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Continuing expansion of Narrow-leaved Cattail (*Typha angustifolia*) and decline of a provincially rare fen in the Holland Marsh, Ontario

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Abstract
At the time of European settlement, an extensive graminoid wetland existed at the confluence of the East and West Holland Rivers at the southern end of Lake Simcoe, Ontario. However, by 1925, clearing and draining of the marsh for specialty agriculture (i.e., market gardens) had begun and, by the 1940s, ~46% of the wetland had been cleared and another 13% was lost before 2016. Concurrent with marsh conversion has been an increase in Narrow-leaved Cattail (*Typha angustifolia*) in the remnant wetland. This study documents the change in the Holland Marsh wetland by delineating boundaries between marsh, fen, and shrub communities on aerial photographs taken at ~10-year intervals between 1946 and 2015 and documenting vegetation change along transects running perpendicular to tributaries bisecting the wetland. The extent of fen habitat within the Holland Marsh has been decreasing since 1946 at an average rate of 0.24 ha/year because of increases in both shrub and marsh (i.e., *T. angustifolia*) communities. *Typha angustifolia* expansion has been predominantly from along the margins of the Holland River where soil phosphorus concentration is significantly higher than in the core of the fen. Beyond 30 m from the river, vegetation dominance shifts from *T. angustifolia* to sedges (Cyperaceae). Managing phosphorus loading from upstream land uses will be of critical importance in protecting this habitat, which is rare in southern Ontario.

Key words: Fen eutrophication; Lake Simcoe; *Typha*; phosphorus; cattail invasion; fen decline; *Carex*; photointerpretation

Introduction

It has been estimated that over half of the total area of wetland in North America has been lost as a result of European settlement (Davidson 2014), with some of the greatest pressures in Canada occurring in southern Ontario (NWWG 1988). For example, at the time of European settlement, an extensive graminoid wetland existed at the confluence of the East and West Holland Rivers at the southern end of Lake Simcoe. This wetland was described variously as a "quaking bog, a typical sphagnum area, which quivers and shakes under people walking upon it" (Saunders 1947: 169); "an open bog, which quakes as one passes over it" (Devitt 1939: 239); or composed of "almost pure carpets of Canada bluejoint [*Calamagrostis canadensis*] … extending for thousands of acres" (Mayall 1938: 18).

However, by 1925, draining and clearing of the marsh for specialty agriculture (i.e., market garden crops) had begun and, by the 1940s, ~4600 ha (or 46% of the wetland) had been cleared (Sendel 1992), with an additional 13% lost up to 2016 (Kissel and Choi 2018). Despite this extensive clearing, evaluation of the Holland Marsh under the Ontario Wetland Evaluation System in 1984 mapped 272 ha of fen communities (Power *et al*. 1984), making it one of the largest fens in southern Ontario (OMNRF 2013), where fens are considered provincially rare (Bakowsky 1996). Over the years, a number of rare species have been recorded from this fen, including Eastern Prairie Fringed-orchid (*Platanthera lecuophaea* (Nuttall) Lindley), King Rail (*Rallus elegans*), Yellow Rail (*Coturnicops noveboracensis*), Black Tern (*Chlidonias niger*), and numerous regionally rare plants such as Creeping Sedge (*Carex chordorrhiza* L.), Sartwell's Sedge (*Carex sartwellii* Dewey), Slender Cotton-grass (*Eriophorum gracile* W.D.J. Koch ex A. Roth), and Poison Sumac (*Toxicodendron vernix* (L) Kuntze; MTO 1984; Power *et al.* 1984; Cadman *et al.* 2007).

The invasion of cattails (*Typha* spp.) into graminoid wetlands has been observed throughout North America (e.g., Day *et al*. 1988; Wu *et al*. 1997; Woo and Zedler 2002; Wilcox *et al*. 2008; Tuchman *et al*.

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2009; Duval *et al*. 2012; Bansal *et al*. 2019). Three species of cattail are known from the Great Lakes basin: Broad-leaved Cattail (*Typha latifola* L.), which is native to the area; Narrow-leaved Cattail (*Typha angustfolia* L.), which may be a European introduction or a native species that has greatly increased in range; and their hybrid, Blue Cattail (*Typha ×glauca* Godron). Despite uncertainty about the North American origin of *T. angustifolia*, all three species have increased in abundance in the Great Lakes basin since the time of European settlement (Grace and Harrison 1986; Shih and Finkelstein 2008). Their proliferation has been associated with a competitive advantage provided by changes in hydrology (Wilcox *et al*. 1984, 2008; Day *et al*. 1988), sedimentation (Werner and Zedler 2002), and nutrient enrichment (Auclair *et al*. 1976; Wu *et al*. 1997; Duval *et al*. 2012). Nutrient enrichment in the East and West Holland Rivers has long been a concern for watershed managers; concurrent with marsh conversion has been an increase in agriculture and urbanization in these watersheds, which has been associated with increased phosphorus loadings in the East Holland River and Lake Simcoe (Nicholls and MacCrimmon 1975; Johnson and Nicholls 1989; Evans *et al*. 1996; North *et al*. 2013).

The objectives of my study were to determine whether Narrow-leaved Cattail has expanded in the Holland Marsh since agricultural conversion and to assess whether the limits of *T. angustifolia* are associated with abiotic conditions within the marsh.

Methods

Study area and interpretation of aerial photos

Holland Marsh is a 3247-ha wetland complex at the south end of Lake Simcoe at the confluence of the East and West Holland Rivers in York Region and Simcoe County, Ontario (44.19°N, 79.52°W). The two wetland blocks within the Holland Marsh Provincial Wildlife Area selected for this study (104 and 63 ha in size) are separated from one another by a small tributary of the Holland River (Figure 1).

In July 2016, boundaries between vegetation communities were mapped in the field using a handheld global positioning system (GPS) unit (Garmin eTrex 20, Olathe, Kansas, USA) and a set of printed colour aerial photographs from 2015. Communities were defined as marsh where *T. angustifolia* occurred at ≥25% cover, as shrub thicket when shrubs occurred at ≥25% cover (following Lee *et al*. 1998), and graminoid fen otherwise.

These field-mapped boundaries were then digitized on aerial photographs taken in 2015 at a scale of 1:2000 using a minimum mapping unit of 0.01 ha (~10 m × 10 m) in ArcGIS 10.0 (ESRI, Redlands, California, USA). Boundaries between these communities were then mapped on a time series of air photos from the same area taken at approximately decadal intervals (i.e., 1946, 1969, 1978, 1988, 1999, and 2005) each at a scale of 1:2000 and a minimum mapping unit of 0.01 ha (Table 1). These boundaries were mapped based on observed differences in reflectance pattern between fen, marsh, and thicket communities in the 2015 aerial photographs compared with such differences in each successive set of photos in the time series. Because of variations in resolution in the air photos, vegetation boundaries may vary somewhat over the period of record. To minimize the effects of changing photo resolution, a consistent scale (i.e., 1:2000) was used in digitization. After the delineation of all boundaries, the area of each vegetation community was calculated in ArcMap (ESRI).

Vegetation and soil sampling

Plant community composition in the fen and marsh communities was quantified in July and August 2016. Three sets of transects were established: two in the larger (north) block and one in the southern block. Each set was composed of three transects, randomly located along the tributaries, which formed the north and south boundaries of the wetland blocks, and extending up to 250 m long, oriented perpendicular to the boundary between the fen and marsh communities. Five 1-m^2 quadrats were randomly located along each of these transects. The total number of stems of each plant species was counted in a 0.1 m × 0.1 m subsample from the corner of each quadrat. Plant species were identified using Voss and Reznicek (2012). Although no formal vouchers were deposited in a herbarium, a few specimens are in the personal collection of B.A.T.

Soil cores (~20 cm diameter and 10 cm deep) were collected from the centre of each quadrat as determined using a GPS unit. A subsample of soil from each core was weighed and dried at 80°C for 24 h before reweighing to determine soil moisture. Organic matter content of the soil was estimated by combusting the sample for 3 h at 500°C and reweighing to determine the percentage of the sample lost to ignition. Samples were analysed for concentrations of total phosphorus (P), magnesium (Mg), and potassium (K) by the Agriculture and Food Laboratory at the University of Guelph. Briefly, phosphorus was extracted from the samples using a 0.5 mol/L solution of sodium bicarbonate, and the concentration of phosphorus in the extract was determined using a colorimeter. Similarly, magnesium and potassium were extracted from the samples using a 1.0 mol/L solution of ammonium acetate, and their concentration in the extract determined using an inductively coupled plasma–optical emission spectrophotometer.

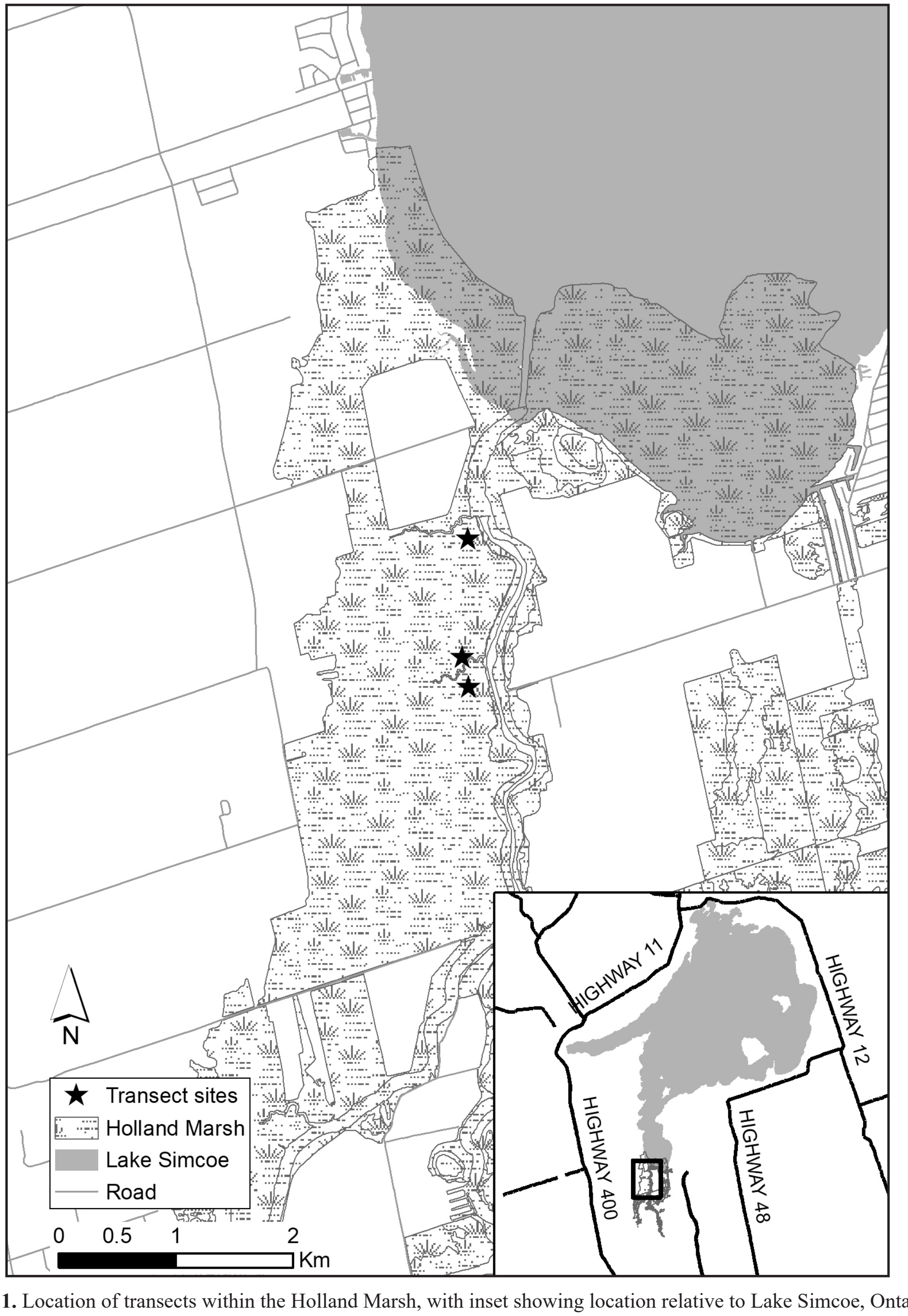

FIGURE 1. Location of transects within the Holland Marsh, with inset showing location relative to Lake Simcoe, Ontario.

Statistical analyses

Change in extent of fen and non-fen communities in the Holland Marsh wetland complex since 1946 was assessed by regressing the total area mapped as fen community against year in which the air photos were taken. The density of stems of *T. angustifolia* and members of the Cyperaceae (including *Carex* spp., *Eleocharis* spp., and *Eriophorum* spp.) was averaged across the four subsamples within each quadrat. The influence of abiotic conditions in the wetland (i.e., distance from the river, soil moisture, organic matter, and soil concentrations of P, Mg, and K) on

TABLE 1. Aerial photographs used in delineating plant communities in the Holland Marsh fen, Ontario.

Year	Photo source	Photo type	Resolution*, cm
1946	Ontario Department of Lands and Forests	Black and white	130
1969	Ontario Department of Lands and Forests	Black and white	130
1978	Ontario Ministry of Natural Resources	Black and white	130
1988	Northway Remote Sensing Limited	Natural colour	130
1999	Triathlon Incorporated	Natural colour	50
2005	First Base Solutions	Natural colour	20
2015	First Base Solutions	Natural colour	15

*Refers to the size of the pixel in the digital image (i.e., the 1946 air photos were of lower resolution than the 2015, as each pixel in the 1946 image covered an area 130 cm in size, as opposed to those more current images which showed features as small as 15 cm). Resolution is a fundamental challenge in comparing current with historical air photos.

their abundance was assessed using linear regression. Similarly, relations between distance from the river and these abiotic conditions were also assessed using linear regression.

Before analysis, all dependent variables were tested for normality, using the Shapiro-Wilk method (Shapiro and Wilk 1965), and any with a significantly ($P < 0.05$) non-normal distribution were transformed. Stem density was log-transformed and soil concentrations of P, Mg, and K were square root-transformed. All analyses were done using R version 3.6.3 (R Core Team 2020).

Results

Marsh communities in the study wetlands were dominated by Narrow-leaved Cattail, but also included species, such as Purple Loosestrife (*Lythrum salicaria* L.; the only non-native), Leatherleaf (*Chamaedaphne calyculata* (L.) Moench), Marsh Cinquefoil (*Comarum palustre* L.), Northern Aster (*Symphyotrichum boreale* (Torrey & A. Gray) A. Love & D. Love), Marsh Fern (*Thelypteris palustris* Schott), Boneset (*Eupatorium perfoliatum* L.), and Spotted Joe Pye-weed (*Eutrochium maculatum* (L.) E.E. Lamont). Fen communities in the study wetlands were of two kinds: one dominated by *Carex* (including Slender Sedge [*Carex lasiocarpa* Ehrhart], Lesser Panicled Sedge [*Carex diandra* Schrank], and Water Sedge [*Carex aquatilis* Wahlenberg]), with *C. palustre*, Elliptic Spike-rush (*Eleocharis elliptica* Kunth), Marsh St. John's Wort (*Hypericum fraseri* (Spach) Steudel), *S. boreale*, and *T. palustris*; or one dominated by *E. gracile* with *C. palustre*, Water Horsetail (*Equisetum fluviatile* L.), *T. palustris*, and Sweet Gale (*Myrica gale* L.) in scattered clumps.

The extent of fen habitat in the Holland Marsh has been decreasing since 1946 at a relatively constant rate of ~0.24 ha/year ($F_{1,5}$ = 130.2, $P < 0.001$; Figure 2). Between 1969 and 1988, much of that conversion was associated with the expansion of shrub communities into the fen (although shrub expansion into the marsh was greater). Shrub expansion into the fen has been non-existent since 1988 (Figures 1, 2). Much of the expansion of *T. angustifolia* into the fen has occurred along the margin of the Holland River, as the *T. angustifolia* margin along the river and its tributaries has gradually increased in width over time, and in the fen in the south block of the wetland (which was encircled by marsh; Figure 3).

In 2016, *T. angustifolia* was significantly ($F_{1,42}$ = 34.92, $P < 0.001$) less abundant beyond ~45 m from the river (Figure 4a). Beyond ~30 m from the river, members of the Cyperaceae (i.e., *Carex* spp. and *Eriophorum* spp.) were significantly more abundant ($F_{1,42}$ = 15.17, $P < 0.001$; Figure 4b). Aside from that small margin of overlap between *Typha* and Cyperaceae communities, these two taxa did not tend to co-occur within the same quadrat; rather, they were significantly ($F_{1,42}$ = 12.64, $P < 0.001$; Figure 5c) negatively associated.

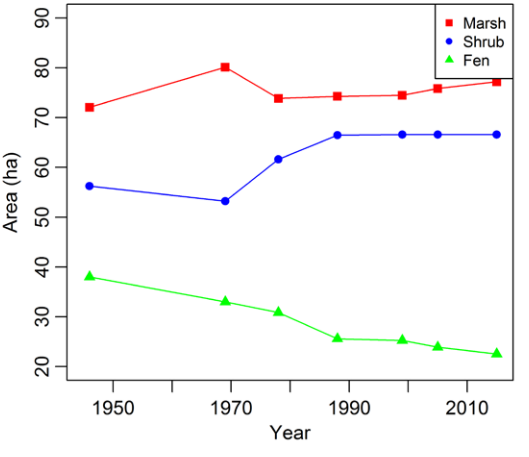

FIGURE 2. Change in extent of wetland communities in the Holland Marsh, Ontario, as interpreted from aerial photographs between 1946 and 2015. Fen area has decreased at an average rate of 0.24 ha/year ($F_{1,5}$ = 130.2, $P < 0.001$).

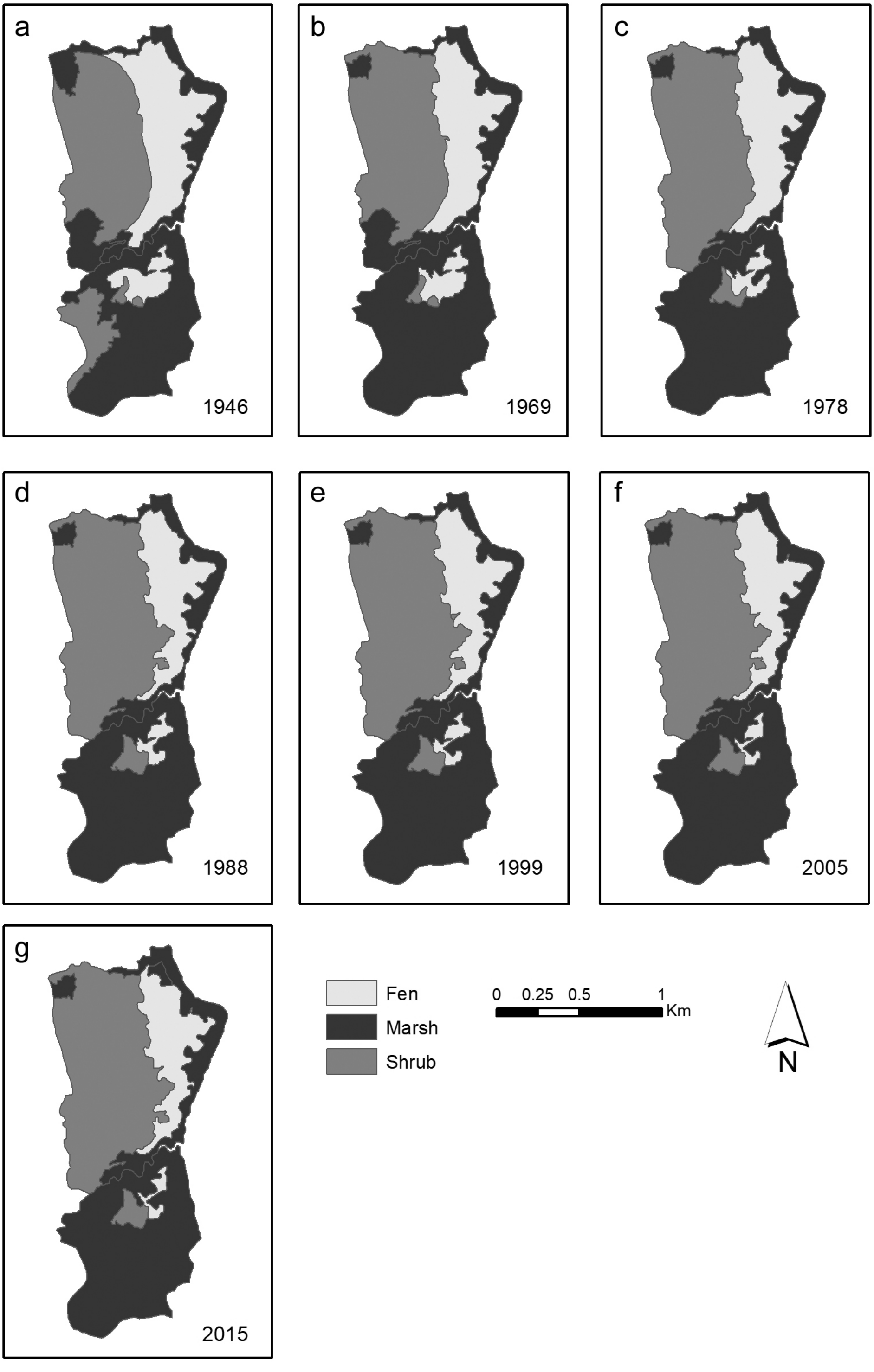

FIGURE 3. Change in distribution of wetland communities in the Holland Marsh, Ontario, as interpreted from a time series of aerial photographs taken between 1946 and 2015. Community boundaries delineated at a scale of 1:2000, with minimum mapping unit of 0.01 ha.

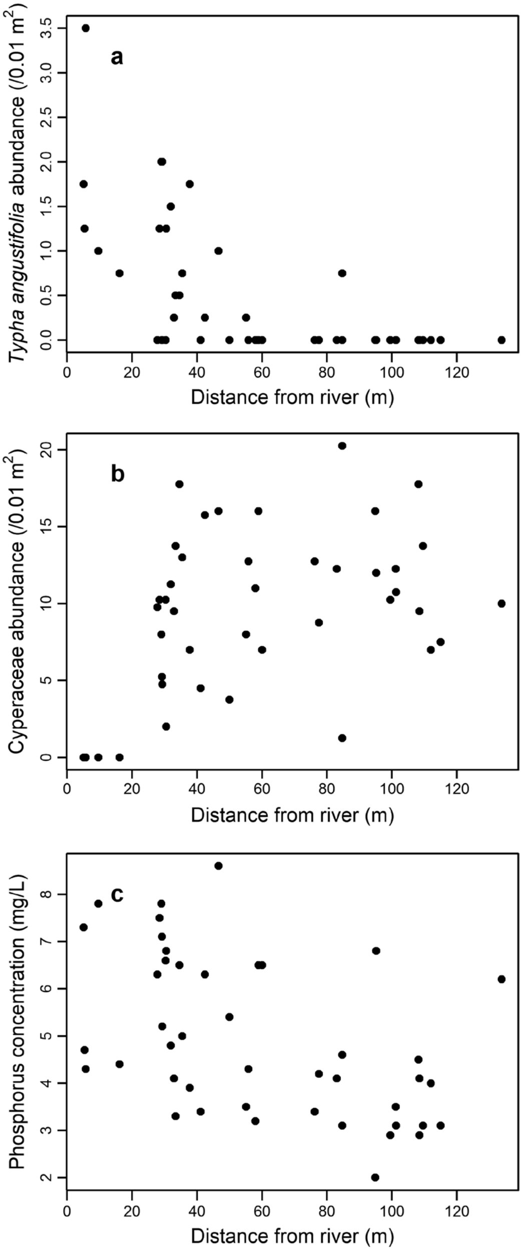

FIGURE 4. Influence of distance from watercourse on the abundance of a. Narrow-leaved Cattail (*Typha angustifolia*; $F_{1,42} = 44.61$, $P < 0.001$), b. members of the Cyperaceae ($F_{1,42} = 26.5$, $P < 0.001$), and c. soil phosphorus concentration ($F_{1,42} = 13.13$, $P < 0.001$).

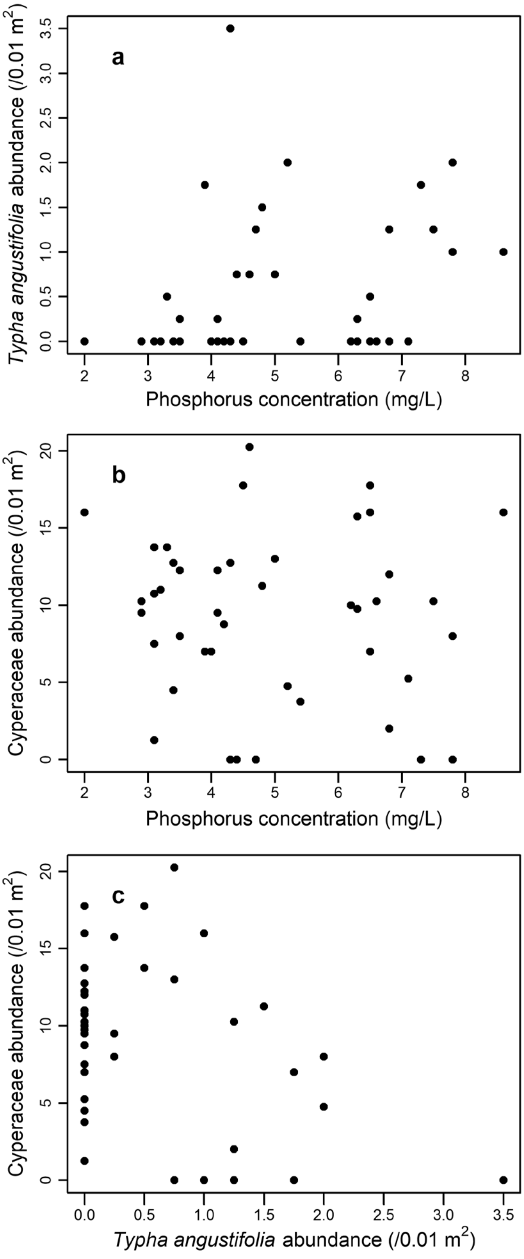

FIGURE 5. Relation between soil phosphorus concentration in the Holland Marsh wetland complex and a. abundance of Narrow-leaved Cattail (*Typha angustifolia*; $F_{1,42} = 6.62$, $P = 0.014$), b. abundance of Cyperaceae ($F_{1,42} = 0.94$, $P = 0.34$). c. Influence of *T. angustifolia* on Cyperaceae abundance ($F_{1,42} = 12.64$, $P < 0.001$).

Phosphorus concentration in the soil decreased in a linear fashion with distance from the river ($F_{1,42} = 13.67$, $P < 0.001$; Figure 4c). Soil moisture, soil organic matter, and the concentration of Mg and K in the soil were not significantly associated with distance from the river ($P > 0.05$ in all cases; data not shown). Soil P concentration was positively associated with *T. angustifolia* abundance ($F_{1,42} = 6.62$, $P =$

0.014; Figure 5a), with *T. angustifolia* not occurring below a soil phosphorus concentration of 3.3 mg/L. The abundance of Cyperaceae, however, did not respond significantly to soil P concentration ($F_{1,42}$ = 0.94, P = 0.34; Figure 5b).

Discussion

At the time of European settlement, *Typha* spp. were a minor component of the flora of marshes in the Great Lakes basin; however, they have been increasing in dominance since that time (Shih and Finkelstein 2008; Wilcox *et al*. 2008; Rippke *et al*. 2010; Wilcox and Bateman 2018; Smith *et al*. 2021). In the Holland Marsh, *T. angustifolia* has been expanding since the 1940s (Figure 2). Over the same period, much of the Holland Marsh wetland has been converted from wetland to farmland (Sendel 1992; Kissel and Choi 2018), and urbanization in its watershed has increased by a factor of four (Eimers *et al*. 2005).

The expansion of species of *Typha* into sedge-dominated fens has been documented elsewhere (Auclair *et al*. 1976; Wilcox *et al*. 1984; Rutchey and Vilchek 1999; Duval *et al*. 2012), with rates ranging from 35 ha/year (Smith 1967) to as much as 306.1 ha/year or 833 ha/year into Sawgrass (*Cladium jamaicense* Crantz)-dominated communities in the Everglades (Wu *et al*. 1997; Rutchey and Vilchek 1999). In the Holland Marsh wetland, *Typha* expansion into the sedge fen has largely been along the Holland River and its tributaries (Figure 3). Studies elsewhere have found similar patterns, with *Typha* invasion into sedge communities associated with an increasing dominance of *Typha* near watercourses and other flow structures, which spread further inland as an invading front (Koch and Reddy 1992; Wu *et al*. 1997; Rutchey and Vilchek 1999). The expansion of *Typha* into *Cladium*-dominated communities in the Everglades has been associated with phosphorus loads in surface waters enriching riparian soils (Koch and Reddy 1992; Newman *et al*. 1998). Similarly, P loads are high in the Holland River, as a result of agricultural and urban influences with its watershed (Johnson and Nicholls 1989; Evans *et al*. 1996). Although much effort has been expended to reduce these loads, a clear relation exists between P concentration in soils in this wetland and distance from the river (Figure 4c).

Within the invading front of *Typha* and the transition zone to sedge fen in the Holland Marsh, soil P concentration is associated with an increased abundance of *T. angustifolia* (Figure 5a), but has no statistically significant relation to the abundance of Cyperaceae (Figure 5b). Fertilization studies have similarly found that the addition of P to natural wetlands or mesocosms increases the abundance of *Typha* spp., but does not tend to influence the abundance of native graminoids including *Carex* (Wetzel and van der Valk 1998; Lorenzen *et al*. 2001; Woo and Zedler 2002). The addition of P fertilizer led to increased leaf and shoot biomass in *Typha* (Wetzel and van der Valk 1998; Miao *et al*. 2000; Woo and Zedler 2002; Steinbachová-Vojtíšková *et al*. 2006), which can allow *Typha* to create more leaf litter in P-enriched wetlands, which in turns tends to decrease the abundance and germination rate of native graminoids (Day *et al*. 1988; Tuchman *et al*. 2009; Larkin *et al*. 2012).

Some have suggested that a threshold may exist in the relation between P availability and *Typha* expansion. For example, Wu *et al*. (1997) found that the probability of cattail invasion into *Cladium*-dominated communities rapidly accelerated when soil P concentration exceeded 400 mg/kg. Above 650 mg/kg, however, the probability of invasion decelerated, which the authors suggested may be because of soil saturation. Duval *et al.* (2012) found a similar threshold for abundance of *Typha* in fen communities in Ontario, with approximately linear increases in abundance up to 60 mg/L of soil phosphate and invasion slowing at higher concentrations. In the Holland Marsh, such a threshold does not yet appear to have been reached (Figure 4a).

Eutrophication, however, is not the only stress in this fen. As with many wetlands remaining in southern Ontario, the Holland Marsh wetland also experiences ongoing stresses associated with expansion of agricultural production, infrastructure development, and local changes to hydrology (Kissel and Choi 2018). In the case of this fen specifically, a network of berms and canals was constructed beginning in the late 1970s along this study site's western boundary as well as ~800 m to the south. Shortly thereafter the greatest rate of shrub expansion occurred in the fen (Figures 2, 3), perhaps associated with a lowering of the water table on the fen's western side, and an interruption of the flow of groundwater rich in calcium and other minerals to this area (MTO 1984).

Hydrologic changes may also be contributing to the expansion of *Typha* in this wetland. As demonstrated by Wilcox *et al.* (2008) and Wilcox and Bateman (2018), an increase in both water levels and water level stability has been associated with *Typha* expansion in wetlands on Lake Ontario. My study site is immediately adjacent to Lake Simcoe, whose water levels have been managed since 1918. Water level management has included an increase in overall depth of water in the lake, and a greater stability in water levels, particularly since 1966 (Environment Canada 2021).

Much effort has been expended to reduce P loading in the Lake Simcoe watershed (North *et al*. 2013; Davidson and de Loë 2016). Although the primary objective of P reduction has been to protect the reproduction of coldwater fish in the lake (North *et al*. 2013), reductions in P loads may also help protect this fen ecosystem. Unfortunately, however, even after the cessation of surface water loadings, P in wetland soils can still spread further into upland areas, because of cycling through plants and detrital material (Koch and Reddy 1992; Bostic *et al*. 2010) and internal eutrophication (Boers and Zedler 2008). As such, active restoration efforts may be necessary to stop the spread of *Typha* in these systems through actions, such as the harvesting of *Typha* shoots and removal of its leaf litter. These actions have been shown to allow *Carex* to recolonize cleared habitat, albeit at a relatively slow rate of expansion (Hall and Zedler 2010; Larkin *et al*. 2012; Lishawa *et al*. 2015; Wilcox *et al*. 2018).

Bradford (2016) argued that watershed-scale approaches to wetland conservation are necessary to understand and manage the impacts that land-use change has on wetland hydrologic regimes. At Holland Marsh, the expansion of *Typha angustifolia* associated with P loading from upstream land use and the reduction in extent of a rare Cyperaceae-dominated fen community gives further support to this argument. The conservation and management of wetlands in landscapes with high levels of human pressure should consider the impacts that land use in the entire watershed has on communities of rare and endangered plants and animals.

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Literature Cited

Auclair, A.N.D., A. Bouchard, and J. Pajaczkowski. 1976. Productivity relations in a *Carex*-dominated ecosystem. Oecologia 26: 9–31. https://doi.org/10.1007/bf00345650

Bakowsky, W.D. 1996. Natural heritage resources of Ontario: S-ranks for communities in site regions 6 and 7. Natural Heritage Information Centre, Ontario Ministry of Natural Resources, Peterborough, Ontario, Canada.

Bansal, S., S.C. Lishawa, S. Newman, B.A. Tangen, D. Wilcox, D. Albert, M.J. Anteau, M.J. Chimney, R.L. Cressey, E. DeKeyser, K.J. Elgersma, S.A. Finkelstein, J. Freeland, R. Grosshans, P. Klug, D.J. Larkin, B.A. Lawrence, G. Linz, J. Marburger, G. Noe, C. Otto, N. Reo, J. Richards, C. Richardson, L. Rodgers, A.J. Schrank, D. Svedarsky, S. Travis, N. Tuchman, and L. Windham-Myers. 2019. *Typha* (cattail) invasion in North American wetlands: biology, regional problems, impacts, desired services, and management. Wetlands 39: 645–684. https://doi.org/10.1007/s13157-019-01174-7

Boers, A.M., and J.B. Zedler. 2008. Stabilized water levels and *Typha* invasiveness. Wetlands 28: 676–685. https://doi.org/10.1672/07-223.1

Bostic, E.M., J.R. White, R. Corstanje, and K.R. Reddy. 2010. Redistribution of wetland soil phosphorus ten years after the conclusion of nutrient loading. Soil Science Society of America Journal 74: 1808–1815. https://doi.org/10.2136/sssaj2008.0316

Bradford, A. 2016. Averting degradation of southern Ontario wetlands due to hydrologic alterations associated with development. Canadian Water Resources Journal 41: 543–553. https://doi.org/10.1080/07011784.2015.1119061

Cadman, M.D., D.A. Sutherland, G.G. Beck, D. Lepage, and A.R. Coutourier. 2007. Atlas of the Breeding Birds of Ontario, 2001–2005. Bird Studies Canada, Environment Canada, Ontario Field Ornithologists, Ontario Ministry of Natural Resources, and Ontario Nature, Toronto, Ontario, Canada.

Davidson, N.C. 2014. How much wetland has the world lost? Long-term and recent trends in global wetland area. Marine and Freshwater Research 65: 934–941. https://doi.org/10.1071/mf14173

Davidson, S.L., and R.C. de Loë. 2016. The changing role of ENGOs in water governance: institutional entrepreneurs? Environmental Management 57: 62–78. https://doi.org/10.1007/s00267-015-0588-8

Day, R.T., P.A. Keddy, J. McNeil, and T. Carleton. 1988. Fertility and disturbance gradients: a summary model for riverine marsh vegetation. Ecology 69: 1044–1054. https://doi.org/10.2307/1941260

Devitt, O.E. 1939. The yellow rail breeding in Ontario. Auk 56: 238–243. https://doi.org/10.2307/4079043

Duval, T.P., J.M. Waddington, and B.A. Branfireun. 2012. Hydrological and biogeochemical controls on plant species distribution within calcareous fens. Ecohydrology 5: 73–89. https://doi.org/10.1002/eco.202

Eimers, M.C., J.G. Winter, W.A. Scheider, S.A. Watmough, and K.H. Nicholls. 2005. Recent changes and patterns in the water chemistry of Lake Simcoe. Journal of Great Lakes Research 31: 322–332. https://doi.org/10.1016/s0380-1330(05)70263-x

Environment Canada. 2021. Historical hydrometric data for Lake Simcoe near Gamebridge. Environment Canada, Ottawa, Ontario, Canada. Accessed 26 July 2021. https://wateroffice.ec.gc.ca/report/historical_e.html?stn=02EC015.

Evans, D.O., K.H. Nicholls, Y.C. Allen, and M.J. McMurtry. 1996. Historical land use, phosphorus loading, and loss of fish habitat in Lake Simcoe, Canada. Canadian Journal of Fisheries and Aquatic Sciences 53: 194–218. https://doi.org/10.1139/f96-012

Grace, J.B., and J.S. Harrison. 1986. The biology of Canadian weeds. 73. *Typha latifolia* L., *Typha angustifolia* L. and *Typha ×glauca* Godr. Canadian Journal of Plant Sciences 66: 361–379. https://doi.org/10.4141/cjps86-051

Hall, S.J., and J.B. Zedler. 2010. Constraints on sedge meadow self-restoration in urban wetlands. Restoration Ecology 18: 671–680. https://doi.org/10.1111/j.1526-100x.2008.00498.x

Johnson, M.G., and K.H. Nicholls. 1989. Temporal and spatial variability in sediment and phosphorus loads to Lake Simcoe, Ontario. Journal of Great Lakes Research 15: 265–282. https://doi.org/10.1016/s0380-1330(89)71481-7

Kissel, A., and A. Choi. 2018. State of the wetlands in the Lake Simcoe watershed. Technical report 2018-01. Ontario Streams, Aurora, Ontario, Canada.

Koch, M.S., and K.R. Reddy. 1992. Distribution of soil and plant nutrients along a trophic gradient in the Florida Everglades. Soil Science Society of America Journal 56: 1492–1499. https://doi.org/10.2136/sssaj1992.03615995005600050026x

Larkin, D.J., M.J. Freyman, S.C. Lishawa, P. Geddes, and N.C. Tuchman. 2012. Mechanisms of dominance by the invasive hybrid cattail *Typha × glauca*. Biological Invasions 14: 65–77. https://doi.org/10.1007/s10530-011-0059-y

Lee, H.T., W. Bakowsky, J. Riley, J. Bowles, M. Puddister, P. Uhlig, and S. McMurray. 1998. Ecological Land Classification for Southern Ontario: First Approximation and Its Application. Ontario Ministry of Natural Resources, Southcentral Science Section, North Bay, Ontario, Canada.

Lishawa, S.C., B.A. Lawrence, D.A. Albert, and N.C. Tuchman. 2015. Biomass harvest of invasive *Typha* promotes plant diversity in a Great Lakes coastal wetland. Restoration Ecology 23: 228–237. https://doi.org/10.1111/rec.12167

Lorenzen, B., H. Brix, I.A. Mendelssohn, K.L. McKee, and S.L. Miao. 2001. Growth, biomass allocation and nutrient use efficiency in *Cladium jamaicense* and *Typha domingensis* as affected by phosphorus and oxygen availability. Aquatic Botany 70: 117–133. https://doi.org/10.1016/s0304-3770(01)00155-3

Mayall, K.M. 1938. The Natural Resources of King Township, Ontario. Royal Canadian Institute, Toronto, Ontario, Canada.

Miao, S.L., S. Newman, and F.H. Sklar. 2000. Effects of habitat nutrients and seed sources on growth and expansion of *Typha domingensis*. Aquatic Botany 68: 297–311. https://doi.org/10.1016/s0304-3770(00)00127-3

MTO (Ministry of Transportation, Ontario). 1984. Highway 89 extension: Highway 11 to York Regional Road 12. Environmental assessment report one stage submission. Ministry of Transportation, Toronto, Ontario, Canada.

Newman, S., J. Schuette, J.B. Grace, K. Rutchey, T. Fontaine, K.R. Reddy, and M. Pietrucha. 1998. Factors influencing cattail abundance in the northern Everglades. Aquatic Botany 60: 265–280. https://doi.org/10.1016/s0304-3770(97)00089-2

Nicholls, K.H., and H.R. MacCrimmon. 1975. Nutrient loading to Cook Bay of Lake Simcoe from the Holland River watershed. Internationale Revue der gesamten Hydrobiologie und Hydrographie 60: 159–193. https://doi.org/10.1002/iroh.19750600202

North, R.L., D. Barton, A.S. Crowe, P.J. Dillon, R.M.L. Dolson, D.O. Evans, B.K. Ginn, L. Håkanson, J. Hawryshyn, H. Jarjanazi, J.W. King, J.K.L. La Rose, L. León, C.F.M. Lewis, G.E. Liddle, Z.H. Lin, F.J. Longstaffe, R.A. MacDonald, L. Molot, T. Ozersky, M.E. Palmer, R. Quinlan, M.D. Rennie, M.M. Robillard, D. Rodé, K.M. Rühland, A. Schwalb, J.P. Smol, E. Stainsby, J.J. Trumpickas, J.G. Winter, and J.D. Young. 2013. The state of Lake Simcoe (Ontario, Canada): the effects of multiple stressors on phosphorus and oxygen dynamics. Inland Waters 3: 51–74. https://doi.org/10.5268/IW-3.1.529

NWWG (National Wetlands Working Group). 1988. Wetlands of Canada. Ecological land classification series 24. Sustainable Development Branch, Environment Canada, Ottawa, Ontario, Canada and Polyscience Publications Inc., Montréal, Quebec, Canada. Accessed 18 February 2022. https://publications.gc.ca/collections/collection_2019/eccc/En73-3-24-eng.pdf.

OMNRF (Ontario Ministry of Natural Resources and Forestry). 2013. Wetland map. Accessed 4 April 2017. https://data.ontario.ca/dataset/wetlands.

Power, M., S. Sherrard, B. Bruinse, C. Hall, M. Gromarfy, C. Leggiadro, and S. Austin. 1984. Wetland data record & evaluation—Holland Marsh Wetlands (updated 1998 & 2012). Ontario Ministry of Natural Resources, Aurora, Ontario, Canada.

R Core Team. 2020. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rippke, M.B., M.T. Distler, and J.M. Farrell. 2010. Holocene vegetation dynamics of an Upper St. Lawrence River wetland: paleoecological evidence for a recent increase in cattail (*Typha*). Wetlands 30: 805–816. https://doi.org/10.1007/s13157-010-0068-0

Rutchey, K., and L. Vilchek. 1999. Air photointerpretation and satellite imagery analysis techniques for mapping cattail coverage in a northern Everglades impoundment. Photogrammetric Engineering and Remote Sensing 65: 185–191.

Saunders, R.M. 1947. Flashing Wings. McClelland and Stewart Ltd., Toronto, Ontario, Canada.

Sendel, E.K. 1992. Land use history of the Holland Marsh drainage scheme south of Bradford, Ontario. B.A. thesis, University of Guelph, Guelph, Ontario, Canada.

Shapiro, S.S., and M.B. Wilk. 1965. An analysis of variance test for normality (complete samples). Biometrika 52: 591–611. https://doi.org/10.2307/2333709

Shih, J.G., and S.A. Finkelstein. 2008. Range dynamics and invasive tendencies in *Typha latifolia* and *Typha angustifolia* in eastern North America derived from herbarium and pollen records. Wetlands 28: 1–16. https://doi.org/10.1672/07-40.1

Smith, I.M., G.E. Fiorino, G.P. Grabas, and D.A. Wilcox. 2021. Wetland vegetation response to record-high Lake Ontario water levels. Journal of Great Lakes Research 47: 160–167. https://doi.org/10.1016/j.jglr.2020.10.013

Smith, S.G. 1967. Experimental and natural hybrids in North American Typha (Typhaceae). American Midland Naturalist 78: 257–287. https://doi.org/10.2307/2485231

Steinbachová-Vojtíšková, L., E. Tylová, A. Soukup, H. Novická, O. Votrubová, H. Lipavská, and H. Čižková. 2006. Influence of nutrient supply on growth, carbohydrate, and nitrogen metabolic relations in *Typha angustifolia*. Environmental and Experimental Botany 57: 246–257. https://doi.org/10.1016/j.envexpbot.2005.06.003

Tuchman, N.C., D.J. Larkin, P. Geddes, R. Wildova, K.J. Jankowski, and D.E. Goldberg. 2009. Patterns of environmental change associated with *Typha* ×*glauca* invasion in a Great Lakes coastal wetland. Wetlands 29: 964–975. https://doi.org/10.1672/08-71.1

Voss, E.G., and A.A. Reznicek. 2012. Field Manual of Michigan Flora. University of Michigan Press, Ann Arbor, Michigan, USA.

Werner, K.J., and J.B. Zedler. 2002. How sedge meadow soils, microtopography, and vegetation respond to sedimentation. Wetlands 22: 451–466. https://doi.org/10.1672/0277-5212(2002)022[0451:hsmsma]2.0.co;2

Wetzel, P.R., and A.G. van der Valk. 1998. Effects of nutrient and soil moisture on competition between *Carex stricta*, *Phalaris arundinacea*, and *Typha latifolia*. Plant Ecology 138: 179–190. https://doi.org/10.1023/a:1009751703827

Wilcox, D.A., S.I. Apfelbaum, and R.D. Hiebert. 1984. Cattail invasion of sedge meadows following hydrologic disturbance in the Cowles Bog wetland complex, Indiana Dunes National Lakeshore. Wetlands 4: 115–128. https://doi.org/10.1007/bf03160491

Wilcox, D.A., and J.A. Bateman. 2018. Photointerpretation analysis of plant communities in Lake Ontario wetlands following 65 years of lake-level regulation. Journal of Great Lakes Research 44: 1306–1313. https://doi.org/10.1016/j.jglr.2018.08.007

Wilcox, D.A., K. Buckler, and A. Czayka. 2018. Controlling cattail invasion in sedge/grass meadows. Wetlands 38: 337–347. https://doi.org/10.1007/s13157-017-0971-8

Wilcox, D.A., K.P. Kowalski, H.L. Hoare, M.L. Carlson, and H.N. Morgan. 2008. Cattail invasion of sedge/grass meadows and regulation of Lake Ontario water levels: photointerpretation analysis of sixteen wetlands over five decades. Journal of Great Lakes Research 34: 301–323. https://doi.org/10.3394/0380-1330(2008)34[301:ciogmi]2.0.co;2

Woo, I., and J.B. Zedler. 2002. Can nutrients alone shift a sedge meadow towards dominance by the invasive *Typha* × *glauca*. Wetlands 22: 509–521. https://doi.org/10.1672/0277-5212(2002)022[0509:cnasas]2.0.co;2

Wu, Y., F.H. Sklar, and K. Rutchey. 1997. Analysis and simulations of fragmentation patterns in the Everglades. Ecological Applications 7: 268–276. https://doi.org/10.1890/1051-0761(1997)007[0268:aasofp]2.0.co;2

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