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Assessment of the Use of Submersed Aquatic Vegetation Data as a Bioindicator for the Upper Mississippi River

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Preface

The Long Term Resource Monitoring Program (LTRMP) was authorized under the Water Resources Development Act of 1986 (Public Law 99-662) as an element of the U.S. Army Corps of Engineers' Environmental Management Program. The LTRMP is implemented by the Upper Midwest Environmental Sciences Center, a U.S. Geological Survey science center, in cooperation with the five Upper Mississippi River System (UMRS) States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin. The U.S. Army Corps of Engineers provides guidance and has overall Program responsibility. The mode of operation and respective roles of the agencies are outlined in a 1988 Memorandum of Agreement.

The UMRS encompasses the commercially navigable reaches of the Upper Mississippi River, as well as the Illinois River and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers. Congress has declared the UMRS as both a nationally significant ecosystem and a nationally significant commercial navigation system. The mission of the LTRMP is to provide decision makers with information for maintaining the UMRS as a sustainable large river ecosystem given its multiple-use character. The long-term goals of the Program are to understand the system, determine resource trends and effects, develop management alternatives, manage information, and develop useful products.

This document satisfies Objective 2.3: Strategy 2.3.1 under Goal 2, Monitor Resource Change of the Operating Plan (U.S. Fish and Wildlife Service 1993). This document was developed with funding provided by the Long Term Resource Monitoring Program.

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Abstract: The potential use of aquatic macrophytes as a bioindicator of the health of the Upper Mississippi River was assessed by analysis of submersed aquatic vegetation and water quality data collected through the Long Term Resource Monitoring Program (LTRMP) in Upper Mississippi River Pools 4, 8, and 13. Data from the main channel border and side channel strata were used because these strata are conducive to rapid data collection and are more susceptible to tributary influences than backwaters. Several aquatic macrophyte attributes were calculated by use of the LTRMP data set. These included percent frequency; relative frequency of exotic, sensitive, and tolerant species; plant abundance; species richness; Simpson's Index of Diversity; Shannon's Diversity and Evenness Index; mean Coefficient of Conservatism; Floristic Quality Index; and the Aquatic Macrophyte Community Index. Simple linear regressions, calculated by use of LTRMP fixed-site water quality data with the aquatic macrophyte attributes, were performed to determine if these attributes correlate with measured water quality attributes. The submersed aquatic vegetation attributes were found to be correlated to light measurements but not to nutrients in the water, thus indicating that the growth and abundance of submersed aquatic vegetation in the Upper Mississippi River may be light limited, but not nutrient limited. Wild celery may be an appropriate indicator species, whereas the mean number of species recorded at a site was the attribute most correlated with water quality.

Key words: Submersed aquatic vegetation, bioindicator, Upper Mississippi River

Introduction

The Clean Water Act requires States to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (Water Pollution Control §Act 101[a]). As part of the Clean Water Act, States are required to report impaired water bodies to the U.S. Congress. Waters are designated as impaired if they fail to meet water quality standards and support beneficial uses. Congress has declared the Upper Mississippi River System to be both a nationally significant ecosystem and a nationally significant commercial navigation system. The water in some reaches of the Upper Mississippi River, however, is listed as impaired by the Minnesota Pollution Control Agency, or the Wisconsin Department of Natural Resources, or both, because it does not meet standards for turbidity, eutrophication, and concentrations of polychlorinated biphenyls (PCBs), mercury, and perfluorooctane sulfonate (PFOS) standards.

The Upper Mississippi River System encompasses the commercially navigable reaches of the Upper Mississippi River, as well as the Illinois River and navigable portions of the Kaskaskia, Black, St.Croix, and Minnesota Rivers. The Long Term Resource Monitoring Program (LTRMP) was authorized under the Water Resources Development Act of 1986 (Public Law 99–662) as an element of the U.S. Army Corps of Engineers' Environmental Management Program to provide decision makers with information needed to maintain the Upper Mississippi River System as a sustainable multiple-use large river ecosystem. The long-term goals of the LTRMP are to increase understanding of the river system, determine resource trends and impacts, develop alternatives for management of the river system, manage information about the river system, and develop useful products. The LTRMP is being implemented by the Upper Midwest Environmental Sciences Center, a U.S. Geological Survey science center, in cooperation with the five Upper Mississippi River System States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin. The U.S. Army Corps of Engineers provides guidance and has overall Program responsibility.

Since the implementation of the LTRMP, fish, water quality, vegetation, and macroinvertebrate data have been collected for various lengths of time from Pools 4, 8, 13, and 26 and Open River Reaches on the Mississippi River and from La Grange Pool on the Illinois River. Presently (2008), aquatic macrophyte data are being collected from Pools 4, 8, and 13.

Purpose and Scope

This report was prepared under Objective 2.3: Strategy 2.3.1 in Goal 2, *Monitoring Resource Change*, of the LTRMP Operating Plan (U.S. Fish and Wildlife Service 1993). The objective of this study was to explore the relation between various aquatic macrophyte attributes and water quality measurements from the LTRMP data set, and an assessment of the use of submersed aquatic vegetation as a bioindicator was initiated.

A bioindicator is a species that is used to monitor the health of an ecosystem. In an aquatic ecosystem, water quality characteristics, such as clarity and the amounts of nutrients in the water, affect plant growth and abundance and thus, also are related to the health of the ecosystem. To enhance the usefulness of submersed aquatic vegetation as a bioindicator to managers and regulators, aquatic macrophyte and water quality data from two locations or strata, the main channel border and the side channel, were used for this study. These strata are conducive to rapid data collection and are closely linked to conditions in tributaries (Wasley 2000). Submersed aquatic vegetation and water quality data from the Upper Mississippi River were analyzed because a reliable long-term data set from the period 1998–2006 was available. This report describes how the data were collected and analyzed, summarizes how the submersed aquatic vegetation attributes were calculated, describes the correlation between the submersed aquatic vegetation attributes and water quality, and summarizes the results of the assessment.

Study Area Description

The area of this study is composed of three pools created by impoundments on the Upper Mississippi River. Pool 4 is between Lock and Dam 3 (Red Wing, Minn.) and Lock and Dam 4 (Alma, Wis; Figure 1). It is 73 km long and includes 14,700 ha of aquatic habitat. Lake Pepin, a large widening of the river formed by the Chippewa River delta, divides Pool 4 into upper and lower portion. Pool 8 is between Lock and Dam 7 (Dresbach, Minn.) and Lock and Dam 8 (Genoa, Wis.). It is 39 km long and encompasses 9,000 ha of aquatic habitat. The upper portion has a riverine aspect with numerous islands and braided channels, whereas the lower portion is a large open expanse of water. The area between Lock and Dam 12 (Bellevue, Iowa) and Lock and Dam 13 (Fulton, Ill.) forms Pool 13. It is 52 km long and includes 11,400 ha of aquatic habitat. Pool 13 is similar to Pool 8, with a more riverine aspect in the upper portion and a large expanse of open water in the lower portion.

Previous Studies

Numerous measures of biological integrity have been developed over the years to assess the condition of freshwater aquatic systems through the use of biological indicators (Karr and Dudley 1981; Barbour et al. 1999; Hawkins et al. 2000; Hawkins and Carlisle 2001). Until recently, some of the most commonly used indicator species and communities have been fish, invertebrate, and plankton (Karr 1981; Angermeier and Schlosser 1987; Lyons et al. 1996; Scott and Hall, Jr. 1997; Mundahl and Simon 1998; Barbour et al. 1999; Schulz et al. 1999; Schleiger 2000; Milewski et al. 2001; Smogor and Angermeier 2001). However, the use of aquatic plants may more appropriately measure aquatic condition because they are nonmobile and cannot flee from rapid environmental changes (Nichols et al. 2000; Clayton and Edwards 2006). In addition, aquatic macrophytes can reflect both the long-term trends and short-term episodes within the watershed (Nichols et al. 2000). Dennison et al. (1993) found submersed aquatic vegetation to be linked to both water clarity and nutrients. The Departments of Natural Resources (DNR) of both Minnesota and Wisconsin are investigating the use of aquatic macrophytes for determining if inland lakes may be impaired according to reporting limits specified by the Clean Water Act (N. Proulx, MN DNR; J. Hauxwell WI DNR, personal communications).

Aquatic macrophytes have been used as bioindicators in riverine systems. Schneider and Melzer (2003) proposed a method for using indicator species of submerged macrophytes to detect differences in the amounts of phosphorus contributed to running waters in Germany. Aquatic macrophyte diversity and trophic indices, abundance, and richness were found to be highly correlated to bicarbonate, calcium, phosphorus, and ammonium nitrogen in streams within the Northern Vosges area of France (Thiebaut et al. 2002). A reference index based on aquatic macrophytes was developed to classify the ecological status of rivers in Germany as high, good, moderate, poor, or bad (Meilinger et al. 2005). Kocic et al. (2008) found that in eastern Croatian channels the presence of individual species was a more successful estimator of nutrients in water than plant association, which is the presence of species consistently found together and grouped into an association. In contrast, Thiebaut et al. (2006) found that aquatic macrophyte richness, abundance, and diversity were not pertinent tools for detecting pollution.

Methods

Data Collection

Aquatic macrophyte data used in this study were collected through the LTRMP from 1998 to 2006 in Pools 4, 8, and 13 of the Upper Mississippi River, using standard LTRMP stratified random sampling protocols (Yin et al. 2000). All aquatic macrophyte data were collected between June 14 and August 9 each year, and sampling locations were randomly selected each year. Each sample location consisted of a 2-m perimeter around the outside of the boat. Sampling sites were in shallow water areas of 2.5 m or less, with the exception of 1998 when sites were distributed in depths of 3 m or

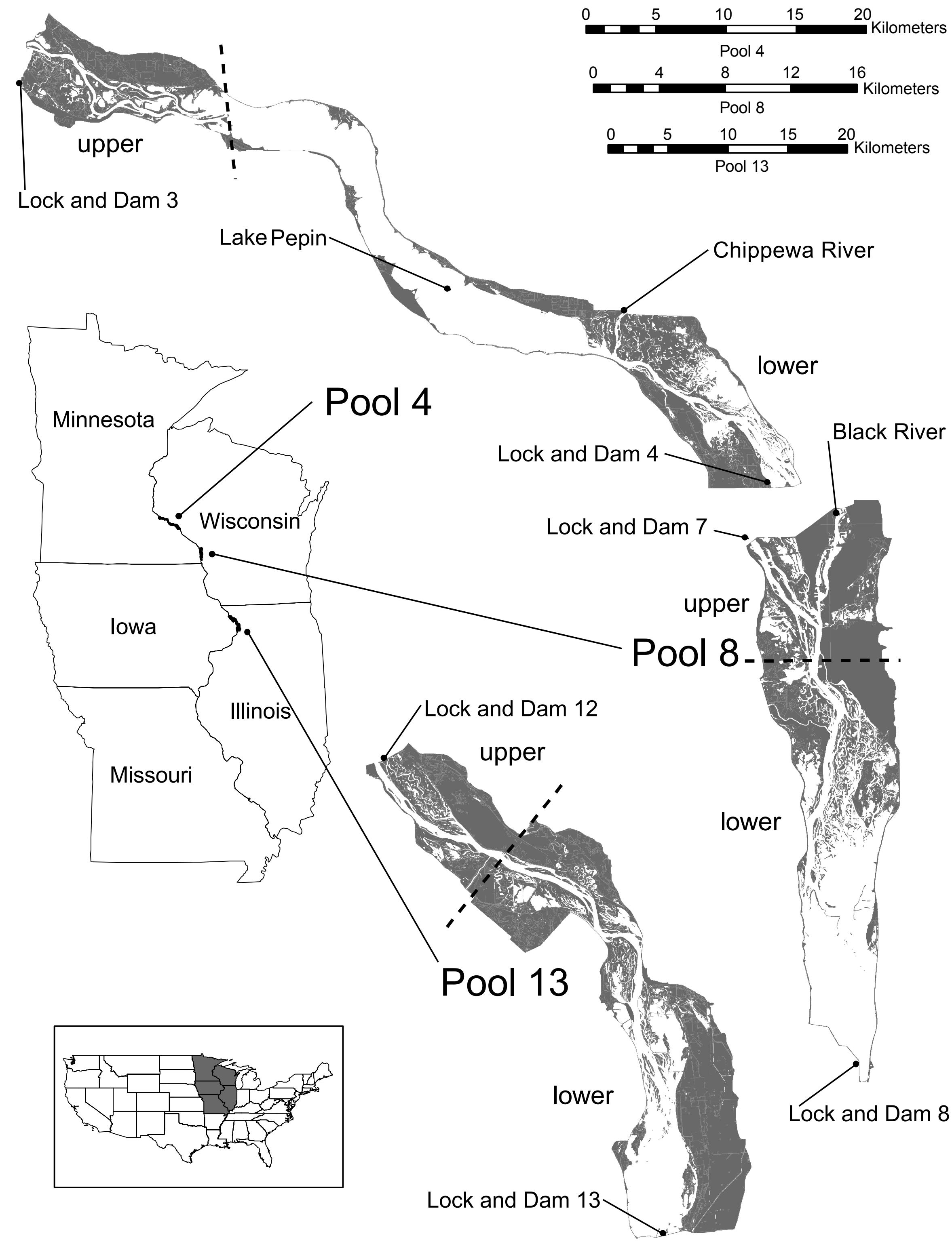

Figure 1. Locations of Pools 4, 8, and 13 of the Upper Mississippi River. The dashed lines reflect the location where each pool was divided into upper and lower portions.

less. Samples were collected from a boat, and six subsampling areas of 1.5 m long by 0.36 m wide were located off each corner and on the right and left sides of the boat. Aquatic macrophytes were collected by use of a two-headed garden rake. All macrophyte species on the rake were identified and recorded. A categorical rake score of 0–5 was given to the submersed aquatic vegetation based on the relative percent in which the vegetation filled the rake teeth. Each subsampling area was also visually inspected for macrophytes not retrieved by the rake, and these were included as visual records. Other species of macrophytes noted outside the subsampling areas but within the site were recorded as additional species.

As part of the LTRMP protocol, shallow water areas were divided into aquatic areas or strata and included main channel border, side channel, isolated backwater, contiguous backwater, impounded, and tributary delta lake. Pool 4 strata were further divided into upper Pool 4 (upstream of Lake Pepin) and lower Pool 4 (downstream of Lake Pepin) because of observed differences in trends of aquatic macrophytes, for example, submersed aquatic vegetation distribution, species richness, frequency of occurrence, and abundance. To help understand these observed differences and be consistent with Pool 4, we also divided Pools 8 and 13 into upper and lower portions. The upper portions of Pools 8 and 13 consisted of the same relative proportion as upper Pool 4 to the rest of Pool 4. Upper Pool 8 was designated as the area above river mile 697 and upper Pool 13 was the area above river mile 548 (Figure 1). For reasons previously described, we focused our study on two strata, main channel border and side channel. In addition, sites sampled in 1998 that were located in water deeper than 2.5 m were eliminated for ease of comparison to subsequent years of data.

Water quality data used in this study were collected through the LTRMP by use of standard sampling protocols (Soballe and Fischer 2004). For comparison to the aquatic macrophyte data, we used fixed-site data from the main channel, represented by one site in the upper portion of each pool and one in the lower portion, collected from 1998 to 2006 between May 1 and July 31. This period was most crucial to submersed aquatic vegetation growth, because most species in the study area begin growing in May and reach their peak biomass in late July or early August. Water quality measurements represent a seasonal mean and included transparency (measured by use of a Secchi disk lowered into the water), turbidity, specific conductance, volatile suspended solids, total suspended solids, soluble reactive phosphorus, dissolved silica, pH, dissolved oxygen, nitrate and nitrite, total nitrogen, ammonium nitrogen, temperature, and total phosphorus (U.S. Geological Survey-LTRMP, 2008).

Data Analysis

Several aquatic macrophyte attributes were calculated by use of the LTRMP data set. These attributes included percent frequency; relative frequency of exotic, sensitive, and tolerant species; plant abundance; species richness; Simpson's Index of Diversity; Shannon's Diversity and Evenness Index; mean Coefficient of Conservatism (Bernthal 2003); Floristic Quality Index (Bernthal 2003); and the Aquatic Macrophyte Community Index (Nichols et al. 2000).

The presence or absence of submersed aquatic vegetation was used to calculate percent frequency, which is an index of prevalence. Percent frequency was calculated by dividing the number of sites with submersed aquatic vegetation or an individual species by the total number of sites. Relative frequency of exotic species was calculated by dividing the number of occurrences of all exotic species by the number of occurrences of all species. Sensitive and tolerant relative frequencies were calculated in the same manner as exotics.

Rake score is the categorical amount of submersed aquatic vegetation, expressed by a rating of 0–5, measured by the relative percent to which submersed aquatic vegetation fills the rake teeth after each rake grab. A rake score was recorded for each of the six subsampling areas within a site location. Abundance for a site location was calculated by adding together the six subsample rake scores of submersed aquatic vegetation. If submersed aquatic vegetation was observed within the 2-m perimeter but was not recorded within any of the six subsampling areas, it was given an abundance of 1. Abundance values could range from 0 to 30.

Species richness and diversity were expressed by use of several different methods. Species richness was calculated three ways: the total number of species recorded in a pool, the total number of species recorded at a site, and the mean number of species recorded at a site. Three indices were used to calculate species richness and diversity. Simpson's Index of Diversity (D) measures the probability that two individuals selected from a sample will belong to different species (Peet 1974) and was calculated as $D = 1 - \sum n / N^2$, where n = the number of occurrences of one species and N = the total number of occurrences of all species. Results from the index can range from 0 to 1, with a 1 indicating a more diverse community. The Shannon Index (H) measures the order or heterogeneity within a community (Peet 1974) and was calculated as $H = -\sum (n/N) * [1\mathrm{n}(n/N)]$. Shannon's Evenness ($E$) incorporates the number of species recorded into the Shannon Index and was calculated as $E = H/\ln S$, where S = total number of species within the community. As in the Simpson's Index, a higher number denotes a more diverse community.

Conservatism was analyzed by examining the mean Coefficient of Conservatism and the Floristic Quality Index (Swink and Wilhelm 1994; Lopez and Fennessy 2002; Bernthal 2003). Nichols (1999) described conservatism as "the estimated probability that a plant is likely to occur in a landscape that is believed to be relatively unaltered from presettlement conditions." The Coefficient of Conservatism assigned to each species is based on "the degree to which a species can tolerate disturbance and its fidelity to undegraded systems" and is a number between 0 and 10 (Bernthal 2003). The Coefficients of Conservatism used within this study were assigned to each species by botanists and field ecologists familiar with the flora of Wisconsin (Bernthal 2003). The Floristic Quality Index (FQI) is a combination of the mean Coefficient of Conservatism and species richness and is calculated as $\overline{C} * \sqrt{N} = \mathrm{FQI}$, where N = the number of species present, excluding exotic species, and $\overline{C}$ = the mean coefficient of conservatism. Francis et al. (2000) found that mean Coefficient of Conservatism was not affected by plot size or sampling season, but species richness was affected by both; therefore, Floristic Quality Index scores were higher due to either larger plots or sampling later in the season. Francis et al. (2000) also suggested making separate calculations of Coefficient of Conservatism and richness, because they can vary in the opposite directions, thus making the Floristic Quality Index less informative. Rooney and Rogers (2002) suggested that mean Coefficient of Conservatism is less sensitive to sample size than Floristic Quality Index and produces more intuitive results. For example, an area may have high species richness, but the species present might have low Coefficient of Conservatism values; however, an area with low species richness may have high Coefficient of Conservatism values. The first area could have a higher Floristic Quality Index score, but intuitively would have a poorer habitat quality than the second area. Both indices were developed to assess wetlands. We were interested in how well they would work in a riverine environment. For comparison with other studies, emergent and floating-leaved species were included in addition to submersed aquatic vegetation.

Taxonomic tolerance information, expressed by Coefficient of Conservatism scores, was applied to the sampled submersed aquatic vegetation according to the following criteria established by Bernthal (2003).

- **0–3** = Taxa found in a wide variety of plant communities and very tolerant of disturbance.
- **4–6** = Taxa typically associated with a specific plant community, but tolerant of moderate disturbance.
- **7–8** = Taxa found in a narrow range of plant communities in advanced stages of succession, but can tolerate minor disturbance.
- **9–10** = Taxa restricted to a narrow range of synecological conditions, with low tolerance of disturbance.

According to the above criteria, species considered sensitive were those that were assigned 7 and higher, whereas species considered tolerant were assigned 3 or less.

The Aquatic Macrophyte Community Index was developed by Nichols et al. (2000) as a "multipurpose tool to assess the biological quality of aquatic plant communities in lakes." We wanted to test the index in a riverine environment. This index consists of seven components:

1. maximum depth of plant growth;
2. percent of littoral zone vegetated;
3. modified Simpson's diversity index;
4–6. relative frequency of submersed, sensitive and exotic species; and
7. taxa number.

The Aquatic Macrophyte Community Index was calculated following the procedures described in Nichols et al. (2000). Each parameter was scaled from 1 to 10, with 10 representing the highest quality condition, and then the parameter scales were summed, resulting in an Aquatic Macrophyte Community Index value between 7 and 70. For comparison with other studies, emergent and floating-leaved species were included in addition to submersed aquatic vegetation.

Simple linear regressions using LTRMP fixed-site water-quality data with the attributes listed above were performed to determine if submersed aquatic vegetation attributes correlate with water quality measurements. Data were analyzed by use of PROC REG (alpha = 0.05) from the SAS statistical programming v9.1 (2003).

Assessment of the Use of Aquatic Vegetation and Water Quality Data

Richness and Diversity

A total of 15 submersed species were found during the sampling period in all pools and strata (Appendix A); however, only 12 species were recorded in any one year, pool, and stratum combination. Species richness ranged from 0 to 12 species in side channel and 0 to 10 species in main channel border strata (Appendixes B and C). The lowest species richness values were found in the upper portions of Pools 4 and 13 in both side channel and main channel border strata (one species each), whereas the highest species richness was in lower Pool 8 side channel (12 species). The maximum number of species recorded at any one site was 10 species in the side channel of lower Pools 4 and 8. The mean number of species recorded per site ranged from 0 in the upper portions of Pools 4, 8, and 13 to 2.0 in lower Pool 4 side channel (Figure 2).

Simpson's Index of Diversity values ranged from 0.00 to 0.88 within the study (Appendixes B and C). Species diversity was consistently greater in the lower portions of the pools than the upper portions of all pools. Upper Pools 4 and 13 had values of 0 in all years, whereas values in upper Pool 8 ranged from 0 to 0.83. Diversity among all lower pools was similar, with lower Pool 13 having the widest range (0.56–0.85) of diversity among all years. As with Simpson's Index, a higher number for the Shannon Index and Evenness indicates a more diverse community. The Shannon Index ranged from 0.00 to 2.26, whereas Evenness ranged from 0.00 to 1.00. Both indices followed the same general pattern as the Simpson's Index.

Frequency of Occurrence, Relative Frequency, and Abundance

In general, a higher percent frequency of submersed aquatic vegetation was more often found in side channels than in main channel borders in all study pools (Figure 2; Appendixes D and E). Furthermore, the lower portions of all study pools had consistently more submersed aquatic vegetation than the upper portions. The highest percent frequency (55 percent) was recorded in the side channel of lower Pool 4 in 2006. The highest percent frequency recorded for an individual species, *Heteranthera dubia*, was 37.5 percent in side channel lower Pool 4 (Figure 2). Species commonly recorded included *H. dubia, Stuckenia pectinatus*, and *Vallisneria americana*.

Two exotic submersed species were recorded during the study, *Myriophyllum spicatum* and *Potamogeton crispus*. The relative frequency of exotic species to native submersed macrophytes changed little from year-to-year and was most often less than 20 percent (Figure 2; Appendixes F and G). The highest relative frequency of

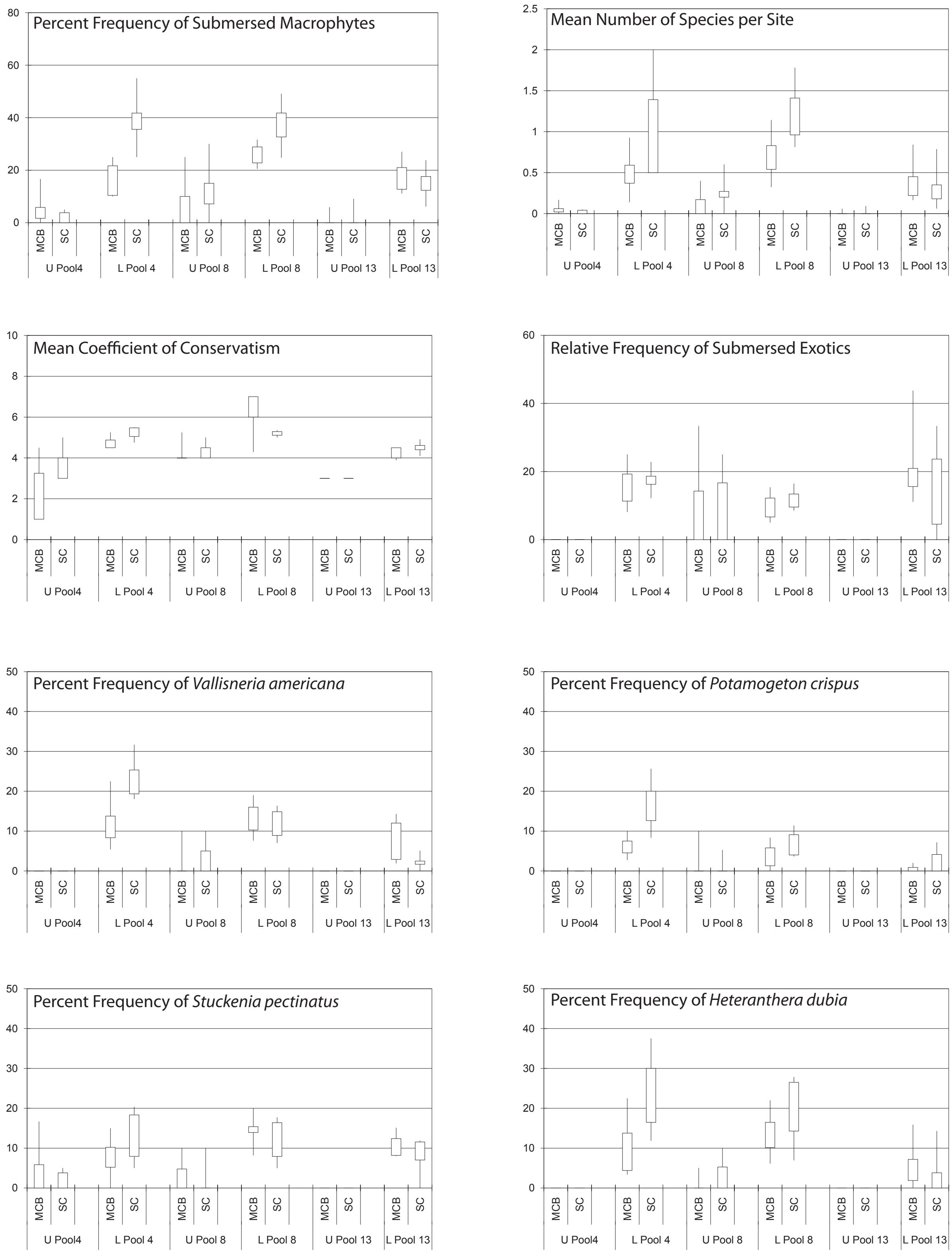

Figure 2. Maximum, 75 percentile, 25 percentile, and minimum for selected macrophyte attributes in main channel border and side channel strata of Pools 4, 8, and 13 of the Upper Mississippi River in 1998-2006. (MCB, main channel border; SC, side channel; U, upper; L, lower)

exotics occurred in lower Pool 13 main channel border (43.8 percent). Sensitive species were almost never recorded during the study period. However, two sensitive species were recorded in the lower Pool 4 side channel, one finding of *P. epihydrus* in 1999 and one of *P. alpinus* in 2000; however, these occurrences were rare and composed only 1.3 percent and 0.9 percent of the relative frequency of submersed aquatic vegetation (Appendixes F and G). Among the species composition found in the study pools, tolerant species such as *Ceratophyllum demersum, Elodea canadensis, M. spicatum, P. crispus,* and *S. pectinatus* composed a large proportion of the submersed community. Although submersed aquatic vegetation was rarely found in upper Pools 4 and 13 in all years, when submersed aquatic vegetation was present 100 percent of the occurrences were tolerant species. The relative frequency of tolerant species in the lower portion of Pools 4 and 13 was 35–67 percent and 50–85 percent, respectively. Similarly, the upper portion of Pool 8 also had a higher relative percent of tolerant species (43–100 percent) than the lower portion (50–84 percent).

Although mean abundance values could range from 0 to 30, the actual ratings ranged from 0 to 3.3 (Appendixes B and C). Side channels in lower Pool 4 in 2005 had the highest abundance values.

Habitat Quality

To compare the results of this study with those of other studies, emergent and floating-leaved species, rather than just submersed species, were included in calculations of the mean Coefficient of Conservatism, Floristic Quality Index, and Aquatic Macrophyte Community Index values (Figure 2; Appendixes F and G). A list of the species and their assigned Coefficient of Conservatism can be found in Appendix A. The mean Coefficient of Conservatism score indicates the sensitivity of the recorded species to the quality of the habitat. Lower scores would indicate the presence of species tolerant of disturbed habitats, whereas higher scores would indicate the presence of species found in less disturbed habitats. Mean Coefficient of Conservatism scores ranged from 2.5 to 5.5.

The Floristic Quality Index is similar to Coefficient of Conservatism, but it incorporates species richness and is considered an index of habitat quality. Again, lower scores indicate poorer habitat quality whereas higher scores can indicate better habitat quality. The Floristic Quality Index scores ranged from 3.0 to 23.9. In general, side channel had higher Floristic Quality Index scores than main channel border, and lower portions of each pool had higher Floristic Quality Index scores than upper portions. Side channels in lower Pools 4 and 8 had some of the highest Floristic Quality Index scores compared with other pools and strata (20-24). In this study, both Coefficient of Conservatism and Floristic Quality Index had a small range of scores and were weakly correlated to the water quality characteristics.

The Aquatic Macrophyte Community Index was the most complex index explored in this study. It incorporated seven community attributes, and low scores represent poorer quality habitat and high scores represent higher quality habitat. Similar to other attributes calculated, the lower portions of all pools scored higher than the upper portions of all pools and side channels frequently scored higher than main channel border strata. The Aquatic Macrophyte Community Index scores among strata ranged from a low of 7 in the upper portion of all study pools to a high of 49 in lower pool side channel strata of Pools 4 and 8.

Correlation of Aquatic Macrophyte and Water Quality Data

In general, nutrient levels and dissolved oxygen were similar in water in all three pools (Figure 3). Light measurements (Secchi transparency, total suspended solids, and turbidity) showed a distinct pattern. Upper Pool 4 and upper and lower Pool 13 had low Secchi transparency readings and high turbidity and suspended solids compared with lower Pool 4 and Pool 8. Lake Pepin, in Pool 4, acts as a settling basin, allowing suspended particles to drop out of the water column and, thus, improve the light regime downstream (Burdis 1997).

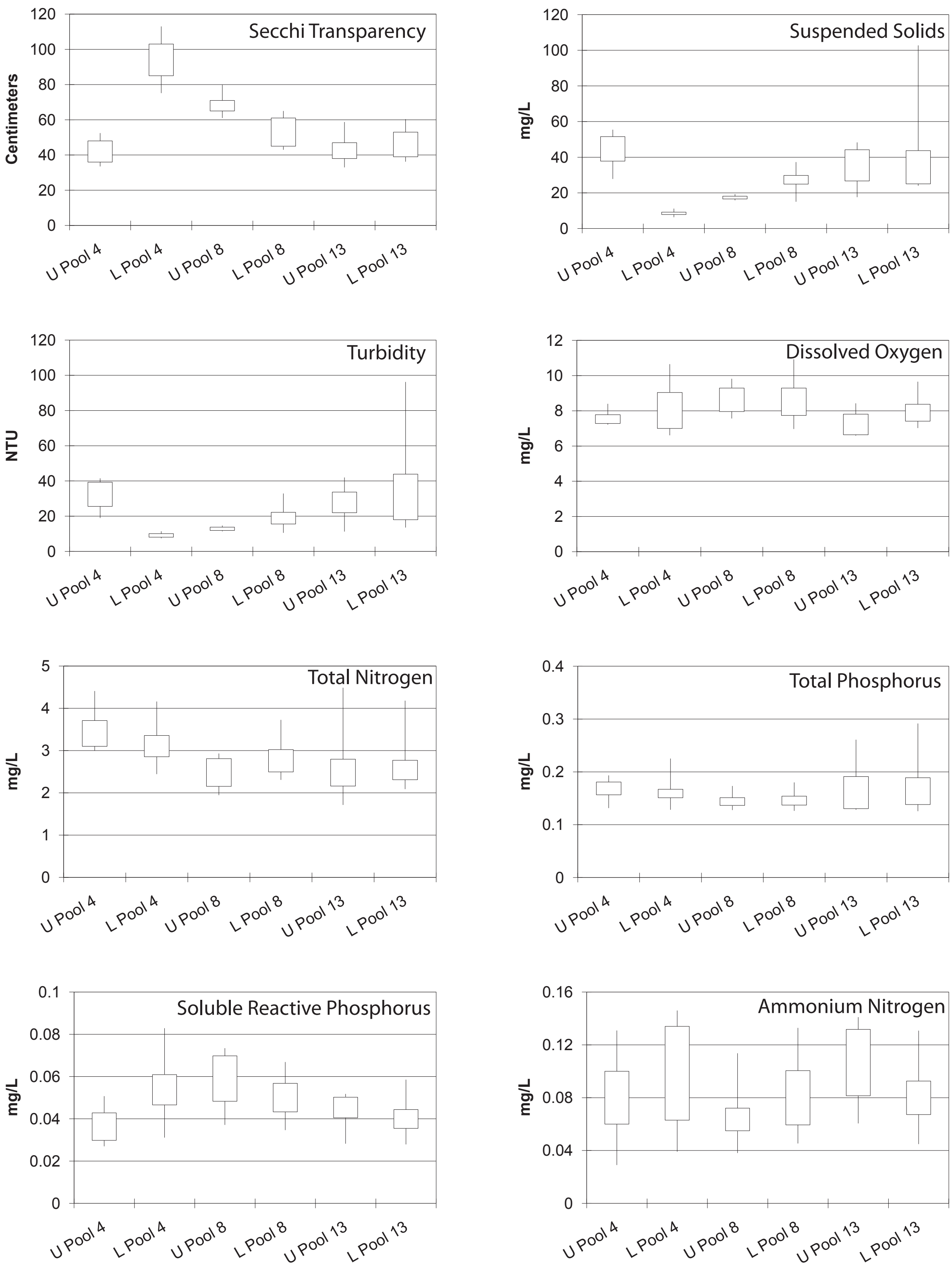

Figure 3. Maximum, 75 percentile, 25 percentile, and minimum for selected water quality measurements from selected Long Term Resource Monitoring fixed sites located in the main channel of Pools 4, 8, and 13 of the Upper Mississippi River, May 1 to July 31, 1998–2006. (NTU, nephelometric turbidtity unit; U, upper; L, lower; mg/L, milligrams per liter)

Submersed aquatic vegetation attributes were found to be correlated to light measurements but not to nutrients, indicating that aquatic vegetation in the Upper Mississippi River may be light limited, but not nutrient limited. Among the regression analyses performed, Secchi transparency had the best correlation to the macrophyte attributes in both main channel border and side channel strata (Figure 4, Table 1). In side channels, percent frequency of *V. americana* or wild celery ($r^2 = 0.50$; $p < 0.0001$)) had the best relation with Secchi transparency, followed by *P crispus* ($r^2 = 0.44$; $p < 0.0001$) and *H. dubia* ($r^2 = 0.37$; $p < 0.0001$). However, the mean number of species recorded at a site ($r^2 = 0.36$; $p < 0.0001$) had the best relation with Secchi transparency and is most correlated with water quality. Percent frequency of *P. crispus* ($r^2 = 0.29$; $p < 0.0001$) and Secchi transparency were most closely correlated in

Table 1. Correlation of macrophyte attributes to selected water-quality characteristics in side channel and main channel border strata.

[All correlations with r square values greater than 0.20 are shown, or if correlation was not greater than 0.20, then the best correlation to a water-quality measurement for each vegetation attribute based on linear regressions by strata is given. Analyses did not include species with less than 20 occurrences; all pools and years are combined; and species represent percent frequency. >, greater than; <, less than]

Attribute	Water quality measurement	Strata	r^2 value	p value
Vallisneria americana	Secchi transparency	Side channel	0.5025	<0.0001
Potamogeton crispus	Secchi transparency	Side channel	0.4385	<0.0001
Heteranthera dubia	Secchi transparency	Side channel	0.3675	<0.0001
Mean number of species recorded at a site	Secchi transparency	Side channel	0.3599	<0.0001
Maximum number of species recorded at a site	Secchi transparency	Side channel	0.3018	<0.0001
Percent frequency of submersed vegetation	Secchi transparency	Side channel	0.2905	<0.0001
Potamogeton crispus	Secchi transparency	Main channel border	0.2875	<0.0001
Elodea canadensis	Secchi transparency	Side channel	0.2819	<0.0001
Mean plant abundance	Secchi transparency	Side channel	0.2762	0.0001
Ceratophyllum demersum	Secchi transparency	Side channel	0.2711	0.0001
Vallisneria americana	Suspended solids	Side channel	0.2561	0.0002
Aquatic Macrophyte Community Index	Secchi transparency	Side channel	0.2403	0.0003
Myriophyllum spicatum	Secchi transparency	Side channel	0.2322	0.0005
Potamogeton crispus	Suspended solids	Side channel	0.2171	0.0006
Ceratophyllum demersum	Suspended solids	Side channel	0.2146	0.0006
Mean number of species recorded at a site	Suspended solids	Side channel	0.2102	0.0007
Total number of species recorded	Secchi transparency	Side channel	0.2062	0.0010
Potamogeton zosteriformis	Dissolved oxygen	Side channel	0.2049	0.0009
Potamogeton nodosus	Secchi transparency	Side channel	0.1750	0.0028
Floristic Quality Index	Secchi transparency	Side channel	0.1738	0.0029
Potamogeton foliosus/pusillus	Secchi transparency	Side channel	0.1511	0.0058
Mean Coefficient of Conservatism	Secchi transparency	Main channel border	0.1424	0.0075
Stuckenia pectinatus	Secchi transparency	Side channel	0.1375	0.0087
Relative frequency of exotic species	Secchi transparency	Side channel	0.1272	0.0119
Relative frequency of tolerant species	Ammonium nitrogen	Side channel	0.1145	0.0187

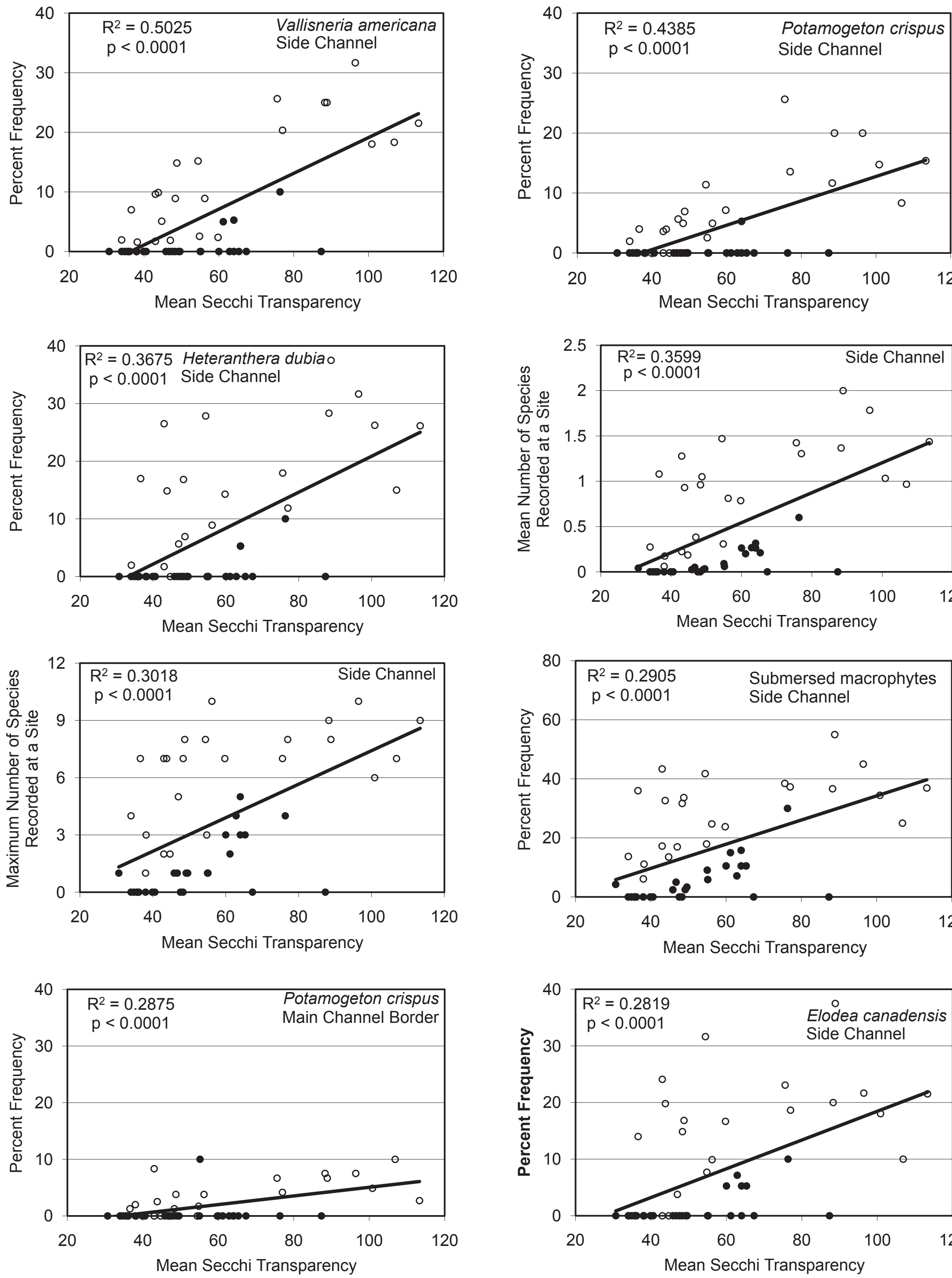

Figure 4. Selected linear regressions of macrophyte attributes and water quality measurements by strata for all years and pools combined. Water quality data represents a seasonal mean from May 1 to July 31. (Open circles indicate lower pool sites, solid circles indicate upper pool sites; Mean Secchi Transparency in centimeters)

main channel borders. Nutrients were not as well correlated to the macrophyte attributes in this analysis. The best relation was between total phosphorus and *E. canadensis* ($r^2 = 0.18$; $p = 0.0018$).

Conclusions

Prior to this study, Pool 4 strata were divided between upper and lower portions of the pool due to observed differences in submersed aquatic vegetation species richness, abundance, and frequency of occurrence. A similar pattern of submersed aquatic vegetation exists in Pools 8 and 13. Human disturbance or natural causes for this pattern may exist and may or may not be related among each of the pools, yet it is clear that conditions in upper portions of each pool are less conducive to submersed aquatic vegetation growth than conditions in lower portions of the pools. One possible reason is the influence of the locks and dams on the pools. Generally, the dams slow current velocities and reduce annual variation in water levels in the lower reaches of a pool (U.S. Geological Survey 1999), perhaps providing better conditions for submersed aquatic vegetation growth. More work is needed to determine the cause of this condition.

Nichols (2001) calculated Floristic Quality Index values for six categories of lakes during four periods in Wisconsin. Median Floristic Quality Index scores ranged from approximately 20 for Southeastern Wisconsin Till Plains Lakes to 35 for Northern Lakes and Forests Seepage Lakes. Using tests from a wide variety of habitats in Michigan, Herman et al. (1997) suggested areas with a Floristic Quality Index less than 20 were mostly degraded, whereas those with scores greater than 35 were floristically important areas from a statewide perspective. Most scores for the Mississippi River fall into the mostly degraded range. However, one standard may not be valid for all habitat types. For example, Rooney and Rogers (2002) found that sand barrens had a lower Floristic Quality Index than northern upland forests, but this did not mean the flora of the sand dunes was of a lower quality. Matthews (2003) suggested comparisons of Floristic Quality Index among different community types or sites surveyed at different times of the year may be invalid. Due to the small range of scores of Coefficient of Conservatism and Floristic Quality Index for this study and their weak correlation to the water quality measurements, these indices may not be appropriate for comparing aquatic vegetation in various portions of the Upper Mississippi River.

Nichols et al. (2000) used the Aquatic Macrophyte Community Index with lake data to compare different ecoregions of Wisconsin. Side channels in lower Pools 4 and 8 generally had Aquatic Macrophyte Community Index values similar to those in lakes in the Southeastern Wisconsin Till Plains Lakes ecoregion. All other pools and strata generally had Aquatic Macrophyte Community Index values similar to those for impoundments in the Southeastern Wisconsin Till Plains Driftless Area Lakes and Mississippi River backwater lakes ecoregion. These two ecoregions (The Southern Wisconsin Till Plains Lakes ecoregion and the Southeastern Wisconsin Till Plains Driftless Area Lakes and Mississippi River Backwater Lakes ecoregion), had the lowest median Aquatic Macrophyte Community Index scores in the Nichols study. Although Aquatic Macrophyte Community Index values for this study were low compared to those of other regions of Wisconsin, the range of scores was fairly large (7–49) and indicates that the index may be useful for comparisons within the Upper Mississippi River.

Submersed aquatic vegetation attributes were found to be correlated to light measurements but not to nutrients. One reason nutrients were not correlated may be that the water quality measurements were obtained from the surface water. In general, aquatic macrophytes obtain nutrients from the sediment rather than the water column (Denny 1972; Barko and Smart 1986). In addition, little difference in nutrient levels was found in the three pools during the years of study. Other studies have suggested nutrients may be limiting in the Upper Mississippi River under certain conditions such as sustained low flow (Rogers 1994; Rogers et al. 1995). In another study on the Upper Mississippi River, Yin and Langrehr (2005) also suggested light may be a limiting factor for submersed aquatic vegetation.

They used analysis of variance to compare the frequency of occurrence of submersed aquatic vegetation to turbidity and water-level fluctuations. They found that turbidity and water-level fluctuations accounted for 82 percent of the variability and that turbidity was a much stronger predictor than water-level fluctuations.

The results of linear regression analysis suggest wild celery may be an appropriate indicator species, whereas mean number of species recorded at a site was the attribute most correlated to water quality. An increase in the size of the study area and an assessment of the relation of aquatic macrophyte data to human disturbance in the area would enhance our knowledge of the Upper Mississippi River ecosystem. More information is needed to determine if submersed aquatic vegetation is an adequate bioindicator for assessing the condition of the Upper Mississippi River.

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Appendix A

List of submersed aquatic, floating-leaved, and emergent species encountered in main channel border and side channels of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006, species codes used in analysis, Coefficient of Conservatism assigned to each species, and species life form.

[CoC, Coefficent of Conservatism; EM, emergent; FV, floating leaved; SAV, submersed aquatic vegetation]

Scientific name	Common name	Species code	Lifeform	CoC
Acer saccharinum L.	silver maple	ACSA2	EM	2
Ceratophyllum demersum L.	coontail	CEDE4	SAV	3
Elodea canadensis Michx.	Canadian waterweed	ELCA7	SAV	3
Heteranthera dubia (Jacq.) MacMil.	water stargrass	ZODU	SAV	6
Lemna minor L.	small duckweed	LEMI3	FV	4
Lemna trisulca L.	star duckweed	LETR	FV	6
Leersia oryzoides (L.) Sw.	rice cutgrass	LEOR	EM	3
Lythrum salicaria L.	purple loosestrife	LYSA2	EM	0
Myriophyllum spicatum L.	Eurasian watermilfoil	MYSP2	SAV	0
Najas flexilis (Willd.) Rostk & Schmidt	nodding waternymph	NAFL	SAV	6
Nelumbo lutea Willd.	American lotus	NELU	FV	7
Nuphar variegata Dur.	yellow pondlily	NULU	FV	6
Nymphaea odorata Aiton	white waterlily	NYTU	FV	6
Phalaris arundinacea L.	reed canarygrass	PHAR3	EM	0
Polygonum amphibium L.	water knotweed	POAM8	EM	5
Pontederia cordata L.	pickerelweed	POCO14	EM	8
Potamogeton alpinus Balbis	alpine pondweed	POAL8	SAV	9
Potamogeton crispus L.	curly pondweed	POCR3	SAV	0
Potamogeton epihydrus Raf.	ribbon-leaf pondweed	POEP2	SAV	8
Potamogeton foliosus Raf /pusillus L.	leafy/small pondweed	NLPW	SAV	6/7
Potamogeton nodosus Poir.	longleaf pondweed	PONO2	SAV	7
Potamogeton richardsonii (Benn.)Rydb.	Richardson's pondweed	PORI2	SAV	5
Potamogeton zosteriformis Fern.	flat-stem pondweed	POZO	SAV	6
Sagittaria latifolia Willd.	broadleaf arrowhead	SALA2	EM	3
Sagittaria rigida Pursh.	stiff arrowhead	SARI	EM	8
Salix exigua Nutt.	sandbar willow	SAEX	EM	2
Schoenoplectus fluviatilis (Torr.) M.T. Strong	river bulrush	SCFL	EM	6
Schoenoplectus tabernaemontani (K.C. Gmel.) Palla	softstem bulrush	SCVA	EM	4
Sparganium eurycarpum Engelm ex Gray	giant burreed	SPEU	EM	5
Spirodela polyrhiza (L.) Schleid.	big duckweed	SPPO	FV	5
Stuckenia pectinatus (L.) Borner	sago pondweed	POPE6	SAV	3
Typha angustifolia L.	narrowleaf cattail	TYAN	EM	0
Typha latifolia L.	broadleaf cattail	TYLA	EM	1
Vallisneria americana Michx.	wild celery	VAAM3	SAV	6
Wolffia columbiana Karst.	Columbian watermeal	WOCO	FV	5
Zannichellia palustris L.	horned pondweed	ZAPA	SAV	7
Zizania aquatica L.	wild rice	ZIAQ	EM	8

Appendix B

Summary of submersed aquatic vegetation diversity attributes in main channel border areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[MCB, main channel border]

Year	Pool	Stratum	Total number of species recorded	Maximum number of species recorded at a site	Mean number of species recorded at a site	Mean plant abundance	Shannon's Diversity index	Shannon's Evenness index	Simpson's Diversity Index
1998	4	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
1998	4	MCB-Lower	4	3	0.14	0.34	1.35	0.98	0.73
1998	8	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
1998	8	MCB-Lower	7	4	0.32	0.92	1.78	0.92	0.81
1998	13	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
1998	13	MCB-Lower	6	3	0.16	0.25	1.58	0.88	0.74
1999	4	MCB-Upper	1	1	0.17	0.08	0.00	0.00	0.00
1999	4	MCB-Lower	7	4	0.50	0.58	1.81	0.93	0.82
1999	8	MCB-Upper	4	4	0.40	0.50	1.39	1.00	0.75
1999	8	MCB-Lower	6	6	0.68	1.15	1.71	0.96	0.81
1999	13	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
1999	13	MCB-Lower	4	3	0.25	0.62	1.03	0.74	0.56
2000	4	MCB-Upper	1	1	0.07	0.07	0.00	0.00	0.00
2000	4	MCB-Lower	7	6	0.50	0.53	1.75	0.90	0.80
2000	8	MCB-Upper	5	3	0.35	0.30	1.55	0.96	0.78
2000	8	MCB-Lower	8	6	0.75	1.05	1.79	0.86	0.81
2000	13	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2000	13	MCB-Lower	4	3	0.32	0.96	1.25	0.90	0.70
2001	4	MCB-Upper	1	1	0.03	0.07	0.00	0.00	0.00
2001	4	MCB-Lower	8	6	0.93	1.55	1.89	0.91	0.83
2001	8	MCB-Upper	1	1	0.05	0.05	0.00	0.00	0.00
2001	8	MCB-Lower	8	6	0.57	1.09	1.83	0.88	0.82
2001	13	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2001	13	MCB-Lower	4	4	0.30	0.81	1.31	0.94	0.71
2002	4	MCB-Upper	1	1	0.03	0.20	0.00	0.00	0.00
2002	4	MCB-Lower	7	7	0.68	0.75	1.82	0.94	0.83
2002	8	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2002	8	MCB-Lower	8	7	0.49	1.04	1.77	0.85	0.80
2002	13	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2002	13	MCB-Lower	5	5	0.20	0.35	1.41	0.88	0.71

Appendix B—Continued

Summary of submersed aquatic vegetation diversity attributes in main channel border areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[MCB, main channel border]

Year	Pool	Stratum	Total number of species recorded	Maximum number of species recorded at a site	Mean number of species recorded at a site	Mean plant abundance	Shannon's Diversity index	Shannon's Evenness index	Simpson's Diversity Index
2003	8	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2003	8	MCB-Lower	8	6	0.54	1.05	1.86	0.89	0.83
2003	13	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2003	13	MCB-Lower	5	4	0.31	0.62	1.53	0.95	0.77
2004	4	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2004	4	MCB-Lower	5	4	0.34	0.46	1.49	0.93	0.76
2004	8	MCB-Upper	1	1	0.05	0.05	0.00	0.00	0.00
2004	8	MCB-Lower	10	7	0.84	1.27	2.04	0.88	0.85
2004	13	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2004	13	MCB-Lower	6	3	0.36	0.44	1.57	0.87	0.75
2005	4	MCB-Upper	1	1	0.05	0.05	0.00	0.00	0.00
2005	4	MCB-Lower	8	8	0.50	0.90	2.03	0.97	0.86
2005	8	MCB-Upper	2	1	0.17	0.28	0.64	0.92	0.44
2005	8	MCB-Lower	10	6	1.00	1.83	2.11	0.92	0.86
2005	13	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2005	13	MCB-Lower	7	5	0.53	1.07	1.77	0.91	0.82
2006	4	MCB-Upper	1	1	0.05	0.05	0.00	0.00	0.00
2006	4	MCB-Lower	7	6	0.40	0.57	1.86	0.96	0.83
2006	8	MCB-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2006	8	MCB-Lower	10	7	1.14	1.72	2.13	0.92	0.87
2006	13	MCB-Upper	1	1	0.06	0.06	0.00	0.00	0.00
2006	13	MCB-Lower	7	7	0.84	1.24	1.88	0.97	0.84

Appendix C

Summary of submersed aquatic vegetation diversity attributes in side channel areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[SC, side channel]

Year	Pool	Stratum	Total number of species recorded	Maximum number of species recorded at a site	Mean number of species recorded at a site	Mean plant abundance	Shannon's Diversity index	Shannon's Evenness index	Simpson's Diversity Index
1998	4	SC-Upper	1	1	0.04	0.04	0.00	0.00	0.00
1998	4	SC-Lower	10	9	1.44	2.08	2.20	0.95	0.88
1998	8	SC-Upper	4	4	0.27	0.47	1.39	1.00	0.75
1998	8	SC-Lower	12	8	1.47	2.45	2.21	0.89	0.87
1998	13	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
1998	13	SC-Lower	7	5	0.38	0.45	1.83	0.94	0.82
1999	4	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
1999	4	SC-Lower	11	8	1.31	1.36	2.19	0.92	0.88
1999	8	SC-Upper	1	1	0.06	0.06	0.00	0.00	0.00
1999	8	SC-Lower	11	7	1.28	1.78	2.11	0.88	0.86
1999	13	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
1999	13	SC-Lower	8	4	0.27	0.33	1.77	0.85	0.77
2000	4	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2000	4	SC-Lower	11	10	1.78	2.10	2.21	0.92	0.88
2000	8	SC-Upper	3	2	0.20	0.30	1.04	0.95	0.63
2000	8	SC-Lower	11	7	1.08	1.36	2.18	0.91	0.87
2000	13	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2000	13	SC-Lower	3	1	0.06	0.02	1.10	1.00	0.67
2001	4	SC-Upper	1	1	0.03	0.03	0.00	0.00	0.00
2001	4	SC-Lower	11	9	1.37	1.58	2.03	0.85	0.85
2001	8	SC-Upper	4	3	0.26	0.16	1.33	0.96	0.72
2001	8	SC-Lower	12	10	0.81	0.93	2.26	0.91	0.88
2001	13	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2001	13	SC-Lower	5	2	0.22	0.38	1.31	0.81	0.67
2002	4	SC-Upper	1	1	0.05	0.10	0.00	0.00	0.00
2002	4	SC-Lower	10	7	0.97	1.02	2.13	0.92	0.87
2002	8	SC-Upper	3	3	0.26	0.21	0.95	0.86	0.56
2002	8	SC-Lower	11	7	0.93	1.45	2.19	0.91	0.87
2002	13	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2002	13	SC-Lower	5	3	0.17	0.27	1.47	0.91	0.74

Summary of submersed aquatic vegetation diversity attributes in side channel areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[SC, side channel]

Year	Pool	Stratum	Total number of species recorded	Maximum number of species recorded at a site	Mean number of species recorded at a site	Mean plant abundance	Shannon's Diversity index	Shannon's Evenness index	Simpson's Diversity Index
2003	8	SC-Upper	3	3	0.21	0.11	1.04	0.95	0.63
2003	8	SC-Lower	12	7	0.96	1.60	2.20	0.88	0.87
2003	13	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2003	13	SC-Lower	7	4	0.27	0.38	1.63	0.83	0.74
2004	4	SC-Upper	1	1	0.02	0.02	0.00	0.00	0.00
2004	4	SC-Lower	11	6	1.03	1.46	2.03	0.85	0.84
2004	8	SC-Upper	6	5	0.32	0.16	1.79	1.00	0.83
2004	8	SC-Lower	10	8	1.05	1.36	2.18	0.95	0.87
2004	13	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2004	13	SC-Lower	4	2	0.19	0.47	1.24	0.89	0.68
2005	4	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2005	4	SC-Lower	10	7	1.43	3.31	2.15	0.93	0.87
2005	8	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2005	8	SC-Lower	10	6	1.41	2.25	2.13	0.93	0.86
2005	13	SC-Upper	1	1	0.09	0.09	0.00	0.00	0.00
2005	13	SC-Lower	7	3	0.31	0.49	1.82	0.94	0.82
2006	4	SC-Upper	1	1	0.03	0.03	0.00	0.00	0.00
2006	4	SC-Lower	10	8	2.00	2.95	2.14	0.93	0.87
2006	8	SC-Upper	4	4	0.60	0.70	1.24	0.90	0.67
2006	8	SC-Lower	9	7	1.78	2.87	2.12	0.97	0.87
2006	13	SC-Upper	0	0	0.00	0.00	0.00	0.00	0.00
2006	13	SC-Lower	8	7	0.79	1.31	1.96	0.94	0.85

Appendix D

Summary of percent frequency of species recorded in main channel border areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[See Appendix A for species codes. MCB, main channel border; SAV, submersed aquatic vegetation]

Year	Pool	Stratum	Percent frequency of sites with							
			CEDE4	ELCA7	MYSP2	NAFL	NLPW	POAL8	POCR3	POEP2
1998	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	4	MCB-Lower	0.00	0.00	0.00	0.00	0.00	0.00	2.70	0.00
1998	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	8	MCB-Lower	6.12	4.08	2.04	0.00	0.00	0.00	0.00	0.00
1998	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	13	MCB-Lower	2.08	2.08	2.08	0.00	0.00	0.00	0.00	0.00
1999	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	4	MCB-Lower	2.08	4.17	0.00	0.00	0.00	0.00	4.17	0.00
1999	8	MCB-Upper	0.00	10.00	0.00	0.00	10.00	0.00	10.00	0.00
1999	8	MCB-Lower	5.00	8.33	0.00	0.00	0.00	0.00	8.33	0.00
1999	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	13	MCB-Lower	0.00	0.00	5.66	0.00	0.00	0.00	0.00	0.00
2000	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	4	MCB-Lower	2.50	5.00	0.00	0.00	0.00	0.00	7.50	0.00
2000	8	MCB-Upper	0.00	0.00	5.00	0.00	5.00	0.00	0.00	0.00
2000	8	MCB-Lower	6.33	13.92	3.80	0.00	0.00	0.00	1.27	0.00
2000	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	13	MCB-Lower	0.00	0.00	12.00	0.00	0.00	0.00	2.00	0.00
2001	4	MCB-Upper	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	4	MCB-Lower	7.50	15.00	0.00	0.00	5.00	0.00	7.50	0.00
2001	8	MCB-Upper	4.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	8	MCB-Lower	11.39	2.53	0.00	0.00	0.00	0.00	3.80	0.00
2001	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	13	MCB-Lower	0.00	0.00	5.56	0.00	0.00	0.00	0.00	0.00
2002	4	MCB-Upper	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	4	MCB-Lower	5.00	7.50	2.50	0.00	0.00	0.00	10.00	0.00
2002	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	8	MCB-Lower	3.80	5.06	1.27	0.00	1.27	0.00	2.53	0.00
2002	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	13	MCB-Lower	0.00	1.85	3.70	0.00	0.00	0.00	0.00	0.00
2003	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	8	MCB-Lower	6.41	6.41	3.85	0.00	0.00	0.00	1.28	0.00
2003	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	13	MCB-Lower	1.92	0.00	5.77	0.00	0.00	0.00	0.00	0.00

Appendix D—Continued

Summary of percent frequency of species recorded in main channel border areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[See Appendix A for species codes. MCB, main channel border; SAV, submersed aquatic vegetation]

			Percent frequency of sites with							
Year	Pool	Stratum	PONO2	POPE6	POR12	POZO	VAAM3	ZAPA	ZODU	SAV
1998	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	4	MCB-Lower	0.00	5.41	0.00	0.00	5.41	0.00	5.41	10.81
1998	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	8	MCB-Lower	0.00	8.16	0.00	0.00	12.24	2.04	6.12	22.45
1998	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	13	MCB-Lower	0.00	8.33	0.00	0.00	2.08	0.00	2.08	12.50
1999	4	MCB-Upper	0.00	16.67	0.00	0.00	0.00	0.00	0.00	16.67
1999	4	MCB-Lower	0.00	10.42	0.00	0.00	10.42	6.25	12.50	20.83
1999	8	MCB-Upper	0.00	10.00	0.00	0.00	0.00	0.00	0.00	10.00
1999	8	MCB-Lower	0.00	16.67	0.00	0.00	16.67	0.00	13.33	28.33
1999	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	13	MCB-Lower	0.00	15.09	0.00	0.00	1.89	0.00	1.89	15.09
2000	4	MCB-Upper	0.00	6.67	0.00	0.00	0.00	0.00	0.00	6.67
2000	4	MCB-Lower	2.50	5.00	0.00	0.00	12.50	0.00	15.00	22.50
2000	8	MCB-Upper	0.00	10.00	0.00	0.00	10.00	0.00	5.00	25.00
2000	8	MCB-Lower	0.00	13.92	1.27	0.00	18.99	0.00	16.46	31.65
2000	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	13	MCB-Lower	0.00	8.00	0.00	0.00	10.00	0.00	0.00	20.00
2001	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33
2001	4	MCB-Lower	0.00	10.00	2.50	0.00	22.50	0.00	22.50	25.00
2001	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.76
2001	8	MCB-Lower	0.00	15.19	1.27	2.53	10.13	0.00	10.13	31.65
2001	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	13	MCB-Lower	0.00	11.11	0.00	0.00	9.26	0.00	3.70	12.96
2002	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33
2002	4	MCB-Lower	0.00	15.00	0.00	0.00	15.00	0.00	12.50	20.00
2002	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	8	MCB-Lower	0.00	13.92	0.00	0.00	7.59	0.00	13.92	22.78
2002	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	13	MCB-Lower	0.00	9.26	0.00	0.00	3.70	0.00	1.85	11.11
2003	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	8	MCB-Lower	1.28	12.82	0.00	0.00	10.26	0.00	11.54	20.51
2003	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	13	MCB-Lower	0.00	7.69	0.00	0.00	7.69	0.00	7.69	9.62

Appendix D—Continued

Summary of percent frequency of species recorded in main channel border areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[See Appendix A for species codes. MCB, main channel border; SAV, submersed aquatic vegetation]

			Percent frequency of sites with							
Year	Pool	Stratum	CEDE4	ELCA7	MYSP2	NAFL	NLPW	POAL8	POCR3	POEP2
2004	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	4	MCB-Lower	0.00	0.00	0.00	0.00	2.44	0.00	4.88	0.00
2004	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	8	MCB-Lower	13.92	17.72	2.53	0.00	3.80	0.00	3.80	0.00
2004	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	13	MCB-Lower	2.00	2.00	6.00	0.00	0.00	0.00	0.00	0.00
2005	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	4	MCB-Lower	6.67	10.00	3.33	0.00	0.00	0.00	6.67	0.00
2005	8	MCB-Upper	0.00	11.11	5.56	0.00	0.00	0.00	0.00	0.00
2005	8	MCB-Lower	7.69	19.23	9.62	0.00	3.85	0.00	5.77	0.00
2005	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	13	MCB-Lower	1.72	12.07	6.90	0.00	0.00	0.00	1.72	0.00
2006	4	MCB-Upper	0.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00
2006	4	MCB-Lower	6.67	6.67	3.33	0.00	0.00	0.00	6.67	0.00
2006	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	8	MCB-Lower	12.00	16.00	6.00	0.00	8.00	0.00	8.00	0.00
2006	13	MCB-Upper	5.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	13	MCB-Lower	12.70	12.70	12.70	0.00	3.17	0.00	0.00	0.00

Appendix D—Continued

Summary of percent frequency of species recorded in main channel border areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[See Appendix A for species codes. MCB, main channel border; SAV, submersed aquatic vegetation]

Year	Pool	Stratum	Percent frequency of sites with							
			PONO2	POPE6	POR12	POZO	VAAM3	ZAPA	ZODU	SAV
2004	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	4	MCB-Lower	0.00	7.32	0.00	0.00	12.20	0.00	7.32	17.07
2004	8	MCB-Upper	0.00	4.76	0.00	0.00	0.00	0.00	0.00	4.76
2004	8	MCB-Lower	2.53	15.19	0.00	1.27	12.66	0.00	10.13	26.58
2004	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	13	MCB-Lower	0.00	8.00	0.00	0.00	14.00	0.00	4.00	22.00
2005	4	MCB-Upper	0.00	5.00	0.00	0.00	0.00	0.00	0.00	5.00
2005	4	MCB-Lower	0.00	6.67	0.00	6.67	6.67	0.00	3.33	10.00
2005	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.67
2005	8	MCB-Lower	0.00	15.38	3.85	0.00	15.38	1.92	17.31	28.85
2005	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	13	MCB-Lower	0.00	12.07	0.00	0.00	8.62	0.00	10.34	17.24
2006	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00
2006	4	MCB-Lower	0.00	0.00	0.00	3.33	10.00	0.00	3.33	10.00
2006	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	8	MCB-Lower	0.00	20.00	2.00	4.00	16.00	0.00	22.00	28.00
2006	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.88
2006	13	MCB-Lower	0.00	12.70	0.00	0.00	14.29	0.00	15.87	26.98

Appendix E

Summary of percent frequency of species recorded in side channel areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[See Appendix A for species codes. SC, side channel; SAV, submersed aquatic vegetation]

			Percent frequency of sites with							
Year	Pool	Stratum	CEDE4	ELCA7	MYSP2	NAFL	NLPW	POAL8	POCR3	POEP2
1998	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	4	SC-Lower	20.00	21.54	12.31	0.00	6.15	0.00	15.38	0.00
1998	8	SC-Upper	7.14	7.14	0.00	0.00	7.14	0.00	0.00	0.00
1998	8	SC-Lower	20.25	31.65	10.13	0.00	10.13	0.00	11.39	0.00
1998	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	13	SC-Lower	9.43	3.77	5.66	0.00	0.00	0.00	5.66	0.00
1999	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	4	SC-Lower	20.34	18.64	8.47	0.00	5.08	0.00	13.56	1.69
1999	8	SC-Upper	5.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	8	SC-Lower	20.48	24.10	12.05	0.00	3.61	0.00	3.61	0.00
1999	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	13	SC-Lower	3.92	0.00	1.96	0.00	1.96	0.00	1.96	0.00
2000	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	4	SC-Lower	16.67	21.67	15.00	0.00	5.00	1.67	20.00	0.00
2000	8	SC-Upper	0.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00
2000	8	SC-Lower	22.00	14.00	9.00	0.00	13.00	0.00	4.00	0.00
2000	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	13	SC-Lower	2.04	0.00	2.04	0.00	0.00	0.00	0.00	0.00
2001	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	4	SC-Lower	26.67	20.00	5.00	1.67	1.67	0.00	11.67	0.00
2001	8	SC-Upper	10.53	5.26	5.26	0.00	0.00	0.00	0.00	0.00
2001	8	SC-Lower	14.85	9.90	1.98	0.99	9.90	0.00	4.95	0.00
2001	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	13	SC-Lower	6.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	4	SC-Lower	18.33	10.00	8.33	0.00	8.33	0.00	8.33	0.00
2002	8	SC-Upper	15.79	0.00	0.00	0.00	5.26	0.00	0.00	0.00
2002	8	SC-Lower	14.85	19.80	4.95	0.00	5.94	0.00	3.96	0.00
2002	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	13	SC-Lower	4.76	0.00	1.59	0.00	0.00	0.00	0.00	0.00
2003	8	SC-Upper	10.53	5.26	0.00	0.00	5.26	0.00	0.00	0.00
2003	8	SC-Lower	20.79	14.85	3.96	0.99	7.92	0.00	4.95	0.00
2003	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	13	SC-Lower	11.67	1.67	0.00	0.00	0.00	0.00	1.67	0.00

Appendix E—Continued

Summary of percent frequency of species recorded in side channel areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[See Appendix A for species codes. SC, side channel; SAV, submersed aquatic vegetation]

			Percent frequency of sites with							
Year	Pool	Stratum	PONO2	POPE6	POR12	POZO	VAAM3	ZAPA	ZODU	SAV
1998	4	SC-Upper	0.00	4.26	0.00	0.00	0.00	0.00	0.00	4.26
1998	4	SC-Lower	7.69	20.00	0.00	6.15	21.54	0.00	26.15	36.92
1998	8	SC-Upper	0.00	0.00	0.00	7.14	0.00	0.00	0.00	7.14
1998	8	SC-Lower	2.53	17.72	1.27	8.86	15.19	1.27	27.85	41.77
1998	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	13	SC-Lower	0.00	11.32	0.00	0.00	1.89	0.00	5.66	16.98
1999	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	4	SC-Lower	8.47	20.34	0.00	0.00	20.34	1.69	11.86	37.29
1999	8	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.88
1999	8	SC-Lower	4.82	16.87	1.20	4.82	9.64	0.00	26.51	43.37
1999	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	13	SC-Lower	1.96	11.76	0.00	0.00	1.96	0.00	1.96	13.73
2000	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	4	SC-Lower	11.67	16.67	0.00	6.67	31.67	0.00	31.67	45.00
2000	8	SC-Upper	0.00	10.00	0.00	0.00	5.00	0.00	0.00	15.00
2000	8	SC-Lower	2.00	11.00	0.00	8.00	7.00	1.00	17.00	36.00
2000	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	13	SC-Lower	2.04	0.00	0.00	0.00	0.00	0.00	0.00	6.12
2001	4	SC-Upper	2.50	0.00	0.00	0.00	0.00	0.00	0.00	2.50
2001	4	SC-Lower	1.67	11.67	0.00	3.33	25.00	0.00	28.33	36.67
2001	8	SC-Upper	0.00	5.26	0.00	0.00	0.00	0.00	0.00	10.53
2001	8	SC-Lower	3.96	10.89	0.00	4.95	8.91	0.99	8.91	24.75
2001	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	13	SC-Lower	1.72	10.34	0.00	0.00	1.72	0.00	1.72	17.24
2002	4	SC-Upper	0.00	5.00	0.00	0.00	0.00	0.00	0.00	5.00
2002	4	SC-Lower	1.67	5.00	0.00	3.33	18.33	0.00	15.00	25.00
2002	8	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	5.26	15.79
2002	8	SC-Lower	3.96	7.92	0.00	5.94	9.90	0.99	14.85	32.67
2002	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	13	SC-Lower	3.17	6.35	0.00	0.00	1.59	0.00	0.00	11.11
2003	8	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.53
2003	8	SC-Lower	2.97	4.95	0.00	7.92	8.91	0.99	16.83	31.68
2003	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	13	SC-Lower	1.67	3.33	0.00	0.00	5.00	0.00	1.67	15.00

Appendix E—Continued

Summary of percent frequency of species recorded in side channel areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[See Appendix A for species codes. SC, side channel; SAV, submersed aquatic vegetation]

			Percent frequency of sites with							
Year	Pool	Stratum	CEDE4	ELCA7	MYSP2	NAFL	NLPW	POAL8	POCR3	POEP2
2004	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	4	SC-Lower	8.20	18.03	1.64	0.00	4.92	0.00	14.75	0.00
2004	8	SC-Upper	5.26	5.26	0.00	0.00	0.00	0.00	5.26	0.00
2004	8	SC-Lower	20.79	16.83	7.92	0.00	6.93	0.00	6.93	0.00
2004	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	13	SC-Lower	3.39	0.00	0.00	0.00	1.69	0.00	0.00	0.00
2005	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	4	SC-Lower	15.38	23.08	7.69	0.00	10.26	0.00	25.64	0.00
2005	8	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	8	SC-Lower	19.64	35.71	12.50	0.00	14.29	0.00	10.71	0.00
2005	13	SC-Upper	9.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	13	SC-Lower	5.13	7.69	2.56	0.00	2.56	0.00	2.56	0.00
2006	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	4	SC-Lower	25.00	37.50	15.00	0.00	12.50	0.00	20.00	0.00
2006	8	SC-Upper	30.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	8	SC-Lower	25.45	36.36	12.73	0.00	16.36	0.00	9.09	0.00
2006	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	13	SC-Lower	11.90	16.67	9.52	0.00	4.76	0.00	7.14	0.00

Appendix E—Continued

Summary of percent frequency of species recorded in side channel areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[See Appendix A for species codes. SC, side channel; SAV, submersed aquatic vegetation]

			Percent frequency of sites with							
Year	Pool	Stratum	PONO2	POPE6	POR12	POZO	VAAM3	ZAPA	ZODU	SAV
2004	4	SC-Upper	0.00	2.44	0.00	0.00	0.00	0.00	0.00	2.44
2004	4	SC-Lower	1.64	8.20	0.00	1.64	18.03	1.64	26.23	34.43
2004	8	SC-Upper	0.00	0.00	0.00	5.26	5.26	0.00	5.26	10.53
2004	8	SC-Lower	2.97	7.92	0.00	12.87	14.85	0.00	6.93	33.66
2004	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	13	SC-Lower	0.00	8.47	0.00	0.00	5.08	0.00	0.00	13.56
2005	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	4	SC-Lower	2.56	7.69	0.00	10.26	25.64	0.00	17.95	38.46
2005	8	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	8	SC-Lower	1.79	10.71	0.00	14.29	7.14	0.00	14.29	37.50
2005	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.09
2005	13	SC-Lower	0.00	7.69	0.00	0.00	2.56	0.00	0.00	17.95
2006	4	SC-Upper	0.00	3.33	0.00	0.00	0.00	0.00	0.00	3.33
2006	4	SC-Lower	2.50	15.00	0.00	10.00	25.00	0.00	37.50	55.00
2006	8	SC-Upper	0.00	0.00	0.00	0.00	10.00	0.00	10.00	30.00
2006	8	SC-Lower	0.00	16.36	0.00	18.18	16.36	0.00	27.27	49.09
2006	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	13	SC-Lower	0.00	11.90	0.00	0.00	2.38	0.00	14.29	23.81

Appendix F

Summary of relative frequency of exotic, tolerant, and sensitive species recorded and Coefficient of Conservatism, Floristic Quality Index, and Aquatic Macrophyte Community Index values for main channel border areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[CoC, Coefficient of Conservatism; FQI, Floristic Quality Index; and AMCI, Aquatic Macrophyte Community Index. The CoC, FQI, and AMCI included floating-leaved and emergent species as well as submersed species. MCB, main channel border]

Year	Pool	Stratum	Relative frequency of exotic species	Relative frequency of tolerant species	Relative frequency of sensitive species	Mean CoC	FQI	AMCI
1998	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
1998	4	MCB-Lower	14.29	42.86	0.00	5.00	8.66	16
1998	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
1998	8	MCB-Lower	5.00	50.00	0.00	4.89	14.67	34
1998	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
1998	13	MCB-Lower	11.11	77.78	0.00	4.20	9.39	18
1999	4	MCB-Upper	0.00	100.00	0.00	3.00	5.20	21
1999	4	MCB-Lower	8.33	41.67	0.00	4.67	14.00	30
1999	8	MCB-Upper	25.00	75.00	0.00	4.00	8.00	22
1999	8	MCB-Lower	12.20	56.10	0.00	4.29	11.34	28
1999	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
1999	13	MCB-Lower	23.08	84.62	0.00	4.50	9.00	18
2000	4	MCB-Upper	0.00	100.00	0.00	3.50	4.95	13
2000	4	MCB-Lower	15.00	40.00	0.00	4.67	11.43	23
2000	8	MCB-Upper	14.29	42.86	0.00	5.25	10.50	25
2000	8	MCB-Lower	6.67	51.67	0.00	4.40	13.91	37
2000	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
2000	13	MCB-Lower	43.75	68.75	0.00	4.50	6.36	15
2001	4	MCB-Upper	0.00	100.00	0.00	3.00	3.00	20
2001	4	MCB-Lower	8.11	43.24	0.00	4.75	13.44	27
2001	8	MCB-Upper	0.00	100.00	0.00	2.50	3.54	20
2001	8	MCB-Lower	6.67	57.78	0.00	4.54	16.36	45
2001	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
2001	13	MCB-Lower	18.75	56.25	0.00	4.00	12.00	26
2002	4	MCB-Upper	0.00	100.00	0.00	3.00	3.00	23
2002	4	MCB-Lower	18.52	59.26	0.00	4.50	11.02	26
2002	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
2002	8	MCB-Lower	7.69	53.85	0.00	4.58	15.88	34
2002	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
2002	13	MCB-Lower	18.18	72.73	0.00	4.50	9.00	17

Appendix F—Continued

Summary of relative frequency of exotic, tolerant, and sensitive species recorded and Coefficient of Conservatism, Floristic Quality Index, and Aquatic Macrophyte Community Index values for main channel border areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[CoC, Coefficient of Conservatism; FQI, Floristic Quality Index; and AMCI, Aquatic Macrophyte Community Index. The CoC, FQI, and AMCI included floating-leaved and emergent species as well as submersed species. MCB, main channel border]

Year	Pool	Stratum	Relative frequency of exotic species	Relative frequency of tolerant species	Relative frequency of sensitive species	Mean CoC	FQI	AMCI
2003	8	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
2003	8	MCB-Lower	9.52	57.14	0.00	4.83	16.74	36
2003	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
2003	13	MCB-Lower	18.75	50.00	0.00	4.50	12.73	34
2004	4	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
2004	4	MCB-Lower	14.29	35.71	0.00	5.25	10.50	18
2004	8	MCB-Upper	0.00	100.00	0.00	3.00	3.00	20
2004	8	MCB-Lower	7.58	63.64	0.00	5.00	18.71	40
2004	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
2004	13	MCB-Lower	16.67	50.00	0.00	4.00	10.58	26
2005	4	MCB-Upper	0.00	100.00	0.00	3.00	3.00	20
2005	4	MCB-Lower	20.00	66.67	0.00	4.50	11.02	29
2005	8	MCB-Upper	33.33	100.00	0.00	3.75	7.50	20
2005	8	MCB-Lower	15.38	57.69	0.00	4.79	17.91	38
2005	13	MCB-Upper	0.00	0.00	0.00	0.00	0.00	7
2005	13	MCB-Lower	16.13	64.52	0.00	3.89	11.67	32
2006	4	MCB-Upper	0.00	0.00	0.00	4.50	6.36	16
2006	4	MCB-Lower	25.00	58.33	0.00	4.50	12.73	34
2006	8	MCB-Upper	0.00	0.00	0.00	4.50	6.36	16
2006	8	MCB-Lower	12.28	54.39	0.00	5.00	17.32	40
2006	13	MCB-Upper	0.00	100.00	0.00	3.00	3.00	22
2006	13	MCB-Lower	15.09	60.38	0.00	4.20	13.28	36

Appendix G

Summary of relative frequency of exotic, tolerant, and sensitive species recorded and Coefficient of Conservatism, Floristic Quality Index, and Aquatic Macrophyte Community Index values in side channel areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[CoC, Coefficient of Conservatism; FQI, Floristic Quality Index; and AMCI, Aquatic Macrophyte Community Index. The CoC, FQI, and AMCI included floating-leaved and emergent species as well as submersed species. SC, side channel border]

Year	Pool	Stratum	Relative frequency of exotic species	Relative frequency of tolerant species	Relative frequency of sensitive species	Mean CoC	FQI	AMCI
1998	4	SC-Upper	0.00	100.00	0.00	3.80	8.50	16
1998	4	SC-Lower	17.65	56.86	0.00	4.88	19.50	45
1998	8	SC-Upper	0.00	50.00	0.00	5.00	14.14	33
1998	8	SC-Lower	13.39	58.27	0.00	5.29	21.83	48
1998	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	7
1998	13	SC-Lower	26.09	82.61	0.00	4.36	14.47	32
1999	4	SC-Upper	0.00	0.00	0.00	4.00	6.93	15
1999	4	SC-Lower	16.88	62.34	1.30	5.50	20.58	43
1999	8	SC-Upper	0.00	100.00	0.00	4.00	5.66	10
1999	8	SC-Lower	12.26	60.38	0.00	5.18	21.34	47
1999	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	7
1999	13	SC-Lower	14.29	71.43	0.00	4.63	13.08	28
2000	4	SC-Upper	0.00	0.00	0.00	3.00	3.00	11
2000	4	SC-Lower	19.63	50.47	0.93	5.31	21.25	49
2000	8	SC-Upper	25.00	75.00	0.00	4.40	9.84	23
2000	8	SC-Lower	12.04	55.56	0.00	5.31	21.25	45
2000	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	7
2000	13	SC-Lower	33.33	66.67	0.00	4.60	10.29	16
2001	4	SC-Upper	0.00	0.00	0.00	5.00	7.07	16
2001	4	SC-Lower	12.20	54.88	0.00	4.75	19.00	45
2001	8	SC-Upper	20.00	100.00	0.00	3.50	7.00	21
2001	8	SC-Lower	8.54	52.44	0.00	5.35	22.07	45
2001	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	7
2001	13	SC-Lower	0.00	76.92	0.00	4.46	16.09	31
2002	4	SC-Upper	0.00	100.00	0.00	3.00	3.00	20
2002	4	SC-Lower	17.24	51.72	0.00	5.47	23.86	42
2002	8	SC-Upper	0.00	60.00	0.00	5.00	8.66	17
2002	8	SC-Lower	9.57	55.32	0.00	5.11	22.25	42
2002	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	7
2002	13	SC-Lower	9.09	72.73	0.00	4.56	13.67	25

Appendix G—Continued

Summary of relative frequency of exotic, tolerant, and sensitive species recorded and Coefficient of Conservatism, Floristic Quality Index, and Aquatic Macrophyte Community Index values in side channel areas of Pools 4, 8, and 13 of the Upper Mississippi River in 1998–2006.

[CoC, Coefficient of Conservatism; FQI, Floristic Quality Index; and AMCI, Aquatic Macrophyte Community Index. The CoC, FQI, and AMCI included floating-leaved and emergent species as well as submersed species. SC, side channel border]

Year	Pool	Stratum	Relative frequency of exotic species	Relative frequency of tolerant species	Relative frequency of sensitive species	Mean CoC	FQI	AMCI
2003	8	SC-Upper	0.00	75.00	0.00	4.25	8.50	30
2003	8	SC-Lower	9.28	51.55	0.00	5.15	23.03	41
2003	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	7
2003	13	SC-Lower	6.25	68.75	0.00	4.73	15.68	25
2004	4	SC-Upper	0.00	100.00	0.00	4.00	8.94	16
2004	4	SC-Lower	15.63	48.44	0.00	5.22	15.67	33
2004	8	SC-Upper	16.67	50.00	0.00	4.43	11.72	32
2004	8	SC-Lower	14.15	57.55	0.00	5.12	21.10	49
2004	13	SC-Upper	0.00	0.00	0.00	0.00	0.00	7
2004	13	SC-Lower	0.00	63.64	0.00	4.10	12.97	26
2005	4	SC-Upper	0.00	0.00	0.00	0.00	0.00	7
2005	4	SC-Lower	22.81	54.39	0.00	5.47	21.17	47
2005	8	SC-Upper	0.00	0.00	0.00	0.00	0.00	7
2005	8	SC-Lower	16.46	63.29	0.00	5.00	20.62	46
2005	13	SC-Upper	0.00	100.00	0.00	3.00	4.24	23
2005	13	SC-Lower	16.67	83.33	0.00	4.44	13.33	31
2006	4	SC-Upper	0.00	100.00	0.00	3.67	6.35	17
2006	4	SC-Lower	17.50	56.25	0.00	5.41	22.31	48
2006	8	SC-Upper	0.00	66.67	0.00	4.50	11.02	33
2006	8	SC-Lower	12.24	56.12	0.00	5.00	20.00	49
2006	13	SC-Upper	0.00	0.00	0.00	3.00	3.00	16
2006	13	SC-Lower	21.21	72.73	0.00	4.91	16.28	33

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13. ABSTRACT (Maximum 200 words) We explored the potential for using aquatic macrophytes as a bioindicator on the Upper Mississippi River (UMR) by using submersed aquatic vegetation (SAV) and water quality data collected through the Long Term Resource Monitoring Program (LTRMP) in UMR Pools 4, 8, and 13. We used data from two strata, the main channel border and the side channel, because they are conducive to rapid data collection and are closely linked to tributary impacts. Several aquatic macrophyte attributes were calculated using the LTRMP data set. These included percent frequency, relative frequency of exotic, sensitive, and tolerant species, plant abundance, species richness, Simpson's Index of Diversity, Shannon's Diversity and Evenness Index, mean Coefficient of Conservatism, Floristic Quality Index, and the Aquatic Macrophyte Community Index. Simple linear regressions using LTRMP fixed site water quality data with the aquatic macrophyte attributes were performed to determine if these attributes correlate with water quality measurements. The SAV attributes were found to be correlated to light measurements but not to nutrients indicating the UMR may be light limited, but not nutrient limited, for SAV. Linear regression analysis suggests wild celery may be an appropriate indicator species whereas mean number of species recorded at a site was the most correlated attribute.			
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Assessment of the Use of Submersed Aquatic Vegetation Data as a Bioindicator for the Upper Mississippi River 2008-T003

The Long Term Resource Monitoring Program (LTRMP) for the Upper Mississippi River System was authorized under the Water Resources Development Act of 1986 as an element of the Environmental Management Program. The mission of the LTRMP is to provide river managers with information for maintaining the Upper Mississippi River System as a sustainable large river ecosystem given its multiple-use character. The LTRMP is a cooperative effort by the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin.