along the shore.

Two water chemistry parameters, chloride and total phosphorus are significantly correlated with several of the metrics (Table 3). Several metrics are also significantly related to several heavy metals, particularly copper, nickel and zinc concentrations in the sediments. These three metals are very toxic to plants and other forms of aquatic life. Chloride had the most consistent response with the plant metrics being significantly correlated to all but the vascular genera, nonvascular taxa and the persistent litter metric. These same three metrics showed moderate correlation with these five chemical variables, but none of these correlations were significant. Out of the ten plant metrics, the persistent litter showed the weakest relationships with these five water and sediment variables. The grasslike metric is related to chloride in the water, and copper, nickel and zinc in

the sediments. The grasslike metric was significantly correlated with the greatest number of chemical variables among the ten metrics.

Table 2. Vegetation metric scores for 44 large depressional wetlands in the North Central Hardwood Forest Ecoregion of Minnesota. Scores of metrics are summed to a total site score (Index of Biological Integrity) which defines the condition category.

| A priori class | SiteName | Vascul Genera | Nonvas | *Carex* Cover | Sensit Species | Toler Taxa | Grass Like | Peren Count | Aquatic Guild | Dom3 | Persist Litter | Plant IBI | Condition category |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ref | Bloom | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 50 | |
| Ref | Minnow | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 50 | |
| Ref | Zager | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 50 | |
| Ref | Prairie | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 46 | Excellent |
| Urb | Battle Crk | 5 | 3 | 1 | 3 | 5 | 5 | 5 | 5 | 5 | 3 | 40 | Conditon |
| Ref | Glacial | 5 | 5 | 5 | 3 | 5 | 3 | 3 | 3 | 3 | 3 | 38 | |
| Urb | Mud | 5 | 1 | 1 | 5 | 3 | 3 | 5 | 5 | 5 | 5 | 38 | |
| Urb | Sunset | 5 | 1 | 3 | 3 | 5 | 5 | 5 | 1 | 5 | 3 | 36 | |
| Ag | Trappers | 5 | 1 | 3 | 3 | 5 | 3 | 3 | 3 | 5 | 5 | 36 | |
| Ag | Bunker | 3 | 1 | 1 | 3 | 5 | 5 | 3 | 3 | 5 | 5 | 34 | |
| Ref | Overby | 3 | 5 | 3 | 5 | 3 | 1 | 3 | 5 | 3 | 3 | 34 | |
| Ref | Elm Crk | 3 | 5 | 3 | 5 | 3 | 3 | 3 | 3 | 3 | 1 | 32 | |
| Ref | Field | 3 | 3 | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 32 | |
| Ag | Sheets Big | 3 | 3 | 3 | 3 | 3 | 3 | 5 | 3 | 5 | 1 | 32 | |
| Ref | Cataract | 3 | 3 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 5 | 30 | |
| Ag | Skarpness | 1 | 1 | 5 | 3 | 5 | 3 | 3 | 1 | 3 | 5 | 30 | |
| Ref | New Londo | 3 | 3 | 1 | 1 | 3 | 1 | 3 | 3 | 5 | 5 | 28 | |
| Urb | Rose Golf | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 | 5 | 28 | Good |
| Ag | Tyrone Be | 1 | 1 | 5 | 3 | 3 | 3 | 3 | 1 | 3 | 5 | 28 | Condition |
| Ref | Lake 21 | 3 | 1 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 26 | |
| Ag | Malardi | 3 | 5 | 3 | 1 | 3 | 3 | 3 | 1 | 3 | 1 | 26 | |
| Ref | Donley Irg | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 1 | 3 | 1 | 24 | |
| Ref | Kasma | 3 | 1 | 1 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 24 | |
| Ag | Lake Park | 1 | 5 | 1 | 3 | 3 | 1 | 1 | 3 | 1 | 3 | 22 | |
| Ref | Lashier | 3 | 3 | 3 | 3 | 1 | 1 | 3 | 3 | 1 | 1 | 22 | |
| Ag | New Prairi | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 3 | 3 | 3 | 22 | |
| Urb | Round | 1 | 1 | 1 | 1 | 5 | 1 | 1 | 1 | 5 | 5 | 22 | |
| Urb | Savage | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 3 | 3 | 3 | 22 | |
| Ag | Seter | 3 | 1 | 1 | 3 | 1 | 3 | 3 | 3 | 3 | 1 | 22 | |
| Ag | Sheets Sm | 3 | 1 | 1 | 1 | 3 | 3 | 3 | 1 | 3 | 3 | 22 | |
| Ag | Sucker No | 3 | 1 | 1 | 1 | 3 | 3 | 3 | 1 | 3 | 3 | 22 | |
| Urb | Legion | 1 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 18 | |
| Urb | Lost | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 18 | |
| Ag | Breen | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 5 | 16 | |
| Urb | Grass | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 3 | 3 | 16 | |
| Ag | Ney | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 5 | 16 | |
| Urb | Turtle | 1 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 1 | 16 | Poor |
| Urb | Wakefield | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 16 | Condition |
| Ag | Davis | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | |
| Urb | Jones | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 12 | |
| Urb | Wood | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | |
| Urb | Casey | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 10 | |
| Ag | Sethre | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 10 | |
| Ag | Sigler | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 10 | |

During field sampling two independent replicate samples were taken within the emergent plant community at six of the 44 study sites. These sites were: Elm Creek; Minnow; Sethre; Skarpness; Mud Lake and Wood Lake. The first two of these sites were a priori reference sites, the second two sites were agricultural sites and the last two were urban sites. The two samples from each site were considered as replicate samples to evaluate the precision or variability in the plant sampling methods. Table 4 presents paired t-test results for these replicate samples by metric and plant IBI. There was no statistical difference between the six replicate samples for any of the metrics or the plant IBI. Plant sampling methods used in this work were therefore considered to be reasonably precise, not prone to high variability and yielded reliable results.

Table 3. Pearson correlation values for ten wetland plant metrics related to important sediment and water chemistry variables.

| *Metric Scores* | *Copper in sediments* | | *Nickel in sediments* | | *Zinc in sediments* | |
|---|---|---|---|---|---|---|
| | r | P | r | P | r | P |
| Vasular genera | -0.483 | 0.054 | -0.418 | 0.287 | -0.456 | 0.112 |
| Nonvascular taxa | -0.197 | 1.000 | -0.224 | 1.000 | -0.160 | 1.000 |
| Carex cover | -0.443 | 0.155 | -0.429 | 0.220 | -0.435 | 0.190 |
| Sensitive species | -0.3391 | 0.521 | -0.390 | 0.528 | -0.404 | 0.391 |
| Tolerant taxa | 0.464 | 0.090 | 0.566 * | 0.004 | 0.496 * | 0.037 |
| Grasslike | -.0.557 * | 0.005 | -0.561 * | 0.004 | -0.574 * | 0.003 |
| Perennial count | -0486 * | 0.049 | -0.501 | 0.032 | -0.461 | 0.098 |
| Aquatic guild | -0.403 | 0.401 | -0.339 | 1.000 | -0.352 | 1.000 |
| Dom3CC | 0.494 * | 0.039 | 0.527 * | 0.014 | 0.466 | 0.086 |
| Persistent litter | 0.182 | 1.000 | 0.327 | 1.000 | 0.302 | 1.000 |
| Composite Scores | | | | | | |
| HDR | 0.535 * | 0.002 | 0.398 | 0.074 | 0.525 * | 0.003 |
| Plant IBI | -0.519 * | 0.018 | -0.531 * | 0.012 | -0.530 * | 0.013 |

| *Metric Scores* | *Chloride in water* | | *Total Phosphorus in water* | |
|---|---|---|---|---|
| | r | P | r | P |
| Vasular genera | -0.485 | 0.051 | -0.407 | 0.364 |
| Nonvascular taxa | -0.390 | 0.531 | -0.365 | 0.886 |
| Carex cover | -0.535 * | 0.011 | -0.408 | 0.361 |
| Sensitive species | -0.581 * | 0.002 | -0.547 * | 0.007 |
| Tolerant taxa | 0.488 * | 0.047 | 0.464 | 0.091 |
| Grasslike | -0.538 * | 0.010 | -0.403 | 0.400 |
| Perennial count | -0.492 * | 0.042 | -.0486 * | 0.050 |
| Aquatic guild | -0.554 * | 0.006 | -0.515 * | 0.021 |
| Dom3CC | 0.486 * | 0.050 | 0.301 | 1.000 |
| Persistent litter | 0.412 | 0.330 | 0.095 | 1.000 |
| Composite Scores | | | | |
| HDR | 0.832 * | 0.000 | 0.690 * | 0.000 |
| Plant IBI | -0.613 * | 0.001 | -0.504 * | 0.029 |

* Represents a significant correlation , $P \leq 0.05$

Karr et al (1986); Simon and Davis (1995) and several other authors reported relationships between drainage area and species richness in stream system biota. Consequently, many sampling methods recommend increasing sample effort as size of the community increases. This relationship has unfortunately partly supported the perception that larger wetlands support more species and are therefore more valuable than smaller wetlands that accordingly would support fewer species. In this work we found essentially no correlation (r = 0.166, P = 0.562) between wetland size and the number of plant genera occurring in the sample. Similarly there was not a statistically significant correlation (r = 0.179, P = 0.489) between the plant IBI results and wetland size. In this same study Helgen (2002) found the total number of invertebrate taxa, however did increase significantly with the size of the wetland (log of acres, p<.004, r =.422).

Table 4. Paired t-Test statistic assuming unequal variances by metric and wetland plant IBI for replicate samples at 6 study sites during 1999. Infer no statistical difference between the sample means if t < T (0.05) = 2.306 with 5 degrees of freedom.

| Metric | t-statistic |
|---|---|
| Vas Genera | -0.2265 |
| Nonv Taxa | 0.4344 |
| *Carex* Cover | 0.1107 |
| Sensitive Species | -0.5659 |
| Tolerant Taxa | 0.3482 |
| Grasslike | -0.6494 |
| Perennials | -0.1013 |
| Aquatic Guild | -0.0826 |
| Prop Dom3 Coverclass | 0.3123 |
| Persistent Litter | -0.1029 |
| Plant IBI | -0.0775 |

To further evaluate the effect of wetland size, we grouped our study set of wetlands into two groups, wetlands larger than 30 acres (n = 20) and wetlands smaller than 30 acres (n = 24). Separation at 30 acres was chosen as it seemed a reasonable size breakpoint to differentiate large depressional wetlands (> 30 acres) from small depressional wetlands (< 30 acres). Using paired t-test analysis and assuming equal variances we were not surprised to find no significant difference [t (-1.13) < T (0.05), 42 = 2.02] for the genera count between small and large depressional wetlands. Again, similarly with the plant IBI there was not a significant difference in the IBI means [t (-1.13) < T (0.05, 42 = 2.02] between small depressional wetlands and large depressional wetlands.

## DISCUSSION

Wetlands are widely recognized for their functional attributes and important biological, geophysical and biogeochemical contributions within a landscape. One of the functional attributes most often attributed to wetlands is water quality protection. In application this function refers to the potential for wetlands to buffer or protect against pollution in downstream waters. Wetlands are however typically not thought of as suffering themselves from water quality degradation. Many of the functions attributed to wetlands exist within a landscape or watershed context.

Many wetland assessment methods have been developed. Most of the wetland

assessment methods use a functional assessment approach. It is noteworthy that the functional assessment approach is typically not taken with other surface water types such as streams and lakes. Assessment methods in these waterbodies typically focus on less subjective or integrative variables such as trophic status (Carlson 1977) or biological integrity (Karr et al 1986, Karr and Chu 1999; Niemela and Feist 2002). Even though lakes and streams provide many of the very same functions as wetlands. For some recognized wetland functions such as long-term nutrient assimilation, lakes and streams may actually be more effective than wetlands.

Largely due to a regulatory framework intended to protect wetlands from drain and fill activities wetland functional assessment methods have attempted to provide an objective basis to approve or condition wetland permits. However, wetland functional assessment tools are largely ineffective at evaluating the condition of wetlands and the degree to which their ecological or biological integrity have been depleted or otherwise polluted. Some of these methods use reference condition concepts and may employ simple estimates of certain observational univariate measures of biology such as plant community richness or relative presence of aggressive or nonnative plant species such as Purple Loosestrife (*Lythrum salicaria*) or Reed canary grass (*Phalaris arundinacea*). Though important determinants of plant community integrity these subjective measures fall short of the intent to assess the biological integrity or what might be termed "health" of the wetland. An evaluation of wetland condition is needed for purposes of monitoring and reporting on status and trends as required in the 305(b) reports (USEPA 1997). To assess the depletion of biological capital inherent within wetland systems a more robust biological or ecological approach is needed. The index of biological integrity (IBI) offers such an approach. The IBI approach can also be used to evaluate the relative success of wetland restorations (Galatowitsh et al 1999). A biological index will also be useful for assessing effectiveness or success of various best management practices. On a larger scale a wetland IBI supports efforts to assess small scale recovery within minor watersheds which in turn relate to measurable incremental improvements in impaired watersheds or drainage basins. Because wetlands integrate the land and water systems, monitoring their condition can serve as effective indicators of watershed condition.

There are two objectives within the work discussed here. The first objective was to validate the expected performance of a proposed (Gernes and Helgen 1999) plant based index of biological integrity (IBI) for depressional wetlands. A second objective was to determine the reliability of this IBI in large depressional wetlands which are frequently recognized as being shallow lakes.

Results discussed here are based on sampling the wetland plant community within the emergent zone. Forty four study sites within the North Central Hardwood Forest Ecoregion, or just across the border in adjacent Ecoregions, were sampled to validate the performance of the plant IBI for large depressional wetlands. Results from this

sampling included 189 plant species representing 58 plant families.

The metric scoring approach used represents a more standardized method than was used previously (Gernes and Helgen 1999). Scoring metrics at three levels based on a trisection of the data follows Karr et al (1986). More recently several investigators have used a 0 to 100 scoring scale, using three, four or five scoring levels (Lyons et al 2001; Mack 2001; and Niemela and Feist 2002). A 0 to 100 scoring scale is more intuitive and easily communicated to a diverse audience. In future work we may recalibrate these metrics to a 0 to 100 scale. However, we intend to wait until completion of another project now underway to examine the statistical power of this index and thereby determine if three or four statistically significant scoring levels should be used.

We presented here several modifications, mostly in the scoring criteria, to the original metrics. In the past, scoring criteria were established by trisecting the data across the range of values with some adjustment made to fit natural breaks as appropriate. Five of the ten metrics presented here were scored by mathematically trisecting the scoring range below the 95th percentile rank as represented by the high quality reference condition. This scoring method eliminated most of the subjectivity and followed a standardized approach. Scoring criteria for the other five metrics were developed from the plot of the metric against the human disturbance gradient. Though this scoring approach was somewhat more subjective it attained scoring thresholds which best fit the curvilinear biological response pattern exhibited by those five metrics and corresponding human disturbance data. Both scoring approaches are recognized as appropriate depending on the shape and nature of the biological response curve (Karr and Chu 1999).

Two new metrics were substituted into the plant IBI. Both of these metrics have been used elsewhere or suggested by other investigators (Fennessy et al 2001; Simon et al 2001). The perennial count metric was substituted for the previously used monocarpic taxa. Both of these metrics apply the concept of plant life history strategy. Rather than relying on a measure of importance in the short-lived annual/biennial plants in the wetland community the perennial count metric evaluated the richness of the longer-lived perennial species. Counts of perennial species in the sample gave a strong response to human disturbance and it was an easy attribute to communicate and evaluate. There was a strong correlation ($r = 0.94$) between the count of perennial species and the number of vascular genera which suggested a high degree of redundancy between them. Though there were clear differences in these two plants community attributes. Perennial count was a count of species compared with genera count, which as the name implies, was based on genera. Perennial count was based on life history strategy and partly represents the stability of the plant community compared with the genera count which is a measure of genera richness and not necessarily related to stability.

The second metric substitution was the dominant three metric being substituted for the previously used dominance metric. Conceptually these two metrics

both represented the equitability or distribution of cover values among the taxa within the sample. The original metric measure resulted from a mathematical formula (Odom 1971). The Dominant 3 taxa metric was calculated as the sum of the relative cover values of the top three dominant taxa. Dominance or dominant one two or three metrics applies important fundamental principles of ecology and have been included in multimetric indexes by several investigators (Kerans and Karr 1994; Simon and Davis 1995; and Simon et al 2001).

The persistent litter metric was the weakest of the ten plant metrics included in the index. Even after making the cover values for the persistent litter taxa proportional to the total cover in each sample, the response of the metric remained statistically weak related to the HDS and the selected chemical factors. There were several reasons why this metric was retained even though it was statistically weak.

Morphologically altered sites often result in a narrow band of emergent plants at the edge of the water. This resulted in one of the confounding issues with the persistent litter metric. Examples of morphologic alterations to wetlands were excavation or instances where water levels have been raised due to dams or berms installed on outlets. Wetlands with these kinds of alterations frequently exhibited characteristic narrow rings of emergent plants at the edge of the water. Typically the emergent fringe vegetation in these wetlands was dominated by plants such as grasses and sedges or shrubs like willows (*Salix* sp.) and dogwoods (*Cornus* sp.) which do not produce recalcitrant or persistent litter, as defined within this metric. Though these wetland plant communities may have scored poorly in other metrics they generally scored well for this metric. In interpreting results from this metric it was important to review data plots to observe the positive correlation response trend to human disturbance (Figure 2-J). Particularly with the reference sites we noted a strong positive trend line, the upper bounds of which is clearly defined with little scatter. Below this trend line there is a great deal of scatter. This wedge shaped trend has been called a factor ceiling distribution (Thompson et al 1996; Karr and Chu 1999). Thompson et al (1996) suggests that the most meaningful ecological information can be taken from the "factor ceiling" line and the points below this line are likely explained by other factors. Additionally when we removed the eight wetlands believed to have experienced a morphological change due to excavation or installation of a berm we found a much stronger statistical relationship between this metric and the HDS ($y = 1.0217x + 5.3993$, $R^2 = 0.52$). In a previous data set (Gernes and Helgen 1999) the persistent litter metric was one of the stronger metrics and represented a strong response to human disturbance ($R^2 = 0.57$). Carbon and nutrient cycling is one of the important plant and microbial community mediated ecological processes occurring in wetlands (Mitsch and Gosselink 1993; Cronk and Fennessy 2001). This metric was intended to be a simple field representation of these processes in the plant community and indicate when they had become unbalanced.

Biological metrics respond to many disturbance factors some of which are

apparent or readily measured, other disturbance factors may be more subtle and less commonly measured or resulted from synergistic combinations of chemical, physical and biological interaction. Metrics developed and presented here were related to an integrated qualitative human disturbance index based on factors of landuse, condition of the immediate buffer and relative ranking of selected chemistry parameters (Helgen 2002). Metrics were also related to single factor water and sediment chemical variables. Even though we found statistically significant correlations between these variables we believe these models could be improved upon by developing a more integrated and precise measurement of human disturbance. However, the approach discussed here shows a satisfactory measure which was relatively inexpensive and easy to develop.

Opponents of wetland biological indexes frequently suggest wetlands are too variable hydrologically, chemically and biologically to develop effective and reliable assessment indexes. Indeed wetlands are complex ecosystems that do vary in response to seasonal changes, climatic cycles or hydrologic disturbances influenced by natural factors like floods or beaver dams. Ecological succession in wetlands (van der Valk 1981), evolution and geologic influences can also result in changes in wetlands, though normally at a slow rate. These various processes have resulted in a great variation in wetlands across the landscape of a state as ecologically diverse as Minnesota. Consequently there are several wetland systems and subsystems as well as hydrogeomorphic classes of wetlands in Minnesota (Cowardin et al 1979; Brinson 1993; Eggers and Reed 1997) which vary regionally. Proper classification of water resources is an essential premise of multimetric index development (Karr and Chu 1999). These wetland classification systems allow us to appropriately stratify these wetland differences and dampen the variability. Accordingly a biological index applicability or comparison domain is restricted to a single or related wetland hydrogeomorphic class and stratified within the same ecoregion where the index has been developed and tested until further validation can be done outside of the initial strata. When following these design principles wetlands are not chaotic highly variable systems. Rather they follow clear patterns and show predictable responses to human perturbations.

The multimetric index we present may be suitable to other wetland types and/or regions of Minnesota. We plan to next test the applicability of this index to the southern region of Minnesota. This will include an expansion to the Western Corn Belt Plains and Northern Glaciated Plains Ecoregions. These ecoregions make up most of the historic prairie biome in Southern Minnesota. We are cautiously optimistic that the index presented and discussed here will readily transfer further south and west since the natural wetland plant communities in this region of Minnesota are similarly dominated by herbaceous plants, mainly grasses, sedges and forbs. There may be a need to recalibrate some of the metrics for these new ecoregions or even possibly substitute in a few new metrics. Work to expand the applicability of the wetland plant biological index will benefit from what has been learned in this current work. Specifically the

aquatic plant community in the near-shore area of depressional wetlands, including large depressional wetlands, located in the North Central Hardwood Forest Ecoregion can be a predictable and effective indicator of the degree of human influence and can be useful for assessing wetland condition or health.

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Appendix 1. Name of 1999 large depressional wetlands with type (Urban, Reference or Agricultural), size in hectares (ha) and acres, County, name of USGS Quad map, lattitude and longitude.

| Site Name | Type | SizeHa | Acres | County | USGS Quad | LAT | LON |
|---|---|---|---|---|---|---|---|
| Battle | Urb | 43.8 | 108.3 | Washington | Lake Elmo | 44 56 29.15 | 92 58 19.38 |
| Bloom | Ref | 12.0 | 29.7 | Becker | Detroit Lakes | 46 50 55.69460 | 95 31 23.30567 |
| Breen | Ag | 12.1 | 29.9 | LeSueur | Cleveland | 44 15 46.90415 | 93 48 35.44467 |
| Bunker | Ag | 19.1 | 47.1 | Todd | Ward Springs | 45 49 00.28470 | 94 50 21.23770 |
| Casey | Urb | 4.9 | 12.1 | Ramsey | White Bear W. | 45 01 16.91169 | 93 00 48.07284 |
| Cateract | Ref | 12.8 | 31.6 | Ottertail | Lake Lida | 46 32 06.06668 | 95 57 29.22868 |
| Davis | Ag | 9.0 | 22.3 | Becker | Lake Park | 46 54 22.44965 | 96 06 09.86690 |
| Donley Lg. N | Ref | 5.5 | 13.6 | Becker | Ogema | 47 01 27.92757 | 95 57 50.07200 |
| Field | Ref | 32.5 | 80.3 | Ottertail | Lake Lida | 46 31 14.32917 | 95 58 09.81661 |
| Glacial | Ref | 71.5 | 176.8 | Pope | Starbuck | 45 31 19.20951 | 95 30 03.59989 |
| Grass | Urb | 10.9 | 26.9 | Hennepin | Minneapolis S. | 44 53 33.19706 | 93 17 47.71030 |
| Jones | Urb | 13.6 | 33.6 | Ramsey | New Brighton | 45 02 43.37 | 93 11 38.69 |
| Kasma | Ref | 7.7 | 19.0 | Hennepin | Rockford/Delano | 45 03 15.14290 | 93 44 52.34807 |
| Lake 21 | Ref | 11.6 | 28.5 | Kandiyohi | Mount Tom | 46 52 07.77224 | 96 05 33.36236 |
| Lake Park | Ag | 39.0 | 96.4 | Becker | Lake Park | 45 19 38.55261 | 95 02 34.57879 |
| Lasher | Ref | 33.6 | 82.9 | Todd | Long Prairie/Round Prairie | 45 55 38.59877 | 94 52 29.62142 |
| Legion | Urb | 8.9 | 21.9 | Hennepin | Minneapolis S. | 44 53 17.27013 | 93 15 39.00662 |
| Leman's | Ref | 39.2 | 97.0 | Hennepin | Anoka | 45 10 30.15657 | 93 24 19.19602 |
| Lost1 | Urb | 9.1 | 22.5 | Hennepin | Osseo | 45 01 57.51566 | 93 24 53.46315 |
| Malardi | Ag | 59.3 | 146.5 | Wright | Waverly | 45 04 58.79821 | 93 53 41.14201 |
| Minnow N | Ref | 16.1 | 39.9 | Becker | Detroit Lakes | 46 51 01.06195 | 95 30 47.62389 |
| Mud | Urb | 9.2 | 22.7 | Hennepin | Osseo | 45 03 40.57093 | 93 27 26.97611 |
| New London | Ref | 11.1 | 27.4 | Kandiyohi | New London | 45 18 51.05390 | 94 57 24.74208 |
| New Prairie | Ag | 11.4 | 28.1 | Pope | Starbuck NW | 45 39 13.31574 | 95 39 17.80007 |
| Ney | Frog | 3.1 | 7.7 | LeSueur | Henderson | 44 32 11.83460 | 93 52 45.46903 |
| Overby N. | Ref | 11.8 | 29.2 | Pope | Terrace | 45 30 26.29752 | 95 18 17.44862 |
| Prairie | Ref | 14.6 | 36.0 | Hennepin | St. Michael | 45 11 28.21865 | 93 38 33.02441 |
| Rose Golf | Urb | 5.4 | 13.2 | Ramsey | New Brighton | 45 00 44.12581 | 93 09 39.02752 |
| Round | Urb | 5.1 | 12.5 | Ramsey | White Bear W | 45 01 30.64834 | 93 06 06.05673 |
| Savage | Urb | 7.3 | 18.0 | Ramsey | White Bear W. | 45 01 06.66486 | 93 05 34.11974 |
| Seter | Ag | 38.1 | 94.2 | Becker | Lake Park | 46 54 56.48542 | 96 05 05.98164 |
| Sethre | Ag | 10.8 | 26.6 | Ottertail | Elizabeth | 46 22 52.60954 | 96 10 37.76033 |
| Sheets Big | Ag | 22.8 | 56.3 | Todd | Bowerville | 46 05 00.54465 | 94 50 20.79452 |
| Sheets Small 1 | Ag | 4.9 | 12.2 | Todd | Bowerville | 46 04 54.46214 | 94 50 19.41290 |
| Sigler | Ag | 18.2 | 45.1 | Sibley | LeSueur | 44 28 11.15878 | 93 58 48.93582 |
| Skarpness E | Ag | 23.8 | 58.7 | Pope | Lake Johanna | 45 29 17.53168 | 95 14 43.35336 |
| Sucker N | Ag | 14.9 | 36.9 | Pope | Starbuck NW | 45 39 08.11753 | 95 38 04.43514 |
| Sunset | Urb | 23.5 | 58.0 | Dakota | OrchardLk/Bloomington | 44 44 55.10034 | 93 19 32.21894 |
| Trappers | Ag | 10.9 | 26.8 | Pope | Lowry | 45 40 16.48051 | 95 30 55.44203 |
| Turtle | Urb | 18.5 | 45.7 | Hennepin | Osseo | 45 02 12.54725 | 93 28 31.80005 |
| Tyrone Bean | Ag | 5.4 | 13.3 | Meeker | Eden Valley | 45 16 56.46809 | 94 32 35.84043 |
| Wakefield | Urb | 8.6 | 21.3 | Ramsey | St. Paul E. | 44 59 47.42034 | 93 02 07.27741 |
| Wood Lake | Urb | 37.9 | 93.8 | Hennepin | MplsS./Bloomington | 44 52 35.14415 | 93 17 28.05746 |
| Zager | Ref | 7.5 | 18.4 | Todd | Ward Springs | 45 48 56.92112 | 94 49 55.82991 |

Appendix 2. Sources of GIS data for analysis of land features around 44 large depressional wetlands in Minnesota.

| GIS layer | Source |
|---|---|
| Landuse, 1990 coverage | http://deli.dnr.state.mn.us/metadata/full/lulcxpy3.html |
| Digital Orthophoto Quads | http://deli.dnr.state.mn.us/metadata/full/doq03im4.html |
| Roads | http://deli.dnr.state.mn.us/metadata/full/dotrdln3.html |
| Digital elevation model, DEM | http://deli.dnr.state.mn.us/metadata/full/dem30im3.html |

Appendix 3. Scoring sheets for the human disturbance gradient scores for large depressional wetlands.

Minnesota Wetland Disturbance Analysis
PRELIMINARY DRAFT RATING FORM (2/08/01)

**Site: Study: Raters: Date:**

## Factor 1. Buffer landscape disturbance

points

Extent and intensity

| | | |
|---|---|---|
| | Best – as expected for reference site, no evidence of disturbance | (0) |
| | Mod.- predominately undisturbed, some human use influence | (6) |
| | Fair – significant human influence, buffer area nearly filled with human use | (12) |
| | Poor–nearly all or all of the buffer human use, intensive landuse surrounding wetland | (18) |

| | Best | | Mod. |
|---|---|---|---|
| | Mature (>20 yr) woodlot, forested | | Old field, CRP or rangeland, |
| | Mature prairie | | Restored prairie (<10 yr) |
| | Other long recovered area | | Young (<20 yr) second growth woodlot |
| | Other wetlands | | Shrubland |
| | | | |

| | Fair | | Poor |
|---|---|---|---|
| | Residential with unmowed areas | | Urban development |
| | Active pasture | | Industrial development |
| | Less intensive agriculture | | Intensive residential/mowed |
| | Turf park, Golf course | | Intensive agriculture |
| | Newly fallowed fields | | Mining in or adjacent to wetland |
| | High road density in buffer area or impervious surfaces | | Active construction activity |
| | | | |

Remarks or comments:

## Factor 2. Landscape (immediate) Influence

points

Extent and intensity

| | | |
|---|---|---|
| | Best – landscape natural, as expected for reference site, no evidence of disturbance | (0) |
| | Mod.- predominately undisturbed, some human use influence | (6) |
| | Fair – significant human influence, landscape area nearly filled with human use | (12) |
| | Poor – nearly all or all of the landscape in human use, isolating the wetland | (18) |

| | Best | | Mod. |
|---|---|---|---|
| | Mature (>20 yr) woodlot, forested | | Old field, CRP or rangeland, |
| | Mature prairie | | Restored prairie (<10 yr) |
| | Other long recovered area | | Young (<20 yr) second growth woodlot |
| | Other wetlands | | Shrubland |
| | | | |

| | Fair | | Poor |
|---|---|---|---|
| | Residential with unmowed areas | | Urban development |
| | Active pasture | | Industrial development |
| | Less intensive agriculture | | Intensive residential/mowed |

| | | | |
|---|---|---|---|
| | Turf park, Golf course | | Intensive agriculture |
| | Newly fallowed fields | | Mining in or adjacent to wetland |
| | High road density or impervious surfaces in immediate landscape | | Active construction activity |

points

## Factor 3. Habitat alteration—immediate landscape

(within and beyond buffer)

Severity and extent of alteration

| | | |
|---|---|---|
| | Best – as expected for reference, no evidence of disturbance | (0) |
| | Mod. –low intensity alteration or past alteration that is not currently affecting wetland | (6) |
| | Fair – highly altered, but some recovery if previously altered | (12) |
| | Poor – almost no natural habitat present, highly altered habitat | (18) |

Vegetation removal disturbances

| | | | |
|---|---|---|---|
| | Mowed, Grazed | | Shrub removal |
| | Tree plantations | | Course woody debris removal |
| | Tree removal | | Removal of emergent vegetation |
| | | | |

Substrate/soil disturbances and sedimentation

| | | | |
|---|---|---|---|
| | Grading/bulldozing | | Vehicle use |
| | Filling | | Sediments input (from inflow or erosional) |
| | Dredging | | Livestock hooves |
| | Other | | |
| | | | |

Other

| | | | |
|---|---|---|---|
| | Fish stocking or rearing | | Other |
| | | | |

Remarks or comments:

points

## Factor 4. Hydrologic alteration

Severity and degree of alteration

| | | |
|---|---|---|
| | Best – as expected for reference, no evidence of disturbance | (0) |
| | Mod. –low intensity alteration or past alteration that is not currently affecting wetland | (7) |
| | Fair – less intense than "poor", but current or active alteration. | (14) |
| | Poor – currently active and major disturbance to natural hydrology | (21) |

| | | | |
|---|---|---|---|
| | Ditch inlet | | Berm or dam |
| | Tile inlet | | Road bed or RR bed |
| | Point source input | | Levee |
| | Installed outlet, weir | | Unnaturally connected to other waters |
| | Dredged | | Dewatering in or near wetland |
| | Graded or fill | | Source water changes |
| | Other | | Drainage |
| | | | |

Remarks or comments:

**Site**________________________________

## Factor 5. Chemical Pollution

points    Severity and degree of pollution

| | |
|---|---|
| | Best - chemical data as expected for reference and no evidence of chemical input (0) |
| | Mod.- selected chemical data in low range, little or no evidence of chemical input (7) |
| | Fair - selected chemical date in mid range, high potential for chemical input (14) |
| | Poor - chemical input is recognized as high, with a high potential for biological harm (21) |

Checklist:

| | | | |
|---|---|---|---|
| | High Cl conc (water) | | Known MMCD treatment |
| | High P conc. (water) | | Evidence of altered DO regime |
| | High N conc. (water) | | Other treatment |
| | High Cu conc. (sediment) | | High input potential |
| | High Zn conc. (sediment) | | Other |
| | | | |

Remarks or comments:

## Additional factors and concerns

points    Used in exceptional cases as described below

Maximum of (4) additional points added to the cumulative disturbance total for reasons described below. Apply on factors 4 and 5.

Factor 1 – Buffer and landscape

Factor 2 – Landscape (immediate influence)

Factor 3 –Habitat alteration

Factor 4– Hydrologic alteration

Factor 5 – Chemical pollution

Additional factors

**Total final disturbance score**

**Site Name**:_______________

Appendix 4. Scores for each factor contributing to total Human Disturbance Scores (HDS) for 44 large depressional wetlands in Minnesota. See text for description of the factors. Data sorted on HDS score.

| Site Name | Type | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 5 | Extra6 | HDS |
|---|---|---|---|---|---|---|---|---|
| Bloom | Ref | 0 | 3 | 0 | 0 | 0 | 0 | 3 |
| Field | Ref | 0 | 3 | 0 | 0 | 3.5 | 0 | 6.5 |
| Minnow | Ref | 0 | 3 | 0 | 0 | 3.5 | 0 | 6.5 |
| Prairie | Ref | 3 | 0 | 6 | 0 | 0 | 1 | 10 |
| Glacial | Ref | 0 | 3 | 3 | 0 | 7 | 0 | 13 |
| Zager | Ref | 0 | 3 | 3 | 0 | 7 | 0 | 13 |
| New London | Ref | 3 | 3 | 3 | 0 | 7 | 0 | 16 |
| Lake 21 | Ref | 0 | 3 | 6 | 0 | 7 | 3 | 19 |
| Leman (Elm Creek) | Ref | 0 | 6 | 0 | 0 | 14 | 0 | 20 |
| Cataract | Ref | 3 | 3 | 3 | 0 | 10.5 | 1 | 20.5 |
| Overby | Ref | 3 | 6 | 3 | 3.5 | 7 | 0 | 22.5 |
| Bunker | Ag | 6 | 6 | 9 | 0 | 3.5 | 3 | 27.5 |
| Donley large | Ref | 3 | 6 | 6 | 7 | 7 | 2 | 31 |
| Lashier | Ref | 6 | 9 | 6 | 7 | 7 | 0 | 35 |
| Kasma | Ref | 6 | 6 | 0 | 10.5 | 14 | 3 | 39.5 |
| Sheet Big | Ag | 6 | 12 | 9 | 7 | 7 | 2 | 43 |
| Mud | Urb | 6 | 9 | 9 | 7 | 14 | 0 | 45 |
| Battle | Urb | 6 | 9 | 9 | 14 | 17.5 | 2 | 57.5 |
| Sheet small | Ag | 9 | 15 | 9 | 10.5 | 10.5 | 4 | 58 |
| TyroneBean | Ag | 6 | 9 | 9 | 14 | 17.5 | 3 | 58.5 |
| Skarpness | Ag | 9 | 18 | 15 | 7 | 10.5 | 0 | 59.5 |
| Sethre | Ag | 12 | 12 | 9 | 14 | 14 | 0 | 61 |
| Ney | Ag | 6 | 12 | 9 | 21 | 10.5 | 4 | 62.5 |
| Trappers | Ag | 9 | 9 | 9 | 17.5 | 14 | 4 | 62.5 |
| Casey | Urb | 9 | 12 | 9 | 17.5 | 14 | 2 | 63.5 |
| New Prairie | Ag | 6 | 15 | 12 | 14 | 17.5 | 2 | 66.5 |
| Seter | Ag | 15 | 12 | 12 | 17.5 | 10.5 | 2 | 69 |
| Sunset | Urb | 12 | 18 | 12 | 14 | 14 | 0 | 70 |
| Turtle | Urb | 9 | 12 | 12 | 17.5 | 21 | 2 | 73.5 |
| Breen | Ag | 15 | 15 | 12 | 10.5 | 17.5 | 4 | 74 |
| Lake Park | Ag | 6 | 15 | 15 | 21 | 14 | 4 | 75 |
| Wood Lake | Urb | 6 | 18 | 12 | 21 | 14 | 4 | 75 |
| Round | Urb | 12 | 18 | 15 | 10.5 | 17.5 | 3 | 76 |
| Davis | Ag | 6 | 15 | 12 | 21 | 21 | 4 | 79 |
| Legion | Urb | 12 | 18 | 12 | 17.5 | 17.5 | 4 | 81 |
| Sigler | Ag | 12 | 18 | 15 | 17.5 | 17.5 | 2 | 82 |
| Malardi | Ag | 15 | 18 | 15 | 14 | 17.5 | 4 | 83.5 |
| Wakefield | Urb | 12 | 15 | 12 | 21 | 21 | 3 | 84 |
| Savage | Urb | 15 | 15 | 15 | 17.5 | 21 | 3 | 86.5 |
| Jones | Urb | 9 | 18 | 18 | 17.5 | 21 | 4 | 87.5 |
| Sucker N | Ag | 15 | 18 | 18 | 14 | 21 | 4 | 90 |
| Rose Golf | Urb | 18 | 18 | 18 | 17.5 | 17.5 | 3 | 92 |
| Lost | Urb | 18 | 18 | 18 | 17.5 | 21 | 4 | 96.5 |
| Grass | Urb | 18 | 18 | 18 | 21 | 21 | 4 | 100 |

Appendix 5. Scores for each factor contributing to total Human Disturbance Scores (HDS) for 44 large depressional wetlands in Minnesota. See text for description of the factors. Data sorted on site name.

| Site Name | Type | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 5 | Extra6 | HDS |
|---|---|---|---|---|---|---|---|---|
| Battle | Urb | 6 | 9 | 9 | 14 | 17.5 | 2 | 57.5 |
| Bloom | Ref | 0 | 3 | 0 | 0 | 0 | 0 | 3 |
| Breen | Ag | 15 | 15 | 12 | 10.5 | 17.5 | 4 | 74 |
| Bunker | Ag | 6 | 6 | 9 | 0 | 3.5 | 3 | 27.5 |
| Casey | Urb | 9 | 12 | 9 | 17.5 | 14 | 2 | 63.5 |
| Cataract | Ref | 3 | 3 | 3 | 0 | 10.5 | 1 | 20.5 |
| Davis | Ag | 6 | 15 | 12 | 21 | 21 | 4 | 79 |
| Donley large | Ref | 3 | 6 | 6 | 7 | 7 | 2 | 31 |
| Field | Ref | 0 | 3 | 0 | 0 | 3.5 | 0 | 6.5 |
| Glacial | Ref | 0 | 3 | 3 | 0 | 7 | 0 | 13 |
| Grass | Urb | 18 | 18 | 18 | 21 | 21 | 4 | 100 |
| Jones | Urb | 9 | 18 | 18 | 17.5 | 21 | 4 | 87.5 |
| Kasma | Ref | 6 | 6 | 0 | 10.5 | 14 | 3 | 39.5 |
| Lake 21 | Ref | 0 | 3 | 6 | 0 | 7 | 3 | 19 |
| Lake Park | Ag | 6 | 15 | 15 | 21 | 14 | 4 | 75 |
| Lashier | Ref | 6 | 9 | 6 | 7 | 7 | 0 | 35 |
| Legion | Urb | 12 | 18 | 12 | 17.5 | 17.5 | 4 | 81 |
| Leman (Elm Creek) | Ref | 0 | 6 | 0 | 0 | 14 | 0 | 20 |
| Lost | Urb | 18 | 18 | 18 | 17.5 | 21 | 4 | 96.5 |
| Malardi | Ag | 15 | 18 | 15 | 14 | 17.5 | 4 | 83.5 |
| Minnow | Ref | 0 | 3 | 0 | 0 | 3.5 | 0 | 6.5 |
| Mud | Urb | 6 | 9 | 9 | 7 | 14 | 0 | 45 |
| New London | Ref | 3 | 3 | 3 | 0 | 7 | 0 | 16 |
| New Prairie | Ag | 6 | 15 | 12 | 14 | 17.5 | 2 | 66.5 |
| Ney | Ag | 6 | 12 | 9 | 21 | 10.5 | 4 | 62.5 |
| Overby | Ref | 3 | 6 | 3 | 3.5 | 7 | 0 | 22.5 |
| Prairie | Ref | 3 | 0 | 6 | 0 | 0 | 1 | 10 |
| Rose Golf | Urb | 18 | 18 | 18 | 17.5 | 17.5 | 3 | 92 |
| Round | Urb | 12 | 18 | 15 | 10.5 | 17.5 | 3 | 76 |
| Savage | Urb | 15 | 15 | 15 | 17.5 | 21 | 3 | 86.5 |
| Seter | Ag | 15 | 12 | 12 | 17.5 | 10.5 | 2 | 69 |
| Sethre | Ag | 12 | 12 | 9 | 14 | 14 | 0 | 61 |
| Sheet Big | Ag | 6 | 12 | 9 | 7 | 7 | 2 | 43 |
| Sheet small | Ag | 9 | 15 | 9 | 10.5 | 10.5 | 4 | 58 |
| Sigler | Ag | 12 | 18 | 15 | 17.5 | 17.5 | 2 | 82 |
| Skarpness | Ag | 9 | 18 | 15 | 7 | 10.5 | 0 | 59.5 |
| Sucker N | Ag | 15 | 18 | 18 | 14 | 21 | 4 | 90 |
| Sunset | Urb | 12 | 18 | 12 | 14 | 14 | 0 | 70 |
| Trappers | Ag | 9 | 9 | 9 | 17.5 | 14 | 4 | 62.5 |
| Turtle | Urb | 9 | 12 | 12 | 17.5 | 21 | 2 | 73.5 |
| TyroneBean | Ag | 6 | 9 | 9 | 14 | 17.5 | 3 | 58.5 |
| Wakefield | Urb | 12 | 15 | 12 | 21 | 21 | 3 | 84 |
| Wood Lake | Urb | 6 | 18 | 12 | 21 | 14 | 4 | 75 |
| Zager | Ref | 0 | 3 | 3 | 0 | 7 | 0 | 13 |

Appendix 6. Water chemistry data for 44 large depressional wetlands in Minnesota with means, medians (med), and standard deviations (SD) for 14 reference (Ref), 14 agricultural- (Ag), and 16 urban- (Urb) influenced wetlands. Data for chlorophyll a (Chl a), chloride (chlor), total Kjedahl nitrogen (N) and total phosphorus (P) are in mg/L. Overall is data for the 44 wetlands.

| | Chloride | | | Nitrogen | | | Phosphorus | | | Chlorophyll a | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Median | SD | Mean | Median | SD | Mean | Median | SD | Mean | Median | SD |
| Ref | 4.75 | 3.8 | 4.5 | 1.22 | 1.02 | 0.5 | 0.08 | 0.034 | 0.11 | 12.1 | 6 | 23.4 |
| Ag | 19.5 | 14 | 16 | 2.01 | 1.86 | 1.2 | 0.24 | 0.124 | 0.33 | 29.3 | 11.2 | 57.5 |
| Urb | 56.9 | 56 | 23 | 1.56 | 1.3 | 0.7 | 0.15 | 0.154 | 0.05 | 32 | 19.3 | 34.33 |
| Overall | 26.7 | 15 | 27 | 1.61 | 1.38 | 0.9 | 0.16 | 0.104 | 0.22 | 24.7 | 7.86 | 41.9 |

Appendix 7. Sediment chemistry data for 44 large depressional wetlands in Minnesota with means, medians (med), and standard deviations (SD) for 14 reference (Ref), 14 agricultural- (Ag), and 16 urban- (Urb) influenced wetlands. Data for copper, nickel, lead and zinc are in mg/kg air dried weight. Turbidity in water is in ntu. Overall is the data for the 44 wetlands.

| | Copper | | | Nickel | | | Lead | | | Zinc | | | Turbidity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Median | SD | Mean | Median | SD | Mean | Median | SD | Mean | Median | SD | Mean | Median | SD |
| Ref | 10.8 | 10.9 | 4.8 | 11.9 | 10.7 | 5.8 | 13.5 | 10.1 | 8.6 | 40.3 | 38.1 | 19 | 2.8 | 2.65 | 1.4 |
| Ag | 14.3 | 14.3 | 6.8 | 14.9 | 15 | 7.3 | 14.3 | 11.8 | 12 | 49.8 | 53.8 | 23 | 9.35 | 3.2 | 19 |
| Urb | 50.8 | 26.3 | 98 | 17.1 | 15.8 | 7.5 | 67.4 | 39.7 | 68 | 95.9 | 71.8 | 51 | 10.6 | 5.9 | 9.2 |
| Overall | 24.8 | 14.7 | 57 | 14.7 | 13.9 | 7.1 | 30.9 | 15 | 46 | 61.4 | 56 | 41 | 7.66 | 3.35 | 13 |

Appendix 8. Water chemistry data for 44 large depressional wetlands in Minnesota. Chlorophyll a (Chl-A); total Kjedahl nitrogen, (N-KJEL); Phaeophytin (PhaeA); and total suspended solids (TSS) are given in mg/L; turbidity in ntu.

| SiteName | Ca | Chl-A | Cl | Mg CaCO3 | N-KJEL | PhaeA | P | TSS | Turbidity |
|---|---|---|---|---|---|---|---|---|---|
| Bloom | 77 | 3.52 | 1 | 46 | 0.98 | 0.64 | 0.015 | 6 | 1.4 |
| Breen | 140 | 8.48 | 12 | 79 | 1.46 | 6.21 | 0.303 | 5.3 | 2.4 |
| Bunker | 25 | 9.24 | 1 | 20 | 0.95 | 1.11 | 0.023 | 17 | 2.5 |
| Casey | 77 | 52.3 | 33 | 41 | 2.32 | 16.4 | 0.185 | 40 | 28 |
| Cateract | 77 | 6.22 | 3.2 | 59 | 2.29 | 4.68 | 0.103 | 17 | 3.2 |
| Davis | 430 | 7.09 | 39 | 460 | 1.84 | 1.49 | 0.202 | 22 | 4.2 |
| Donley Lg. N | 87 | 9.2 | 4.5 | 320 | 1.6 | 2.41 | 0.047 | 4.8 | 2.8 |
| Field | 84 | 8.01 | 1 | 67 | 0.98 | 5.39 | 0.032 | 10 | 3.2 |
| Glacial | 130 | 4.84 | 5.7 | 94 | 0.96 | 1.33 | 0.037 | 3.2 | 2.5 |
| Grass | 30 | 14.5 | 60 | 9.9 | 1.59 | 13.6 | 0.207 | 19 | 5.9 |
| Jones | 82 | 1.15 | 94 | 33 | 0.53 | 0.33 | 0.104 | 3.6 | 3.5 |
| Kasma | 88 | 2.26 | 10 | 52 | 2.08 | 2.73 | 0.429 | 25 | 3.8 |
| Lake 21 | 53 | 10.4 | 8.5 | 90 | 1.06 | 1.53 | 0.028 | 4.8 | 5.8 |
| Lake Park | 190 | 13.2 | 11 | 170 | 1.87 | 3.39 | 0.128 | 3.6 | 2.5 |
| Lasher | 99 | 4.12 | 8.2 | 61 | 1.05 | 4.38 | 0.038 | 3.8 | 2.1 |
| Legion | 45 | 24.1 | 49 | 14 | 1.3 | 7.8 | 0.155 | 6 | 3.1 |
| Leman's | 51 | 6.26 | 16 | 32 | 1.06 | 1.24 | 0.092 | 3.2 | 2.9 |
| Lost1 | 60 | 80.4 | 36 | 28 | 2.99 | 19.4 | 0.181 | 16 | 15 |
| Malardi | 110 | 22.8 | 19 | 84 | 3.47 | 15.8 | 0.255 | 73 | 9.1 |
| Minnow N | 80 | 5.73 | 1 | 46 | 0.68 | 3.41 | 0.018 | 2.4 | 1.1 |
| Mud | 60 | 7.05 | 27 | 33 | 1.29 | 2.63 | 0.097 | 11 | 4.8 |
| New London | 37 | 4.55 | 1 | 60 | 0.98 | 1.25 | 0.032 | 6 | 1.9 |
| New Prairie | 72 | 23.5 | 14 | 89 | 1.94 | 9.73 | 0.413 | 6 | 7.3 |
| Ney | 44 | 2.96 | 6.9 | 49 | 0.9 | 2.46 | 0.053 | 12 | 2.2 |
| Overby N. | 73 | 7.71 | 4.4 | 59 | 0.96 | 1.48 | 0.025 | 3.2 | 1.1 |
| Prairie | 43 | 2.92 | 1 | 40 | 0.88 | 1.11 | 0.025 | 9.6 | 2.5 |
| Rose Golf | 35 | 72.5 | 54 | 13 | 1.57 | 6.25 | 0.153 | 18 | 16 |
| Round | 33 | 107 | 58 | 12 | 2.37 | 6.36 | 0.132 | 23 | 22 |
| Savage | 41 | 44.6 | 47 | 19 | 2.35 | 4.67 | 0.197 | 24 | 27 |
| Seter | 59 | 1.35 | 50 | 180 | 1.51 | 0.92 | 0.065 | 3.6 | 1.1 |
| Sethre | 190 | 6.73 | 19 | 300 | 1.98 | 2.61 | 0.068 | 5.2 | 2.6 |
| Sheets Big | 42 | 4.23 | 10 | 38 | 1.02 | 1.97 | 0.029 | 1.2 | 0.96 |
| Sheets Small 1 | 35 | 2.77 | 3.1 | 38 | 0.95 | 3.7 | 0.039 | 2.8 | 1.9 |
| Sigler | 80 | 26.5 | 14 | 110 | 1.82 | 12.4 | 0.151 | 11 | 3.8 |
| Skarpness E | 93 | 31.9 | 4.6 | 59 | 2.06 | 6.43 | 0.093 | 13 | 10 |
| Sucker N | 120 | 238 | 49 | 120 | 5.81 | 27.7 | 1.38 | 90 | 81 |
| Sunset | 63 | 1.31 | 58 | 59 | 1.09 | 2.05 | 0.077 | 4 | 2.5 |
| Trappers | 160 | 56.8 | 24 | 210 | 2.28 | 4.05 | 0.119 | 19 | 13 |
| Turtle | 100 | 5.04 | 36 | 55 | 1.02 | 4.38 | 0.251 | 8 | 4.5 |
| Tyrone Bean | 160 | 13.7 | 36 | 120 | 2.22 | 4.61 | 0.454 | 7 | 5.1 |
| Wakefield | 65 | 29 | 110 | 27 | 1.1 | 5.55 | 0.099 | 12 | 7.3 |
| Wood Lake | 40 | 6.94 | 58 | 9.7 | 0.98 | 3.78 | 0.152 | 8 | 2.8 |
| Zager | 5.5 | 92.9 | 1 | 5 | 1.55 | 23.2 | 0.142 | 24 | 4.9 |

Appendix 9. Field water data for conductivity, pH, and temperature from 44 large depressional wetlands in Minnesota.

| SiteName | Conductivity (uS) | Field pH | Temp(°C) |
|---|---|---|---|
| Battle | 0.497 | 8.74 | 28.5 |
| Bloom | 0.237 | 8.14 | 23.1 |
| Breen | 0.44 | 7.33 | 25.1 |
| Bunker | 0.101 | 9.4 | 22.5 |
| Casey | 0.347 | 8.08 | 27.1 |
| Cataract | 0.26 | 8.2 | 21.9 |
| Davis | 1.44 | 7.7 | 19.3 |
| Donley Lg. N | 0.723 | 8.2 | 20.9 |
| Field | 0.225 | 8.73 | 20.4 |
| Glacial | 0.453 | 7.67 | 24.8 |
| Grass | 0.324 | 8 | 28 |
| Jones | 0.391 | 6.07 | 15.5 |
| Kasma | 0.226 | 9.48 | 23.6 |
| Lake 21 | 0.281 | 8.7 | 24.1 |
| Lake Park | 0.626 | 7.47 | 19.5 |
| Lasher | 0.336 | 7.91 | 24.1 |
| Legion | 0.292 | 7.02 | 23.2 |
| Leman's | 0.187 | 7.89 | 18.9 |
| Lost1 | 0.276 | 8.14 | 21.3 |
| Malardi | 0.348 | 6.68 | 18.3 |
| Minnow N | 0.24 | 8.1 | 22.3 |
| Mud | 0.258 | 8.7 | 24.5 |
| New London | 0.197 | 9.34 | 26 |
| New Prairie | 0.296 | 9.34 | 22.1 |
| Ney | 0.241 | 10.9 | 29.2 |
| Overby N. | 0.286 | 8.56 | 25.8 |
| Prairie | 0.142 | 8.85 | 20.1 |
| Rose Golf | 0.267 | 8.81 | 20.3 |
| Round | 0.285 | 9 | 23.1 |
| Savage | 0.263 | 9.15 | 23.3 |
| Seter | 0.584 | 10.5 | 23.5 |
| Sethre | 0.786 | 7.45 | 18 |
| Sheets Big | 0.194 | 7.95 | 25.1 |
| Sheets Small 1 | 0.156 | 9.06 | 24.3 |
| Sigler | 0.389 | 7.91 | 23.7 |
| Skarpness W | 0.299 | 8.13 | 23.1 |
| Sucker N | 0.56 | 9.2 | 21.6 |
| Sunset | 0.406 | 9.18 | 26.4 |
| Trappers | 0.795 | 8.79 | 26.6 |
| Turtle | 0.399 | 7.04 | 23 |
| Tyrone Bean | 0.531 | 7.83 | 20.5 |
| Wakefield | 0.545 | 8.39 | 26.4 |
| Wood Lake | 0.303 | 7.17 | 24.2 |
| Zager | 0.024 | 5.96 | 24.1 |

Appendix 10. Sediment chemistry analysis from 44 large depressional wetlands in Minnesota. Concentrations are expressed as mg/kg air dried weight of sediment.

| Site Name | AL | AS | B | BA | BE | CA | CD | CO | CR | CU |
|---|---|---|---|---|---|---|---|---|---|---|
| Battle | 6219 | 5.198 | 7.331 | 52.782 | 0.267 | 12374 | 1.066 | 7.464 | 17.994 | 16.928 |
| Bloom | 2116 | 3.118 | 3.758 | 26.224 | 0.16 | 6595.3 | 0.48 | 1.919 | 6.396 | 3.278 |
| Breen | 14069 | 7.11 | 23.995 | 182.45 | 0.889 | 20551 | 0.711 | 9.065 | 22.75 | 22.75 |
| Bunker | 4296.6 | 3.121 | 1.84 | 41.848 | 0.24 | 3165.2 | 0.48 | 2.881 | 12.803 | 13.843 |
| Casey | 3662.3 | 4.793 | 2.297 | 36.246 | 0.3 | 18251 | 0.599 | 5.991 | 15.976 | 17.574 |
| Cataract | 3912.2 | 3.121 | 5.201 | 37.768 | 0.32 | 11358 | 0.48 | 3.841 | 9.202 | 6.561 |
| Davis | 12039 | 7.923 | 12.725 | 145.5 | 0.96 | 43934 | 0.88 | 8.964 | 20.728 | 24.25 |
| Donley Lg. | 5565 | 5.441 | 18.004 | 92.178 | 0.48 | 53059 | 0.56 | 6.561 | 9.922 | 14.803 |
| Field | 10596 | 6.493 | 13.253 | 109.05 | 0.445 | 20624 | 0.623 | 5.693 | 19.569 | 11.919 |
| Glacial | 6632.4 | 4.452 | 9.132 | 88.356 | 0.457 | 15482 | 0.685 | 5.365 | 11.301 | 9.817 |
| Grass | 4614.6 | 6.04 | 2.576 | 46.902 | 0.355 | 8422.4 | 1.332 | 5.952 | 29.314 | 30.735 |
| Jones | 12561 | 12.554 | 12.02 | 128.35 | 0.801 | 10351 | 2.137 | 13.89 | 30.05 | 45.409 |
| Kasma | 5642.3 | 7.515 | 22.445 | 115.53 | 0.501 | 26058 | 0.802 | 11.623 | 10.822 | 16.333 |
| Lake 21 | 3781.5 | 4.001 | 4.712 | 74.239 | 0.267 | 27844 | 0.533 | 4.09 | 9.335 | 6.313 |
| Lake Park | 7424.8 | 4.962 | 27.371 | 101 | 0.64 | 74667 | 0.88 | 7.443 | 13.125 | 22.089 |
| Lasher | 1592 | 10.277 | 19.753 | 49.383 | 0.267 | 22536 | 1.068 | 3.871 | 3.871 | 12.012 |
| Legion | 3468.2 | 3.818 | 2.93 | 40.133 | 0.266 | 3218.3 | 0.533 | 2.752 | 9.945 | 42.797 |
| Leman's | 11387 | 8.794 | 17.189 | 143.37 | 0.533 | 12948 | 1.066 | 6.263 | 18.921 | 18.121 |
| Lost1 | 4818.2 | 28.146 | 6.659 | 78.313 | 0.444 | 14757 | 0.71 | 5.771 | 13.585 | 389.88 |
| Malardi | 4848.3 | 8.123 | 27.297 | 75.633 | 0.266 | 13870 | 1.065 | 3.995 | 8.123 | 9.987 |
| Minnow N | 3392.3 | 4.254 | 9.218 | 77.188 | 0.203 | 13413 | 0.709 | 2.33 | 6.28 | 9.319 |
| Mud | 6937.7 | 4.798 | 5.678 | 85.246 | 0.48 | 4772.9 | 0.48 | 4.078 | 14.474 | 11.435 |
| New London | 8260.7 | 4.907 | 11.517 | 122.88 | 0.601 | 13058 | 0.701 | 6.41 | 16.324 | 16.625 |
| New Prairie | 9947.3 | 9.2 | 41.333 | 107.6 | 0.533 | 24697 | 0.8 | 7.067 | 16.533 | 17.2 |
| Ney | 7440.9 | 4.085 | 6.247 | 154.91 | 0.641 | 9868.6 | 0.641 | 8.41 | 13.616 | 14.658 |
| Overby N. | 7744.2 | 5.2 | 13.067 | 147.47 | 0.533 | 37504 | 0.8 | 8.133 | 11.6 | 14.667 |
| Prairie | 3242 | 4.438 | 3.983 | 40.626 | 0.228 | 4360.4 | 0.683 | 3.642 | 6.714 | 4.552 |
| Rose Golf | 2482.7 | 3.907 | 2.304 | 25.444 | 0.2 | 2922.9 | 0.701 | 5.009 | 10.719 | 12.121 |
| Round | 2209.3 | 3.857 | 2.274 | 19.778 | 0.198 | 2646 | 0.593 | 3.362 | 8.702 | 10.581 |
| Savage | 12294 | 7.321 | 11.181 | 107.55 | 0.532 | 7976 | 1.997 | 7.987 | 30.616 | 37.537 |
| Seter | 5417.5 | 3.603 | 9.848 | 101.12 | 0.48 | 39733 | 0.48 | 5.765 | 10.008 | 12.73 |
| Sethre | 6271.6 | 7.736 | 45.615 | 56.686 | 0.4 | 20384 | 0.8 | 6.669 | 11.604 | 17.739 |
| Sheets Big | 2973.5 | 5.2 | 9.867 | 46.133 | 0.267 | 8108.9 | 0.8 | 3.333 | 5.467 | 7.733 |
| Sheets Small | 1585.2 | 3.122 | 1.841 | 22.658 | 0.16 | 2917.9 | 0.48 | 2.162 | 3.523 | 2.402 |
| Sigler | 10097 | 6.725 | 12.73 | 149.32 | 0.721 | 16147 | 0.48 | 8.327 | 16.173 | 16.013 |
| Skarpness E | 3124.5 | 3.471 | 2.759 | 49.032 | 0.267 | 3070.6 | 0.534 | 2.848 | 5.161 | 4.271 |
| Sucker N | 2930.1 | 3.463 | 7.103 | 53.984 | 0.266 | 43286 | 0.533 | 3.64 | 6.659 | 6.57 |
| Sunset | 7552.2 | 7.771 | 8.571 | 116.12 | 0.571 | 22546 | 0.686 | 7.429 | 14.857 | 17.714 |
| Trappers | 5106.6 | 4.086 | 18.565 | 80.036 | 0.533 | 70174 | 0.533 | 6.04 | 9.682 | 13.591 |
| Turtle | 19319 | 10.8 | 25.6 | 180.93 | 1.067 | 12826 | 0.933 | 9.733 | 33.067 | 28.533 |
| Tyrone Bean | 14943 | 10.309 | 36.999 | 197.14 | 0.802 | 46595 | 0.687 | 11.34 | 23.711 | 22.451 |
| Wakefield | 5108.5 | 6.505 | 2.625 | 39.715 | 0.228 | 9223 | 1.027 | 7.646 | 19.972 | 30.699 |
| Wood Lake | 5292.6 | 5.47 | 9.117 | 92.08 | 0.456 | 8380.8 | 1.14 | 7.293 | 15.84 | 19.145 |
| Zager | 5764 | 3.116 | 1.838 | 39.712 | 0.32 | 1695.2 | 0.479 | 2.717 | 15.022 | 6.792 |

Appendix 10 (cont.). Sediment chemistry analysis from 44 large depressional wetlands in Minnesota. Concentrations are expressed as mg/kg air dried weight of sediment.

| Site Name | FE | K | LI | MG | MN | MO | NA | NI | P | PB |
|---|---|---|---|---|---|---|---|---|---|---|
| Battle | 6219.0 | 5.2 | 7.3 | 52.8 | 0.267 | 12373.8 | 1.1 | 7.5 | 18.0 | 16.9 |
| Bloom | 2116.0 | 3.1 | 3.8 | 26.2 | 0.160 | 6595.3 | 0.5 | 1.9 | 6.4 | 3.3 |
| Breen | 14068.9 | 7.1 | 24.0 | 182.4 | 0.889 | 20551.0 | 0.7 | 9.1 | 22.8 | 22.8 |
| Bunker | 4296.6 | 3.1 | 1.8 | 41.8 | 0.240 | 3165.2 | 0.5 | 2.9 | 12.8 | 13.8 |
| Casey | 3662.3 | 4.8 | 2.3 | 36.2 | 0.300 | 18250.6 | 0.6 | 6.0 | 16.0 | 17.6 |
| Cataract | 3912.2 | 3.1 | 5.2 | 37.8 | 0.320 | 11358.3 | 0.5 | 3.8 | 9.2 | 6.6 |
| Davis | 12039.2 | 7.9 | 12.7 | 145.5 | 0.960 | 43934.4 | 0.9 | 9.0 | 20.7 | 24.3 |
| Donley Lg. | 5565.0 | 5.4 | 18.0 | 92.2 | 0.480 | 53059.4 | 0.6 | 6.6 | 9.9 | 14.8 |
| Field | 10595.5 | 6.5 | 13.3 | 109.1 | 0.445 | 20624.4 | 0.6 | 5.7 | 19.6 | 11.9 |
| Glacial | 6632.4 | 4.5 | 9.1 | 88.4 | 0.457 | 15481.7 | 0.7 | 5.4 | 11.3 | 9.8 |
| Grass | 4614.6 | 6.0 | 2.6 | 46.9 | 0.355 | 8422.4 | 1.3 | 6.0 | 29.3 | 30.7 |
| Jones | 12561.1 | 12.6 | 12.0 | 128.3 | 0.801 | 10350.7 | 2.1 | 13.9 | 30.1 | 45.4 |
| Kasma | 5642.3 | 7.5 | 22.4 | 115.5 | 0.501 | 26058.0 | 0.8 | 11.6 | 10.8 | 16.3 |
| Lake 21 | 3781.5 | 4.0 | 4.7 | 74.2 | 0.267 | 27843.5 | 0.5 | 4.1 | 9.3 | 6.3 |
| Lake Park | 7424.8 | 5.0 | 27.4 | 101.0 | 0.640 | 74666.7 | 0.9 | 7.4 | 13.1 | 22.1 |
| Lasher | 1592.0 | 10.3 | 19.8 | 49.4 | 0.267 | 22535.9 | 1.1 | 3.9 | 3.9 | 12.0 |
| Legion | 3468.2 | 3.8 | 2.9 | 40.1 | 0.266 | 3218.3 | 0.5 | 2.8 | 9.9 | 42.8 |
| Leman's | 11387.0 | 8.8 | 17.2 | 143.4 | 0.533 | 12948.0 | 1.1 | 6.3 | 18.9 | 18.1 |
| Lost | 4818.2 | 28.1 | 6.7 | 78.3 | 0.444 | 14756.9 | 0.7 | 5.8 | 13.6 | 389.9 |
| Malardi | 4848.3 | 8.1 | 27.3 | 75.6 | 0.266 | 13869.5 | 1.1 | 4.0 | 8.1 | 10.0 |
| Minnow N | 3392.3 | 4.3 | 9.2 | 77.2 | 0.203 | 13412.7 | 0.7 | 2.3 | 6.3 | 9.3 |
| Mud | 6937.7 | 4.8 | 5.7 | 85.2 | 0.480 | 4772.9 | 0.5 | 4.1 | 14.5 | 11.4 |
| New London | 8260.7 | 4.9 | 11.5 | 122.9 | 0.601 | 13057.6 | 0.7 | 6.4 | 16.3 | 16.6 |
| New Prairie | 9947.3 | 9.2 | 41.3 | 107.6 | 0.533 | 24697.3 | 0.8 | 7.1 | 16.5 | 17.2 |
| Ney | 7440.9 | 4.1 | 6.2 | 154.9 | 0.641 | 9868.6 | 0.6 | 8.4 | 13.6 | 14.7 |
| Overby N. | 7744.2 | 5.2 | 13.1 | 147.5 | 0.533 | 37503.9 | 0.8 | 8.1 | 11.6 | 14.7 |
| Prairie | 3242.0 | 4.4 | 4.0 | 40.6 | 0.228 | 4360.4 | 0.7 | 3.6 | 6.7 | 4.6 |
| Rose Golf | 2482.7 | 3.9 | 2.3 | 25.4 | 0.200 | 2922.9 | 0.7 | 5.0 | 10.7 | 12.1 |
| Round | 2209.3 | 3.9 | 2.3 | 19.8 | 0.198 | 2646.0 | 0.6 | 3.4 | 8.7 | 10.6 |
| Savage | 12294.1 | 7.3 | 11.2 | 107.6 | 0.532 | 7976.0 | 2.0 | 8.0 | 30.6 | 37.5 |
| Seter | 5417.5 | 3.6 | 9.8 | 101.1 | 0.480 | 39732.6 | 0.5 | 5.8 | 10.0 | 12.7 |
| Sethre | 6271.6 | 7.7 | 45.6 | 56.7 | 0.400 | 20384.2 | 0.8 | 6.7 | 11.6 | 17.7 |
| Sheets Big | 2973.5 | 5.2 | 9.9 | 46.1 | 0.267 | 8108.9 | 0.8 | 3.3 | 5.5 | 7.7 |
| Sheets Small | 1585.2 | 3.1 | 1.8 | 22.7 | 0.160 | 2917.9 | 0.5 | 2.2 | 3.5 | 2.4 |
| Sigler | 10096.9 | 6.7 | 12.7 | 149.3 | 0.721 | 16146.5 | 0.5 | 8.3 | 16.2 | 16.0 |
| Skarpness E | 3124.5 | 3.5 | 2.8 | 49.0 | 0.267 | 3070.6 | 0.5 | 2.8 | 5.2 | 4.3 |
| Sucker N | 2930.1 | 3.5 | 7.1 | 54.0 | 0.266 | 43286.1 | 0.5 | 3.6 | 6.7 | 6.6 |
| Sunset | 7552.2 | 7.8 | 8.6 | 116.1 | 0.571 | 22546.3 | 0.7 | 7.4 | 14.9 | 17.7 |
| Trappers | 5106.6 | 4.1 | 18.6 | 80.0 | 0.533 | 70173.7 | 0.5 | 6.0 | 9.7 | 13.6 |
| Turtle | 19318.6 | 10.8 | 25.6 | 180.9 | 1.067 | 12825.7 | 0.9 | 9.7 | 33.1 | 28.5 |
| Tyrone Bean | 14942.8 | 10.3 | 37.0 | 197.1 | 0.802 | 46594.7 | 0.7 | 11.3 | 23.7 | 22.5 |
| Wakefield | 5108.5 | 6.5 | 2.6 | 39.7 | 0.228 | 9223.0 | 1.0 | 7.6 | 20.0 | 30.7 |
| Wood Lake | 5292.6 | 5.5 | 9.1 | 92.1 | 0.456 | 8380.8 | 1.1 | 7.3 | 15.8 | 19.1 |
| Zager | 5764.0 | 3.1 | 1.8 | 39.7 | 0.320 | 1695.2 | 0.5 | 2.7 | 15.0 | 6.8 |

Appendix 10 (cont.). Sediment chemistry analysis from 44 large depressional wetlands in Minnesota. Concentrations are expressed as mg/kg air dried weight of sediment.

| Site Name | RB | S | SI | SR | TI | V | ZN |
|---|---|---|---|---|---|---|---|
| Battle | 353.22 | 3402.9 | 1512.7 | 17.461 | 356.55 | 26.125 | 63.712 |
| Bloom | 211.87 | 612.75 | 280.15 | 7.995 | 144.15 | 6.796 | 14.072 |
| Breen | 235.5 | 2135 | 1436.7 | 41.235 | 123.08 | 46.39 | 85.225 |
| Bunker | 212.04 | 741.75 | 1095.3 | 8.242 | 199.24 | 11.762 | 30.726 |
| Casey | 264.6 | 1042.1 | 1105.8 | 10.684 | 271.19 | 21.368 | 53.02 |
| Cataract | 212.04 | 335.59 | 682.54 | 11.202 | 68.974 | 14.243 | 24.725 |
| Davis | 212.09 | 2491.4 | 1502 | 61.305 | 67.067 | 33.533 | 73.229 |
| Donley Lg. | 212.04 | 5813.5 | 1388.8 | 74.335 | 64.893 | 20.084 | 44.329 |
| Field | 235.71 | 2089.2 | 731.33 | 33.445 | 307.32 | 32.466 | 38.248 |
| Glacial | 302.51 | 1422.4 | 1485.2 | 18.036 | 144.29 | 21.575 | 37.899 |
| Grass | 235.4 | 1783.8 | 1096.2 | 9.416 | 140.97 | 19.454 | 185.65 |
| Jones | 353.92 | 8141.3 | 2195.1 | 24.04 | 200.33 | 42.07 | 190.45 |
| Kasma | 265.53 | 2571.7 | 1618.5 | 33.968 | 68.837 | 22.244 | 61.723 |
| Lake 21 | 235.61 | 1276.4 | 1003.2 | 22.138 | 147.68 | 12.625 | 24.45 |
| Lake Park | 212.09 | 6561.3 | 1289.8 | 103.72 | 46.258 | 28.491 | 56.983 |
| Lasher | 353.69 | 8072.9 | 1547.3 | 16.95 | 42.843 | 9.209 | 36.036 |
| Legion | 235.29 | 995.43 | 961.42 | 7.192 | 85.327 | 11.099 | 54.961 |
| Leman's | 353.1 | 4813.6 | 1881.7 | 28.781 | 167.49 | 38.508 | 75.417 |
| Lost | 235.29 | 2076.1 | 1181.6 | 17.936 | 128.75 | 16.249 | 77.603 |
| Malardi | 352.86 | 5630.4 | 1738.2 | 25.832 | 106.53 | 18.642 | 45.539 |
| Minnow N | 268.44 | 1627.8 | 1151.6 | 15.6 | 81.341 | 8.408 | 40.215 |
| Mud | 211.92 | 1426.1 | 1131.1 | 13.595 | 96.042 | 20.472 | 63.015 |
| New London | 265.4 | 1664.4 | 1512 | 22.634 | 133.4 | 24.737 | 75.814 |
| New Prairie | 353.33 | 4406.8 | 1909.3 | 34.933 | 150.93 | 38.8 | 82.666 |
| Ney | 212.26 | 574.21 | 1299 | 22.026 | 79.215 | 22.427 | 50.621 |
| Overby N. | 353.33 | 1400.8 | 2061.2 | 29.2 | 96.133 | 20.267 | 47.467 |
| Prairie | 301.57 | 530.07 | 1123.9 | 7.283 | 124.27 | 11.152 | 22.304 |
| Rose Golf | 265.46 | 981.01 | 988.43 | 5.81 | 122.41 | 12.923 | 66.015 |
| Round | 262.05 | 685.29 | 779.33 | 4.747 | 168.9 | 9.988 | 61.112 |
| Savage | 352.74 | 4946.9 | 1958.2 | 22.496 | 349.82 | 40.865 | 176.51 |
| Seter | 212.17 | 1522.9 | 1275.9 | 51.561 | 50.12 | 14.171 | 34.988 |
| Sethre | 353.45 | 12686 | 1507.6 | 36.412 | 68.956 | 27.743 | 57.353 |
| Sheets Big | 353.33 | 3627.7 | 1394.5 | 16.533 | 87.333 | 8.533 | 61.2 |
| Sheets Small | 212.17 | 735.95 | 851.08 | 4.163 | 62.77 | 5.044 | 10.969 |
| Sigler | 212.17 | 1656.1 | 1367.1 | 34.027 | 79.664 | 30.665 | 58.847 |
| Skarpness E | 235.82 | 354.26 | 1169.8 | 6.852 | 73.682 | 9.433 | 19.221 |
| Sucker N | 235.29 | 342.46 | 1187.7 | 37.558 | 64.994 | 11.188 | 18.024 |
| Sunset | 302.86 | 2235.4 | 1794.6 | 23.886 | 112.12 | 25.257 | 53.943 |
| Trappers | 235.4 | 4104.6 | 1434.1 | 82.789 | 68.843 | 19.098 | 36.598 |
| Turtle | 353.33 | 4116.4 | 1819.2 | 29.6 | 209.33 | 74.666 | 100.27 |
| Tyrone Bean | 303.55 | 4373.2 | 1839.8 | 48.339 | 226.58 | 51.89 | 75.373 |
| Wakefield | 302.43 | 3023.7 | 1393.1 | 10.613 | 239.09 | 25.221 | 116.41 |
| Wood Lake | 301.99 | 2959 | 1636.8 | 15.043 | 99.145 | 20.969 | 79.544 |
| Zager | 211.75 | 485.9 | 1063 | 8.949 | 238.27 | 19.816 | 21.334 |

Appendix 11. p values (a.) and r values (b.) for ten invertebrate metrics and for the invertebrate IBI scores for 44 large depressional wetlands.

a. Table of p values for Pearson correlation coefficients (r) between measures of disturbance and the 10 invertebrate metrics and total invertebrate IBI score. Water and chemistry factors were log transformed.

| Factor | ChiroTaxa | CorixProp | Dom3 | ETSD | IntolTaxa | Leech | Odonata | Snail | TolProp | TotalTaxa | IBI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HDS | .000014 | .05 | .009 | .00044 | .0000019 | .040 | .00073 | .006 | ns | .000022 | .0000005 |
| Chloride | .000028 | ns | .0134 | .0217 | .00045 | ns | .007 | .024 | ns | .00021 | .0000283 |
| Chlorophyll | ns | ns | ns | .0065 | .00623 | ns | .0021 | .029 | .044 | .013 | .000698 |
| Nitrogen | .039 | ns | .021 | .0031 | .00085 | ns | .036 | ns | .0017 | ns | .000698 |
| Phosphorus | .000021 | ns | .0009 | .0013 | .000195 | ns | .00061 | .022 | .016 | .0025 | .0000171 |
| TSS | ns | ns | ns | .0032 | ns | ns | .0015 | .022 | ns | .0014 | .000797 |
| Turbidity | .029 | .048 | ns | .0092 | .011 | ns | .00013 | .009 | .003 | .00028 | .0000044 |
| Sed Cu | .0186 | ns | ns | .026 | ns | ns | .012 | .021 | ns | .0071 | .00668 |
| Sed Ni | .0016 | ns | ns | .035 | .035 | ns | .04 | ns | ns | ns | .0449 |
| Sed Pb | ns | ns | ns | ns | ns | ns | .019 | .025 | ns | .020 | ns |
| Sed Zn | ns | ns | ns | ns | ns | ns | .011 | .031 | ns | .017 | .0397 |

b. Table of Pearson correlation coefficients (r) between measures of disturbance and the 10 invertebrate metrics and total invertebrate IBI score.

| Factor | ChiroTaxa | CorixProp | Dom3 | ETSD | IntolTaxa | Leech | Odonata | Snail | TolProp | TotalTax | IBI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HDS | .605 | .296 | .404 | .507 | .649 | .311 | .490 | .408 | ns | .594 | .715 |
| Turbidity | .329 | .296 | ns | .388 | .382 | ns | .545 | .387 | .437 | .522 | .631 |
| Phosphorus | .595 | ns | .473 | .471 | .533 | ns | .497 | .345 | .362 | .445 | .599 |
| Chloride | .587 | ns | .379 | .354 | .506 | ns | .402 | .341 | ns | .531 | .587 |
| Chlorophyll | ns | ns | ns | .404 | .406 | ns | .450 | .329 | .304 | .372 | .492 |
| Nitrogen | .312 | ns | .353 | .436 | .485 | ns | .317 | ns | .460 | ns | .492 |
| TSS | ns | ns | ns | .435 | ns | ns | .464 | .345 | ns | .465 | .487 |
| Sed Cu | .354 | ns | ns | .335 | ns | ns | .377 | .347 | ns | .400 | .403 |
| Sed Ni | .461 | ns | ns | .319 | .318 | ns | .311 | ns | ns | ns | .304 |
| Sed Pb | ns | ns | ns | ns | ns | ns | .353 | .337 | ns | .351 | ns |
| Sed Zn | .378 | ns | ns | ns | ns | ns | .379 | .325 | ns | .357 | .311 |

Appendix 12a. Metric scores and IBI scores for replicate samples from six large depressional wetlands, Donley, Lost, Minnow, Sheets Small, Skarpness and Wood Lake.

| Site Name | Site Type | ChiroTaxa | CorixProp | Dom3Prop | ETSD | IntolTaxa | Leech | Odonata | Snail | TolProp | TotalTaxa | IBI | Condition |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Donley Large S | Ref | 5 | 5 | 3 | 1 | 1 | 5 | 3 | 3 | 1 | 5 | 32 | mod |
| Donley Lg. N | Ref | 3 | 5 | 5 | 3 | 1 | 5 | 3 | 5 | 3 | 5 | 38 | exc |
| Lost 2 | Urb | 3 | 1 | 3 | 3 | 1 | 3 | 1 | 1 | 1 | 1 | 18 | poor |
| Lost1 | Urb | 3 | 1 | 1 | 1 | 1 | 5 | 1 | 1 | 3 | 1 | 18 | poor |
| Minnow S | Ref | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 50 | exc |
| Minnow N | Ref | 5 | 3 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 46 | exc |
| Sheets Small 2 | Ag | 5 | 5 | 1 | 3 | 3 | 3 | 5 | 3 | 1 | 5 | 34 | mod |
| Sheets Small 1 | Ag | 5 | 5 | 1 | 3 | 3 | 3 | 5 | 3 | 1 | 5 | 34 | mod |
| Skarpness W | Ag | 3 | 5 | 1 | 3 | 1 | 5 | 3 | 3 | 1 | 5 | 30 | mod |
| Skarpness E | Ag | 3 | 5 | 1 | 3 | 3 | 5 | 1 | 3 | 1 | 3 | 28 | mod |
| WoodLake2 | Urb | 5 | 5 | 5 | 3 | 5 | 5 | 5 | 1 | 5 | 5 | 44 | exc |
| Wood Lake | Urb | 1 | 5 | 5 | 3 | 3 | 5 | 1 | 1 | 5 | 3 | 32 | mod |

Appendix 12b. Data used to score each metric for replicate samples from six large depressional wetlands, Donley, Lost, Minnow, Sheets Small, Skarpness and Wood Lake.

| Site Name | Site Type | ChiroTaxa | CorixProp | Dom3Prop | ETSD | IntolTaxa | Leech | Odonata | Snail | TolProp | TotalTaxa |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Donley Large S | Ref | 14 | 0.300 | 0.718 | 2 | 2 | 6 | 4 | 4 | 0.7459 | 56 |
| Donley Lg.N | Ref | 10 | 0.269 | 0.394 | 4 | 1 | 5 | 4 | 7 | 0.536 | 58 |
| Lost 2 | Urb | 7 | 0.828 | 0.588 | 4 | 0 | 3 | 2 | 3 | 0.7088 | 31 |
| Lost 1 | Urb | 9 | 0.920 | 0.765 | 2 | 0 | 5 | 2 | 2 | 0.668 | 36 |
| Minnow S | Ref | 19 | 0.323 | 0.494 | 10 | 5 | 6 | 8 | 8 | 0.3483 | 63 |
| Minnow N | Ref | 21 | 0.370 | 0.381 | 8 | 4 | 6 | 6 | 7 | 0.275 | 64 |
| Sheets Small 2 | Ag | 16 | 0.064 | 0.814 | 5 | 3 | 3 | 7 | 6 | 0.834 | 69 |
| Sheets Sm 1 | Ag | 19 | 0.102 | 0.837 | 6 | 4 | 4 | 7 | 6 | 0.83 | 68 |
| Skarpness W | Ag | 11 | 0.185 | 0.897 | 5 | 1 | 5 | 4 | 4 | 0.9168 | 52 |
| Skarpness E | Ag | 12 | 0.139 | 0.763 | 6 | 3 | 5 | 3 | 4 | 0.906 | 49 |
| WoodLake2 | Urb | 14 | 0.070 | 0.538 | 5 | 5 | 5 | 6 | 3 | 0.294 | 56 |
| WoodLake | Urb | 4 | 0.056 | 0.534 | 4 | 3 | 5 | 2 | 3 | 0.193 | 39 |

Appendix 13. List of plant taxa counted for the sensitive species metric. TSN is the taxonomic serial number. Count is the number of times the taxa was observed in the large depressional wetland project samples.

| Plant Scientific Name | Plant Family | tsn | Count |
|---|---|---|---|
| *Calla palustris* | Araceae | 42546 | |
| *Asclepias incarnata* | Asclepiadaceae | 30241 | 5 |
| *Gymnocarpium dryopteris* | Aspleniaceae | 17579 | |
| *Corylus cornuta* | Betulaceae | 19507 | |
| *Campanula aparinoides* | Campanulaceae | 34476 | 4 |
| *Lobelia kalmii* | Campanulaceae | 34525 | |
| *Linnaea borealis* | Caprifoliaceae | 35314 | |
| *Symphoricarpos albus* | Caprifoliaceae | 35332 | 1 |
| *Chara* sp. | Characeae | 9421 | 1 |
| *Cornus canadensis* | Cornaceae | 27816 | |
| *Carex aquatilis* | Cyperaceae | 39374 | 3 |
| *Carex atherodes* | Cyperaceae | 39449 | 5 |
| *Carex diandra* | Cyperaceae | 39448 | 1 |
| *Carex disperma* | Cyperaceae | 39577 | |
| *Carex echinata* | Cyperaceae | 39582 | |
| *Carex flava* | Cyperaceae | 39606 | |
| *Carex lasiocarpa* | Cyperaceae | 39459 | 7 |
| *Carex oligosperma* | Cyperaceae | 39729 | 1 |
| *Carex retrorsa* | Cyperaceae | 39783 | |
| *Carex richardsonii* | Cyperaceae | 39784 | |
| *Carex rostrata* | Cyperaceae | 39464 | 6 |
| *Carex trisperma* | Cyperaceae | 39853 | |
| *Cladium mariscoides* | Cyperaceae | 39880 | |
| *Dulichium arundinaceum* | Cyperaceae | 40009 | 6 |
| *Eriophorum angustifolium* | Cyperaceae | 40080 | |
| *Eriophorum chamissonis* | Cyperaceae | 40093 | |
| *Eriophorum gracile* | Cyperaceae | 40096 | |
| *Eriophorum spissum* | Cyperaceae | 40102 | |
| *Eriophorum tenellum* | Cyperaceae | 40103 | |
| *Eriophorum virginicum* | Cyperaceae | 40105 | |
| *Eriophorum viridi-carinatum* | Cyperaceae | 40106 | |
| *Rhynchospora* sp. | Cyperaceae | 40144 | |
| *Rhynchospora alba* | Cyperaceae | 40151 | |
| *Rhynchospora capillacea* | Cyperaceae | 40156 | |
| *Rhynchospora fusca* | Cyperaceae | 40172 | |
| *Scirpus validus* | Cyperaceae | 40239 | 11 |
| *Drosera intermedia* | Droseraceae | 22013 | |
| *Andromeda glaucophylla* | Ericaceae | 23466 | |
| *Arctostaphylos uva-ursi* | Ericaceae | 23530 | |
| *Gaultheria hispidula* | Ericaceae | 23653 | |
| *Ledum groenlandicum* | Ericaceae | 23546 | |
| *Vaccinium macrocarpon* | Ericaceae | 23599 | |
| *Vaccinium oxycoccos* | Ericaceae | 505635 | |
| *Myriophyllum spicatum* | Haloragaceae | 27039 | |
| *Myriophyllum verticillatum* | Haloragaceae | 27040 | 2 |
| *Hypericum boreale* | Hypericaceae | 21427 | |
| *Triadenum* sp. | Hypericaceae | 21472 | |

Appendix 13 continued

| Plant Scientific Name | Plant Family | tsn | Count |
|---|---|---|---|
| *Triadenum fraseri* | Hypericaceae | 21473 | 2 |
| *Iris* sp. | | 43191 | |
| *Iris versicolor* | Iridaceae | 43196 | 5 |
| *Sisyrinchium montanum* | Iridaceae | 43269 | |
| *Juglans cinerea* | Juglandaceae | 19250 | |
| *Triglochin maritimum* | Juncaginaceae | 505588 | |
| *Triglochin palustre* | Juncaginaceae | 38989 | |
| *Scutellaria galericulata* | Lamiaceae | 32798 | 16 |
| *Scutellaria ovata* | Lamiaceae | 32772 | |
| *Scutellaria parvula* | Lamiaceae | 32776 | |
| *Utricularia* sp. | Lentibulariaceae | 34443 | 2 |
| *Utricularia cornuta* | Lentibulariaceae | 34447 | |
| *Utricularia gibba* | Lentibulariaceae | 34452 | |
| *Utricularia intermedia* | Lentibulariaceae | 34454 | 3 |
| *Utricularia macrorhiza* | Lentibulariaceae | 34445 | 17 |
| *Utricularia minor* | Lentibulariaceae | 34457 | 2 |
| *Utricularia resupinata* | Lentibulariaceae | 34463 | |
| *Clintonia borealis* | Liliaceae | 42903 | |
| *Smilacina stellata* | Liliaceae | 43038 | |
| *Smilacina trifolia* | Liliaceae | 43039 | |
| *Streptopus roseus* | Liliaceae | 43046 | |
| *Tofieldia glutinosa* | Liliaceae | 43051 | |
| *Lycopodium inundatum* | Lycopodiaceae | 17015 | |
| *Menyanthes trifoliata* | Menyanthaceae | 30102 | |
| *Nelumbo lutea* | Nymphaeaceae | 18398 | |
| *Circaea alpina* | Onagraceae | 27563 | |
| *Epilobium strictum* | Onagraceae | 27326 | |
| *Arethusa bulbosa* | Orchidaceae | 43491 | |
| *Calopogon tuberosus* | Orchidaceae | 43506 | |
| *Cypripedium acaule* | Orchidaceae | 43534 | |
| *Cypripedium arietinum* | Orchidaceae | 43540 | |
| *Goodyera tesselata* | Orchidaceae | 43596 | |
| *Liparis loeselii* | Orchidaceae | 43623 | |
| *Listera cordata* | Orchidaceae | 43634 | |
| *Pogonia ophioglossoides* | Orchidaceae | 43441 | |
| *Larix laricina* | Pinaceae | 183412 | |
| *Ammophila breviligulata* | Poaceae | 40448 | |
| *Calamagrostis canadensis* | Poaceae | 40544 | 9 |
| *Calamagrostis inexpansa* | Poaceae | 40551 | |
| *Cinna latifolia* | Poaceae | 40584 | |
| *Glyceria borealis* | Poaceae | 40841 | 3 |
| *Glyceria canadensis* | Poaceae | 40842 | |
| *Glyceria grandis* | Poaceae | 502812 | 6 |
| *Glyceria septentrionalis* | Poaceae | 40840 | 1 |
| *Polygala paucifolia* | Polygalaceae | 29306 | |
| *Potamogeton gramineus* | Potamogetonacea | 39032 | 2 |
| *Potamogeton illinoensis* | Potamogetonacea | 39035 | 1 |
| *Potamogeton natans* | Potamogetonacea | 39008 | 3 |
| *Potamogeton praelongus* | Potamogetonacea | 39042 | |
| *Potamogeton robbinsii* | Potamogetonacea | 504559 | |

Appendix 13 continued

| Plant Scientific Name | Plant Family | tsn | Count |
|---|---|---|---|
| *Trientalis borealis* | Primulaceae | 24053 | |
| *Riccia fluitans* | Ricciaceae | 15633 | 15 |
| *Ricciocarpus natans* | Ricciaceae | -30 | 3 |
| *Potentilla anserina* | Rosaceae | 24687 | |
| *Potentilla fruticosa* | Rosaceae | 24710 | |
| *Potentilla palustris* | Rosaceae | 24676 | 1 |
| *Spiraea alba* | Rosaceae | 25329 | 1 |
| *Spiraea tomentosa* | Rosaceae | 25342 | |
| *Salix candida* | Salicaceae | 22514 | |
| *Sarracenia purpurea* | Sarraceniaceae | 21993 | |
| *Parnassia glauca* | Saxifragaceae | 24210 | |
| *Ribes glandulosum* | Saxifragaceae | 24466 | |
| *Ribes hirtellum* | Saxifragaceae | 24470 | |
| *Melampyrum lineare* | Scrophulariaceae | 33651 | |
| *Viola lanceolata* | Violaceae | 22094 | |
| *Viola pedata* | Violaceae | 22130 | |

Appendix 14. Counts of plant attributes which were developed into metrics for 44 large depressional wetlands in Central Minnesota. Replicate samples collected from the same sites on the same date.

| SiteName | SiteType | Sample | VascGen | NonVas | CarexCov | SensitTaxa | TolerTaxa | GrassLk | Peren | AquaGuild | Domin3 | PersisLit% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Battle Creek | Urb | Primary | 20 | 1 | 0.2 | 2 | 22.9 | 7 | 24 | 11 | 26.3 | 18.8 |
| Bloom | Ref | Primary | 25 | 2 | 4.5 | 12 | 10.6 | 14 | 41 | 13 | 22.1 | 5.4 |
| Breen | Ag | Primary | 4 | 0 | 0 | 0 | 100.0 | 1 | 2 | 2 | 49.5 | 0.0 |
| Bunker | Ag | Primary | 12 | 0 | 0.2 | 2 | 13.6 | 9 | 16 | 8 | 34.7 | 4.2 |
| Casey | Urb | Primary | 5 | 0 | 0 | 1 | 63.6 | 2 | 5 | 1 | 72.6 | 58.1 |
| Cataract | Ref | Primary | 11 | 1 | 1 | 3 | 29.2 | 3 | 6 | 6 | 42.4 | 0.6 |
| Davis | Ag | Primary | 2 | 1 | 0 | 1 | 60.0 | 0 | 1 | 3 | 84.2 | 52.6 |
| Donley large | Ref | Primary | 8 | 0 | 1.1 | 2 | 29.4 | 6 | 10 | 3 | 53.6 | 45.5 |
| Elm Creek | Ref | Primary | 9 | 2 | 0.5 | 5 | 27.8 | 4 | 12 | 5 | 49.5 | 39.6 |
| Elm Creek | Ref | Replicate | 11 | 2 | 2 | 5 | 33.3 | 5 | 12 | 5 | 40.8 | 36.2 |
| Field | Ref | Primary | 12 | 1 | 2.5 | 4 | 28.6 | 3 | 14 | 6 | 42.3 | 21.2 |
| Glacial | Ref | Primary | 15 | 3 | 2.5 | 7 | 18.2 | 4 | 15 | 8 | 40.8 | 25.5 |
| Grass | Urb | Primary | 6 | 0 | 0 | 1 | 41.7 | 2 | 7 | 2 | 59.2 | 20.4 |
| Jones | Urb | Primary | 3 | 0 | 0 | 1 | 60.0 | 0 | 3 | 1 | 97.3 | 95.9 |
| Kasma | Ref | Primary | 12 | 0 | 0 | 2 | 46.7 | 3 | 10 | 5 | 54.9 | 30.5 |
| Lake 21 | Ref | Primary | 8 | 0 | 0.5 | 1 | 33.3 | 3 | 9 | 7 | 51.7 | 34.5 |
| Lake Park | Ag | Primary | 4 | 2 | 0.1 | 3 | 42.9 | 1 | 3 | 5 | 77.6 | 34.5 |
| Lashier | Ref | Primary | 10 | 1 | 0.5 | 1 | 45.5 | 1 | 9 | 6 | 66.1 | 49.6 |
| Legion | Urb | Primary | 5 | 1 | 0 | 2 | 57.1 | 1 | 4 | 5 | 72.2 | 30.9 |
| Lost | Urb | Primary | 4 | 0 | 0 | 1 | 41.7 | 1 | 4 | 1 | 57.1 | 1.4 |
| Malardi | Ag | Primary | 10 | 2 | 1.5 | 2 | 40.0 | 4 | 11 | 3 | 50.8 | 38.1 |
| Minnow | Ref | Primary | 21 | 4 | 4.5 | 11 | 13.6 | 9 | 29 | 14 | 18.3 | 7.3 |
| Minnow | Ref | Replicate | 17 | 2 | 1.5 | 5 | 16.1 | 9 | 24 | 10 | 24.2 | 16.5 |
| Mud | Urb | Primary | 20 | 0 | 0.2 | 4 | 29.6 | 6 | 17 | 10 | 33.8 | 15.0 |
| Mud | Urb | Replicate | 16 | 0 | 0.5 | 1 | 26.1 | 5 | 14 | 9 | 22.6 | 15.8 |
| New London | Ref | Primary | 9 | 1 | 0 | 1 | 28.6 | 2 | 9 | 8 | 36.7 | 0.0 |
| New prairie | Ag | Primary | 8 | 0 | 0 | 0 | 30.8 | 2 | 8 | 6 | 43.8 | 21.9 |
| Ney | Ag | Primary | 5 | 0 | 0 | 0 | 42.9 | 2 | 4 | 4 | 72.7 | 0.0 |
| Overby | Ref | Primary | 9 | 2 | 0.5 | 6 | 26.7 | 1 | 9 | 9 | 58.8 | 26.5 |
| Prairie | Ref | Primary | 22 | 1 | 3 | 9 | 18.4 | 11 | 25 | 11 | 21.3 | 17.7 |
| Rose Golf | Urb | Primary | 7 | 1 | 0.5 | 2 | 40.0 | 4 | 10 | 2 | 57.1 | 0.0 |
| Round | Urb | Primary | 2 | 0 | 0 | 0 | 20.0 | 1 | 5 | 1 | 35.6 | 5.0 |
| Savage | Urb | Primary | 10 | 0 | 0 | 0 | 42.9 | 2 | 7 | 7 | 50.4 | 32.4 |
| Seter | Ag | Primary | 9 | 0 | 0 | 2 | 46.2 | 5 | 10 | 6 | 51.3 | 51.9 |
| Sethre | Ag | Primary | 4 | 0 | 0 | 1 | 60.0 | 0 | 3 | 4 | 80.0 | 40.0 |
| Sethre | Ag | Replicate | 5 | 0 | 0.1 | 1 | 50.0 | 1 | 4 | 4 | 95.9 | 41.1 |
| Sheets Big | Ag | Primary | 11 | 1 | 1.5 | 4 | 31.6 | 6 | 17 | 7 | 34.7 | 35.3 |
| Sheets Small | Ag | Primary | 9 | 0 | 0 | 1 | 27.3 | 5 | 10 | 3 | 44.4 | 29.6 |
| Sigler | Ag | Primary | 6 | 0 | 0 | 1 | 75.0 | 2 | 4 | 4 | 69.3 | 39.6 |
| Skarpness | Ag | Primary | 7 | 0 | 3 | 1 | 16.7 | 5 | 8 | 4 | 48.1 | 9.6 |
| Skarpness | Ag | Replicate | 13 | 0 | 3 | 3 | 19.0 | 9 | 14 | 6 | 33.5 | 22.3 |
| Sucker North | Ag | Primary | 9 | 0 | 0 | 0 | 40.0 | 4 | 8 | 4 | 44.0 | 30.2 |
| Sunset | Urb | Primary | 15 | 0 | 2 | 2 | 13.3 | 7 | 21 | 2 | 35.4 | 22.7 |
| Trappers | Ag | Primary | 17 | 0 | 0.5 | 4 | 24.2 | 4 | 16 | 8 | 36.0 | 2.4 |
| Turtle | Urb | Primary | 5 | 1 | 0 | 2 | 62.5 | 1 | 4 | 5 | 75.5 | 47.2 |
| Tyrone Bean | Ag | Primary | 7 | 0 | 3.5 | 2 | 35.7 | 4 | 8 | 4 | 42.9 | 6.1 |
| Wakefield | Urb | Primary | 7 | 1 | 0 | 1 | 50.0 | 2 | 8 | 6 | 66.7 | 46.7 |

Appendix 14 continued.

| SiteName | SiteType | Sample | Vasc Gen | Non Vas | Carex Cov | Sensit Taxa | Toler Taxa | Grass Lk | Peren | Aqua Guild | Domin3 | Persis Lit% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wood | Urb | Primary | 4 | 1 | 0 | 1 | 57.1 | 2 | 3 | 3 | 71.4 | 44.4 |
| Wood | Urb | Replicate | 8 | 1 | 0.5 | 2 | 40.0 | 4 | 7 | 7 | 56.6 | 28.9 |
| Zager | Ref | Primary | 18 | 2 | 2.1 | 7 | 7.1 | 12 | 24 | 9 | 34.8 | 7.0 |

Appendix 15. List of plant taxa considered to be tolerant for the tolerant taxa metric. All nonnative wetland taxa are included as tolerant. TSN is the taxonomic serial number. Count is the number of times the taxa was observed in the large depressional wetland project samples.

| SciName | FAMILY | TSN | Origin | Count |
|---|---|---|---|---|
| *Ruellia humilis* | Acanthaceae | 34379 | Nonnative | |
| *Amaranthus blitoides* | Amaranthaceae | 20723 | Nonnative | |
| *Amaranthus retroflexus* | Amaranthaceae | 20745 | Nonnative | |
| *Impatiens capensis* | Balsaminaceae | 29182 | Native | 3 |
| *Impatiens pallida* | Balsaminaceae | 29189 | Native | |
| *Impatiens* sp. | Balsaminaceae | 29181 | | 10 |
| *Berberis* sp. | Berberidaceae | 18814 | Nonnative | |
| *Berberis thunbergii* | Berberidaceae | 18835 | Nonnative | |
| *Catalpa* sp. | Bignoniaceae | 34312 | Nonnative | |
| *Catalpa speciosa* | Bignoniaceae | 34315 | Nonnative | |
| *Myosotis arvensis* | Boraginaceae | 31692 | Nonnative | |
| *Myosotis scorpioides* | Boraginaceae | 31697 | Nonnative | |
| *Myosotis sylvatica* | Boraginaceae | 31698 | Nonnative | |
| *Hackelia virginiana* | Boraginaceae | 31921 | Native | |
| *Armoracia rusticana* | Brassicaceae | 23044 | Nonnative | |
| *Barbarea vulgaris* | Brassicaceae | 22741 | Nonnative | |
| *Capsella* sp. | Brassicaceae | 22765 | Nonnative | |
| *Capsella bursa-pastoris* | Brassicaceae | 22766 | Nonnative | |
| *Erysimum cheiranthoides* | Brassicaceae | 22933 | Nonnative | |
| *Lepidium perfoliatum* | Brassicaceae | 22974 | Nonnative | |
| *Nasturtium microphyllum* | Brassicaceae | 23254 | Nonnative | |
| *Nasturtium officinale* | Brassicaceae | 23255 | Nonnative | |
| *Rorippa* sp. | Brassicaceae | 22991 | Nonnative | |
| *Rorippa austriaca* | Brassicaceae | 22995 | Nonnative | |
| *Rorippa islandica* | Brassicaceae | 22992 | Nonnative | |
| *Rorippa sessiliflora* | Brassicaceae | 23013 | Nonnative | |
| *Rorippa sinuata* | Brassicaceae | 23014 | Nonnative | |
| *Rorippa sylvestris* | Brassicaceae | 23017 | Nonnative | |
| *Sisymbrium* sp. | Brassicaceae | 23311 | Nonnative | |
| *Sisymbrium altissimum* | Brassicaceae | 23312 | Nonnative | |
| *Subularia aquatica* | Brassicaceae | 23023 | Nonnative | |
| *Butomus* sp. | Butomaceae | 38885 | Nonnative | |
| *Butomus umbellatus* | Butomaceae | 38886 | Nonnative | |
| *Cannabis* sp. | Cannabinaceae | 19108 | Nonnative | |
| *Cannabis sativa* | Cannabinaceae | 19109 | Nonnative | |
| *Cleome* sp. | Capparaceae | 22613 | Nonnative | |
| *Cleome serrulata* | Capparaceae | 22626 | Nonnative | |
| *Lonicera morrowii* | Caprifoliaceae | 35299 | Nonnative | |
| *Lonicera tatarica* | Caprifoliaceae | 35306 | Nonnative | |
| *Lonicera x bella* | Caprifoliaceae | 35286 | Nonnative | |
| *Symphoricarpos orbiculatus* | Caprifoliaceae | 35337 | Nonnative | |
| *Arenaria serpyllifolia* | Caryophyllaceae | 20270 | Nonnative | |
| *Myosoton* sp. | Caryophyllaceae | 20313 | Nonnative | |
| *Myosoton aquaticum* | Caryophyllaceae | 20314 | Nonnative | 1 |
| *Saponaria* sp. | Caryophyllaceae | 20038 | Nonnative | |
| *Saponaria officinalis* | Caryophyllaceae | 20039 | Nonnative | |
| *Scleranthus annuus* | Caryophyllaceae | 20360 | Nonnative | |

Appendix 15 continued

| SciName | FAMILY | TSN | Origin | Count |
|---|---|---|---|---|
| *Spergularia* sp. | Caryophyllaceae | 20150 | Nonnative | |
| *Spergularia rubra* | Caryophyllaceae | 20153 | Nonnative | |
| *Stellaria graminea* | Caryophyllaceae | 20181 | Nonnative | |
| *Stellaria media* | Caryophyllaceae | 20169 | Nonnative | |
| *Atriplex hortensis* | Chenopodiaceae | 20538 | Nonnative | |
| *Chenopodium album* | Chenopodiaceae | 20592 | Nonnative | |
| *Chenopodium botrys* | Chenopodiaceae | 20596 | Nonnative | |
| *Chenopodium glaucum* | Chenopodiaceae | 20610 | Nonnative | |
| *Chenopodium glaucum var. salinum* | Chenopodiaceae | 533465 | Nonnative | |
| *Coriospermum* sp. | Chenopodiaceae | 20641 | Nonnative | |
| *Coriospermum hyssopifolium* | Chenopodiaceae | 20642 | Nonnative | |
| *Kochia* sp. | Chenopodiaceae | 20693 | Nonnative | |
| *Kochia scoparia* | Chenopodiaceae | 20696 | Nonnative | |
| *Salsola iberica* | Chenopodiaceae | 520948 | Nonnative | |
| *Commelina communis* | Commelinaceae | 39127 | Nonnative | |
| *Achillea* sp. | Compositae | 35422 | Nonnative | |
| *Achillea millefolium* | Compositae | 35423 | Nonnative | |
| *Anthemis* sp. | Compositae | 36329 | Nonnative | |
| *Anthemis cotula* | Compositae | 36330 | Nonnative | |
| *Artemisia biennis* | Compositae | 35451 | Nonnative | |
| *Artemisia stelleriana* | Compositae | 35439 | Nonnative | |
| *Chamomilla suaveolens* | Compositae | 510768 | Nonnative | |
| *Cirsium arvense* | Compositae | 36335 | Nonnative | |
| *Cirsium vulgare* | Compositae | 36428 | Nonnative | |
| *Coreopsis lanceolata* | Compositae | 37139 | Nonnative | |
| *Coreopsis tinctoria* | Compositae | 37153 | Nonnative | |
| *Helenium flexuosum* | Compositae | 36016 | Nonnative | |
| *Lactuca serriola* | Compositae | 36608 | Nonnative | |
| *Madia* sp. | Compositae | 38017 | Nonnative | |
| *Madia glomerata* | Compositae | 38029 | Nonnative | |
| *Matricaria maritima* | Compositae | 38076 | Nonnative | |
| *Senecio vulgaris* | Compositae | 36194 | Nonnative | |
| *Sonchus* sp. | Compositae | 38420 | Nonnative | 1 |
| *Sonchus arvensis* | Compositae | 38421 | Nonnative | |
| *Sonchus asper* | Compositae | 38424 | Nonnative | |
| *Sonchus oleraceus* | Compositae | 38427 | Nonnative | |
| *Taraxacum* sp. | Compositae | 36199 | Nonnative | |
| *Taraxacum officinale* | Compositae | 36213 | Nonnative | |
| *Tussilago* sp. | Compositae | 38582 | Nonnative | |
| *Tussilago farfara* | Compositae | 38583 | Nonnative | |
| *Ambrosia artemisiifolia* | Compositae | 36496 | Native | |
| *Ambrosia trifida* | Compositae | 36521 | Native | |
| *Conyza canadensis* | Compositae | 37113 | Native | |
| *Erigeron annuus* | Compositae | 35804 | Native | |
| *Iva xanthifolia* | Compositae | 36041 | Native | |
| *Ipomoea* sp. | Convolvulaceae | 30758 | Nonnative | |
| *Ipomoea hederacea* | Convolvulaceae | 503177 | Nonnative | |
| *Ipomoea purpurea* | Convolvulaceae | 30789 | Nonnative | |
| *Alliaria petiolata* | Cruciferae | 184481 | Nonnative | |
| *Cyperus esculentus* | Cyperaceae | 39888 | Nonnative | |

Appendix 15 continued

| SciName | FAMILY | TSN | Origin | Count |
|---|---|---|---|---|
| *Cyperus rotundus* | Cyperaceae | 39900 | Nonnative | |
| *Cyperus erythrorhizos* | Cyperaceae | 39887 | Native | |
| *Elaeagnus angustifolia* | Elaeagnaceae | 27770 | Nonnative | |
| *Euphorbia cyathophora* | Euphorbiaceae | 28060 | Nonnative | |
| *Centaurium* sp. | Gentianaceae | 30026 | Nonnative | |
| *Centaurium pulchellum* | Gentianaceae | 30036 | Nonnative | |
| *Agrostis stolonifera var. major* | Gramineae | 185229 | Nonnative | |
| *Myriophyllum alterniflorum* | Haloragaceae | 503903 | Nonnative | |
| *Myriophyllum spicatum* | Haloragaceae | 27039 | Nonnative | |
| *Iris pseudacorus* | Iridaceae | 43194 | Nonnative | |
| *Juncus balticus* | Juncaceae | 39223 | Native | 1 |
| *Glechoma hederacea* | Labiatae | 502801 | Nonnative | |
| *Glechoma* sp. | Lamiaceae | 500297 | Nonnative | |
| *Leonurus cardiaca* | Lamiaceae | 32548 | Nonnative | |
| *Marrubium* sp. | Lamiaceae | 32560 | Nonnative | |
| *Marrubium vulgare* | Lamiaceae | 32561 | Nonnative | |
| *Mentha* sp. | Lamiaceae | 32264 | Nonnative | |
| *Mentha arvensis* | Lamiaceae | 32265 | Nonnative | 1 |
| *Mentha cardiaca* | Lamiaceae | 32266 | Nonnative | |
| *Mentha spicata* | Lamiaceae | 32272 | Nonnative | |
| *Nepeta* sp. | Lamiaceae | 32622 | Nonnative | |
| *Nepeta cataria* | Lamiaceae | 32623 | Nonnative | |
| Perilla sp. | Lamiaceae | 32633 | Nonnative | |
| *Perilla frutescens* | Lamiaceae | 32634 | Nonnative | |
| *Lotus corniculatus* | Leguminosae | 26362 | Nonnative | |
| *Lupinus polyphyllus* | Leguminosae | 25921 | Nonnative | |
| *Medicago lupulina* | Leguminosae | 503721 | Nonnative | |
| *Melilotus* sp. | Leguminosae | 26148 | Nonnative | |
| *Melilotus alba* | Leguminosae | 26149 | Nonnative | |
| *Melilotus officinalis* | Leguminosae | 26150 | Nonnative | |
| *Robinia pseudo-acacia* | Leguminosae | 26185 | Nonnative | |
| *Trifolium* sp. | Leguminosae | 26204 | Nonnative | |
| *Trifolium hybridum* | Leguminosae | 26261 | Nonnative | |
| *Trifolium pratense* | Leguminosae | 26313 | Nonnative | |
| *Trifolium repens* | Leguminosae | 26206 | Nonnative | 1 |
| *Vicia sativa* | Leguminosae | 26355 | Nonnative | |
| *Lemna* sp. | Lemnaceae | 42588 | Native | |
| *Lemna minor* | Lemnaceae | 42590 | Native | 38 |
| *Lemna trisulca* | Lemnaceae | 42595 | Native | 24 |
| *Spirodela polyrhiza* | Lemnaceae | 42599 | Native | 28 |
| *Wolffia columbiana* | Lemnaceae | 42602 | Native | 8 |
| *Wolffia punctata* | Lemnaceae | 42604 | Native | |
| *Asparagus* sp. | Liliaceae | 42782 | Nonnative | |
| *Asparagus officinalis* | Liliaceae | 42784 | Nonnative | |
| *Ornithogalum* sp. | Liliaceae | 42753 | Nonnative | |
| *Ornithogalum umbellatum* | Liliaceae | 42754 | Nonnative | |
| *Lythrum salicaria* | Lythraceae | 27079 | Nonnative | 8 |
| *Abutilon sp.* | Malvaceae | 21659 | Nonnative | |
| *Abutilon theophrasti* | Malvaceae | 21674 | Nonnative | |
| *Morus alba* | Moraceae | 19066 | Nonnative | |

Appendix 15 continued

| SciName | FAMILY | TSN | Origin | Count |
|---|---|---|---|---|
| *Plantago lanceolata* | Plantaginaceae | 32874 | Nonnative | |
| *Plantago major* | Plantaginaceae | 32887 | Nonnative | |
| *Agropyron repens* | Poaceae | 40382 | Nonnative | 2 |
| *Agrostis gigantea* | Poaceae | 40414 | Nonnative | 2 |
| *Agrostis stolonifera* | Poaceae | 40400 | Nonnative | 1 |
| *Alopecurus pratensis* | Poaceae | 40438 | Nonnative | |
| *Arrhenatherum elatius* | Poaceae | 41443 | Nonnative | |
| *Bromus japonicus* | Poaceae | 40479 | Nonnative | 1 |
| *Bromus tectorum* | Poaceae | 40524 | Nonnative | |
| *Dactylis* sp. | Poaceae | 193445 | Nonnative | |
| *Dactylis glomerata* | Poaceae | 193446 | Nonnative | |
| *Digitaria* sp. | Poaceae | 203845 | Nonnative | |
| *Digitaria ischaemum* | Poaceae | 40637 | Nonnative | |
| *Digitaria sanguinalis* | Poaceae | 40604 | Nonnative | |
| *Echinochloa crusgalli* | Poaceae | 40668 | Nonnative | |
| *Eleusine* sp. | Poaceae | 41690 | Nonnative | |
| *Eleusine indica* | Poaceae | 41692 | Nonnative | |
| *Elymus arenarius* | Poaceae | 40678 | Nonnative | |
| *Eragrostis cilianensis* | Poaceae | 40719 | Nonnative | |
| *Eragrostis pilosa* | Poaceae | 40755 | Nonnative | |
| *Festuca arundinacea* | Poaceae | 40810 | Nonnative | |
| *Festuca pratensis* | Poaceae | 40822 | Nonnative | |
| *Lolium* sp. | Poaceae | 40891 | Nonnative | |
| *Lolium perenne* | Poaceae | 40893 | Nonnative | |
| *Phalaris canariensis* | Poaceae | 41336 | Nonnative | |
| *Phleum* sp. | Poaceae | 41061 | Nonnative | |
| *Phleum pratense* | Poaceae | 41062 | Nonnative | 1 |
| *Poa annua* | Poaceae | 41107 | Nonnative | |
| *Poa compressa* | Poaceae | 41082 | Nonnative | |
| *Poa nemoralis* | Poaceae | 41146 | Nonnative | |
| *Poa trivialis* | Poaceae | 41163 | Nonnative | |
| *Puccinellia distans* | Poaceae | 41197 | Nonnative | |
| *Setaria* sp. | Poaceae | 41229 | Nonnative | |
| *Setaria faberi* | Poaceae | 41244 | Nonnative | |
| *Setaria glauca* | Poaceae | 41246 | Nonnative | |
| *Setaria italica* | Poaceae | 41248 | Nonnative | |
| *Setaria verticillata* | Poaceae | 41232 | Nonnative | |
| *Alopecurus aequalis* | Poaceae | 40436 | Native | |
| *Beckmannia syzigachne* | Poaceae | 41325 | Native | |
| *Echinochloa muricata* | Poaceae | 40672 | Native | |
| *Phalaris arundinacea* | Poaceae | 41335 | Native | 42 |
| *Phragmites australis* | Poaceae | 41072 | Native | 2 |
| *Echinochloa* sp. | Poaceae | 40667 | | |
| *Phlox maculata* | Polemoniaceae | 30961 | Nonnative | |
| *Polygonum aviculare* | Polygonaceae | 20876 | Nonnative | |
| *Polygonum cespitosum* | Polygonaceae | 504509 | Nonnative | |
| *Polygonum convolvulus* | Polygonaceae | 20853 | Nonnative | |
| *Polygonum cuspidatum* | Polygonaceae | 20889 | Nonnative | |
| *Polygonum hydropiper* | Polygonaceae | 20856 | Nonnative | |
| *Polygonum orientale* | Polygonaceae | 20909 | Nonnative | |

Appendix 15 continued

| SciName | FAMILY | TSN | Origin | Count |
|---|---|---|---|---|
| *Polygonum persicaria* | Polygonaceae | 20915 | Nonnative | |
| *Rumex acetosa* | Polygonaceae | 504901 | Nonnative | |
| *Rumex acetosella* | Polygonaceae | 20934 | Nonnative | |
| *Rumex crispus* | Polygonaceae | 20937 | Nonnative | |
| *Rumex longifolius* | Polygonaceae | 504913 | Nonnative | |
| *Rumex obtusifolius* | Polygonaceae | 20939 | Nonnative | |
| *Rumex stenophyllus* | Polygonaceae | 20977 | Nonnative | |
| *Polygonum pensylvanicum* | Polygonaceae | 20861 | Native | 1 |
| *Rumex altissimus* | Polygonaceae | 20949 | Native | |
| *Rumex maritimus* | Polygonaceae | 20965 | Native | 3 |
| *Rumex maritimus var. fueginus* | Polygonaceae | 526568 | Native | |
| *Rumex mexicanus* | Polygonaceae | 20966 | Native | |
| *Rumex verticillatus* | Polygonaceae | 20946 | Native | |
| *Rumex* sp. | Polygonaceae | 20933 | | |
| *Portulaca* sp. | Portulacaceae | 20418 | Nonnative | |
| *Portulaca oleracea* | Portulacaceae | 20422 | Nonnative | |
| *Potamogeton crispus* | Potamogetonaceae | 39007 | Nonnative | 4 |
| *Potamogeton pectinatus* | Potamogetonaceae | 39010 | Native | 5 |
| *Potamogeton pusillus* | Potamogetonaceae | 39017 | Native | 5 |
| *Potamogeton strictifolius* | Potamogetonaceae | 39047 | Native | 10 |
| *Anagallis* sp. | Primulaceae | 24042 | Nonnative | |
| *Anagallis arvensis* | Primulaceae | 24043 | Nonnative | |
| *Lysimachia nummularia* | Primulaceae | 23993 | Nonnative | |
| *Lysimachia thyrsiflora* | Primulaceae | 24000 | Native | 9 |
| *Ranunculus acris* | Ranunculaceae | 18583 | Nonnative | |
| *Ranunculus repens* | Ranunculaceae | 18642 | Nonnative | |
| *Ranunculus sceleratus* | Ranunculaceae | 18576 | Nonnative | |
| *Ranunculus circinatus var. subrigidus* | Ranunculaceae | 195009 | Native | |
| *Ranunculus cymbalaria* | Ranunculaceae | 18600 | Native | |
| *Ranunculus flammula* | Ranunculaceae | 18604 | Native | |
| *Ranunculus gmelinii* | Ranunculaceae | 504726 | Native | |
| *Ranunculus hispidus* | Ranunculaceae | 18613 | Native | |
| *Ranunculus lapponicus* | Ranunculaceae | 18620 | Native | |
| *Ranunculus macounii* | Ranunculaceae | 18625 | Native | |
| *Ranunculus pensylvanicus* | Ranunculaceae | 18637 | Native | |
| *Ranunculus recurvatus* | Ranunculaceae | 18641 | Native | |
| *Rhamnus cathartica* | Rhamnaceae | 28573 | Nonnative | 3 |
| *Rhamnus frangula* | Rhamnaceae | 28579 | Nonnative | |
| *Agrimonia gryposepala* | Rosaceae | 25095 | Nonnative | |
| *Potentilla argentea* | Rosaceae | 24691 | Nonnative | |
| *Rosa multiflora* | Rosaceae | 24833 | Nonnative | |
| *Rosa rugosa* | Rosaceae | 24811 | Nonnative | |
| *Rosa woodsii* | Rosaceae | 24847 | Nonnative | |
| *Ptelea* sp. | Rutaceae | 28990 | Nonnative | |
| *Ptelea trifoliata* | Rutaceae | 28992 | Nonnative | |
| *Salix alba* | Salicaceae | 22498 | Nonnative | |
| *Ribes odoratum* | Saxifragaceae | 24490 | Nonnative | |
| *Tiarella* sp. | Saxifragaceae | 24529 | Nonnative | |
| *Tiarella cordifolia* | Saxifragaceae | 24530 | Nonnative | |
| *Penstemon digitalis* | Scrophulariaceae | 33881 | Nonnative | |

Appendix 15 continued

| SciName | FAMILY | TSN | Origin | Count |
|---|---|---|---|---|
| *Penstemon pallidus* | Scrophulariaceae | 33967 | Nonnative | |
| *Veronica arvensis* | Scrophulariaceae | 33411 | Nonnative | |
| *Veronica officinalis* | Scrophulariaceae | 33398 | Nonnative | |
| *Veronica serpyllifolia* | Scrophulariaceae | 33423 | Nonnative | |
| *Physalis ixocarpa* | Solanaceae | 30602 | Nonnative | |
| *Physalis pubescens* | Solanaceae | 30607 | Nonnative | |
| *Solanum dulcamara* | Solanaceae | 30414 | Nonnative | 4 |
| *Typha* sp. | Typhaceae | 42324 | Native | |
| *Typha angustifolia* | Typhaceae | 42325 | Native | 6 |
| *Typha latifolia* | Typhaceae | 42326 | Native | 8 |
| *Typha x glauca* | Typhaceae | 42328 | Native | 27 |
| *Aegopodium sp.* | Umbelliferae | 29566 | Nonnative | |
| *Aegopodium podagraria* | Umbelliferae | 29567 | Nonnative | |
| *Cicuta maculata* | Umbelliferae | 29456 | Native | 6 |
| *Cicuta* sp. | Umbelliferae | 29455 | | 2 |
| *Laportea* sp. | Urticaceae | 19126 | Native | |
| *Laportea canadensis* | Urticaceae | 19127 | Native | |
| *Urtica* sp. | Urticaceae | 19151 | Native | |
| *Urtica dioica* | Urticaceae | 19152 | Native | 1 |
| *Verbena hastata* | Verbenaceae | 32071 | Native | 1 |
| *Verbena* sp. | Verbenaceae | 32070 | | |