10-2003

Differences in Sedge Fen Vegetation Upstream and Downstream from a Managed Impoundment

Kurt P. Kowalski
U.S. Geological Survey

Douglas A. Wilcox
The College at Brockport, dwilcox@brockport.edu

Repository Citation

Kowalski, Kurt P. and Wilcox, Douglas A., "Differences in Sedge Fen Vegetation Upstream and Downstream from a Managed Impoundment" (2003). *Environmental Science and Ecology Faculty Publications*. 26.
https://digitalcommons.brockport.edu/env_facpub/26

Citation/Publisher Attribution:
Source: American Midland Naturalist, Vol. 150, No. 2 (Oct., 2003), pp. 199-220
Published by: The University of Notre Dame
Stable URL: http://www.jstor.org/stable/3566548

The University of Notre Dame

Differences in Sedge Fen Vegetation Upstream and Downstream from a Managed Impoundment
Author(s): Kurt P. Kowalski and Douglas A. Wilcox
Reviewed work(s):
Source: *American Midland Naturalist*, Vol. 150, No. 2 (Oct., 2003), pp. 199-220
Published by: The University of Notre Dame
Stable URL: http://www.jstor.org/stable/3566548
Accessed: 10/04/2012 13:58

Am. Midl. Nat. 150:199–220

The American Midland Naturalist

Published Quarterly by The University of Notre Dame, Notre Dame, Indiana

Vol. 150 October 2003 No. 2

Am. Midl. Nat. 150:199–220

Differences in Sedge Fen Vegetation Upstream and Downstream from a Managed Impoundment

KURT P. KOWALSKI[1] AND DOUGLAS A. WILCOX

U.S. Geological Survey, Great Lakes Science Center, 1451 Green Road, Ann Arbor, Michigan 48105

ABSTRACT.—The U.S. Fish and Wildlife Service proposed the restoration of wetlands impacted by a series of drainage ditches and pools located in an extensive undeveloped peatland in the Seney National Wildlife Refuge, Michigan. This study examined the nature and extent of degradation to the Marsh Creek wetlands caused by alteration of natural hydrology by a water-storage pool (C-3 Pool) that intersects the Marsh Creek channel. We tested the hypothesis that a reduction in moderate-intensity disturbance associated with natural water-level fluctuations below the C-3 dike contributed to lower species richness, reduced floristic quality and a larger tree and shrub component than vegetation upstream from the pool. Wetland plant communities were sampled quantitatively and analyzed for species richness, floristic quality and physiognomy. Aerial photographs, GIS databases and GPS data contributed to the characterization and analysis of the Marsh Creek wetlands. Results showed that there was lower species richness in vegetated areas downstream from the pool, but not the anticipated growth in shrubs. Wetland vegetation upstream and downstream from the pool had similar floristic quality, except for a greater number of weedy taxa above the pool. Seepage through the pool dike and localized ground-water discharge created conditions very similar to those observed around beaver dams in Marsh Creek. In essence, the dike containing the C-3 Pool affected hydrology and wetland plant communities in a manner similar to an enormous beaver dam, except that it did not allow seasonal flooding episodes to occur. Management actions to release water from the pool into the original Marsh Creek channel at certain times and in certain amounts that mimic the natural flow regime would be expected to promote greater plant species richness and minimize the negative impacts of the dike.

INTRODUCTION

Seney National Wildlife Refuge (SNWR), in Michigan's Upper Peninsula (Fig. 1), encompasses more than 38,600 ha of streams, pools, uplands and wetlands. The refuge was established in 1935 and is managed by the U.S. Fish and Wildlife Service for the primary purpose of providing habitat for waterfowl and other wildlife species. In the early 1900s, ditches totaling about 30 km in length were dug across a 20,000-ha section of undeveloped fen peatland on private land in an attempt to prepare the land for agricultural use. After the

---

[1] Corresponding author: Telephone (734)214-9308; FAX (734)214-7230; e-mail: kurt_kowalski@usgs.gov

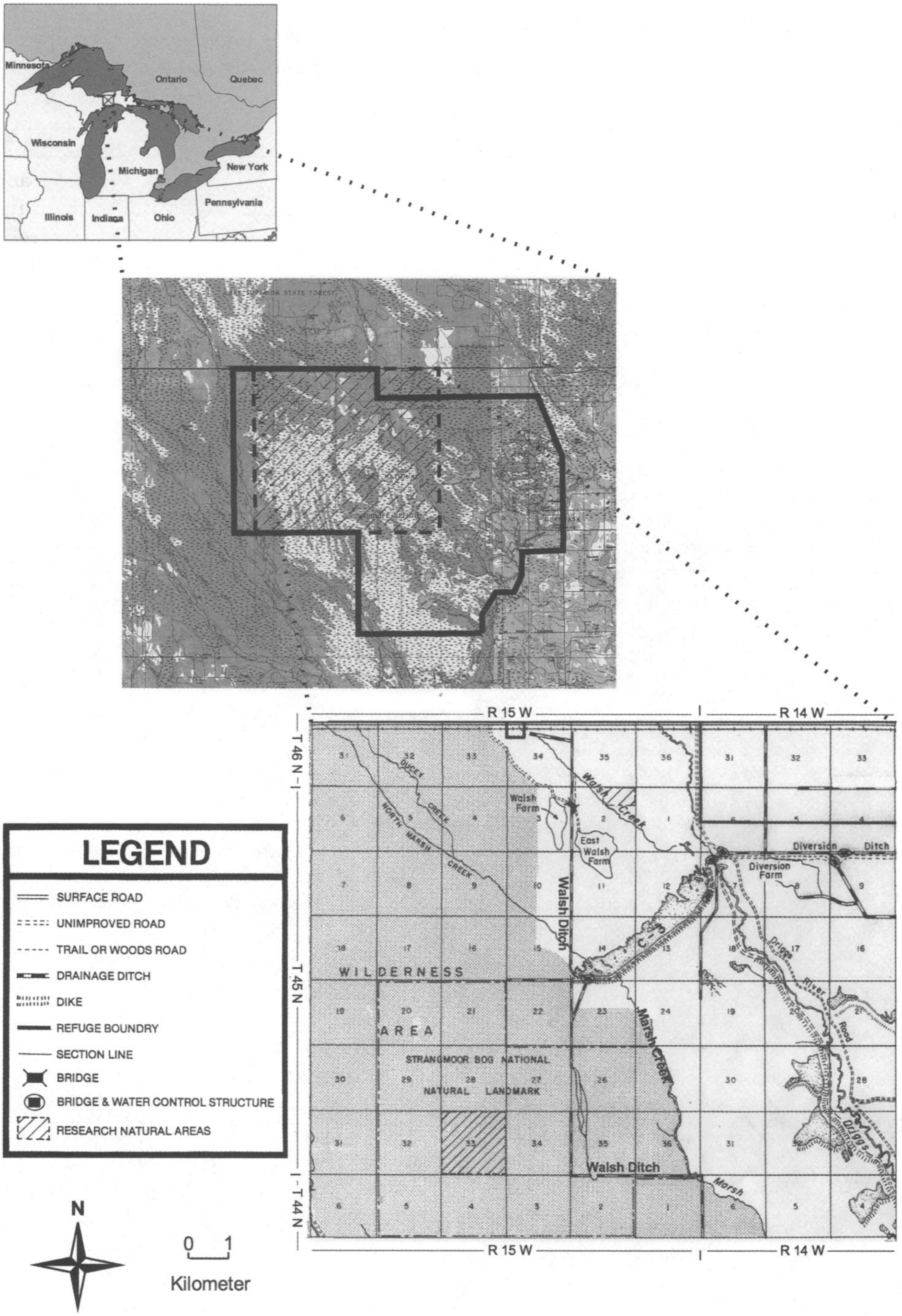

FIG. 1.—Location map of Seney National Wildlife Refuge and the study area. Federal Township and Range System section numbers are labeled

agricultural effort failed, the federal government acquired the land and drainage ditches and created the refuge. Dikes, water-storage pools and additional drainage ditches were constructed by the Civilian Conservation Corps in the late 1930s, and they changed the natural surface drainage on the refuge dramatically (Fjetland, 1973; Anderson, 1982).

Most water-storage pools found on the refuge have water-control structures in their retaining dikes that allow managers to control water levels in the pools and release water directly into an existing creek channel or ditch. The amount, frequency, duration and timing of water discharge into the creeks, therefore, have been related historically to the management goals for the pools rather than to the natural flow regime of the creeks. Because one of the major management goals of the refuge focuses on providing habitat for waterfowl, water levels in the pools that promote expanses of open water are maintained by opening the water-control structures only during a few times of the year (*e.g.*, during the spring snow melt). The result is a discharge pattern similar to that found on regulated rivers (*i.e.*, reduced variability), which can result in a decrease in plant species richness in adjacent plant communities (Nilsson *et al.*, 1991; Nilsson *et al.*, 1997; Jansson *et al.*, 2000). Similarly, studies have shown that periodic moderate intensity disturbance, which can result from flooding and scouring during high water-levels, will increase species richness (Loucks, 1970; van der Valk and Davis, 1976; Grubb, 1977; Connell, 1978; Pollock *et al.*, 1998).

It is well known that changing the amount, frequency or duration of water-level fluctuations can also impact the diversity of plant community types (Harris and Marshall, 1963; Keddy and Reznicek, 1986; Wilcox and Meeker, 1991; Hudon, 1997; Shay *et al.*, 1999). The creeks and rivers that run through SNWR normally have large variations in water level, ranging from flooding conditions during spring snow melt to very low levels during late summer (Sweat, 2001). The drainage ditches and water-storage pools on the refuge redirect the flow of surface water and interfere with the natural fluctuations in water level, thereby affecting bordering plant communities. Beaver dams, of which there are many in the refuge, can alter localized hydrology similarly, although their impacts are much more localized.

Although ditches, dikes and pools impact many parts of SNWR, refuge managers targeted the main wetlands and waterways in the northwestern portion of refuge (*e.g.*, Marsh Creek, Walsh Ditch and C-3 Pool) for restoration (*see* Fig. 1). They proposed to restore the natural hydrologic regime in this area to reduce sand deposition into the Manistique River caused by ditch erosion, reduce erosion of peat from the wetlands, restore surface flows to the Marsh Creek channel and bordering wetlands and minimize the negative environmental impacts of the ditches in the adjacent designated wilderness area (*see* Fig. 1). The proposed restoration included redirecting the water that was being released from the C-3 Pool primarily through Walsh Ditch. This action would reduce the erosion occurring in the ditch and also could reestablish surface flow down Marsh Creek, thereby improving the wetlands and wildlife habitat near Marsh Creek. The proposed restoration approach reflected the recent Fish and Wildlife Service policy shift toward ecosystem management (*e.g.*, wetland restoration through mimicry of the natural hydrologic regime; U.S. Fish and Wildlife Service, 2001).

An understanding of the current environmental conditions in the area proposed for restoration was needed to make informed decisions about how the restoration should proceed. Because Marsh Creek is an obvious route for redirection of some of the water from the C-3 Pool, examination of Marsh Creek and adjacent wetlands was deemed necessary to complete an overall assessment of the area proposed for restoration. The primary objective of this study, therefore, was to define the nature and extent of degradation to the Marsh Creek wetlands caused by alteration of natural hydrology (which includes beaver dams). Specifically, we tested the hypothesis that a reduction in moderate-intensity disturbance associated with natural water-level fluctuations below the C-3 dike contributed to lower species richness, reduced floristic quality and a larger tree and shrub component than vegetation upstream from the pool.

METHODS

STUDY AREA

Bounded by the Driggs River on the east, highway M-28 on the north and a designated wilderness area on the west and south, the study area contains two creeks, a ditch and a diked, open-water pool (*see* Fig. 1). The study area is generally poorly drained (Sypulski, 1941; Anderson, 1982), and ground-water discharge and recharge areas are common (Sinclair, 1959). Broadleaf deciduous forests with occasional stands of red, white and jack pine often dominate upland areas, and a mixture of sedges, grasses and low shrubs dominate the low wetland areas (Sypulski, 1941; Anderson, 1982).

The study area and much of the refuge is covered by sedge peat, often over 1 m in depth (Heinselman, 1965; Sweat, 2001), that likely began forming between 4000 and 9500 y ago (Heinselman, 1965). The peat is underlain by sandy glacial lake deposits (Sinclair, 1959) that slope S 75° E at 1.1–1.3 m/km (Heinselman, 1965). These sandy sediments, deposited as glacial outwash as the last (Valders) ice receded (Heinselman, 1965), were inundated by the Lake Algonquin high-water phase of the glacial Great Lakes (Hough, 1958). Shore processes reworked the sediments approximately 9500–10000 y ago during the post-Algonquin period (Heinselman, 1965) and left behind sand knolls thought to be dunes (Berquist, 1936). Silt and clay, either mixed with sand or occurring as individual layers in addition to sand, form glacial deposits ranging from a few centimeters to over 30-m thick. Sedimentary rocks of Richmond age (*e.g.*, shale and limestone beds 15–91 m thick) are the youngest bedrock unit in the northwest portion of SNWR with Trenton limestone occurring underneath (Dutton, 1968).

The historic channel of Marsh Creek is intersected by a dike and the 284-ha C-3 Pool built in the early 1940s. The pool is oriented N 55° E, making it tangential to the general slope of the area. Before a water-control structure was built in 1997, there was no mechanism to release water from the pool into the old Marsh Creek channel. Calcium-rich ground water, precipitation and seepage through the dike were the only sources of water for the creek and surrounding rich fen (Kowalski, 2000; Sweat, 2001). These sources provided enough water to support beaver activity and keep the channel full but with little flow. Moreover, the water table was near ground level, which allowed extensive sedge mats and sedge peat deposits to remain intact.

VEGETATION MAPPING: PHOTO INTERPRETATION, GIS AND GPS

Geospatially referenced vegetation maps covering the study area were created using color-infrared aerial photographs, a geographic information system (GIS) and global positioning system (GPS) technology. The vegetation maps promoted analysis of the geographic distribution of landscape features and plant communities, simplified calculation of area covered by plant associations and provided a valuable view of the system as a whole.

Seven photographs (Table 1), imaged in September 1997 at a nominal scale of 1:6000, were prepared following the standard procedures outlined by Owens and Hop (1995) to, among other things, minimize the warpage and distortion errors normally associated with aerial photographs. The boundaries of major vegetation associations and other landscape features were digitized into a GIS and verified during ground-truthing exercises and during wetland plant sampling in 1998.

TABLE 1.—Summary of the color-infrared aerial photographs interpreted for Marsh Creek wetland analysis. The number of ground control points (GCPs) identified in each photo, the output root-mean-square error (RMSE) of each GIS transformation and the control-point RMSE for each image rectified are provided. All photos were taken 21 September 1997 at a nominal scale of 1:6000

Line #	Frame #	# of GCPs	GIS RMSE (m)	Image RMSE (m)
2	48	6	1.80	1.40
2	49	6	N/A	1.40
2	50	6	N/A	1.43
7	103	6	5.05	1.58
7	104	7	4.27	1.42
7	105	8	4.18	1.39
7	106	5	1.68	1.41

A 100-m buffer was created around the GIS polygons representing Marsh Creek; this buffer was used to clip the vegetation polygons in the vector coverages. Buffering the creek polygons minimized the quantification of natural differences in plant communities attributed to landscape features (*e.g.*, sand dunes) and reduced the area of examination to the immediate vicinity of the creek. Each contact print from the 1997 photo set listed in Table 1 was scanned, georectified and used to create a mosaic that provided spatially-referenced image data for the whole study site. A mapping grade GPS receiver was used to collect the geographic control data used by the GIS. Distortions inherent in aerial photographs, photo-interpretation errors of commission and omission, digitizing error, transformation errors and errors in GPS data were identified and minimized when possible (*see* Table 1 for RMSE values).

ANALYSIS OF WETLAND VEGETATION BORDERING MARSH CREEK

Wetland plant communities were sampled during July and August 1998 in four different locations on Marsh Creek (Fig. 2) that were stratified with respect to the influence of the C-3 Pool and localized beaver dams: one approximately 450 m upstream from the C-3 Pool in an area not influenced directly by beaver activity (MC-1), one downstream from the C-3 Pool approximately 120 m from the outlet in an area influenced directly by the pool (MC-2), one approximately 910 m downstream from the C-3 Pool in a location upstream from and influenced directly by a beaver dam (MC-3) and one approximately 540 m downstream from the C-3 Pool in a location with minimal influence by beaver activity (MC-4).

At each site, a 100-m centerline was established perpendicular to water flow in the creek (Fig. 3). A series of 50-m transects that roughly paralleled water flow were then placed perpendicular to the centerline. The transects occurred 2, 5, 10, 30, 60 and 100 m from the edge of the water and extended 25 m on each side of the centerline to promote the identification of vegetation patterns grading away from the creek. Half of the transects were located within the first 10 m from the edge of the water because we anticipated that a shift in plant communities was most likely to occur as a result of different hydrologic conditions. Each transect was divided into five equal-length segments to be used for placement of sampling quadrats.

The plant communities in each of the five segments of the 50-m transects were sampled for species present and percent cover of herbaceous taxa within 1 × 1 m quadrats. One quadrat was placed randomly in each segment and centered on the transect. Those quadrats dominated by woody regeneration (seedlings $\leq$1 m tall) or shrubs ($>$1 m tall and $\leq$2.5 cm dbh) were sampled in 3 × 3 m plots, centered around the 1 × 1 m quadrats, for species

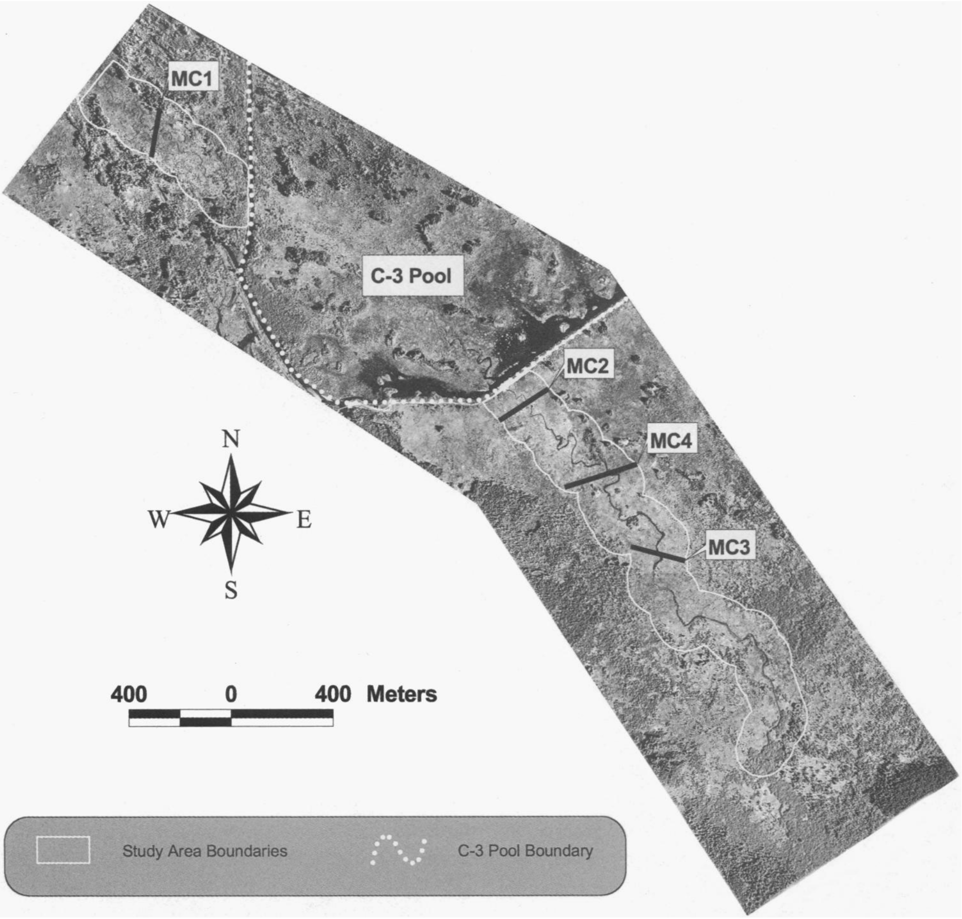

FIG. 2.—Rectified vertical aerial photographs of Marsh Creek near the C-3 Pool. The images were derived from color - infrared contact prints. *See* Figures 4 and 5 for detailed vegetation maps of the study area delineated in white. Plant sampling transects are identified. An earthen dam borders the C-3 Pool and defines its boundary

present, percent cover, diameter at breast height (dbh) and total stem count of woody species only. The same variables were sampled in quadrats dominated by mature trees (>1 m tall and >2.5 cm dbh), except that 5 × 5 m plots, centered on the 3 × 3 m and 1 × 1 m plots, were used and only mature trees were sampled in that 5 × 5 m area. Plant communities were quantitatively sampled in quadrats along the transects to produce data consistent with other studies and expedite data collection. Plant nomenclature follows Gleason and Cronquist (1991).

Plant data were analyzed using the inventory and transect computer programs found in the Floristic Quality Assessment (FQA) created by Michigan Department of Natural Resources (Herman *et al.*, 1996). The FQA programs use a database containing a coefficient of conservatism (C) assigned *a priori* to each species found in Michigan. The C value

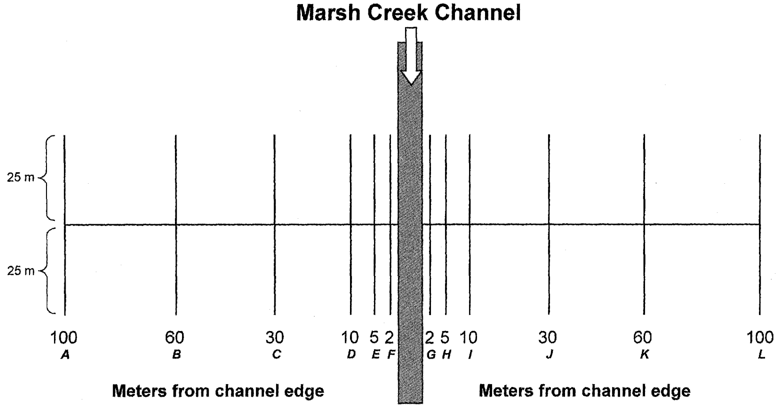

FIG. 3.—Schematic of plant sampling transect locations used to quantitatively sample plant communities at Marsh Creek. An alphabetic character was used to name each transect

represents an estimated probability that a plant is likely to occur in a landscape relatively unaltered from presettlement conditions (Herman *et al.*, 1996). The C value ranges from 0 to 10, with higher numbers representing a higher level of probability that a plant is likely to occur in a landscape relatively unaltered from what is believed to be a presettlement condition (Herman *et al.*, 1996). Low C values (*i.e.*, $C \leq 3$) are considered weedy species.

The inventory and transect programs produce, among other things, a mean coefficient of conservatism ($C = \sum C/n$, n = total number of plant taxa included in the analysis) and a floristic quality index ranking ($FQI = * \sqrt{n}$) that measures the extent to which conservative (*i.e.*, low tolerance to disturbance and/or high fidelity to specific habitat integrity) plants are present at a site (Wilhelm and Masters, 1995). The FQI value is the best FQA indicator of floristic diversity for a site because it uses the mean square root of the number of species to account for differences in the size of sample area and to facilitate comparison of FQI values among different sites. The FQA programs also use a coefficient of wetness (W) for each species that relates to the five main National Wetland Indicator Categories (*e.g.*, OBL, FACW–, FACU+) given by Reed (1988) and estimates the probability that a plant species will occur in a wetland.

We chose these analysis tools because they are based on information specific to Michigan and use standard procedures to analyze input data sets objectively. For the analyses in this study, only the identified vascular plants were used because the nonvascular and unidentifiable plants were not assigned *a priori* a coefficient of conservatism by the assessment. Outputs from the inventory computer program and the transect computer program provided summary information on plant species sampled in each transect. The program output allowed us also to examine the distribution of facultative or upland plants sampled within each site.

The FQA transect program requires a single percent cover value for each species sampled in each transect. This study had five quadrats in each transect, so the mean percent cover value was calculated for each plant species and used in the FQA transect program. Importance values (IV) for physiognomic categories were calculated for each transect using the FQA transect computer program. Importance values are calculated by summing the relative frequency (RFRQ) and relative cover class (RCOV) of each physiognomic category and dividing by 2 [*i.e.*, (RFRQ + RCOV)/2].

RESULTS

GEOSPATIAL DATA AND DELINEATED VEGETATION TYPES

Digital orthophotos and twenty ground-control points (GCPs) distributed throughout the study site provided the geographic control necessary to georeference vegetation maps and rectify images created from aerial photographs. Analysis and subsequent digitizing of 1:6000 CIR aerial photos (*see* Fig. 2) resulted in a vegetation map showing current distribution of major plant associations (Fig. 4). The 47.84 ha of land mapped downstream from the C-3 Pool were classified into seven different categories, based primarily on physiognomy (*see* Fig. 4, Table 2). The sedge classification covered 24.17 ha, or 50.5% of the area mapped downstream from the pool, and occurred mostly in the northern 75% of the lower Marsh Creek wetland. In contrast, shrub was the most frequently occurring vegetation category and was most dominant in the most southern section of the lower Marsh Creek site. The tree classification covered the second largest area at 11.85 ha or 24.8% of the area mapped downstream from the C-3 Pool. Nine beaver dams were observed in the approximately 2581 meters of Marsh Creek below the pool, although none were found immediately down slope from the pool.

In the mapped section of Marsh Creek located upstream from the C-3 Pool, the shrub/sedge category clearly covered the most area at 11.97 ha or 66.5% of the mapped area of 18.01 ha (Fig. 5). Unlike the area below the C-3 Pool, the sedge classification neither covered a large percentage of the mapped area nor occurred frequently. Upland, however, occurred in 11 individual locations and covered over 12% of the area. Similar to the area below the pool, shrub was the most frequently occurring vegetation category in the upper Marsh Creek wetland. It was mapped primarily in the northern and southeastern sections of the upstream study area. Five beaver dams were scattered along the approximately 1138 meters of Marsh Creek studied up slope from the pool.

TAXA RICHNESS

Seventy-one vascular plants and mosses were identified in the two-hundred forty 1 × 1 m herbaceous sampling quadrats (Table 3). Eleven shrub taxa were identified in the fifty-three 3 × 3 m shrub quadrats, and two tree species were identified in the six 5 × 5 m tree quadrats. *Calamagrostis canadensis*, *Carex lacustris* and *Carex stricta* occurred in one or more of the quadrats on most transects. *Spiraea alba* and *Solidago canadensis* were very common at upper Marsh Creek but uncommon in lower Marsh Creek (*i.e.*, below the C-3 Pool).

Total species richness was calculated for sites MC1 through MC4. MC1, upstream from the C-3 Pool, had the greatest number of species (48). Downstream transects MC4 (31), MC2 (28) and MC3 (25) had fewer species. Within the 1 × 1 m quadrats, MC1 had the greatest number of species (46), followed by MC4 (29), MC2 (26) and MC3 (25). MC1 and MC4 had the greatest number of species in the 3 × 3 m quadrats (7 in each), followed by MC3 (4) and MC2 (3). MC1 was the only site with species sampled in the 5 × 5 m quadrats (2).

No clear pattern of species richness was evident for forbs, shrubs and trees when they were viewed across transects (Fig. 6). Most transects had an increase in species richness near the creek, although the amount of increase varied. The unusually high species richness value of 21 observed in the 60-m east transect of MC1 was not apparent in any of the other transects.

FLORISTIC QUALITY ASSESSMENT

The FQA inventory results for all transects are summarized in Table 4. The MC1 transect had the largest number of native vascular plant species (44) and adventive (*i.e.*, non-native)

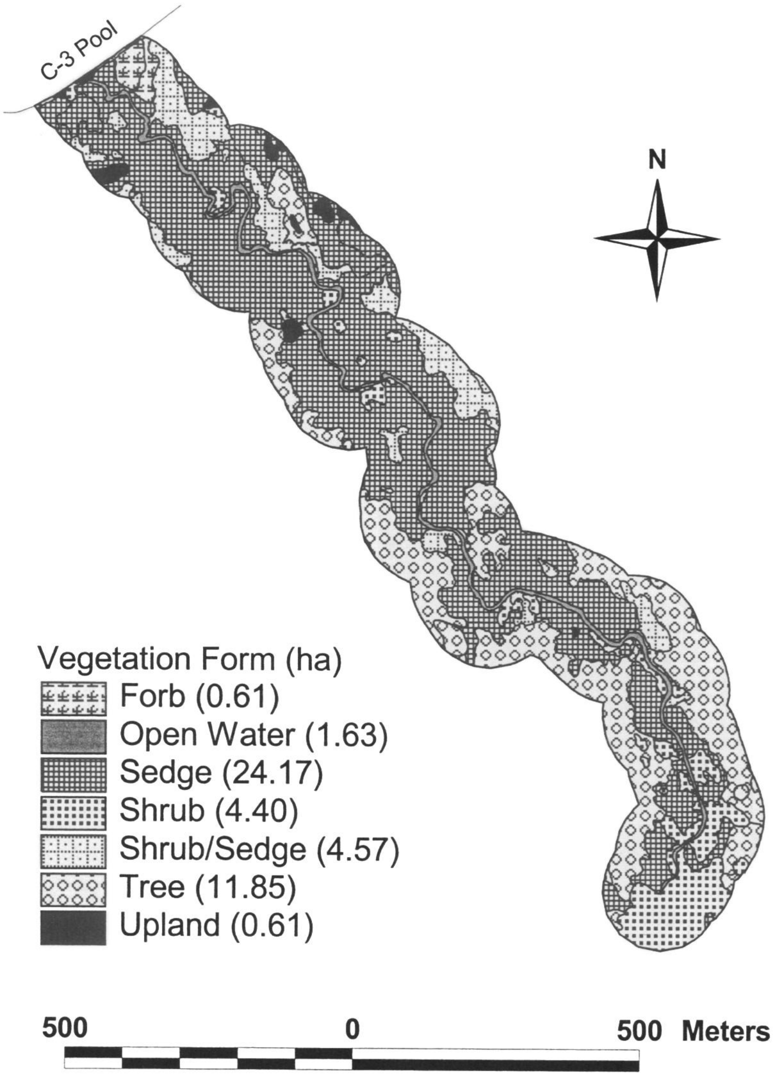

FIG. 4.—Detailed GIS map of vegetation boundaries in Marsh Creek downstream from the C-3 Pool in Seney National Wildlife Refuge. Vegetation types were delineated from color-infrared aerial photographs. *See* Figure 2 for location in relation to C-3 Pool

vascular plant species (4). The MC2 transect was the only other transect where adventive species (3) were found. Although the MC1 transect also had the lowest mean coefficient of conservatism (3.8) and the lowest Mean C value, it had the largest mean wetness score (Mean W) of −2.1 that translates into an average Michigan wetland category of FACW−. The MC2, MC3 and MC4 transects had mean wetness scores that translate to FACW+. The FQI values were lowest (21.0) at MC2 immediately below the pool but were higher at MC1 (26.1) and farther downstream from MC2.

TABLE 2.—Summary statistics for Mersh Creek land-cover classes delineated in GIS databases

	Downstream from the C-3 Pool			Upstream from the C-3 Pool		
	Frequency	Area (ha)	Percentage	Frequency	Area (ha)	Percentage
Forb	3	0.61	1.3	1	0.05	0.3
Open water	1	1.63	3.4	2	0.87	4.8
Sedge	22	24.17	50.5	3	0.50	2.8
Shrub	43	4.40	9.2	27	2.16	12.0
Shrub/Sedge	15	4.57	9.6	8	11.97	66.5
Tree	13	11.85	24.8	9	0.24	1.3
Upland	13	0.61	1.3	11	2.22	12.3
TOTALS	110	47.84	100.0	61	18.01	100.0

The MC1 transect had also the largest number of species in the forb physiognomic group (27) and the only two tree species found in the study site. All transects had similar distribution across physiognomic groups, but the relative importance values associated with each group varied by site. The sedge physiognomic group, however, had the largest importance value for all of the sites. The MC4 transect was slightly unusual in that there were two species, *Betula pumila* and *Vaccinium angustifolium*, that were only found in the MC4 3 × 3 m quadrats.

The weedy species ($C \leq 3$) showed no clear pattern across the study sites, except that upstream MC1 had a larger number of weedy species immediately next to the creek and along the 60-m east transect than the others (Fig. 7A). Similarly, the adventive species showed no observable pattern, except for a spike in MC1 on the 60-m east transect, which was the transect bordering an upland (Fig. 7B). Facultative and facultative upland species were most common in MC1 (15) followed by MC2 (3), MC4 (2) and MC3 (1).

DISCUSSION

EFFECTS OF C-3 POOL ON PLANT COMMUNITIES

Results of this study support our hypothesis that elimination of the moderate disturbances associated with naturally fluctuating water levels contributed to lower species richness and altered physiognomy of wetland plant communities down slope from the C-3 Pool. The total number of plant, shrub and tree species observed at upstream transect MC1 was 48. All sites below the C-3 Pool had at least 35% fewer species than MC1, with MC3 (approximately 910 m below the C-3 Pool) showing the largest difference with 48% fewer species. Examination of the number of species found in the 1 × 1 m quadrats reinforces this disparity. All of the transects below the C-3 Pool had more than 36% fewer herbaceous species than MC1, suggesting that there are at least small differences in the environmental conditions in the wetland up slope and down slope from the C-3 Pool.

The number and location of drier upland islands likely contribute to the effects of different environmental conditions and differences in species richness above and below the C-3 pool. The uplands and transitional areas surrounding them provide habitat for a suite of plant species adapted to drier and more variable hydrologic conditions. Many of these plants are considered facultative or facultative upland (Reed, 1988) and have the ability to survive in a variety of hydrologic and environmental conditions, so they are often found in wetland areas, upland areas and the gradient in between upland and wetland. Our results found over 50% more facultative and facultative upland species in MC1 than in the other

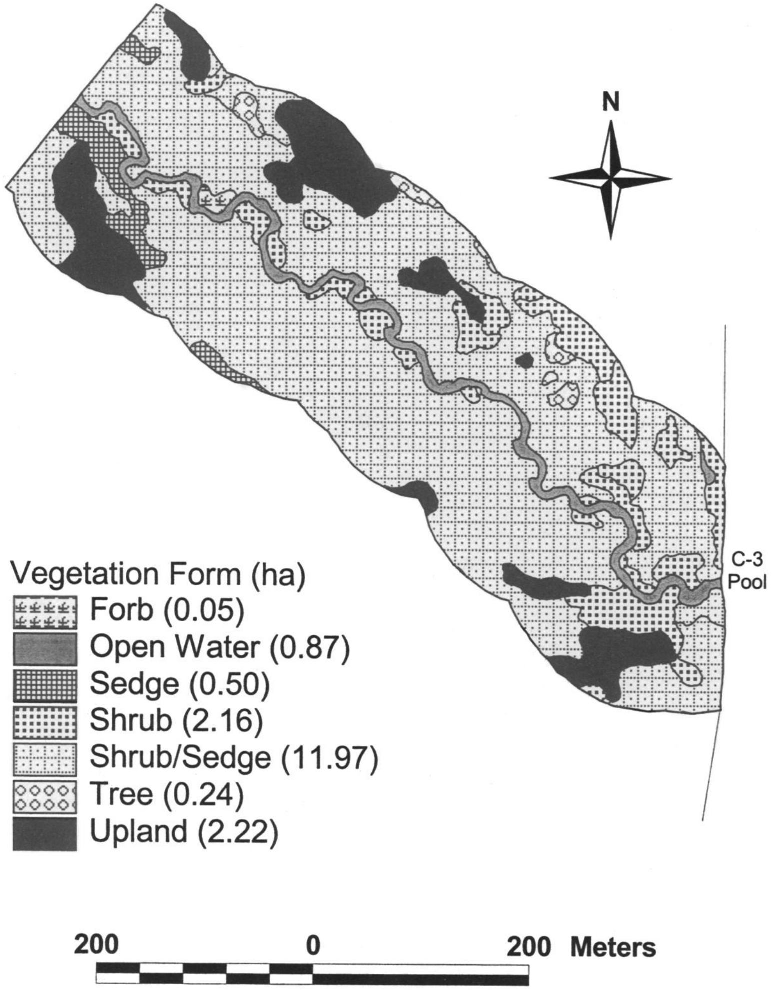

FIG. 5.—Detailed GIS map of vegetation boundaries in Marsh Creek upstream from the C-3 Pool in Seney National Wildlife Refuge. Vegetation types were delineated from color-infrared aerial photographs. *See* Figure 2 for location in relation to C-3 Pool

three sites combined, although the upland areas did not appear to be affecting the vegetation forms around them (*see* Figs. 4, 5). The presence of these adaptable plants increases the mean wetness values, as observed in MC1, and contributes to greater species richness values than are often found in areas with plants dependent on specific hydrologic conditions (*e.g.*, MC2–4).

It is likely that the lower plant species richness in the wetland below the C-3 pool is correlated with the altered surface hydrology. The pool is inhibiting water flow into Marsh Creek and removing all of the high and low water levels that would occur naturally (Sweat, 2001). The occasional flooding episodes that likely would result in an increase in species

Table 3.—Presence/absence of plant and moss species sampled in Marsh Creek wetlands. Brackets indicate taxa that were not included in the species richness calculations. Column letters correspond to transect locations identified in Figure 3

	Transect																																															
	MC1												MC2												MC3												MC4											
Species name	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L
Herbaceous (1 × 1 m quadrats)																																																
Achillea millefolium L.											x	x																																				
Alnus incana (L.) Moench.																															x														x	x	x	
Asclepias incanata L.				x		x																						x	x	x	x	x																
Aster puniceus L.									x			x													x												x											
Athyrium filix-femina (L.) Roth.																												x		x		x											x		x			
Bromus ciliatus L.															x					x											x						x	x		x				x				
Calamagrostis canadensis (Michaux) Beauv.	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Campanula aparinoides Pursh				x	x													x	x						x			x	x	x		x								x	x	x						x
Carex bebbii (L. H. Bailey) Fen.																																								x								
Carex interior L. Bailey																								x																								
Carex lacustris Willd.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x	x	x
Carex lasiocarpa Ehrh.													x		x								x	x			x									x	x									x	x	x
Carex stricta Lam.	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Carex utriculata F. Boott.												x																																				
Cicuta bulbifera L.						x																								x																		
Cirsium arvense (L.) Scop.														x				x	x	x																												
Cirsium palustre (L.) Scop.				x	x	x	x	x			x																																					
[*Cirsium* sp.]																																												x				
Dryopteris cristata (L.) A. Gray.																x	x		x		x					x	x	x		x	x	x	x				x				x	x	x	x	x			
Epilobium angustifolium L.											x																																					
Epilobium ciliatum Raf.					x																																											
Epilobium leptophyllum Raf.							x	x					x	x	x								x	x	x		x		x			x	x												x		x	

TABLE 3.—Continued

	Transect																																															
	MC1												MC2												MC3												MC4											
Species Name	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L
Eriophorum gracile Koch.																								x																								
Eriophorum tenellum Nutt.																																																x
Euthamia graminifolia (L.) Nutt.											x																																					
Fragaria virginiana Duchesne							x				x	x																																				
Galium asprellum Michaux				x	x	x	x	x											x	x																					x	x		x				
Galium trifidum L.	x	x				x	x	x	x				x						x						x		x	x		x																		
Geum aleppicum Jacq.							x																																									
Glyceria canadensis (Michx.) Trin.									x																																							
Habenaria obtusata (Banks) Richardson												x																																				
Hieracium aurantiacum L.											x																																					
Hypericum ellipticum Hook.																											x	x																				x
Impatiens capensis Meerb.			x				x	x																																			x					
Lycopus americanus Muhl					x	x																																										
Lysimachia terrestris (L.) BSP.																																																x
Lysimachia thyrsiflora L.													x					x					x	x		x	x	x	x		x						x								x	x	x	x
Monarda fistulosa L.								x																																								
Myrica gale L.							x																				x	x	x	x	x												x	x	x			
Onoclea sensibilis L.																											x	x	x		x	x																
Phalaris arundinacea L.																			x												x																	
Pinus resinosa Aiton.											x																																					
Poa alsodes A. Gray												x																																				
Poa palustris L.																						x							x												x							
Poa pratensis L.							x	x											x																													
Polygonum amphibium L.	x	x						x	x				x	x					x	x					x	x	x																					
Populus tremuloides Michx.											x	x																																				

TABLE 3.—Continued

	Transect																																															
	MC1												MC2												MC3												MC4											
Species Name	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L
Potentilla fruticosa L.																																																x
Pteridium aquilinum (L.) Kuhn.											x																																					
Ribes lacustre (Pers.) Poiret										x		x																																				
Rosa palustris Marshall																		x	x	x									x		x											x	x	x				
Rubus allegheniensis T. C. Porter					x																																											
Rubus hispidus L.											x	x																																				
Rubus idaeus L.			x	x	x	x	x	x	x		x																																		x			
Rubus pubescens Raf.											x																																					
Rumex orbiculatus A. Gray		x																																														
Salix bebbiana Sarg.												x			x																																	
Salix lucida Muhl.																																																x
Salix petiolaris J. E. Smith	x	x									x											x	x	x		x											x									x	x	
[*Salix* sp.]																											x																					
Scirpus cyperinus (L.) Kunth				x					x		x	x													x		x	x								x												
Scutellaria galericulata L.			x		x	x	x	x											x								x	x	x	x	x																	x
Solidago canadensis L.			x	x	x	x	x	x	x	x	x	x																																	x			
Solidago gigantea Aiton.																					x																								x			
Sphagnum fimbriatum Wils.																x																																
Spiraea alba Duroi	x	x	x	x	x	x	x	x	x	x	x	x																															x			x		
Taraxacum officinale Weber											x																																					
Thalictrum dasycarpum Fischer & Ave - Lall.						x																																										

TABLE 3.—Continued

	Transect																																															
	MC1												MC2												MC3												MC4											
Species Name	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L	A	B	C	D	E	F	G	H	I	J	K	L
Typha latifolia L.													x	x	x								x	x																								
Urtica dioica L.						x													x	x																												
[*Viola* spp.]						x																				x	x																				x	x
Shrub (3 × 3 m Quadrats)																																																
Alnus incana (L.) Moench.											x																				x												x		x	x	x	
[*Amelanchier* sp.]											x																																					
Betula pumila L.																																															x	
Myrica gale L.							x																								x												x			x		
Ribes lacustre (Pers.) Poiret												x																																				
Rosa palustris Marshall																															x												x					
Salix bebbiana Sarg.											x	x			x																																	
Salix lucida Muhl.															x																															x		
Salix petiolaris J. E. Smith	x	x		x					x		x															x											x									x	x	
Spiraea alba Durol	x	x	x	x	x	x	x	x	x	x	x	x			x																												x			x	x	
Vaccinium angustifolium Aiton.												x																																				
Tree (5 × 5 m Quadrats)																																																
Pinus resinosa Aiton.											x																																					
Populus tremuloides Michx.											x	x																																				

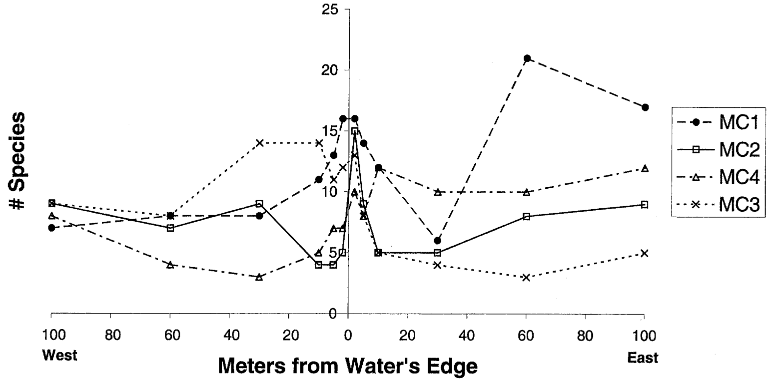

FIG. 6.—Summary of species richness values for all five quadrats sampled on each transect plotted according to distance from the edge of Marsh Creek

richness (Barrat-Segretain and Amoros, 1996; Bornette *et al.*, 1998; Amoros *et al.*, 2000) are removed. A possible explanation for lower species richness observed below the C-3 Pool, therefore, is that without moderate disturbances to allow new plant species to colonize the sites, the wetland plant communities become dominated by the few species most suited to that habitat (*e.g.*, *Carex stricta*, *Calamagrostis canadensis*, *Alnus incana*). Once established, the dominant species inhibit the colonization of other taxa until the next disturbance event.

The increased uniformity observed in species richness values is also reflected in the physiognomic character of plant communities below the C-3 Pool. Although all of the study sites are in the same wetland complex and have similarities in beaver activity, ground-water hydrology, slope, surficial geology and bedrock, the area below the C-3 Pool had fewer uplands and shrub/sedge vegetation forms than the area upstream from the C-3 Pool (*see* Figs. 4, 5). A mix of shrubs and sedges covers most of the upstream area where the water levels fluctuate naturally and moderate disturbance associated with certain events (*e.g.*, spring floods) occurs. The area below the C-3 Pool is under a different water-level fluctuation profile. Prior to construction of the Marsh Creek structure in 1997, seepage was the only way water passed through the C-3 Pool dike into Marsh Creek (Sweat, 2001). The normal short-term fluctuations in creek water level associated with spring snow melt and large rain events, therefore, were effectively removed. Without the natural high and low water levels, the flow regime appeared very similar to a regulated river and supported the domination of a limited suite of plant species that are most adapted to those hydrologic conditions.

Differences observed in species richness and vegetation forms between sites were not completely paralleled by physiognomic differences in the vegetation. The FQA analyses showed that all four study sites have a similar distribution of species across physiognomic groups, but important differences were noted. The MC1 site, with its natural water-level fluctuations and upland areas, had a very large number of forb species (27) as compared to the other sites and had relatively high shrub species richness (8). The large number of forbs, however, did not make the forb importance value (IV) unusually high because the frequency and cover of the shrub species and the cover of sedge species present at MC1 were large also. Examination of the species IV revealed that *Spiraea alba* was the shrub species most frequently sampled, and it produced the largest amount of cover in MC1. Because *S. alba* is a clonal shrub that grows in open wet areas (Barnes and Wagner, 1981), the large cover value

TABLE 4.—Summary of species richness and importance values for each physiognomic group sampled in the Marsh Creek wetlands (1 × 1 m quadrats only). The mean coefficient of conservatism (C) and wetness (W), as calculated using the floristic quality assessment inventory program, contribute to the floristic quality index (FQI) value identified in the last column

	Physiognomic group [Number of species (IV)]						Native Species	Total Species	Mean C with adventives	Mean W with adventives	FQI Value (Natives only)
	Fern	Forb	Grass	Sedge	Shrub	Tree					
Transect											
MC1	1(1.1)	27(23.9)	4(11.1)	4(40.1)	8(21.3)	2(2.4)	44	48	3.8	−2.1	26.1 (27.3)
MC2	1(1.4)	11(12.5)	5(19.0)	5(62.9)	3(4.1)	0(0)	25	28	4.0	−3.9	21.0 (21.8)
MC3	3(4.8)	10(10.3)	4(16.4)	4(64.0)	4(4.6)	0(0)	25	25	5.0	−4.5	25.0 (25.0)
MC4	2(1.8)	11(8.6)	3(17.9)	5(60.1)	8(11.6)	0(0)	31	31	5.0	−4.1	27.7 (27.7)

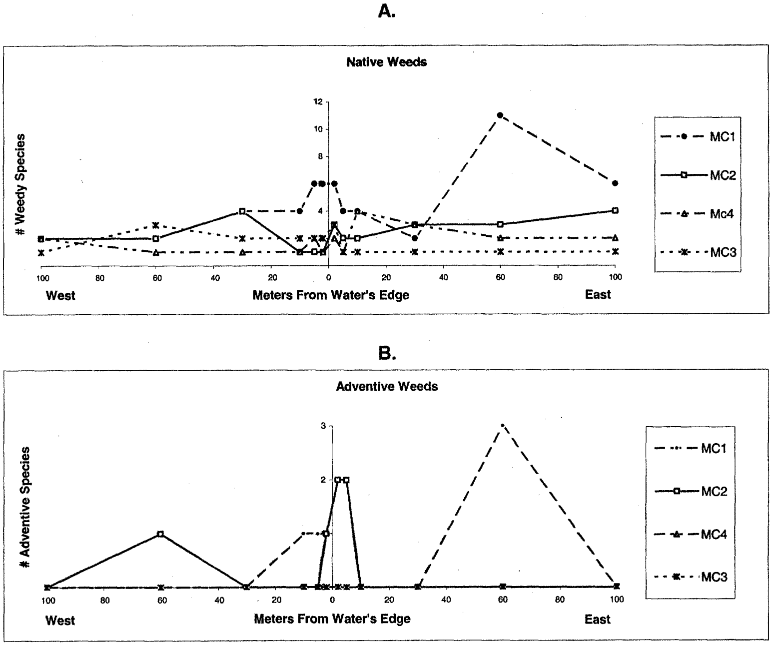

FIG. 7.—Number of native and adventive weedy species (C ≤ 3) identified in transect quadrats sampled at MC1, MC2, MC3 and MC4. Note the change in the scale of the y-axis between Figures 7A and 7B

observed for the shrub physiognomic group in MC1 seems appropriate. The *Spiraea* clones can grow together closely and form a thicket, thereby producing a large amount of cover in a small area.

Finally, anticipated conditions of drying and the hypothesized increase in tree and shrub growth down slope from a dike, such as those observed by Jeglum (1975), were not apparent in this study. In fact, the wetland area sampled directly in the down slope shadow of the C-3 dike had no trees and very few shrubs. In addition to reduced water-level fluctuations in the creek, wetter conditions from water seeping through the dike and possible disturbance during dike construction could have affected shrub colonization. Beaver activity also could have affected the vegetation present, especially shrubs and trees, but no signs of beaver activity were observed in the area immediately downstream from the C-3 dike. Results of the vegetation survey supported personal observations that it is much wetter immediately below the C-3 Pool dike than elsewhere in the wetland. Since surface water historically has not been allowed to cross the C-3 dike, the increase in water is most likely due to a combination of seepage through the dike, regional ground-water discharge and precipitation. There was likely enough consistent ground-water discharge and water seeping through the dike to allow plant taxa more adapted to wet conditions (*e.g., Typha* spp.) to survive. Well-established *Typha* colonies were found only within 175 m of the C-3 dike.

EFFECTS OF THE C-3 POOL ON FLORISTIC QUALITY

Since the FQA computes the C value relative to the number of species sampled, it provides a means to characterize the natural quality of flora at a study site in addition to species richness. Herman *et al.* (1996) noted that most undeveloped land in Michigan registers a FQI value of less than 20 and has minimal significance from a natural quality perspective, meaning that it is not likely to be critical to the long-term survival of Michigan's native biodiversity. Areas with a FQI value higher than 35 are floristically important from a statewide perspective, and areas with a FQI value greater than 50 are extremely rare and represent a significant component of Michigan's native biodiversity (Herman *et al.*, 1996).

Although some differences were noted, our results did not support our hypothesis that reduced variability of water-level fluctuations caused by the C-3 Pool would negatively impact floristic quality. The native FQI values calculated in this study ranged from 21.8 to 27.7. Although rich fens are often thought to have a high floral species richness, the FQI values for the study sites in this rich fen were not high, likely because the influence of surface water throughout the system did not support a diversity of ground-water-dependent fen species. Surface-water inputs (*e.g.*, precipitation and seepage through the dike) supplemented ground water to maintain a full creek channel for most of the year, even in the areas down slope from the C-3 Pool. The range in FQI values among the study sites therefore was limited, suggesting that the C-3 Pool was not greatly affecting the floristic quality of the wetlands immediately downstream from it.

Some plant species were found only in the MC1 transect, and some species were found only in the sites below the C-3 Pool. Examination of these plant taxa revealed differences in the number of weedy species present upstream and downstream from the pool. The taxa that occurred only in MC1 were quite weedy, except *Glyceria canadensis*, *Rumex orbiculatus* and *Poa alsodes*. Most of the species also had a greater W (wetness) value. Since smaller wetness values represent a preference for wetter habitats, our results suggest that this site is slightly drier than the other sites below the C-3 Pool. From analysis of the geographic location of the weedy species, it became evident that most of the weedy species were found in the 60-m east transect in MC1. The 60-m-east transect bordered on upland, so many of the taxa sampled were tolerant of the drier conditions found near upland areas. The low level of disturbance downstream from the pool minimized the invasion of weedy species.

The pool did not seem to affect the frequency or distribution of adventive plant species. In fact, adventive species were not a large component of any of the wetland plant communities. Only 8% of the species sampled at MC1 and 11% of those at MC2 were adventives. No adventive species were found at the other two sites, likely because they remain relatively undisturbed. Their geographic location buffers them from the dike and other human disturbances associated with the C-3 Pool and, therefore, limits the opportunities for adventive species to colonize.

EFFECTS OF BEAVER ACTIVITY

Finally, the effects of beaver dams and beaver activity on wetland plant communities were examined by comparing the data collected at MC3 with the data collected at MC4. The MC3 site was situated immediately upstream from a beaver dam in the creek, whereas MC4 was situated such that there was minimal influence from beaver activity. The entire reach of creek supports beaver populations, so it was impossible to select a site that totally excluded beaver influence. Examination of the shrub data revealed the most information about the effects of beaver dams. The MC3 site, upstream from a dam, had half the number of shrub species and a much lower shrub importance value than MC4, immediately downstream from a dam. It is possible either that the beaver had already cut down all of the shrubs within reach of the beaver pool or that most shrubs do not grow as well in the flooded wetlands immediately upstream from a beaver dam. A combination of these two possibilities, however, is the most probable answer. Fewer shrubs were observed at MC3 likely because beaver removed existing shrubs after the dam was built and regeneration was inhibited by the consistently high water levels caused by the dam. The number of cut stems is unknown since this study sampled only living shrubs and trees. There were likely at least a few shrubs and small trees present before the dam was built, otherwise there would not have been enough food and dam-building material (*i.e.*, shrubs and trees) to support a beaver population. The water backed up behind the dam probably inhibited new shrubs from growing from seed, which caused the number of shrubs to remain low. Because shrubs were not competing for light and space, sedges and other wetland plants tolerant of standing water became established.

CONCLUSIONS

The application of geospatial technologies, quantitative plant sampling and floristic quality analyses led to a much clearer understanding of how the alteration of the natural hydrology impacted Marsh Creek and surrounding wetlands. Our results supported the hypothesis that the wetland vegetation downstream from the C-3 Pool, which hasn't had natural water-flow patterns since the early 1940s, would have lower species richness than wetland vegetation upstream from the pool. The seasonal water-level fluctuations and associated disturbances found on upstream portions of Marsh Creek were moderated downstream by the presence of the pool. The moderated water-level fluctuations, in addition to the presence of limited numbers of upland areas, contributed to fewer plant taxa in the wetlands downstream from the pool. Anticipated differences in the floristic quality between upstream and downstream areas, however, were not apparent. The FQA analyses showed that the area downstream from the pool was floristically similar to the upstream area, except for an elevated number of weedy species above the pool that was likely correlated to the natural water-level fluctuations of Marsh Creek and the presence of upland islands. Similarly, our results showed that wetland vegetation in the two areas had similar distribution across physiognomic groups, with one surprising exception. Clonal shrubs (*e.g.*, *Spiraea alba*) were much more common in the area upstream from the pool rather than in the anticipated downstream areas.

Not only was our hypothesis regarding increased tree and shrub growth downstream from the pool not supported, our results showed exactly the opposite. Sedges dominated the physiognomy of the plant communities in the downstream wetland, suggesting that conditions were most suited to support a limited suite of plant species that were most adapted to the relatively static hydrologic conditions. The natural water-level fluctuations occurring in the upstream wetlands promoted a greater variety of vegetation including a large number of shrubs.

Beaver dams in the channel, however, reduced the number of shrub species in areas immediately upstream from the dams below the C-3 Pool. Flooding behind and around the dams allowed beavers to use bordering shrub communities for forage and building material and minimized shrub regrowth. The two study sites below the C-3 Pool with the fewest shrubs were located immediately upstream from a beaver dam (MC3) and immediately downstream from the C-3 Pool (MC2).

Seepage through the C-3 dike and localized ground-water discharge created conditions very similar to those observed around the beaver dams. In essence, the dike containing the C-3 Pool acted like an enormous beaver dam except that it did not allow seasonal flooding episodes to occur. The big difference between this dike and a beaver dam is that the pool dike contains a water-control structure that can be operated in a manner that minimizes the impact to downstream creeks and wetlands. Releasing water from the pool into the original

Marsh Creek channel at certain times and in certain amounts that mimic the natural flow regime would be expected to promote greater plant species richness and minimize the negative impacts of the dike.

Acknowledgments.—We thank Mike Tansy for his support while working on the refuge and Mike Sweat for sharing his knowledge of hydrology. We are thankful to Eugene Jaworski and Yichun Xie for lending their expertise in GIS and wetland ecology. We are grateful to Steve Chadde, Matt Whipple, and Ryan McDonald for their assistance with field work and Walt Loope for review of an early version of this manuscript. This article is Contribution 1177 of the USGS Great Lakes Science Center.

LITERATURE CITED

AMOROS, C., G. BORNETTE AND C. P. HENRY. 2000. A vegetation-based method for ecological diagnosis of riverine wetlands. *Environmental Management,* **25**(2):211–227.

ANDERSON, S. H. 1982. Effects of the 1976 Seney National Wildlife Refuge wildfire on wildlife and wildlife habitat. U. S. Department of Interior, Fish and Wildlife Service, Resource Publication 146, Washington, D. C. 28 p.

BARNES, B. V. AND W. H. WAGNER. 1981. Michigan trees: a guide to the trees of Michigan and the Great Lakes Region. University of Michigan Press, Ann Arbor. 383 p.

BARRAT-SEGRETAIN, M. H. AND C. AMOROS. 1996. Recovery of riverine vegetation after experimental disturbance: a field test of the patch dynamics concept. *Hydrobiologia,* **321**:53–68.

BERQUIST, S. 1936. The Pleistocene history of the Tahquamenon and Manistique drainage region of the northern peninsula of Michigan. Michigan Geological Survey Publication 40, Geological Survey 34. 140 p.

BORNETTE, G., C. AMOROS AND N. LAMOUROUX. 1998. Aquatic plant diversity in riverine wetlands: the role of connectivity. *Freshwater Biology,* **39**:267–283.

CONNELL, J. H. 1978. Diversity in tropical rain forests and coral reefs. *Science,* **199**:1302–1310.

DUTTON, C. E. 1968. Summary report on the geology and mineral resources of the Huron, Seney, Michigan Islands, Green Bay, and Gravel Island National Wildlife Refuges of Michigan and Wisconsin. *U. S. Geological Survey Bulletin,* **1260**-I:1–14.

FJETLAND, C. A. 1973. History of water management at the Seney National Wildlife Refuge. Master of Science Thesis, Michigan State University. 106 p.

GLEASON, H. A. AND A. CRONQUIST. 1991. Manual of vascular plants of Northeastern United States and adjacent Canada, 2nd ed. New York Botanical Garden, New York. 910 p.

GRUBB, P. J. 1977. The maintenance of species-richness in plant communities: the importance of the regeneration niche. *Biological Reviews,* **52**:107–145.

HARRIS, S. W. AND W. H. MARSHALL. 1963. Ecology of water-level manipulations on a northern marsh. *Ecology,* **44**(2):331–343.

HERMAN, K. D., L. A. MASTERS, M. R. PENSKAR, A. A. REZNICEK, G. S. WILHELM AND W. W. BRODOWICZ. 1996. Floristic quality assessment with wetland categories and computer application programs for the State of Michigan. Michigan Department of Natural Resources, Wildlife Division, Natural Heritage Program and U. S. Department of Agriculture, Natural Resources Conservation Service, Rose Lake Plant Materials Center, MI. 50 p.

HEINSELMAN, M. L. 1965. String bogs and other patterned organic terrain near Seney, upper Michigan. *Ecology,* **46**(1–2):185–188.

HOUGH, J. L. 1958. Geology of the Great Lakes. University of Illinois Press, Urbana. 313 p.

HUDON, C. 1997. Impact of water level fluctuations on St. Lawrence River aquatic vegetation. *Canadian Journal of Fisheries and Aquatic Sciences,* **54**(12):2853–2865.

JANSSON, R., C. NILSSON, M. DYNESIUS AND E. ANDERSSON. 2000. Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. *Ecological Applications,* **10**:203–224.

JEGLUM, J. K. 1975. Vegetation-habitat changes caused by damming a peatland drainageway in northern Ohio. *The Canadian Field-Naturalist,* **89**:400–412.

KEDDY, P. A. AND A. A. REZNICEK. 1986. Great lakes vegetation dynamics: the role of fluctuating water levels and buried seeds. *Journal of Great Lakes Research,* **12**(1):25–36.

KOWALSKI, K. P. 2000. Analysis of wetland plant communities and environmental conditions: a wetland restoration project in Seney National Wildlife Refuge. Master of Science Thesis, Eastern Michigan University. 84 p.

LOUCKS, O. L. 1970. Evolution of diversity, efficiency, and community stability. *American Zoologist,* **10**: 17–25.

NILSSON, C., A. EKBLAD, M. GARDFJELL AND B. CARLBERG. 1991. Long-term effects of river regulation on river margin vegetation. *Journal of Applied Ecology,* **28**:963–987.

NILSSON, C., R. JANSSON AND U. ZINKO. 1997. Long-term responses of river-margin vegetation to water-level regulation. *Science,* **276**:789–800.

OWENS, T. AND K. D. HOP. 1995. Long term resource monitoring program standard operating procedures: field station photointerpretation. National Biological Service, Environmental Management Technical Center, Onalaska, WI, USA. LTRMP 95-P008-2. 7 p.

POLLOCK, M. M., R. J. NAIMAN AND T. A. HANLEY. 1998. Plant species richness in riparian wetlands—a test of biodiversity theory. *Ecology,* **79**(1):94–105.

REED, P. B., JR. 1988. National list of plant species that occur in wetlands: North Central (Region 3). U. S. Fish and Wildlife Service Biological Report 88(26.3). 99 p.

SHAY, J. M., P. M. DE GEUS AND M. R. M. KAPINGA. 1999. Changes in shoreline vegetation over a 50-year period in the Delta Marsh, Manitoba in response to water levels. *Wetlands,* **19**(2):413–425.

SINCLAIR, W. C. 1959. Reconnaissance of the ground-water resources of Schoolcraft County, Michigan. Michigan Geological Survey Progress Report 22. 84 p.

SWEAT, M. J. 2001. Hydrology of C-3 watershed, Seney National Wildlife Refuge, Michigan. Water-Resources Investigations Report 01-4053. 25 p.

SYPULSKI, J. L. 1941. The Seney National Wildlife Refuge. New York State Ranger School Alumni News, p. 24–29.

U. S. FISH AND WILDLIFE SERVICE. 2001. Biological integrity, diversity, and environmental health. Service Manual. National Wildlife Refuge System Part 601 FW3. Release Number 366. 7 p.

VAN DER VALK, A. J. AND C. B. DAVIS. 1976. Changes in the composition, structure, and production of plant communities along a perturbed wetland coenocline. *Vegetatio,* **32**(2):87–96.

WILCOX, D. A. AND J. E. MEEKER. 1991. Disturbance effects on aquatic vegetation in regulated and unregulated lakes in northern Minnesota. *Canadian Journal of Botany,* **69**:1542–1551.

WILHELM, G. S. AND L. A. MASTERS. 1995. Floristic quality assessment in the Chicago Region and application computer programs. Morton Arboretum, Lisle, IL. 17 p.

SUBMITTED 5 MARCH 2002 17 March 2003 ACCEPTED 5 MAY 2003