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Dan Svedarsky

Richard Grosshans

Henry David Venema

Susan N. Ellis-Felege
University of North Dakota, susan.felege@und.edu

J. Bruggman

See next page for additional authors

Authors
Dan Svedarsky, Richard Grosshans, Henry David Venema, Susan N. Ellis-Felege, J. Bruggman, Aaron Ostlund, and Jeff Lewis

Integrated management of invasive cattails (*Typha* spp.) for wetland habitat and biofuel in the Northern Great Plains of the United States and Canada: A review

D. Svedarsky[1], R. Grosshans[2], H. Venema[2], S. Ellis-Felege[3], J. Bruggman[3], A. Ostlund[4] and J. Lewis[4]

[1]Northwest Research and Outreach Center, University of Minnesota, Crookston, MN, USA
[2]International Institute for Sustainable Development, Winnipeg, MB, Canada
[3]University of North Dakota, Grand Forks, ND, USA
[4]Red River Basin Commission, Fargo, ND, USA

SUMMARY

On many public lands in the Great Plains region of the USA and Canada, cattail (*Typha* spp.) growth has far exceeded the 50:50 distribution recommended for optimum wetland wildlife habitat. Excessive cattail growth is the primary concern of wetland managers and its integrated management is reviewed here. The coverage of this mostly hybrid cattail (*T. latifolia* × *T. angustifolia*) is often over 90 % and if partially removed for habitat enhancement represents a substantial biomass resource in sites such as conservation wetlands, water retention basins and roadside drainage ditches. Available biomass is estimated to be 3,000 kg/ha assuming a 50 % harvest rate. Cattail control using mowing, herbicides, and burning is expensive, therefore if harvest logistics can be improved along with developing biomass markets, harvest management would become much more viable. Energy values of cattails are comparable to wood pellets at 20 MJ/kg. Cattails can be simultaneously managed for wetland wildlife, harvested for biofuel, serve as a partial substitute for coal, generate carbon credits, and remove phosphorus from the watershed. Cattails extract nitrogen and phosphorous from runoff water that enters rivers and lakes that could be used for agricultural fertiliser while reducing eutrophication. Additionally, rural economies could be boosted by harvesting a renewable energy resource, especially in areas with little fossil fuels or unsustainable biomass practices.

KEY WORDS: hybrid cattail, biofuel, integrated wetland management

INTRODUCTION

Wetlands are essential features of the North American, Northern Great Plains landscape. They capture excess nutrients and other pollutants from runoff before they reach rivers and lakes, stabilise water supplies during drought and floods, and enhance biodiversity. They are home to a wide range of specialised plants and animals and provide a unique setting for wildlife recreation, especially wildlife watching and hunting (Mitsch & Gosselink 2015). Wetlands have been systematically destroyed for cropland and other land use developments. However, awareness of the ecological services that wetlands provide has grown, leading the USA and Canada to accelerate efforts to conserve and restore them. In addition to direct losses, the quality of remaining wetlands has suffered. For example, many wetlands have been dramatically altered by non-native invasive plants such as purple loosestrife (*Lythrum salicaria*), reed canary grass (*Phalaris arundinacea*) and common reed (*Phragmites australis*). Others, like cattail (*Typha* spp.), may be more difficult to define because they have both native and non-native origins as well as an invasive hybrid. As a group, invasive wetland species can aggressively crowd out other plants, reduce biodiversity, and alter wetland functions.

Hybrid cattails (*Typha* × *glauca*), a cross between the native broadleaf cattail (*Typha latifolia*) and the non-native narrowleaf cattail (*T. angustifolia*) introduced from Europe, in particular, have become a significant problem in Northern Great Plains wetlands over the last 50 years. Svedarsky (1992) observed a dramatic example of hybrid cattail invasion in the early 1990s while doing a biological inventory of the Burnham Creek Wildlife Management Area (BCWMA), a flood control impoundment project near Crookston, Minnesota. Part of the project involved diverting nutrient-rich runoff into a formerly drained hardstem bulrush (*Scripus acutus*) marsh that had been primarily fed by saline seepage water. The runoff water drowned out wet prairie and sedge lowlands, which were rapidly colonised by hybrid cattail. The bulrush marsh was more slowly invaded and eventually dominated by cattails as well. The area adjacent to the BCWMA was to become the Glacial Ridge National Wildlife

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Refuge (GRNWR). Launched in 2001, the refuge was billed as the largest contiguous prairie and wetland restoration project in the USA (Gerla *et al*. 2012). Within this 9,308-ha landscape, about 1,214 ha of shallow wetlands were restored, most without water control structures. Predictably, most of these wetlands soon became dominated by cattails in wetter parts and reed canary grass (*Phalaris arundincea*) and willows (*Salix spp*.) in fringe areas. This vast habitat complex became the impetus to explore a multi-functional approach of reducing cattails for wetland wildlife management in the area, while looking for ways to harvest cattails as a resource.

On many public lands (national wildlife refuges, wildlife management areas, waterfowl production areas, flood control impoundments) in Minnesota, cattail growth has far exceeded the 50:50 distribution or "hemi-marsh" recommended by Murkin *et al*. (1982) and Weller (1975) for optimum wetland wildlife habitat. Figure 1 shows an optimum configuration of open water and emergent vegetation or "hemi-marsh" that has been enhanced by muskrat (*Ondatra zibethicus*) activity.

Grosshans *et al*. (2006) and others at the International Institute for Sustainable Development (IISD) in Manitoba, Canada began work in 2005 to evaluate whether cattails could be harvested to remove nutrients, primarily phosphorus, entering Lake Winnipeg, and secondarily whether cattail biomass could be used for bioenergy, generation of carbon offsets, and other higher value bioproducts (Cicek *et al.* 2006, Grosshans & Grieger 2013, Grosshans 2014). Similarly, Vaicekonyte *et al*. (2014) explored common reed for potential biodiversity management and bioenergy potential in North America, as did Carson *et al.* (2018) who applied harvest management of invasive cattail and common reed to restore coastal wetland habitats around the Great Lakes and use of the material for bioenergy. All of these studies suggested using cattail and common reed biomass as a partial substitute for fossil fuels could help mitigate climate change by reducing greenhouse gas emissions (Cieck *et al*. 2006), and that cattail-dominated basins could be managed simultaneously for bioremediation, bioenergy and wetland wildlife habitat management (Berry *et al*. 2017).

Figure 1. Hemi-marsh located near Waconia, Minnesota and open water accentuated by muskrat activity. 10 April 2016.

History of cattails

Common or broadleaf cattail (*Typha latifolia*) is native to North America (Kantrud 1992). The status of the narrowleaf cattail (*T. angustifolia*) as a native or introduced species from Europe is unclear. In the 1830s, two species of narrowleaf cattail (*T. gracilis*), a native, and *T. angustifolia* were reported in eastern North America. By the 1850s, taxonomists had merged them into one species, *T. angustifolia* (Kantrud 1992). Prior to the 1880s, *T. angustifolia* had only been collected in a few wetlands along the North Atlantic coast. It spread west to the Great Lakes during the late 1800s and continued westward during the early and mid-20th century. Disturbed wetlands along roads, ditches, and railroads provided the likely pathway. It was first recorded in Wisconsin in the 1920s, Iowa in the 1930s, and North Dakota in the 1940s. It has spread rapidly across much of the remaining Great Plains in the last 50 years. According to Kantrud (1992), "even more noticeable in the prairie pothole region has been the great increase in wetlands dominated by the robust plant that most botanists consider a hybrid between common cattail and narrowleaf cattail, named *T.* × *glauca*."

Kantrud (1992) reported that many pastured, semi-permanent wetlands in western Minnesota and the eastern Dakotas were dominated by semi-open stands of hardstem bulrush just a few decades ago but when they were idled soon became dominated by dense stands of cattails. Another problem with cattail-choked wetlands is large numbers of migrating blackbirds (i.e., Red-winged Blackbirds [*Agelaius phoeniceus*], Common Grackles [*Quiscalus quiscula*] and Yellow-headed Blackbirds [*Xanthocephalus xanthocephalus*]) roost there and damage nearby crop fields (Linz & Homan 2011). Thus, an integrated wetland management system could reduce the density and height of taller emergent plants while increasing use by breeding ducks and reducing roosting habitat for crop-damaging blackbirds.

Biology of cattails

The best approach to managing a species is to find a vulnerable physical or physiological stage within its life cycle. By using a holistic approach to coordinate control tactics with specific seasons of growth, dormancy or reproduction, managers can better accomplish restoration goals with reduced effort, less money spent, and less habitat disturbed.

Cattails thrive in an environment of fluctuating water levels and high fertility. Their seeds germinate rapidly on mudflats, and they quickly recolonise after human or natural disturbances. They grow in a wide range of shallow water depths depending on species, age, and condition. Maximum water depths are typically one metre, although greater depths can be tolerated for brief periods. Cattail also grows as floating mats on the water's surface, helping it colonise deeper water than it could grow in otherwise (Linde *et al*. 1976). Once established, cattail can alter its habitat. New stems and root/rhizome masses grow and accumulate on dead stalks and other organic material. As materials accumulate, nutrient and carbon cycles are altered, impacting surrounding plant species (Keyport *et al*. 2019) and light is prevented from reaching the substrate which physically excludes other plants (Gleason *et al.* 2012). Cattails do filter polluted runoff containing sediment, fertiliser and heavy metals, so by capturing these pollutants, they prevent, or at least delay, them from having larger negative effects in the environment. If harvested, these pollutants could be removed from the environment.

Cattails root from their rhizomes, which are underground stems. Rhizomes anchor the plant in the substrate and send out water and nutrient-absorbing roots. Clonal propagation occurs via rhizome growth. Cattails grow back year after year utilising stored energy in rhizomes. Often a large dense stand consists of only a few genetically unique plants. Each is connected by a network of rhizomes from which emerge dozens of stalks (Linde *et al*. 1976). These stalks, 1–3 m high, have long, sheathing leaves emerging from the base of the plant. Cattail leaves are full of spongey aerenchyma cells, which bring oxygen to rhizomes even when the substrate is underwater and the leaves are dead (Linde *et al*. 1976).

As the European narrowleaf cattail spread westward in North America in the past 100 years, and its range overlapped with the native broadleaf cattail, they hybridised. The native broadleaf cattail prefers shallower water and is less robust than narrowleaf. Hybrid cattail is more resilient in a wider range of hydrologic conditions than either parent thus allowing it to be extremely invasive. Travis *et al*. (2010) attributed the increasing invasiveness of cattail throughout the past few decades to be caused in large part by the emergence of this new hardy hybrid.

Cattail dominance is largely due to its rapid growth and large carbohydrate reserves in the rhizomes. From a management perspective, if dead leaves have been cut and old stalks are submerged, flooding a stand inhibits energy metabolism and weakens the plant (Murkin *et al*. 2000). Linde *et al.* (1976) determined that carbohydrate reserves are lowest just as the green spikes emerge, generally sometime in mid-June. This is the ideal time to cut stalks as this both limits the cattail's ability to produce viable seed and prevents the build-up of carbohydrate reserves in rhizomes. Combining midsummer mowing with spring flooding severely weakens plants and may allow other wetland plants to establish. However, water levels and wildlife use in early to mid-summer often restricts accessibility during this time.

From late November to late April, cattail plants go dormant and release fluffy, wind-dispersed seeds, as many as 20–700,000 per inflorescence (Baldwin & Cannon 2007). Over the years the stalks, which grow quickly but decompose slowly, build up in the stand and shade out other plants. As they decompose, often in methane-producing anaerobic conditions, captured nutrients are released back into the system.

REGIONAL HIGHLIGHTS

Nature based solutions for water, nutrient, and energy management - Manitoba, Canada

Lake Winnipeg, in Manitoba, Canada, is the 10th largest freshwater lake in the world, and has been slowly deteriorating over the past century due to eutrophication by phosphorus enrichment, which causes oxygen-depleting algae blooms. Much of the phosphorus, primarily from agricultural runoff and municipal wastewater, enters the lake during snowmelt and flooding in spring as well as large summer rain events from the surrounding watershed (McCullough *et al*. 2012). At almost 1 million km^2, this basin is the second largest in Canada, draining four provinces and four USA states. Since 2012, harvest management of cattail and other emergent plants has been explored to reduce phosphorus loading to Lake Winnipeg, and use the harvested biomass for sustainable bio-products and low carbon renewable energy to replace fossil fuels (Grosshans 2014, 2016; Grosshans & Grieger 2013, Grosshans *et al.* 2014, Berry *et al*. 2017).

Initial research focused on a harvest site at the Netley-Libau Marsh located where the Red River flows into Lake Winnipeg (Cicek *et al.* 2006, Grosshans 2014). The Red River is the source of 30 % of the nitrogen and 60 % of the phosphorus to Lake Winnipeg, even though comprising only 11 % of the inflow. Grosshans (2014, 2016) demonstrated that effects of harvesting on the wetland were minimal, phosphorus absorbed by cattails was removed in harvested biomass, and the biomass could serve as sustainable low-carbon energy. Further, by displacing coal with harvested biomass, carbon offset credits were generated that could be sold to fund watershed management efforts through a voluntary carbon offset market (Grosshans *et al*. 2014). Using wetlands or cattail for nutrient removal was a not a new idea, nor was burning biomass for energy, but the approach was innovative for not looking at these problems in isolation or as a cost, but holistically considering environmental, economic, and social benefits together (Berry *et al*. 2017).

Grosshans *et al*. (2014) applied these research concepts at a larger scale in the Pelly's Lake water retention wetlands, on marginal agricultural lands, and in roadside ditches to demonstrate the benefits of harvest management to reduce phosphorus loading in the Lake Winnipeg watershed. Low lying marginal lands, water retention sites, and municipal ditches collect runoff from the watershed and naturally concentrate nutrients from non-point source runoff. They evaluated the management of these areas by harvesting the emergent plants and assessing phosphorus removal during the growing season. They also found that harvesting restores degraded wetland habitat, it improves biodiversity, and the biomass can be used for energy and bioproducts (Grosshans & Greiger 2013, Grosshans *et al*. 2014, Berry *et al*. 2017).

In 2014, the Government of Manitoba banned the use of coal for space heating, which increased demand for biomass fuel and provided a market for harvested cattail for use in larger coal burning boiler systems. Based on approximately 1 to 8 kg of phosphorus in one large square cattail bale or 5 to 15 kg per hectare, harvest management from 2012 to 2015 removed almost 1,000 kg of phosphorus and 10,000 kg of nitrogen from the Lake Winnipeg watershed, equivalent to the phosphorus in 3,000 bags of lawn fertiliser.

With the market demand for biomass, cattail fuel products were competitive with wood-based fuel pellets and were used for space heating in larger boiler facilities on Manitoba's Hutterite Colonies and at Providence University College (Grosshans *et al.* 2014, Berry *et al.* 2017). Lignite coal from Estevan, Saskatchewan used in Manitoba has a total cost of \$100 to \$120/T including transportation, plus an added coal tax. Biomass has a cost of \$50/T to \$100/T for bulk coarse fuel such as woodchips, sawdust, or chipped cattail, and \$120/T to \$180/T for processed fuel products such as fuel pellets. Over 1,500 tonnes of blended biomass fuel (primarily cattail/wood and cattail/grass/wood) and 1,500 tonnes of wood-based fuel pellets produced generated 5,000 tonnes of CO_2 equivalents of offsets. Analysis indicates blended cattail/wood fuel pellets have excellent burn characteristics, low ash (3 %), and energy comparable to wood pellets at 19.8 MJ/kg. Pure cattail fuel pellets contain 6 % ash after burning and up to 90 % of the phosphorus (Grosshans 2014). The rest of the phosphorus is bound in clinkers or slag in the boiler system. Fertiliser trials showed that the phosphorus in the ash is not readily available in the short term but releases slowly when land applied (Grosshans *et al.* 2014). This applied research demonstrated the commercialisation of biomass such as cattails is viable for bioenergy, as well as for higher value bioproducts, biocarbon, and biogas if market demand exists. The additional environmental benefits of harvesting this biomass as a component of sustainable watershed management elevates the environmental profile and sustainability of such biomass products and offset credits (Berry *et al.* 2017).

In addition to the nutrient capture, biomass, and carbon offset benefits, harvesting combined with water level management in the Pelly's Lake water retention site has restored almost 300 hectares of valuable wetland habitat. Figure 2 shows an aerial view of the Pelly's Lake Watershed Management Project in operation retaining runoff water in early spring (March 20, 2015). Culvert gates are closed in the autumn and the earthen dam and spillway control the level of water retained in the site during spring runoff. The areas of harvested cattail in the deepest sections closest to the earthen dam are fully under water, but once culvert gates are opened (allowed after June 15) water levels will drop and new wetland habitat will emerge. The ability to dewater the site allows for harvest management and collection of biomass in the autumn. The numbers and diversity of migrating waterfowl has increased significantly during the period of spring flooding as a result of autumn harvest and removal of dense stands of cattails.

Cattail control through herbicides - The Dakotas, USA

The use of herbicides to control and manage cattail dominated marshes and reduce crop predation by flocks of blackbirds was the focus of a 1992 cattail management symposium in Fargo, North Dakota (Linz 1992). Sunflowers were the primary crop of interest since 69 % of the sunflowers grown in the United States in 1992 were grown in North Dakota. Herbicide management continued over several years under the sponsorship of USDA-Animal and Plant Health Inspection Service (APHIS), National Sunflower Growers Association, North Dakota State University, South Dakota State University, and the U.S. Fish and Wildlife Service. Linz *et al*. (1992) began evaluating use of Rodeo (Glyphosate)

Figure 2. Aerial view of the Pelly's Lake Water Management Project in operation retaining spring runoff water (20 March 20 2015). Wetland habitat extends to the horizon, areas of harvested cattail in the deepest section closest to the earthen dam is fully under water. Opening of the gated culverts (right side of photo) will lower water levels allowing new wetland habitat to emerge. The ability to control water levels allows for autumn harvest of biomass.

herbicide in 1989 to fragment cattail stands and found July/August applications temporarily controlled cattails for two years and were effective in deterring blackbirds. In 1990, they treated 70–90 % areal coverage of their study sites but reduced that in 1991 to 50–70 %. Enhanced waterfowl use was noted, however, they suggested there was a probable decrease in rail (*Rallus limicola, Porzana carolina*) and Marsh Wren (*Cistothorus palustris*) use until cattails grew back. Reducing cattail coverage limited the number of Red-winged Blackbirds, Yellow-headed Blackbirds, and Marsh Wrens (Linz *et al*. 1996). A 70:30 open water to emergent vegetation ratio was recommended by Linz *et al*. (1992) to simultaneously deter roosting blackbirds and benefit wetland wildlife. Messersmith *et al*. (1992) found cattail control was good to excellent when Glyphosate was applied at 2.5–3.5 kg/ha and suggested the best application time was from late July to early September. Another species that may have benefitted from glyphosate-treated wetlands was Black Tern (*Chlidonias niger*); a species considered endangered in some states. Linz *et al.* (1994) found a positive relationship between Black Tern numbers and dead cattail coverage.

Solberg & Higgins (1993) found waterfowl breeding pairs increased in glyphosate-treated wetlands in northeastern South Dakota in 1986 and 1987. Henry & Higgins (1994) found no detrimental effects on six species of invertebrates (a primary food source of waterfowl and shorebirds) due to Glyphosate treatment. Linz *et al*. (1999) assessed the response of six invertebrate species one and two years post-treatment after reducing cattail coverage with Glyphosate and observed similar numbers of invertebrates between treated and reference wetlands.

Herbicide control of cattails received “cautious support” (Stromstad 1992) by wildlife interests at the Fargo symposium. Concern was raised that often cattail-dominated marshes provide the only winter cover for Ring-necked pheasants (*Phasianus colchicus*) and White-tailed deer (*Odocoileus virginianus*) in intensely farmed landscapes of the Dakotas. Larger cattail-choked wetlands might be more desirable to open up than smaller ones. Creating spatially dispersed openings in these larger marshes could enhance their winter cover values while still discouraging blackbirds. A mosaic pattern would be better than strips or blocks.

Wildlife habitat restoration and bioenergy through cattail management - Minnesota, USA

In the 1980s, Johnson *et al*. (1987) explored the value of cattails (planted *T. angustifolia*) in a managed constructed wetland as a bioremediation tool to remove nutrients (N, P, and K) from sugar beet processing effluent at Crookston in northwest Minnesota. August harvest extracted the most nutrients, but the material was too wet for practical use as an energy crop. They used late autumn–winter harvested material (using a field chopper or baler) for spreading on agricultural fields and estimated a yield of 15–20 T/ha (Dubbe *et al.* 1988). In 2012, Svedarsky *et al*. (2016) identified 43,356 ha of wetlands in northwest Minnesota dominated by cattails in excess of the 50:50 desired ratio of open water to emergent vegetation. Most were under public ownership, which increases the potential to extract a biomass harvest while simultaneously enhancing wetland wildlife habitat.

Glacial Ridge National Wildlife Refu*ge*

Glacial Ridge National Wildlife Refuge (GRNWR) is a 9,339-ha prairie and wetland restoration project in northwest Minnesota that was initiated in 2001, where a total of 8,098 ha of prairie and 1,240 ha of shallow wetlands were restored. Bruggman (2017) evaluated 23 shallow wetlands in the refuge to determine effects of mowing, fire, chemicals and chemical combined with fire at reducing cattails. He found live cattail increased by 12 % after mowing in the first year but then returned to pretreatment levels after two years. Fire alone increased the amount of live cattail by 68 % one year after treatment and 54 % two years post-treatment. Glyphosate-only application resulted in a 73 % reduction one year after treatment but only a 24 % reduction two years after treatment. All other species of vegetation were affected negatively by chemical and fire but little by other treatments. Bruggman (2017) concluded that a single management action may not be enough to control cattails.

Overall, bird species richness was not influenced by treatments likely due to some species benefiting from a treatment, while others did not. Red-winged Blackbird abundance decreased after the use of chemicals but increased after chemical × fire. There was a trend for decreased Marsh Wren abundance following the use of chemicals and fire, Sedge Wrens (*Cistothorus platensis*) increased after fire, and Swamp Sparrows (*Melospiza georgiana*) generally benefited from all treatments.

Bruggman (2017) found amphibian species richness was not affected by treatments. Boreal Chorus Frog (*Pseudacris maculata*) abundance did not change relative to treatments; however, there was an increasing trend after mowing. Dragonfly abundance was not statistically affected by the treatments but tended to decrease after fire and chemical × fire treatment. Damselfly abundance tended to increase after chemical treatment and

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mowing. He concluded that chemicals were the best cattail control method; however, wetland systems are complex with members of a community affected differently by various treatments.

North Ottawa Impoundment

The North Ottawa Impoundment (NOI) near Breckenridge in west-central Minnesota was constructed for downstream flood control and can be managed to allow cattail to be harvested for nutrient extraction (Lewis 2014). The 777-ha impoundment has eight 65-ha cells and two 130-ha cells with a storage capacity exceeding 17.7 M m^3 during flood events and receives water from a 19,421-ha agriculture dominated watershed of the Red River basin. Secondary goals of the impoundment are to improve water quality by removing nutrients from surface runoff through wetland processes and biomass harvesting, wildlife habitat enhancement, and downstream flow augmentation. Preliminary reductions in sediments and nutrients have been documented during water quality monitoring, and a moist soils and shallow wetland rotation has resulted in improved habitat conditions for migratory waterfowl and shorebirds.

Harvesting aquatic biomass for nutrient recovery in impoundments is a somewhat unique practice in the agricultural areas of the Northern Great Plains of the USA, especially when undertaken at this scale. Harvest within cells was facilitated by dropping water levels and using conventional harvesting equipment. An autumn harvest proved biomass with lower moisture content could be used as fibre (board, insulation, bio-composites) and for densified fuel pellets, cubes or briquettes for bioenergy use. Being able to utilise the harvested biomass offers increased economic returns, which could be necessary to sustain harvest management of water retention projects.

MANAGEMENT TECHNIQUES

Cattail management has been of great interest over the last 50 years in the Northern Great Plains of North America. Management is challenged by several variables including wetland depth, nutrient status, salinity, source of inflow water, natural sanctuary versus former cropland, type of cattail (it is assumed that hybrid cattail is or will be present and dominant), water level control options, and desired outcomes for a particular basin. Drought occurrence is another important variable as is the availability of livestock if grazing is to be considered part of a control option. Muskrats can be a significant but dynamic natural variable since their population levels may be affected by drought, over-winter water levels, fur prices and disease. Clearly, not all management options will work in a given area, and management plans will often require more than one practice be applied.

A number of previous review papers have addressed the biology and control options for cattails (Linde *et al*. 1976, Sojda & Solberg 1993, Baldwin & Cannon 2007), but none have included harvest management as a viable option. Various traditional control methods are briefly reviewed here followed by a more detailed discussion of harvest management.

Prescribed fire

The landscape of the Northern Great Plains is adapted to fire. Burning can suppress dominant plants such as cattails and give less aggressive plants a better chance of growing. Fire management is often limited by water levels and plant moisture conditions, soft soil conditions that cause difficulties for accessing the site, and volatile cattail seeds that can be dangerous. Gleason *et al*. (2012) studied six wildlife areas ranging from Agassiz NWR in northwest Minnesota to the Iroquis NWR in western New York to evaluate the comparative effects of growing season versus dormant season burns. The study concluded: 1) water level control is key during either season but the necessary infrastructure is often lacking; 2) growing-season burns are generally preferred to damage cattails due to low carbohydrate reserves present in the rhizomes at that time; and 3) a combination of methods is commonly applied for success. While fire management eliminates dense dead cattail debris allowing other plants to grow, Bruggman (2017) observed that fire management actually promoted cattail growth by the end of the growing season, and that fire alone increased the amount of live cattail by 68 % one year after treatment and 54 % two years post-treatment.

Chemical

Herbicide use to control cattails is still a common practice in some USA state and federal agencies. It is relatively quick to apply, requires minimal labour if spraying is contracted, and can be done regardless of water levels depending on the regulatory clearance of the chemical. The herbicide, Glyphosate, is a systemic chemical that is most effective when applied to the leaf surface in late summer. This is the period of maximum carbohydrate movement to rhizomes and the chemical moves from the leaf surface throughout the plant. Glyphosate blocks a unique metabolic pathway that produces key amino acids in plants. This pathway does not occur in animals or invertebrates, so the chemical is currently labelled safe for aquatic use in the United States, but its use is not allowed in aquatic environments in Canada. Globally Glyphosate use is under debate and whether it is carcinogenic to humans (Cressey 2015).

Lawrence *et al.* (2016) evaluated Glyphosate effects on hybrid cattail in Michigan along with mowing and removal (harvest). They found that while chemical treatment was an effective control, it caused a release of nutrients (N and P) from dead and decaying plant material, which could accelerate growth of other invasive plant species and the eutrophication of receiving waters. It also reduced the diversity of other plant species presumably because of chemical effects as well as shading by the canopy of dead cattail material. This pulse of nutrients and increase in cattail productivity following Glyphosate treatment was also found in experimental mesocosm treatments by researchers in Manitoba, suggesting once Glyphosate is in the water it could in fact aid in the spread of cattail (Grosshans pers. comm.). Herbicide resistance to Glyphosate has also been found to occur. Zheng *et al*. (2017) found that absorption of the herbicide glyphosate is four-times greater for native cattail, suggesting herbicide application could be causing resistance to occur in the hybrid and could ultimately aid the spread of the more glyphosate-resistant hybrid while eliminating native species. Lawrence *et al*. (2016) recommended that cattail harvest would be better than herbicides at removing nutrients from the system and would not reduce the biodiversity of other wetland plants. Other herbicides that have been effective for cattail control include Habitat@ (Imazapyr) and Clearcast@ (Imazamox). Both chemicals have been reported as having greater selectivity and longevity than Glyphosate (Rogers & Black 2012).

Mowing

The effectiveness of mowing for cattail control depends primarily on the season and other factors such as water levels. If stems can be cut at, or below, water or ice level, the rhizomes and roots could be deprived of oxygen if water levels can be raised and the site flooded for a long enough period of time (Murkin *et al*. 2000). Mowing is most effective for cattail control in mid-summer, just as the flowering spikes appear, and when carbohydrate reserves are lowest. Repeated annual mowing for several years may be necessary.

A difficulty with mowing as a management tool is access to wetland sites and this may require tracked vehicles. Mowing in frozen conditions is often more convenient but will have little effect on the rhizomes without subsequent increases in water levels. In fact, winter mowing of wetland margins without increases in spring water levels may increase cattail seed germination by removing the dead overstorey. Typically, cattail stalks need to be covered with at least 15 cm of water, and possibly more for hybrid cattail with well-developed rhizomes. Some field managers recommend 0.7 to 1 m of inundation to have much of an effect.

Mowing also has relevance to nutrient management in runoff water, particularly in cattail filled road-side ditches. These drainage ditches are often mowed in the autumn when dry to provide better drainage and for snow management. This has the effect, however, of releasing a flush of nutrients when the shredded material breaks down over the winter, releasing nutrients during spring runoff. Harvesting and removing this biomass would remove the captured phosphorus, preventing its release. The application and effectiveness of mowing and other physical alteration techniques are discussed more thoroughly in Baldwin & Cannon (2007) and Sojda & Solberg (1993).

Grazing

Grazing by native herbivores (*Bison bison* and *Cervus canadensis*) was once a natural disturbance of wetlands that can be simulated by grazing cattle. Increasingly, grazing is used in conjunction with prescribed fire as a management tool in areas with uplands for grazing. The practice is known as "Patch-Burn-Grazing" (Fuhlendorf & Engle 2004) and this "flash grazing" is being applied on many public wildlife areas in the USA. Cattle, as well as bison, are attracted to the new growth following a burn as well as to the mud, which they coat their lower legs with to deter insects. This technique is being applied at the Glacial Ridge National Wildlife Refuge and is adding a significant element of heterogeneity to the landscape. Such "stomped-down" perimeters of cattail marshes are attractive feeding areas for shorebirds (due to the openness and manure deposits) and can provide a level of cattail control if applied periodically. Like mowing, grazing effects are short-lived unless incorporated into site maintenance plans.

Mero *et al*. (2015) used prescribed burning and grazing, alone and in combination, to manage common reed in a large marsh system in Hungary. All three treatments were effective in adding the heterogeneity of open areas to the wetlands and improving marshland bird habitat. They recommended late summer burning followed by grazing as essential to maintaining high diversity. This management period is timed to avoid the breeding season and precede migration and wintering birds; it may also be an appropriate management option in the Northern Great Plains.

Muskrats are an effective aquatic grazer and can be a significant control factor for cattails. Their population dynamics can be rather complex and there is little that humans can do except regulate fur harvest and control water levels in situations where such is possible. Higher over-winter water levels are generally beneficial to muskrat and Sojda & Solberg (1993) recommended 1.2 to 1.5 m depths are needed in most areas. Some practitioners believe the robust rhizomes, heavy root mass and high stem density of mature hybrid cattail stands are unattractive to muskrats, which is particularly true of floating root masses, therefore muskrat impacts may be most pronounced in newly established cattail stands.

Water level manipulation

Well-timed flooding or draining of wetlands can limit cattail growth and is commonly used together with defoliation techniques, such as mowing or harvesting. Flooding can prevent seedlings from germinating and cut off oxygen to rhizomes if stalks are cut far enough below the water level (Murkin *et al*. 2000). However, water manipulations are often challenging, expensive and unrealistic for shallow wetlands of the Northern Great Plains. In addition, it can indirectly affect the over-winter survival of muskrats.

Harvest management

Cattail management can involve an integrated approach of harvest and removal of plant material from wetland basins. This approach can maximise wetland habitat restoration, nutrient capture and removal, and energy content of harvested biomass. Earlier work by Dubbe *et al*. (1988) and Johnson *et al*. (1987) in the late 1970s in Minnesota evaluated harvesting cattails for nutrient bioremediation and cattail biomass for bioenergy use. In Canada, Grosshans (2014, 2016) and Grosshans *et al*. (2014) began applying integrated concepts of harvesting cattail and other emergent plants for phosphorus capture, bioenergy, and carbon offsets at the landscape scale within the watershed of Lake Winnipeg, in Manitoba Canada in 2005. In the United States, Svedarsky (2016) and Bruggman (2017) evaluated wildlife benefits of cattail harvest management compared to traditional cattail management techniques in northern prairie wetlands in Minnesota, while Carson *et al*. (2018), Keyport *et al*. (2019), and Lawrence *et al*. (2016) examined harvest management for biodiversity and control of invasive cattail and common reed in the coastal wetlands of the Great Lakes. Both the Canada and US cases proved harvest management of cattail was effective for control of cattail and improved wetland habitat and biodiversity. At the same time, similar research and applied management was being carried out in Europe on harvest management of common reed and other emergent plants from rewetted peatlands, under the concept of "paludiculture" (Wichtmann *et al*. 2016). Paludiculture research demonstrated the use of rewetted peatlands for cultivation of wetland biomass, which allowed the re-establishment and maintenance of ecosystem services; carbon sequestration and storage, nutrient retention, and provision of biomass for use (Wichtmann *et al.* 2016).

These studies all demonstrated that successful harvest management of large emergent wetland plants such as cattail and common reed can improve wetland habitat and biodiversity. Also, by harvesting these unconventional biomass sources, multiple other environmental and economic benefits are gained. Additional economic benefits can be as simple as using the biomass for livestock bedding, compost, bioenergy, and higher value bioproducts, but also when additional market values are monetised - including biodiversity payments, carbon sequestration and GHG offsets, and the value of recovered nutrients such as phosphorus through water quality offset credits (Berry *et al*. 2017).

Burning fossil fuels releases ancient carbon that was previously permanently stored in the ground. Unlike burning fossil fuels, biomass is considered a low-carbon fuel source. Plants require CO_2 and actively take CO_2 out of the atmosphere when they grow. When biomass is combusted for energy production, CO_2 taken out of the atmosphere during growth is re-released back into the atmosphere. A complete life-cycle analysis from "cradle to gate" was conducted in Manitoba for harvesting cattail and producing densified fuel pellets (Valdez 2014). This study showed a net reduction in carbon emissions, proving cattails harvested to displace coal use did result in lower carbon emissions.

In general, cattails as a biomass source provide advantages over other conventional biomass sources in addition to the benefits from harvesting: they grow in wet marginal land areas unsuitable for agriculture unless drained; are a renewable resource; and replanting is not necessary. Furthermore, the biomass is a "waste resource" from harvest management and is not purpose grown or harvested simply for energy use, thus competing with crops for food.

Harvesting a wetland basin will typically require specialised equipment. If a basin has water level control, this can both facilitate access for harvesting and be used to control cattails by flooding. Challenges and methods are described in the following sections.

Seasonality

Harvest timing depends on the goal. If managing primarily for nutrient removal, summer or early autumn would be optimum (Grosshans 2014). This could also reduce stand density if harvest occurs before the plant has stored sufficient energy to prepare for the next growing season. On the other hand, if the goal of the harvest is sustainable bioenergy or habitat, dormant season harvest (winter, spring) could be best. During this period cattails have stored energy for the next growing season in substrate rhizomes, they are drier, and there is no significant decline in energy content. In addition, many of the elements that can cause issues in boiler systems (i.e. silica, potassium, magnesium) are removed from the plant tissues as a result of natural drying and winter freeze-thaw cycles (Grosshans 2014).

Bruggman (2017) and Grosshans (2014) suggested an earlier harvest could have the greatest positive effect on wetland wildlife habitat, but a late autumn/winter harvest generally provides the greatest number of advantages. It avoids direct effects on wildlife, removes cattails, improves habitat, captures nutrients, harvests biomass, and would be best for most current equipment capabilities while having the least effect on substrate. The late season window may be limited however since there are fewer warm days to allow harvested biomass to adequately dry out before collection and storage, and a heavy snow early in the year could affect harvesting and limit collection.

Equipment

There are three general approaches to harvest cattails: 1) cut, swath, and bale material (square or round bales); 2) cut, chop, and blow chopped material into a hopper; and 3) cut with an amphibious machine that operates in water to cut and gather biomass.

Baling. If conditions are dry enough to use conventional agricultural equipment for cutting and swathing, then baling is an efficient method to collect cattail biomass when harvest sites are at some distance from processing sites (Grosshans & Grieger 2013). Bales allow longer term storage of biomass material and reduce shipping costs. Grosshans *et al.* (2014) preferred a rotary disc mower with conditioning rollers, used for cutting forage crops, to cut heavy stands of cattail (Figure 3). Conditioning rollers crush stems and allow cattail swaths to dry faster compared to straight cutting, thus reducing the time needed until baling (Figure 3). This method involves two passes; one to swath and another to bale. Tyre pressures are lowered to increase flotation on softer sediment and reduce damage to the wetland. If conditions are too wet and soil conditions too soft to allow conventional equipment, specialised tracked equipment such as machinery used in Europe (Figure 4) will be required for harvesting cattail and common reed (Wichtmann *et al*. 2016).

Chopping. Collection with a forage chopper, where material is cut, chopped, and blown into a towed wagon in a single pass, could be an efficient harvest method, provided material is transported and used within a short time. A variety of biomass choppers operate in Europe that are typically track-mounted and blow material into a bin on the machine itself or into a towed wagon (Wichtmann *et al.* 2016). In Minnesota, a conventional forage harvester was used by Dubbe *et al*. (1988) and at the North Ottawa project after de-watering an artificial wetland cell (Lewis 2014). A challenge of forage chopping, however, is material handling and the light volume of the collected material. If it is too dry it creates considerable wind-blown dust, but if too wet, it could ferment if stock-piled for too long. The latter would

Figure 3. Rotary disc mower swathing cattail (*Typha*) at Pelly's Lake, Manitoba, Canada during the autumn harvest in September 2013 (left); and baling dry cattail with a large square baler (right).

not be an issue if it were used for biogas production and a processing plant was nearby. Regardless, storage and transport present a larger problem with chopped material than baled because of the light volume and density, making transportation of the material any considerable distance challenging.

Transportation. As with any place-bound resource, transportation is a significant cost determinant. Distances from a harvest site to a processing site and from processing to consumption sites are also key cost determinants. Locating processing facilities close to biomass supply sites is beneficial to generate significant quantities of biomass. Large square bales are easier to transport than round bales; however, a square baler requires more horsepower to operate than round balers.

Processing. Cattail or common reed biomass can be used in a variety of forms depending on the energy system, whether it is whole bales, shredded, or a densified fuel product (Grosshans *et al.* 2014, Wichtman *et al*. 2016). Heating systems capable of feeding course bulk biomass such as woodchips or sawdust can utilise shredded cattail, which is best blended with shredded wood for a more uniform feedstock. Systems that require smaller densified fuel (i.e. fuel pellets) require further size reduction, accomplished through a variety of tub-grinders or shredders. This material goes to a "densifier" which forms the material through steam and heat into compressed fuel products such as pellets or cubes, ready for storage, long distance shipping, and combustion (Grosshans *et al*. 2014).

After densifying, torrefaction is an optional step that can be added, depending on the end goal. Torrefaction is a thermo-chemical treatment (roasting) of biomass at 200–320 °C (390–600 °F) in the absence of oxygen at atmospheric conditions (Tiffany *et al.* 2013). It produces a solid, dry, brittle, blackened material (i.e., biocoal) and substantial amounts of volatile gasses that can be combusted in the process. Advantages of torrefaction include higher energy density, more homogeneous composition, hydrophobic (repels water), elimination of biological activity, and improved grindability. The resulting biocoal typically has 130 % of the energy per unit of mass compared to un-torrefied biomass, so the energy content is similar to traditional coal. Like coal, it can be stored outside since it is hydrophobic in contrast to most biomass pellets (Tiffany *et al.* 2013). It is also feasible to co-fire up to 15 % biomass with coal without any boiler modification. (Leroux (2012).

NEXT STEPS

There are logistical challenges of harvesting cattails for management, but projects like Grosshans *et al.* (2014) have demonstrated not only the commercial feasibility of using cattails for fuel and biomass products, but also the associated co-benefits of wetland management, water quality remediation, nutrient recovery for fertiliser, enhanced wildlife habitat, and possible stimulation of rural economies through local product markets and carbon and water quality offsets (Grosshans *et al*. 2016, Berry *et al*.

Figure 4. Examples of specialised wetland harvesters from Europe. Left: the tracked wetland harvester Pisten Bully GreenTech 100 (left) manufactured by Kässbohrer (source: http://www.offpisteagri.co.uk/pictures-worth-seeing.html). Right: the Sumo -Quaxi Machine from Austria that cuts and bales (source: http://duene-greifswald.de/doc/rrr2013/talks/Harvesting%20Techniques%202_Beckmann%202013%20-%20Harvesting%20Technologies%20for%20reeds%20in%20Austria.pd.

2017). Further systems thinking is needed to simultaneously consider the multiple stacked environmental and economic benefits of harvest management, including identifying bioenergy demand and local biomass markets by commercial and residential sectors. The approach must also include a complete life cycle analysis of energy and economics of harvesting, transport, and processing (Valdez 2014). New approaches for funding management projects emphasising their importance as natural infrastructure solutions to reduce risk and lessen the effects of climate change should also be considered. Insurance rebates, municipal natural infrastructure funding, and green bond investments could increase the ability and willingness of communities to explore and adopt management projects as natural infrastructure solutions (Moudrak *et al*. 2019).

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Author for correspondence:
Professor Daniel Svedarsky, Northwest Research and Outreach Center, University of Minnesota, Crookston, MN, USA. Tel: 218-686-6872; E-mail: dsvedars@crk.umn.edu