RESTORATION PRACTICE

Sedge/Grass Meadow Restoration on Former Agricultural Lands along a Lake Ontario Drowned-River-Mouth Tributary

Douglas A. Wilcox and Alexander J. Healy

ABSTRACT

Restoration of sedge/grass meadow habitat was implemented on former agricultural lands adjacent to a Lake Ontario drowned-river-mouth tributary at an elevation that historically supports this community type. Four hectares of land were disked in spring and seeded with diverse wetland mixes containing sedges, grasses, and forbs, with additional *Calamagrostis canadensis* (bluejoint) and *Carex stricta* (upright sedge) seeds added. Seedling plugs of *C. canadensis* and *C. stricta* were also planted. Mowing at a height of 45 cm to control tall, invasive annual weeds prior to seed-set was conducted as an adaptive management practice. Three years after implementation, *C. canadensis* and *C. stricta* were not found, but seeded *Carex vulpinoidea* (fox sedge) was dominant, and seeded *Carex lupulina* (hop sedge) and *Carex lurida* (shallow sedge) were also present. Most invasive annuals were rare, but canopies created by larger perennials may pose future problems. Although a greenhouse seed-bank emergence study was conducted, field sampling suggested that plants growing on adjacent lands were a better predictor of future plant communities, with select seeded species serving as a secondary predictor. Failure of some sedges to survive after seeding likely was not related to stratification or diurnal temperature range. However, inadequate soil moisture related to soil type and a second-year drought likely played a role, as might loss of viability of seeds during storage. Future efforts on similar lands might use fresh *Carex* seeds broadcast in autumn for over-winter stratification, and specially developed seed mixes could focus on species that established at the site and native species found nearby, while avoiding some potential problem species.

Keywords: *Carex*, Great Lakes, invasive species, seed bank, wetland restoration

Restoration Recap

- Sedge/grass meadows in Lake Ontario wetlands have been reduced by cattail invasion following regulation of lake levels, creating a need for restoration of this habitat type.
- We undertook restoration on former agricultural lands near the lake at an elevation range that typically maintains sedge/grass meadow without cattail invasion.
- In spring, 4 ha of land were disked, seeded with diverse wetland mixes, and planted with seedling plugs of *Calamagrostis canadensis* (bluejoint) and *Carex stricta* (upright sedge) at approximate 1-m spacing.
- Three years after implementation, seeded *Carex vulpinoidea* (fox sedge) was dominant in some areas, seeded *Carex lupulina* (hop sedge) and *Carex lurida* (shallow sedge) were present, the two planted species were not found, and invasive annuals were rare, likely due to mowing at a 45-cm height before seed-set.
- In addition to periodic inadequate soil moisture, overall results may have been affected by viability of seeds during storage, thus suggesting that future efforts of this type might consider seeding carefully-designed seed mixes in autumn for over-winter stratification.
- Results also suggest that species found on adjacent lands should be evaluated as a potential source of new plants.

Supplementary materials are freely available online at: http://uwpress.wisc.edu/journals/journals/er-supplementary.html

Ecological Restoration Vol. 34, No. 2, 2016
ISSN 1522-4740 E-ISSN 1543-4079

In the Laurentian Great Lakes, diversity of wetland plant communities is maintained by climate-driven, quasi-periodic fluctuations in lake levels (Baedke and Thompson 2000, Wilcox et al. 2007, Johnston et al. 2012). High lake levels occurring every several decades eliminate upland invaders and canopy-dominating emergent plants, and

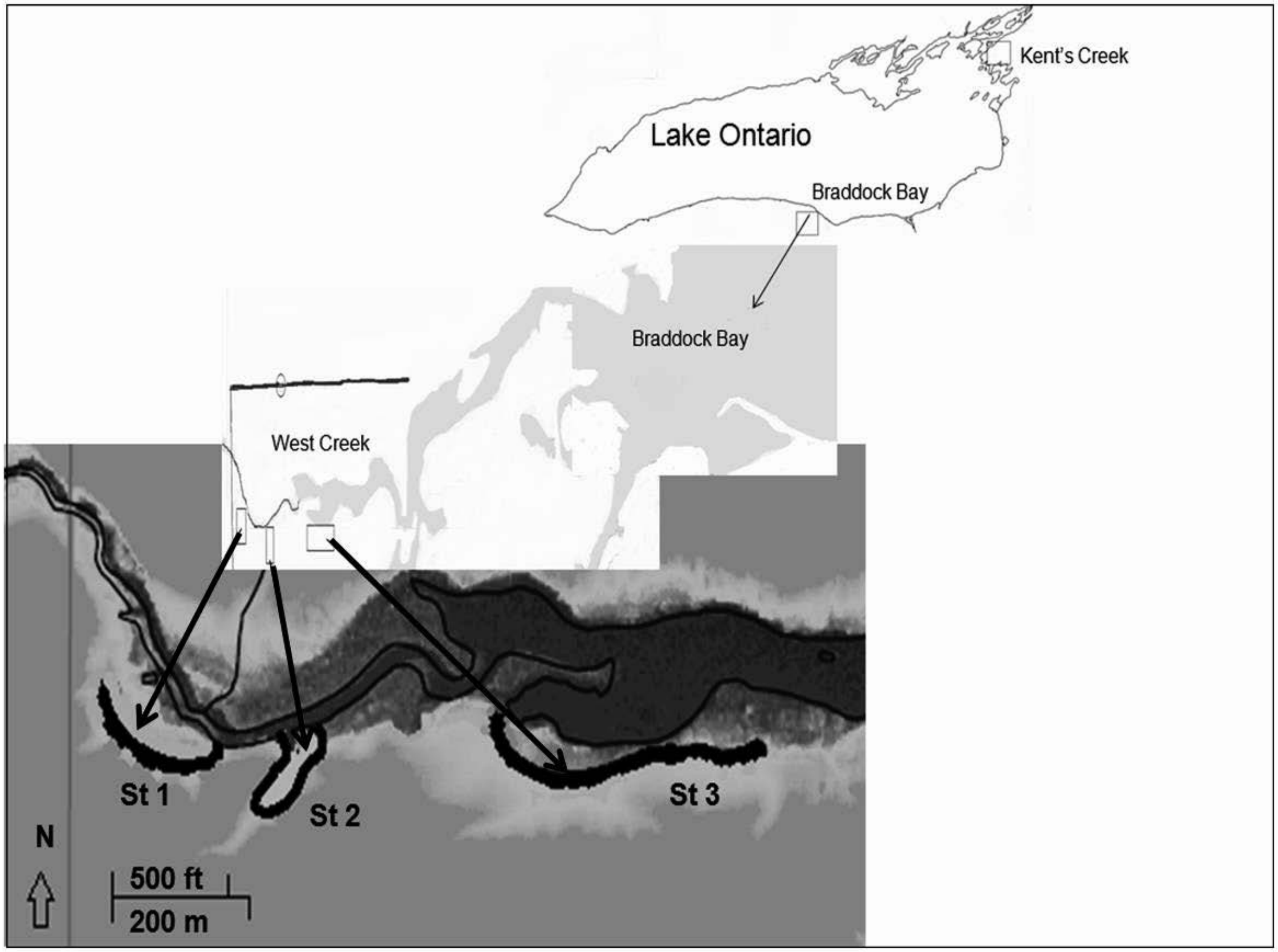

Figure 1. Map of study sites 1, 2, and 3 adjacent to the shore of West Creek, a drowned river mouth tributary to Braddock Bay along the south shore of Lake Ontario in Monroe County, New York, USA. The southern perimeter of each site is delineated by a line created from GPS points demarcating an elevation of 75.60 m (IGLD85), the typical upper limit of sedge/grass meadow in Lake Ontario. Also shown is the location of reference site Kents Creek in northeast Lake Ontario.

intervening low levels allow less competitive understory plants to grow from seeds or propagules (Keddy and Reznicek 1986, Wilcox and Nichols 2008). At higher elevations in the wetlands, sedges and grasses hold a competitive advantage over more robust plants, such as cattails, because they can tolerate low lake-level periods when soil moisture is low (Wilcox et al. 2008).

Wetland sedge/grass meadow habitat along the shores of Lake Ontario has decreased substantially since regulation of lake levels began with operation of the St. Lawrence Seaway in about 1960 (Wilcox et al. 2008). Regulation of Lake Ontario water levels under Plan 1958DD beginning in 1960 compressed the range from approximately 1.5 m to about 0.7 m and eliminated years with low lake levels (Wilcox et al. 2005). As a result, sedges and grasses at higher elevations along the wetland shore lost their competitive advantage and were largely replaced by cattails (primarily *Typha ×glauca*) that are never subjected to low water conditions. State and federal agencies have thus placed an emphasis on restoring this habitat type, which provides critical habitat for species such as *Esox lucius* (northern pike) and *Cistothorus platensis* (sedge wren) (Environment Canada 2002). This project took advantage of a unique opportunity to attempt such restoration on low-lying agricultural lands where sedge/grass meadow would likely have existed historically.

In January 2009, the New York State Department of Environmental Conservation (NYSDEC) acquired a parcel of agricultural land adjacent to a tributary to Lake Ontario near Rochester, New York, with plans to restore it to provide wildlife habitat. Although much of the property was upland, low-lying areas near the creek presented an opportunity for sedge/grass meadow restoration. Studies on restoration of sedge-dominated communities are not uncommon, especially in the midwestern United States (e.g., Ashworth 1997, Budelsky and Galatowisch 1999, van der Valk et al. 1999, Bohnen and Galatowitsch 2005, Kettenring and Galatowitsch 2007a, Aronson and Galatowitsch 2008, Hall and Zedler 2010). However, little has been done on this topic in Great Lakes wetlands and is rare on former agricultural lands (Wang et al. 2013). Our objectives in this work were to restore wetland sedge/grass meadow on low-lying agricultural lands, evaluate the results, and explore means of improving survival of target species to enlighten future efforts to restore this plant community type.

Methods

Study Sites

The study area was former agricultural land, typically farmed for corn or soybeans, adjacent to West Creek at its confluence with Braddock Bay of Lake Ontario in Hilton, Monroe County, New York (Figure 1). The creek is a drowned river mouth influenced by both the hydrology of the lake and flow from the creek (Albert et al. 2005). Three somewhat elongated sites at lower elevation and separated by 100 to 250 m were deemed suitable for restoration to wetland sedge/grass meadow in a January 2009 site visit. Site boundaries were surveyed and staked in May 2009 to fall within the 75.35 to 75.60 m (International Great Lakes Datum 1985 (IGLD85)) elevation range where sedge/grass meadow has been shown to be resistant to cattail invasion in Lake Ontario wetlands (Wilcox and Xie 2007). A total of 4 ha in three units was delineated using a Global Positioning System (GPS), and data were entered into a Geographic Information System (GIS) to display GPS waypoints and provide map boundaries in which established vegetation and Light Detection and Ranging (LIDAR) elevation information could be viewed. Elevation data were obtained in the North American Datum of 1983 (NAD 83) and converted to IGLD85 for use in mapping (NGS 2012).

The three study sites contained upland weeds and areas with natural wetland vegetation but showed little sign of wetland invasive species, except for small patches of *Lythrum salicaria* (purple loosestrife) near the creek at one site. The shores of West Creek adjacent to the former agricultural field contained emergent vegetation (mostly cattails); the upland side consisted of more than 81 ha of higher elevation cropland targeted by NYSDEC for grassland restoration, which would provide a buffer zone fringing the proposed wetland restoration areas.

Site 1 (Figure 1) was approximately 1.2 ha in area and contained a mixture of dry and wet habitats at the base of a small hill, with clay/silt soils on the upland side and more sandy loam closer to the creek. The wetter portion of the site supported stands of *T.* ×*glauca* and *Bolboschoenus fluviatilis* (river bulrush). Sites 2 and 3 were on flatter land with only slight elevation gradients. Site 2 (0.8 ha) had uniform clay/silt soil and contained a stand of *B. fluviatilis* in the wettest area. Site 3 (2.0 ha) had a sandy loam soil close to the creek, which gradually became clay/silt with distance from the creek. No large, obvious stands of wetland emergent vegetation were noted, but small remnants of sedge/grass meadow were observed near the creek.

Reference Site

Appropriate reference conditions were needed to depict natural variability in emergent communities and provide insight into potential trajectories resulting from restoration to wetland sedge/grass meadow (Clewell and Aronson 2013). Lake Ontario/upper St. Lawrence River wetlands classified as drowned river-mouth served as published regional wetland reference data (Wilcox et al. 2005). A study site located at Kents Creek (see Figure 1) served as an immediate reference. Its broad basin provided extensive areas of unflooded wetland at an elevation conducive to the growth of sedges and grasses but too dry to support cattails (Wilcox et al. 2008). Wetland sedge/grass meadow vegetation was surveyed for percent cover in an area of Kents Creek in July 2010 using ten random, haphazardly-placed 1-m² quadrats (e.g., Wilcox et al. 2002, Wilcox 2012) to identify species and estimate percent cover.

Seed-Bank Emergence Study

A greenhouse seed-bank emergence study was conducted to identify wetland and upland plant species that could potentially establish in the restoration sites. Near-surface soils were collected to approximately 5-cm depth (Baldwin et al. 2001) in May 2009 from locations at the three sites. Four soil samples were collected at Sites 1 and 3, while two soil samples were collected at smaller Site 2. Following collection, soil samples were placed in cold storage for three months.

Soil samples were spread evenly to a depth of 2.5 cm over 1.3 cm of sterile potting soil in 25.4 cm × 25.4 cm trays (with perforations), placed in continuously flooded 25.4 cm × 52 cm trays, and elevated sufficiently to create continuously moist but unflooded conditions in sample soils (Leck 2003). Light was provided by sun and artificial means on a 06:00 to 21:00 daily schedule. The study began in September 2009 to avoid potential negative temperature effects on growth during the hot summer months (Nicol et al. 2003, Bakker et al. 2005) and was terminated in early July 2010.

Sample trays were monitored at 3- to 4-day intervals to ensure that no plants emerged and died before being observed. All specimens (stems) were counted and identified to the lowest possible taxonomic level (generally species) during the first true-leaf stage before being removed, unless unidentifiable. Seedlings deemed difficult to identify were replanted to allow further growth until the plants flowered, unless there was only one noticeable species representative, thus avoiding premature death due to disturbance. Some plants were not removed until study completion because they never flowered and uncertainty existed concerning their identification (e.g., *Carex,* which has failed to flower during other seed-bank emergence studies [Leck 2003]).

Restoration Site Implementation

The three restoration areas were disked in May 2010 to expose fresh soil and remove much of the old plant growth. The natural emergent vegetation at Sites 1 and 2 was not disked, and small areas at all three sites were disked but not planted to serve as controls. Southern Tier Consulting (West Clarksville, New York–approximately 130 km from the restoration site) prepared 3.9 kg of Northeast Wetland Diversity Mix and 12.7 kg of Northeast Wetland Hummock Mix (Table S1) for the planted areas that contained a variety of native wet-meadow species (USDA and NRCS 2010, webSURGE, LLC 2012). Before sowing the mixtures, both were mixed together with about 200 g of *Calamagrostis canadensis* (bluejoint) and 100 g of *Carex stricta* (upright sedge) seeds and moist sand and then cold-stratified for six weeks to promote germination. A shoulder broadcast grass-seed spreader was used to sow seeds in the planted areas in June 2010, when temperature conditions suitable for germination were present. Natural wetland (N) and disked control (C) areas were not seeded.

Calamagrostis canadensis (1000) and *C. stricta* (2000) seedling plugs were also purchased from Southern Tier Consulting and planted at approximately 1-m intervals in the three sites in June 2010. Planting was avoided in areas with standing water and in natural wetland and control areas. At Site 3, planting was confined closer to the water edge, near denser vegetation, due to the potential threat of herbivory by *Branta canadensis* (Canada Geese).

Pre-Restoration Sampling

Pre-restoration plant communities were characterized in July 2009 by field sampling for percent cover in sites where they occurred, using random, haphazardly-placed quadrats within the four dominant vegetation types (bulrush [BR], clover [CL], old field [OF], and sedge [SD]) across the three sites. All ten OF quadrats were sampled in Site 1, along with six BR and four CL quadrats. Four BR and two CL quadrats were sampled in Site 2. All ten SD quadrats were sampled in Site 3, in addition to four CL quadrats.

Post-Implementation Sampling

Post-implementation sampling, initially conducted during August 2010 (data labeled by site, community type, year; e.g., 1P10), was similar to pre-restoration sampling and used random, haphazardly-placed quadrats to estimate species percent cover in the three planted areas (1P10, 2P10, 3P10), untreated natural wetland (1N10, 2N10), and control areas (1C10, 2C10, 3C10). Sampling of each treatment type consisted of 20 quadrats, with the exception of 10 quadrats in smaller and less diverse Site 2. Sampling in the smaller control areas consisted of three quadrats in 1C10 and 2C10 and four quadrats in 3C10. Mowing in early August 2010 by the former property owner at 45-cm height to control tall annual weeds in Site 3 created a third variable (3PM10), in which 20 quadrats were sampled that year, while reducing the remaining 3P10 to 10 quadrats. Post-implementation sampling in August 2011, 2012, and 2013 used 20 quadrats in the Site 3 planted area. All other sampling was conducted as in previous years, with all planted areas at Sites 1, 2, and 3 mowed at 45-cm height in August each year after sampling.

Data Analyses

Seed-bank emergence data were assessed as mean stem counts by sampling site for soils collected at each of the three study sites. For field sampling data, the relative contribution of an individual species to surveyed community composition was determined using Importance Values (IV), which were calculated as the sum of relative frequency and relative mean percent cover for all groupings of data (treatment) and used to develop summary statistics. Wetland indicator status for plant species was determined according to Lichvar (2013).

Community data from 2009 pre-restoration through 2013 post-restoration study site samples were also analyzed in sample × Importance Value matrices using non-metric multidimensional scaling (NMDS) (McCune and Grace 2002) with autopilot on, Sorensen distance, and no species weighting. Forty-three plant taxa with a frequency of at least two quadrat occurrences that were among the five most important taxa in at least one sample were included in the ordination. Axis 1 and 2 scores for study site samples were graphed in a two-dimensional plot to show the species composition and dominance dissimilarities or similarities among sampled communities. Axis 1 and 2 scores for plant taxa were also graphed in a two-dimensional plot to explain the variation shown in the study site community plot.

Results

Reference Site

Sampling of the reference site at Kents Creek identified 13 taxa, including five taxa not found at the study site. *Carex lacustris* (hairy sedge) (IV = 67.6) and *C. canadensis* (58.2) were dominant, while *Impatiens capensis* (jewelweed) (19.0), *Lathyrus palustris* (marsh pea) (15.8) and *Verbena hastata* (swamp verbena) (10.0) were prominent (Table S2).

Seed-Bank Emergence Study

At Site 1, the seed-bank emergence study identified 22 taxa, including 10 species that did not occur in quadrats later sampled in the field. *Cerastium glomeratum* (sticky chickweed) was dominant (mean stem count from four samples = 34.3), while *Festuca filiformis* (fineleaf sheep fescue) (11.8), *Panicum flexile* (wiry panicgrass) (9.8), *Plantago major* (common plantain) (8.3) and *Carex* spp.

(6.8) were prominent (Table S3). At Site 2, the seed-bank study identified 21 taxa, including 14 species that did not occur in field sampling. *Carex* spp. was dominant (mean stem count from two samples = 75.0), while *L. salicaria* (40.0) and *F. filiformis* (15.0) were prominent. At Site 3, 24 taxa were identified in seed-bank samples, including 14 species not found in the field. *Cerastium glomeratum* (mean stem count from four samples = 51.0) was dominant, while *P. flexile* (22.3), *F. filiformis* (15.5), and *P. major* (11.3) were prominent.

Pre-restoration Plant Communities (OF, CL, SD, BR)

The old field (OF) community sampled at Site 1 in 2009 contained 30 taxa (Table S4). *Juncus tenuis* (poverty rush) (IV = 45.4) and *Ambrosia artemisiifolia* (annual ragweed) (28.7) were dominant, but *Alisma triviale* (northern water plantain) (19.3), *Trifolium pratense* (red clover)(15.8), *Salsola tragus* (prickly Russian thistle) (13.4), and *Hypericum perforatum* (common St. Johnswort) (10.3) were also prominent. Five OF species also occurred in seed-bank samples, and 17 OF taxa were found in 2010–2013 sampling of the restored areas.

The clover (CL) community sampled in 2009 identified 22 plant taxa (Table S4). *Trifolium pratense* (IV = 98.1 Site 1, 103.6 Site 2, 88.9 Site 3) was dominant, although *Rumex obtusifolius* (bitter dock) was also prominent at Site 1 (42.4) and Site 2 (60.5). Other prominent species included *H. perforatum* (15.0) at Site 1, *Tanacetum vulgare* (common tansy) (18.9) at Site 2, *Agrostis stolonifera* (creeping bentgrass) (16.3) at Site 3, and *A. artemisiifolia* at all three sites (14.7, 16.9, 7.3). Five CL taxa were found in the seed-bank study, and 16 of the CL taxa were sampled in the restored areas in 2010–2013.

Sampling of the sedge (SD) community at Site 3 in 2009 identified 20 taxa (Table S4). *Carex* spp. (IV = 37.6) and *A. artemisiifolia* (37.6) were dominant, and *A. triviale* (18.8) and *Poa* spp. (18.7) were prominent. Three taxa were also found in the seed-bank study, and 13 taxa occurred in the restored areas sampled in 2010–2013.

Sampling of the bulrush (BR) community in July 2009 detected 18 plant species (Table S4). *Bolboschoenus fluviatilis* (IV = 95.1 Site 1; 73.8 Site 2) was dominant, but *C. canadensis* (53.4) was co-dominant at Site 2. Other prominent species included *Eutrochium purpureum* (sweetscented joe pye weed) (22.0) and *Equisetum arvense* (field horsetail) (14.7) at Site 1 and *Monarda fistulosa* (wild bergamot) (15.9) at Site 2, as well as *Persicaria lapathifolia* (curlytop knotweed) (14.3, 10.3) and *A. stolonifera* (13.8, 5.0) at both Sites 1 and 2. Only four BR species were found in the seed-bank study. Nine of the BR species were later found in sampling of natural wetland (N) in 2010–2013, and 13 BR species were sampled in the restored areas.

Natural Wetland Plant Communities (1N10, 1N11, 1N12, 1N13, 2N10, 2N11, 2N12, 2N13)

Plants communities in the natural (N) wetland areas at Site 2 largely overlapped with those of the pre-restoration area sampled as BR in 2009 but, at Site 1, included a stand of hybrid cattail (*T.* ×*glauca*) (Table S5). Site 1 sampling of 27 taxa in 2010 was reduced to 18 and 15 taxa the next two years and rebounded to 24 taxa in 2013. Site 2 remained nearly stable at 14, 12, and 12 taxa in 2010–2012 but increased to 22 taxa in 2013. Dominance at both sites changed little across years from 2010 to 2013, with IV of *B. fluviatilis* ranging from a low of 44.6 at Site 1 in 2010 to a high of 103.4 at Site 2 in 2011.

Control Area Plant Communities (C10, C11, C12, C13)

Sampling in 2010 of the control areas (C) that were disked but not planted identified 25 taxa, dominated by *A. artemisiifolia* (IV = 36.1 Site 1, 15.5 Site 2, 31.3 Site 3), *Trifolium pratense* (42.2 Site 1, 60.2 Site 2, 18.7 Site 3), *Hordeum jubatum* (foxtail barley) (21.0 Site 1, 18.6 Site 2, 26.1 Site 3), and *Xanthium strumarium* (rough cocklebur) (4.6 Site 1, 13.1 Site 2, 12.1 Site 3) (Table S6). Those species were much reduced in 2011 and 2012 sampling, and of them, only *X. strumarium* remained in 2013 sampling. *Agrostis stolonifera* (41.2 Site 1, 71.9 Site 2, 44.7 Site 3) became dominant in 2011–2013, *Epilobium hirsutum* (codlins and cream) was also dominant in 2012 (90.3 Site 1, 24.4 Site 2, 42.5 Site 3) but was not found in 2013. *Symphyotrichum puniceum* (purplestem aster) was also dominant in 2013 (69.6 Site 1, 32.3 Site 2, 27.0 Site 3). The number of taxa identified increased to 38 in 2011, returned to 25 in 2012, and was reduced to 20 in 2013.

Restored Site 1 Plant Communities (1P10, 1P11, 1P12, 1P13)

Sampling of Site 1 in 2010, two months after planting and seeding (1P10), identified 26 taxa (Table 1). *Trifolium pratense* (IV = 39.2), *A. artemisiifolia* (25.9), and *H. jubatum* (22.6) were dominant, and seedling *Carex* not yet identifiable to species were present (17.4). In 2011, sampling of 1P11 identified 36 taxa. *Agrostis stolonifera* (40.5) was dominant and *T. pratense* reduced in dominance (20.0); unidentified *Carex* spp. (18.9) and *Carex vulpinoidea* (fox sedge) (1.1) were present. Sampling in 2012 (1P12) identified 30 taxa. *Epilobium hirsutum* (49.8) and *A. stolonifera* (42.1) were dominant. Unidentifiable *Carex* was still found, but *Carex lupulina* (hop sedge) (2.0) had matured enough to be identifiable. In this drought year, total *Carex* (11.7) was much reduced from previous years. Six species that were prominent in the first two years were not found in 2012 sampling at Site 1, including previously dominant *H. jubatum*, while *T. pratense* was reduced to an IV of 2.0. In 2013, 1P13 sampling totaled 43 taxa (Table 1).

Table 1. Importance Values of taxa calculated from sampling of haphazardly-placed 1×1 m quadrats in planted (P) areas at restoration Sites 1, 2, and 3 adjacent to West Creek near Braddock Bay of Lake Ontario. Taxa with < 3 observations are not shown unless IV > 3, in the seed mix, or found in the seed-bank emergence study.

	P Site 1				P Site 2				P Site 3				PM Site 3
Taxa	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2010
Abutilon theophrasti	1.1	—	—	—	2.3	—	—	—	1.6	0.6	—	—	—
Acalypha rhomboidia	12.9	—	—	—	—	—	—	—	—	—	—	—	—
Agrostis stolonifera	—	40.5	42.1	31.6	—	44.3	40.2	31	—	7.4	19.9	31.5	—
Alisma triviale	3.2	—	—	—	1.4	—	1.8	—	—	—	—	—	—
Ambrosia artimesiifolia	25.9	3.6	4	4.1	33.1	5.2	—	7.3	39.8	9.5	3.0	—	20.6
Asclepias incarnata	—	0.7	—	—	—	—	—	1.4	—	0.6	1.4	—	—
Bidens spp.	7.3	2.3	—	—	6.4	7.4	—	—	—	0.8	—	—	—
Bidens frondosa	—	—	—	—	—	—	—	—	—	—	1.1	—	—
Bidens tripartita	—	0.7	—	0.7	—	—	—	1.1	—	—	0.6	0.8	—
Bolboschoenus fluviatilis	2.4	5.7	—	—	2.8	4.7	1.8	1.3	—	3.9	4.7	4.2	—
Bromus ciliatus	—	—	—	0.8	—	—	—	1.1	—	—	—	2	—
Calamagrostis canadensis	—	—	—	4.6	—	—	—	—	—	2.1	2.5	5.3	—
Calystegia sepium	—	1.3	4.9	1.2	—	3.6	7.4	12	—	5.2	5.3	6.6	—
Carex spp. (total)	17.4	18.9	9.7	0.8	36.5	26.3	25.3	—	18.2	33.6	6.8	—	29.2
Carex lacustris	—	—	—	1.8	—	—	—	—	—	—	—	—	—
Carex lupulina	—	—	2	—	—	—	1.7	7.5	—	—	6.7	6.5	—
Carex lurida	—	—	—	—	—	—	—	1.3	—	—	3.3	1	—
Carex vulpinoidea	—	1.1	—	27.5	—	—	4.2	35.6	—	—	19.3	34.1	—
Cicuta bulbifera	—	—	1	2	—	—	—	—	—	—	1.3	—	—
Cirsium vulgare	—	—	2.1	—	—	—	—	1.3	—	—	0.7	—	—
Convolvulus arvensis	1.5	1.6	—	0.7	1.4	—	—	—	—	0.9	—	—	2.7
Cyperus odoratus	5.2	—	—	0.7	4.3	—	—	—	8.9	3.4	—	—	0.8
Echinochloa crusgalli	—	—	—	—	—	—	—	—	3.1	—	—	—	—
Elymus canadensis	—	—	2.6	2.1	—	—	1.8	—	—	1.4	—	—	—
Epilobium hirsutum	3.6	14	49.8	6.3	—	1.8	48.9	2.3	3.1	1.2	33.1	—	—
Equisetum sylvaticum	*2*	5.1	3.9	3.6	—	—	—	—	—	—	—	—	2.1
Eupatorium perfoliatum	—	2.2	4.7	1.5	—	1.8	5.8	1.2	—	1.9	7.5	3.4	—
Euthamia graminifolia	—	—	1.8	—	—	—	8.4	—	—	1.3	3.5	—	—
Fraxinus pennsylvanica	—	—	1	0.7	—	—	—	—	—	—	—	1.8	—
Glyceria grandis	—	—	—	1.8	—	—	—	—	—	—	—	—	—
Glyceria striata	0.8	—	—	—	6.6	—	—	—	—	—	—	—	—
Hordeum jubatum	22.6	3.5	—	—	22.6	1.6	—	—	30.9	10.3	—	—	34.3
Impatiens capensis	—	—	—	—	—	—	—	2.4	—	1.2	—	0.8	—
Juncus canadensis	—	—	1.8	4.2	—	—	—	3.5	—	—	—	—	—
Juncus effusus	—	0.7	2.4	2.4	—	—	2.2	2.4	—	—	—	0.8	—
Juncus tenuis	1.8	1.8	6.5	—	—	5.9	5.7	—	—	1.4	0.6	—	—
Lactuca serriola	—	6.4	18.9	15.1	—	—	2.9	6.4	—	—	1.2	—	—
Lathyrus palustris	—	—	—	—	—	1.6	6.7	8.7	—	—	22.3	50.9	—
Leersia oryzoides	—	—	2.9	—	—	—	—	—	—	—	—	—	—
Linum usitatissimum	—	15.5	—	1.4	—	20.6	—	—	—	—	0.7	—	—
Lycopus americanus	—	15.8	—	0.9	—	—	—	—	—	—	0.8	—	—
Lycopus virginicus	5.3	—	—	—	—	—	—	—	—	—	—	3.1	0.7
Lysimachia ciliata	—	2.2	1	—	—	—	—	—	—	5.7	0.6	—	0.8
Lythrum salicaria	—	0.7	1.5	0.8	2.9	—	—	1.1	—	—	—	—	—
Melissa officinalis	—	0.9	1	7	—	—	—	—	—	—	1	—	—
Oxalis corniculata	1.7	0.7	1.1	0.8	2.7	1.5	5	2.4	—	—	1.8	0.8	0.7
Panicum capillare	4.2	—	—	4.4	2.7	3.5	—	—	1.6	—	—	—	2.9
Plantago major	—	4.4	2	0.8	—	—	1.7	1.2	—	3.1	3.6	—	—
Poaceae spp.	5.4	—	—	—	2.3	—	—	—	—	2.1	1.4	—	2.5
Persicaria amphibia	—	—	—	0.9	1.8	1.8	1.8	1.3	—	1.3	1.3	7.3	—
Persicaria lapathifolia	14	3.6	—	2	10.6	—	—	2.3	8.6	0.8	—	—	5.9

Taxa	P Site 1				P Site 2				P Site 3				PM Site 3
	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2010
Populus deltoides	—	0.7	—	0.8	—	—	—	—	—	0.6	0.6	1.7	—
Rumex obtusifolius	6.6	0.9	1.2	0.8	—	6.9	—	—	—	4.9	3.4	1.6	7.6
Salsola tragus	—	—	—	—	—	4.2	—	—	—	—	—	—	—
Setaria faberi	3.2	—	—	—	—	—	—	—	—	—	—	—	—
Solanum carolinense	—	—	—	3.7	1.3	—	—	—	—	2.7	1.6	1.6	1.2
Solidago spp.	—	—	—	—	—	—	—	2.4	—	—	4.7	—	—
Solidago canadensis	—	—	17.6	26.7	—	8	8.8	23.1	—	—	9.8	7.6	—
Solidago nemoralis	—	0.9	—	—	—	—	—	2.4	—	—	0.7	—	3.7
Solidago rugosa	—	2.4	—	—	—	2.3	—	—	—	8.2	—	—	—
Stachys tenuifolia	—	—	—	—	—	—	—	—	—	—	5.1	—	—
Symphyotrichum spp.	—	3.2	—	—	4.2	—	—	1.1	—	—	—	7.9	2.9
Symphyotrichum lanceolatum	—	—	2.6	3	—	1.7	4.2	5.4	—	0.6	0.7	—	—
Symphyotrichum puniceum	—	—	—	22.3	—	—	—	8.3	—	—	—	7.6	—
Taraxacum officinale	1.9	0.9	4.7	3.7	—	6.1	8.7	4.8	—	1	1	2.6	0.8
Trifolium pretense	39.2	20	2	—	30.1	—	2	2.5	26.6	12	5.7	—	17.3
Trifolium repens	—	1.7	—	—	—	14.9	1.7	1.7	—	6.8	5.5	0.8	—
Verbena hastata	—	0.7	—	—	—	—	2.6	—	—	3.1	0.7	—	—
Vicia tetrasperma	—	—	—	—	—	—	—	—	8.3	13.9	—	—	8
Xanthium strumarium	6.9	14.4	—	—	20	20.5	—	10.1	44.9	37.1	1.9	1.7	12.6

Agrostis stolonifera (31.6), *C. vulpinoidea* (27.5), *Solidago canadensis* (Canada goldenrod) (26.7) and *S. puniceum* (22.3) were dominant. Previously prominent *T. pratense* and *X. strumarium* were not observed in 1P13 sampling, and *A. artemisiifolia* was reduced (4.1). Nineteen taxa identified in pre-restoration sampling of CL, SD, and BR communities at Site 1 remained in 2013 (Table 1, Table S4). Only seven taxa were found in both the seed-bank study and 2013 sampling of Site 1 (Table 1, Table S3). Eleven species that were seeded at Site 1 were sampled in 2013: *C. canadensis*, *C. lupulina*, *Carex lurida* (shallow sedge), *C. vulpinoidea*, *Elymus canadensis* (Canada wildrye), *Eupatorium perfoliatum* (common boneset), *Glyceria grandis* (American mannagrass), *Juncus effusus* (common rush), *P. major*, *Symphyotrichum novae-angliae* (New England aster), and *S. puniceum* (Table 1, Table S1).

Restored Site 2 Plant Communities (2P10, 2P11, 2P12, 2P13)

First year sampling of Site 2 (2P10) identified 23 taxa (Table 1). Unidentifiable seedling *Carex* spp. (IV = 36.5), *A. artemisiifolia* (33.1), *T. pratense* (30.0), *H. jubatum* (22.6), and *X. strumarium* (20.0) were dominant. In 2011, 23 taxa were again found in Site 2 (2P11). *Agrostis stolonifera* (44.3) was dominant, and other prominent taxa included *Carex* spp. (26.3), *Linum usitatissimum* (common flax) (20.6), and *X. strumarium* (20.5). A total of 25 taxa were identified in 2012 sampling (2P12). *Epilobium hirsutum* (48.9) and *A. stolonifera* (40.2) were dominant and *Carex* spp. (25.3) was prominent. Identifiable *C. lupulina* (1.7) and *C. vulpinoidea* (4.2) were also found in sampling. Five species that were prominent in the first two years were not found in 2012 sampling at Site 2, including *X. strumarium*, while *T. pratense* was reduced to an IV of 2.0. Sampling of 2P13 in 2013 identified 35 taxa (Table 1). *Carex vulpinoidea* (35.6), *A. stolonifera* and *C. canadensis* (23.1) were dominant. Previously dominant *E. hirsutum* was reduced to an IV of 2.3, and *C. lupulina* (7.5) and *C. lurida* (1.3) were identified to species in 2013. Five taxa identified in pre-restoration sampling of BR and CL communities at Site 2 remained in 2013 (Table 1, Table S4). Only five taxa were found in both the seed-bank study and 2013 sampling of Site 2 (Table 1, Table S3). Eight species that were seeded at Site 2 were sampled in 2013: *Asclepias incarnata* (swamp milkweed), *C. lupulina*, *C. lurida*, *C. vulpinoidea*, *E. perfoliatum*, *J. effusus*, *P. major*, and *S. puniceum* (Table 1, Table S1).

Restored Site 3 Plant Communities (3PM10, 3P10, 3P11, 3P12, 3P13)

In 2010, sampling of the mowed portion of Site 3 (3PM10) identified 25 taxa (Table 1), dominated by *H. jubatum*(IV = 34.3) and seedling *Carex* spp. (29.2). In unmowed areas (3P10), 12 taxa were identified, with dominance by *X. strumarium* (44.9), *A. artemisiifolia* (39.8), *H. jubatum* (30.9), and *T. pratense* (26.6), while *Carex* spp. (18.2) was also prominent. One year later in 2011 (3P11), Site 3 sampling identified 41 taxa. *Xanthium strumarium* (37.1) and *Carex* spp. (33.6) were dominant. Sampling of Site 3 in 2012 (3P12) identified 43 taxa. *Epilobium hirsutum* (33.1) and *L. palustris* (22.3) were dominant, and prominent species included *A. stolonifera* (19.9) and *C. vulpinoidea* (19.3). *Carex lupulina* (6.7) and *C. lurida* (3.3) were also found, while unidentifiable *Carex* spp. decreased. *Hordeum jubatum* that was dominant in the first two years was not found in 2012, and three other species were greatly reduced:

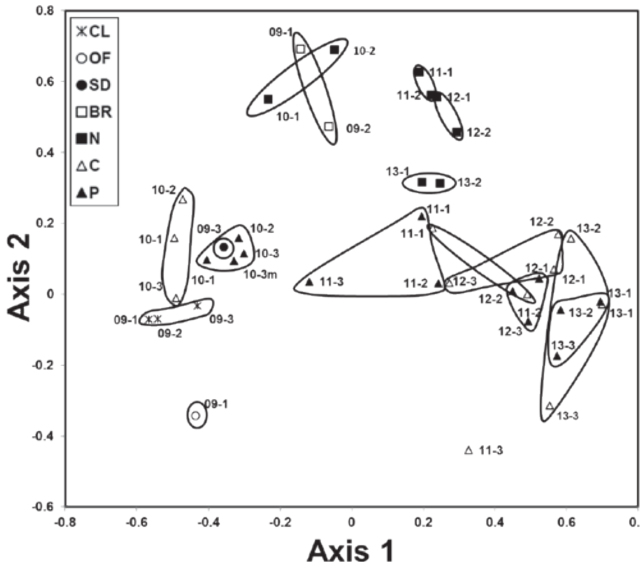

Figure 2. Two-dimensional plot of sampling sites from NMDS ordination of sample site/vegetation type/year × Importance Value matrix for 2009–2013 data from restoration site adjacent to West Creek along south shore of Lake Ontario, Monroe County, New York, USA. Data labels are abbreviated as year-site (e.g., 09-1 for sample year 2009 and Site 1), with vegetation types noted in the key: CL = clover, OF = old field, SD = sedge, BR = bulrush, N = natural, C = control, and P = planted.

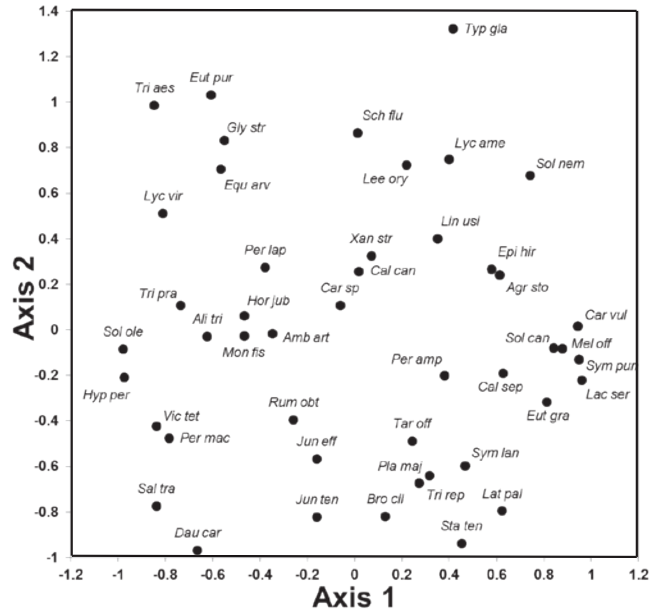

Figure 3. Two-dimensional plot of selected taxa from NMDS ordination of sample site/vegetation type/year × Importance Value matrix for 2009–2013 data from restoration site adjacent to West Creek along south shore of Lake Ontario, Monroe County, New York, USA. Species codes are the first three letters of the genus followed by the first three letters of the specific epithet. Species names are found in Table 1.

A. artemisiifolia (3.0), *T. pratense* (5.7), and *X. strumarium* (1.9). In 2013, sampling of Site 3 (3P13) identified 30 taxa. *Lathyrus palustris* (50.9), *C. vulpinoidea* (34.1), and *A. stolonifera* (31.5) were dominant, while no other taxa had an IV exceeding 8. *Carex lupulina* (6.5) and *C. lurida* (1.0) were present in 2013. *Ambrosia artemisiifolia*, *H. jubatum*, and *T. pratense* that were prominent in previous years were not found, and *X. strumarium* was reduced to an IV of 1.7 Eleven taxa identified in pre-restoration sampling of CL and SD communities at Site 3 remained in 2013 (Table 1, Table S4). Five taxa were found in both the seed-bank study and 2013 sampling of Site 3 (Table 1, Table S3). Eight species that were seeded at Site 3 were sampled in 2013: *C. canadensis*, *C. lupulina*, *C. lurida*, *C. vulpinoidea*, *E. perfoliatum*, *J. effusus*, *S. puniceum*, and *V. hastata* (Table 1, Table S1).

Ordination of Plant Communities

The NMDS ordination procedure produced an ordination with final stress = 19.60, final stability = 0.0000, and number of iterations = 135. Study site community and species scores were graphed separately. CL, SD, OF, and BR communities in 2009 plotted substantially away from all communities sampled in 2011–2013 (Figure 2). The clover (CL) and remnant sedge (SD) communities plotted in a grouping near the 2010 unplanted control (C) and the 2010 planted (P) communities that did not yet show evidence from restoration efforts. CL was largely influenced by *T. pratense* and *R. obtusifolius*, while SD was influenced by *Carex* spp. and *A. artemisiifolia* (Figure 3, Table S4). Prominence of *J. tenuis* likely caused OF to plot lower on Axis 2; BR plotted away from this grouping of communities also, with *B. fluviatilis* having a major influence and *C. canadensis* also affecting BR Site 2. The untreated, natural community (N) plotted with BR in 2010, again influenced by the prevalence of *B. fluviatilis* (Figures 2 and 3, Table S5). In 2011 and 2012, N shifted on Axis 1 with greater influence from *T. ×glauca* and *Leersia oryzoides* (rice cutgrass) and shifted on Axis 2 in 2013 with greater influence from *X. strumarium*.

The unplanted C community plotted near CL and SD in 2010, likely because of the influence of *A. artemisiifolia*, *T. pratense*, and *H. jubatum* (Figures 2 and 3, Table S6). In 2011 and 2012, C communities at Sites 1 and 2, with influence from *A. stolonifera*, *E. hirsutum*, *L. usitatissimum*, *S. canadensis*, *Euthamia graminifolia* (flat-top goldentop), and *X. strumarium*, shifted to the right on Axis 1. In 2011, the C plant community at Site 3 was an outlier with greater influence from *Symphyotrichum lanceolatum* (white panicle aster), *P. major*, *L. palustris*, and *Stachys tenuifolia* (smooth hedgenettle), which were not present in Sites 1 and 2. In 2013, C shifted further to the right on Axis 1, with added influence from *S. puniceum*, *L. palustris,* and *Melissa officinalis* (common balm).

In 2010, the planted areas (P) at all three restoration sites plotted similarly; they were distinct from but adjacent to control areas (C), clover (CL), and sedge (SD) (Figure 2), likely because lack of growth of planted species yielded insubstantial cover. The mowing treatment 3PM (10-3M) plotted similarly to the non-mowed planted areas. Taxa that influenced the 2010 P communities in the ordination included *T. pratense, A. artemisiifolia, Carex* spp., *H. jubatum, P. lapathifolia* and *X. strumarium* (Figure 3, Table 1). In 2011, P communities plotted to the right of those in 2010 on Axis 1 (Figure 2). Influential taxa included at Sites 1 and 2 were *A. stolonifera, Carex* spp., *L. usitatissimum* and *X. strumarium* (Figure 3, Table 1); *T. pratense, A. artemisiifolia, H. jubatum,* and *P. lapathifolia* that were prominent in 2010 had declined. Site 3 had similar influences but was driven much more by *Carex* spp. and *X. strumarium*. Planted (P) communities for all sites plotted very close to each other in 2012 and were separated from 2011 communities along Axis 1 (Figure 2). Greatly influential species were *E. hirsutum* and *A. stolonifera,* but *T. pratense, A. artemisiifolia, H. jubatum, L. usitatissimum, X. strumarium,* and *P. lapathifolia* were either not sampled or were further reduced (Figure 3, Table 1). In 2013, P shifted farther to the right from 2012 communities along axis 1. Dominants that influenced their ordination included *A. stolonifera, C. vulpinoidea, S. canadensis, S. puniceum,* and *L. palustris,* while other previously influential species continued to decline. Although control (C) and P communities plotted nearby but separately in 2010–2012, they overlapped in 2013.

Change in Wetland Indicator Status

Across all pre-restoration plant communities in areas where disking and seeding occurred (CL, OF, SD), sampling in 2009 identified 7 wetland obligate (OBL), 11 facultative wetland (FACW), 5 facultative (FAC), 8 facultative upland (FACU), and 8 upland (UPL) species. Sampling of planted areas (P) in 2013 identified 14 OBL, 18 FACW, 8 FAC, 14 FACU, and 2 UPL species, while unplanted control areas (C) had 4, 6, 6, 5, and 1, respectively. This suggests that wetland species (whether targeted or invasive) are increasing in prevalence over upland species as a result of restoration and management actions.

Discussion

Plant Sources as Predictors of Future Community Composition

In this wetland restoration project on lands previously used for agriculture, sources of the plant species still present in disked and planted areas (P) in 2013 are of interest, as they might serve as predictors that can advise for future projects. Sources include migrants from adjacent lands not disked or seeded, remnant species that survived at the site, seed-bank species, and actively seeded/transplanted species. The most prominent P species in 2013 were *A. stolonifera,* (also found in BR, CL, OF, and SD in 2009; N in 2011–2013), *C. vulpinoidea* (seeded; found in N in 2011–2013), *S. canadensis* (found in N in 2012–2013), *S. puniceum* (seeded; found in N in 2013), *Lactuca serriola* (prickly lettuce) (seedbank; found in N in 2013), and *L. palustris* (found in CL in 2009). Altogether, 32 of 52 species sampled in P areas in 2013 were also found in BR in 2009 and N across years. This suggests that adjacent natural wetlands that were not disked and seeded were a key source of the species that thrived or were present in the 2013 community. Plants growing on adjacent lands may thus be a good predictor of future plant community composition on low-lying agricultural lands subject to wetland restoration, contingent on implementation actions, development of suitable hydrology, and dispersion characteristics of individual species.

Some species from pre-restoration plant communities that were later disked survived through sampling in 2013 (12 in CL, 14 in OF, 11 in SD), but they are perhaps less important than those from adjacent lands. We are unsure if the survivors are solely remnants from pre-restoration or also seed-bank species that were not detected in the greenhouse study. The prominence of *S. puniceum* and *C. vulpinoidea* was likely a result of seeding. Although found less frequently, *C. lupulina* and *C. lurida* almost surely arrived via our seeding. Survival of remnant species is also subject to implementation and adaptive management actions, such as mowing, as well as hydrologic conditions. Remnants may also continue to decrease over time and are likely not a good predictor of future plant communities. The number of seed-bank-study species identified across years in field sampling varied from 6 to 10 to 8 to 8. Given that 35 taxa were found in the seed-bank study and that 52 species were sampled in planted areas (P) in 2013, the seed-bank results do not seem to be a good predictor.

The seeding/transplanting effort introduced 42 species across the planted area (P). Sampling in 2010–2013 identified 2, 9, 13, and 12 of those species, respectively. A total of 15 species were identified across years. New seeded species were recorded each year as they reached an identifiable stage or were released by the mowing treatment that reduced the dominance of broad canopy annuals. We suggest that seeding/transplanting is a partial predictor of the developing plant community, but it is clearly affected by the species-specific habitat requirements of the seeds and new seedlings, competition, and soil moisture conditions related to drought, as in 2012.

Success of Carex Species

Carex seeds germinated, and seedlings were observed during the first growing season after seeding, although they could not be identified to species. Subsequent sampling in the following years identified *C. lupulina, C. lurida,*and *C. vulpinoidea;* however, seeded *Carex comosa* (longhair sedge), *Carex crinita* (fringed sedge), and *C. stricta* were never observed. Seeds had been stratified (Budelsky and Galatowitsch 1999, Schutz and Rave 1999, Schutz 2000, Kettenring and Galatowitsch 2007b) before broadcasting, and the regional diurnal temperature range during the first 30 days after seeding was 25.5/15.5°C not far from the optimal range of 27/15°C for most *Carex* species suggested by Kettenring and Galatowitsch (2007a, b). Seeds of the most prevalent sedge, *C. vulpinoidea,* remain viable during storage and require no stratification (Kettenring and Galatowitsch 2007a).

Among species not found in the field, seeds of *C. stricta* have low viability and require stratification (van der Valk et al. 1999, Kettenring and Galatowitsch 2007a); they also germinate better at higher temperatures (35/30°C, after stratification) than at our site (Kettenring and Galatowitsch 2007b). Loss of viability during storage is the suspected cause of failure to germinate (Baskin et al. 1996, Budelsky and Galatowitsch 1999, van der Valk et al. 1999). Reasons for the lack of *C. comosa* and *C. crinita* in the field are not known. *Carex comosa* germinates better at 27/15°C with stratification (Kettenring and Galatowitsch 2007b) and is not affected by soil moisture (Kettenring and Galatowitsch 2011a). In controlled experiments, fringed sedge has been shown to germinate well (Shipley and Parent 1991).

Transplanted seedlings of *C. stricta* failed to survive, likely because they are sensitive to soil moisture, especially during the first growing season (Wetzel and van der Valk 1998, van der Valk et al. 1999, Budelsky and Galatowitsch 2004). *Calamagrostis canadensis* seedlings also failed to survive; they fare better on soils with greater organic content (Wilson and Keddy 1985, Ashworth 1997), which were clearly lacking at our site.

Fate of Other Plants

Several plant species that were very common in the first two or three years following implementation were much reduced or not found in 2013 sampling of the restored areas (P). *Ambrosia artemisiifolia, L. usitatissimum, P. lapathifolia,* and *X. strumarium* are annuals that may have been reduced by competition as other species grew and filled open space, and they were likely affected by the mowing treatment if they had not yet gone to seed. Observations suggest that mowing surely reduced *X. strumarium,* as it continued to persist in adjacent unmowed areas. Substantial reductions in perennial *H. jubatum* and biennial/perennial *T. pratense* from 2010 to 2011 and beyond, as well was perennial *E. hirsutum* from 2012 to 2013 are unexplained.

Progress Toward Sedge/Grass Meadow Restoration in 2013

By 2013, species found in pre-restoration sampling had mostly been displaced. The annual mowing treatment likely resulted in near eradication of canopy-dominating *X. strumarium* and perhaps other annuals. The planted (P) and unplanted Control (C) areas had largely converged. Six species from the Kents Creek reference site were present, and 21 sedge/grass meadow species from the Lake Ontario regional data base (Wilcox et al. 2005) were found. *Calamagrostis canadensis* failed to establish and *C. stricta* was never observed, despite both being seeded and transplanted at the three sites. However, other *Carex* species did establish, and mean percent cover of total *Carex* by year from 2010 to 2013 was 7.1, 8.1, 2.8, and 14.5 at Site 1; 21.0, 12.7, 10.5, and 21.7 at Site 2; and 5.3, 28.5, 20.3, and 24.1 at Site 3. *Carex vulpinoidea* accounted for much of the increase, from 0% cover at all sites in 2010 to 13.9, 19.0, and 20.4% cover at Sites 1–3, respectively, in 2013. In some locations not sampled by haphazard quadrat placement, *C. vulpinoidea* had formed mats several meters across with nearly 100% cover. The marked decrease in total *Carex* at all three sites in 2012 was likely the result of reduced May–August precipitation, which dropped to about 26 cm from an average of about 40 cm in other years.

Trajectories of Our Study Sites

The future of this restoration project is partly dependent on expansion of sedges in competition with remnant invasive species. Expansion would likely be vegetative rather than from seed (Stanley et al. 2005, Hall and Zedler 2010). FAC annuals such as *L. serriola* and *X. strumarium* are likely no longer of major concern due to the effects of mowing. Invading perennials *S. canadensis* (FACU) and *A. stolonifera* (FACW) or taller grasses such as *Phragmites australis* (common reed) may pose greater long-term problems that cannot be handled by mowing (Kolos and Banaszuk 2013). *Solidago canadensis* is recognized as a non-native invasive species in Europe and Asia, with indications that it possesses allelopathic properties (Sun et al. 2006). Control efforts are focusing on indigenous fungal isolates (Tang et al. 2013). Control of *A. stolonifera* in North America has focused on herbicide applications on golf courses (Beam et al. 2006, James and Christians 2007). Since such methods are not applicable in restored wetlands, other options for controlling these perennials need to be explored if they produce cover dense enough to affect desired species. Perhaps more troublesome are FACW *L. palustris* and OBL *S. puniceum,* the latter of which was in the seed mixture and seems to have taken hold by 2013. With its tall stature (up to 2 m) and broad branching, *S. puniceum* may compete with sedges for light. *Lathyrus palustris* was the most dominant plant at Site 3 by 2013 and is increasing at Site 2; it forms dense mats about a half meter in height, under which little else grows. Selective mowing closer to the ground of the more expansive patches of *Lathyrus* may allow spread of other species from adjacent areas.

Lake Ontario water-level fluctuations (Wilcox et al. 2008, USGS) will also affect this project as they progress through cycles that result in modest inundation to exposed soils ranging from moist to dry. Lengthy, severe droughts occurring during years with low lake levels may impact sedge/grass meadows.

Recommendations

If time and resources are available, seed-bank emergence studies may provide insights on future results, especially since the seed bank will likely differ from site to site (van der Valk and Davis 1976), but they are not required. Pre-restoration surveys should be conducted on adjacent lands to identify potential desired native species that do not require seeding, as well as invasive species that will need to be controlled or whose presence might reverse the decision to implement the restoration. Some species do not establish well from adjacent lands on their own, however. Seed rain of *Carex* species is limited; thus, sowing is recommended for restoration sites (Kettenring and Galatowitsch 2011b).

Rather than using commercially available regional seed mixtures for graminoids and forbs across whole restoration areas, test plots at different elevations (variable soil moisture) could be used to alter those mixtures or design site-specific mixtures. Use of fresh *Carex* seed from the year produced could help address seed viability problems (van der Valk et al. 1999). This would necessitate seeding later in the year and stratification in the field over winter. Other phased seeding and planting could be tested also. If a site with potential for low soil moisture conditions similar to the one in this study was to be seeded, we would recommend not to seed or plant *C. canadensis* or *C. stricta* unless proven methods were identified and tested or irrigation was possible. Rhizome transplants for *C. stricta* are also not recommended (Yetka and Galatowitsch 1999, Budelsky and Galatowitsch 2004).

Some *Carex* species in the mixture we used fared well and should be retained if environmental conditions are similar to our sites. *Carex vulpinoidea* might become the dominant species across large areas of all three sites. *Carex lupulina* and *C. lurida* also grew from seed and are expanding more slowly. *Carex lacustris,* which is very common in Lake Ontario sedge/grass meadows (Wilcox et al. 2005), might be added to the mixture, although seed viability may be a concern (Budelsky and Galatowitsch 1999, van der Valk et al. 1999, Kettenring and Galatowitsch 2007a, b).

Other taxa might be avoided in a new seed mixture, depending on desired outcome. Some species in our mixture never appeared in the field, so funds could be saved by deleting them. Seeding of *L. palustris, Solidago* spp., and *Symphyotrichum* spp. (especially *S. puniceum*) should be evaluated carefully, as they can become dominant and require cutting low to the ground when tall canopy annuals are being mowed. *Agrostis stolonifera* was very prevalent at our site by 2013, but it was not dense enough to warrant immediate concern. Continued monitoring for all invasives is recommended for as many years as possible because restoration takes time.

Acknowledgments

Major funding for this project was provided by the Great Lakes Restoration Initiative through the National Fish and Wildlife Foundation-Sustain Our Great Lakes Community Grants Program. We extend thanks to Heidi Kennedy of NYSDEC for helping to coordinate implementation actions at the site and arranging for DEC purchase of seed mixes and seedlings. Mark Greenwell conducted the mowing operations. John Bateman, Aaron Heminway, and Brad Mudrzynski helped in seeding and planting and Andie Graham assisted in vegetation sampling. Suggestions from two anonymous referees and the Associate Editor greatly improved readability of the manuscript.

References

Albert, D.A., D.A. Wilcox, J.W. Ingram and T.A. Thompson. 2005. Hydrogeomorphic classification for Great Lakes coastal wetlands. *Journal of Great Lakes Research* 31(S1):129–146.

Aronson, M.F.J. and S.M. Galatowitsch. 2008. Long-term vegetation development of restored prairie pothole wetlands. *Wetlands* 38:883–895.

Ashworth, S.M. 1997. Comparison between restored and reference sedge meadow wetlands in south-central Wisconsin. *Wetlands* 17:518–527.

Baedke, S.J. and T.A. Thompson. 2000. A 4,700-year record of lake level and isostasy for Lake Michigan. *Journal of Great Lakes Research* 26:416–426.

Bakker, C., H.F. de Graaf, W.H.O. Ernst and P.M. van Bodegom. 2005. Does the seed bank contribute to the restoration of species-rich vegetation in wet dune slacks? *Applied Vegetation Science* 8:39–48.

Baldwin, A.H., M.S. Egnotovich and E. Clarke. 2001. Hydrologic change and vegetation of tidal freshwater marshes: Field, greenhouse, and seed-bank experiments. *Wetlands* 21:519–531.

Baskin, C.C., E.W. Chester and J.M. Baskin. 1996. Effect of flooding on annual dormancy cycles in buried seeds of two wetland *Carex* species. *Wetlands* 16:84–88.

Beam, J.B., W.L. Barker and S.D. Askew. 2006. Selective creeping bentgrass (*Agrostis stolonifera*) control in cool-season turfgrass. *Weed Technology* 20:340–344.

Bohnen, J.L. and S.M. Galatowitsch. 2005. Spring Peeper Meadow: Revegetation practices in a seasonal wetland restoration in Minnesota. *Ecological Restoration* 23:172–181.

Budelsky, R.A. and S.M. Galatowitsch. 1999. Effects of moisture, temperature, and time on seed germination of five wetland *Carices*: Implications for restoration. *Restoration Ecology* 7:86–97.

Budelsky, R.A. and S.M. Galatowitsch. 2004. Establishment of *Carex stricta* Lam. seedlings in experimental wetlands with implications for restoration. *Plant Ecology* 175:91–105.

Clewell, A.F. and J. Aronson. 2013. *Ecological Restoration: Principles, Values, and Structure of an Emerging Profession*. Washington, DC: Island Press.

Environment Canada. 2002. *Where Land Meets Water: Understanding Wetlands of the Great Lakes*. Paper 37. digitalcommons.brockport.edu/wr_misc/37.

Hall, S.J. and J.B. Zedler. 2010. Constraints on sedge meadow self-restoration in urban wetlands. *Restoration Ecology* 18:671–680.

James, M.A. and N.E. Christians. 2007. Mesotrions controls creeping bentgrass (*Agrostis stolonifera*) in Kentucky bluegrass. *Weed Technology* 21:402–405.

Johnston, J.W., E.P. Argyilan, T.A. Thompson, S.J. Baedke, K. Lepper, D.A. Wilcox and S.L. Forman. 2012. A Sault-outlet-referenced mid- to late-Holocene paleohydrograph for Lake Superior constructed from strandplains of beach ridges. *Canadian Journal of Earth Science* 49:1263–1279.

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* 12:25–36.

Kettenring, K.M. and S.M. Galatowitsch. 2007a. Temperature requirements for dormancy break and seed germination vary greatly among 14 wetland *Carex* species. *Aquatic Botany* 87:209–220.

Kettenring, K.M. and S.M. Galatowitsch. 2007b. Tools for *Carex* revegetation in freshwater wetlands: Understanding dormancy loss and germination temperature requirements. *Plant Ecology* 193:157–169.

Kettenring, K.M. and S.M. Galatowitsch. 2011a. *Carex* seedling emergence in restored and natural prairie wetlands. *Wetlands* 31:273–281.

Kettenring, K.M. and S.M. Galatowitsch. 2011b. Seed rain of restored and natural prairie wetlands. *Wetlands* 31:283–294.

Kolos, A. and P. Banaszuk. 2013. Mowing as a tool for wet meadows restoration: Effect of long-term management on species richness and composition of sedge-dominated wetland. *Ecological Engineering* 55:23–28.

Leck, M.A. 2003. Seed-bank and vegetation development in a created tidal freshwater wetland on the Delaware River, Trenton, New Jersey, USA. *Wetlands* 23:310–343.

Lichvar, R.W. 2013. The National Wetland Plant List: 2013 wetland ratings. *Phytoneuron* 49:1–241.

McCune, B. and J. Grace. 2002. *Analysis of Ecological Communities*. Gleneden Beach, OR: Mjm Software Design.

NGS (National Geodetic Survey). 2012. IGLD 85 height conversion. Communications and Outreach Branch, NOAA, Silver Spring, MD. www.ngs.noaa.gov.

Nicol, J.M., G.G. Ganf and G.A. Pelton. 2003. Seed banks of a southern Australian wetland: The influence of water regime on the final floristic composition. *Plant Ecology* 168:191–205.

Schutz, W. 2000. Ecology of seed dormancy and germination in sedges (*Carex*). *Perspectives in Plant Ecology, Evolution, and Systematics* 3:67–89.

Schutz, W. and G. Rave. 1999. The effect of cold stratification and light on the seed germination of temperate sedges (*Carex*) from various habitats and implications for regenerative strategies. *Plant Ecology* 144:215–230.

Shipley, B. and M. Parent. 1991. Germination responses of 64 wetland species in relation to seed size, minimum time to reproduction, and seedling relative growth rate. *Functional Ecology* 5:111–118.

Stanley, K.E., P.G. Murphy, H.H. Prince and T.M. Burton. 2005. Long-term ecological consequences of anthropogenic disturbance on Saginaw Bay coastal wet meadow vegetation. *Journal of Great Lakes Research* 31(S1):147–159. Sun, B., J. Tan, Z. Wan, F. Gu and M. Zhu. 2006. Allelopathic effects of extracts from *Solidago canadensis* L. against seed germination and seedling growth of some plants. *Journal of Environmental Science* 18:304–309.

Tang, W., J. Kuang and S. Qiang. 2013. Biological control of the invasive alien weed *Solidago canadensis*: Combining an indigenous fungal isolate of *Sclerotium rolfsii* SC64 with mechanical control. *Biocontrol Science and Technology* 23:1133–1136.

USDA and NRCS. 2010. The plants database, version 3.5. National Plant Data Center, Baton Rouge, LA. www.plants.usda.gov.

van der Valk, A.G., T.L. Bremholm and E. Gordon. 1999. The restoration of sedge meadows: Seed viability, seed germination requirements, and seedling growth of *Carex* species. *Wetlands* 19:756–764.

van der Valk, A.G. and C.B. Davis. 1976. The seed banks of prairie glacial marshes. *Canadian Journal of Botany* 54:1832–1838.

Wang, G., B. Middleton and M. Jiang. 2013. Restoration potential of sedge meadows in hand-cultivated soybean fields in northeastern China. *Restoration Ecology* 21:801–808.

webSURGE, LLC. 2012. Catalog—Seed mixes. Southern Tier Consulting, Inc., West Clarksville, NY. www.southerntierconsulting.com.

Wetzel, P.R. and A.G. van der Valk. 1998. Effects of nutrients and soil moisture on competition between *Carex stricta*, *Phalaris arundinacea*, and *Typha latifolia*. *Plant Ecology* 138:179–190.

Wilcox, D. A. 2012. Response of wetland vegetation to the post-1986 decrease in Lake St. Clair water levels: Seed-bank emergence and beginnings of the *Phragmites australis* invasion. *Journal of Great Lakes Research* 38:270–277.

Wilcox, D.A., J.W. Ingram, K.P. Kowalski, J.E. Meeker, M.L. Carlson, Y. Xie, G.P. Grabas, K. L. Holmes and N.J. Patterson. 2005. Evaluation of water level regulation influences on Lake Ontario and Upper St. Lawrence River coastal wetland plant communities: Final project report. International Joint Commission, Ottawa, Ontario and Washington, DC.

Wilcox, D.A., K.P. Kowalski, H.L. Hoare, M.L. Carlson and H.N. Morgan. 2008. Cattail invasion of sedge/grass meadows in Lake Ontario: photointerpretation analysis of sixteen wetlands over five decades. *Journal of Great Lakes Research* 34:301–323.

Wilcox, D.A., J.E. Meeker, P.L. Hudson, B.J. Armitage, M.G. Black and D.G. Uzarski. 2002. Hydrologic variability and the application of index of biotic integrity metrics to wetlands: A Great Lakes evaluation. *Wetlands* 22:588–615.

Wilcox, D.A. and S.J. Nichols. 2008. The effects of water-level fluctuations on vegetation in a Lake Huron wetland. *Wetlands* 28:487–501.

Wilcox, D.A., T.A. Thompson, R.K. Booth and J.R. Nicholas. 2007. Lake-level variability and water availability in the Great Lakes. U.S. Geological Survey Circular 1311.

Wilcox, D.A. and Y. Xie. 2007. Predicting wetland plant community responses to proposed water-level regulation plans for Lake Ontario: GIS-based modeling. *Journal of Great Lakes Research* 33:751–773.

Wilson, S.D. and P.A. Keddy. 1985. Plant zonation on a shoreline gradient: Physiological response curves of component species. *Journal of Ecology* 73:851–860.

Yetka, L.A. and S.M. Galatowitsch. 1999. Factors affecting revegetation of *Carex lacustris* and *Carex stricta* from rhizomes. *Restoration Ecology* 7:162–171.

Douglas A. Wilcox (corresponding author), Department of Environmental Science and Biology, SUNY–The College at Brockport, Brockport, NY, USA 14420, dwilcox@brockport.edu.

Alexander J. Healy, Department of Environmental Science and Biology, SUNY–The College at Brockport, Brockport, NY, USA 14420.