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Submersed Aquatic Vegetation Trends in Impounded and Backwater Habitat Types of Pool 13, Upper Mississippi River System: 1994–2000

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Submersed aquatic vegetation (SAV) was sampled from 1994–2000 at fixed sites along established transects in Pool 13 of the Upper Mississippi River System (UMRS), as part of the Long Term Resource Monitoring Program (LTRMP). These data were used to quantify the annual percent frequency of occurrence and mean relative density of SAV within three backwaters (Brown's Lake, Savanna Bay, and Spring Lake) and the impounded area of Pool 13. This investigation used Spearman rank correlation to assess the strength of bivariate relationships between measurements of SAV abundance and biological, physical, and hydrological variables at fixed water quality monitoring sites within vegetation monitoring areas. In backwater habitats, the percent frequency of occurrence and mean relative density of SAV exhibited significant negative correlations ($P < 0.05$) with May–August median turbidity and mean velocity. Mean velocity and median turbidity were strongly correlated, which suggested that water inputs from channel habitats caused observed differences in water clarity, as well as subsequent differences in the percent frequency of occurrence and mean relative density of SAV. In the impounded area of Pool 13, the percent frequency of occurrence and mean relative density of SAV increased during the period of study and was strongly correlated with rooted floating-leaved vegetation (RFV). None of the other physical or hydrological variables analyzed for the impounded area demonstrated significant correlations. The cause for the lack of significant relationships between independent variables and measurements of SAV abundance in the impounded area of Pool 13 are uncertain, but the differences may be due to previously established SAV beds creating favorable near-shore habitat with increased water clarity and reduced velocities when compared to main channel habitat.

INDEX DESCRIPTORS: submersed aquatic vegetation, rooted floating-leaf vegetation, Upper Mississippi River System, Long Term Resource Monitoring Program, transect, percent frequency of occurrence, mean relative density, backwater, impounded.

From 1994 to 2000, the Long Term Resource Monitoring Program (LTRMP) quantified the presence and relative density of submersed aquatic vegetation along established transects in Pool 13, Upper Mississippi River System (UMRS). Prior to implementation of the LTRMP, there had been little peer-reviewed documentation of submersed aquatic vegetation distribution, abundance and trends within Pool 13, UMRS (Peck and Smart 1986). The objectives of this report were as follows: 1) investigate the strength of bivariate relationships between observed measures of annual submersed aquatic vegetation and physical, biological, and hydrological variables, and 2) compare and contrast the backwater and impounded habitats of Pool 13 through examination of relationships between submersed aquatic vegetation (SAV) and independent variables within backwater and impounded habitats. The goal of this investigation was to provide resource managers with increased information regarding the relative importance of independent variables that influence observed patterns in SAV presence and abundance.

METHODS

Pool 13, UMRS, contains braided backwater channels, backwater lakes, and a large open impounded area (Fig. 1). Pool 13 is bounded to the north by Lock and Dam 12, Bellevue, Iowa at Mississippi river mile 556.7 (M556.7) and to the south by Lock and Dam 13, Fulton, Illinois at M522.5. Pool 13 is 54.7 km long (Rasmussen 1979) and 6.0 km across at its widest point. Contiguous backwater lake habitats are characterized as off channel areas with low velocity and connection to channel habitats at reference river discharge, while impounded habitats are large open areas in the lower ends of navigation pools with relatively uniform depth and velocity (Wilcox 1993). Contiguous backwater habitat comprised 2,810 ha (28%) and impounded habitat comprised 3,560 ha (36%) of the total 9,991 ha of aquatic habitats in Pool 13 in 1989 (Rogers et al. 1995). The three backwater locations in this study were Brown's Lake, Savanna Bay, and Spring Lake (Fig. 1). Four vegetation sampling locations were present in the impounded area of Pool 13 (Fig. 1).

The method for sampling aquatic vegetation was modified from a technique used by Jessen and Lound (1962) and was designed to investigate aquatic vegetation along straight line transects that traverse a backwater location, typically perpendicular to the shoreline (Rogers and Owens 1995). Transect arrangement and spacing (50 m to 100 m intervals) in each study location was determined by the size of the area and the historic presence of vegetation in the area. The number of transects per location ranged from a minimum of 12 transects in Savanna Bay and Spring Lake to a maximum number of 17 transects in the impounded area (Table 1). The number of sites per transect ranged from 4 to 50 depending upon the amount of open water at the sampling location. Sampling occurred between July 15 and August 31 in years 1994–2000. Transects were sampled at 15 to 30 m intervals along a fixed compass bearing unique to that location. Each interval was a site. Our analyses included only sites sampled in all years.

Within a site, a sample was taken once at each of three different sub-sample locations at the bow of the boat. A modified garden rake was dipped into the water and lowered until it reached the substrate at each of the three sub-sample locations (Rogers and Owens 1995).

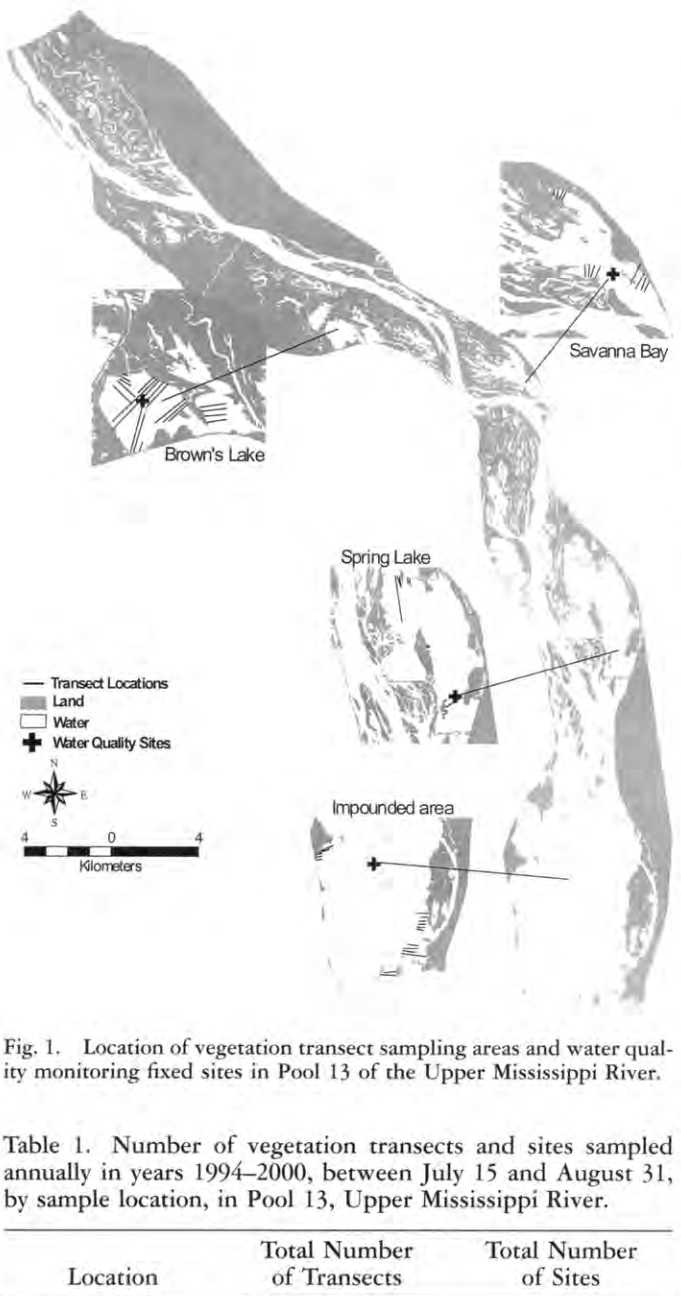

Fig. 1. Location of vegetation transect sampling areas and water quality monitoring fixed sites in Pool 13 of the Upper Mississippi River.

Table 1. Number of vegetation transects and sites sampled annually in years 1994–2000, between July 15 and August 31, by sample location, in Pool 13, Upper Mississippi River.

Location	Total Number of Transects	Total Number of Sites
Brown's Lake	15	292
Savanna Bay	12	123
Spring Lake	12	154
Impounded area	17	303

The rake was twisted 360°, and SAV was brought vertically out of the water and into the boat. SAV was considered present at a site if it occurred on any of the three rakes lifted at a site. Rooted floating-leaved vegetation (RFV) was considered present at a site if it was visually observed within a 1.5 m radius of the bow of the sampling boat.

SAV was given a relative density value of 1 to 4 at sites where vegetation was present, based on the number of rake-lifts containing vegetation and the relative abundance of vegetation on the sample rake. A rating of 1, 2, or 3 was assigned to a site when vegetation was present on 1, 2, or 3 rakes, respectively. A rating of 4 was reserved for sites where vegetation completely covered the rake teeth at all three sub-sampling locations. Relative density ratings from 1998 were excluded from analysis due to incorrect application of the rating methodology.

One fixed water-quality monitoring site was located within each backwater area and in the upper portion of the impounded area (Fig. 1). Turbidity, surface velocity, temperature, and water depth were measured biweekly at each of the four fixed water quality monitoring sites between May 1 and August 31, 1994–2000 using established LTRMP methodology (Soballe 2000). Water depth was used as an indicator of water stage at each site because it was measured over time at the same location.

Annual May–August median turbidity, mean velocity, mean temperature, and stage variability were calculated for each of the four water-quality monitoring sites for each of the seven sampling years. A seven-year mean May–August stage value was calculated for each water monitoring site using 1994–2000 data, and a May–August mean difference in stage from the seven-year mean was calculated for each monitoring site, for each year. Median turbidity was used as the measure of central tendency for water clarity rather than mean turbidity, because turbidity data were severely right skewed by single observations after high wind or heavy rainfall events. For each year, percent frequency of occurrence values for SAV within the three backwater locations and one impounded study location were calculated using the following formula:

$$\text{percent frequency of occurrence} = \left(\frac{a}{b}\right) \times 100$$

where a = the number of sites with vegetation present, and b = the total number of sites.

Spearman rank correlation was used to test the strength of bivariate relationships between the annual percent frequency and mean density rating of SAV and physical, biological, and hydrological parameters. Backwater and impounded habitats were analyzed separately in an effort to identify differential responses to independent variables among the two habitat types. Statistical Analysis System (SAS 1996) was used for data analyses and bivariate relationships were considered significant at $P \leq 0.05$.

RESULTS

Fifteen species of SAV and two species of RFV were encountered in Pool 13 during the study period (Table 2). The percent frequency of occurrence for SAV in backwater habitats ranged from a high of 88% in Brown's Lake during 1998 to a low of 6% in Savanna Bay during 1999 (Table 3). The percent frequency of occurrence for SAV in the impounded area ranged from a high of 96% during 1998 to a low of 56% during 1994 (Table 3). Savanna Bay exhibited the lowest percent frequency of occurrence for SAV within all study years, and the impounded area exhibited the highest percent frequency of occurrence in all study years except 1994 (Table 3).

Mean relative density values for SAV at vegetated backwater sites ranged from 1.1–2.5 with the highest value occurring in Brown's Lake in 1994, and the lowest value occurring in Savanna Bay in 1999 (Table 4). Mean relative density values for SAV at vegetated impounded sites ranged from 1.7–2.1 with the highest value occurring in 1999 and the lowest value occurring in 1995 (Table 4).

The percent frequency of occurrence of SAV in backwater habitats exhibited a strong negative correlation with May–August median turbidity (Table 5; Fig. 2) and May–August mean velocity (Table 5; Fig. 3). The percent frequency of occurrence of SAV in backwater

Table 2. List of submersed aquatic vegetation (SAV) and rooted floating-leaved vegetation (RFV) species sampled in Pool 13, Upper Mississippi River in 1994–2000.

Scientific Name	Common Name	Life Form
Ceratophyllum demersum L.	coontail	SAV
Elodea canadensis Michx.	Canadian waterweed	SAV
Heteranthera dubia Jacq.	water stargrass	SAV
Myriophyllum spicatum L.	Eurasian watermilfoil	SAV
Najas flexilis Willd.	nodding waternymph	SAV
Najas guadalupensis Spreng.	southern waternymph	SAV
Nelumbo lutea Willd.	American lotus	RFV
Nymphaea odorata Paine	American white water lily	RFV
Potamogeton crispus L.	curly-leaf pondweed	SAV
Potamogeton foliosus Raf.	leafy pondweed	SAV
Potamogeton nodosus Poir.	longleaf pondweed	SAV
Potamogeton pusillus L.	small pondweed	SAV
Potamogeton zosteriformis Fern.	flat-stem pondweed	SAV
Stuckenia pectinatus L.	sago pondweed	SAV
Utricularia macrorhiza Le Conte	common bladderwort	SAV
Vallisneria americana Michx.	wild celery	SAV
Zannichellia palustris L.	horned pondweed	SAV

Table 3. The percent frequency of occurrence of submersed aquatic vegetation at transect sites during July 15–August 31 sampling in years 1994–2000, by sample location in Pool 13, Upper Mississippi River.

	Year						
Location	1994	1995	1996	1997	1998	1999	2000
Brown's Lake	81	71	68	69	88	35	59
Savanna Bay	21	28	17	21	51	6	18
Spring Lake	49	49	41	56	54	62	82
Impounded area	56	80	75	91	96	93	93

Table 4. The mean relative density of submersed aquatic vegetation at transect sites during July 15–August 31 sampling in years 1994–2000, by sample location in Pool 13, Upper Mississippi River. Density categories ranged from 0 (no SAV) to 4 (high density).

	Year						
Location	1994	1995	1996	1997	1998	1999	2000
Brown's Lake	2.5	1.8	2.0	2.0	nd	1.5	1.7
Savanna Bay	1.7	1.4	1.5	1.4	nd	1.1	1.5
Spring Lake	1.6	1.5	1.8	1.9	nd	2.0	2.0
Impounded area	1.8	1.7	1.8	1.9	nd	2.1	1.9

nd=No relative density data available for 1998.

habitats was also significantly correlated with the percent frequency of occurrence of RFV (Table 5). None of the other physical or hydrological characteristics examined were significantly correlated with the percent frequency of occurrence of SAV in backwater habitats (Table 5).

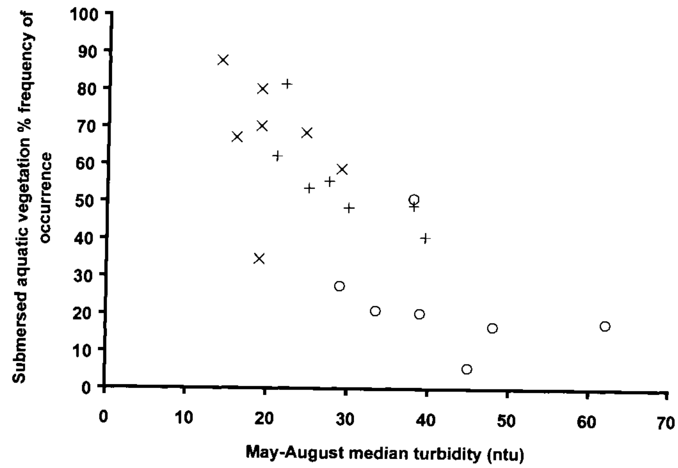

Fig. 2. Relationship between the mean percent frequency of occurrence of submersed aquatic vegetation (SAV) at Brown's Lake (X), Savanna Bay (O) and Spring Lake (+) transect locations and May–August median turbidity at corresponding backwater water quality sites in Pool 13 of the Upper Mississippi River in years 1994–2000.

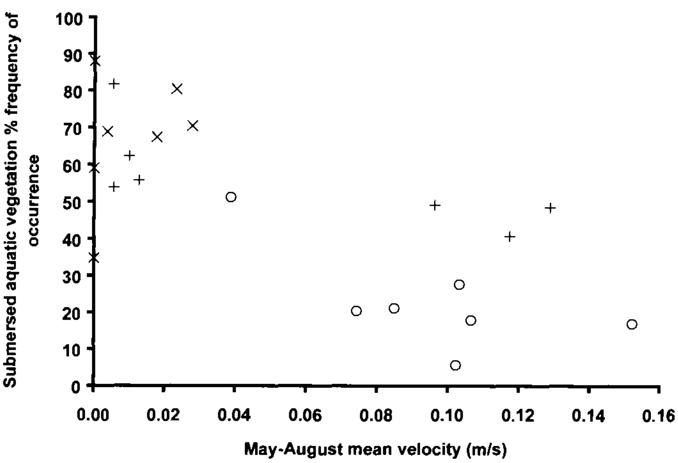

Fig. 3. Relationship between the mean percent frequency of occurrence of submersed aquatic vegetation (SAV) at Brown's Lake (X), Savanna Bay (O) and Spring Lake (+) transect locations and May–August mean velocity at corresponding backwater water quality sites in Pool 13 of the Upper Mississippi River in years 1994–2000.

Correlation analysis between the mean relative density of SAV at vegetated backwater sites and independent variables yielded similar results to those found for the percent frequency of occurrence of SAV (Table 5). The mean relative density of SAV at vegetated backwater sites was significantly correlated with May–August median turbidity, May–August mean velocity, and the percent frequency of occurrence of RFV (Table 5).

The three backwater locations exhibited a gradient of SAV presence that was strongly related to backwater median turbidity (Fig. 2) and mean velocity (Fig. 3). The presence of this gradient can be explained by the different physical constituents existing within each backwater creating a unique environment for vegetative growth when comparing among backwater habitats. Correlation analysis suggested that water clarity and surface velocity were primary causative agents with respect to SAV frequency of occurrence and relative density (Table 5). May–August turbidity and surface velocity in back-

Table 5. Spearman correlations between the percent frequency of occurrence and mean relative density for submersed aquatic vegetation at transect locations and selected physical and water quality characteristics in Pool 13 of the Upper Mississippi River from 1994–2000.

Phyisical, Biological, or Hydrological Variable	Backwaters						Impounded					
	% Freq. Occurrence			Relative Density			% Freq. Occurrence			Relative Density		
	r	P	n	r	P	n	r	P	n	r	P	n
May–August mean difference in stage from 1994–2000	−0.044	0.8513	21	0.214	0.3939	18	−0.578	0.1741	7	0.147	0.7809	6
May–August mean temperature	0.270	0.2363	21	0.024	0.9255	18	0.559	0.1925	7	−0.086	0.8717	6
May–August mean velocity	−0.684	0.0006	21	−0.574	0.0127	18	−0.288	0.5307	7	0.485	0.3287	6
May–August median turbidity	−0.822	<0.0001	21	−0.708	0.0010	18	−0.432	0.3325	7	−0.257	0.6228	6
May–August stage variability	−0.112	0.6294	21	0.0176	0.9448	18	−0.577	0.1754	7	−0.273	0.6004	6
RFV % freq. of occurrence	0.596	0.0044	21	0.517	0.0279	18	0.775	0.0408	7	0.829	0.0416	6
Year (time)	0.039	0.8656	21	−0.072	0.7762	18	0.847	0.0162	7	0.600	0.2080	6

water habitats were significantly correlated ($r = 0.749$, $n = 21$, $P = 0.0001$), which indicated that backwater habitats subject to flow from channel habitats were more likely to be turbid and, therefore, exhibit reduced occurrence and density of SAV. The relationship among measures of SAV, velocity, and turbidity suggested that backwaters exhibiting low SAV occurrence may be shifted up the backwater vegetation gradient by reducing flow inputs from channel habitats, or vice versa.

Within impounded habitat, the percent frequency of occurrence of SAV was significantly positively correlated with year and the percent frequency of occurrence of RFV (Table 5). The mean relative density of SAV at vegetated impounded sites was significantly correlated with the percent frequency of occurrence of RFV (Table 5). None of the other physical or hydrological characteristics examined were significantly correlated with the percent frequency of occurrence or mean relative density of SAV at impounded area locations.

DISCUSSION

In backwater habitats, there was a strong relationship between water clarity (i.e., turbidity) and both the presence and relative density of SAV. The relationship between water clarity and submersed vegetation is well understood and has been extensively studied (e.g., Carter et al. 1985, Roseboom et al. 1991, Nichols 1992). It was not surprising to find that both the presence and density of SAV was correlated with water clarity, but the strength of the relationship was unexpected given the dynamic nature of the Upper Mississippi River. Vegetation communities within Pool 13 are subject to annual variation in water levels and subsequent water depths, gradients of perturbation, sediment loads, and velocities. Despite the annual variation in the previously mentioned variables, May–August turbidity exhibited the strongest correlation with observed measures of SAV presence and density.

Within the impounded area, correlation analysis indicated that percent frequency of occurrence of SAV increased during the study period and exhibited a positive relationship with the presence of RFV. Similarly, the relative density of SAV exhibited a positive correlation with the presence of RFV. Submersed vegetation in Pool 13 incurred major declines in abundance as a result of the 1993 flood-event (Gent and Blackburn 1994). Since 1993, the frequency of occurrence of SAV and RFV has steadily increased in abundance within Pool 13 impounded habitat and by 1997, surpassed pre-flood levels (Yin et al. 2000). The lack of results indicating significant relationships between physical parameters and SAV measures in impounded habitat may largely be due to small sample size ($n = 7$), but it may also be indicative of aquatic vegetation's ability to proliferate in impounded habitat independently of changes in thalweg turbidity and velocity. It is plausible that the density and occurrence of vegetation in impounded habitat, within a given year, may depend largely on the previous year's vegetation abundance and density.

Submersed vegetation grows in beds in impounded habitat and locations near beds typically have greater water clarity when compared to impounded channel habitats and can cause significant increases in the depth of the photic zone by causing clear water microclimates in shoreward areas (Kahl 1993). The bed areas act as clear water refuge from the relatively turbid waters and wave action of non-vegetated impounded habitat and are ideal for the establishment of additional submersed vegetation. Once established, vegetation beds in the impounded area may continue to expand until reaching a maxima or decline in response to a major perturbation such as the 1993 flood.

Since the early 1990s, the LTRMP has collected data documenting yearly trends in aquatic vegetation, water quality, macroinvertebrates, and fisheries (USGS 1999). Long-term monitoring data provides insight into the processes responsible for observed patterns in biological communities, which supplies resource managers with information valuable for making informed ecosystem management decisions. In the Upper Mississippi River System, observed vegetation patterns are a reflection of systemic controls (e.g., climate, land-use, geology) and local controls (e.g., water velocity, water depth, sediments) influence upon local habitat suitability. Systemic and local controls are continuously changing, which causes vegetation patterns to be dynamic. The UMRS has a diversity of aquatic habitat types supporting a unique vegetation community. Much of the diversity in fauna is directly attributable to the dynamic nature of the river and the resulting dynamic vegetation patterns.

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