AQUATIC INVERTEBRATE, VEGETATION, AND HYDROLOGY ASSESSMENT OF LONG MEADOW LAKE PRIOR TO EFFECTS OF HYDROLOGICAL MANIPULATIONS

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ABSTRACT

Functions of wetlands include improving water quality, reduction of flood impacts, shoreline stabilization, and habitat for many organisms including birds, invertebrates, fishes, and mammals. Long Meadow Lake (LML) is a large riverine wetland complex within the Minnesota Valley National Wildlife Refuge (MVNWR) near Minneapolis, Hennepin County, MN. Historically, LML water levels fluctuated on a wet-dry cycle, but alterations to the wetland have resulted in stagnant hydrology and largely monotypic vegetation. The MVNWR and the U.S. Army Corps of Engineers propose to construct a new water control structure on the 526-ha (1,300-ac) LML complex to efficiently manage for waterfowl and shorebird production by promoting key plant and invertebrate species through reintroduction of fluctuating wet and dry periods. However, collection of baseline data on current vegetation, aquatic invertebrates, and water quality is necessary to measure future impacts of water manipulations on flora and fauna, and to determine the efficacy of management actions. The objectives of my study were to: (1) identify and characterize current invertebrate and aquatic vegetation strata present in LML; (2) assess the overall condition of LML by calculating an Index of Biotic Integrity (IBI) score using aquatic invertebrates, aquatic vegetation, and hydrology measurements; and (3) compare and contrast selected aquatic vegetative habitats and associated benthic and epiphytic invertebrate communities. Aquatic invertebrate and vegetative data were collected from 30 sites within LML. Water and sediment samples also were collected to test for chemical pollutants. To identify potential relationships between invertebrate community composition and variation in structural and environmental habitat characteristics (e.g., vegetation composition, water quality, sediment contamination), I used nonmetric multidimensional scaling (NMDS). My findings indicate that LML is biologically impaired and is not fully supporting its aquatic life designated use. There were no strongly significant relationships to human disturbance around LML. However, the degradation of aquatic and terrestrial habitats within LML from surrounding land uses likely is related to chemistry and sediment loading. The average vegetation IBI score of 33.3 from 100 reflects the low plant diversity of LML. Total phosphorus, chloride, and turbidity had a negative effect on some of the vegetation metrics, while other metrics responded favorably to these parameters. The vegetation IBI scores were significantly different between habitats in 2004 (Kruskal-Wallis $H = 11.68$, df = 5, $P = 0.039$) but not in 2005 (Kruskal-Wallis $H = 10.23$, df = 5, $P = 0.069$). The overall mean invertebrate IBI score from 2004 and 2005 combined was 45.5, which indicates impairment in relation to invertebrate composition. Invertebrates were more abundant at sites where submersed vegetation was interspersed with emergent vegetation, rather than at sites with only submergent vegetation or floating-leaved vegetation. Chloride, nickel, copper, and turbidity were negatively correlated with certain invertebrate communities within LML. The invertebrate IBI scores were significantly different between IBI scores and habitat in 2004 (F = 2.793, df = 5, $P = 0.04$) and in 2005 (F = 3.234, df = 5, $P = 0.023$). Tukey-Kramer HSD determined that there were no differences between the IBI scores and habitats in 2004 but there were differences in scores between habitats in 2005. Invertebrate taxa represented in LML likely adapted to its habitats and conditions from occasional inputs of contaminants from the surrounding landscape. This study provides baseline data on vegetation, invertebrate, and water quality characteristics of LML prior to wet-dry cycle management, assesses the current degree of wetland ecosystem condition, and discusses management implications for proper timing of water manipulation to improve habitat and forage structure for wildlife.

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INTRODUCTION

Wetlands are dynamic natural environments influenced by both natural processes and human activity (Tiner 1998). The dynamic nature of northern freshwater marsh wetlands in North America is the result of fluctuating water regimes caused by extreme variability of the climate (Kantrud et al. 1989, Murkin et al. 2000a). Annual variations in spring runoff, summer precipitation, and evapotranspiration result in cyclical fluctuations in water levels within prairie basins (Murkin et al. 2000a). These changes in water levels from dry to flooded conditions often are referred to as the wet-dry cycle (van der Valk and Davis 1978). The water regime (i.e., the depth and duration of flooding) associated with the wet-dry cycle is the primary influence on productivity of northern prairie marsh wetlands (Murkin et al. 2000a). van der Valk and Davis (1978) identified four stages of the wet-dry cycle: dry marsh, regenerating marsh, degenerating marsh, and lake marsh. During the dry marsh stage, wetlands undergo a complete or partial drawdown during drought conditions. Drawdowns encourage seeds of annual and emergent plants to germinate on the exposed substrate (van der Valk and Davis 1978, Welling et al. 1988). Shallow moist soil conditions initially attract shorebirds and other species that forage on exposed invertebrates and small fish (Murkin and Caldwell 2000), but animals that rely on standing water depart or develop mechanisms to tolerate drought (Murkin 1989).

The regenerating marsh stage begins when the drought ends and the wetland becomes flooded. Flooding eliminates annual plants, and perennial emergent species expand through rapid vegetative growth (van der Valk and Davis 1978). Submersed species also germinate during the regenerating stage and become an important part of the macrophyte community. Invertebrate richness and abundance increases as species that were dormant or absent during the drought reappear within the wetland and exploit the diverse habitat structure provided by expanding vegetation (Murkin and Kadlec 1986a, Neckles et al. 1990, Murkin et al. 1991). Expanding vegetation and invertebrate populations provide habitat and food for a variety of birds and other wildlife species re-colonizing the wetland (Weller and Fredrickson 1974, van der Valk and Davis 1978, Swanson and Duebbert 1989, Murkin and Caldwell 2000). For example, many waterfowl species feed much of the year on submersed plants and tubers but shift to a diet of wetland invertebrates as a source of protein and calcium for egg laying (Swanson et al. 1979, Murkin 1989). Duck broods feed exclusively on invertebrates because plants do not provide nutrients essential for growth and feather production (Murkin and Caldwell 2000).

With continued flooding, emergent vegetation begins to die off from herbivory (e.g., muskrats; Clark 1994), the direct effects of prolonged inundation (i.e., anoxia), and disease (van der Valk and Davis 1978). In this early transition from regenerating to degenerating marsh, emergent macrophytes and open water are present in roughly equal proportions in an interspersed pattern (Weller and Fredrickson 1974, Murkin and Caldwell 2000). This pattern, described as "hemi-marsh," typically exhibits the highest habitat diversity, invertebrate abundance, and wildlife use within prairie marsh wetlands (Murkin and Kadlec 1986b, Murkin et al. 1997, Murkin and Caldwell 2000). However, as flooding continues, increased loss of vegetation reduces the richness and abundance of invertebrates which affect wildlife that depend on vegetation and invertebrates for cover and food (Weller and Fredrickson 1974). Reduction in the standing crop of macrophytes during the degenerating marsh stage also influences nutrient budgets and detrital pathways, resulting in declining wetland productivity (Murkin 1989).

Sustained inundation eventually limits emergent vegetation to a narrow band along the shallow fringe of the basin, and the wetland enters the lake marsh stage (van der Valk and Davis 1978, van der Valk 2000). Nutrient cycling and productivity typically decline to their lowest levels during this stage (Murkin et al. 2000b). The lack of vegetative cover exposes the water surface to wind and wave action, increasing turbidity, decreasing light penetration, and thus reducing growth and survival of submersed vegetation and algae (Nelson and Kadlec 1984, Murkin et al. 2000a). Wetland invertebrates and vertebrates that depend on living plants and detrital resources subsequently disappear or decline in numbers (Reid 1983, Murkin and Kadlec 1986a, Neckles et al. 1990, Murkin et al. 1991). The wetland typically exists in this stage, and productivity remains low, until a drought or artificial drawdown occurs and stimulates new plant germination during the dry marsh stage (van der Valk and Davis 1978, Murkin et al. 2000b). Under natural conditions, transitions between stages of the wet-dry cycle are gradual, and it may be difficult to discern when one stage ends and the next begins (Murkin et al. 2000a). Changes in climate during the cycle (e.g., prolonged droughts or rainy periods) may cause reversal or acceleration of transitions between one stage and another (Murkin and Caldwell 2000).

Human activities that alter or eliminate the wet-dry cycle also result in concomitant changes in wetland productivity and diversity. The hydrology of many northern marsh wetlands have been artificially stabilized to provide permanent water sources with little variation in depths for wildlife habitat, recreation, and drinking water (Weller 1981, Kaminski and Prince 1981, Batt 2000). Changes in marsh hydrology from cyclical to permanently flooded conditions have also resulted from alterations to adjacent upland and riverine habitats (Mitsch and Gosselink 2000). When permanent flooding depth is higher than the long-term tolerance level of the emergent plants, the wetland typically advances to, and remains at, the relatively unproductive lake marsh stage (van der Valk and Davis 1978, Batt 2000). Without exposure of the basin soil, annual and emergent species are prevented from germinating and re-establishing (Welling et al. 1988), and invertebrate and vertebrate use remains limited (Murkin et al. 1997). Compared to wetlands exhibiting a wet-dry cycle, permanently flooded habitats have increased numbers of vertebrate and invertebrate predators that prey on invertebrates (Skelly 1997). Over a period of years, permanent flooding may transform marsh wetlands into stagnant, muck-bottomed, winter-kill lakes (Batt 2000).

However, when prolonged flooding occurs at depths less than the long-term tolerance level of emergent plants, dense monotypic stands of flood tolerant species such as cattail (*Typha* spp.) can dominate, eventually eliminating other species of plants as well as existing open water areas (Murkin and Ward 1980, Waters and Shay 1990, Murkin et al. 1997). These monocultures are unproductive invertebrate habitats (Murkin and Ross 2000) and also are not preferred habitat for most vertebrate species (Weller 1981, Kaminski and Price 1981, Smith et al. 1989). For example, if shallow flooding is permanent, dense patches of emergent vegetation will persist until the plants are eliminated by disease, herbivory, or increases in water depths beyond tolerance levels of the species (Murkin et al. 1997). The wetland may then transition to an unproductive open-water wetland with cattail-dominated fringes (Batt 2000). Thus, the fluctuating cycles of natural droughts or artificial drawdowns and subsequent reflooding at appropriate depths are critical for maintaining the overall long-term productivity of freshwater marsh wetlands in the northern prairie region of North America (van der Valk and Davis 1978, Murkin et al. 2000c).

Long Meadow Lake (LML) is a large riverine wetland complex within the Minnesota Valley National Wildlife Refuge (MVNWR; Fig. 1). Historically, LML water levels fluctuated on a wet-dry cycle (Zischke and Cole 1987). However, blockage of the original wetland outlet from bridge and road construction increased frequency of flooding from the adjacent Minnesota River. Additionally, stormwater runoff into LML from surrounding communities in the last 50 years has gradually increased the depth and length of flooding (Zischke and Cole 1987). Because of these alterations, the wet-dry cycle within LML has been eliminated and water levels have been maintained at artificially high levels for ≥ 30 years. A survey of LML in 1987 (Zischke and Cole 1987) indicated that historic vegetation communities had been significantly altered and much of the wetland was dominated by dense patches of cattails and water lilies. Surveys also indicated lower invertebrate richness and abundance within LML when contrasted with two reference wetlands (Zischke and Cole 1987). Elimination of the wet-dry cycle and subsequent changes in vegetation and invertebrate communities in LML are thought to be major factors limiting the wildlife habitat potential and overall productivity of the wetland (Zischke and Cole 1987, USACOE 2000, V. L. Sherry, MVNWR, personal communication).

Several community-based biotic indices have been developed to assess the condition of aquatic ecosystems (e.g., Karr 1981, Lenat 1993) or to assess organic pollution (Hilsenhoff 1977). Currently, the most commonly used bioassessment technique in the United States is the Index of Biotic Integrity (IBI; e.g., Karr 1981, Hilsenhoff 1988, Helgen and Gernes 2002, Tangen et al. 2003). The IBI originally used fish to assess lotic systems, but recently wetland IBIs have been developed to integrate aquatic plant and invertebrate communities (Helgen and Gernes 2002, Lillie et al. 2002, Wilcox et al. 2002, Tangen et al. 2003, Genet and Bourdaghs 2006). Other indices such as the Floristic Quality Index (FQI) also have been used to monitor the condition of native plant communities (Swink and Wilhelm 1994, Bernthal 2003, DeKeyser et al. 2003). Because of their direct responses to both short and long-term changes in hydrology, macrophytic plants are considered reliable indicators of wetland condition (Wentworth et al. 1988, van der Valk and Squires 1992, van der Valk et al. 1994, Adamus 1996, Helgen and Gernes 2001). Wetland invertebrate communities also are considered indicators of wetland conditions because they respond to changes in hydrology (Batzer et al. 1999, Murkin and Ross 2000), exhibit a range of sensitivity to degradation of water quality (Warwick 1980, Rosenberg and Resh 1993, Rainbow 1996, Euliss and Mushet 1999, Helgen and Gernes 2001), are directly linked to composition and structure of macrophytic vegetation (Voigts 1976, Murkin and Ross 2000), and are important components of wetland food webs for wildlife (Swanson and Duebbert 1989, Wissinger 1999, Murkin and Caldwell 2000).

When hydrology has been artificially stabilized, active water-level management (i.e., drawdown and reflooding) of marsh wetlands is required to restore long-term productivity by creating an artificial wet-dry cycle (Fredrickson and Taylor 1982, Smith et al. 1989, Mitsch and Gosselink 2000, Murkin et al. 2000c). The MVNWR installed a water control structure along the periphery of LML in October of 2006 to artificially drawdown the wetland and eventually return it to a wet-dry cycle (V. L. Sherry, MVNWR, personal communication). To assess responses of LML to wet-dry cycle management, any potential changes in the wetland must be referenced to current conditions (Mitsch and Wilson 1996, Mitsch and Gosselink 2000, Seabloom and van der Valk 2003). However, the last survey of LML plant and invertebrate communities occurred in 1987 (Zischke and Cole 1987). Presumably, sustained flooding of LML has continued to alter biotic communities within the wetland since this survey. Therefore, a new baseline assessment of the aquatic plant and invertebrate communities within LML is needed prior to installation of the water control structure and future wet-dry cycle management.

OBJECTIVES

My first objective was to characterize the composition and structure of aquatic plant and macroinvertebrate communities within LML. I classified LML by dominant vegetation cover types and then sampled vegetation attributes within each type. I sampled macroinvertebrate communities from each vegetation cover type during the summers of 2004 and 2005. Water and soil samples were collected from each site in 2004 and combined with plant and macroinvertebrate data to calculate an Index of Biotic Integrity for LML. The degree to which LML currently is degraded was estimated by the outcomes of the metrics used by Helgen and Gernes (2002) and Genet and Bourdaghs (2006).

My second objective was to examine potential relationships between invertebrate communities and both biotic and abiotic habitat attributes within LML. To fulfill the second objective I used multivariate analyses to statistically relate richness, abundance, and other invertebrate metrics to variation in vegetation composition, water quality, and sediment characteristics.

METHODS

Study Area

Long Meadow Lake is a 525-ha riverine wetland complex within the Minnesota River floodplain in Hennepin county, Minnesota, USA (44^{o}50’ N, 93^{o}13’ W) (Fig. 1). The Minnesota River meanders 58 km through a broad floodplain carved by glaciers approximately 11,000 years ago during the Pleistocene Epoch (Sames and Merriam 1980, Wright 1990, USCOE 2000). Land use within the lower Minnesota River watershed consists primarily of agriculture and urban development, which potentially degrades water quality and influences wetland flora and fauna. LML is found within the North Central Hardwood Forest (NCHF) ecoregion (Fig. 2). The most common habitat types along the river floodplain included a mixture of bottomland forest and marsh habitats. Bottomland forest cover included mixtures of American elm (*Ulmus americana*), eastern cottonwood (*Populus deltoides*), green ash (*Fraxinus pennsylvanica*), silver maple (*Acer saccharinum*), red maple (*A. rubrum*), white oak (*Quercus alba*), northern red oak (*Q. rubra*), and northern pin oak (*Q. ellipsoidalis*). Dominant vegetation in LML consisted of cattails, river bulrush (*Schoenoplectus fluviatilis*), and white water lilies (*Nymphaea odorata*). Marshes and small lakes were formed on hummocky, poorly drained soils from unsorted till and outwash sand that were left by retreating glaciers (USCOE 2000). Grain terminals, quarries, and landfills are present in the floodplain, as well as numerous roads and railways that cross through the area (USCOE 2000).

Minnesota Valley National Wildlife Refuge (MVNWR) in Bloomington, Minnesota, USA, manages 5,665 ha of the river valley. Since its inception in 1976, MVNWR is one of the few national wildlife refuges located within a major metropolitan area, the Twin Cities. LML is influenced by flooding of the adjacent Minnesota River, which drains much of southwestern Minnesota, and flows northeastward into the Twin Cities metropolitan area towards its convergence with the Mississippi River. LML is located on the left bank of the Minnesota River and is separated from the river by a natural levee 150 m wide. At an elevation of 213 m, LML is also the input point for ≥ 23 storm sewers and groundwater discharges. An abandoned roadway and bridge divides the marsh into two basins, which are named “Upper Long Meadow Lake” and “Lower Long Meadow Lake”, respectively. At high river stages, the two basins merge as the river backs up into LML. Otherwise, (i.e., at low river stages) the basins are connected by shallow channels under the bridge. The Minnesota River frequently experiences torrential spring floods, although it did not flood in 2002 or 2003. However, significant flooding did occur in 2004 and 2005. In 2004, precipitation was below normal from June through August, but annual precipitation was above normal because of snow and rain. From June through August 2005, precipitation was near normal but Minneapolis-St. Paul experienced the wettest year on record with 33.41 in. because of a combination of snow and rain from January to December 2005

(NCDC 2006). Water levels in LML ranged from 0.5 m to 2.4 m. If the river floods, it can introduce suspended sediments and produce turbid conditions during high water periods. Over the course of a summer, the suspended material will settle and cover growing vegetation (USCOE 2000). During normal water conditions, water is supplied from natural springs, seepage, runoff, and stormwater discharge (USCOE 2000).

Field Sampling

Vegetation. I used the original cover type designations of Zischke and Cole (1987) and field validation to identify five aquatic vegetation cover types currently within LML (Figs. 3 and 4): 1) water lilies; 2) cattails; 3) river bulrush; 4) submergents; and 5) "minors," representing a mixed community of softstem bulrush (*Schoenoplectus tabernaemontani*) and purple loosestrife (*Lythrum salicaria*). Common reed (*Phragmites australis*), a sixth cover type identified by Zischke and Cole (1987) was eliminated after field validation because it currently exists only as small patches along dry edges of LML.

Vegetation was sampled between July-August 2004 and 2005 using methods outlined by Gernes and Helgen (2002). I established a 100-m^2 releve plot (5 × 20 m or 10 × 10 m) within each vegetation type (Fig. 4). The corners of each quadrat were staked with rebar and flagged, and I used a Global Positioning System (GPS) unit to record coordinates of the plot center. Plots were divided into four equal subplots for easier identification and recording of plant species. I recorded the percent areal cover of all plant species within each subplot. Cover estimates were based on six classes (Table 1). Unknown plant species were collected and pressed for later identification. Taxonomic nomenclature followed Gleason and Cronquist (1991) and the Integrated Taxonomic Information System (2006).

Macroinvertebrates. I collected macroinvertebrates during June-July 2004 and 2005 from six permanent sample sites randomly selected from each vegetation cover plot (N = 30 sites), using methods outlined by Murkin et al. (1983), Gernes and Helgen (2002), and Genet and Bourdaghs (2006) (Fig. 4). Two dipnet efforts (4-5 sweeps/effort) were conducted at each site with a D-frame net (600-µm mesh) within 1-m^2. The depths of sweeps were limited to ≤ 1-m from the surface. Contents of each sweep were transferred to a 30 × 40 cm frame (1.25 cm wire screen) contained in a larger water-filled tray. With a squirt bottle filled with water, I searched through vegetation for 10 minutes for invertebrates as they passed through the screen into the tray. Samples were searched twice, the remaining vegetation on top of the screen was discarded, and then the contents in the tray were passed through a 200-µm net sieve into labeled jars of 95% ethyl alcohol for preservation.

To capture mobile and nocturnal invertebrates missed by dipnets, 10 horizontally-oriented activity traps (Fig. 5) were placed in each vegetation cover plot (Murkin et al. 1983, Gernes and Helgen 2002, Genet and Bourdaghs 2006) for 48 hours. Two traps (1-2 m apart) were placed along each of 5 points within the plot, with pairs of traps spaced at approximately 6-m intervals. Traps were placed approximately 10 cm under the surface in water <1 m deep and approximately 15-20 cm under the surface in deeper water. Trap openings were directed towards emergent vegetation, or if no emergents were present, then openings were placed towards submergent vegetation. Air pockets were removed from traps prior to deployment to reduce predator activity. Activity trap contents were rinsed through a 200-µm nylon net sieve into jars and preserved in 95% alcohol. Invertebrates captured in dipnets and activity traps were identified to either species or genus following the nomenclature of Hilsenhoff (1995) and Merritt and Cummins (1996). In dipnet samples, Chironomidae larvae were identified to genus by Dr. Leonard Ferrington, University of Minnesota.

Water and Soil Samples. During July of 2004 and 2005 I measured subsurface water temperature (^{o}C), conductivity (µS/cm), saturated dissolved oxygen (%), dissolved oxygen (mg/L), pH, and turbidity (ntu) at each sample site with an YSI 6820 Sonde water quality meter. During July of 2004, a water sample from each site was collected and preserved in acidified containers to estimate concentrations of total P, Cl, and NO_3-N. During sampling I measured water depth (m) at each site.

I collected 2 sediment cores from each site using a Wildco stainless steel 2-inch hand corer. Cores were used to estimate concentrations of Ag, Al, As, Ba, Be, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, and Zn. The 2 cores for each site were combined and transferred to a sanitized plastic bag for analysis. The University of Wisconsin-Stevens Point Water and Environmental Analysis Laboratory analyzed water samples according to Eaton et al. (1995). Sediment samples were analyzed according to *Methods for the Determination of Metals in Environmental Samples Supplement 1* (1994).

Data Analyses

Human Disturbance Score. I employed multimetric indices (metrics; Karr and Chu 1999, Gernes and Helgen 2002, Genet and Bourdaghs 2006) to describe structural and functional composition of vegetation and invertebrate communities in LML. Because these metrics may, at least indirectly, indicate effects of point, multiple point, and non-point sources of human disturbance on biological communities (Karr and Chu 1999, Cole et al. 2003) I also used them to assess the degree to which LML currently is degraded. Biological "dose response" curves are plotted against a disturbance gradient to measure human impacts on wetlands (Karr and Chu

1999). I used the water and sediment data combined with qualitative assessments of land use impacts to calculate a human disturbance score (HDS) for LML following methods of Gernes and Helgen (2002). An HDS score, ranging from 0-100, was assigned to each site based on 5 factors: 1) degree of human disturbance of a 50-m buffer around the wetland (Fig. 6); 2) extent and intensity of human land use within the surrounding landscape; 3) habitat alterations and human activities within the landscape; 4) degree of alteration to wetland hydrology; and 5) relative concentration of chemical pollution indicators in water and sediment (Gernes and Helgen 2002). A ranking of 0 represented reference or least-impacted conditions. I used ArcGIS 9.0 combined with 2005 orthophotos (Minnesota Valley National Wildlife Refuge 2006) to establish 50-m and 500-m buffers around LML to estimate the degree of human disturbance.

Vegetation Metrics. I applied the Wetland Vegetation IBI for Depressional Wetlands (Gernes and Helgen 2002) with some modifications from MPCA (J. A. Genet and M. Bourdaghs, MPCA, personal communication) to calculate metrics for LML vegetation (Table 2). The metrics created by Gernes and Helgen (2002) focused on the development and validation of IBIs for semi-permanently to permanently flooded emergent depressional wetlands located in the NCHF ecoregion (Fig. 2). The wetland vegetation IBI consists of 10 metrics based on 4 components: 1) species richness of vascular and nonvascular taxa; 2) community composition including cover of sedges (Carex spp.), aquatic species, perennials, and graminoid guilds; 3) tolerance and sensitivity measures; and 4) ecological process attributes based on dominance and persistent litter taxa (Table 2; Gernes and Helgen 2002). I used percent coverage of vegetation (Table 1) to assign a numerical score for each plant species present in the site. A numeric IBI score was calculated with a combination of discrete and continuous (Fig. 7) metric scoring methods for each site (Gernes and Helgen 2002, Genet and Bourdaghs 2006, J. A. Genet and M.

Bourdaghs, MPCA, personal communication). Further explanation of using both discrete and continuous scoring can be found in Genet and Bourdaghs (2006). I performed a paired samples t-test to test the difference in vegetation IBI scores between 2004 and 2005, after normality was achieved using Kolmogorov–Smirnov tests. I conducted a Kruskal-Wallis test, a non-parametric test, after variances were not equal by testing the homogeneity of variances. I then plotted each metric against the HDS score to assess potential influences of human disturbance.

Invertebrate Metrics. I calculated 10 invertebrate metrics (Table 3) that characterized structural and functional composition of invertebrate communities within LML following methods outlined by Gernes and Helgen (2002) and Genet and Bourdaghs (2006). I compared IBI scores among the 5 cover types to identify preliminary relationships between vegetation composition and invertebrate communities. To test the difference in invertebrate IBI scores between 2004 and 2005, I conducted a paired samples t-test, after the data were distributed normally using Kolmogorov–Smirnov tests. After variances were checked using a test of homogeneity of variances, One-Way Analysis of Variance (ANOVA) was performed to test the differences of IBI scores between habitats in 2004 and 2005. A post-hoc test (Tukey-Kramer Honestly Significant Difference (HSD)) was run to verify significant differences in IBI scores between habitats. I then plotted individual metrics against the water chemistry data and the human disturbance rating (Gernes and Helgen 2002). I plotted the overall IBI score for LML against the human disturbance rating to evaluate robustness of the metric scores (Gernes and Helgen 2002).

Invertebrate Habitat Relationships. Ordination methods were used to identify potential relationships between the LML invertebrate community and variation in habitat and environmental attributes (e.g., vegetation composition, water quality, sediment contamination).

Nonmetric multidimensional scaling (NMDS), a nonparametric ordination technique, was performed on combined dipnet and activity trap data. This approach was used because it assumes no underlying distribution of the data, is robust to data departures from normality, and therefore is suggested for use with ecological data (McCune and Mefford 1999). The macroinvertebrate abundance data were log (x+1) transformed to reduce the influence of numerically dominant taxa (Krebs 1989, McCune and Mefford 1999). The transformed data were used for all subsequent multivariate analyses. Because rare taxa may introduce bias into data that prevents ordination techniques from extracting major patterns in community composition (Gauch 1982, Tangen et al. 2003), I omitted taxa that occurred at only 1 site and represented <0.5% of the total abundance in that sample (Cole et al. 2003).

Habitat and environmental variables to be correlated with macroinvertebrate NMDS ordinations were checked for normality using normal probability plots and Kolmogorov–Smirnov tests. Data were log (x+1) transformed when necessary to achieve or better approximate normality. Variables were correlated with the resulting ordination axes to examine whether major patterns in community structure were correlated with measured physical or chemical gradients. The original macroinvertebrate data were also correlated with the ordination axes to determine which taxa were most responsible for producing the major ordination patterns. The environmental variables and invertebrate data were corrected for test-wide error rates for multiple tests, and *P*-values were Bonnferoni-adjusted with a nominal $\alpha < 0.05$. Finally, variables that were significantly related to NMDS axes were correlated using Spearman rank correlation coefficients with invertebrate metrics to examine relationships between habitat conditions and structural and functional attributes of macroinvertebrate communities. Statistical analyses were conducted with MS Excel, SPSS 14.0, and JMP 5.1.2; and NMDS was performed with PC-ORD

Version 4.17. For all analyses, *P*-values of correlation coefficients were considered significant at $\alpha < 0.05$.

RESULTS

Vegetation. Sixty-eight plant taxa were collected from the 30 sampling sites and 80 species were identified in 2004 and 2005 (Appendix 1). Emergent taxa primarily consisted of cattails and river bulrush. Dominant submersed taxa included waterweed (*Elodea nuttallii*) and coontail (*Ceratophyllum demersum*); and pondweeds such as sago (*Stuckenia pectinata*) and leafy pondweed (*Potamogeton foliosus*). Floating-leaved plants including white water-lily were the dominant plants that covered the middle section of the basins across LML, with some small pockets of American lotus (*Nelumbo lutea*) occurring near the wetland edge. Sporadic stands of northern wild rice (*Zizania palustris* var. *interior*) were present near the edges of river bulrush or cattail stands. Since wild rice is an annual, some stands present in 2004 were not present or increased in quantity in 2005. In general, the wild rice population in 2005 increased dramatically in other areas of LML, particularly in the western part of LML. Wild rice requires stable water levels and particular soil to proliferate.

Macroinvertebrates. A total of 147 macroinvertebrate taxa were collected from the 30 sampling sites in 2004 and 2005 (n = 28,152 specimens and n = 47,053 specimens, respectively) (Appendix 2). A total of 163 macroinvertebrate species was collected and identified. Aquatic insects comprised 79% of the samples. In 2004, 134 species were collected and 140 species were collected in 2005. Identified taxa included: Coleoptera (beetles), Ephemeroptera (mayflies), Heteroptera (true bugs), Odonata (dragonflies and damselflies), Trichoptera (caddisflies), Diptera (flies), and Lepidoptera (butterflies and moths). Non-insect taxa included Amphipoda (scuds), Gastropoda (snails), Hirudinea (leeches), and Sphaeriidae (fingernail clams). Hydracarina (mites), Isopoda (isopods), Arenea (spiders), and various terrestrial insects and arthropods were not included in the identification.

In 2004, cattail (CAT) sites accounted for 38.2% of the total invertebrates collected (Table 4), whereas submergent (SBM) sites accounted for 17.4% of invertebrates. Smaller percentages of total invertebrates collected came from river bulrush (BUL) (17.1%), floating-leaved/lilypad (LP) (12.2%), softstem bulrush (SST) (9.7%), and purple loosestrife (PL) sites (5.4%). In 2005, SST sites ranked first in the percentage of collected invertebrates (31.1%), followed by CAT (17.9%), BUL (15.5%), SBM (14.1%), LP (11.8%), and PL sites (9.7%) (Table 4). In both 2004 and 2005, Amphipods, Dipterans, Gastropods, and Heteropterans were the most common (100% frequency of occurrence) taxa for all sampling sites. Bugs (Heteropterans) accounted for the most abundant taxon with 4,863 and 1,339 individuals in 2004 and 2005, respectively (Tables 5 and 6). Heteropterans accounted for ≥ 50% of all invertebrates collected in 2004 and 43% in 2005 (Fig. 8). Of these totals, corixids accounted for 50% of the total Heteropterans in 2004 and 67% in 2005. Amphipods accounted for 23% of all specimens in 2004 (n = 6,850 individuals) and 28% in 2005 (n = 14,950 individuals; Fig. 8). In 2004, leeches were present in all of the samples, whereas Chironomids, Coleopterans, and Odonates were present in 90% of the samples. Mayflies and caddisflies were present in >75% of the samples and *Nymphula* moths were detected in 50% of the samples (Table 4).

In 2005, Chironomids and Coleopterans were present in 100% of the samples, whereas leeches, mayflies, caddisflies, and dragonflies/damselflies were accounted for in ≥ 90% of the samples. *Nymphula* moths were present in slightly more than 50% of the samples (Table 6). Chironomids were detected in only 6% of the samples in 2004 (n = 1,940 individuals; Fig. 8) and comprised 96% of all Dipterans. In 2005, Chironomids comprised 7% of the samples (n = 4,093 individuals; Fig. 8), representing 92% of all Dipterans. Although chironomids were present in only a small percentage of samples in both years, 38 genera were identified and 6 of the taxa were considered to be "rare" (L. Ferrington, University of Minnesota, personal communication).

Human Disturbance Score. Human Disturbance Scores from LML sites ranged from 17 to 100, with a mean of 62 (Appendix 3). Scores for river bulrush (BUL) sites ranged from 33 to 100, with an average of 63. The HDS scores for CAT sites ranged from 17 to 94 with a mean of 55, and scores for LP sites ranged from 46 to 76 with an average of 65. Scores for PL sites ranged from 66 to 95 with an average of 84, and SBM sites ranged from 39 to 76 with a mean of 58. Finally, SST sites ranged from 48 to 59 with an average of 52. Seventeen sites scored in the mid-disturbance range (<33-67) and 12 sites were in the most disturbed range (>67-100). Only 1 site was below the disturbance range (17).

Disturbance scores were influenced by chemical parameters. Presence of specific chemicals was deemed significant when compared to chemistry data for reference depressional wetlands in the region (Helgen and Gernes 2002). Concentrations of most metals and chemicals in LML sediment and water samples were average or slightly above average. When compared to other reference wetlands in Minnesota, LML exhibited high levels of copper, nickel, lead, zinc, chloride, and phosphorus. According to Gernes and Helgen (2002) these metals and chemicals were previously found to influence invertebrate and vegetation metrics. Nitrate-nitrogen levels were not significantly different in all of the LML sites (<0.02 mg/l).

Compared to reference wetlands in Minnesota, concentrations of metals in LML sediments were above normal (Table 7, Appendix 4). However, these concentrations were comparable to agricultural and urban-influenced wetlands from across Minnesota (Gernes and Helgen 2002). Among vegetation types, BUL sites had the highest concentrations of copper

(25.3 mg/kg) and zinc (92.7 mg/kg) (Table 6). Nickel concentrations were highest at SBM sites (23.2 mg/kg), while PL sites had high concentrations of lead (28.3 mg/kg). However, PL sites had the lowest concentrations of copper (19.6 mg/kg), nickel (16.8 mg/kg), and zinc (82.9 mg/kg). Lead concentrations also were low at CAT sites (15.9 mg/kg). Despite the presence of these metals within LML samples, only concentrations of nickel were above average when compared to other urban-influenced wetlands in Minnesota (Gernes and Helgen 2002). In contrast, lead concentrations at LML were lower when compared to urban-influenced wetlands.

Concentrations of chloride (108.8 mg/l) and phosphorus (1.22 mg/l) were highest at PL sites (Table 8) and second-highest at SST sites (Table 8). Concentrations of chloride and phosphorus were similar at BUL, CAT, and LP sites and lowest at SBM sites (Table 8).

When turbidity levels were recorded in 2004, mean values were lowest at LP sites, followed by SBM, BUL, CAT, PL, and SST sites in ascending order (Table 9). In 2005, LP sites again registered the lowest average turbidity values, followed by CAT, BUL, SBM, SST, and PL sites in ascending order (Table 10). As turbidity increased, dissolved oxygen decreased (Tables 9 and 10). In both 2004 and 2005, mean dissolved oxygen concentrations were highest at SBM sites (7.23 mg/l), followed by CAT sites (5.67 mg/l), and PL sites (1.15 mg/l). The pH level was tested within its normal range (7.4) across all sample sites. There were elevated levels of pH within SBM sites because photosynthesis was occurring, which also increased dissolved oxygen levels (Tables 9 & 10). Additional details of all water and sediment chemistry data are presented in Appendices 4-7.

Vegetation Metrics. Vegetation IBIs were calculated according to the structural and functional composition of vegetation communities. I considered sites with scores <42.2 to be biologically impaired (i.e., unable to fully support aquatic life; J. A. Genet and M. Bourdaghs, MPCA, personal communication). In 2004, 10 sites, distributed across habitat types, scored >42.2 ($\bar{x}$ = 49.7; Appendix 8). The mean IBI score for all 30 sites in 2004 was 34.2. Because the metrics focus heavily on emergent vegetation communities, scores for LP and SBM were particularly low. As a result, LP and SBM sites received low or no scores for the following metrics: Graminoid Richness, Perennial Richness, Nonvascular Richness, Carex Cover, Persistent Litter Cover, and Sensitive Taxa. When LP and SBM sites were excluded, the mean vegetation IBI score for LML sites in 2004 was 43.2.

In 2005, 7 sites received vegetation IBI scores ≥ 42.2 ($\bar{x}$ = 48.5; Appendix 9). The mean IBI score for all sites was 32.7. As in 2004, LP and SBM sites received low scores because they did not contain emergent communities. When LP and SBM sites were excluded, the mean vegetation IBI score for LML sites in 2005 was 39.1. The overall mean IBI score for both 2004 and 2005 combined was 33.3. Vegetation IBI scores were not significantly different between 2004 and 2005 (t = 1.354, df = 29, P = 0.186). Vegetation IBI scores were significantly different between habitats (i.e., BUL, CAT, LP, PL, SBM, and SST) in 2004 (Kruskal-Wallis H = 11.68, df = 5, P = 0.039). IBI scores were not significantly different between habitats in 2005 (Kruskal-Wallis H = 10.23, df = 5, P = 0.069).

Vegetation metrics varied in their response to the various measures of disturbance in both 2004 and 2005 (Tables 11 and 12). In 2004, none of the metrics showed a significant relationship to HDS, whereas in 2005 the Nonvascular Richness measure was marginally significant towards HDS (P = 0.091, r = 0.314). Metrics that were significantly correlated (P <0.05) with chemical parameters in 2004 included Graminoid Richness, Aquatic Guild Richness, Persistent Litter Cover, Vegetation IBI, and Perennial Richness (Table 11). In 2004, total phosphorus in water was positively related to 5 metrics (Graminoid Richness, Perennial

Richness, Vascular Genera Richness, Persistent Litter Cover, and Dominant 3 Cover) and the IBI (Table 11). Phosphorus was also negatively correlated with Aquatic Guild Richness (Table 11). Cadmium was negatively correlated with 4 metrics (Graminoid Richness, Perennial Richness, Vascular Genera Richness, and Tolerant Taxa Ratio) and the IBI (Table 11).

In 2005, chloride was positively related to Perennial Richness and the IBI (Table 12). Turbidity was negatively correlated with Aquatic Guild Richness and positively correlated to Graminoid Richness (Table 12). Arsenic was negatively correlated with Graminoid Richness, Perennial Richness, Tolerant Taxa Ratio, Vascular Genera Richness, Carex Cover, and the IBI (Table 12).

Invertebrate Metrics. I considered sites with invertebrate IBI scores <48 to be biologically impaired or unable to support invertebrate communities (i.e., lack of vegetative cover or debris; J. A. Genet and M. Bourdaghs, MPCA, personal communication). In 2004, 11 sites had invertebrate IBI scores >48 ($\bar{x}$ = 55.8; Appendix 10). The mean IBI score for all 30 sites was 46.6. In 2005, 15 sites received invertebrate IBI scores >48 ($\bar{x}$ = 54.2; Appendix 11). The 2005 mean IBI score for all 30 sites was 44.7. The overall mean IBI score from 2004 and 2005 combined was 45.5, which indicates impairment in aquatic systems in relation to invertebrate composition. Invertebrate IBI scores were not significantly different between 2004 and 2005 ($t = -0.983$, df = 29, $P = 0.334$). Invertebrate IBI scores were significant between habitats (i.e., BUL, CAT, LP, PL, SBM, and SST) in 2004 ($F = 2.793$, df = 5, $P = 0.04$) and in 2005 ($F = 3.234$, df = 5, $P = 0.023$). Tukey-Kramer HSD determined that there were no significant differences in invertebrate IBI scores between habitats in 2004 but there were significant differences in IBI scores between CAT and SBM sites in 2005.

Metrics that showed the most significant relationships with chemical parameters in 2004 were Tolerants Proportion and Chironomidae Taxa Richness (Table 13). There were no significant relationships between HDS and invertebrate metrics. Chloride was positively correlated with Total Taxa Richness and negatively correlated with Corixidae Proportion (Table 13). Turbidity was positively correlated with Snail Taxa Richness and negatively correlated with Chironomidae Taxa Richness (Table 13). Among the metals (copper, lead, nickel, and zinc) quantified by MPCA as toxic to aquatic life, only nickel was significantly correlated with invertebrate metrics. Nickel was negatively correlated with the abundance of pollution-tolerant genera and positively correlated with the abundance of Chironomid genera (Table 13). However, other metals including arsenic, selenium, and silver also were correlated with invertebrate metrics (Table 13).

In 2005, invertebrate metrics correlated with water and sediment chemistry parameters included Snail Taxa Richness, Total Taxa Richness, and overall IBI (Table 14). In 2005, the HDS was weakly correlated with Odonata Taxa Richness (Table 14). Chloride was negatively correlated with the presence of intolerant taxa but positively correlated to presence of leeches (Table 14). Turbidity was negatively correlated with abundance of tolerant genera and ETSD but showed a positive correlation to the abundance of snail taxa (Table 14). Among metals, copper exhibited the strongest negative relationships with Snail Taxa Richness, Total Taxa Richness, and IBI (Table 14). Copper concentrations also were weakly correlated with Chironomidae Taxa Richness (Table 14). Nickel had a negative correlation with the abundance of snail taxa, Total Taxa Richness, and IBI (Table 14). Other metals correlated with invertebrate metrics included aluminum, arsenic, barium, beryllium, chromium, and silver (Table 14). Although most of the chemicals and metals were not significantly correlated with invertebrate metrics; chloride, turbidity, and nickel were consistently correlated with the presence or absence of certain macroinvertebrate taxa (Table 14). Pollution-intolerant macroinvertebrates tended to be absent from LML sites with high levels of chemical disturbance.

Invertebrate Habitat Relationships. Chemical parameters measured in 2004 and 2005 were analyzed to produce four NMDS ordinations. The NMDS produced two three-dimensional ordinations that explained 89% of the variation in the original sample space for 2004 environmental variables. In 2004, conductivity and chloride were negatively correlated with NMDS axis 1 (Fig. 9 and Table 15), when standardized by habitat. No variables were significantly correlated with axes 2 and 3. When data were not standardized by habitat, silver in sediment had a strong positive correlation with axis 2 and conductivity was positively correlated with axis 3 (Fig. 10 and Table 16). Using Bonnferoni corrections, no environmental variables were significant. Some macroinvertebrate taxa (i.e., those dependent upon habitat) were significantly correlated with NMDS axes 1, 2, and 3 (Table 17) when Bonnferoni corrections were applied. These taxa were largely responsible for the resulting ordination patterns on the axes. Macroinvertebrate taxa that were not standardized by habitat and were significantly correlated with NMDS axes 2 and 3 are presented in Table 18.

For 2005 environmental variables, NMDS produced two ordinations that explained 85% of the variation in the original sample space. When the data were not standardized by habitat, conductivity and chloride were positively correlated to axis 2 (Fig. 11 and Table 19). No variables were significantly correlated to axes 1 or 3. When standardized by habitat, conductivity and chloride were negatively correlated to axis 3 (Fig. 12 and Table 20). No environmental variables were significantly correlated to axes 1 or 2. None of the environmental variables were significant using Bonnferoni corrections. Macroinvertebrate taxa that were significantly correlated with NMDS axes 2 and 3 are presented in Table 21 and Table 22 after the corrections.

DISCUSSION

Wetlands are recognized for their biological, geophysical, and functional attributes within landscapes. Water quality protection is one function of wetlands that provides protection against pollution in downstream waters or runoff. Wetland functional assessment tools are ineffective at evaluating the condition of wetlands or their degree of biological or ecological degradation (Gernes and Helgen 2002). Some assessments do not directly measure biological communities in wetlands and may measure only one component (i.e., vegetation) while ignoring other components (i.e., invertebrates) (Gernes and Helgen 2002). Currently, IBIs can be used to evaluate wetland condition by incorporating a variety of direct and indirect measures that potentially influence wetland functions. The metrics developed by MPCA were intended for large, depressional wetlands with emergent vegetation and semi-permanent to permanent water regimes in the NCHF ecoregion. Although LML is within the NCHF ecoregion, it is a large riverine wetland with elevated water levels embedded within an urban landscape which posed a unique situation since there are no other large urban-influenced wetlands with the same hydrologic regime to compare the results to. Thus, application of IBI metrics developed for other wetland types and landscape conditions to LML must be viewed cautiously, but the application does provide insight to the conditions present in LML.

Vegetation. The emergent community of LML primarily consisted of river bulrush and narrow-leaved cattails (*Typha angustifolia*) with some arrowhead (*Sagittaria* spp.) and giant bur-reed (*Sparganium eurycarpum*). American white water-lily dominated the open water spectrum with some patches of American lotus. Dominant submergents included waterweed, coontail, and pondweeds including sago and leafy pondweed, species common in deep-water habitats. Bladderwort (*Utricularia vulgaris*) was present at some sites and is considered a sensitive indicator of pollution (Farmer 1990). Northern wild rice production increased dramatically on the western edge of LML in 2005, probably because water levels were more stable in 2005 and flooding was not as intense as it was in 2004. In addition to purple loosestrife, reed canary grass (*Phalaris arundinacea*), Canada thistle (*Cirsium arvense*), and the non-native species curly-leaf pondweed (*Potamogeton crispus*) were encountered at some sites within LML. Surprisingly, I did not detect Eurasian milfoil (*Myriophyllum spicatum*), another nonnative aquatic invader, within LML. This is surprising because of the hydrologic connectivity of LML with the Minnesota River and its tributaries.

Combining the vegetation IBIs for 2004 and 2005, LML received a mean overall score of 33.3, which is below the supporting threshold level of 42.2. The score reflects the low diversity of LML's plant community. The IBI scores between 2004 and 2005 were found to not be significantly different because the low scores are reflected across LML and shows that the same general vegetation community has persisted with no significant change. The IBI scores were significantly different among habitats in 2004 because of the low scores presented by LP and SBM sites. It is important to note, however, that the vegetation metrics were biased against LP and SBM sites, because these habitat types were not part of the emergent community. However, even when LP and SBM sites were excluded, the mean combined 2004 and 2005 IBI score was 41.2. In both years, PL sites received high scores because of the high species diversity associated with this habitat type because the sites were on the shoreline and are not dominated by the major plants present on LML. The BUL, CAT, and SST sites were dominated primarily by their respective species and contained few other species other than aquatic plants. The presence or absence of individual plant species can strongly influence overall IBI scores for a particular site. Thus, differences in IBI scores between 2004 and 2005 may represent temporal fluctuations in the presence of individual species. For example, some species detected in a given year were annuals and other species may have been displaced by competitively dominant plant species between years.

The metrics indicated that total phosphorus, chloride, and turbidity were related to vegetation parameters. Total phosphorus was positively correlated with Graminoid Richness (number of native wetland *Poaceae, Cyperaceae,* and *Juncaceae* species), abundance of native wetland perennial and vascular species, plant species that have been identified as “persistent leaf litter” (e.g., river bulrush, softstem bulrush, giant bur-reed, cattails, smartweed (*Polygonum* spp.), purple loosestrife), and overall vegetation IBI. Total phosphorus concentrations also were negatively correlated, albeit weakly, with native aquatic species. Flood-intolerant species have shown reduced uptake of phosphorus because of energy requirements, but no effect or enhanced uptake of phosphorus in flood-tolerant species (Mitsch and Gosselink 2000). Chloride amounts were positively related to native perennial wetland species, sensitive plant species, plants defined by “persistent litter”, and the overall plant IBI score. Plants have developed adaptations to compliment their structural composition. Adaptations include barriers to prevent or control the entry of salts and organs specialized to excrete salt from the system (Mitsch and Gosselink 2000). Some plants may not have the ability to regulate the osmotic concentration of the cells at a high enough level to allow the absorption of water, which can prevent plants from establishing in areas of high concentrations of chloride (Mitsch and Gosselink 2000). Turbidity also appeared to have an effect on presence or absence of native aquatic plants. Turbid conditions can occur because of lack of plants to anchor the sediment. In turbid conditions, suspended particles reduce light penetration and trap heat from the sun, thereby increasing water temperature (Wetzel 2001). Because light penetration is reduced, photosynthesis tends to decline or cease, leading to concomitant decreases in dissolved oxygen in the water (Wetzel 2001). Lack of light penetration can prevent native plants from establishing. As it was discovered in other Wisconsin wetlands (Lillie 2004), turbidities were lowest at sites with sufficient amounts of rooted aquatic vegetation since it can reduce wave action and inhibit suspended solids. In contrast, nitrate-nitrogen levels were not considered abnormally high at any of the sample sites, perhaps because plants largely used up significant amounts of nitrate, particularly in late summer when plant growth rates may have been especially high (Wetzel 2001).

Macroinvertebrates. Changes in hydrological conditions such as low dissolved oxygen levels or increased turbidity may influence invertebrate populations. When data from 2004 and 2005 were combined, the mean invertebrate IBI score for LML was 45.5, below the designated "ideal biological threshold" of 48. Sites within LML that received favorable metric scores had low percentages of Corixidae present, low percentages of pollution-tolerant taxa when compared to intolerant taxa, and moderate or high richness of Odonata, Ephemeroptera, Trichoptera, Sphaeriidae (fingernail clams), Gastropoda (snail), and Chironomidae taxa. There was no significant difference of invertebrate IBI scores between 2004 and 2005, which suggests that invertebrate communities are well-established and have become tailored to LML's hydrological regime and vegetation composition. The 2004 and 2005 invertebrate IBI scores were significant among habitats present in LML. Tukey-Kramer HSD showed no significant difference in IBI scores between BUL, CAT, LP, PL, SBM, or SST sites for 2004 IBI scores. Tukey-Kramer HSD showed a significant difference in IBI scores between CAT and SBM sites in 2005. CAT sites had higher invertebrate IBI scores ($\bar{x}$ = 56.4) than SBM sites (($\bar{x}$ = 39.3). CAT sites scored favorably with a lower proportion of corixids, a higher proportion of Ephemoroptera, Trichoptera, Sphaeriidae, and Odonata taxa, and increased richness of snail and leech taxa, and overall total taxa richness. Despite scoring moderately well in these metrics, overall macroinvertebrate abundance and richness from all sites were considerably lower when compared to values reported from Wisconsin wetlands (Lillie 2004), even though benthic samples were not collected in this study. Wetlands with relatively static water regimes such as LML tend to support predatory fish, which may reduce the abundance of invertebrates (Batzer et al. 1999).

My results also indicate that overall, invertebrates were more abundant at sites where submersed vegetation was interspersed with emergent vegetation (e.g., SST, CAT, and BUL). Sites with only submersed vegetation or floating-leaved/lilypads mixed with open water tended to support lower invertebrate numbers. These associations between invertebrate abundance and macrophytic vegetation communities are consistent with those reported by Voights (1976). Living and dead emergent vegetation provides critical habitat substrates for invertebrates, particularly when submersed vegetation is sparse or absent (Murkin et al. 1991). Murkin and Ross (2000) reported that availability of macrophyte litter varies depending on the decomposition rates of the plant species present. They found that bulrush and whitetop (*Lepidium draba*) litter decomposed quickly, whereas reed grass and cattails decomposed more slowly, which provided invertebrate substrate for longer periods. My results indicate that invertebrate composition in cattail sites was higher when compared to river bulrush sites. Cattail sites accounted for 38.2% of invertebrates in sampled in 2004, compared to 17.1% in river bulrush sites. In 2005, cattail sites ranked second in invertebrates sampled, behind softstem bulrush, but more productive than river bulrush sites. These results also indicate that submersed vegetation was important for invertebrate abundance as it ranked second in 2004, accounting for 17.4% of invertebrates, and ranked behind river bulrush in 2005 with 14.1%. PL sites ranked the lowest in invertebrate abundance. A number of factors may explain the paucity of invertebrates at PL sites, including the lack of emergent vegetation, relatively low representation of submergents, low dissolved oxygen concentrations, increased turbidity, and increased pollution from metals and chemicals in sediment and water.

Understanding threshold levels of invertebrate responses to chemicals has been a focus for many researchers. Toxicity stress can modify morphological, feeding, and behavioral changes in macroinvertebrates (Anderson et al. 1980, Heinis et al. 1990, Johnson et al. 1993). The metrics I evaluated indicated that chloride, turbidity, nickel, and copper were either positively or negatively correlated with certain invertebrate communities in LML. Chloride levels were negatively correlated with presence of intolerant taxa and the proportion of Corixidae taxa. Intolerant taxa may decrease from higher levels of chloride, whereas corixids are more adaptable and pollution-tolerant to an extent (deSzalay and Resh 1996, Brix et al. 2001, Benbow and Merritt 2004, Herbst 2006). Chloride was positively correlated to the presence of leeches and total taxa. Variation in LML turbidity was related to the presence of snails, chironomids, dragonflies/damselflies, mayflies, caddisflies, and fingernail clams. The presence of these taxa decreased at sample sites with higher levels of turbidity. Turbidity also appeared to influence the proportion of disturbance-tolerant invertebrates, as the proportion of this group was negatively correlated with increasing turbidity, which can affect the total taxa composition of LML. Copper and nickel were the two metals that were correlated with the largest number of invertebrate metrics. Snail Taxa Richness and Total Taxa were negatively correlated to both metals.

Additionally, the overall IBI score and proportion of tolerant invertebrate taxa were negatively influenced by copper and nickel.

In 2004, taxa associated with the Chironomidae Richness metric appeared most sensitive to concentrations of metals within LML. Chironomids were negatively correlated with arsenic, barium, beryllium, nickel, and silver. In contrast, data collected in 2005 indicated that Snail Taxa Richness was the metric associated with the largest number of metals, including aluminum, arsenic, barium, beryllium, cadmium, chromium, copper, nickel, and zinc.

Human Disturbance Gradient. None of the metrics I measured demonstrated strong significant relationships to human disturbance. However, the degradation of wetland habitats within LML from surrounding land uses likely is related to chemistry and sediment loading. Sites with the lowest HDS scores were situated away from the city of Bloomington and close to the Minnesota River, or away from major disturbances (e.g., stormwater pipes, walking trails, impermeable surfaces including roads and bridges). The 4 metals (copper, lead, nickel, and zinc), chloride, and nitrate-nitrogen previously reported by MPCA to be statistically significant influences on most metrics and toxic to aquatic life were not significant for most of the LML metrics. Sources of copper and lead in residential soil may include lead and copper-based plumbing or lead-based paint. Nickel and zinc naturally occur in small amounts in soil, water, and air, and can be released by manufacturing facilities (US EPA 2007). High chloride levels are most likely delivered into LML from runoff of road salts used as deicing agents in the winter (Marsalek 2003). Fertilizers from lawns and farms within the surrounding landscape are a probable cause of high levels of phosphorus in LML. Not surprisingly, PL sites had the highest concentrations of chloride (108.8 mg/l) and phosphorus (1.22 mg/l). PL sites were located in or near areas where runoff was prevalent. However, SST sites had the second highest concentrations of chloride (100.8 mg/l) and phosphorus (0.273 mg/l). SST sites were located farther away from Bloomington's storm water pipes and were shielded from high levels of wave action, which could explain why chloride and phosphorus concentrations may be present for longer periods in these areas. SBM sites had the lowest levels of chloride (72 mg/l) and phosphorus (0.164 mg/l), and were located away from emergents so wave action and current may have contributed to lower concentrations of these substances. Emergent plants (e.g., bulrushes and cattails; Gupta et al. 1994, McJannet et al. 1995, Ye et al. 1997, Chandra and Kulshreshtha 2004) and submergents (e.g., coontail and waterweed; Mayes et al. 1977, Garg and Chandra 1990, Chandra and Kulshreshtha 2004) within wetlands have been previously found to facilitate removal of pollution or trace metals through root absorption. This could explain why levels and potential effects of chemicals and metals in LML did not appear to be as severe as reported from other urban-influenced wetlands in the region. Spring flooding from the Minnesota River may also function to dilute concentrations of these substances.

Invertebrate Habitat Relationships. Before I applied the Bonnferoni corrections to the environmental and invertebrate data, the indirect relationships between environmental gradients appeared to be factors useful for characterizing invertebrate communities. When standardized by habitat, conductivity and chloride were negatively correlated with axis 1 in 2004 and axis 3 in 2005. The NMDS outputs suggest that the taxa that were negatively correlated with the associated environmental variables (e.g., conductivity and chloride) were associated in emergent sites (e.g., BUL, CAT, and SST) in 2004 as well as some submergent sites in 2005. When the data were not standardized, conductivity was positively correlated with axis 3 and silver was positively correlated with NMDS axis 2 in 2004. In 2005, conductivity and chloride were positively correlated with axis 2. The NMDS outputs imply that the taxa that were positively correlated with the environmental variables (e.g., chloride and conductivity) were associated in emergent sites, while taxa positively correlated to silver were associated in floating-leaved/lily pad sites and submergents. Taxa that were correlated to other environmental variables may indicate that they could be associated with sites that have chemical concentration levels that are within the norm.

Spearman rank correlations indicated that chloride levels were negatively related to total taxa richness and intolerant taxa. This potential relationship suggests that increased focus should be placed on amounts of road salt entering LML through stormwater pipes and from impermeable surface run-off. It is possible that interactions between invertebrate taxa and environmental gradients were not more strongly evident in the NMDS analyses because of these and other indirect relationships. After the Bonnferroni corrections were applied, none of the environmental gradients were significantly related to invertebrate taxa. Even though the Bonnferroni corrections indicated that chloride (and other environmental gradients) were not significantly related to invertebrate taxa, monitoring chloride input is still important because of its elevated concentration levels already present in LML. Although chloride levels in LML were not lethal doses (Blasius and Merritt 2002), the prolonged presence of chloride in LML can have a deleterious effect on various fauna and flora. Invertebrates vary in their response to chloride stress. Through osmoregulation, invertebrates can either tolerate wide fluctuations in salinity or survive within narrow osmotic limits (Mitsch and Gosselink 2000, Blasius and Merritt 2002, Marsalek 2003, Soucek and Kennedy 2005). The taxa currently represented in LML likely adapted to conditions and habitats favored by the current hydrological regime and tolerant of occasional inputs of contaminants from the surrounding landscape. If the current distribution and abundance of hydrophytic vegetation and associated invertebrate communities are considered undesirable by LML managers, altering urban influences to water and sediment chemistry to reduce negative impacts as well as manipulating hydrology will be necessary.

MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

Habitat management is used to achieve desired richness, abundance, and distribution of target organisms, typically by manipulating vegetative communities (Payne 1992). Manipulation of wetland wildlife habitat for both game and non-game species can be active (direct) or passive (indirect). Direct management is focused on optimizing the surrounding wetland conditions for wildlife and is used when "(1) it provides the nucleus for improving a larger area of habitat, (2) it is the only way to provide a missing essential habitat factor, or (3) it restores habitat damaged or altered by human activity or catastrophic weather which cannot be restored naturally within a reasonable time" (Payne 1992). Management suggestions presented here are focused on direct management by use of a new stop-log water control structure installed in LML during October 2006. Future management will likely focus on maximizing habitat and food requirements for waterfowl and shorebirds, since MVNWR is part of the Upper Mississippi River Basin Flyway. The basin is a global flyway for 60% of all North American bird species (Nature Conservancy 2004). Management should focus on re-introducing drawdowns because fluctuating hydrology, including periodic droughts, are major influences on the long-term productivity of hydrophytic vegetation within wetlands and associated faunal communities.

Among the most common techniques for managing wetland vegetation communities and promoting diversity is manipulation of water levels. In many cases, drawdowns are used when the ratio of open water to vegetation has increased dramatically (e.g., from herbivory, disappearance of aquatic vegetation from sustained flooding at depth, plant disease; Payne 1992, Murkin et al. 1997). Drawdowns stimulate germination and rapid growth of perennials and annuals (Kadlec 1960, Linde 1969, Payne 1992). Cover plants are allowed to recover after being lost from wave action, ice action, and continuous deep flooding (Linde 1969, Payne 1992). Emergent vegetation propagated by drawdowns is used by breeding waterfowl as cover and nesting material when re-flooded the following spring (Payne 1992). Drawdowns are also necessary for marshes supporting muskrats. Extended periods of flooding will reduce the number of muskrats (Payne 1992). Drawdowns can be used to kill undesirable fish species including carp and bullheads. These species and others typically up-root aquatic vegetation and cause turbidity in the water column from floating sediments. Increased turbidity in turn impedes light penetration for plant growth, further reducing vegetative cover within wetlands (Linde 1969, Payne 1992). Wetlands and marshes subjected to long-term conditions of acidity, salinity, turbidity, and accumulations of vegetation debris are prime candidates for artificial drawdowns (Payne 1992). Drawdowns facilitate decomposition of debris, solidify the organic bottom, and help remove pollutants through stimulating new plant growth, which may improve the clarity and oxygen concentration in the water once re-flooding occurs. Some situations require water levels to be raised to impede dense and extensive marsh vegetation and to change plant succession from moist-soil and upland types to shallow and deepwater aquatics (Linde 1969).

Marsh management for wildlife includes creating and/or maintaining mudflat (moist-soil areas), hemi-marsh (shallow marsh), and deep marsh (open-water marsh) habitats (van der Valk and Davis 1978, Bookhout et al. 1989, Payne 1992). Drawdowns are essential to expose invertebrates and food plants on mudflats, which attract and support abundant waterfowl populations (Payne 1992, Murkin and Caldwell 2000). Optimal marsh habitat typically is considered to contain a mixture of mudflat, shallow marsh, and deep marsh components. Wetlands focused on waterfowl production should have lesser percentages of deep marsh area, whereas wetlands managed for other wildlife should contain more deep marsh and shallow marsh habitats (Bookhout et al. 1989, Payne 1992).

Mudflats can be maintained for >10 years and are managed for dense stands of moist-soil plants such as barnyardgrass, panic grass, smartweeds, beggarticks, nutsedges, and rice cutgrass (Bookhout et al. 1989). Long periods of drawdown can result in monotypic stands of plants and encourage undesirable invasive plants such as willow, narrow-leaved cattails (Smith and Kadlec 1985, Grace and Wetzel 1997), and purple loosestrife, which may require 4-5 years of control with high water and mechanical or chemical control (Payne 1992). Payne (1992) suggested that 1-2 years of deepwater management followed by drying, disking, or herbicide application would be adequate to eliminate invasives.

The goal for hemi-marsh conditions is to produce non-persistent emergent vegetation from seed-producing annual vegetation. A spring drawdown is required in April or May before being re-flooded in late summer or early fall. Water management should produce conditions that have a 1:1 ratio of emergent plants to open water with interspersed patches of 0.1-0.2 ha (Bookhout et al. 1989, Payne 1992). During the growing season, water levels are held 10-30 cm deep with a 15-cm adjustment level as migrating or wintering waterfowl consume layers of seeds (Payne 1992).

Water levels for deep marsh are 30-120 cm deep in the main basin during the growing season and are used by diving ducks, although widgeon, gadwalls, and shovelers use them (Bookhout et al. 1989, Payne 1992). Deep marshes are used more to control undesirable vegetation than to promote waterfowl use per se. Two to three years of water at ≥ 76 cm deep is enough to hinder undesirable plants (Payne 1992). Water levels must be maintained at normal pool level during nesting and brood rearing for maximum waterfowl production. Water levels for waterfowl vary from 15 cm to 370 cm, with 30-120 cm considered optimum. Water levels over 150 cm are too deep for major food plants to attract breeding ducks (Payne 1992). When the impoundment is full, about 20% should be less than 30 cm deep for shorebirds.

Drawdowns can be cyclic or non-cyclic, complete or partial, fast or slow, and early or late in a season. For marsh management, it is often recommended that the ratio of vegetation to open water should be kept between 30-70%, with 50% considered optimum (Verry 1989). For cyclic management, drawdowns conducted on 2-4 year intervals are favorable for waterfowl (Linde 1969). A common practice is to draw down a wetland for 2-3 consecutive years, skip 1-2 years, and expose half the bottom for at least 3 months during the growing season every 2-3 years (Payne 1992). These conditions can reduce some species of submerged and floating leaved plants during the first year of re-flooding, while other species such as water smartweed and northern naiad proliferate (Payne 1992). Subsequent drawdowns will introduce plant species that will not benefit waterfowl as emergents increase in the mudflats (e.g., purple loosestrife and cattails).

Drawdowns should be conducted at LML with attention to both vegetation and invertebrate responses. Chironomids are a major portion of the diet of later-nesting and re-nesting waterfowl in more permanent wetlands (Krapu 1974). A study by Talent et al. (1982) reported that mallard hens selected brood rearing areas with high chironomid densities. Wrubleski (1989) found that elimination of submersed vegetation had a major effect on invertebrate communities, which in turn influenced avian use of wetlands. The various stages of the wet-dry cycle, if implemented through water control of LML, will affect different types of invertebrates as the wetland transitions from a more-or-less permanent lake stage, to drawdowns, and back to re-flooding. The diversity of the seed bank will determine the vegetation developing in the basin and habitat structure and food availability, and the quality of water re-flooding the wetland also affects invertebrate populations. As indicated by Lillie (2004), water stability in wetlands is not desirable and should be managed for change because the hydrologic cycle controls wetland habitat, which is the focus for attracting waterfowl and shorebirds.

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Table 1. Cover classes for estimating areal coverage by plant species, Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2004 - 2005.

Cover Value	Cover Class (CC)	
5	75-100%	complete or nearly complete cover
4	50-74%	large group, definitely more than 50 % cover
3	25-49%	small group of plants, near 50% cover
2	5-24%	plant is common in plot, more than 5% cover
1	1-4%	plant is established well, but minimal cover
0.5	<1%	plant is rare, insignificant cover

Adapted from Gernes and Helgen (1999, 2002).

Table 2. Scoring criteria for 10 vegetation metrics within $100m^2$ releve plots, Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2004 - 2005.

Metric Name	Description of the Metric	Disturbance Response
Aquatic Guild	Number of native aquatic species.	Decrease
Dominant 3 Taxa	Proportion of 3 most abundant species divided by total abundance.	Increase
Graminoid Richness	Number of native wetland *Poaceae* , *Cyperaceae* , and *Juncaceae* species combined.	Decrease
Persistent Litter	Proportion of total abundance occupied by species that have been identified to be "persistent leaf litter".	Increase
Tolerant Taxa Ratio	Number of disturbance tolerant taxa divided by total the taxa richness.	Decrease

Metric Name	Description of the Metric	Discrete Criteria
Carex Cover Richness	Sum of native wetland *Carex* species combined cover.	≥ 10, score = 10 0.6-9.9, score = 5 ≤ 0.5, score = 0
Nonvascular Taxa	Number of nonvascular taxa in sample.	≥ 2, score = 10 1, score = 5 0, score = 0
Perennial Richness	Number of all native wetland perennial species.	≥ 18, score = 10 6 - 17, score = 5 ≤ 5, score = 0
Sensitive Species	Number of native wetland taxa sensitive to disturbance.	≥ 5, score = 10 2 -4, score = 5 ≤ 3, score = 0
Vascular Genera Richness	Number of native vascular genera.	≥ 20, score = 10 9 - 19, score = 5 ≤ 8, score = 0

Adapted from Gernes and Helgen (2002) and Genet and Bourdaghs (2006).

Table 3. IBI scoring criteria for 10 macroinvertebrate metrics, and observed responses to human disturbance, Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2004 - 2005.

Metric	Sampling Method	Description of Metric	Disturbance Response
Proportion metrics			
Corixidae Proportion†	activity trap	Abundance of Corixidae divided by total abundance of Hemiptera and Coleoptera.	Increase
Dominant 3 Proportion	dipnet	Total abundance of top 3 genera divided by total abundace of all macroinvertebrates collected.	Increase
Tolerants Proportion	dipnet	Total abundance of tolerant genera divided by total abundace of all macroinvertebrates collected.	Increase
Taxa richness metrics			
Chironomid Taxa	dipnet	Taxa richness of Chironomidae.	Decrease
Leech Taxa	dipnet & activity trap	Taxa richness of leeches.	Decrease
Odonata Taxa	dipnet & activity trap	Taxa richness of Odonata.	Decrease
Snail Taxa	dipnet & activity trap	Taxa richness of aquatic native snails.	Decrease
Total Taxa†	dipnet & activity trap	Total abundance of macroinvertebrate taxa from Amphipoda, Chironomidae, Coleoptera, Hirudinea, Sphaeriidae, Heteroptera, Ephemeroptera, Odonata, Gastropoda, and Trichoptera.	Decrease
Sensitivity metrics			
ETSD	dipnet & activity trap	Taxa richness of Ephemeroptera and Trichoptera, plus presence of Sphaeriidae and Anisoptera.	Decrease
Intolerant Taxa†	dipnet & activity trap	Richness of intolerant taxa.	Decrease

Adapted from Gernes and Helgen (2002) and Genet and Bourdaghs (2006).

† Metric required a $Log_{10}(x+1)$ transformation.

Table 4. Summary of macroinvertebrate abundance for 6 habitat types [cattail (CAT), submergents (SBM), floating-leaved/lilypad (LP), softstem bulrush (SST), purple loosestrife (PL), river bulrush (BUL)], Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2004 - 2005. Data are from dipnets (m^2) and activity traps combined (n=360).

SITE ID	2004 Total	2004 Percent Occurrence	2005 Total	2005 Percent Occurrence
BUL	4,819	17.1%	7,281	15.5%
CAT	10,758	38.2%	8,441	17.9%
LP	3,436	12.2%	5,570	11.8%
PL	1,521	5.4%	4,497	9.6%
SBM	4,887	17.4%	6,620	14.1%
SST	2,731	9.7%	14,646	31.1%

Table 5. Summary of macroinvertebrate abundance and frequency of occurrence for all 30 sampling sites in 2004, Long Meadow Lake, Minnesota Valley National Wildlife Refuge. Data represent means ± standard error (SE), and range of means among all samples from dipnets (m^2) and activity traps combined (n=360).

	Macroinvertebrate Abundance (number of individuals per m^2)		
Variable	**Mean ± SE**	**Range**	**Percent Occurrence**
Amphipoda	228 ± 29	69-718	100%
Coleoptera	35 ± 7	0-146	90%
Chironomidae*	65 ± 16	0-375	90%
Total Diptera	68 ±16	2-381	100%
Ephemeroptera	8 ± 2	0-32	77%
Gastropoda	37 ± 5	3-124	100%
Heteroptera	508 ± 157	7-4,863	100%
Hirudinea	32 ± 6	1-117	100%
Lepidoptera	4 ± 2	0-28	50%
Odonata	12 ± 2	0-54	93%
Trichoptera	10 ± 4	0-101	87%

*Chironomidae totals are only from dipnets.

Table 6. Summary of macroinvertebrate abundance and frequency of occurrence for all 30 sampling sites in 2005, Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2004 - 2005. Data represent means ± standard error (SE), and range of means among all samples from dipnets (m^2) and activity traps combined (n=360).

	Macroinvertebrate Abundance (number of individuals per m^2)		
Variable	**Mean ± SE**	**Range**	**Percent Occurrence**
Amphipoda	498 ± 64	46-1644	100%
Coleoptera	51 ± 11	1-258	100%
Chironomidae*	136 ± 36	3-1,060	100%
Total Diptera	148 ±36	11-1067	100%
Ephemeroptera	25 ± 12	0-322	93%
Gastropoda	61 ± 10	11-215	100%
Heteroptera	245 ± 46	15-1,339	100%
Hirudinea	15 ± 3	0-44	93%
Lepidoptera	2 ± 1	0-11	57%
Odonata	14 ± 3	0-72	93%
Trichoptera	19 ± 5	0-103	90%

*Chironomidae totals are only from dipnets.

Table 7. Sediment chemistry data for all 30 sites grouped by habitat within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2004 - 2005. Units are mg/kg from ICP analysis.

	Copper			Nickel			Lead			Zinc		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
BUL	25.3	22.8	10	22.8	24.3	1.38	18.5	18.9	2.62	92.7	95.9	10.6
CAT	21.9	21.7	1.64	22.9	23.4	1.54	15.9	15.6	1.28	87.3	89.1	5.52
LP	22.7	21.5	1.38	22.6	21.7	2.03	22.3	20.7	1.76	86.1	89	2.97
PL	19.6	22.5	6.6	16.8	18.6	3.08	28.3	24.4	11.1	82.9	90	27.8
SBM	22.1	22	0.867	23.2	22.8	1.05	18.3	17.8	4.15	84	81.8	6.02
SST	23.1	22	1.32	24	23.6	0.451	20.8	19	6.13	89.9	91.4	6.6

Table 8. Water chemistry data for all 30 sites grouped by habitat within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2004 - 2005. Data are in mg/l.

	Chloride			Nitrate-Nitrogen			Phosphorus		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
BUL	76.6	74.5	12.7	0.02	0.02	0	0.208	0.164	0.039
CAT	78.6	80.8	17.4	0.02	0.02	0	0.285	0.246	0.052
LP	75.2	81.8	15.2	0.02	0.02	0	0.206	0.217	0.043
PL	108.8	135	30.3	0.02	0.02	0	1.22	0.851	0.474
SBM	72	64.8	17.3	0.02	0.02	0	0.164	0.16	0.024
SST	100.8	90.5	12.7	0.02	0.02	0	0.273	0.167	0.12

Table 9. Water chemistry data for all 30 sites grouped by habitat within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2004.

	Conductivity (µS/cm)			DO (mg/l)			pH			Turbidity (ntu)		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
BUL	0.607	0.614	0.06	4.26	3.78	1.37	7.41	7.19	0.288	8.92	7.8	2.29
CAT	0.631	0.668	0.558	5.53	5.49	0.518	7.3	7.3	0.029	11.8	9.7	2.63
LP	0.584	0.641	0.066	4.61	4.63	0.758	7.47	7.47	0.044	7.82	7.65	1.61
PL	0.797	0.748	0.078	3	2.17	1.63	7.5	7.4	0.268	27.6	32.4	7.39
SBM	0.55	0.562	0.041	7.19	7.01	0.949	7.88	7.65	0.245	8.02	7.45	2.85
SST	0.662	0.663	0.011	3.68	3.88	0.76	7.17	7.18	0.084	30.87	16.3	22.05

Table 10. Water chemistry data for all 30 sites grouped by habitat within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2005.

	Conductivity (µS/cm)			DO (mg/l)			pH			Turbidity (ntu)		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
BUL	0.59	0.56	0.073	5.16	2.88	1.96	7.28	7.09	0.179	4.42	3.9	1.3
CAT	0.537	0.481	0.075	5.67	5.62	0.791	7.28	7.22	0.069	2.66	2.7	0.648
LP	0.588	0.572	0.076	5.3	4.71	1.71	7.32	7.2	0.151	2.66	1.82	1.12
PL	0.714	0.754	0.081	1.15	1.11	0.274	7.1	7.02	0.101	14.4	17	4.41
SBM	0.537	0.512	0.074	7.23	5.05	2	7.77	7.39	0.33	4.9	2.39	2.79
SST	0.759	0.776	0.023	3.47	2.94	0.747	7.2	7.1	0.167	9.37	2.7	6.77

Table 11. Pearson correlation coefficients (r) between 2004 vegetation metrics and IBI and measures of human disturbance for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge. Water and sediment chemistry data were Log10 transformed. * indicates statistically significant correlations (*P* < 0.05). ** indicates marginally significant correlations (*P* < 0.10), ns = not significant (*P* > 0.10).

	Aquatic Guild Richness	Graminoid Richness	Perennial Richness	Vascular Genera Richness	Nonvascular Richness	Carex Cover	Dominant 3 Cover	Persistent Litter Cover	Sensitive Taxa	Tolerant Taxa Ratio	Vegetation IBI
HDS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Water Chemistry:											
Chloride (mg/L)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Nitrate-Nitrogen (mg/L)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Phosphorus (mg/L)	-0.322**	0.634*	0.510*	0.462*	ns	ns	0.330**	0.463*	ns	ns	0.473*
Conductivity (µS/cm)	ns	0.325**	ns	ns	ns	0.357*	ns	0.408*	ns	ns	0.343**
Turbidity (NTU)	-0.374*	ns	ns	ns	ns	ns	ns	0.416*	ns	ns	ns
Sediment Chemistry:											
Aluminum (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Arsenic (mg/kg)	ns	-0.488*	-0.335**	-0.334**	ns	-0.347**	ns	ns	ns	ns	-0.323**
Barium (mg/kg)	0.313**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Beryllium (mg/kg)	0.318**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cadmium (mg/kg)	ns	-0.582*	-0.416*	-0.418*	ns	ns	ns	ns	ns	-0.369*	-0.408*
Chromium (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.321**	ns
Copper (mg/kg)	ns	-0.361*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Iron (mg/kg)	ns	ns	ns	ns	ns	ns	-0.316**	ns	ns	ns	ns
Lead (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Manganese (mg/kg)	-0.383*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Nickel (mg/kg)	ns	-0.404*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Selenium (mg/kg)	-0.387*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Silver (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Zinc (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 12. Pearson correlation coefficients (r) between 2005 vegetation metrics and IBI and measures of human disturbance for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge. Water and sediment chemistry data were Log10 transformed. * indicates statistically significant correlations (*P* < 0.05). ** indicates marginally significant correlations (*P* < 0.10), ns = not significant (*P* > 0.10).

	Aquatic Guild Richness	Graminoid Richness	Perennial Richness	Vascular Genera Richness	Nonvascular Richness	Carex Cover	Dominant 3 Cover	Persistent Litter Cover	Sensitive Taxa	Tolerant Taxa Ratio	Vegetation IBI
HDS	ns	ns	ns	ns	0.314**	ns	ns	ns	ns	ns	ns
Water Chemistry:											
Chloride (mg/L)	ns	ns	0.364*	ns	ns	ns	ns	0.336**	0.315**	ns	0.399*
Nitrate-Nitrogen (mg/L)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Phosphorus (mg/L)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Conductivity (µS/cm)	ns	ns	ns	ns	ns	ns	ns	ns	0.438*	ns	ns
Turbidity (NTU)	-0.384*	0.372*	ns	ns	ns	ns	ns	0.322**	ns	ns	ns
Sediment Chemistry:											
Aluminum (mg/kg)	ns	ns	ns	ns	ns	ns	0.384*	ns	ns	ns	ns
Arsenic (mg/kg)	ns	-0.414*	-0.364*	-0.334**	ns	-0.347**	ns	ns	ns	-0.413*	-0.313**
Barium (mg/kg)	ns	ns	ns	ns	ns	ns	0.424*	ns	ns	ns	ns
Beryllium (mg/kg)	ns	ns	0.363*	ns	ns	ns	0.338**	ns	ns	ns	ns
Cadmium (mg/kg)	ns	-0.487*	ns	ns	ns	ns	ns	-0.369**	ns	-0.311**	ns
Chromium (mg/kg)	ns	ns	ns	ns	ns	ns	0.336**	ns	ns	ns	ns
Copper (mg/kg)	0.395*	-0.358*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Iron (mg/kg)	ns	ns	-0.330**	ns	ns	ns	0.359*	ns	ns	ns	ns
Lead (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Manganese (mg/kg)	ns	ns	ns	ns	ns	ns	ns	-0.398*	ns	ns	ns
Nickel (mg/kg)	ns	-0.356*	ns	ns	ns	ns	ns	ns	ns	-0.349**	ns
Selenium (mg/kg)	-0.305**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Silver (mg/kg)	ns	ns	ns	ns	ns	ns	ns	-0.447*	ns	-0.378*	ns
Zinc (mg/kg)	0.356*	ns	ns	ns	ns	ns	0.337**	ns	ns	ns	ns

Table 13. Pearson correlation coefficients (r) between 2004 macroinvertebrate metrics and IBI and measures of human disturbance for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge. Water and sediment chemistry data were Log10 transformed. * indicates statistically significant correlations (*P* < 0.05). ** indicates marginally significant correlations (*P* < 0.10), ns = not significant (*P* > 0.10).

	Dominant 3 Proportion	Corixidae Proportion	Tolerants Proportion	Odonata Taxa Richness	Leech Taxa Richness	Snail Taxa Richness	Total Taxa Richness	Intolerant Taxa Richness	Chironomidae Taxa Richness	ETSD	Invertebrate IBI
HDS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Water Chemistry:											
Chloride (mg/L)	ns	-0.349**	ns	ns	ns	ns	0.372*	ns	ns	ns	ns
Nitrate-Nitrogen (mg/L)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Phosphorus (mg/L)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Conductivity (µS/cm)	-0.379*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Turbidity (NTU)	ns	ns	ns	ns	ns	0.347*	ns	ns	-0.308	ns	ns
Sediment Chemistry:											
Aluminum (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Arsenic (mg/kg)	ns	ns	ns	ns	ns	-0.316**	ns	ns	0.439*	ns	ns
Barium (mg/kg)	ns	ns	-0.344**	ns	ns	ns	ns	ns	0.350**	ns	ns
Beryllium (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	0.332**	ns	ns
Cadmium (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Chromium (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Copper (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Iron (mg/kg)	ns	ns	-0.333**	ns	ns	ns	ns	ns	ns	ns	ns
Lead (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Manganese (mg/kg)	ns	ns	-0.315**	ns	ns	ns	ns	ns	ns	ns	ns
Nickel (mg/kg)	ns	ns	-0.361*	ns	ns	ns	ns	ns	0.353**	ns	ns
Selenium (mg/kg)	ns	ns	ns	ns	0.547*	ns	0.319**	ns	ns	0.435*	ns
Silver (mg/kg)	0.327**	ns	-0.398*	ns	ns	ns	ns	ns	0.490*	ns	ns
Zinc (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 14. Pearson correlation coefficients (r) between 2005 macroinvertebrate metrics and IBI and measures of human disturbance for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge. Water and sediment chemistry data were Log10 transformed. * indicates statistically significant correlations (*P* < 0.05). ** indicates marginally significant correlations (*P* < 0.10), ns = not significant (*P* > 0.10).

	Dominant 3 Prop.	Corixidae Prop.	Tolerants Prop.	Odonata Taxa Richness	Leech Taxa Richness	Snail Taxa Richness	Total Taxa Richness	Intolerant Taxa Richness	Chironomidae Taxa Richness	ETSD	Invertebrate IBI
HDS	ns	ns	ns	0.352**	ns	ns	ns	ns	ns	ns	ns
<u>Water Chemistry:</u>											
Chloride (mg/L)	ns	ns	ns	ns	0.308**	ns	ns	-0.470*	ns	ns	ns
Nitrate-Nitrogen (mg/L)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Phosphorus (mg/L)	ns	ns	ns	0.307**	ns	ns	ns	ns	ns	ns	ns
Conductivity (mS/cm)	ns	-0.398*	ns	ns	0.375*	ns	ns	-0.321**	ns	ns	ns
Turbidity (NTU)	ns	ns	-0.317**	ns	ns	0.353**	ns	ns	ns	-0.310**	ns
<u>Sediment Chemistry:</u>											
Aluminum (mg/kg)	ns	ns	ns	ns	ns	-0.498*	ns	ns	ns	ns	-0.324**
Arsenic (mg/kg)	ns	ns	ns	ns	ns	-0.536*	ns	ns	ns	ns	ns
Barium (mg/kg)	ns	ns	ns	ns	ns	-0.503*	-0.326**	ns	ns	ns	-0.315**
Beryllium (mg/kg)	ns	ns	ns	ns	ns	-0.555*	ns	ns	ns	ns	ns
Cadmium (mg/kg)	ns	ns	ns	ns	ns	-0.310**	ns	ns	ns	ns	ns
Chromium (mg/kg)	ns	ns	ns	ns	ns	-0.411*	ns	ns	ns	ns	ns
Copper (mg/kg)	ns	ns	ns	ns	ns	-0.476*	-0.414*	ns	-0.306**	ns	-0.447*
Iron (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Lead (mg/kg)	ns	ns	-0.309**	ns	ns	ns	ns	ns	ns	ns	ns
Manganese (mg/kg)	0.367*	ns	ns	-0.305**	ns	ns	ns	ns	ns	ns	ns
Nickel (mg/kg)	ns	ns	ns	ns	ns	-0.578*	-0.357*	ns	ns	ns	-0.369*
Selenium (mg/kg)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Silver (mg/kg)	ns	ns	-0.320**	ns	ns	ns	-0.351**	ns	ns	ns	-0.375*
Zinc (mg/kg)	ns	ns	ns	ns	ns	-0.382*	ns	ns	ns	ns	ns

Table 15. Correlation coefficients (r) of measured chemical variables correlated with resultant ordination axes from nonmetric multidimensional scaling (NMDS) of data collected from 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2004. Data were standardized by habitat.

	Correlation with NMS axis		
Variable	1	2	3
Water chemistry:			
Conductivity (µS/cm)*	-0.501[§]	-0.348	0.094
Dissolved oxygen (mg/l)[†]	-0.348	0.140	-0.119
Dissolved oxygen (%)[†]	-0.277	0.166	-0.045
pH	0.008	0.266	-0.057
Temperature (^{o}C)[†]	0.196	0.225	-0.193
Turbidity (ntu)[†]	-0.049	-0.037	0.037
Chloride*	-0.468[§]	-0.151	0.319
Nitrate-nitrogen	XX	XX	XX
Phosphorus[†]	-0.065	0.072	0.149
Sediment chemistry:			
Aluminum[†]	0.023	0.146	0.247
Arsenic	-0.161	0.348	0.203
Barium	-0.083	0.084	0.071
Beryllium	XX	XX	XX
Cadmium	-0.083	0.084	0.071
Cobalt	XX	XX	XX
Chromium	-0.083	0.084	0.071
Copper	-0.083	0.084	0.071
Iron	-0.083	0.084	0.071
Lead	-0.083	0.084	0.071
Manganese	-0.083	0.084	0.071
Nickel	-0.083	0.084	0.071
Selenium[†]	-0.083	-0.122	0.072
Silver	-0.289	0.378	0.422
Zinc	-0.083	0.084	0.071

* Variables were significantly correlated with one of the three ordination axes (before Bonnferoni corrections).
[†] Variables were log (x + 1) transformed prior to correlation analysis.
[§] $P < 0.05$.
XX Variable had low value or had no variance.

Table 16. Correlation coefficients (r) of measured chemical variables correlated with resultant ordination axes from nonmetric multidimensional scaling (NMDS) of data collected from 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2004. Data were not standardized by habitat.

	Correlation with NMS axis		
Variable	1	2	3
Water chemistry:			
Conductivity (µS/cm)*	0.246	0.147	0.558§
Dissolved oxygen (mg/l)†	0.371	0.158	0.051
Dissolved oxygen (%)†	0.301	0.185	-0.006
pH	0.119	0.021	-0.236
Temperature (°C)†	0.026	-0.086	-0.293
Turbidity (ntu)†	-0.072	-0.041	0.277
Chloride	0.225	0.358	0.361
Nitrate-nitrogen	XX	XX	XX
Phosphorus†	0.060	0.085	-0.086
Sediment chemistry:			
Aluminum†	-0.050	0.315	-0.062
Arsenic	0.218	0.403	-0.188
Barium	0.069	0.210	0.003
Beryllium	XX	XX	XX
Cadmium	0.069	0.210	0.003
Cobalt	XX	XX	XX
Chromium	0.069	0.210	0.003
Copper	0.069	0.210	0.003
Iron	0.069	0.210	0.003
Lead	0.069	0.210	0.003
Manganese	0.069	0.210	0.003
Nickel	0.069	0.210	0.003
Selenium†	0.037	0.057	0.159
Silver*	0.259	0.574§	-0.176
Zinc	0.069	0.210	0.003

* Variables were significantly correlated with one of the three ordination axes (before Bonnferoni corrections).

† Variables were log (x + 1) transformed prior to correlation analysis.

§ $P < 0.05$.

XX Variable had low value or had no variance.

Table 17. Invertebrate taxa that were significantly correlated (*P* < 0.05) with resultant ordination axes from nonmetric multidimensional scaling (NMDS) of data collected from 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2004. Data were standardized by habitat.**

Axis 1	Axis 2	Axis 3
Amphipoda: Gammarus pseudolimnaeus*	Aeshnidae: Aeshna	Amphipoda: Gammarus pseudolimnaeus
Amphipoda: Hyalella azteca*	Caenidae: Caenis*	Amphipoda: Hyalella azteca
Chironomidae: Ablabesmyia*	Ceratopogonidae: Bezzia	Chironomidae: Acricotopus*
Chironomidae: Labrundinia*	Chironomidae: Ablabesmyia*	Chironomidae: Corynoneura*
Chironomidae: Parachironomus	Chironomidae: Cladopelma*	Chironomidae: Cricotopus*
Chironomidae: Polypedilum*	Chironomidae: Cricotopus*	Chironomidae: Cryptotendipes*
Coenagrionidae: Coenagrion*	Chironomidae: Cryptotendipes*	Chironomidae: Dicrotendipes*
Coenagrionidae: Enallagma*	Chironomidae: Dicrotendipes*	Chironomidae: Parachironomus*
Coenagrionidae: Ischnura*	Chironomidae: Endochironomus*	Chironomidae: Paratanytarsus*
Corixidae: Palmacorixia	Chironomidae: Glyptotendipes*	Chironomidae: Polypedilum*
Corixidae: Sigara	Chironomidae: Nanocladius*	Chironomidae: Procladius*
Corixidae: Trichocorixia	Chironomidae: Orthocladiinae*	Chironomidae: Pseudochironomus*
Dytiscidae: Laccophilus*	Chironomidae: Parachironomus*	Chironomidae: Tanytarsus*
Haliplidae: Peltodytes*	Chironomidae: Paratanytarsus*	Coenagrionidae: Coenagrion
Leptoceridae: Oecetis*	Chironomidae: Procladius*	Coenagrionidae: Enallagma
Notonectidae: Notonecta	Chironomidae: Tanytarsus*	Coenagrionidae: Ischnura
Scirtidae: Cyphon*	Dytiscidae: Agabus	Dytiscidae: Dytiscus
	Dytiscidae: Celina	Dytiscidae: Ilybius
	Dytiscidae: Hydaticus	Haliplidae: Peltodytes
	Dytiscidae: Hydroporus	Pleidae: Neoplea striola
	Dytiscidae: Hydrovatus	Polycentropodidae: Polycentropus*
	Dytiscidae: Hygrotus	Pyralidae: Nymphula ekthilipsis*
	Dytiscidae: Liodessus	Veliidae: Microvelia*
	Haliplidae: Haliplus	
	Haliplidae: Peltodytes	
	Hydrophilidae: Berosus	
	Hydrophilidae: Tropisternus	
	Isopoda: Asellus	
	Scirtidae: Cyphon	
	Scirtidae: Scirtes	

*Taxon positively correlated with the axis indicated.
** Invertebrate data was Bonnferoni-corrected.

Table 18. Invertebrate taxa that were significantly correlated (*P* < 0.05) with resultant ordination axes from nonmetric multidimensional scaling (NMDS) of data collected from 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2004. Data were not standardized by habitat.**

Axis 1	Axis 2	Axis 3
Chironomidae: Cricotopus*	Amphipoda: Hyalella azteca*	Aeshnidae: Aeshna*
Chironomidae: Endochironomus*	Chironomidae: Acricotopus*	Amphipoda: Gammarus pseudolimnaeus*
Chironomidae: Orthocladiinae*	Chironomidae: Corynoneura*	Amphipoda: Hyalella azteca*
Chironomidae: Parachironomus*	Chironomidae: Cricotopus*	Caenidae: Caenis
Chironomidae: Tanypus*	Chironomidae: Cryptotendipes*	Ceratopogonidae: Bezzia*
Coenagrionidae: Coenagrion	Chironomidae: Dicrotendipes*	Chironomidae: Ablabesmyia
Coenagrionidae: Enallagma	Chironomidae: Endochironomus*	Chironomidae: Cladopelma
Coenagrionidae: Ischnura	Chironomidae: Glyptotendipes*	Chironomidae: Cricotopus
Corixidae: Palmacorixia*	Chironomidae: Microtendipes*	Chironomidae: Cryptotendipes
Corixidae: Sigara*	Chironomidae: Orthocladiinae*	Chironomidae: Endochironomus
Corixidae: Trichocorixia*	Chironomidae: Parachironomus*	Chironomidae: Labrundinia
Dytiscidae: Hydaticus	Chironomidae: Paratanytarsus*	Chironomidae: Paratanytarsus
Dytiscidae: Hydrovatus	Chironomidae: Polypedilum*	Chironomidae: Procladius
Dytiscidae: Hygrotus	Chironomidae: Procladius*	Chironomidae: Tanytarsus
Dytiscidae: Ilybius	Chironomidae: Psectrocladius*	Corixidae: Sigara*
Dytiscidae: Laccophilus	Chironomidae: Pseudochironomus*	Corixidae: Trichocorixia*
Haliplidae: Peltodytes	Chironomidae: Tanytarsus*	Diptera: Ephydridae*
Hydrophilidae: Enochrus	Coenagrionidae: Coenagrion	Dytiscidae: Agabus*
Hydrophilidae: Tropisternus	Coenagrionidae: Enallagma	Dytiscidae: Celina*
Isopoda: Asellus	Coenagrionidae: Ischnura	Dytiscidae: Hydaticus*
Notonectidae: Notonecta*	Corixidae: Palmacorixia*	Dytiscidae: Hydroporus*
Scirtidae: Cyphon	Corixidae: Sigara*	Dytiscidae: Hydrovatus*
Scirtidae: Scirtes	Corixidae: Trichocorixia*	Dytiscidae: Hygrotus*
Veliidae: Microvelia	Dytiscidae: Dytiscus	Dytiscidae: Laccornis*
	Dytiscidae: Ilybius	Dytiscidae: Liodessus*
	Haliplidae: Peltodytes	Gerridae: Neogerris*
	Mesoveliidae: Mesovelia*	Haliplidae: Peltodytes*
	Notonectidae: Buenoa*	Hydrophilidae: Berosus*
	Notonectidae: Notonecta*	Hydrophilidae: Tropisternus*
	Polycentropodidae: Polycentropus*	Isopoda: Asellus*
	Pyralidae: Nymphula ekthilipsis*	Lestidae: Lestes*
		Pleidae: Neoplea striola*
		Scirtidae: Cyphon *
		Stratiomyidae: Odontomyia*

* Taxon positively correlated with the axis indicated.
** Invertebrate data was Bonnferoni-corrected.

Table 19. Correlation coefficients (r) of measured chemical variables correlated with resultant ordination axes from nonmetric multidimensional scaling (NMDS) of data collected from 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2005. Data were not standardized by habitat.

	Correlation with NMS axis		
Variable	1	2	3
Water chemistry:			
Conductivity (µS/cm)*	-0.170	0.524§	0.065
Dissolved oxygen (mg/l)†	-0.081	0.099	0.333
Dissolved oxygen (%)†	-0.099	0.113	0.319
pH	-0.083	0.329	0.34
Temperature (°C)†	-0.385	0.296	-0.101
Turbidity (ntu)†	0.181	0.057	-0.412
Chloride*	-0.244	0.528§	-0.156
Nitrate-nitrogen	XX	XX	XX
Phosphorus†	-0.050	0.14	-0.025
Sediment chemistry:			
Aluminum†	-0.095	0.267	0.152
Arsenic	-0.214	0.204	0.300
Barium	0.034	0.182	0.033
Beryllium	XX	XX	XX
Cadmium	0.034	0.182	0.033
Cobalt	XX	XX	XX
Chromium	0.034	0.182	0.033
Copper	0.034	0.182	0.033
Iron	0.034	0.182	0.033
Lead	0.034	0.182	0.033
Manganese	0.034	0.182	0.033
Nickel	0.034	0.182	0.033
Selenium†	-0.091	0.353	-0.131
Silver	0.082	0.155	0.333
Zinc	0.034	0.182	0.033

* Variables were significantly correlated with one of the three ordination axes (before Bonnferoni corrections).
† Variables were log (x + 1) transformed prior to correlation analysis.
§ $P < 0.05$.
XX Variable had low value or had no variance.

Table 20. Correlation coefficients (r) of measured chemical variables correlated with resultant ordination axes from nonmetric multidimensional scaling (NMDS) of data collected from 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2005. Data were standardized by habitat.

	Correlation with NMS axis		
Variable	1	2	3
Water chemistry:			
Conductivity (µS/cm)*	0.236	-0.157	-0.436§
Dissolved oxygen (mg/l)†	-0.057	-0.343	-0.065
Dissolved oxygen (%)†	-0.036	-0.332	-0.075
pH	0.044	-0.397	-0.345
Temperature (°C)†	0.353	0.027	-0.217
Turbidity (ntu)†	0.057	0.395	-0.188
Chloride*	0.389	-0.022	-0.434§
Nitrate-nitrogen	XX	XX	XX
Phosphorus†	0.135	-0.057	-0.121
Sediment chemistry:			
Aluminum†	0.107	-0.251	-0.195
Arsenic	0.112	-0.363	-0.130
Barium	-0.009	-0.059	-0.158
Beryllium	XX	XX	XX
Cadmium	-0.009	-0.059	-0.158
Cobalt	XX	XX	XX
Chromium	-0.009	-0.059	-0.158
Copper	-0.009	-0.059	-0.158
Iron	-0.009	-0.059	-0.158
Lead	-0.009	-0.059	-0.158
Manganese	-0.009	-0.059	-0.158
Nickel	-0.009	-0.059	-0.158
Selenium†	0.180	0.059	-0.318
Silver	-0.124	-0.395	-0.095
Zinc	-0.009	-0.059	-0.158

* Variables were significantly correlated with one of the three ordination axes (before Bonnferoni corrections).

† Variables were log (x + 1) transformed prior to correlation analysis.

§ $P < 0.05$.

XX Variable had low value or had no variance.

Table 21. Invertebrate taxa that were significantly correlated (*P* < 0.05) with resultant ordination axes from nonmetric multidimensional scaling (NMDS) of data collected from 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2005. Data were not standardized by habitat.**

Axis 1	Axis 2	Axis 3
Chironomidae: Apedilum*	Amphipoda: Hyalella azteca	Chironomidae: Acricotopus
Chironomidae: Corynoneura*	Baetidae: Baetis	Chironomidae: Chironomus
Chironomidae: Cricotopus*	Baetidae: Callibaetis	Chironomidae: Procladius
Chironomidae: Dicrotendipes*	Chironomidae: Ablabesmyia	Coenagrionidae: Ischnura
Chironomidae: Einfeldia*	Chironomidae: Labrundinia	Dytiscidae: Celina
Chironomidae: Endochironomus*	Chironomidae: Larsia	Dytiscidae: Dytiscus
Chironomidae: Glyptotendipes*	Chironomidae: Polypedilum	Dytiscidae: Hydroporus
Chironomidae: Labrundinia*	Corixidae: Hesperocorixia*	Dytiscidae: Hydrovatus
Chironomidae: Larsia	Corixidae: Palmacorixia*	Dytiscidae: Hygrotus
Chrysomelidae: Donaciinae*	Corixidae: Sigara*	Dytiscidae: Laccophilus
Dytiscidae: Celina	Corixidae: Trichocorixia*	Dytiscidae: Liodessus
Dytiscidae: Hydrovatus	Gyrinidae: Dineutus	Dytiscidae: Lioporeus
Dytiscidae: Hygrotus	Isopoda: Asellus*	Haliplidae: Peltodytes
Dytiscidae: Liodessus*	Notonectidae: Buenoa	Hydrophilidae: Berosus
Haliplidae: Peltodytes	Pleidae: Neoplea striola*	Hydrophilidae: Enochrus
Isopoda: Asellus	Pyralidae: Nymphula ekthilipsis	Hydrophilidae: Tropisternus
Leptoceridae: Oecetis*	Scirtidae: Cyphon	Isopoda: Asellus
Nepidae: Ranatra	Scirtidae: Scirtes	Leptoceridae: Leptocerus*
Pleidae: Neoplea striola	Stratiomyidae: Odontomyia/Hedriodiscus	Lestidae: Lestes
Scirtidae: Scirtes		Notonectidae: Notonecta*
		Scirtidae: Cyphon
		Scirtidae: Scirtes
		Stratiomyidae: Stratiomys
		Tipulidae: Tipula

* Taxon positively correlated with the axis indicated.
** Invertebrate data was Bonnferoni-corrected.

Table 22. Invertebrate taxa that were significantly correlated (*P* < 0.05) with resultant ordination axes from nonmetric multidimensional scaling (NMDS) of data collected from 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2005. Data were standardized by habitat.**

Axis 1	Axis 2	Axis 3
Baetidae: Callibaetis	Aeshnidae: Aeshna*	Baetidae: Baetis*
Chironomidae: Apedilum	Amphipoda: Gammarus pseudolimnaeus	Baetidae: Callibaetis*
Chironomidae: Chironomus*	Amphipoda: Hyalella azteca	Chironomidae: Ablabesmyia*
Chironomidae: Cricotopus	Caenidae: Caenis	Chironomidae: Cricotopus
Chironomidae: Dicrotendipes	Chironomidae: Acricotopus*	Chironomidae: Labrundinia*
Chironomidae: Einfeldia	Chironomidae: Chironomus*	Chironomidae: Larsia*
Chironomidae: Endochironomus	Chironomidae: Procladius*	Chironomidae: Polypedilum*
Chironomidae: Glyptotendipes	Coenagrionidae: Ischnura*	Chironomidae: Pseudochironomus*
Chironomidae: Labrundinia	Corixidae: Sigara	Coenagrionidae: Enallagma*
Chironomidae: Nanocladius	Corixidae: Trichocorixia	Corixidae: Hesperocorixia
Chironomidae: Paratanytarsus	Dytiscidae: Celina*	Corixidae: Palmacorixia
Chironomidae: Polypedilum	Dytiscidae: Dytiscus*	Corixidae: Sigara
Chrysomelidae: Donaciinae	Dytiscidae: Hydaticus*	Corixidae: Trichocorixia
Dytiscidae: Celina*	Dytiscidae: Hydroporus*	Gerridae: Trepobates*
Dytiscidae: Hydroporus*	Dytiscidae: Hydrovatus*	Gyrinidae: Dineutus*
Dytiscidae: Hydrovatus*	Dytiscidae: Hygrotus*	Mesoveliidae: Mesovelia*
Dytiscidae: Hygrotus*	Dytiscidae: Laccophilus*	Notonectidae: Buenoa*
Haliplidae: Haliplus*	Dytiscidae: Laccornis*	Pleidae: Neoplea striola
Haliplidae: Peltodytes*	Dytiscidae: Liodessus*	Pyralidae: Nymphula ekthilipsis*
Hydrophilidae: Tropisternus*	Dytiscidae: Lioporeus*	Scirtidae: Cyphon*
Isopoda: Asellus*	Dytiscidae: Neoporus*	Scirtidae: Scirtes*
Leptoceridae: Oecetis	Haliplidae: Peltodytes*	
Nepidae: Ranatra	Hydrophilidae: Berosus*	
Notonectidae: Notonecta	Hydrophilidae: Enochrus*	
Pleidae: Neoplea striola*	Hydrophilidae: Tropisternus*	
Scirtidae: Scirtes*	Isopoda: Asellus*	
Stratiomyidae: Stratiomys*	Leptoceridae: Leptocerus	
Tipulidae: Helius*	Lestidae: Lestes*	
	Notonectidae: Notonecta	
	Pleidae: Neoplea striola	
	Scirtidae: Cyphon*	
	Stratiomyidae: Stratiomys*	
	Tipulidae: Tipula*	

* Taxon positively correlated with the axis indicated.
** Invertebrate data was Bonnferoni-corrected.

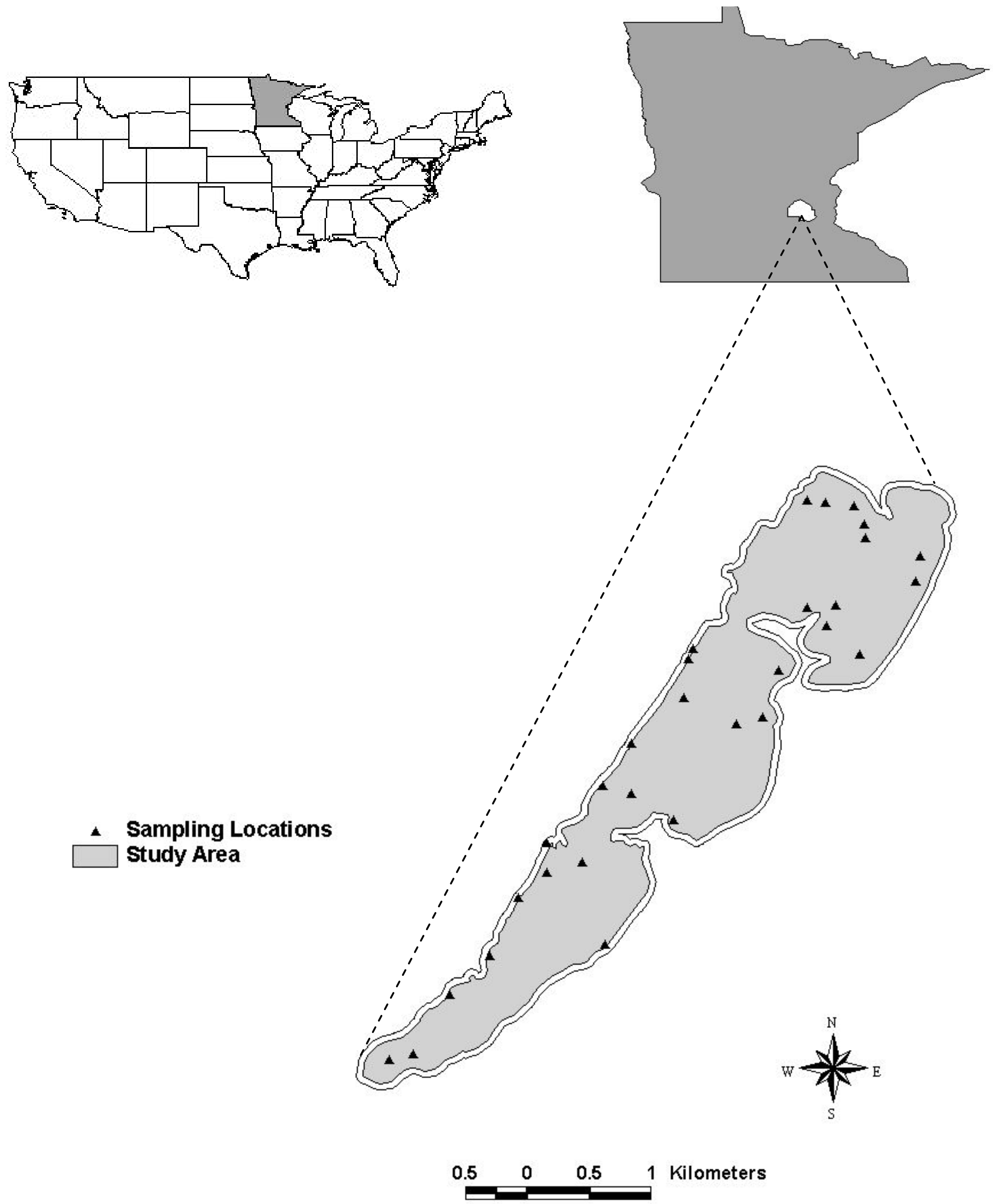

Figure 1. Map of study area showing 30 sampling locations, Long Meadow Lake, Minnesota Valley Wildlife Refuge, Hennepin County, Minnesota, USA, 2004 – 2005.

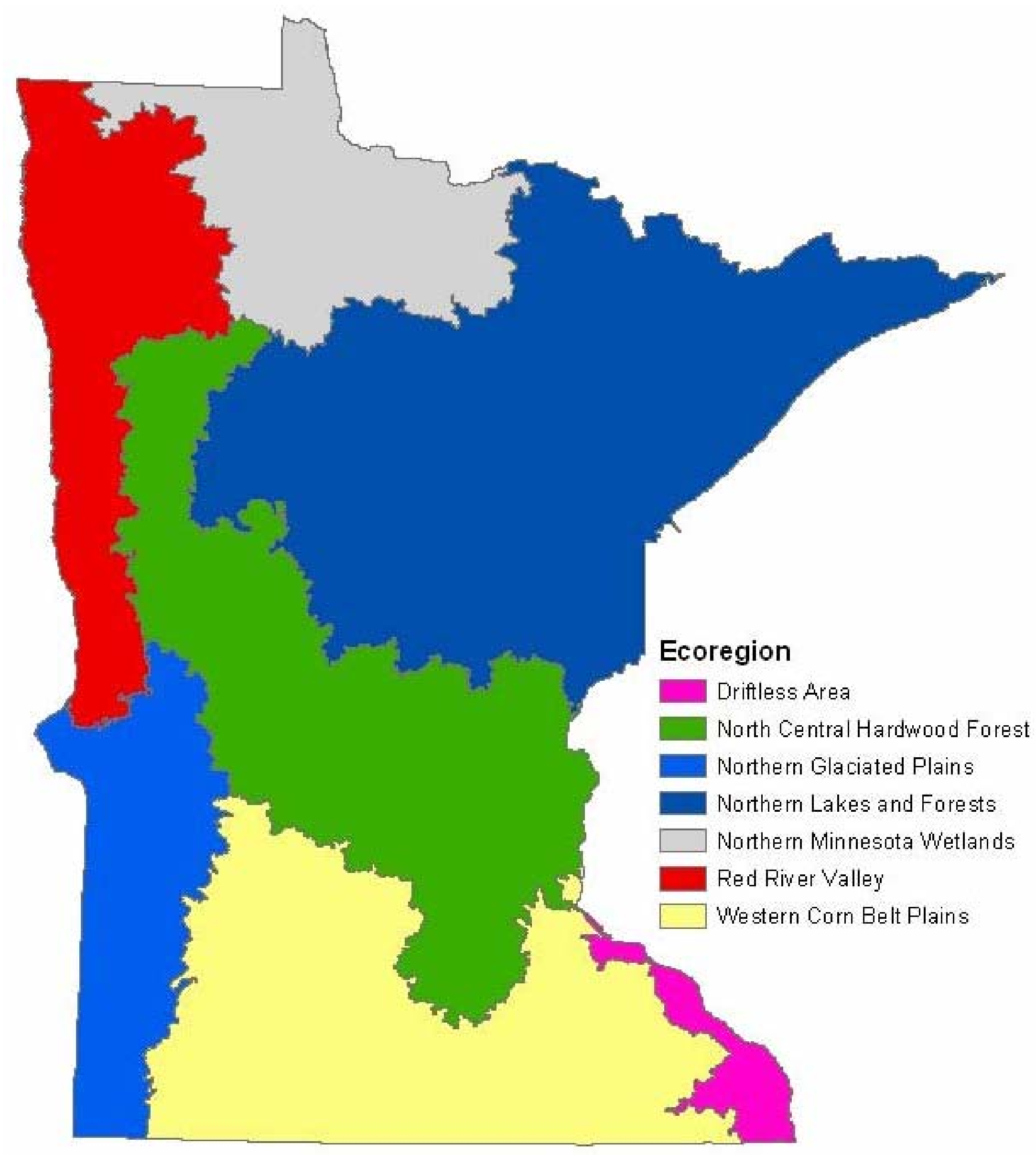

Figure. 2. Omernik Level III ecoregions in Minnesota (Omernik 1987, Genet and Bourdaghs 2006).

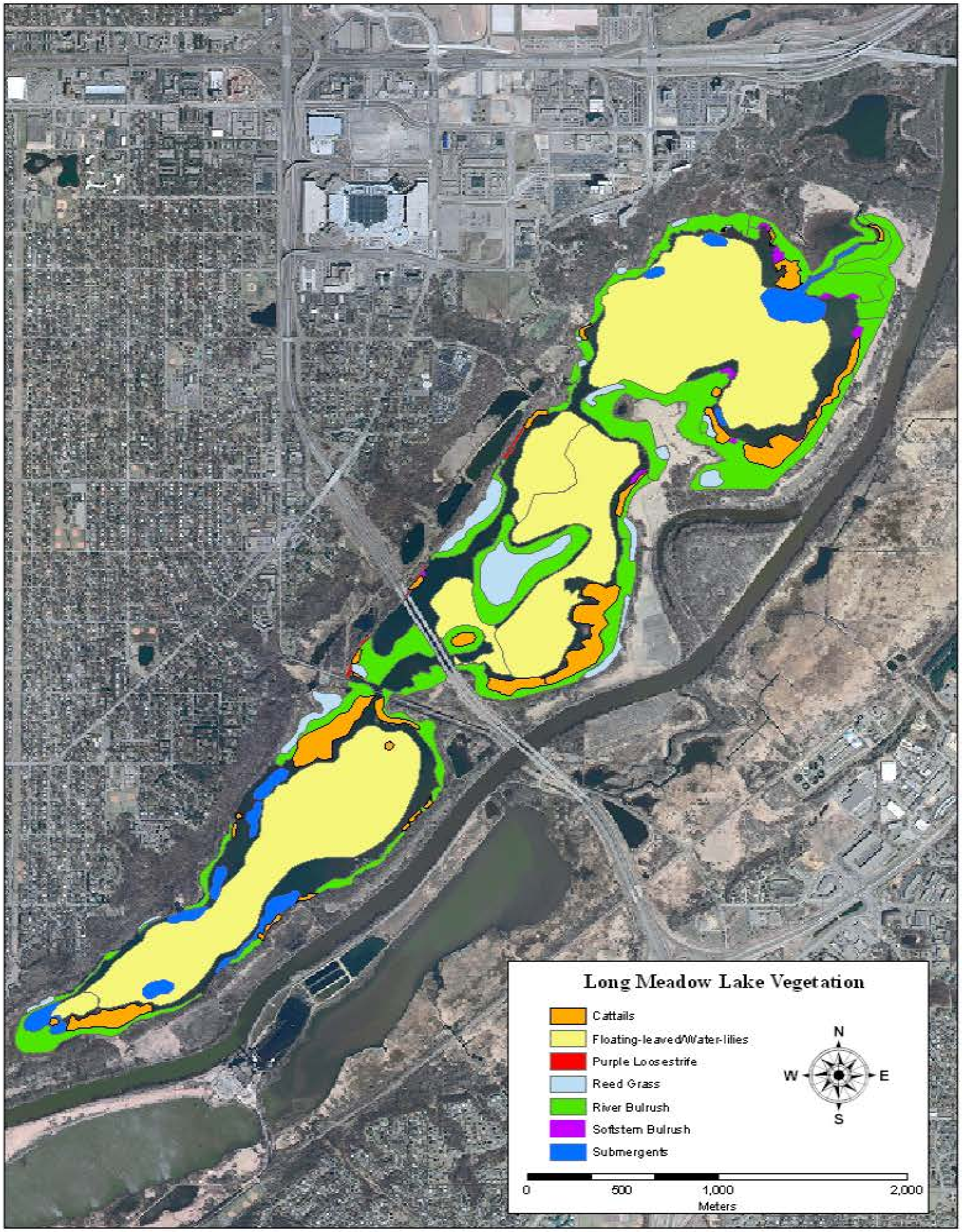

Figure 3. Major vegetation cover types present on Long Meadow Lake, Minnesota Valley National Wildlife Refuge, Hennepin County, Minnesota, USA, 2004 – 2005.

Figure 4. Map of 30 sampling points, stratified by vegetative habitat type, on Long Meadow Lake, Minnesota Valley National Wildlife Refuge, Hennepin County, Minnesota, USA, 2004 – 2005.

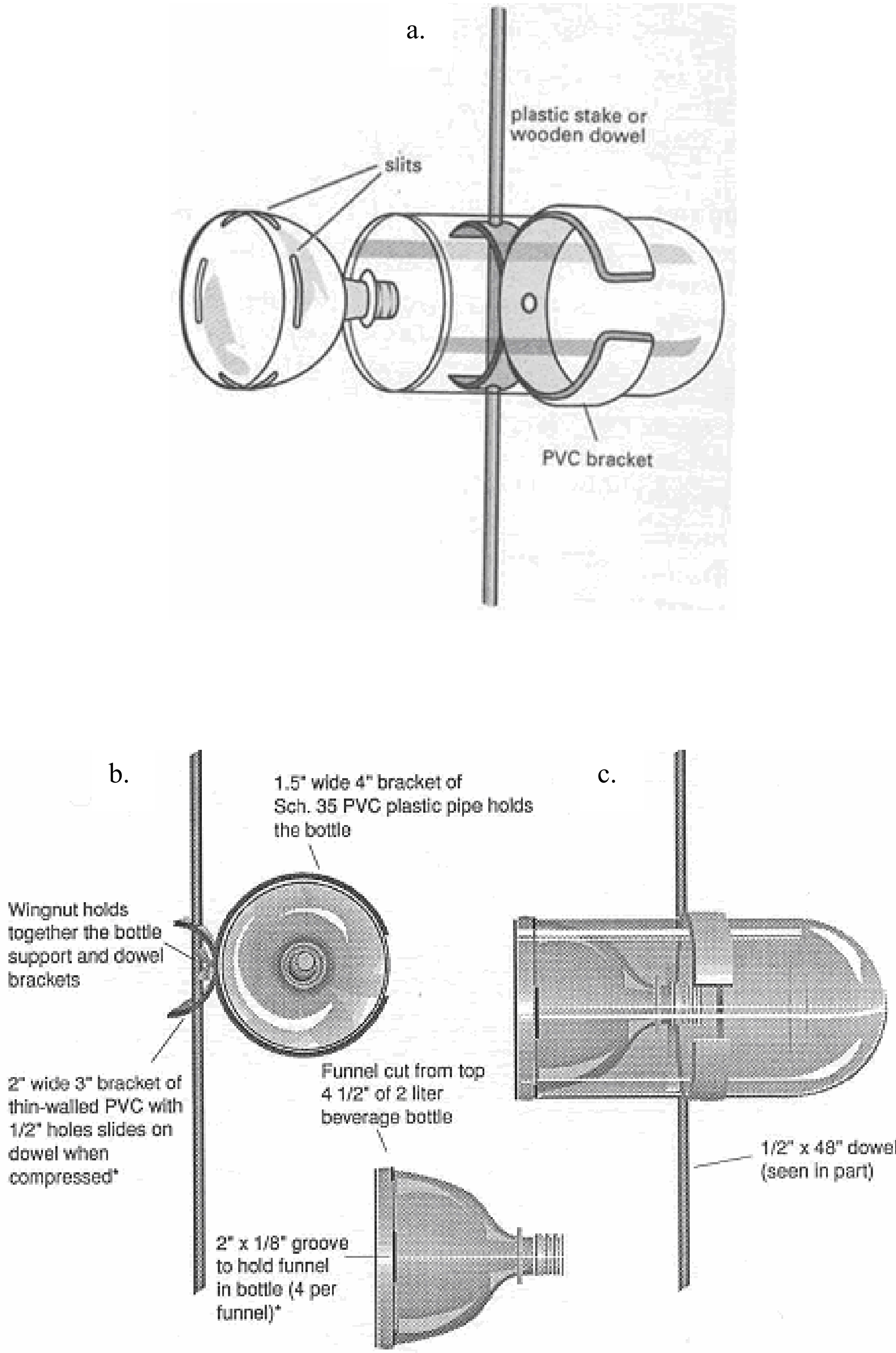

Figure 5. Activity trap design a) illustrating adjustable PVC bracket and funnel grooves b) illustrating frontal view into funnel and c) illustrating lateral view. Adapted from Genet and Bourdaghs (2006).

Figure 6. Human Disturbance Gradient boundaries around Long Meadow Lake, Minnesota Valley National Wildlife Refuge, Hennepin County, Minnesota, USA, 2004 – 2005.

Metrics that Decrease with Increasing Disturbance:

$$\text{Score} = \left(\frac{\text{metric value - minimum value}}{\text{95th percentile value- minimum value}}\right) \text{x } 10$$

Metrics that Increase with Increasing Disturbance:

$$\text{Score} = \left(\left(\frac{\text{metric value - 5th percentile value}}{\text{maximum value- 5th percentile value}}\right) \text{x } 10\right)$$

Figure 7. Formulas for determining continuous metric scores (Genet and Bourdaghs 2006).

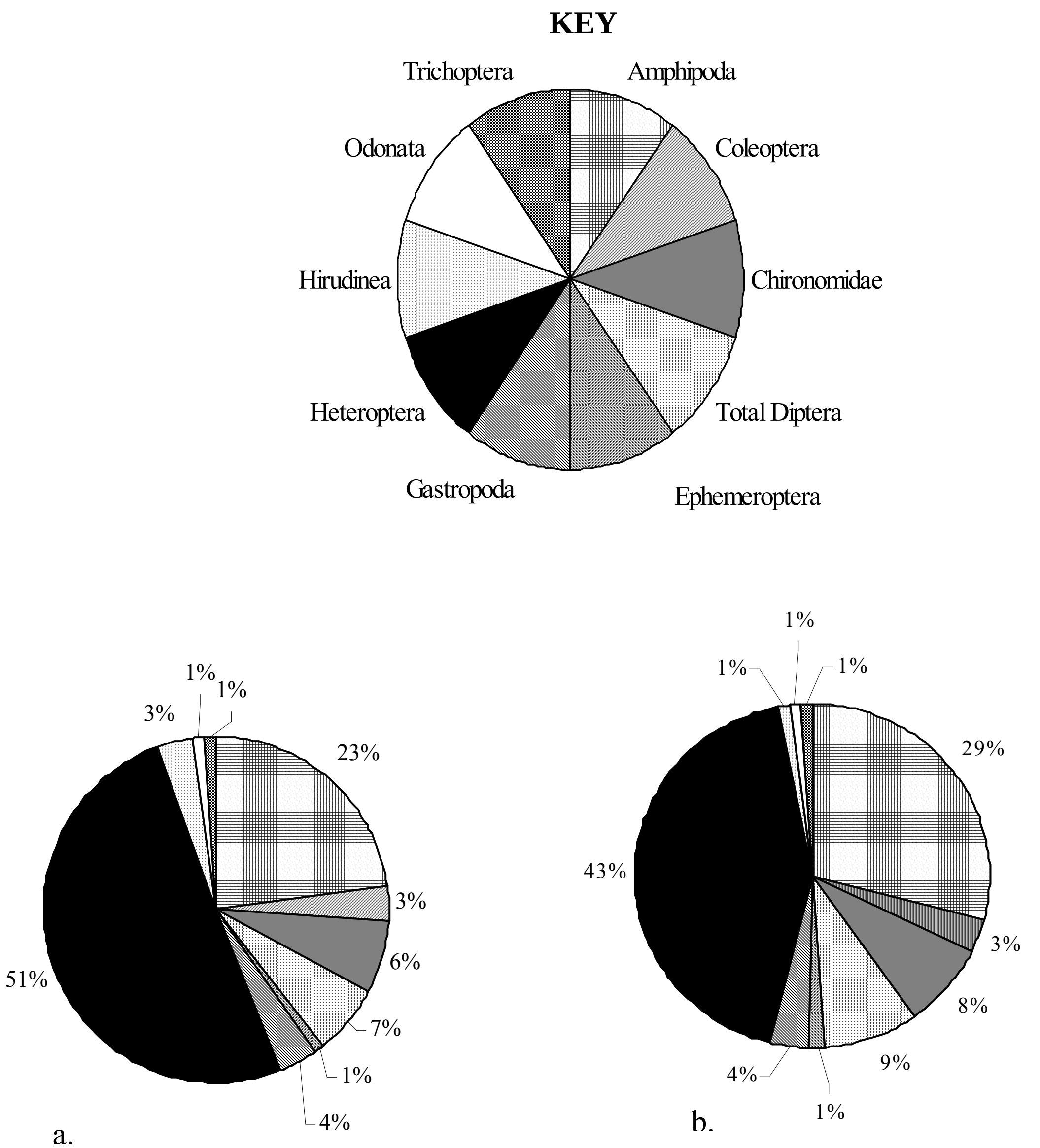

Figure 8. Percent composition of macroinvertebrate taxa collected from dipnets (m2) and activity traps in Long Meadow Lake, Hennepin County, Minnesota, USA in a) 2004 and b) 2005.

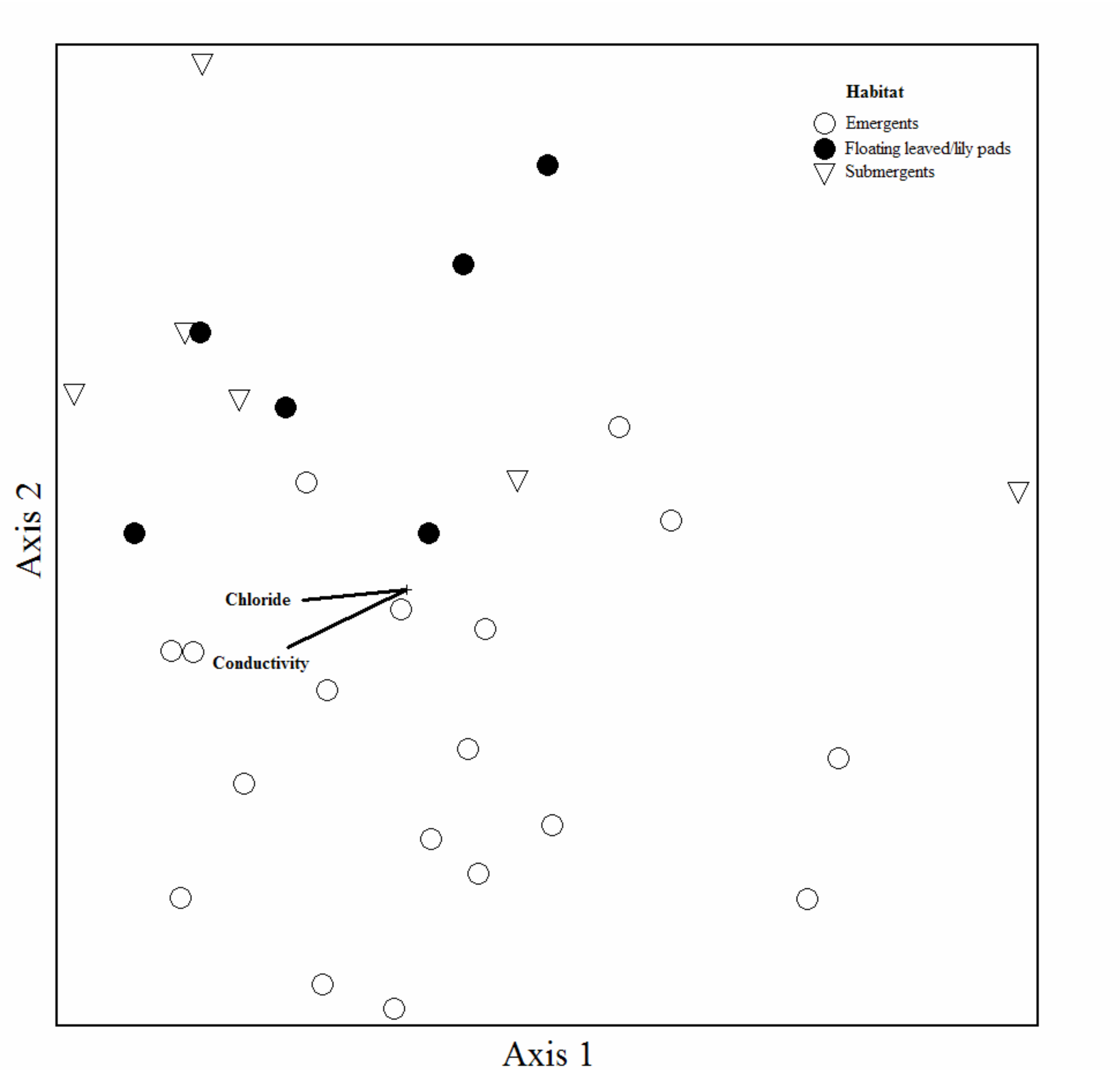

Figure 9. Nonmetric multidimensional scaling (NMDS) bi-plots of invertebrate communities sampled from 30 sites (separated by habitat) within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2004. Plots include vector overlays of environmental variables significantly correlated (*P* < 0.05) to NMDS axes. Data were standardized by habitat.

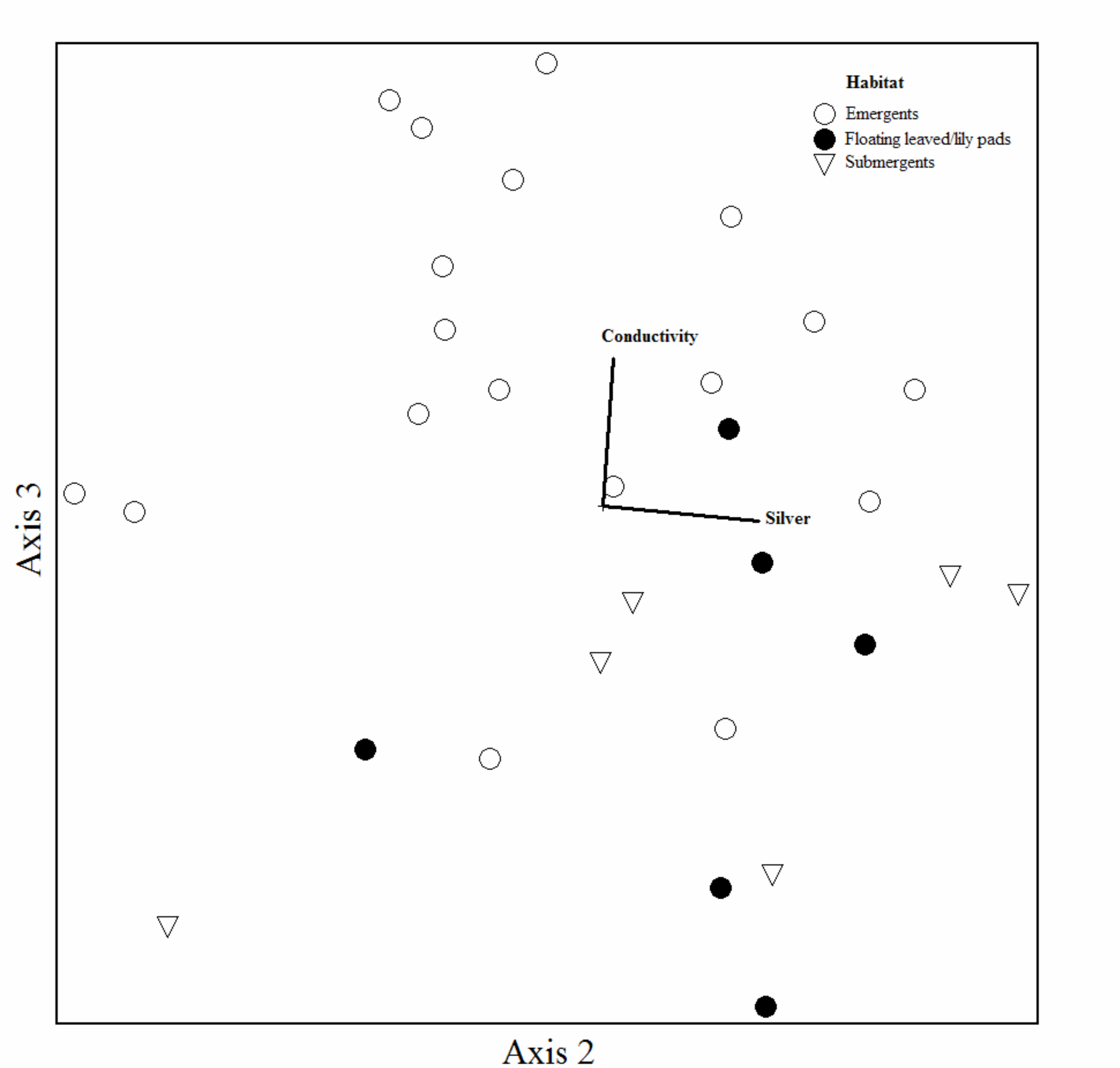

Figure 10. Nonmetric multidimensional scaling (NMDS) bi-plots of invertebrate communities sampled from 30 sites (separated by habitat) within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2004. Plots include vector overlays of environmental variables significantly correlated (*P* < 0.05) to NMDS axes. Data were not standardized by habitat.

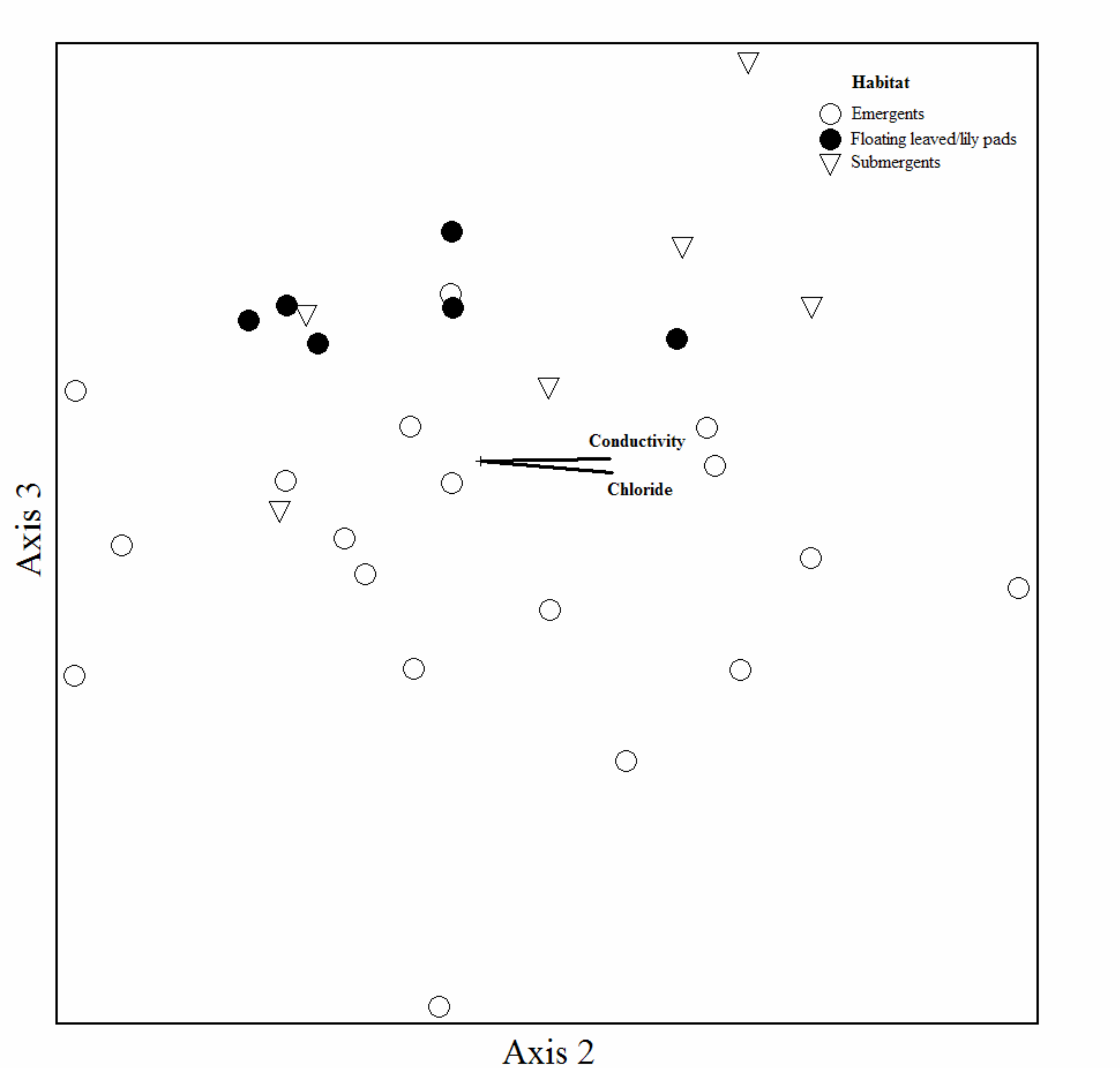

Figure 11. Nonmetric multidimensional scaling (NMDS) bi-plots of invertebrate communities sampled from 30 sites (separated by habitat) within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2005. Plots include vector overlays of environmental variables significantly correlated (*P* < 0.05) to NMDS axes. Data were not standardized by habitat.

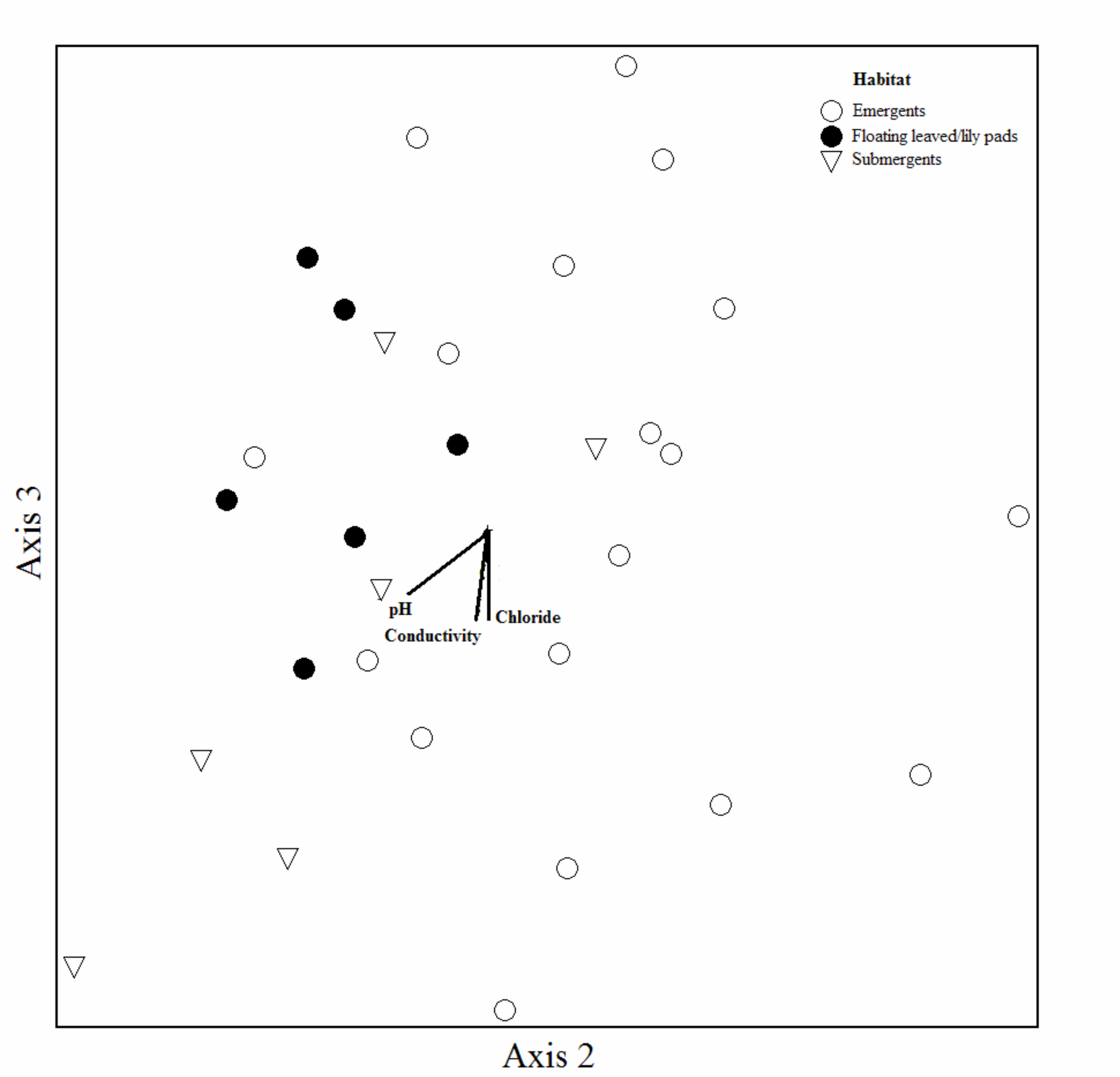

Figure 12. Nonmetric multidimensional scaling (NMDS) bi-plots of invertebrate communities sampled from 30 sites (separated by habitat) within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2005. Plots include vector overlays of environmental variables significantly correlated (*P* < 0.05) to NMDS axes. Data were standardized by habitat.

Appendix 1. Scientific and common names of vegetation found at sample sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2004 and 2005.

Scientific name	Family	Common name
Acer saccharinum	Aceraceae	silver maple
Sagittaria graminea	Alismataceae	grassy arrowhead
Sagittaria latifolia	Alismataceae	broadleaf arrowhead
Sagittaria rigida	Alismataceae	sessilefruit arrowhead
Rhus glabra	Anacardiaceae	smooth sumac
Sium suave	Apiaceae	hemlock waterparsnip
Asclepias incarnata	Asclepiadaceae	swamp milkweed
Bidens cernua	Asteraceae	nodding beggartick
Cirsium arvense	Asteraceae	Canada thistle
Cirsium vulgare	Asteraceae	bull thistle
Solidago canadensis	Asteraceae	Canada goldenrod
Solidago spp.	Asteraceae	goldenrod
Xanthium strumarium	Asteraceae	rough cocklebur
Erigeron philadelphicus	Asteraceae	Philadelphia fleabane
Eupatorium perfoliatum	Asteraceae	common boneset
Impatiens capensis	Balsaminaceae	orange jewelweed
Sambucus nigra ssp. *canadensis*	Caprifoliaceae	common elderberry
Ceratophyllum demersum	Ceratophyllaceae	coontail
Atriplex patula	Chenopodiaceae	spear saltbush
Carex spp.	Cyperaceae	sedge
Carex vulpinoidea	Cyperaceae	fox sedge
Cyperus esculentus	Cyperaceae	yellow nutsedge
Cyperus spp.	Cyperaceae	flatsedge
Eleocharis acicularis	Cyperaceae	needle spikerush
Eleocharis palustris	Cyperaceae	common spikerush
Eleocharis spp.	Cyperaceae	spikerush
Schoenoplectus fluviatilis	Cyperaceae	river bulrush
Schoenoplectus tabernaemontani	Cyperaceae	softstem bulrush
Apios americana	Fabaceae	groundnut
Lathyrus palustris	Fabaceae	marsh pea
Melilotus alba	Fabaceae	yellow sweetclover
Vicia americana	Fabaceae	American vetch
Elodea nuttallii	Hydrocharitaceae	western waterweed
Iris versicolor	Iridaceae	harlequin blueflag
Lycopus americanus	Lamiaceae	American water horehound
Scutellaria lateriflora	Lamiaceae	blue skullcap
Stachys palustris	Lamiaceae	marsh hedgenettle

continued on next page

Appendix 1 (cont.). Scientific and common names of vegetation found in sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2004 and 2005.

Scientific name	Family	Common name
Mentha arvensis	Lamiaceae	wild mint
Lemna minor	Lemnaceae	common duckweed
Lemna trisulca	Lemnaceae	star duckweed
Spirodela polyrhiza	Lemnaceae	giant duckweed
Wolffia columbiana	Lemnaceae	Columbian watermeal
Utricularia vulgaris	Lentibulariaceae	common bladderwort
Lythrum salicaria	Lythraceae	purple loosestrife
Najas flexilis	Najadaceae	nodding waternymph
Nelumbo lutea	Nelumbonaceae	American lotus
Nymphaea odorata	Nelumbonaceae	American white waterlily
Leersia oryzoides	Poaceae	rice cutgrass
Phalaris arundinacea	Poaceae	reed canary grass
Phragmites australis	Poaceae	common reed
Zizania palustris var. *interior*	Poaceae	northern wildrice
Polygonum amphibium	Polygonaceae	water knotweed
Polygonum amphibium var. *emersum*	Polygonaceae	longroot smartweed
Rumex maritimus	Polygonaceae	golden dock
Potamogeton crispus	Potamogetonaceae	curly-leaf pondweed
Potamogeton foliosus	Potamogetonaceae	leafy pondweed
Potamogeton zosteriformis	Potamogetonaceae	flatstem pondweed
Stuckenia pectinata	Potamogetonaceae	sago pondweed
Rhamnus cathartica	Rhamnaceae	common buckthorn
Riccia fluitans	Ricciaceae	liverwort
Geum laciniatum	Rosaceae	rough avens
Potentilla paradoxa	Rosaceae	Paradox cinquefoil
Salix spp.	Salicaceae	willow
Solanum sp.	Solanaceae	nightshade
Sparganium eurycarpum	Sparganiaceae	giant burreed
Typha angustifolia	Typhaceae	narrowleaf cattail
Typha x *glauca*	Typhaceae	white cattail
Boehmeria cylindrica	Urticaceae	small-spike false nettle
Pilea pumila	Urticaceae	Canadian clearweed
Urtica dioica ssp. *gracilis*	Urticaceae	stinging nettle
Verbena hastata	Verbenaceae	swamp verbena
Vitis riparia	Vitaceae	riverbank grape
Zannichellia palustris	Zannichelliaceae	horned pondweed

Appendix 2. Family and scientific names of invertebrates identified in Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2004-05. **indicates "rare" status.

Coleoptera

Chrysomelidae: *Donaciinae* spp.
Curculionidae: *Listronotus* spp.
Curculionidae: *Notiodes* spp.
Curculionidae: *Onychylis* spp.
Curculionidae: *Tanysphyrus* spp.
Dytiscidae: *Agabus* spp.
Dytiscidae: *Celina* spp.
Dytiscidae: *Coptotomus* spp.
Dytiscidae: *Dytiscus* spp.
Dytiscidae: *Hydaticus* spp.
Dytiscidae: *Hydroporus* spp.
Dytiscidae: *Hydrovatus* spp.
Dytiscidae: *Hygrotus* spp.
Dytiscidae: *Ilybius* spp.
Dytiscidae: *Laccophilus* spp.
Dytiscidae: *Laccornis* spp.
Dytiscidae: *Liodessus* spp.
Dytiscidae: *Lioporeus* spp.
Dytiscidae: *Nebrioporus* spp.
Dytiscidae: *Neoporus* spp.
Elmidae: *Dubiraphia* spp.
Elmidae: *Microcylloepus* spp.
Elmidae: *Stenelmis* spp.
Gyrinidae: *Dineutus* spp.
Haliplidae: *Haliplus* spp.
Haliplidae: *Peltodytes* spp.
Hydrophilidae: *Berosus* spp.
Hydrophilidae: *Enochrus* spp.
Hydrophilidae: *Hydrochara* spp.
Hydrophilidae: *Tropisternus* spp.
Scirtidae: *Cyphon* spp.
Scirtidae: *Scirtes* spp.
Staphylinidae: *Stenus* spp.

Diptera

Ceratopogonidae: *Bezzia* spp.
Chironomidae: Chironomini: *Apedilum* spp.**
Chironomidae: Chironomini: *Chironomus* spp.
Chironomidae: Chironomini: *Cladopelma* spp.
Chironomidae: Chironomini: *Cryptochironomus* spp.
Chironomidae: Chironomini: *Cryptotendipes* spp.
Chironomidae: Chironomini: *Dicrotendipes* spp.
Chironomidae: Chironomini: *Einfeldia* spp.
Chironomidae: Chironomini: *Endochironomus* spp.
Chironomidae: Chironomini: *Endotribelos* spp.
Chironomidae: Chironomini: *Glyptotendipes* spp.
Chironomidae: Chironomini: *Hyporhygma* spp.**

Diptera (continued)

Chironomidae: Chironomini: *Lauterborniella* spp.
Chironomidae: Chironomini: *Microtendipes* spp.
Chironomidae: Chironomini: *Nilothauma* spp.**
Chironomidae: Chironomini: *Parachironomus* spp.
Chironomidae: Chironomini: *Paratanytarsus* spp.
Chironomidae: Chironomini: *Phaenopsectra* spp.
Chironomidae: Chironomini: *Polypedilum* spp.
Chironomidae: Chironomini: *Polypedilum fallax*
Chironomidae: Chironomini: *Pseudochironomus* spp.
Chironomidae: Chironomini: *Sartheria* spp.
Chironomidae: Chironomini: *Tanytarsus* spp.
Chironomidae: Chironomini: *Xenochironomus* spp.
Chironomidae: Chironomini: *Zavreliella* spp.
Chironomidae: Orthocladiinae: *Acricotopus* spp.
Chironomidae: Orthocladiinae: *Corynoneura* spp.
Chironomidae: Orthocladiinae: *Cricotopus* spp.
Chironomidae: Orthocladiinae: *Limnophyes* spp.
Chironomidae: Orthocladiinae: *Metriocnemus* spp.
Chironomidae: Orthocladiinae: *Nanocladius* spp.
Chironomidae: Orthocladiinae: *Psectrocladius* spp.
Chironomidae: Orthocladiinae: *Thienemanniella* spp.
Chironomidae: Tanypodinae: *Ablabesmyia* spp.
Chironomidae: Tanypodinae: *Labrundinia* spp.**
Chironomidae: Tanypodinae: *Larsia* spp.**
Chironomidae: Tanypodinae: *Monopelopia* spp.**
Chironomidae: Tanypodinae: *Procladius* spp.
Chironomidae: Tanypodinae: *Tanypus* spp.
Culicidae: *Culex* spp.
Ephydridae: *Cirrula* spp.
Ephydridae: *Parydra/Ochthera* spp.
Ephydridae: *Ephydra* spp.
Psychodidae spp.
Sciomyzidae: *Cyclorrhaphous-Brachycera* spp.
Sciomyzidae: *Sepedon* sp.
Stratiomyidae: *Odontomyia* spp.
Stratiomyidae: *Odontomyia/Hedriodiscus* spp.
Stratiomyidae: *Stratiomys* spp.
Tabanidae: *Chrysops* spp.
Tipulidae: *Prionocera fuscipennis*
Tipulidae: *Tipula* spp.
Tipulidae: *Helius* spp.

Ephemeroptera

Baetidae: *Baetis* spp.
Baetidae: *Callibaetis* spp.
Caenidae: *Caenis* spp.

Appendix 2 (cont.). Family and scientific names of invertebrates identified in Long Meadow Lake, Minnesota Valley National Wildlife Refuge, in 2004-05.

Heteroptera
Belostomatidae: *Belostoma flumineum*
Corixidae: *Hesperocorixia* spp.
Corixidae: *Palmacorixia* spp.
Corixidae: *Sigara* spp.
Corixidae: *Trichocorixia* spp.
Gerridae: *Gerris* spp.
Gerridae: *Limnoporus* spp.
Gerridae: *Neogerris* spp.
Gerridae: *Trepobates* spp.
Mesoveliidae: *Mesovelia* spp.
Nepidae: *Ranatra* spp.
Notonectidae: *Buenoa* spp.
Notonectidae: *Notonecta* spp.
Pleidae: *Neoplea striola*
Veliidae: *Microvelia* spp.

Lepidoptera
Pyralidae: *Nymphula ekthilipsis*

Trichoptera
Hydroptilidae: *Agraylea* spp.
Hydroptilidae: early instar-not keyed
Leptoceridae: *Leptocerus* spp.
Leptoceridae: *Oecetis* spp.
Leptoceridae: *Triaenodes* spp.
Polycentropodidae: *Cernotina* spp.
Polycentropodidae: *Neureclipsis* spp.
Polycentropodidae: *Polycentropus* spp.

Odonata
Aeshnidae: *Aeshna* spp.
Aeshnidae: *Anax* spp.
Aeshnidae: *Epiaeschna heros*
Coenagrionidae: *Coenagrion* spp.
Coenagrionidae: *Enallagma* spp.
Coenagrionidae: *Ischnura* spp.
Corduliidae: *Epitheca* spp.
Lestidae: *Lestes* spp.
Libellulidae: *Erythemis simplicicollis*
Libellulidae: *Libellula* spp.
Libellulidae: *Pachydiplax longipennis*

Non-Insect Taxa
Crustaceans
Amphipoda: *Hyalella azteca*
Amphipoda: *Gammarus pseudolimnaeus*
Isopoda: *Asellus* spp.

Hirudinea
Erpobdellidae: *Erpobdella punctata*
Glossiphonidae: *Batracobdella phalera*
Glossiphonidae: *Batracobdella picta*
Glossiphonidae: *Helobdella elongata*
Glossiphonidae: *Helobdella fusca*
Glossiphonidae: *Helobdella papillata*
Glossiphonidae: *Helobdella stagnalis*
Glossiphonidae: *Helobdella triserialis*
Glossiphonidae: *Placobdella hollensis*
Glossiphonidae: *Placobdella montifera*
Glossiphonidae: *Placobdella multilineata*
Glossiphonidae: *Placobdella ornata*
Glossiphonidae: *Placobdella* spp.

Gastropoda
Planar snail: *Gyralus* spp.
Planar snail: *Gyralus crista*
Planar snail: *Helisoma anceps*
Planar snail: *Helisoma* spp.
Planar snail: *Helisoma trivolvis* (Planorbella)
Planar snail: *Planorbula* spp.
Planar snail: *Promenetus exacuous*
Spired snail: *Amnicola* spp.
Spired snail: *Fossaria* spp.
Spired snail: *Lymnaea* spp.
Spired snail: *Lymnaea elodes*
Spired snail: *Physa* spp.
Spired snail: *Somatogyrus* spp.
Spired snail: *Stagnicola elodes*
Spired snail: *Stagnicola exilis*
Spired snail: *Stagnicola reflexa*
Spired snail: *Valvata tricarinata*
Spired snail: *Viviparus* spp.

Sphaeriidae: (Fingernail clams)

Appendix 3. Human Disturbance Scores (HDS) for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2004-2005.

Site ID	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Extra 6	HDS
BUL1	6	6	8	0	19	1	40
BUL2	0	12	0	0	21	0	33
BUL3	2	18	14	16	20	1	71
BUL4	1	6	14	8	22	0	51
BUL5	1	19	18	15	28	0	81
BUL6	14	16	22	23	28	1	104*
CAT1	0	3	8	8	21	0	40
CAT2	6	18	17	15	20	0	76
CAT3	1	2	0	1	13	0	17
CAT4	7	8	7	16	27	0	65
CAT5	13	19	18	17	27	0	94
CAT6	1	3	8	8	20	0	40
LP1	1	18	13	15	28	1	76
LP2	1	13	15	7	28	0	64
LP3	0	9	8	8	21	0	46
LP4	0	12	9	8	28	0	57
LP5	9	12	16	15	21	0	73
LP6	0	20	17	16	20	0	73
PL1	9	13	16	26	28	0	92
PL2	7	14	17	18	10	0	66
PL3	13	19	18	17	28	0	95
SBM1	1	19	18	0	20	0	58
SBM2	1	15	10	1	12	0	39
SBM3	2	6	12	9	20	0	49
SBM4	9	12	10	8	20	0	59
SBM5	8	15	17	8	28	0	76
SBM6	9	13	10	17	20	0	69
SST1	0	12	9	8	19	0	48
SST2	2	8	12	9	28	0	59
SST3	1	3	10	15	21	0	50

* Score was rounded down to 100 to fall within 0-100 scoring range. See Gernes and Helgen (2002) for explanation of scoring criteria.

Appendix 4. Sediment chemistry data for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2004-2005. Results in mg/kg.

Site ID	Ag	Al	As	Ba	Be	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Se	Zn
BUL1	0.09	13888	9.8	189.6	0.8	0.3	<0.06	37.3	20.6	20269	476.2	23.6	13.5	<1.2	85.8
BUL2	0.13	27510	10.8	210.0	0.8	0.5	<0.06	36.0	43.9	9147	225.0	24.9	25.8	<1.2	118.9
BUL3	0.03	6972	5.5	82.1	0.3	0.5	<0.06	12.6	14.7	24184	924.4	16.4	9.6	<1.2	46.3
BUL4	0.17	37665	9.4	204.3	0.9	0.5	<0.06	40.2	22.6	17215	392.8	24.9	16.5	<1.2	98.8
BUL5	0.14	27098	9.4	231.7	0.9	0.6	<0.06	23.1	26.9	24265	565.6	25.2	21.2	<1.2	113.4
BUL6	0.11	18663	9.8	167.6	0.7	0.6	<0.06	26.9	23.0	10725	237.8	22.0	24.6	<1.2	92.9
CAT1	0.06	14064	8.8	180.4	0.7	0.5	<0.06	20.9	22.1	18113	677.1	21.2	18.7	1.3	88.6
CAT2	0.02	32321	9.5	193.7	0.8	0.4	<0.06	33.3	19.4	15384	237.0	22.6	13.1	<1.2	79.8
CAT3	0.11	9405	7.2	103.6	0.4	0.5	<0.06	14.6	16.1	24948	769.9	16.5	12.9	<1.2	66.3
CAT4	0.16	42775	13.5	227.7	1.0	0.6	<0.06	42.7	25.5	32433	552.5	25.9	19.7	<1.2	106.7
CAT5	0.12	27510	7.7	241.8	0.9	0.5	<0.06	33.5	27.1	22157	497.1	27.0	13.3	<1.2	89.6
CAT6	0.14	16542	11.1	183.8	0.8	0.5	<0.06	36.2	21.3	10703	252.0	24.1	17.8	<1.2	93.0
LP1	0.08	28682	13.2	181.1	0.8	0.4	<0.06	34.9	28.8	14338	656.3	32.3	21.1	<1.2	92.6
LP2	0.13	19410	10.7	169.5	0.7	0.5	<0.06	26.9	24.1	22067	680.4	22.1	26.4	<1.2	92.0
LP3	0.27	11646	8.4	148.7	0.5	0.8	<0.06	16.7	19.9	21651	692.0	19.7	20.3	<1.2	77.8
LP4	0.23	12332	9.2	166.5	0.6	0.6	<0.06	17.6	22.3	16661	458.6	21.6	19.0	<1.2	89.0
LP5	0.06	8457	12	135.2	0.4	0.7	<0.06	13.9	20.6	15895	132.8	18.3	28.7	1.8	76.0
LP6	0.2	28503	10	173.8	0.7	0.4	<0.06	31.2	20.3	20395	302.2	21.7	18.0	<1.2	89.0
PL1	0.14	13486	4.9	130.8	0.4	0.5	<0.60	22.0	29.3	17631	501.1	21.0	24.4	<1.2	127.1
PL2	<0.02	6109	2.9	68.8	0.2	0.1	<0.06	8.9	7.0	8966	398.3	10.8	11.3	<1.2	31.6
PL3	0.11	13413	8	161.3	0.4	0.6	<0.06	17.9	22.5	19141	362.0	18.6	49.1	<1.2	90.0
SBM1	0.08	13135	6.3	117.8	0.5	0.7	<0.06	23.2	21.9	13353	618.5	22.0	14.2	<1.2	65.3
SBM2	0.18	10359	7	138.8	0.5	0.7	<0.06	15.6	19.5	12268	542.6	19.5	10.9	<1.2	72.8
SBM3	0.16	20259	11.3	176.2	0.7	0.6	<0.06	24.4	22.1	20618	543.4	23.2	21.3	1.6	83.4
SBM4	0.13	27146	11.1	185.8	0.8	0.6	<0.06	32.2	23.8	23219	720.9	25.1	21.9	<1.2	98.6
SBM5	0.15	12728	9.1	171.2	0.7	0.6	<0.06	20.0	25.2	16630	772.0	22.3	35.1	<1.2	103.6
SBM6	0.13	43872	7.4	253.6	1.0	0.3	<0.06	42.8	20.3	18640	485.0	26.9	6.4	<1.2	80.2
SST1	0.08	13187	10.4	142.1	0.7	0.5	<0.06	21.2	21.5	19460	458.0	23.6	11.2	<1.2	77.8
SST2	0.08	20217	12.9	164.0	0.7	0.7	<0.06	25.9	25.7	22480	672.0	24.9	32.2	2.1	100.5
SST3	0.14	32840	11.4	201.8	0.8	0.5	<0.06	33.9	22.0	22047	568.2	23.5	19.0	2.9	91.4

Appendix 5. Water chemistry data for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge, 2004-2005. Results in mg/l.

Site ID	P	NO2+NO3(N)	Cl
BUL1	0.111	<.02	82.5
BUL2	0.159	<.02	66.5
BUL3	0.357	<.02	49.5
BUL4	0.169	<.02	38
BUL5	0.296	<.02	116
BUL6	0.154	<.02	107
CAT1	0.261	<.02	90
CAT2	0.493	<.02	34.5
CAT3	0.231	<.02	26.5
CAT4	0.18	<.02	130
CAT5	0.381	<.02	119
CAT6	0.165	<.02	71.5
LP1	0.226	<.02	23
LP2	0.209	<.02	118
LP3	0.225	<.02	73
LP4	0.379	<.02	90.5
LP5	0.109	<.02	106
LP6	0.086	<.02	40.5
PL1	0.652	<.02	143
PL2	0.851	<.02	48.5
PL3	2.162	<.02	135
SBM1	0.171	<.02	35
SBM2	0.148	<.02	28.5
SBM3	0.184	<.02	116
SBM4	0.09	<.02	42
SBM5	0.124	<.02	123
SBM6	0.264	<.02	87.5
SST1	0.167	<.02	86
SST2	0.139	<.02	126
SST3	0.512	<.02	90.5

Appendix 6. 2004 field water chemistry data for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge.

Site ID	Conductivity (mS/cm)	DO (mg/l)	Field pH	Temp (°C)	Turbidity (ntu)
BUL1	0.623	3.56	7.36	25.4	2.7
BUL2	0.604	8.13	7.23	24.8	17.1
BUL3	0.528	0.33	7.05	24.5	13.5
BUL4	0.371	8.27	8.81	30.0	4.6
BUL5	0.781	1.25	6.86	23.7	5.6
BUL6	0.735	3.99	7.15	23.0	10.0
CAT1	0.711	7.09	7.17	27.9	8.5
CAT2	0.443	3.95	7.29	25.6	4.6
CAT3	0.495	5.11	7.36	28.4	8.4
CAT4	0.787	4.39	7.30	26.1	22.6
CAT5	0.724	5.86	7.29	22.8	15.8
CAT6	0.624	6.77	7.37	23.8	10.9
LP1	0.369	3.43	7.49	27.4	7.8
LP2	0.747	5.45	7.52	23.8	7.5
LP3	0.591	4.73	7.41	26.7	9.9
LP4	0.704	4.53	7.33	26.3	5.9
LP5	0.691	7.50	7.65	29.0	13.8
LP6	0.404	2.01	7.44	25.4	2.0
PL1	0.950	6.14	8.01	26.9	32.4
PL2	0.748	2.17	7.10	20.0	37.3
PL3	0.694	0.694	7.40	25.6	13.1
SBM1	0.434	4.30	7.51	26.5	18.4
SBM2	0.500	5.57	7.45	27.6	0.5
SBM3	0.623	10.14	9.00	25.6	1.1
SBM4	0.643	8.36	8.09	27.7	13.2
SBM5	0.449	5.66	7.46	27.3	6.1
SBM6	0.648	9.09	7.79	22.6	8.8
SST1	0.681	3.88	7.18	26.0	2.1
SST2	0.643	4.89	7.31	26.6	16.3
SST3	0.663	2.28	7.02	27.1	74.2

Appendix 7. 2005 field water chemistry data for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge.

Site ID	Conductivity (mS/cm)	DO (mg/l)	Field pH	Temp (°C)	Turbidity (ntu)
BUL1	0.756	3.08	7.11	22.3	8.7
BUL2	0.567	9.34	7.68	27.8	2.2
BUL3	0.456	1.07	6.87	20.6	7.5
BUL4	0.366	12.89	7.97	23.9	4.5
BUL5	0.842	1.91	6.99	21.0	3.3
BUL6	0.552	2.67	7.06	26.1	0.33
CAT1	0.723	7.38	7.23	22.8	0.77
CAT2	0.431	4.16	7.15	21.3	2.8
CAT3	0.387	4.77	7.09	22.7	2.6
CAT4	0.793	6.46	7.50	23.2	4.6
CAT5	0.355	3.17	7.21	25.9	4.2
CAT6	0.531	8.10	7.47	26.9	0.97
LP1	0.283	1.78	7.07	21.3	0.83
LP2	0.794	1.15	6.89	20.6	3.6
LP3	0.558	12.72	7.79	28.5	7.6
LP4	0.776	5.13	7.15	21.9	0.5
LP5	0.585	6.71	7.75	25.6	0.63
LP6	0.530	4.29	7.25	20.2	2.8
PL1	0.830	1.11	7.30	25.8	5.8
PL2	0.754	1.64	7.02	22.2	17.0
PL3	0.557	0.693	6.98	25.0	20.4
SBM1	0.387	4.21	7.32	21.6	18.0
SBM2	0.384	2.67	6.95	21.9	0.37
SBM3	0.749	3.94	7.38	22.3	4.3
SBM4	0.712	14.44	8.78	24.5	5.8
SBM5	0.636	5.88	7.40	25.6	0.43
SBM6	0.354	12.23	8.81	28.5	0.47
SST1	0.788	2.94	6.98	22.4	2.7
SST2	0.776	4.94	7.53	23.4	2.5
SST3	0.714	2.52	7.10	22.4	22.9

Appendix 8. 2004 Vegetation IBI Scores for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge.

Site ID	Aquatic Guild Richness	Graminoid Richness	Perennial Richness	Vascular Genera Richness	Nonvascular Richness	Carex Cover	Dominant 3 Cover	Persistent Litter Cover	Sensitive Taxa	Tolerant Taxa Ratio	IBI Score
BUL1	8.2	1.7	5.0	5.0	5.0	0	5.6	6.7	0	7.8	44.9
BUL2	10.0	0.9	5.0	5.0	0	0	4.0	5.5	0	5.3	35.6
BUL3	4.5	0.9	0	0	0	0	1.7	5.3	0	5.8	18.1
BUL4	8.2	2.6	5.0	5.0	0	0	3.8	2.9	5.0	8.1	40.6
BUL5	8.2	1.7	5.0	5.0	5.0	0	1.4	4.4	5.0	5.3	41.0
BUL6	7.3	0.9	5.0	5.0	0	0	2.2	4.7	0	4.7	29.8
CAT1	6.4	3.4	5.0	5.0	0	0	5.1	9.3	5.0	6.9	46.0
CAT2	7.3	2.6	5.0	5.0	0	0	3.6	9.8	5.0	6.5	44.7
CAT3	8.2	0.9	5.0	5.0	5.0	0	3.8	5.0	5.0	5.2	43.0
CAT4	7.3	1.7	5.0	5.0	0	0	2.6	10.0	5.0	7.1	43.6
CAT5	5.5	0.9	5.0	5.0	5.0	0	2.0	5.3	5.0	5.9	39.5
CAT6	10.0	1.7	5.0	5.0	5.0	0	8.3	9.9	5.0	6.2	56.1
LP1	6.4	0.9	0	5.0	0	0	1.8	0	0	4.7	18.8
LP2	7.3	1.7	0	5.0	0	0	5.5	0	0	4.7	24.2
LP3	7.3	0	0	0	0	0	3.1	0	0	4.0	14.3
LP4	6.4	0	0	0	0	0	1.1	0	0	3.0	10.5
LP5	7.3	0	0	5.0	0	0	3.6	0	0	4.0	19.8
LP6	7.3	0	0	5.0	0	0	2.0	0	0	5.5	19.8
PL1	5.5	4.3	5	10.0	0	10.0	6.0	9.9	5.0	6.3	61.9
PL2	5.5	6.0	10	10.0	0	0	6.7	9.9	5.0	6.6	59.6
PL3	7.3	3.4	10	10.0	0	0	8.4	8.6	0	5.9	53.6
SBM1	7.3	0	0	5.0	0	0	6.1	0	0	5.4	23.8
SBM2	7.3	0.9	5	5.0	0	0	4.1	0	0	5.9	28.2
SBM3	7.3	0.9	0	5.0	0	0	3.0	0	0	4.1	20.2
SBM4	4.5	0	0	0	0	0	0.7	0	0	7.1	12.3
SBM5	8.2	1.7	5	5.0	0	0	4.4	0	0	4.2	28.5
SBM6	9.1	0.9	5	5.0	0	0	4.4	0	0	5.3	29.7
SST1	7.3	1.7	5	5.0	0	0	4.3	9.2	5.0	6.2	43.7
SST2	6.4	1.7	5	5.0	0	0	6.6	9.3	0	4.7	38.7
SST3	3.6	2.6	5	5.0	0	0	4.7	9.9	0	5.6	36.4

Appendix 9. 2005 Vegetation IBI Scores for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge.

Site ID	Aquatic Guild Richness	Graminoid Richness	Perennial Richness	Vascular Genera Richness	Nonvascular Richness	Carex Cover	Dominant 3 Cover	Persistent Litter Cover	Sensitive Taxa	Tolerant Taxa Ratio	IBI Score
BUL1	8.2	1.7	5.0	5.0	0	0	2.6	5.4	0	4.3	32.1
BUL2	10.0	0.9	5.0	5.0	0	0	2.1	7.1	5.0	5.6	40.7
BUL3	5.5	0.9	0	0	0	0	2.6	3.7	0	4.7	17.4
BUL4	7.3	4.3	5.0	10.0	0	0	5.7	3.6	0	6.3	42.2
BUL5	7.3	1.7	5.0	5.0	0	0	5.1	1.7	0	4.1	29.8
BUL6	7.3	0.9	5.0	5.0	0	0	5.0	4.8	0	5.4	33.4
CAT1	8.2	3.4	5.0	10.0	0	0	3.1	2.0	5.0	7.9	44.6
CAT2	8.2	1.7	5.0	5.0	0	0	5.1	9.7	0	7.7	42.3
CAT3	9.1	1.7	5.0	5.0	0	0	1.9	3.6	0	5.2	31.5
CAT4	8.2	1.7	5.0	5.0	0	0	10.0	3.2	5.0	6.2	44.2
CAT5	7.3	0.9	5.0	5.0	5.0	0	5.1	4.6	0	3.1	35.9
CAT6	8.2	1.7	5.0	5.0	0	0	7.1	6.0	0	5.2	38.2
LP1	8.2	0.9	5.0	5.0	0	0	0.5	0	0	4.7	24.3
LP2	6.4	0.9	0	5.0	0	0	2.3	0	0	4.0	18.5
LP3	8.2	0.9	5.0	5.0	0	0	6.6	0	0	4.7	30.4
LP4	8.2	0.9	0	5.0	0	0	4.0	0	0	4.1	22.1
LP5	8.2	0	5.0	5.0	0	0	0	0	0	3.3	21.5
LP6	6.4	0	0	0	0	0	3.0	0	0	4.7	14.1
PL1	8.2	3.4	10.0	10.0	0	10.0	2.4	6.6	5.0	7.8	63.4
PL2	6.4	5.1	10.0	10.0	0	0	0.8	6.5	5.0	8.1	51.8
PL3	8.2	3.4	10.0	10.0	0	0	10.0	6.9	5.0	7.4	60.8
SBM1	8.2	0.0	5.0	5.0	0	0	0	0	0	4.7	22.9
SBM2	8.2	0.9	5.0	5.0	0	0	0	0	0	6.4	25.4
SBM3	5.5	0.9	0	5.0	0	0	2.3	0	0	2.8	16.4
SBM4	7.3	0.9	0	0	0	0	4.2	0	0	4.7	17.0
SBM5	9.1	0.9	5.0	5.0	5.0	0	3.0	0	0	5.6	33.6
SBM6	8.2	0.9	0	5.0	0	0	2.5	0	0	4.7	21.3
SST1	6.4	2.6	5.0	5.0	0	0	5.3	2.0	5.0	5.3	36.6
SST2	8.2	1.7	5.0	5.0	0	0	2.4	2.0	5.0	6.0	35.3
SST3	5.5	2.6	5.0	5.0	0	0	7.8	3.7	0	4.7	34.3

Appendix 10. 2004 Invertebrate IBI Scores for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge.

Site ID	Dominant 3 Proportion	Corixidae Proportion	Tolerants Proportion	Odonata Taxa Richness	Leech Taxa Richness	Snail Taxa Richness	Total Taxa Richness	Intolerant Taxa Richness	Chironomidae Taxa Richness	ETSD	IBI Score
BUL1	3.5	8.0	8.6	4.9	4.3	6.3	4.5	4.3	3.5	5.0	52.8
BUL2	1.8	7.8	9.9	8.2	5.7	3.8	3.0	4.3	1.0	3.8	49.2
BUL3	3.5	6.9	10.0	3.3	4.3	5.0	0.9	5.4	1.0	5.0	45.2
BUL4	9.5	10.0	7.3	4.9	2.9	8.8	3.2	2.7	2.5	5.0	56.7
BUL5	5.4	9.1	3.5	6.6	2.9	5.0	5.1	7.0	6.5	8.8	59.8
BUL6	6.1	4.3	9.5	6.6	4.3	8.8	5.3	4.3	7.0	5.0	61.0
CAT1	3.8	5.4	6.6	4.9	4.3	3.8	2.6	4.3	0	5.0	40.7
CAT2	3.8	9.5	10.0	6.6	2.9	3.8	0.9	2.7	0	3.8	43.7
CAT3	5.5	9.3	7.5	4.9	5.7	2.5	2.3	2.7	4.5	5.0	49.9
CAT4	4.8	1.8	4.1	4.9	4.3	2.5	3.8	4.3	7.0	2.5	40.0
CAT5	6.0	3.6	3.1	3.3	2.9	6.3	1.7	0	2.0	3.8	32.6
CAT6	5.5	0.5	8.8	4.9	2.9	1.3	3.4	5.4	5.5	6.3	44.4
LP1	7.8	6.7	4.0	0	1.4	1.3	1.3	5.4	8.0	1.3	37.0
LP2	6.0	3.9	8.9	8.2	2.9	1.3	3.8	4.3	6.0	6.3	51.5
LP3	7.2	1.2	4.1	3.3	2.9	0	1.5	2.7	5.5	3.8	32.0
LP4	3.5	4.2	6.1	3.3	5.7	1.3	1.9	0	3.0	3.8	32.7
LP5	4.8	8.1	5.0	1.6	1.4	1.3	0.2	2.7	3.5	5.0	33.7
LP6	5.3	3.3	7.9	3.3	4.3	0	1.7	4.3	5.5	6.3	41.8
PL1	3.0	3.6	8.3	3.3	2.9	7.5	2.1	2.7	0	2.5	35.9
PL2	4.2	3.2	8.7	3.3	2.9	5.0	2.6	2.7	0.5	2.5	35.5
PL3	9.9	7.8	6.3	3.3	4.3	5.0	4.9	4.3	7.0	3.8	56.5
SBM1	6.3	10.0	4.2	3.3	2.9	7.5	0.6	4.3	2.5	1.3	42.8
SBM2	8.1	8.0	5.7	6.6	4.3	2.5	4.0	6.3	5.0	6.3	56.7
SBM3	6.1	5.3	4.3	4.9	2.9	1.3	0.6	4.3	3.5	6.3	39.4
SBM4	4.9	0.7	3.7	0	1.4	2.5	0	2.7	4.5	0	20.5
SBM5	7.6	0.5	4.1	3.3	4.3	2.5	3.2	6.3	7.0	5.0	43.7
SBM6	8.5	2.1	2.8	1.6	2.9	1.3	2.8	2.7	7.5	3.8	35.8
SST1	4.7	3.5	7.5	3.3	2.9	2.5	1.1	4.3	2.0	5.0	36.6
SST2	3.7	5.7	7.5	4.9	5.7	5.0	5.1	7.0	5.5	7.5	57.6
SST3	3.8	8.1	8.0	4.9	10.0	6.3	6.6	4.3	3.0	7.5	62.5

Appendix 11. 2005 Invertebrate IBI Scores for all 30 sites within Long Meadow Lake, Minnesota Valley National Wildlife Refuge.

Site ID	Dominant 3 Proportion	Corixidae Proportion	Odonata Taxa Richness	Leech Taxa Richness	Snail Taxa Richness	Total Taxa Richness	ETSD	Chironomidae Taxa Richness	Tolerants Proportion	Intolerant Taxa Richness	IBI Score
BUL1	5.3	8.5	3.3	5.7	3.8	2.8	5.0	5.0	6.8	5.4	51.5
BUL2	2.9	1.2	1.6	4.3	2.5	0.4	2.5	1.5	3.7	2.7	23.3
BUL3	5.7	7.4	3.3	4.3	7.5	2.6	3.8	3.0	10.0	2.7	50.1
BUL4	5.1	9.9	3.3	4.3	6.3	1.9	2.5	4.5	8.2	4.3	50.2
BUL5	4.3	6.9	3.3	5.7	3.8	2.3	2.5	4.0	8.8	2.7	44.3
BUL6	2.7	5.6	6.6	4.3	2.5	3.6	5.0	4.0	10.0	5.4	49.7
CAT1	5.3	9.1	4.9	5.7	5.0	5.3	7.5	4.5	9.4	4.3	61.1
CAT2	5.1	5.7	6.6	4.3	2.5	5.1	10.0	5.5	10.0	7.0	61.7
CAT3	4.7	7.8	3.3	4.3	5.0	5.5	7.5	5.5	10.0	5.4	58.9
CAT4	5.2	1.9	4.9	4.3	3.8	3.8	5.0	5.0	7.7	4.3	45.9
CAT5	2.2	8.5	4.9	4.3	5.0	1.9	2.5	1.5	8.8	2.7	42.3
CAT6	6.5	6.7	4.9	4.3	10.0	7.4	7.5	6.5	9.2	5.4	68.4
LP1	5.9	8.6	3.3	0	0	2.6	6.3	4.5	6.0	5.4	42.4
LP2	8.0	2.9	0	1.4	2.5	0.9	3.8	4.0	2.6	2.7	28.7
LP3	8.3	3.3	3.3	5.7	3.8	2.6	7.5	3.5	5.1	5.4	48.3
LP4	1.6	4.6	3.3	2.9	5.0	1.5	2.5	2.0	6.0	2.7	32.0
LP5	1.7	9.0	4.9	1.4	3.8	1.9	7.5	3.0	10.0	4.3	47.5
LP6	4.2	0.6	6.6	2.9	2.5	3.8	7.5	7.5	9.0	5.4	50.0
PL1	2.6	5.9	4.9	7.1	7.5	4.3	5.0	3.0	8.2	4.3	52.8
PL2	4.9	2.8	6.6	4.3	10.0	6.6	2.5	5.5	7.3	4.3	54.7
PL3	7.6	10.0	4.9	2.9	8.8	4.0	3.8	3.5	3.9	4.3	53.6
SBM1	5.0	9.0	1.6	1.4	5.0	4.0	2.5	6.5	3.9	5.4	44.3
SBM2	5.9	5.8	4.9	2.9	2.5	2.8	3.8	6.0	8.0	6.3	48.7
SBM3	7.7	4.5	1.6	2.9	1.3	0.6	3.8	4.0	4.3	2.7	33.3
SBM4	3.7	6.3	0	0	2.5	0	3.8	1.5	8.0	2.7	28.4
SBM5	5.3	1.2	8.2	1.4	3.8	3.4	7.5	6.0	5.9	4.3	46.9
SBM6	6.2	5.2	3.3	1.4	0	1.1	5.0	4.5	5.2	2.7	34.5
SST1	3.0	6.8	4.9	5.7	3.8	3.4	3.8	1.5	9.3	4.3	46.4
SST2	4.6	1.2	4.9	5.7	5.0	5.3	6.3	5.5	5.4	4.3	48.1
SST3	3.9	3.4	4.9	4.3	3.8	6.4	5.0	7.5	3.0	4.3	46.3