ECOLOGICAL RESPONSES AND EFFICACY OF CATTAIL TREATMENT METHODS: PHASE I

Megan Fitzpatrick[1] and Ed Zlonis[1]

SUMMARY OF FINDINGS (Primary heading)

We conducted a pilot (Phase I) study to evaluate logistics for a future full-scale (Phase II) study comparing the effectiveness and ecological responses of prairie pothole wetlands to several cattail control treatments. Our Phase I work included gathering information about invasive cattail treatments from MN DNR managers and one season of field data collection.

Through information-gathering (discussions and a survey of MN DNR managers), we were able to ensure that our proposed Phase II focus (cattail treatments in seasonal prairie pothole wetland using herbicide, roller-chopping, disking, and scraping) and dependent variables (vegetation metrics, waterfowl pair counts) align with manager information needs. We also summarized additional information needs that are outside the scope of our current study but could be addressed in future studies, such as efficacy of treatments for floating cattail mats and MN DNR's aerial herbicide spraying program for cattails.

In our field work, we gathered preliminary data from a small sample of wetlands (n=26) that will inform Phase II hypotheses. However, our primary goal was to obtain logistical information for planning a viable Phase II. For example, through intraclass correlation coefficients and bootstrapping simulations with Phase I data, we identified the importance of capturing within-wetland variation in our Phase II sampling scheme and the importance of carefully identifying the wetland area to be sampled, to avoid capturing variable amounts of the wetland-upland gradient. We also found that time required for vegetation surveys was about twice what we expected, and this information will help us plan appropriate staffing levels for a Phase II. Along similar lines, we identified vegetation metrics that were highly correlated with others and could be dropped from Phase II methods to save time in the field, with minimal loss of information (e.g., coverage of "all cattail" in addition to specific classes of cattail, and cattail stem/leaf touches on a vertical pole). Phase I vegetation surveys also allowed us to assess feasible levels of plant taxonomic identification for staff (broad for temporary natural resource technicians, with contractors necessary for extensive species-level ID).

We also familiarized ourselves with the emerging technology of uncrewed aerial vehicles (UAVs, i.e. drones) as a survey tool. We developed a methodology (UAV flight speed, height) to count waterfowl, learned about time required for UAV-based waterfowl surveys (3-6 wetlands per day), and developed materials for training future researchers/technicians in duck identification from overhead. We also found that cattail-dominated patches can be differentiated from other vegetation in UAV-based aerial imagery.

INTRODUCTION

Cattails (*Typha* spp.), especially non-native species (*T. angustifolia*, *T. x glauca*) have dramatically increased in abundance in the Prairie Pothole Region (PPR) since the mid-twentieth century (Kantrud 1986, Bansal et al. 2019). Cattails form dense monotypic stands that displace other aquatic plants and impact wetland birds, amphibians, and fish via changing

[1]Minnesota Department of Natural Resources, Wetland Wildlife Populations and Research Group

habitat structure and displacing food resources (Bansal et al. 2019). MN DNR Wildlife staff and other wetland managers in the region must make decisions about methods of cattail control, including choice of initial treatment and follow-up treatments in subsequent years. However, there is limited scientific information available to help managers choose among many treatment options. Consequently, we proposed research to fill gaps in knowledge pertaining to cattail treatment effectiveness and longevity in prairie pothole wetlands. This report describes a Phase I study to evaluate the logistics and necessary sample size for a larger Phase II before-after-control impact (BACI) study comparing treatment effectiveness and ecological responses of wetlands for a variety of cattail control treatments in PPR wetlands.

The Wildlife Section's Wetlands Management Program (WMP) staff (John Maile, Adam Kleinschmidt, Sarah Kvidt, and Jacob Rambow) are partners in this research. The Wetlands Management Program restores and enhances small (<50 acre) wetlands in priority complexes within the prairie region of Minnesota.

History and Biology of Cattail Invasion

The increasing dominance of cattails in Minnesota wetlands can largely be attributed to human-facilitated spread of invasive narrowleaf cattail (*T. angustifolia*) and the subsequent hybrid species *T. x glauca* (cross of *T. latifolia* and *T. angustifolia*) along with 20th century land use and climate changes (Bansal et al. 2019). *T. x glauca* is an especially effective invader that tends to dominate even its parental species (Bansal et al. 2019).

Several key aspects of cattail biology have contributed to its ability to dominate modern wetlands. Cattails are prolific reproducers. Wind-dispersed cattail seeds (thousands per inflorescence) can disperse over 1 km and remain viable in the soil for decades (Sojda and Solberg 1993, Bansal et al. 2019). Cattails also reproduce asexually via rhizomes (underground, horizontal stems), and contain stored carbohydrates (starch). Each growing season, rhizomes elongate and form vertical shoots that grow to become new stems, allowing the plant to form large clonal stands (Sojda and Solberg 1993). Starch energy stores allow the rhizomes and shoots to start growing early in the spring and spread rapidly (Sojda and Solberg 1993, Bansal et al. 2019). Under the right conditions, cattail clones can detach from the substrate and survive as floating mats, which may be wind-blown to other areas of the wetland, facilitating spread.

Cattails also tend to outcompete native vegetation in high-nutrient conditions and to thrive in stable hydrologic regimes. In the PPR, conversion of grasslands to agriculture, with associated runoff, sedimentation, and wetland drainage (consolidation drainage), has generally led to fewer, deeper wetlands with higher nutrient loads and reduced water level variability (Kantrud 1986, Wiltermuth 2016, Bansal et al. 2019). Increased precipitation associated with the regional decadal wet-dry cycle and global climate change has also contributed to deeper and more stable water conditions suitable for cattail dominance. Once established, the large amounts of litter produced by cattail stands (especially *T x. glauca*) create a positive-feedback loop, increasing nutrient levels and shading out native other species (Farrer and Goldberg 2009).

Impacts of Cattail Spread on Prairie Pothole Wildlife

Cattail dominance changes the physical structure and aquatic plant community in wetlands, impacting wildlife food resources and habitat. While cattail itself has little food value to wildlife, the dense stands of spreading vegetation displace native emergent and submerged forage species important in wetland food webs (Bansal et al. 2019). Recent work shows that cattail removal increases availability of high-value forage plants for waterbirds (Lishawa et al. 2020). Cattail may also reduce the diversity and abundance of aquatic invertebrates, fragment amphibian habitat, and impact fish (*reviewed in* Bansal et al. 2019).

Cattail's propensity to spread has reduced and even eliminated the availability of open water habitat in many prairie pothole wetlands. A mix of open water and emergent vegetation is important for many avian species. A "hemi-marsh" state, or 50:50 ratio of emergent vegetation to open water, tends to maximize the density and diversity of wetland-breeding birds (Weller and Spatcher 1965, Sojda and Solberg 1993, *but see* Galt 2010) and is a common management goal. For waterfowl, hemi-marsh conditions may act as a cue to high invertebrate food availability while visually isolating waterfowl pairs (Kaminski and Prince 1981, Murkin et al. 1982, 1997, Kantrud 1986). Dense emergent vegetation may also hinder access to nest sites (upland-nesting ducks), allow predators to access nesting islands, and force diving ducks to walk to nests (Kantrud 1986). Duck broods generally exhibit preference for semi-open or open emergent vegetation, which may provide cover without impeding movement (Kantrud 1986, Bansal et al. 2019). Similarly to waterfowl, reduced cattail coverage is associated with increased densities of American coots (*Fulica americana*) and black terns (*Chlidonias niger*) (Linz et al. 1997, Linz and Homan 2011).

Research on ecological responses to cattail control has raised concerns about some secretive marshbirds that rely on substantial emergent vegetation (e.g. sora, *Porzana carolina*; Virginia rail, *Rallus limicola*; American bittern, *Botaurus lentiginosus* (Linz et al. 1992, 1997, Linz and Homan 2011, *but see* Hill 2021). However, researchers suggest that managing for hemi-marsh conditions, mixing open water with live and dead emergent vegetation, may provide a way to balance the needs of species requiring varying levels of emergent cover (Linz et al. 1992, 1997, Linz and Homan 2011, Bruggman 2017, Hill 2021). Hill et al. (2023) found significant increases in sora and Virginia rail abundance following herbicide application (three years post-treatment) for cattail control in prairie pothole wetlands.

Cattail Management

Cattail control methods can be grouped into two broad categories: herbicides and physical disturbances. Herbicides, distributed by helicopter or ground equipment (e.g. amphibious vehicles like Marsh Masters®), are commonly used by managers because they are relatively inexpensive per unit area treated and can be applied across a wide spectrum of wetland conditions, though they raise concerns about potential impacts to nontarget wildlife and herbicide resistance (Bansal et al. 2019, Svedarsky et al. 2019). The most commonly employed herbicides for cattail control are glyphosate (e.g. Rodeo®, Aqua Neat®) and Imazapyr (e.g. Habitat®). Herbicides are usually most effectively applied in late summer, when they will be most rapidly transferred from leaves to the rhizomes and the rest of the plant alongside photosynthetically-generated carbohydrates (Sojda and Solberg 1993, Svedarsky et al. 2019).

Physical disturbances include burning (growing season or winter), grazing, machine-based mechanical disturbances (mowing, disking, cutting, crushing, scraping) with or without litter removal, and water level control (Sojda and Solberg 1993, Bansal et al. 2019, Svedarsky et al. 2019). Generally, physical disturbances tend to be more expensive to implement with more logistical constraints to application. Treatments targeting the plant's photosynthetic capacity (e.g. grazing, mowing) are usually most effectively conducted in midsummer, when rhizome starch stores are at their annual minimum (Sojda and Solberg 1993). Treatments are also most effective when followed by flooding above the level of severed stems, which deprives the rhizomes of oxygen. This creates an energy limitation for growing shoots, often killing the plant before it can reach the water surface (Sojda and Solberg 1993, Bansal et al. 2019). However, installation of water control structures is expensive and is not practical in a large proportion of wetlands important to Minnesota wildlife.

Because cattail's rhizome system allows the plant to recover from damage, multiple treatments are often needed for successful control (Bansal et al. 2019, Lishawa et al. 2020). Some recent studies have compared the efficacy of cattail treatment combinations in prairie wetlands. For example, Kostecke et al. (2004) studied prescribed burning combined with grazing at varying intensity or disking in plots within a large (>800 ha) pool with controlled water levels (i.e., with drawdown during treatment and flooding afterwards). Cattail abundance one year after treatment was lowest in plots that received high disturbance treatment combinations (prescribed fire followed by disking or high intensity grazing), and higher in low intensity treatments, with burn-only plots actually having higher cattail abundance than control plots. Disking and the moderate disturbance treatments (burn plus low intensity graze and burn alone) had the highest species diversity. Kostecke et al. (2004) concluded that prescribed burning followed by disking had the best outcome (low cattail, high species diversity). In a second example, Anderson et al. (2019) conducted a study of short-term effects of imazapyr, prescribed fire, cattle grazing, and combinations (seasonality unspecified) on cattail biomass 1-2 years post-treatment in Sherburne National Wildlife Refuge (prairie-oak savanna transitional zone of MN). Only burning had a consistent negative impact on cattail biomass, whether alone or in combination with grazing and/or herbicide. However, biomass measurements included living and dead material combined, such that herbicide alone was not expected to have a large impact. In a BACI study of herbicide, fire, and mowing at Glacial National Wildlife Refuge (northern tallgrass ecoregion of MN), Bruggman (2017) found that aerial glyphosate treatment (early September) decreased live cattail coverage while increasing dead coverage, as expected, though impacts had started to decline by the end of the study (second year post-treatment). In contrast to Anderson et al. (2019) but similarly to Kostecke et al. (2004), prescribed fire led to increased live cattail coverage with little change in dead coverage. Chemical treatment followed by prescribed fire (same fall season) was less effective than chemical treatment alone, yielding decreases in live cattail in the first year post-treatment but increases above pre-treatment levels in Year 2. Prescribed fire may promote cattail growth, as it is a fast colonizer post-disturbance and may take advantage of nutrients released by fire more rapidly than other species (Bruggman 2017).

Given the ubiquity of cattail on the larger landscape, treatments and even treatment combinations usually do not have permanent effects (e.g., Larson et al. 2020). However, effects of different treatments vary and last for varying amounts of time. Thus, information about initial effectiveness and longevity of cattail treatments are needed. Though studies have tested some treatment combinations, there are gaps in knowledge about some treatment combinations in common use or of high interest to MN DNR managers for prairie pothole wetlands, especially those involving a combination of chemical and physical disturbances with growing use in shallow WMA wetlands (e.g., disking, roller-chopping).

OBJECTIVES

Our Phase I goal was to evaluate the logistics and necessary sample size for a potential larger-scale BACI study of the ecological responses (cattail coverage, waterfowl pair and brood use, native plant reoccurrence, aquatic invertebrate abundance) of wetlands to a variety of cattail control treatment regimens. Specific objectives were as follows:

1. Coalesce information from DNR managers regarding previous cattail treatments and observed impacts. Use information to refine Phase II treatment plans. Also, consider feasibility of a companion study utilizing existing remotely sensed data to evaluate effectiveness of those past herbicide treatments.
2. Evaluate logistical challenges and feasibility of randomly assigning treatment regimens to wetlands (i.e., determine whether sample sizes can be met despite dropping wetlands from the study where random treatments could not be achieved).
3. Test uncrewed aerial vehicles (UAVs, i.e. drones) as a method to survey vegetative response

as well as waterfowl pairs/broods accurately in cattail-heavy environments (e.g., Bushaw et al. 2021).

4. Evaluate time required to survey a wetland for dependent variables. Use to estimate achievable sample sizes/staff needed for Phase II project.
5. Evaluate variation in dependent variables (cattail coverage, waterfowl pair and brood use, native plant reoccurrence, aquatic invertebrate abundance) among Phase I wetlands. Use to estimate sample size required for informative Phase II results.

METHODS

Manager survey (Objective 1)

Survey Introduction and Methods

One of our goals for the Phase I study was to coalesce information from DNR managers regarding previous cattail treatments and observed impacts and use that information to refine Phase II treatment plans (Objective 1). We also wanted to learn about managers' treatment goals to help us interpret study results in a practical context, and about manager information needs to help plan future research projects (beyond this project's Phase II). We had numerous informal conversations with Wetlands Management Program staff and Wildlife Area managers about these topics. Additionally, we conducted an e-mail survey of Wildlife staff's methods, observations, goals, and information needs pertaining to non-native cattail management. We gathered information through a survey because Wildlife Area Managers had previously identified cattail control evaluation as a top wetland-related research need to the Wetland Wildlife Populations and Research Group (WWPRG), leading us to suspect that many Wildlife staff would have observations and information needs. A survey format allowed us to reach a large number of people and to obtain a large amount of information in an organized format.

Our survey methods are described in detail in Appendix 1. We created and distributed the survey using Qualtrics software. Our goal was to survey Wildlife staff who manage non-native cattail. We e-mailed the survey to 311 Wildlife staff by combining pre-existing Outlook e-mail distribution lists for the four DNR Regions and Central Office. In the e-mail, we asked Wildlife Staff who manage non-native cattail species as part of their work to fill out the survey, and for other staff to disregard the survey. The survey had 15 questions. Question formats were free response and multiple choice (single or multiple response options selectable).

Data analysis

Our goal for the survey was to capture a wide range of ideas and observations, rather than test hypotheses. Thus, for open-ended questions, we summarize the range of ideas and observations discussed, but we did not formally code the responses. We summarized results for closed-ended survey questions as percentages. We anticipated that some respondents would have observations based on the same treatments on the same waterbodies, e.g., multiple Area staff from the same Area office, or Habitat Program staff collaborating with Area staff. We also anticipated that people listing the same work area would having varying levels of overlap in their experiences. For example, managers based in satellite offices might report on wetlands in a subset of the Area, or the full Area. Due to this uncertainty, and because our primary goal was to gather a variety of observations and ideas from as many Wildlife staff members who manage cattails as possible, rather than to obtain a quantitative summary of cattail-related management actions, we did not attempt to average or otherwise combine survey results by Area.

Dissemination

We created a report describing survey results (Appendix 1). The report is intended primarily for internal use in the WWPRG, but we will share it via e-mail with survey participants, Regional Wildlife Managers, and Habitat Team/Program leaders.

Field study (Objectives 2-5)

We collected field data in spring-summer 2023 to test potential field methods for surveying vegetation and waterfowl, evaluate logistics, and inform our estimate of necessary sample sizes of wetlands and vegetation plots for a Phase II BACI study (Objectives 2-5).

Study Area

Our study area was the PPR of western Minnesota. The PPR is a region of the Great Plains, extending from Alberta, Canada, to Iowa, USA, including western Minnesota (Krapu and Duebbert 1989). The PPR contains thousands of glacial-created depressional wetlands with high productivity that provide migration and breeding habitat for a substantial portion of North America's waterfowl (Hayashi 2016, Batt et al. 1989).

Study Design and Study Sites

Given the short Phase I timeframe, we used a cross-sectional study design (versus a BACI) to collect data from a combination of untreated wetlands and wetlands that had recently (1-3 years prior) been treated for cattail. This allowed us to evaluate our field methods over a range of wetland conditions that we expected to encounter during the Phase II study. Our study included 26 seasonal and semi-permanent prairie pothole wetlands on WMAs in western Minnesota ranging up to 25 acres in size (Fig. 1, Table 1).

Our original Phase I goal was to survey 25 wetlands, including 5 untreated wetlands and 20 wetlands that had recently received one of the four treatments under consideration for a Phase II study (n = 5 wetlands per treatment type). Targeted treatments included: (1) glyphosate treatment (i.e., single treatment in late summer-fall via helicopter or Marsh Master), (2) glyphosate treatment followed by roller-chopping (which cuts and crushes vegetation; to be conducted in the same season as herbicide treatment), (3) glyphosate treatment followed by disking (same timing), and (4) glyphosate treatment followed by winter burning. We selected these treatments with the long-term aim of testing whether the addition of mechanical disturbance (roller-chopping, disking, burning) extends potential benefits achieved by herbicide. Roller-chopping and winter burning can be conducted across a wider range of annual wetland/precipitation conditions than disking (i.e., disking is restricted to dry wetlands where equipment will not get stuck). However, disking may offer longer-term benefits by mechanically cutting rhizomes and bringing native plant seeds closer to the surface to promote germination. Burning during winter was of interest because it removes cattail litter and may allow ash to blow away from the ice-covered wetlands, reducing the nutrient pulse that promotes cattail growth (e.g. Kostecke et al. 2004, Bruggman 2017).

However, due to logistical challenges, not all treatment groups were available for surveys in 2023. The unavailable treatment types were glyphosate followed by disking and glyphosate followed by winter burning. Four wetlands had been roller-chopped following glyphosate treatment, though the treatments were in subsequent years rather than the same year as proposed (i.e., glyphosate treatment in 2021 and roller-chopping in 2022). Consequently, we followed our proposed back-up plan in case of insufficient sample sizes in treatment groups, and selected wetlands that would encompass the variety of wetland conditions we expected encounter in a Phase II study. (We note that WMP is now regularly conducting our full suite of proposed Phase II treatments on WMAs, such that we do not expect to encounter the same level of logistical challenges to treatments in the Phase II study.)

Our Phase I sample of wetlands included 11 untreated wetlands, 11 glyphosate-treated wetlands, and 4 (all available) wetlands with glyphosate treatment followed by roller-chopper treatment (hereafter "glyphosate plus roller-chop" wetlands). Treatments had been conducted by the Wetland Management Program and Area Wildlife managers. We selected wetlands in two geographical clusters to reduce travel costs: 12 wetlands near Morris, MN (Fergus Falls/Glenwood Wildlife Area) and 14 wetlands near Willmar, MN (New London Wildlife Area). Wetlands were not selected randomly but were selected based on the following criteria: cattail treatment status, accessibility, low likelihood of receiving other management that would confound treatments (e.g. prescribed fire), and the goal of obtaining similar wetland size and type distributions in each treatment group. WMP staff and Area Wildlife managers advised on site selection.

Waterfowl surveys

We conducted waterfowl pair and brood surveys on each of the 26 wetlands using a quadcopter UAV equipped with a thermal and RGB (visual-spectrum) camera. UAVs are becoming a more common tool in wildlife research, with particular utility for surveys of relatively small areas that are difficult to access or contain visual obstructions (Chabot and Bird 2012, Linchant et al. 2015, Christie et al. 2016, Obermoller et al. 2021). Recent studies have compared data collected from UAVs against ground-based methods in surveys of geese, ducks, and other wetland birds (e.g. Chabot and Bird 2012, Pöysä et al. 2018, Bushaw et al. 2020, 2021, McKellar et al. 2021, Ryckman et al. 2022). Bushaw et al. (2021) found that duck brood detection rates in UAV (multirotor equipped with a thermal infrared and visible-spectrum camera) surveys of prairie pothole wetlands in Manitoba and Minnesota were approximately twice those of ground crews at the same sites. The pattern was driven particularly by dabbling duck species, which tend to hide in emergent vegetation when disturbed (Bushaw et al. 2021).

We conducted two pair surveys and two brood surveys per wetland to account for early-arriving/early-breeding species (e.g. mallards [*Anas platyrhynchos*]) and later-arriving/later-breeding species (e.g. blue-winged teal [*Spatula discors*]). For each round of surveys, we began in the south near Willmar and ended in the north near Morris.

We used UAV survey methods similar to those of Bushaw (2021): flying transects across the wetland; locating pairs/broods using the thermal camera; and identifying species using the optical camera. We hired a contractor to provide and pilot the UAV (Steve Fines, Fines Aerial Imaging, LLC). The UAV was a quadcopter model (DJI Matrice 300 RTK, DJI, Shenzhen, China) equipped with thermal and visual-spectrum imaging cameras (DJI Zenmuse H20T, DJI, Shenzhen, China; thermal camera 640×512 pixels with 13.5mm focal length; visual-spectrum zoom camera 1920x1080 pixels with 6.83-119.94 mm lens; wide visual-spectrum camera with 1920x1080 pixels and 4.5mm lens) (Fig. 2). All cameras were contained in the same housing, facilitating viewing of the same ground area with both infrared and visual-spectrum wavelengths. For each wetland, the contractor piloted the UAV from a launch site along the roadside 132-1093 m from the wetland (mean 603 ± 209 m standard deviation). Two researchers (MJF and technician) watched a monitor mirroring the UAV's camera view and provided direction to the pilot regarding when to stop the UAV and redirect the camera to examine potential waterfowl (Fig. 2). A generator or the contractor's electric vehicle were used to power the equipment.

We searched for waterfowl using the thermal camera while the pilot flew the UAV in transects over the wetland. Transects were pre-programmed for 43 m (140 ft) altitude, with 25% overlap between adjacent transects. After initial experimentation to find the maximum flight speed at which we could comfortably examine the camera view for waterfowl, we flew transects at a speed of 7 mph (3.1 m/s). When potential waterfowl were sighted, we switched to the RGB zoom camera's view to identify species, numbers of adults and young, social group classification, adult sex, and age class of any young. We counted all waterfowl (ducks and geese; no swans encountered) adults and young in the field. We also counted American coots, as these birds were of such a similar size and shape to ducks that we could not differentiate their signatures from ducks using the thermal camera and thus needed to examine each individual. We aimed to avoid missing waterfowl by investigating all questionable thermal signatures with the visual-spectrum camera. We aimed to avoid double-counting individual waterfowl moving across the wetland by marking waterfowl locations on a paper map. We lowered the UAV to 40 m (130 ft) altitude when needed for challenging identifications. Full videos of each survey (including both thermal and RGB cameras) were saved to allow for later double-checking of species identification and duckling age class in the office.

We conducted early pair surveys on April 25-26 (Willmar) and May 1-3 (Morris) and later pair surveys on May 15-17 (Willmar followed by Morris). We conducted early brood surveys on June 28-30 (Willmar) and July 6-8 (Morris) and later brood surveys on July 18-20 (Willmar) and July 25- 27 (Morris). We conducted brood surveys between sunrise and 10:00, when ambient temperatures were cooler, to ensure detection of waterfowl in thermal imagery, following Mitchell et al.'s (2022) methods for brood surveys. However, during spring pair surveys, we found that waterfowl pairs remained visible in thermal imagery throughout most the day, with the thermal camera continuing to show a variation in thermal reflectance on the landscape rather than a "washed-out" image of more uniform high thermal reflectance. We speculate that this was due to a combination of cooler ground and water temperatures compared to those in July brood surveys, along with early spring emergent vegetation condition (dead-standing or minimal growth in May, compared to tall live vegetation in July). Consequently, we conducted pair surveys over a longer period of the day (dawn to 14:30) to minimize travel costs.

For pair surveys, we calculated indicated breeding pairs for each species as the sum of the number of pairs, number of lone males, and number of males in groups of 2-4 individuals (U.S. Fish and Wildlife Service and Canadian Wildlife Service 1987). We summarized number of indicated pairs and number of broods per wetland and per acre of wetland as boxplots to informally examine patterns across wetland treatments.

Vegetation surveys

The UAV pilot for our waterfowl surveys used the same equipment to collect high-resolution aerial imagery (RGB bands) and produced orthomosaics of our study wetlands shortly after the completion of brood surveys (late July). To explore the level of botanical detail visible in imagery, we displayed orthomosaics in ArcMap (version 10.8.2, Environmental Systems Research Institute, Inc., Redlands, CA, USA) with ground-based vegetation survey data from quadrats (see below) displayed as points overlaying the imagery.

We conducted ground-based vegetation surveys as soon as possible following brood surveys (August 15-September 22, 2023). We collected vegetation data from sample points in a grid pattern. For the pilot study, we wanted to oversample at least some wetlands and use the resulting data to choose an appropriate sample size/distance between points for the longer-term study. Consequently, we set a minimum of approximately 20 sample points per wetland, and a maximum distance of 50m between sample points. These criteria resulted in points that were more closely spaced in smaller wetlands, and more widely spaced in larger wetlands, with the 50-m distance limit becoming pertinent for wetlands >12 acres (Table 2). We chose the 20-point minimum and 50 m maximum criteria based on estimated time required to survey a sample point, with the goal of surveying two wetlands per day for most wetlands. However, we found that surveys were taking longer than was feasible (> 1 day per wetland), and consequently altered our sampling intensity to a minimum of 10 points per wetland and a maximum distance of 75 m between sample points (Table 2). We automated sample point creation using R (R version 4.2.2, https://www.R-project.org/) with packages sf (Pebesma 2018) and mapview (version 2.11.0, https://CRAN.R-project.org/package=mapview).

We navigated to sample points using handheld GPS units (Garmin Montana 680t, Garmin Ltd., Olahe, Kansas, USA). At each sample point, we collected data from a 1-m x 1-m quadrat composed of PVC piping (1/2” diameter). The quadrat floated on the water surface if water was present. We collected several metrics from each quadrat (Table 3): visual obstruction reading (measure of vegetation height and density) using a Robel pole (Robel et al. 1970); number of cattail stem/leaf touches on 0.5-m sections of a 1.5-m pole (Hill 2021); percent foliar (aerial) cover (Rowe 2022) of several plant categories in the quadrat (Table 4); water depth; maximum within-quadrat heights of cattail, other herbaceous vegetation, and woody vegetation; and cattail litter depth. Where water was present, we collected relative biomass on a plant rake (Yin et al. 2000). We also took a photo of each quadrat using a phone or tablet (from south side of quadrat facing north) for reference if needed during data analysis.

We summarized wetland-level averages of seven selected metrics (number of live cattail stems in quadrat, maximum cattail height (live or dead) in quadrat, cattail litter depth, and coverages of live cattail, dead standing cattail, cattail litter, and sedges and rushes) as boxplots to informally examine patterns across wetland treatments. These metrics were selected to reflect proposed Phase II priorities – cattail abundance and types of cover that replace cattail. We also examined correlations (Spearman’s ρ) between vegetation metrics to explore whether any could be dropped to save time in the field without losing much information in a Phase II study.

Additionally, wildlife biometricians conducted two analyses to assist with assessment of variation in vegetation metrics within and among wetlands. First, to explore whether more variation in cattail abundance tended to occur among wetlands versus within wetlands, they calculated the intraclass correlation coefficient (a measure of the proportion of variation in the data that occurs among groups, i.e. wetlands, as opposed to within groups, i.e., among quadrats within wetlands; Krebs 1989) for two selected metrics of cattail abundance, number of cattail stems and cattail coverage. To be conservative, intraclass correlation coefficients were computed for data from treated wetlands only, as untreated wetlands (based on field observations) were relatively homogenous. Second, to explore the impact of sampling intensity (number of quadrats per wetland and per unit wetland area) on precision of wetland-level means for selected vegetation metrics, biometricians simulated (bootstrapping with replacement) the effect of varying number of quadrats using our data from the four wetlands with relatively large numbers of quadrats (6-21 quadrats per wetland). Two of these wetlands were sampled at high intensity (7.4-38.0 quadrats per acre) because they were the first two wetlands surveyed prior to adjusting sampling intensity for logistical feasibility. The other two wetlands had higher numbers of quadrats simply because they were large (0.7-0.8 quadrats per acre). Simulations were conducted for each wetland by random sampling (with replacement) a given sample size of quadrats from the dataset 500 times. They simulated sample sizes from 5 quadrats to 40 quadrats at intervals of 5 (i.e. n = 5, 10, 15…40 quadrats). Selected vegetation metrics were number of live cattail stems in quadrat, maximum cattail height in quadrat, cattail litter depth, and coverages of live cattail, dead standing cattail, cattail litter, and sedges and rushes. We visually examined the distributions of simulated data in box plots and biometricians calculated the coefficient of variation for each combination of wetland, vegetation metric, and simulated sample size.

Aquatic invertebrate surveys

In our Phase I proposal, we proposed to sample aquatic invertebrates prior to following our first round of waterfowl pair surveys, following our second round of waterfowl brood surveys, and during aquatic vegetation surveys. We proposed to survey invertebrates with activity traps, as opposed to dip nets or other active sampling methods, because we anticipated changing cattail coverage in each wetland during our long-term study, and emergent vegetation conditions activity traps are more amenable to consistent sampling in stands of emergent vegetation (Murkin et al. 1983).

After pricing out the parts cost for our proposed aquatic invertebrate activity trap design (following Hanson et al. 2000, Mitchell et al. 2022) at $37/trap, we delayed aquatic invertebrate surveys to August (during vegetation surveys) with the goal of designing and testing a less expensive model of a similar shape/size based on an F-style HDPE jug. We were particularly interested in potential to reduce trap construction cost due to the eventual need to scale up trap numbers for a longer-term study, and we estimated that we might be able to cut trap costs by approximately 30%. We tested prototype traps in study wetland Eldorado 36 (following our first round of pair surveys) and later prototypes at Bemidji Slough WMA (Bemidji, MN) in June. After multiple prototypes, our final design cost $31 per trap. Given the ultimate similarity in cost between two designs, we decided to proceed with the original model, as it had been tested in the literature. (However, the F-style jug trap has advantages in being lightweight and having a more secure back opening and may be worth further testing in the future.)

There were two challenges associated with the delayed timing of our final trap deployment. First, drought conditions occurred in 2023, such that most of our wetlands were dry by the time our vegetation survey season started. Second, we were deploying traps during vegetation surveys, which we found were taking longer than estimated (refer to Vegetation surveys subsection), such that we did not have time to deploy invertebrate traps in many wetlands within the time frame of the field season. Due to the relative importance of vegetation data compared to aquatic invertebrate data for our Phase II goals, we chose to prioritize vegetation surveys over aquatic invertebrate surveys. We conducted aquatic invertebrate surveys in three (Cuka 98, Eldorado 36, and Eldorado 18) of the six wetlands still containing surface water in the drought.

Following Mitchell et al. (2022), we deployed 3 traps per wetland at pre-established locations. Traps were placed on three evenly spaced transects extending from the center of the wetland to shore (one trap per transect), with one trap as near the shoreline as possible (water depth ≥15.4 cm), one trap at 45% of the distance from the shoreline to the centroid, and one trap at 90% of the distance from the shoreline to the centroid (near the basin centroid). We randomly selected the bearing of the first transect and placed the second two transects at 120° and 240° degrees from the first. We randomly selected which transect would receive which trap position (near shore, 45% to centroid, 90% to centroid). We automated sample point creation for all wetlands using R (though only three wetlands were actually sampled) with packages sf, geosphere (version 1.5-18, https://CRAN.R-project.org/package=geosphere), and mapview.

Following Mitchell et al. (2022), final traps were modified from Hanson et al. (2000) to be a single compartment rather than three stacked compartments. Traps were shaped as rectangular boxes (external dimensions 26.4 cm tall x 16.2cm wide x 10 inches deep; composed of 0.48-cm plexiglass sheets) with a narrowing entrance (horizontal opening narrowing to 1.27cm wide) on one side and a fish guard (0.64-cm wire mesh) placed 1 cm inside the opening. The back sides of the traps were removable to retrieve invertebrates. Backs were secured to the trap with buckles and nylon webbing, and we used foam weatherstripping at the junction help form a tight seal. The bottom side of the trap was also slightly longer than the top to provide support for the back piece. Traps had two eye bolts in the top so that they could be suspended from t-posts at the desired height in the water.

We navigated to sample points using handheld GPS units. At each point, we suspended traps from t-posts using a t-post bracket (FarmGard, Midwest Air Technologies, Long Grove, IL) and paracord tied to each eye bolt. We adjusted the length of the two paracord pieces to suspend the trap horizontally with 15.4cm below the water and 10.16cm above the water (Hanson et al. 2000). We deployed traps for approximately 24 hours (Mitchell et al. 2022, Hanson et al. 2000) (range 19.5-23.2 hours), and recorded deployment and retrieval times. To retrieve invertebrates, we poured trap contents through a large 500-μm mesh sieve. We then alternately rinsed the trap into the sieve with a spray bottle and visually inspected the trap to remove any remaining invertebrates. We transferred invertebrates into a 1-L plastic bottles with 95% ethanol for transport to the lab.

In the lab, we transferred samples into a 90mm x 90 mm square petri dish with 36 imprinted squares (14mm x 14mm) and identified aquatic invertebrates using a trinocular stereomicroscope (Laxco, 6.5-53x magnification) with a digital camera and monitor attachment. We identified molluscs to class and to family when possible. We identified all other aquatic invertebrates to order and to family when possible. We identified invertebrates using Thorp and Covich (2001), with supplemental use of Bouchard (2004), Helgen (2002), and the digital resource macroinvertebrates.org (http://www.macroinvertebrates.org). For particularly numerous taxa (i.e. zooplankton in some samples), we used a fixed area count (25%) (Mitchell 2022, Terry 2021).

RESULTS

Manager survey (Objective 1)

Survey results are described in detail in Appendix 1. Fifty-one people responded to the survey, including 35 Wildlife Area staff from 25 Areas distributed across four Regions (1-4 respondents per Area), along with 7 Roving Crew staff, 6 Shallow Lakes Habitat Program (hereafter “Shallow Lakes”) staff, and 3 Wetlands Management Program (hereafter “Wetlands Management”) staff. In a multiple-choice question about whether non-native cattail control was an important priority in their work area, most (88%) of survey respondents indicated that non-native cattail control is a “very important” or “moderately important”, as opposed to “minimally important”, “not important”, or “not sure” (Appendix 1).

Respondents described use of 17 treatment methods for non-native cattail in 12 types of water bodies. Herbicide applied aerially and herbicide applied via ground equipment (like a Marsh Master®) were the most commonly listed treatments (82% and 78% of respondents, respectively). A wider variety of treatments were used in small, shallow wetlands and shallow lakes compared to larger, deeper lakes, river, and impoundments (Appendix 1). In free response, herbicide was commonly listed as the most effective or one of the most effective treatments, but respondents described variable longevity of herbicide outcomes. Respondents who specifically discussed longevity of treatment impacts said that they observed longest-term results from scrapes, aerial herbicide followed by roller chopping (preferably preceded by drawdown and followed by flooding), and prescribed burning followed by flooding. A wide variety of other most-effective treatments and treatment combinations were reported, possibly in part because staff work on a variety of different water body types in different ecoregions.

Management goals generally included decreasing cattail coverage, increasing open water coverage, creating pockets of open water (e.g. hemi-marsh conditions), and/or increasing native plant diversity and abundance. Wild rice and endangered submerged aquatic plants (sheathed pondweed) were mentioned as specific priority native species. Numerous respondents had a goal of creating hemi-marsh conditions (ratio of approximately 50% vegetation to 50% open water). Other themes included reductions in floating cattail mats and/or maintaining water flow through water control structures and inlets/outlets.

Respondents indicated that treatment goals vary by treatment and by wetland condition prior to treatment. For example, one respondent said that a realistic treatment goal for a wetland lacking open water might be 25% open water lasting for 4-5 years, whereas a wetland in better condition might achieve a more ideal goal of 40-80% open water. Another respondent contrasted fall mowing and aerial herbicide. Fall mowing is expected to have short-term impacts, and an associated short-term goal would be open water and northern pintail (*Anas acuta*) use in the following spring. Aerial herbicide is expected to have longer-term effects and might have a goal of creating open water lasting for multiple years. Respondents who mentioned a time component to their goals said that a successful treatment would last longer than 3 years, or longer than 4-5 years.

Some respondents described treatment goals in terms of benefits to wildlife or humans. Specifics were most often waterfowl-related: diversified nesting cover, or improved wetland use or duck production. Other respondents mentioned increased shorebird use, or general wildlife diversity and use. Two respondents mentioned access for waterfowl hunters.

Respondents described a variety of research information needs including effectiveness of cattail treatments for environments ranging from temporary and seasonal wetlands to larger/deeper shallow lakes and impoundments; results of on-going treatments (e.g. DNR aerial herbicide spraying program); and underlying factors impacting treatment effectiveness (such as nutrient enrichment) (Appendix 1).

Field study (Objectives 2-5)

Vegetation surveys

We conducted vegetation surveys on all 26 wetlands. One of the planned untreated wetlands was accidentally roller-chopped shortly prior to our vegetation survey, yielding sample sizes of n=10 untreated wetlands, n=11 glyphosate-treated wetlands, n=4 glyphosate plus roller-chop wetlands, and n=1 wetland that was roller-chopped only, shortly before the survey.

Vegetation surveys using our pilot season methods took approximately 0.5-1 day for wetlands with approximately 10 sample points and approximately 1-2 days for wetlands with approximately 20 sample points, depending on wetland size and condition, with surveyor speed increasing with experience after the first 2-3 wetlands surveyed.

We graphically explored patterns in vegetation metrics from ground surveys via boxplots. Metrics of live cattail abundance (i.e. mean number of live cattail stems per quadrat, maximum cattail height, and percent coverage of live cattail) tended to be highest in untreated wetlands, intermediate in glyphosate plus roller chop wetlands, and low in glyphosate-treated wetlands (Fig. 3A, Fig. 3B, Fig. 4A). In the single roller-chopped wetland, maximum cattail height was lower than all other treatments, whereas number of live cattail stems and percent coverage of live cattail was more intermediate (similar to glyphosate plus roller chop wetlands).

Coverage of dead standing cattail was also highest in untreated wetlands and lower in glyphosate-treated wetlands (Fig. 4C). Dead standing cattail was lowest in glyphosate plus roller-chop and the single roller-chopped wetland.

Coverage of cattail litter was fairly high in all types of wetlands, though it was more variable in the treatment groups with larger sample sizes (untreated and glyphosate) (Fig. 4B). On the other hand, cattail litter depth was highest in glyphosate-treated and untreated wetlands, and lower in glyphosate plus roller-chop and the roller-chopped wetlands (Fig. 3C).

Coverage of sedges and rushes tended to be higher in glyphosate-treated wetlands and the roller-chop wetland compared to untreated wetlands and glyphosate plus roller-chopped wetlands (Fig. 4D).

The intraclass correlation coefficients indicated that, for treated wetlands in the pilot study, most of the variation in number of live cattail stems (77.5% of variation, 95% CI [48.4%, 96.8%]) and coverage of live cattail (77.4%, 95% CI [48.3%, 96.7%]) was due to within-wetland (between quadrat) variation, as opposed to between-wetland variation.

In bootstrapping simulations, the number of quadrats per unit area necessary to achieve a given coefficient of variation tended to be higher for the two smaller wetlands (Gopher Ridge 02 and 03) than for the two larger wetlands (Grace Marshes 99 and Eldorado 18), and for more rare vegetation categories (e.g. sedge and rush coverage) than for more common vegetation categories (e.g. cattail litter coverage) (Table 5).

In visual exploration of UAV-collected aerial imagery, we found that cattail-dominated patches of vegetation in imagery were characterized by a darker green color when compared to other vegetation (Fig. 5). Patches of open water and bare soil could also be differentiated. We are continuing to assess whether other types of non-cattail vegetation can be reliably distinguished, especially in more diverse patches of vegetation. (Refer to Discussion for challenges.)

Correlation between pairs of ground-based vegetation metrics varied considerably (Fig. 6). Variable pairs with very strong correlation (>0.8) were live cattail stem count and coverage of live cattail; cattail maximum height and coverage of live cattail; coverage of cattail litter and coverage of all cattail (litter plus dead-standing plus live; refer to Table 4); and maximum woody vegetation height and coverage of woody vegetation less than 3 m tall (the more common category of woody vegetation).

Seventeen variable pairs had strong correlation (0.6-0.8). Ten of these were correlations among various metrics of live and dead-standing cattail abundance (cattail touches at 0-50cm height, cattail touches at 50-100cm height, cattail touches at 100-150cm height, cattail live stem count, coverage of live cattail, coverage of dead standing cattail, and maximum cattail height), and two were correlations between cattail litter depth and other cattail abundance metrics (coverage of cattail litter, coverage of all cattail). Four were correlations between the Robel pole measure of visual obstruction and metrics of cattail abundance (live cattail stem count, cattail touches at 100-150cm, cattail maximum height, coverage of live cattail). Maximum height of herbaceous vegetation and coverage of grass were also strongly correlated, reflecting the frequency of grass (especially reed canary grass) in our quadrats.

Waterfowl surveys

We counted a total of 141 indicated pairs in the 52 spring pair surveys. Pairs occurred on 18 of the 26 wetlands. The most common species were blue-winged teal (71 pairs) and mallard (45 pairs), followed by northern shoveler (*Spatula clypeata*; 9 pairs). The total number of indicated mallard pairs was similar between the first and second rounds of spring surveys, whereas the number of blue winged teal and northern shoveler pairs was considerably (3-8 times) larger in the second round of pair surveys compared to the first (Table 6). Other species with less than 5 indicated pairs observed were gadwall (*Mareca strepera*), wood duck (*Aix sponsa*), redhead (*Aythya americana*), hooded merganser (*Lophodytes cucullatus*), ring-necked duck (*Aythya collaris*), and canvasback (*Aythya valisineria*). The number of indicated pairs tended to be highest in glyphosate plus roller-chop wetlands, followed by glyphosate-treated wetlands and untreated wetlands (Fig. 7).

We counted a total of 21 broods in 52 summer brood surveys, with broods occurring on 8 of the 26 wetlands. The most common species were mallards (8 broods) and blue-winged teal (6 broods), followed by hooded mergansers (4 broods), and northern pintails and wood ducks (1 brood each). Data were right-skewed (zero-heavy), and brood counts did not appear to differ systematically between untreated, glyphosate-treated, and glyphosate plus roller-chop wetlands (Fig. 8).

We were able to survey 3-6 wetlands per day in our sunrise to 10:00 window, with time required depending on number of duck-like thermal signatures encountered, wetland size, and drive time between sites.

Aquatic invertebrate surveys

Due to time constraints (vegetation surveys requiring longer than anticipated in the field) and project priorities (vegetation and waterfowl data, deadlines for Phase II and LCCMR research proposals), we identified invertebrates from 6 of the 9 traps (Table 7 and Table 8). As expected, the most numerous species were crustacean zooplankton (cladocerans and copepods). Dipteran larvae (e.g. Chaeboridae, Chaoboridae, Chironomidae), springtails, and hemipterans were the most common orders of larger-bodied aquatic invertebrates.

DISCUSSION

Manager survey (Objective 1)

Survey responses suggested that research pertaining to cattail treatment methods would be useful for MN DNR Wildlife management work. Eighty-eight percent of 51 staff from 25 Wildlife Areas across the state indicated that cattail treatment is a moderate to high management priority in their work area. Respondents described a variety of research information needs, including effectiveness of cattail treatments for environments ranging from temporary and seasonal wetlands to larger/deeper shallow lakes and impoundments; results of on-going treatments (e.g. DNR aerial herbicide spraying program); and underlying factors impacting treatment effectiveness (such as nutrient enrichment). Our Phase II study topic aligns with information needs (cattail treatment efficacy on seasonal wetlands), and our proposed Phase II response variables align with metrics used to assess treatment success (cattail coverage versus open water coverage, waterfowl use). However, because the wide range of information needs cannot be feasibly addressed in a single study (e.g., different cattail treatments are possible in different wetland types), additional future studies beyond our Phase II may be warranted in the future. For example, treatment of floating mats was a commonly described challenge for management that a Phase II study of seasonal wetlands will not address.

Field Study (Objectives 2-5)

Vegetation surveys

Phase I vegetation surveys provided information for hypothesizing trends for a Phase II study, along with logistical information to inform our Phase II plans.

In ground-based surveys, we observed a mix of expected and unexpected patterns. We generally expected that cattail abundance (live, dead standing, and litter) would be highest in untreated wetlands, lower in glyphosate-treated wetlands, and lowest in wetlands that had received glyphosate plus roller-chopping (i.e., two types of treatment). Metrics of live cattail abundance (i.e. mean number of live cattail stems per quadrat, maximum cattail height, and percent coverage of live cattail) tended to be higher in untreated wetlands compared to glyphosate-treated wetlands, as expected. However, contrary to expectation, glyphosate plus roller-chop wetlands had intermediate values for these three metrics of live cattail abundance. This may simply be a function of a small sample size and similar wetland conditions (n=4 wetlands on two adjacent WMAs), or roller-chopping may have promoted new cattail growth. We note that roller-chopping was conducted approximately one year after glyphosate treatment in these pilot wetlands, whereas we propose to roller-chop in the same season as glyphosate treatment in the Phase II study. Roller-chopping in the Phase II study may have a different impact on cattails, as it will not allow a spring growth period between glyphosate treatment and roller-chopping. Number of live cattail stems and coverage of live cattail were also intermediate in the single roller-chopped wetland. These were primarily live stems that had been flattened by the recent roller-chop, as reflected in the low average maximum cattail height.

Glyphosate-treated wetlands also tended to have less coverage of dead standing cattail than untreated wetlands. This may have occurred if glyphosate reduced the annual regrowth of live cattail stems, while older dead stems continued to break down over time. Conversely, metrics of cattail litter abundance (depth and coverage) had similar distributions between untreated and glyphosate-treated wetlands, suggesting that glyphosate does little to decrease cattail litter depth 1-2 years following treatment.

Glyphosate plus roller-chop wetlands and the roller chopped wetland tended to have reduced litter depth and dead standing cattail coverage, but had similar litter coverage, compared to untreated and glyphosate-treated wetlands. These patterns reflect the crushing treatment by the roller chopper (flattening vertical structure without removing biomass from the wetland).

We expected to find more sedges and rushes in wetlands with higher cattail treatment intensities (i.e., lowest sedge/rush coverage in untreated wetlands, followed by glyphosate-treated wetlands, followed by glyphosate plus roller chop wetlands). Coverage of sedges and rushes tended to be higher in glyphosate-treated wetlands compared to the untreated wetland as expected, suggesting these species may be able to replace cattail following glyphosate treatment. Unexpectedly, sedge and rush coverage was lowest in the glyphosate plus roller-chop wetlands, and live cattail abundance was high. However, this pattern may simply be a function of small sample size and similar wetland conditions.

One key logistical take-aways from the pilot season was a more informed estimation of time required to survey a wetland using our quadrat method (approximately 0.5-1 day for 10 sample points and approximately 1-2 days for 20 sample points, depending on wetland size and condition). Actual time was about twice as long as anticipated, and this information will be critical for Phase II planning.

Intraclass correlation coefficients and bootstrapping simulations emphasized the importance of capturing within-wetland variation in our sampling. This was particularly true for more rare vegetation categories (e.g., sedges and rushes) compared to more common categories (e.g., cattail litter). Bootstrap simulations also indicated higher levels of within-wetland variation (higher quadrat numbers required to achieve a given coefficient of variation) in the two smaller, more intensively sampled wetlands (Gopher Ridge 02 and 03) compared to the two larger wetlands (Grace Marshes 99 and Eldorado 18). This pattern may be an effect the larger wetlands being fairly homogenous over large areas. For the smaller wetlands, variability in vegetation data may have been further intensified by the sampling areas incorporating a higher proportion of upland compared to the larger wetlands' sampling areas. For Gopher Ridge 03 in particular, the wetland boundary and subsequent grid of sample points (created in advance from aerial imagery for all wetlands) incorporated a shrub ring around the wetland (which was not present when the aerial imagery was collected) and some of the drier area around the wetland (reed canary grass and forbs), such that we were capturing a large amount of vegetation of change with elevation. This highlights the importance of carefully defining our intended sampling areas in Phase II work. Phase I methodology adjustments might include field verification of wetland boundaries prior to the first year of vegetation surveys and shrinking the sampling area from the boundaries slightly to focus on the wetland interior, rather than edges.

Overall, the within-wetland variation that we observed highlights the importance of incorporating complementary vegetation survey methods into our Phase II plans. That is, UAV-collected aerial imagery will provide context for patchiness of vegetation in relation to our sampling points. Complementarily, ground survey points will provide data to help interpret aerial imagery (e.g., coverage of different vegetation types, water depth). Photographs taken at each quadrat were also helpful for providing context to results during data analysis, and the practice of photographing each quadrat should be continued in a Phase II.

We found that cattail-dominated patches of vegetation were differentiable (darker green color) in UAV-collected imagery. We also note that prior studies have also succeeded in differentiating cattail-dominated patches from other vegetation types; Lishawa et al. 2013, Lishawa et al. 2020. We are continuing to assess whether other types of non-cattail vegetation are reliably differentiable, especially in more diverse patches of vegetation. One challenge we are encountering in comparing UAV-collected aerial imagery to ground data is that the data was collected in different phenological timeframes (a short period in late July for aerial imagery versus a longer period in August through September for ground surveys), such that vegetation condition changed somewhat between collection of the two datasets. Additionally, uncertainty in our handheld GPS units (typically ± 5-10 meters per the manufacturer website) created uncertainty in the exact location in our 1-m^2 quadrats. Modifications for Phase II methodology might include marking quadrat corners in a way that would be visible from a UAV (e.g., with flags) and subsequently collecting aerial imagery within the next few days.

Correlations among variables indicated that we may be able to drop some vegetation measures from our methods to save time in the field without much loss of information. For example, coverage of all cattail (cattail litter, dead standing cattail, and live cattail all together) was very strongly correlated with coverage of cattail litter and could be dropped. Number of cattail stem/leaf touches on segments of a vertical pole were strongly correlated with live and dead standing cattail coverage and might also be candidates for removal.

Waterfowl surveys

Similarly to vegetation surveys, Phase I waterfowl surveys provided information for hypothesizing trends for a Phase II study, along with logistical information to inform our Phase II plans.

In spring waterfowl pair surveys, number of indicated breeding pairs tended to be higher in wetlands treated for cattail compared to untreated wetlands, as expected. Number of indicated pairs was highest in glyphosate plus roller chop wetlands. Roller-chopping may particularly promote early spring waterfowl pair use in the years immediately following treatment via reduced dead standing cattail coverage (which was reflected in our vegetation survey data) and associated larger open water area. However, we acknowledge the small sample size and similar wetland conditions (n=4 wetlands on two adjacent WMAs) in the glyphosate-roller chop treatment group. Also as expected, numbers of pairs of of later-migrating species (e.g., blue-winged teal, northern shoveler) were higher in the second round of indicated pair surveys compared to the first, highlighting the utility of conducting two rounds of pair surveys for the prairie pothole waterfowl community.

On the other hand, patterns were not discernable in brood counts. The data were zero heavy, with broods occurring on just 8 wetlands with a variety of treatment types (3 untreated wetlands, 4 glyphosate-treated wetlands, and 1 glyphosate plus roller chop wetland). Zero-inflated count data are not unusual for duck brood counts in the PPR. For example, Mitchell et al. (2022) found broods on 40% of wetlands, and Walker et al. (2013) detected broods of any given species on less than 15% of wetland visits. This pattern may have been exaggerated by drought conditions in 2023, which caused several of our study wetlands to dry completely by the time of the second brood survey. Zero-inflated data consisting mostly of small counts (1-2 broods per wetland) would likely require a large sample of wetlands to distinguish differences in brood use between wetland treatments. Given this result, and our narrowing focus on seasonal wetlands to facilitate random assignment of wetland treatments between study wetlands (refer to Phase II research proposal), we have proposed to drop brood surveys from our Phase II study.

Though we propose to drop brood surveys from our Phase II study, our Phase I experience with using UAVs to survey broods was valuable. Recent work suggests that UAVs can substantially improve duck brood detection probability in prairie pothole wetlands (Bushaw et al. 2021). Our experience with UAV survey logistics, such as flight speeds and altitudes to detect and identify duck broods, and experience with of number of wetlands that can be surveyed for broods per day, will likely facilitate future studies in our research group.

Aquatic invertebrate surveys

We acquired aquatic invertebrate data from a small sample of wetlands due to the unexpected time needed to experiment with trap construction materials and to conduct vegetation surveys. We anticipate dropping aquatic invertebrate sampling from Phase II plans to prioritize acquisition of sufficient vegetation data, given limitations to budget and project staff size. However, because aquatic invertebrates are crucial food resources for most duck species, especially breeding females and ducklings (e.g. Drilling et al. 2020), we anticipate that future studies in our research group will benefit from our pilot work. In particular, we constructed a set of invertebrate traps designed for sampling food resources available to ducklings (Hanson et al. 2000), which can be deployed at different depths within the water column to sample various foraging depths for adult ducks. We also developed methods to streamline collection of trap contents (e.g., use of a floating sieve) and gathered a collection of resources for identification of prairie wetland aquatic invertebrate prey. Working through keys with pilot season samples was also informative for future work. We found that we could reliably identify aquatic macroinvertebrates to order using our resources. However, family-level identification was more difficult. For studies where family-level identification is a goal, a collaborator with entomology or aquatic invertebrate expertise to confirm identity of type specimens would be valuable.

Conclusions

In conclusion, the Phase I study produced valuable information for planning a Phase II BACI study of cattail treatment efficacy and ecological responses. In addition to revealing potential patterns and plant and waterfowl responses to treatment, key takeaways for Phase II planning included the information that UAV waterfowl surveys will likely work well for our purposes, time required for vegetation surveys using quadrats and waterfowl surveys using UAVs, and a better sense of plant taxonomic level that seasonal technicians can be trained to reliably identify. The plant survey data also allowed us to assess which of our vegetation metrics are highly correlated, so we are choosing Phase II metrics accordingly to maximize efficiency of time spent in the field. Analysis of variation in vegetation metrics within and among wetlands confirmed that we should collect vegetation data via multiple methods and suggested that we should confirm sample area boundaries in the field prior to the first field season of a Phase II, rather than relying on aerial imagery. Finally, Phase I work produced knowledge and materials that will be useful for training Phase II field crews. For example, we now have sample images of waterfowl from UAVs to practice species identification from above, and plan to produce diagrams to help crew practice estimating percent cover in quadrats.

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LITERATURE CITED

Anderson, S. L., D. A. McGranahan, T. J. Hovick, and A. R. Hewitt. 2019. Passerine and secretive marsh bird responses to cattail management in temperate wetlands. Wetlands Ecology and Management 2:283–293.

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. E. Klug, D. J. Larkin, B. A. Lawrence, G. Linz, J. Marburger, G. Noe, C. Otto, N. Reo, J. Richards, C. Richardson, L. R. 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, Ecosystem Services, and Management. Wetlands 39:645–684.

Batt, B. D. J., M. G. Anderson, C.D. Anderson, and F. D. Caswell. 1989. Use of prairie potholes by North American ducks. Pages 204–227 *in*: A. van der Valk, editor. Northern Prairie Wetlands. Ames: Iowa State University Press.

Bouchard, R. W., Jr. 2004. Guide to aquatic invertebrates of the Upper Midwest. L. Ferrington and M. Karius, editors. St. Paul, MN.

Bruggman, J. J. 2017. Impacts Of Cattail Management Techniques On Plant, Bird, Amphibian, And Invertebrate Communities In Shallow Wetlands Of Northwestern Minnesota. University of North Dakota.

Bushaw, J. D., K. M. Ringelman, M. K. Johnson, T. Rohrer, and F. C. Rohwer. 2020. Applications of an unmanned aerial vehicle and thermal-imaging camera to study ducks nesting over water. Journal of Field Ornithology 91:409–420.

Bushaw, J. D., C. V. Terry, K. M. Ringelman, M. K. Johnson, K. M. Kemink, and F. C. Rohwer. 2021. Application of unmanned aerial vehicles and thermal imaging cameras to conduct duck brood surveys. Wildlife Society Bulletin 45:274–281.

Chabot, D., and D. M. Bird. 2012. Evaluation of an off-the-shelf unmanned aircraft system for surveying flocks of geese. Waterbirds 35:170–174.

Christie, K. S., S. L. Gilbert, C. L. Brown, M. Hatfield, and L. Hanson. 2016. Unmanned aircraft systems in wildlife research: current and future applications of a transformative technology. Frontiers in Ecology and the Environment 14:241–251.

Drilling, N. , R. D. Titman, and F. McKinney. 2020. Mallard (*Anas platyrhynchos*), version 1.0. *in* S. M. Billerman, editor. Birds of the World. Cornell Lab of Ornithology, Ithaca, NY, USA. https://library.dnr.state.mn.us:2074/10.2173/bow.mallar3.01

Farrer, E. C., and D. E. Goldberg. 2009. Litter drives ecosystem and plant community changes in cattail invasion. Ecological Applications 19:398–412.

Galt, A. 2010. Effects of sediment removal techniques on avian communities and vegetational attributes in restored prairie pothole wetlands. Fort Hays State University.

Hanson, M. A., C. C. Roy, N. H. Euliss, K. D. Zimmer, M. R. Riggs, and M. G. Butler. 2000. A surface-associated activity trap for capturing water-surface and aquatic invertebrates in wetlands. Wetlands 20:205–212.

Hayashi, M., G. van der Kamp, and D. O. Rosenberry. 2016. Hydrology of Prairie Wetlands: Understanding the Integrated Surface-Water and Groundwater Processes. Wetlands 36:237–254. <http://dx.doi.org/10.1007/s13157-016-0797-9>.

Helgen, J. 2002. A citizen's guide to biological assessment of wetlands: the macroinvertebrate index of biological integrity (IBI). St. Paul, MN.

Hill, N. M. 2021. Secretive marshbird response to invasive wetland plant management in the Prairie Pothole Region of Minnesota. University of Minnesota.

Hill, N. M., D. H. Johnson, T. R Cooper, A. A. Arhcer, and D. E. Andersen. 2023. Marshbird response to herbicide control of cattail in northwestern Minnesota. The Journal of Wildlife Management 87:e22484.

Kaminski, R. M. and H. H. Prince. 1981. Dabbling duck and aquatic macroinvertebrate responses to manipulated wetland habitat. The Journal of Wildlife Management 45:1–15.

Kantrud, H. A. 1986. Effects of vegetation manipulation on breeding waterfowl in prairie wetlands - a literature review. Fish and Wildlife Technical Report 3. Washington, D.C.

Krebs, C. J. 1989. Ecological Methodology. Harper & Row. New York, NY, USA.

Krapu, G. L., and H. F. Duebbert. 1989. Prairie Wetlands: Characteristics, Importance to Waterfowl, and Status. Pages 811–828 *in* R. R. Sharitz and J. W. Gibbons, editors. Freshwater Wetlands and Wildlife, DOE Symposium Series No. 61. OSDOE Office of Scientific and Technical Information, Oak Ridge, TN.

Larson, D. M., J. Riens, S. Myerchin, S. Papon, M. G. Knutson, S. C. Vacek, S. G. Winikoff, M. L. Phillips, and J. H. Giudice. 2020. Sediment excavation as a wetland restoration technique had early effects on the developing vegetation community. Wetlands Ecology and Management 28:1–18.

Linchant, J., J. Lisein, J. Semeki, P. Lejeune, and C. Vermeulen. 2015. Are unmanned aircraft systems (UASs) the future of wildlife monitoring? A review of accomplishments and challenges. Mammal Review 45:239–252.

Linz, G. M., D. L. Bergman, and W. J. Bleier. 1992. Progress on managing cattial marshes with rodeo herbicide to disperse roosting blackbirds. Proceedings of the Fifteenth Vertebrate Pest Conference.

Linz, G. M., D. L. Bergman, D. C. Blixt, and C. McMurl. 1997. Response of American Coots and Soras to herbicide-induced vegetation changes in wetlands. Journal of Field Ornithology 68:450–457. <http://www.jstor.org/stable/4514248>.

Linz, G. M., and H. J. Homan. 2011. Use of glyphosate for managing invasive cattail (*Typha* spp.) to disperse blackbird (Icteridae) roosts. Crop Protection 30:98–104.

Lishawa, S. C., D. J. Treering, L. M. Vail, O. McKenna, E. C. Grimm, N. C. Tuchman. 2013. Reconstructing plant invasions using historical aerial imagery and pollen core analysis: Typha in the Laurentian Great Lakes. Diversity and Distributions 19:14-28.

Lishawa, S. C., E. M. Dunton, D. R. Pearsall, A. M. Monks, K. B. Himmler, B. D. Carson, B. Loges, and D. A. Albert. 2020. Wetland waterbird food resources increased by harvesting invasive cattails. Journal of Wildlife Management 84:1326–1337.

McKellar, A. E., N. G. Shephard, and D. Chabot. 2021. Dual visible-thermal camera approach facilitates drone surveys of colonial marshbirds. Remote Sensing in Ecology and Conservation 7:214–226.

Mitchell, B. J., C. V Terry, K. M. Ringelman, A. K. Janke, K. M. Kemink, and M. J. Anteau. 2022. Wetland occupancy by duck broods in cropland - dominated landscapes of the United States Prairie Pothole Region. The Journal of Wildlife Management 87:e22347.

Murkin, H. R., P. G. Abbott, and J. A. Kadlec. 1983. A comparison of activity traps and sweep nets for sampling nektonic invertebrates in wetlands. Freshwater Invertebrate Biology 2:99–106.

Murkin, H. R., R. M. Kaminski, and R. D. Titman. 1982. Responses of dabbling ducks and aquatic invertebrates to an experimentally manipulated cattail marsh. Canadian Journal of Zoology 60:2324–2332.

Murkin, H. R., E. J. Murkin, and J. P. Ball. 1997. Avian habitat selection and prairie wetland dynamics : A 10-year experiment. Ecological Society of America 7:1144–1159.

Obermoller, T. R., A. S. Norton, E. S. Michel, and B. S. Haroldson. 2021. Use of drones with thermal infrared to locate white-tailed deer neonates for capture. Wildlife Society Bulletin 45: 682-689.

Pebesma, E. 2018. Simple Features for R: Standardized support for spatial vector data. The R Journal 10: 439-446. <https://doi.org/10.32614/RJ-2018-009>

Pöysä, H., J. Kotilainen, V. M. Väänänen, and M. Kunnasranta. 2018. Estimating production in ducks: a comparison between ground surveys and unmanned aircraft surveys. European Journal of Wildlife Research 64:2–5.

Ryckman, M. D., K. Kemink, C. J. Felege, B. Darby, G. S. Vandeberg, and N. E. F. Susan. 2022. Behavioral responses of blue-winged teal and northern shoveler to unmanned aerial vehicle surveys. PLoS ONE 17:1–13.

Sojda, R. S., and K. L. Solberg. 1993. Management and control of cattails. Fish and Wildlife Leaflet 13. Washington, D.C.

Svedarsky, D., R. Grosshans, H. D. Venema, S. N. Ellis-Felege, J. Bruggman, A. Ostlund, and J. Lewis. 2019. 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. Mires and Peat 25:1–14.

Terry, C. V. 2021. Brood abundance and invertebrate availability in crop-dominated landscapes in the Prairie Pothole Region. Thesis, Louisiana State University, Baton Rouge, Lousiana, USA <https://digitalcommons.lsu.edu/gradschool_theses>.

Thorp, J., and A. Covich, editors. 2001. Ecology and classification of North American freshwater invertebrates. 2nd edition. Academic Press, San Diego, CA.

Rohwer, F. C., W. P. Johnson, and E. R. Loos. 2020. Blue-winged teal (*Spatula discors*), version 1.0. *in* A. F. Poole and F. B. Gill, editors. Birds of the World. Cornell Lab of Ornithology, Ithaca, NY, USA. https://library.dnr.state.mn.us:2074/10.2173/bow.buwtea.01

U.S. Fish and Wildlife Service and Canadian Wildlife Service. 1987. Standard operating procedures for aerial waterfowl breeding ground population and habitat surveys in North America. America. US Fish and Wildlife Service, Office of Migratory Bird Management, Laurel, Maryland, USA.

Walker, J., J. J. Rotella, J. H. Schmidt, C. R. Loesch, R. E. Reynolds, M. S. Lindberg, J. K. Ringelman, S. E. Stephens. 2013. Distribution of duck broods relative to habitat characteristics in the prairie pothole region. The Journal of Wildlife Management 77: 392-404.

Weller, M., and C. Spatcher. 1965. Role of habitat in the distribution and abundance of marsh birds. Special Report No. 43. Ames, Iowa.

Wiltermuth, M. T., and M. J. Anteau. 2016. Is consolidation drainage an indirect mechanism for increased abundance of cattail in northern prairie wetlands? Wetlands Ecology and Management 24: 533-544.

TABLES

Table 1. Characteristics of wetlands in Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands. Wetlands were untreated or had recently received a treatment for cattail management: glyphosate herbicide (glyph), applied by Marsh Master (mm) or helicopter (heli); or glyphosate treatment followed by treatment with a roller-chopper (glyph-roller).

Wetland name	WMA	Cluster [b]	Treatment[d]	Area (acres)[a]	Wetland type[g]	Diskability[c]	Treatment year[f]
Cin 01	Cin	GW	untreated	4.5	3	Yes	NA
Cin 09	Cin	GW	untreated	0.9	3	Yes	NA
Cin 22	Cin	GW	untreated	1.0	3	Yes	NA
Eldorado 13	Eldorado	GW	glyph (mm)	0.6	3	Yes	2020
Eldorado 18	Eldorado	GW	glyph (heli)	23.4	3	Possibly	2021
Eldorado 36	Eldorado	GW	glyph (heli)	5.6	3	Possibly	2021
Hegg Lake 09	Hegg Lake	GW	glyph (heli)	4.4	3	Unlikely	2021
Hegg Lake 23	Hegg Lake	GW	glyph (mm)	1.5	3	Unlikely	2021
Hegg Lake 26	Hegg Lake	GW	glyph (heli)	8.9	4	Unlikely	2021
Marple 07	Marple	GW	glyph (mm)	2.2	3	Possibly	2022
Marple 11	Marple	GW	glyph (mm)	1.1	3	Possibly	2022
Shuck 02	Shuck	GW	untreated	8.5	4	Unlikely	NA
Cuka 98	Cuka	NL	untreated	4.8	4	Unassessed	NA
Cuka 99	Cuka	NL	untreated	13.1	4	Unassessed	NA
Gopher Ridge 02	Gopher Ridge	NL	glyph-roller	2.7	3	Possibly	2021 and 2022
Gopher Ridge 03	Gopher Ridge	NL	untreated	0.5	3	Possibly	NA
Gopher Ridge 04[h]	Gopher Ridge	NL	untreated/ roller[h]	5.2	4	Unlikely	NA
Gopher Ridge 05	Gopher Ridge	NL	glyph-roller	2.5	3	Unlikely	2021 and 2022
Gopher Ridge 06	Gopher Ridge	NL	glyph-roller	1.9	3	Unlikely	2021 and 2022
Grace Marshes 30	Grace Marshes	NL	untreated	2.8	3	Possibly	NA
Grace Marshes 35	Grace Marshes	NL	untreated	1.6	3	Yes	NA
Grace Marshes 99	Grace Marshes	NL	untreated	25.6	3	Unassessed	NA
Rau Prairie Pothole 05	Rau Prairie Pothole	NL	glyph-roller	4.8	3	Unlikely	2021 and 2022
Rau Prairie Pothole 06	Rau Prairie Pothole	NL	glyph (heli)	6.0	3	Unlikely	2021
Whitefield 10	Whitefield	NL	glyph (mm)	0.5	3	Possibly	2021
Whitefield 28	Whitefield	NL	glyph (mm)	3.0	3	Possibly	2021

[a]Based on National Wetlands Inventory (NWI) GIS layer, with minor manual adjustments; area of Type 3 wetland (shallow marsh) plus Type 4 wetland (deep marsh; not present in all study wetlands).

[b]Wetlands in the Glenwood (GW) Area were clustered near Morris, MN; Wetlands in the New London (NL) Area were clustered near Willmar, MN

[c]Personal assessment of whether wetlands were likely to be able to be disked by Adam Kleinschmidt (i.e., will the disking equipment get stuck in the mud). Assessment was based on how likely wetlands are to dry out (related to wetland type 3 vs. 4 and wetland area) and sediment characteristics. Yes = can probably disk in most years; Possibly = can probably disk in some years with dry weather; Unlikely = probably cannot be disked in most or all years; unassessed means we added the wetlands last minute and Adam has not done a wetland assessment there.

[d]Wetland treatment for cattail, without specifying method of glyphosate application; unt = untreated; glyph = glyphosate application (either via helicopter or Marsh Master); roller = treatment with a roller-chopper; heli_roller means glyphosate treatment followed by roller-chopper treatment in the subsequent year. (All glyphosate-roller chopper treatments happened to have glyphosate treatment via helicopter.)

[e]Wetland treatment for cattail, specifying how glyphosate was applied; ; unt = untreated; heli = glyphosate application via helicopter; mm = glyphosate application via Marsh Master; roller = treatment with a roller-chopper; heli_roller means glyphosate treatment followed by roller-chopper treatment in the subsequent year. (All glyphosate-roller chopper treatments happened to have glyphosate treatment via helicopter.)

[f]Year wetland was treated. All wetlands were surveyed in 2023.

[g]Circular 39 wetland type, based on Adam's in-person wetland assessment. Type 3 = shallow marsh; Type 4 = deep marsh.

[h]Gopher Ridge 04 was an untreated wetland that was accidentally roller-chopped before the vegetation survey was conducted. Waterfowl surveys were conducted on this wetland prior to treatment, while the vegetation surveys reflect conditions shortly after roller-chopping.

Table 2. Number of points sampled in quadrat-based wetland vegetation surveys in a Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands. Wetlands were untreated or had recently received a treatment for cattail management: glyphosate herbicide (glyph), applied by Marsh Master (mm) or helicopter (heli); or glyphosate treatment followed by treatment with a roller-chopper (glyph-roller). Most wetlands were sampled at consequently with a maximum distance of 75m between sample points and a minimum of 10 sample points, with the goal of surveying two wetlands per day. The first two wetlands surveyed (designated with superscript b) were sampled at a higher intensity (maximum distance of 50m between sample points and minimum of 20 sample points per wetland), after which we reduced sampling intensity for feasibility (need to sample approximately 2 wetlands per day).

Wetland name	Treatment[a]	acres	Number sample points	Points per acre	Approximate time required to survey (to nearest half-day)
Gopher Ridge 03[b]	untreated	0.5	19[b]	41.6[b]	1.5
Whitefield 10	glyph (mm)	0.5	8	16.9	0.5
Eldorado 13	glyph (mm)	0.6	9	14.1	1.0
Cin 22	untreated	1.0	11	10.7	0.5
Cin 09	untreated	0.9	9	10.1	0.5
Marple 11	glyph (mm)	1.1	11	9.9	0.5
Gopher Ridge 02[b]	glyph-roller	2.7[b]	20[b]	7.5[b]	2.0
Grace Marshes 35	untreated	1.6	11	6.7	0.5
Hegg Lake 23	glyph (mm)	1.5	10	6.7	0.5
Gopher Ridge 06	glyph-roller	1.9	10	5.2	0.5
Marple 07	glyph (mm)	2.2	11	5.1	0.5
Gopher Ridge 05	glyph-roller	2.5	10	4	1.0
Grace Marshes 30	untreated	2.8	9	3.2	0.5
Whitefield 28	glyph (mm)	3.0	9	3	0.5
Cuka 98	untreated	4.8	11	2.3	1.0
Hegg Lake 09	glyph (heli)	4.4	10	2.3	1.0
Cin 01	untreated	4.5	10	2.2	0.5
Rau Prairie Pothole 05	glyph-roller	4.8	10	2.1	0.5
Gopher Ridge 04	roller	5.2	10	1.9	0.5
Rau Prairie Pothole 06	glyph (heli)	6.0	11	1.8	0.5
Eldorado 36	glyph (heli)	5.6	8	1.4	0.5
Hegg Lake 26	glyph (heli)	8.9	11	1.2	0.5
Shuck 02	untreated	8.5	9	1.1	0.5
Cuka 99	untreated	13.1	11	0.8	1.0
Grace Marshes 99	untreated	25.6	21	0.8	1.0
Eldorado 18	glyph (heli)	23.4	16	0.7	1.0

[a]Wetland treatment for cattail: unt = untreated; glyph = glyphosate application (either via helicopter or Marsh Master); roller = treatment with a roller-chopper; heli_roller means glyphosate treatment followed by roller-chopper treatment in the subsequent year. (All glyphosate-roller chopper treatments happened to have glyphosate treatment via helicopter.)

[b]Wetland was sampled with a high density of points (maximum distance of 50m between sample points and minimum of 20 sample points per wetland) compared to most wetlands

Table 3. Vegetation metrics collected at quadrats during wetland vegetation surveys in a Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands. We plan to survey these response variables in the Phase II study unless otherwise indicated in the footnotes.

Metric	Description
Robel pole[a]	Metric of vegetation density. Value recorded is the height of the lowest unobstructed 5-cm section of a Robel pole (a 1.5-m, 1.25" diameter PVC pipe marked in 5-cm increments) held vertically at the northeast corner of the quadrat, as observed by a person standing 1.5 m away (9 cm behind the southwest corner of the quadrat) with their head held 1 m above the ground. Reference: Robel et al. (1970)
Cattail stem/leaf touches[a]	Metric of cattail density at varying heights above ground. Number of cattail stem/leaves (live or dead) touching a vertical pole (1.5-m, 1.25" diameter PVC pipe), with data collected from 3 segments of the pole: 0-0.5 m, 0.5-1.0 m, and 1.0-1.5 m above ground. Reference: Hill (2021)
Foliar (aerial) cover	Estimated percent cover of earth surface below the quadrat for each of several vegetation and substrate categories (Table 4).
Water depth	Water depth, measured at the northeast corner of the quadrat, with depth measured from top of sediment or top of litter layer if litter present. Measured using a standard 12"/30-cm ruler or 3-m expandable ruler.
Vegetation heights[a]	Within the quadrat, maximum height of cattail (live or dead status recorded), herbaceous vegetation other than cattail, and woody vegetation. Measured using a 3-m expandable ruler.
Cattail litter depth	Cattail litter depth in northeast corner of the quadrat, measured using a standard 12"/30-cm ruler inserted gently into the litter. Only measured in dry conditions or shallow water.
Plant rake biomass[b]	Relative biomass ranking (0-5; Yin et al. 2000) of submerged aquatic vegetation collected on a plant rake dragged for 1 m along the east side of the quadrat. Only measured in quadrats with water. Our plant rake was constructed by welding together the heads two 14-pronged, square-headed garden rakes (34.6 cm wide with 6-cm tines), similarly to Yin et al. (2000).

[a]Measures of vertical structure were strongly ($0.6 < r < 0.8$) to very strongly ($r > 0.8$) correlated with horizontal measures of abundance (coverage, live stem count). We anticipate dropping 1-2 of these vertical metrics from the Phase II to reduce time (cost) of field surveys.

[b]We expect to encounter submerged aquatic vegetation rarely in the Phase II due to our focus on seasonal wetlands but will record them if present.

Table 4. Plant and substrate categories for which percent foliar (aerial) coverage was measured in a Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands. We used broad plant categories that could be reliably differentiated by seasonal technicians with beginner levels of plant identification experience. Some categories are subcategories of larger categories. We defined foliar cover as the two-dimensional area of the plant type covering the ground surface, from overhead, ignoring overlap between plants within the same category, as a percentage of total quadrat area. I.e., for each plant category, we imagined percent cover as a shadow on the ground if the sun were directly overhead and all other plant categories were absent (with a few exceptions indicated in the table). We included vegetation rooted within the quadrat and ignored vegetation hanging over the quadrat from plants rooted outside of it. Unless otherwise indicated, we considered live vegetation only. We plan to use these categories in the Phase II study unless otherwise noted in the footnotes.

Plant/substrate type	Description
Water	Water above the level of the soil or litter layer (if litter present), between plant stems and floating leaves (if present)
Bare soil	Soil without a covering of litter or water. Only recorded if bare soil present (i.e., we did not imagine bare soil coverage in the absence of other categories).
Cattail – all[a]	Total coverage of cattail litter, dead standing cattail, and live cattail
Cattail, live	Green, moist cattail
Cattail, dead standing	Dry, brown cattail that is raised off the ground, i.e. stray stems that were not flatted by snow over previous winter. Stems may be bent/broken and fold back toward ground at the tips.
Cattail litter	Brown cattail composing a relatively flat layer on the ground (though may be mounded)
Non-cattail-graminoids – all[b]	All graminoids besides cattail. I.e., “grass-like” plants besides cattail (*Typha*), including grasses (Poaceae), sedges (Cyperaceae), rushes (Juncaceae), and bur-reed (*Sparganium*).
Sedges and rushes	Cyperaceae and Juncaceae, grouped due to expertise needed to differentiate Cyperaceae lacking 3-edges stems/3-ranked leaves from Juncaceae, especially if floral characteristics are absent
Bur-reed	*Typhaceae* besides cattail
Grasses	Poaceae (graminoids with hollow stems and nodes)
Reed Canary grass[c]	*Phalaris arundinacea*. Native and non-native strains occur in Minnesota but are not visually differentiable (Anderson et al. 2021)
Phragmites australis[c,d]	We attempted to differentiate between native (ssp. *americanus*) and non-native (ssp. *australis*) varieties of *P. australis*. However, hybrid plants with intermediate characteristics exist in Minnesota[c].
Other grass[e]	Poaceae besides *P. arundinacea* and *Phragmites* spp. Represents primarily native grasses.
Forbs	herbaceous angiosperms that are not graminoids
Equisetum spp.	
Woody vegetation less than 3m tall	Relatively small plants with woody stems (e.g., shrubs or small trees)
Woody vegetation greater than 3m tall	Relatively large plants with woody stems. Included as a category in case large trees unexpectedly encountered.

Plant/substrate type	Description
Submerged aquatic vegetation[f]	Aquatic species rooted in the substrate with the majority of the plant is below the water surface at maturity. Includes submerged sections of heterophyllous aquatic plants (plants that are rooted in the substrate that form both submerged and floating leaves, e.g. some pondweeds).
Floating-leaved plants[f]	Aquatic plants rooted in the substrate with most leaves floating on the water surface at maturity (e.g. yellow or white water lily), and floating leaves of heterophyllous aquatic plants (plants that are rooted in the substrate that form both submerged and floating leaves, e.g. some pondweeds). Recorded as coverage at water surface.
Free-floating plants	Floating aquatic species not rooted in the substrate, e.g. *Lemna* spp. Recorded as coverage at water surface.

[a]Coverage of cattail – all will be dropped as a category in the Phase II study due to its strong correlation (r = 0.89) with cattail litter in the pilot season

[b]"Non-cattail graminoids" was included in the Phase I study as a precaution in case field staff were regularly unable to differentiate grasses from sedges/rushes. Grasses were differentiable by field staff, and consequently we will drop the broader, less informative category of non-cattail graminoids. Non-cattail graminoid coverage was very strongly correlated with coverage of grass (r = 0.86), strongly correlated with coverage of reed canary grass (r = 0.69), and moderately correlated with coverage of sedges and rushes (r = 0.55).

[c]*P. australis* and *P. arundinacea* were recorded in addition to the broader grass (Poaceae) category because they are common monoculture-forming wetland species in our study area. Recording these species will further our goal of detecting whether non-native cattail is replaced by monocultures (often non-native) or diverse native vegetation following treatment.

[d]Hybrid *P. australis* occurs in Minnesota, with morphological characteristics intermediate between the two parental varieties (https://maisrc.umn.edu/phragmites-genetics). Due to potential for unreliable classification based on morphological characteristics, we will record total *P. australis* coverage in addition to the coverage of each variety (if multiple varieties are present).

[e]This category was added partway through the field season at the suggestion of Wetlands Management Program staff and will be retained for the Phase II.

[f]We expect to encounter these plant types rarely in the Phase II due to our focus on seasonal wetlands but will record them if present.

Table 5. Number of quadrats necessary to achieve a coefficient of variation ≤13% for wetland-level average values of 7 selected vegetation metrics, based on bootstrap simulations of varying quadrat numbers from vegetation survey data in a Phase I pilot study of cattail treatment efficacy in prairie pothole wetland. Units are number of quadrats per wetland, with corresponding number of quadrats per acre of wetland area reported parenthetically. A 13% coefficient of variation typically corresponds to a confidence interval size equal to approximately 25% of the expected value for the variable. Sample sizes simulated were 5 to 40 quadrats per wetland (n = 5, 10, 15…40 quadrats per wetland). Bootstrapping (random sampling of quadrats with replacement, n = 500 replicates per simulated sample size) was conducted using data from the four study wetlands with the largest numbers of quadrats. Two of these wetlands were sampled at high intensity and the other two wetlands had higher numbers of quadrats simply because they were large. Where 40 simulated plots did not achieve coefficient of variation ≤13%, values are labeled ">40"

Wetland	Wetland size	Number plots sampled in field (plots per acre)	Number of live cattail stems	Cattail litter depth	Cattail max. height	Live cattail coverage	Dead standing cattail coverage	Cattail litter coverage	Sedges and rushes coverage
Gopher Ridge 02	2.7	20 (7.4)	>40 (>14.8)	30 (11.1)	35 (13)	>40 (>14.8)	>40 (>14.8)	10 (3.7)	>40 (>14.8)
Gopher Ridge 03	0.5	19 (38.0)	>40 (>80)	>40 (>80)	>40 (>80)	>40 (>80)	>40 (>80)	>40 (>80)	>40 (>80)
Grace Marshes 99	25.6	21 (0.8)	30 (1.2)	25 (1)	15 (0.6)	30 (1.2)	35 (1.4)	20 (0.8)	>40 (>1.6)
Eldorado 18	23.4	16 (0.8)	35 (1.8)	35 (1.5)	15 (0.6)	>40 (>1.7)	>40 (>1.7)	10 (0.4)	>40 (>1.7)

Table 6. Number of indicated waterfowl pairs observed in two rounds of waterfowl surveys of 26 wetlands in a Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands. The first round of surveys was April 23-May 3 and the second round was May 15-27. Wetlands were clustered near Willmar, MN, and Morris, MN.

Species	Round 1 indicated pairs	Round 2 indicated pairs
Blue-winged teal (*Spatula discors)*	16	55
Canvasback (*Aythya valisineria*)	1	0
Gadwall (*Mareca strepera*)	4	0
Hooded merganser(*Lophodytes cucullatus)*	0	3
Mallard (*Anas platyrhynchos)*	22	23
Northern Shoveler (*Spatula clypeata)*	1	8
Redhead (*Aythya americana*)	1	2
Ring-necked duck (*Aythya collaris*)	0	1
Wood duck (*Aix sponsa*)	3	1

Table 7. Counts of aquatic invertebrates captured in a subset of 6 activity traps from a Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands. Samples are named as the wetland name (WMA name and wetland ID number), followed by a hyphen and sample ID number (1-3).

Phylum/sub phylum	Class/ subclass	Order	Common name	Cuka 98-1	Eldorado 18-2	Eldorado 18-3	Eldorado 36-1	Eldorado 36-2	Eldorado 36-3	Total
Crustacea - zooplankton	Copepoda		copepods	3	85	170	24	512	21	815
Crustacea - zooplankton	Ostracoda		ostracods		22	53	1	4		80
Crustacea - zooplankton	Cladocera		cladocerans		2400	14852	517	3068	275	21112
Arachnida		Trombiformes (Hydrachnidia)	water mites		13	10		5		28
Hexapoda		Coleoptera[a]	beetles		6	1	1	2		10
Hexapoda		Collembola	springtails		155	133		2	1	291
Hexapoda		Diptera[b]	flies		78	79	11	320	1	489
Hexapoda		Ephemoptera[c]	mayflies		13					13
Hexapoda		Hemiptera[d]	true bugs	21	53	21	2	81	1	179
Hexapoda		Odonata[e]	dragonflies and damselflies	4			3	1	2	10
Mollusca	Gastropoda[f,g]		snails	14	4	4	1	8		31
Annelida	Hirudinea		leeches			1				1
Total				42	2829	15324	560	4003	301	23059

[a]Likely Coleoptera families included Dysticidae, Elmidae, Haliplidae, Scirtidae, and Hydrophilidae
[b]Likely Dipteran families included Chaeboridae, Chaoboridae, Chironomidae, and a pupa of unknown family
[c]Ephemopterans were challenging to identify, especially when incomplete specimens appeared to have lost gills
[d]Likely Hemipteran families included Corixidae, Notonectidae, Corixidae, Pleidae, Notonectidae, Mesovelidae, Corixidae, Gerridae, Veliidae, and Notonectidae, and unknown
[e]Likely Odonata families included Coenagrionidae and Aeshnidae
[f]Gastropoda also includes freshwater limpets, but no limpets were captured
[g]Snails included Planorbidae (ramshorn snails; planospiral shells), Physidae (bladder snails; spiral shells with sinistral coiling direction), and unidentified snails with spiral shells with dextral coiling direction. Presence/absence of operculum is a key identification feature for differentiating snails within this group, and opercula are not visible on dead specimens. Phase II projects identifying aquatic invertebrates could sort live dextral spiraled snails in the field based on presence/absence of opercula before preservation, and/or consult a local invertebrate expert for other potential key features given the subset of species in our study area.

Table 8. Catch per unit effort (invertebrates per hour) of aquatic invertebrates captured in a subset of 6 activity traps in a Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands. Samples are named as the wetland name (WMA name and wetland ID number), followed by a hyphen and sample ID number (1-3).

Phylum/sub phylum	Class/ subclass	Order	Common name	Cuka 98-1	Eldorado 18-2	Eldorado 18-3	Eldorado 36-1	Eldorado 36-2	Eldorado 36-3	Total
Crustacea - zooplankton	Copepoda		copepods	0.13	4.21	8.40	1.21	25.86	1.08	6.64
Crustacea - zooplankton	Ostracoda		ostracods		1.09	2.62	0.05	0.20		0.65
Crustacea - zooplankton	Cladocera		cladocerans		118.81	733.43	26.00	154.95	14.11	171.90
Arachnida		Trombiformes (Hydrachnidia)	water mites		0.64	0.49		0.25		0.23
Hexapoda		Coleoptera[a]	beetles		0.30	0.05	0.05	0.10		0.08
Hexapoda		Collembola	springtails		7.67	6.57		0.10	0.05	2.37
Hexapoda		Diptera[b]	flies		3.86	3.90	0.55	16.16	0.05	3.98
Hexapoda		Ephemoptera[c]	mayflies		0.64					0.11
Hexapoda		Hemiptera[d]	true bugs	0.91	2.62	1.04	0.10	4.09	0.05	1.46
Hexapoda		Odonata[e]	dragonflies and damselflies	0.17			0.15	0.05	0.10	0.08
Mollusca	Gastropoda[f,g]		snails	0.60	0.20	0.20	0.05	0.40		0.25
Annelida	Hirudinea		leeches			0.05				0.01
Total				1.81	140.05	756.74	28.16	202.17	15.45	187.75

[a]Likely Coleoptera families included Dysticidae, Elmidae, Haliplidae, Scirtidae, and Hydrophilidae
[b]Likely Dipteran families included Chaeboridae, Chaoboridae, Chironomidae, and a pupa of unknown family
[c]Ephemopterans were challenging to identify, especially when incomplete specimens appeared to have lost gills
[d]Likely Hemipteran families included Corixidae, Notonectidae, Corixidae, Pleidae, Notonectidae, Mesovelidae, Corixidae, Gerridae, Veliidae, and Notonectidae, and unknown
[e]Likely Odonata families included Coenagrionidae and Aeshnidae
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dead specimens. Phase II projects identifying aquatic invertebrates could sort live dextral spiraled snails in the field based on presence/absence of opercula before preservation, and/or consult a local invertebrate expert for other potential key features given the subset of species in our study area.

FIGURES

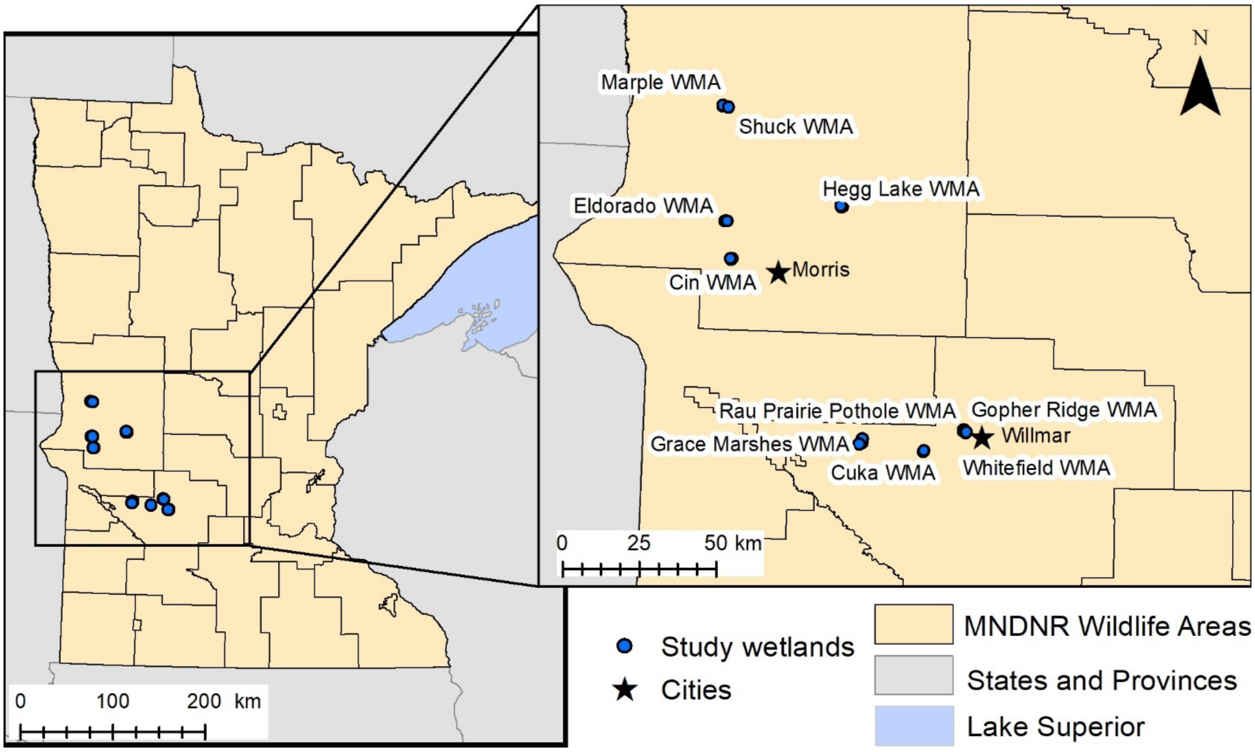


Figure 1. Locations of 26 wetlands in a Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands.

Figure 2. Photograph of UAV launch site for a waterfowl brood survey at Hegg Lake WMA in July 2023 showing typical equipment set-up for 2023 waterfowl pair and brood surveys. The UAV pilot launched the UAV (quadcopter, visible in the air above the road) from a lanchpad (orange mat) along a quiet roadside. A monitor in the back of the pilot's vehicle displayed live imagery from the drone camera, with a small map showing the drone's location on an inset screen. During data collection, two researchers watched the monitor from chairs behind the vehicle and coordinated with the pilot to investigate potential waterfowl sightings in thermal imagery and to collect data (counts, species, sex, and age class of waterfowl).

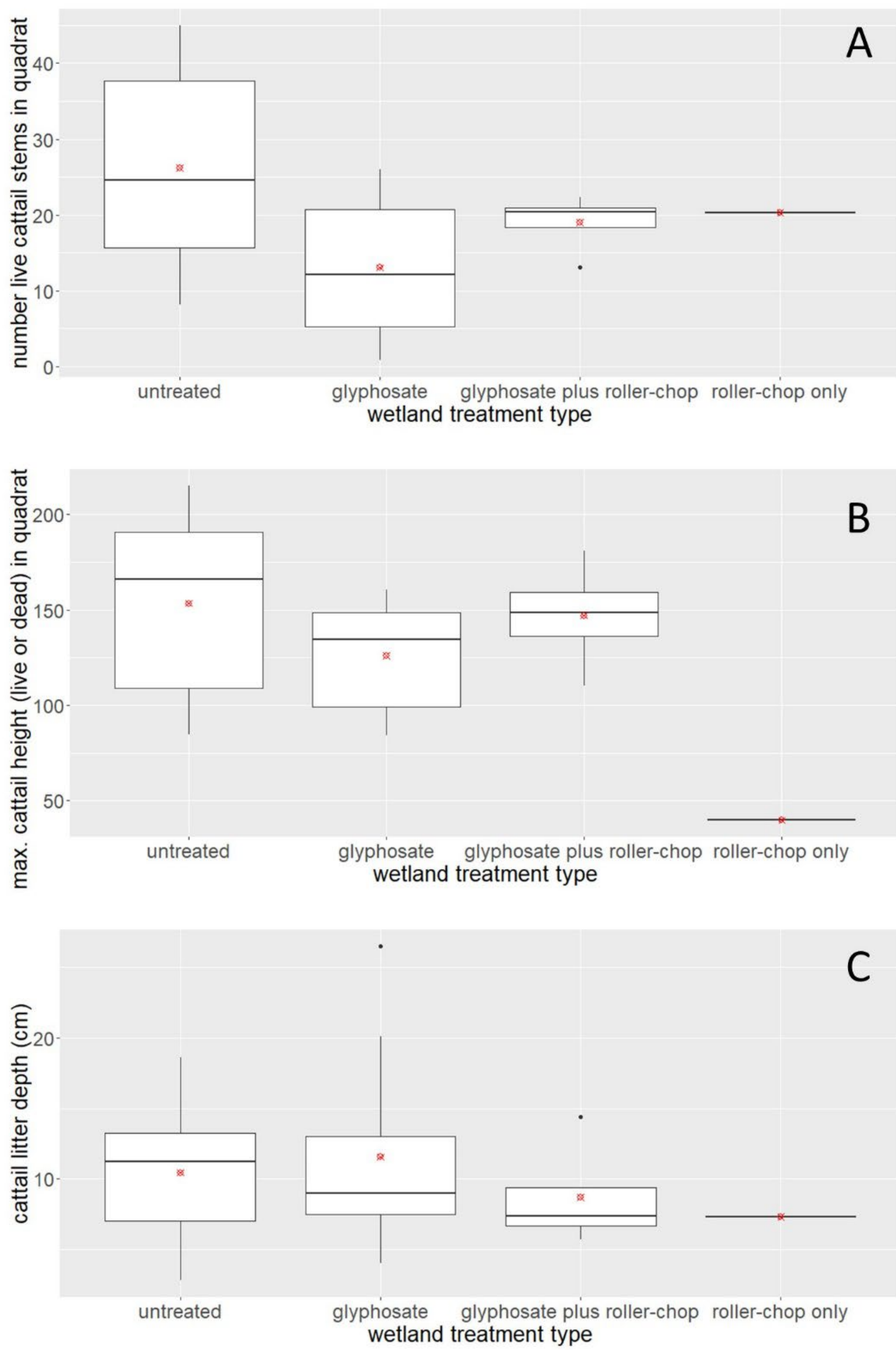


Figure 3. Boxplots comparing the distribution of wetland-level average (A) number of live cattail stems, (B) maximum cattail height, and (C) cattail litter depth from quadrat-based vegetation surveys for each of four treatment groups in a Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands. We surveyed 10 untreated wetlands, 11 glyphosate-treated wetlands, 4 glyphosate plus roller-chop wetlands, and 1 wetland that was roller-chopped only. Red dots with cross-hairs show average values for each treatment group.

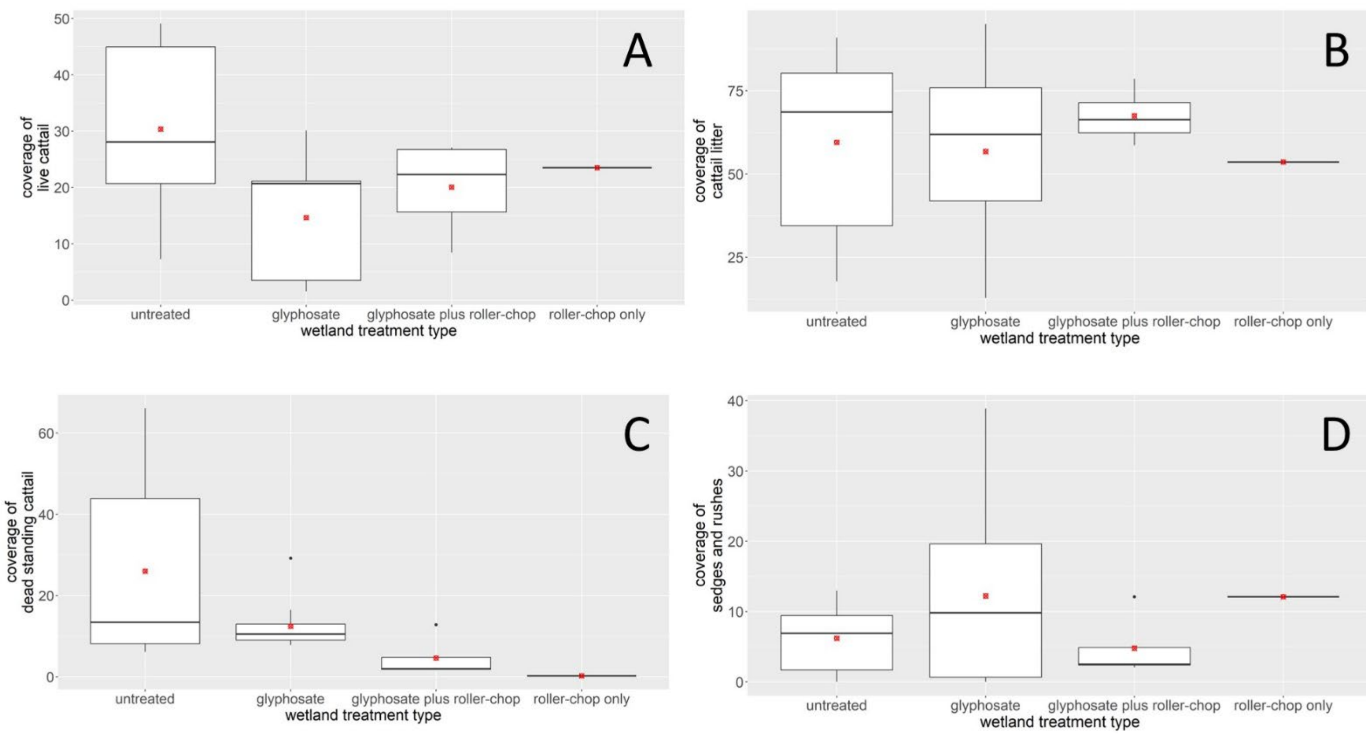


Figure 4. Boxplots showing the distribution of wetland-level average foliar coverage of (A) live cattail, (B) cattail litter, (C) dead standing cattail, and (D) sedges and rushes from four treatment groups in a Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands. Coverage values were collected in 1m x 1m quadrats. We surveyed 10 untreated wetlands, 11 glyphosate-treated wetlands, 4 glyphosate plus roller-chop wetlands, and 1 wetland that was roller-chopped only. Red dots with cross-hairs show average values for each treatment group.

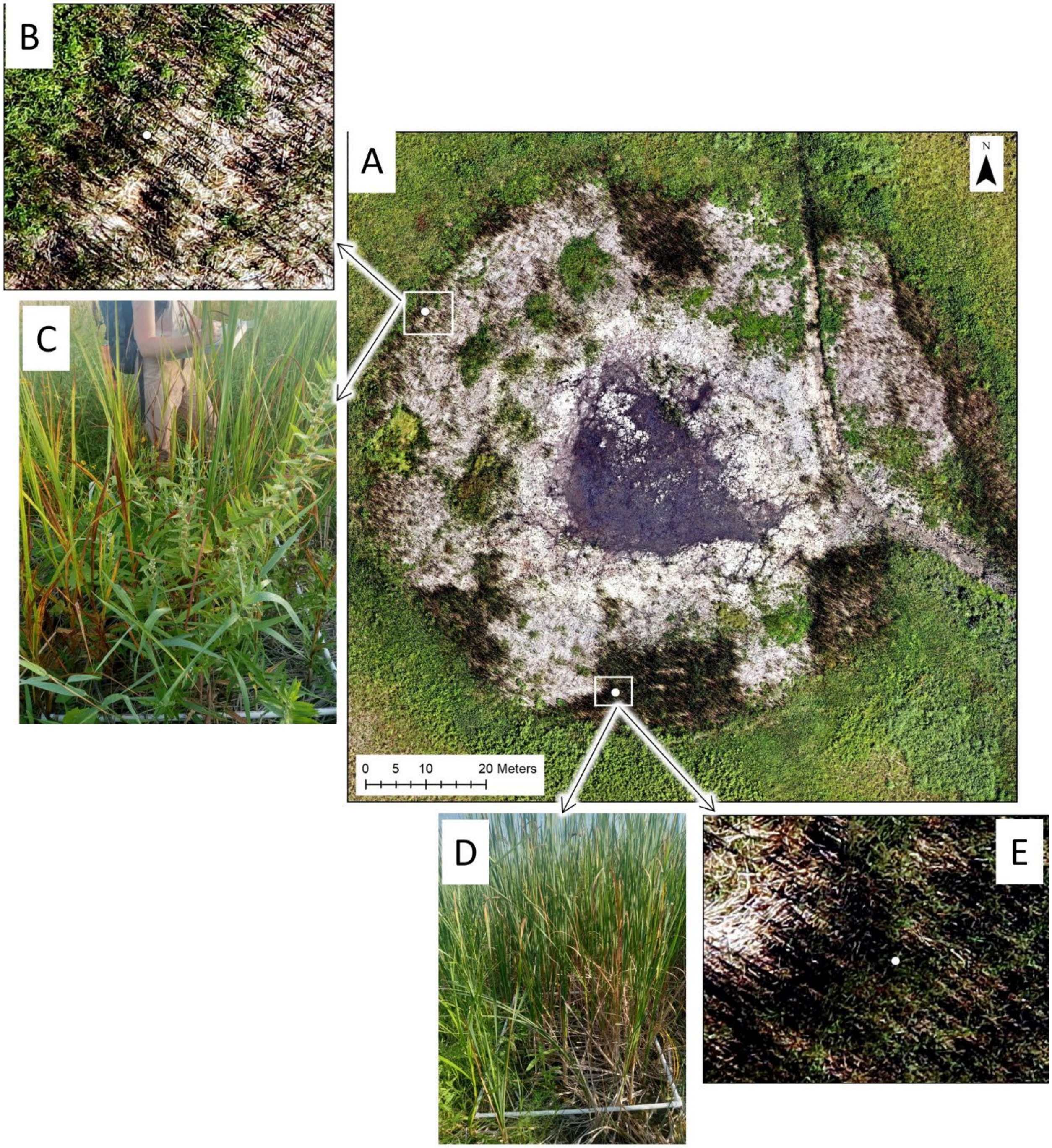


Figure 5. (A) Orthomosaic of a wetland (Gopher Ridge 05) created from UAV-collected aerial imagery in July 2023, with two white dots showing locations of two example quadrats placed in the wetland. The southern point is in an area dominated by cattail, while the upper point is in an area near the edge of the wetland containing a mix of cattails, grasses, and forbs. Cattail-dominated areas are a darker color than other vegetation in the image. Panels (B) and (E) show zoomed in views of the area around the quadrats (with extent marked with white squares in Panel A). Panels C and D show ground-level photographs of the quadrats for comparison. Ground photographs were collected in late August and so do not reflect exact conditions captured in the orthomosaic.

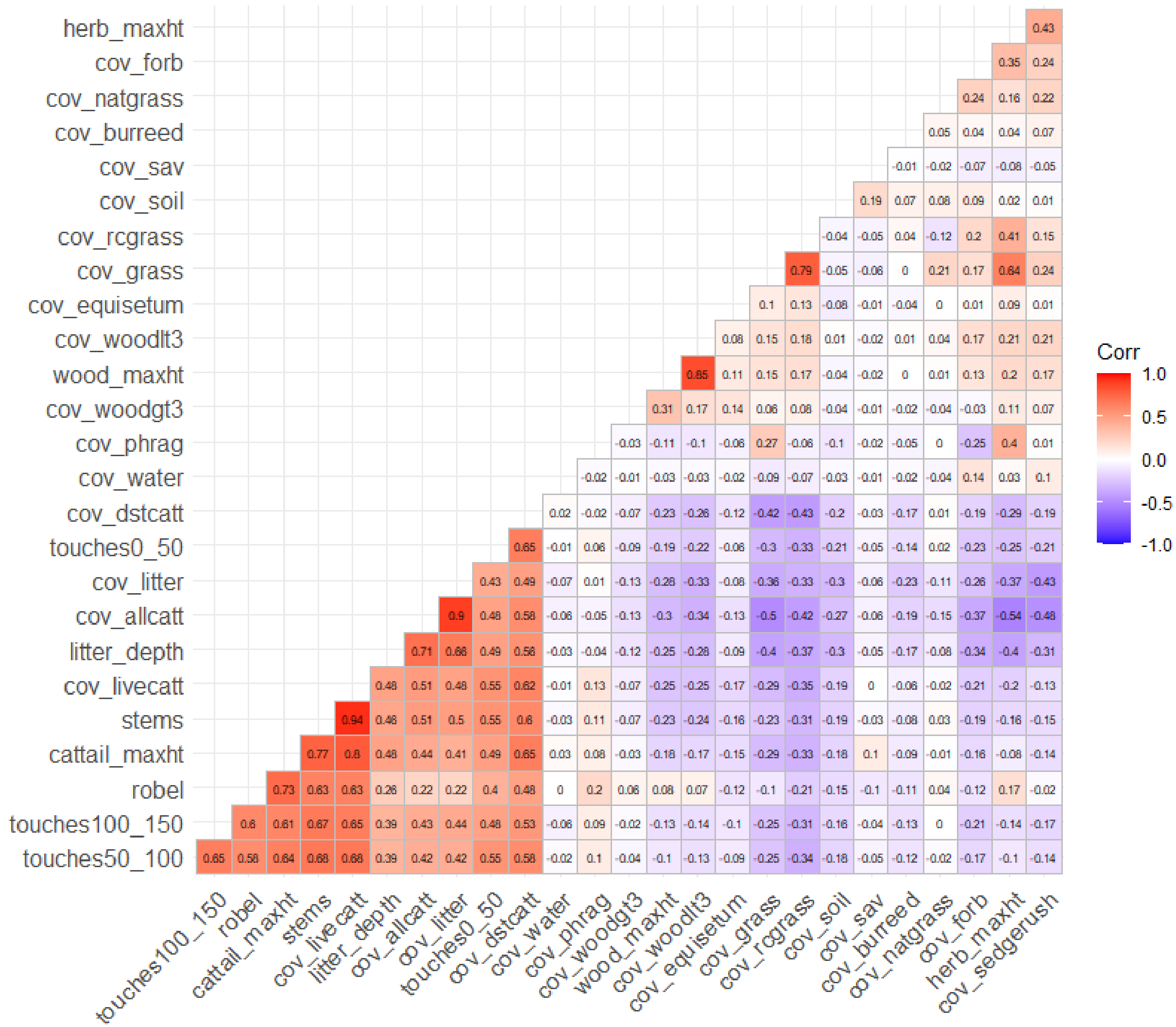


Figure 6. Correlation matrix showing correlations between a selected subset of continuous response variables in quadrat-based vegetation surveys of 26 prairie pothole wetlands in a Phase I pilot study of cattail treatment efficacy. Variables are abbreviated as follows: robel = lowest visible 5-cm unit on 3-m Robel pole; cattail_maxht = maximum height of cattail (live or dead) in quadrat; herb_maxht = maximum height of herbaceous vegetation in quadrat besides cattail; wood_maxht = maximum height of woody vegetation in quadrat (up to 3m); touches0_50 = number of cattail stem/leaf touches (alive or dead) on pole from top of cattail litter layer to 50cm height; touches50_100 = number of cattail stem/leaf touches (alive or dead) on pole from 50cm height to 100cm height; touches100_150 = number of cattail stem/leaf touches (alive or dead) on pole from 100cm height to 150 height; litter_depth = depth of cattail litter in northeast corner of quadrat; stems = number live cattail stems in quadrat; cov_allcatt = percent cover of “cattail-all” (live, standing dead, and litter) in quadrat; cov_livecatt = percent cover of live cattail in quadrat; cov_dstcatt = percent cover of dead standing cattail in quadrat; cov_litter = percent cover of cattail litter in quadrat; cov_burreed = percent cover of burreed in quadrat; cov_forb = percent cover of forbs in quadrat; cov_grass = percent cover of all grasses combined in quadrat; cov_natgrass = percent cover of grass other than reed canary grass and *P. australis* in quadrat; cov_rcgrass = percent cover of reed canary grass in quadrat; cov_sav = percent cover of submerged aquatic vegetation in quadrat; cov_sedgerush = percent cover of sedges

and rushes in quadrat; cov_equisetum = percent cover of *Equisetum* in quadrat; cov_woodgt3 = percent cover of woody vegetation greater than 3m tall in quadrat; cov_woodlt3 = percent cover of woody vegetation less than 3m tall in quadrat; cov_soil = percent cover of bare soil in quadrat; cov_water = percent cover of open water in quadrat.

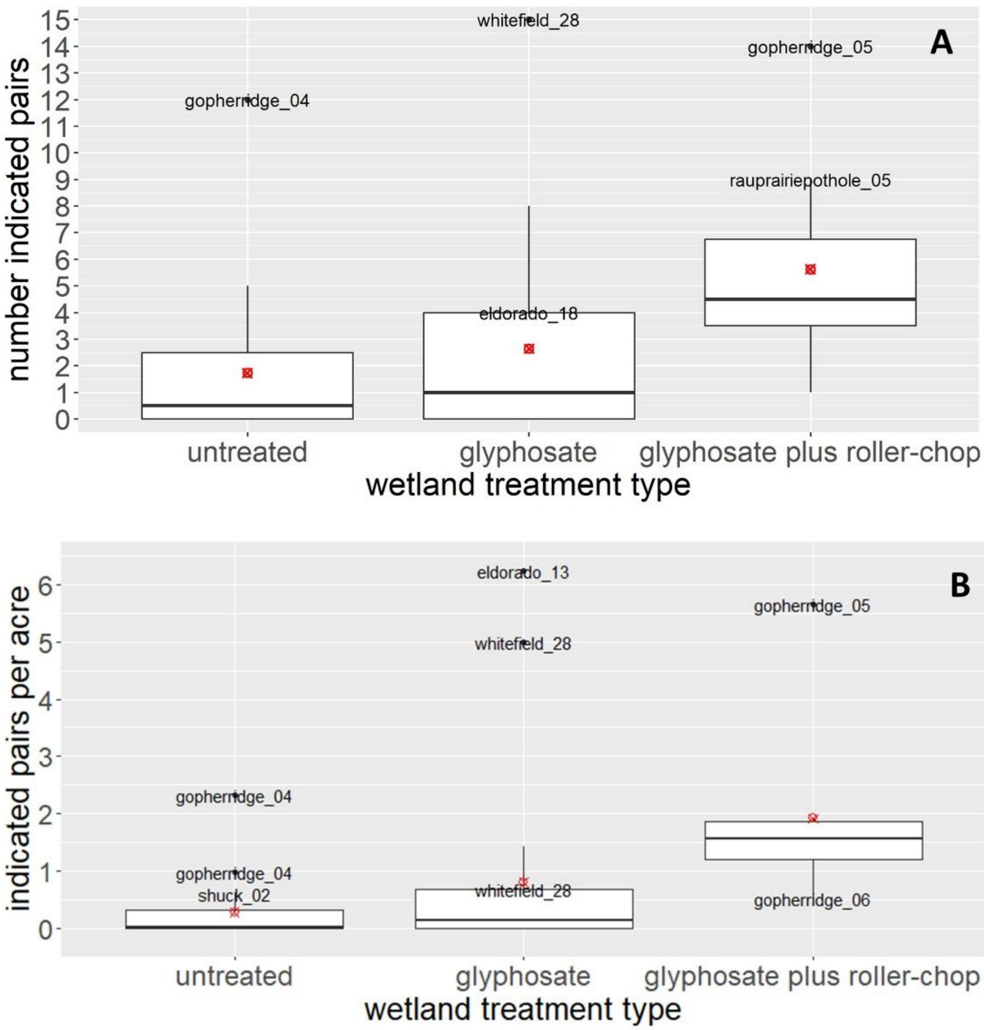


Figure 7. Boxplots showing the distribution of (A) total number of indicated duck breeding pairs (two surveys per wetland), and (B) corresponding pair density (indicated pairs per acre wetland area) from surveys of wetlands in three treatment groups in a Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands. We surveyed 11 untreated wetlands, 11 glyphosate-treated wetlands, and 4 glyphosate plus roller-chop wetlands. Red dots with cross-hairs show average values for each treatment group.

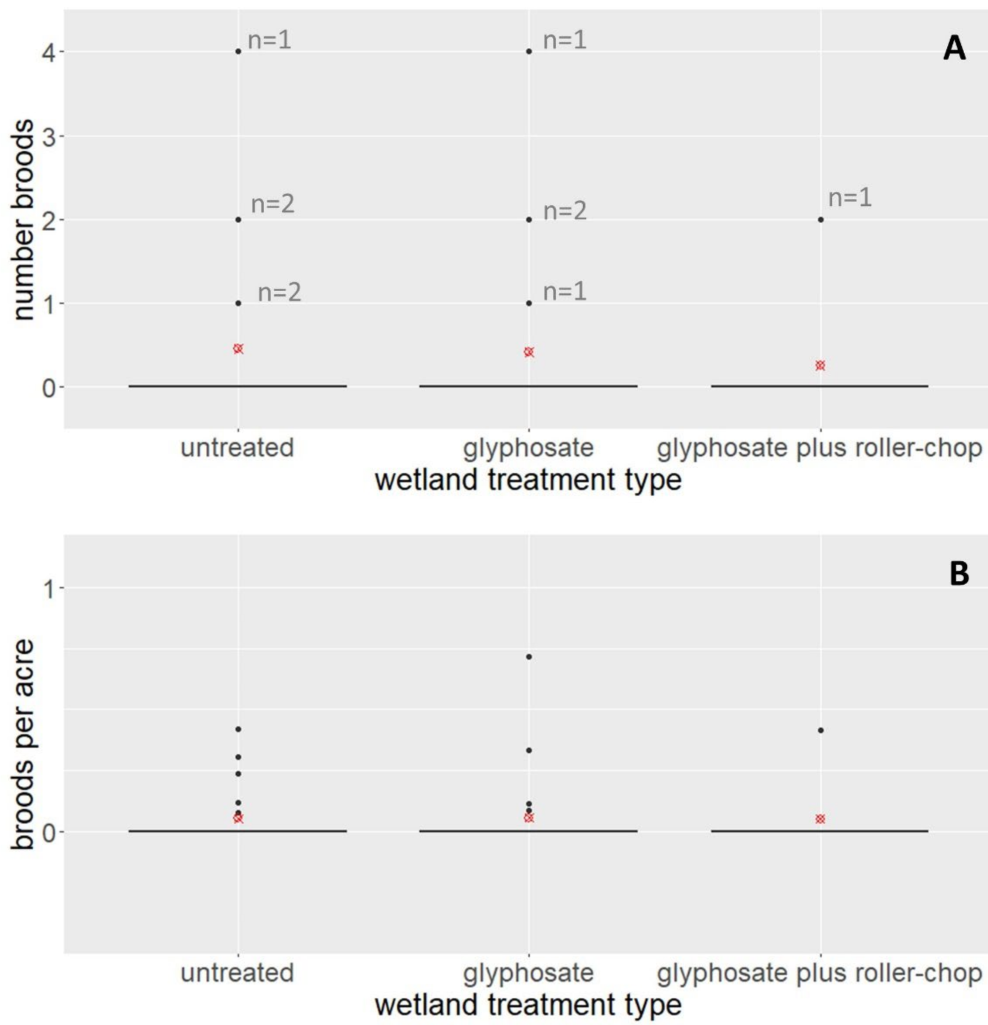


Figure 8. Boxplots showing the distribution of (A) total number of duck broods (two surveys per wetland), and (B) corresponding brood density (broods per acre wetland area) from surveys of wetlands in three treatment groups in a Phase I pilot study of cattail treatment efficacy in prairie pothole wetlands. We surveyed 11 untreated wetlands, 11 glyphosate-treated wetlands, and 4 glyphosate plus roller-chop wetlands. Red dots with cross-hairs show average values for each treatment group.

APPENDIX 1: NON-NATIVE CATTAIL (*TYPHA* SPP.) MANAGEMENT SURVEY OF MINNESOTA DNR WILDLIFE STAFF

Non-Native Cattail (*Typha* spp.) Management Survey of Minnesota DNR Wildlife Staff

Megan Fitzpatrick, Research Scientist II
Wetland Wildlife Populations and Research Group
Minnesota Department of Natural Resources
June 5, 2024

Photo by Adam Kleinschmidt

Table of Contents

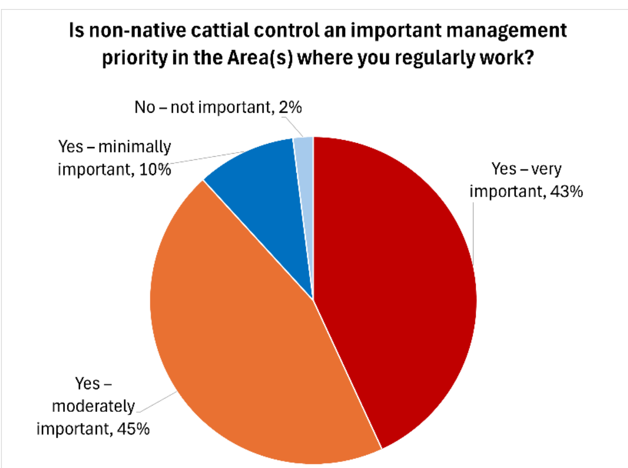
Executive Summary

Non-native cattail (*Typha angustifolia*, and especially the hybrid *T. x glauca*) have proliferated in Minnesota's wetlands, degrading wildlife habitat structure, displacing wildlife food resources, impeding wetland recreation, and creating a challenge for MN DNR's wetland managers (Fig. 1). To identify information needs and inform research project development, the Minnesota Department of Natural Resources (MN DNR) Wetland Wildlife Population and Research Group (WWPRG) surveyed Wildlife Section staff about their methods, observations, and goals pertaining to non-native cattail management. This report describes the survey results.

EXECUTIVE SUMMARY FIGURE 1. A DUCKLING'S POINT OF VIEW OF INVASIVE CATTAIL: THICK, SINGLE-SPECIES STAND IMPEDING WILDLIFE MOVEMENT AND LACKING PREFERRED FOOD PLANTS. PHOTO BY CURT VACEK.

MN DNR Wildlife Section Invasive Cattail Information Needs

Survey responses indicated that research pertaining to cattail treatment methods would be useful to DNR wetland management work. Fifty-one people responded to the survey, including 35 Wildlife Area staff from 25 Areas, along with Shallow Lakes Habitat Program, Wetlands Management Program, and Roving Crew staff. A large majority (88%) of respondents indicated that non-cattail treatment is an important management priority in their work area due to the problems that it creates for wildlife habitat, native plant diversity, water level management, and wetland accessibility for recreationists (Fig. 2). Respondents described a variety of research information needs (pg. 16), including effectiveness of cattail treatments for environments ranging from temporary and seasonal wetlands to larger/deeper shallow lakes and impoundments; results of on-going treatments (e.g. DNR aerial herbicide spraying program); and underlying factors impacting treatment effectiveness (such as nutrient enrichment).



EXECUTIVE SUMMARY FIGURE 2. PERCENT RESPONSES TO THE MULTIPLE-CHOICE QUESTION, "IS NON-NATIVE CATTAIL CONTROL AN IMPORTANT MANAGEMENT PRIORITY IN THE AREAS WHERE YOU REGULARLY WORK?" IN A SURVEY OF MN DNR WILDLIFE SECTION STAFF WHO MANAGE NON-NATIVE CATTAIL AS PART OF THEIR WORK (N=51 RESPONDENTS). UNDERLYING DATA ARE IN TABLE S1.

Observations Informative to Research Design

Survey responses contained a plethora of valuable information for planning research related to invasive cattail treatments and putting research results into context. MN DNR Wildlife staff use a variety of invasive cattail treatments, with herbicide being the most common. Staff shared benefits and limitations of 17 treatment methods, which will help researchers choose relevant treatments to study on various types of wetlands. Respondents' treatment goals and wetland conditions triggering treatment indicate researchers should consider response variables that measure cattail coverage, open water coverage, abundance and diversity of native plants (especially wild rice) and animals (especially waterfowl) to provide information pertinent to management goals. Yet, variation in responses revealed that researchers should consider the treatment goals and pre-treatment conditions typical to particular study areas, wetland types, and cattail treatments of interest when designing studies and interpreting results. Based on reported retreatment rates, studies will likely need to follow wetlands for at least 4-6 years to discover differences in treatment longevity. Importantly, respondents pointed out that time, funding, equipment availability, and weather/ground conditions were all limiting practical factors to treating cattail, such that they needed to prioritize which wetlands received treatment. Researchers should thus consider studying cattail treatments with potential to be feasible to implement at broad scale, or that have potential for long-lasting benefits on priority wetlands.

Introduction

Non-native cattail species (*Typha angustifolia*, and especially the hybrid *T. x glauca*) have proliferated in North American wetlands over the past century, forming dense, monotypic stands and displacing other species of emergent and submerged aquatic vegetation (Kantrud 1986, Bansal et al. 2019). Cattails form dense monotypic stands, displacing other aquatic plants and impacting wetland birds, amphibians, and fish via changing habitat structure and displacing food resources (Bansal et al. 2019), and creating a challenge for MN DNR's wetland managers. The Wetland Wildlife Population and Research Group (WWPRG), in collaboration with the DNR Wetlands Management Program and the U.S. Fish and Wildlife Service, has proposed a study to compare the effectiveness of several control treatments for non-native cattail in seasonal prairie pothole wetlands (Fitzpatrick et al. 2024). To inform this work and development of future research projects, we sent an informal, information-gathering survey to DNR Wildlife staff to learn about their methods, observations, and goals pertaining to non-native cattail management. We will use the information gathered in this survey to incorporate DNR Wildlife information needs into research plans and interpretation of research results.

In this report, we summarize the survey results. Our goal in this survey was to capture a wide range of ideas and observations, rather than test hypotheses. We report results for closed-ended survey questions as percentages. For open-ended questions, we summarize the range of ideas and observations discussed, but we did not formally code the responses. This report is intended primarily for internal use in WWPRG, plans but we will share the report with any interested MN DNR staff.

Methods

We aimed to survey Wildlife staff who manage non-native cattail as part of their work. We restricted our survey to the Wildlife section after learning from colleagues that other Sections/Divisions (e.g., Fisheries, Ecological and Water Resources) conduct little non-native cattail management.

We created and distributed the survey using Qualtrics software. We created a distribution list of 311 Wildlife staff by combining pre-existing Outlook e-mail distribution lists for the four DNR Regions and Central Office (#DNR_@FAW Wild R1, #DNR_@FAW Wild R2, #DNR_@FAW Wild R3, #DNR_@FAW Wild R4, and #DNR_@FAW Central Office). In e-mails, we asked Wildlife Staff who manage non-native cattail (*Typha*) species as part of their work to fill out the survey, and for other staff to disregard the survey. All e-mails contained an opt-out link for future communications. The survey was open for three weeks (Feb. 23-March 15), and we sent four e-mails reminders to recipients who had not yet completed the survey over the course of the three weeks. We obtained approval from Regional Wildlife Managers and Habitat Team and Program supervisors prior to distributing the survey.

Survey questions are shown in Appendix 1.1. The survey had 15 questions, with some questions having multiple parts. Questions were free response or multiple choice with single or multiple response options selectable. Some multiple choice questions included an "other" answer choice to capture information not covered by the provided answer choices. In these cases, we included a free response question asking for specification if "other" was selected.

We anticipated that some respondents would have observations based on the same treatments on the same waterbodies, e.g., multiple Area staff from the same area, or Habitat Program staff collaborating with Area staff. We also anticipated that people listing the same work area would having varying levels of overlap in their experiences. For example, managers based in satellite offices might report on wetlands in a subset of the Area, or the full Area. Due to this uncertainty, and because our primary goal was to gather a variety of observations and ideas from as many Wildlife staff members who manage cattails as possible, rather than to obtain a quantitative summary of cattail-related management actions, we did not attempt to average or otherwise combine survey results by Area.

Results

Respondents

Fifty-one people responded to the survey, including 35 Wildlife Area staff from 25 Areas distributed across four Regions (1-4 respondents per Area), along with 7 Roving Crew staff, 6 Shallow Lakes Habitat Program (hereafter "Shallow Lakes") staff, and 3 Wetlands Management Program (hereafter "Wetlands Management") staff.

Importance of non-native cattail management

Most (88%) of survey respondents indicated that non-native cattail control is a "very important" or "moderately important" management priority in the Areas where they regularly work (Figure 1, Table S1).

We also asked respondents to list the biggest problems that non-native cattail created in their work area. Respondents described numerous problems relating to cattail's tendency to eliminate open water, displace native vegetation, and form floating mats, with implications for wildlife habitat, wild rice, recreation, and water level management (Box 1).

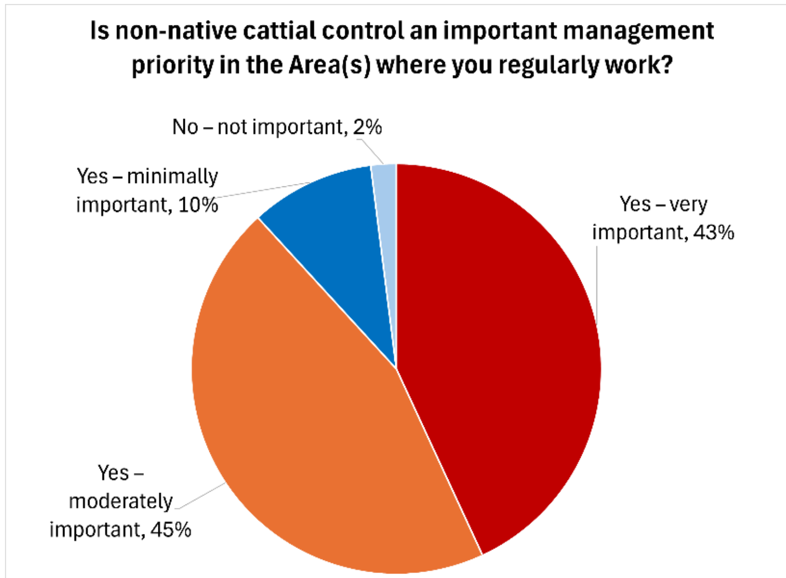


FIGURE 1. PERCENT RESPONSES TO THE MULTIPLE-CHOICE QUESTION, "IS NON-NATIVE CATTAIL CONTROL AN IMPORTANT MANAGEMENT PRIORITY IN THE AREAS WHERE YOU REGULARLY WORK?" IN A SURVEY OF MN DNR WILDLIFE SECTION STAFF WHO MANAGE NON-NATIVE CATTAIL AS PART OF THEIR WORK (N=51 RESPONDENTS). DATA UNDERLYING THIS FIGURE ARE IN TABLE S1.

Goals when treating cattail

We asked, "What are your goals when treating cattail? That is, what do you consider a successful outcome?" Forty-two respondents shared management goals.

Box 1. Reported Problems Created by Cattail in MN DNR Wildlife Areas

- Cattail eliminates or severely impedes open water habitat in many wetland types, including sheet water, seasonal/temporary wetlands, hemi-marshes, semi-permanent wetlands, and impoundments.
- Cattail creates monocultures and displaces native plant communities, leading to loss of plant biodiversity, loss of wildlife habitat diversity, and loss of submerged aquatic plants (high-value wildlife food).
- Cattail degrades habitat for wildlife, reducing wildlife abundance and diversity. Specific wildlife taxa described were waterfowl, other marsh birds, shorebirds, amphibians, and fish (fish nurseries).
- Waterfowl were a frequently mentioned wildlife taxon. Reported problems pertaining to waterfowl habitat degradation included loss of open water or pockets of open water in various wetland types, and degradation of habitat in sedge meadows formerly used for nesting and brood-rearing, shallow water wetlands, seasonal/temporary wetlands, semi-permanent wetlands, sheet water, large impoundments, pair ponds, brood ponds, and migration areas.
- Floating cattail mats interfere with water control structures and/or block outlets of water bodies, impeding flow and raising water levels.
- Cattail impacts wild rice. Problems reported were destructive impacts of floating mats directly on wild rice and indirect effects of floating mats blocking waterbody inlets and outlets, creating water levels unfavorable to wild rice.
- Cattail (rooted and floating mats) limits accessibility of wetlands and waterbodies and hinders boat travel for hunters, wild ricers, kayakers, bird watchers, and other members of the public.
- Cattail degrades wetland aesthetics, leading to public concerns.

Management goals corresponded with problems created by non-native cattail (Box 1). Management goals generally included decreasing cattail coverage, increasing open water coverage, creating pockets of open water (e.g. hemi-marsh conditions), and/or increasing native plant diversity and abundance. Wild rice and endangered submerged aquatic plants (sheathed pondweed) were mentioned as specific priority native species. One respondent mentioned that native vegetation could compete with cattail and prevent cattail from re-establishing dominance.

Numerous (19) respondents reported goals of creating hemi-marsh conditions (ratio of approximately 50% vegetation to 50% open water). A few respondents said that any decrease in cattail coverage and increase in open water area would be considered a success, with one respondent commenting that they did not have percentage-based expectations due to the highly variable treatments results between wetlands. Another respondent mentioned that a definition of success also depended on the condition of the wetland prior to treatment – a realistic treatment goal for a wetland lacking open water might be 25% open water lasting for 4-5 years, whereas a wetland in better condition might achieve a more ideal goal of 40-80% open water.

Several (5) respondents specifically mentioned reductions in floating mats specifically as a goal. A few (3) respondents listed a goal of maintaining water flow through water control structures and inlets/outlets.

A few respondents mentioned that goals vary by treatment. For example, one respondent contrasted fall mowing and aerial herbicide. Fall mowing is expected to have short-term impacts, and an associated short-term goal would be open water and northern pintail use in the following spring. Aerial herbicide is expected to have longer-term effects and might have a goal of creating open water lasting for multiple years. Another respondent contrasted burning and flooding, where any trend of decreasing cattail would be considered a success, to aerial herbicide, where a higher bar for success would be <50% cattail coverage for 3 or more years. Respondents who discussed herbicide specifically said that their immediate goal was 90-95% complete kill (not just top kill) of cattails. Respondents who mentioned a time component to their goals said that a successful treatment would last longer than 3 years, or longer than 4-5 years.

Some respondents described treatment goals in terms of benefits to wildlife or humans. Specifics were most often waterfowl-related: diversified nesting cover, or improved wetland use or duck production. Other respondents mentioned increased shorebird use, or general wildlife diversity and use. Two respondents mentioned access for waterfowl hunters.

Decisions about where and when to treat cattail

We asked, “What conditions trigger you to treat a wetland for cattail?” Some respondents answered that they did not have a specific metric, or that their job duties did not entail deciding where to treat for cattail. However, most (40 respondents) shared some conditions.

Several respondents shared practical limitations to applying treatments in addition to descriptions of triggering wetland conditions. Staff time, funding, equipment availability, and weather/ground conditions were limiting factors. Therefore, the wetland condition “triggers for treatment” described below are used in decision making, but all wetlands in these conditions are not necessarily treated or treated immediately when they reach the “trigger” state.

Regarding wetland conditions triggering treatment, high cattail coverage and low open water coverage were common themes. Some respondents shared approximate percentages of cattail coverage that triggered treatment, ranging ≥50% to ≥90% coverage by cattail. Other respondents looked for cattail monoculture, or cattail monoculture in large areas of the wetland. Some respondents indicated a complete lack of open water was a trigger, while others indicated that declining area of open water was a trigger.

Another common theme was degradation of native plant communities. Some respondents referred to absence of native communities, while others referred to low plant diversity. One respondent mentioned waiting to spray aerial herbicide until the wetland was at least 75% covered with cattails to avoid destroying native plants. On the other hand, another respondent mentioned a strategy of treating some wetlands while they are still in “fair” condition, before cattails spread enough to become a management concern. (Specific treatments were not referenced and may have involved targeting patches of cattail monoculture.)

Additional themes regarding treatment triggers were cattail blocking water flow or lake outlets, and/or interfering with water level control; cattail creating access obstructions; declining wild rice; expansion into moist soil units; declining bird use; treatment in accordance with aquatic plant management plans following drawdowns; and public desire to treat specific basins.

Where floating mats were specifically mentioned, treatment triggers included expansion into open water, blockage to outlets and drainages, and destruction of wild rice or other aquatic plants.

In the context of limitations to staff time and resources, several respondents shared how they prioritize wetlands for treatment. Priority wetlands were part of wetland complexes (i.e., in areas with other wetlands), important waterfowl feeding and resting areas, wetlands surrounded by high quality upland nesting habitat, or new wetland restorations. Other factors included whether the manager thought it likely that treatment would be successful, practical choices to get the best outcome for effort/funds expended. For example, numerous wetlands in the same area needing treatment, proximity to loading and support sites, and lack of permitting issues all lead to more wetlands getting treated per dollar and per unit of staff time.

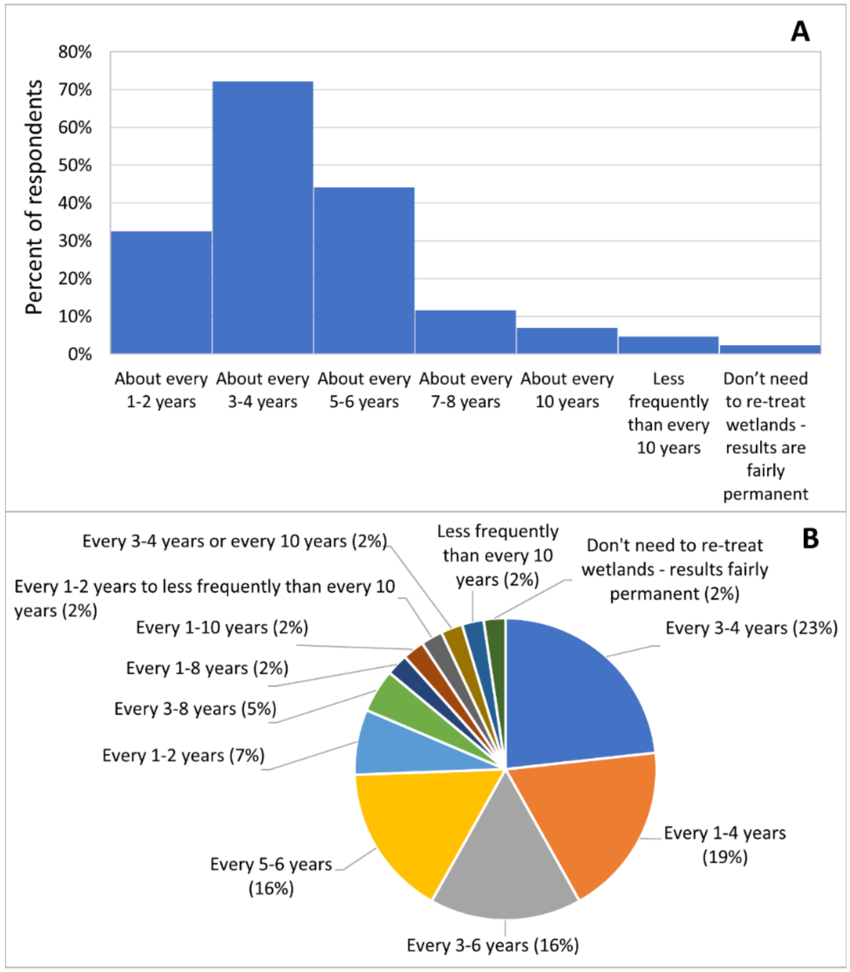


FIGURE 2. HOW OFTEN PRACTITIONERS NEED TO RE-TREAT WETLANDS FOR NON-NATIVE CATTAIL TO MEET MANAGEMENT GOALS, FROM A SURVEY OF MN DNR WILDLIFE SECTION STAFF WHO MANAGE NON-NATIVE CATTAIL AS PART OF THEIR WORK. THE QUESTION WAS POSED AS A MULTIPLE CHOICE QUESTION WITH MULTIPLE RESPONSES POSSIBLE. PANEL A SHOWS THE PERCENT OF RESPONDENTS (N=43) WHO SELECTED EACH INDIVIDUAL ANSWER CHOICE. PANEL B SHOWS THE PERCENTAGE OF RESPONDENTS WHO SELECTED EACH COMBINATION OF ANSWER CHOICES. IN PANEL B, WHERE RESPONDENTS CHOSE SEVERAL CONSECUTIVE OPTIONS, COMBINATION LABELS ARE ABBREVIATED. FOR EXAMPLE, IF A RESPONDENT CHOSE "ABOUT EVERY 1-2 YEARS" AND "ABOUT EVERY 3 TO 4 YEARS", THE COMBINATION IS LABELED "1-4 YEARS". DATA UNDERLYING THE FIGURE ARE SHOWN IN TABLE S2 (PANEL A) AND TABLE S3 (PANEL B).

How long do treatments last?

We asked respondents, "How often do you find you need to re-treat wetlands to meet management goals?", with multiple choice options ranging from "About every 1-2 years" to "About every 7-8 years", and additional options of "About every 10 years", "Less frequently than every 10 years" and "Don't need to retreat wetlands – results are fairly permanent" (Fig. 2A). Respondents were allowed to select multiple options (Fig. 2B). Most (43 of 51) survey respondents answered the question.

Responses were right-skewed, i.e., most respondents selected shorter time frames (Fig. 1A). About half (53%) of respondents selected an overall time frame of about every four years or less (every 1-2 years and/or every 3-4 years) (Fig. 2B). Most (88%) respondents selected a time frame of about every six years or less (every 1-2 years and/or every 3-4 years and/or every 5-6 years). Six percent of respondents selected wider time ranges (e.g., 1-10 years). Only one respondent (3%) indicated that treatment results are fairly permanent, such that retreatment is usually not required.

Cattail management methods used

We asked what cattail treatment methods respondents use via a multiple-choice question allowing multiple selections, with the option to list up to three additional treatments (Table 1). For each treatment selected, we asked two follow-up questions. First, we asked about the type(s) of water body in which the respondent typically applies the treatment: small/shallow wetlands (defined as less than approximately 50 acres), shallow lakes (greater than 50 acres but less than 15 feet deep), larger/deeper lakes, and/or rivers, with the option to list other water body types. Asking about water body type was important because some treatments are possible only in particular types of water bodies or may work with varying effectiveness in different types of water bodies. Secondly, we asked what time of year the respondent typically applies the treatment. This was important because some treatments (e.g. prescribed fire) might be conducted at different times of year with different goals/outcomes. We also included a free response text box where respondents could optionally provide any additional comments about the treatment.

The most commonly listed treatments overall were herbicide treatments, applied aerially (82% of respondents) and via ground equipment like Marsh Masters® (78%). Herbicide was followed by prescribed fire (69%). However, free response comments indicated that cattail control is usually not the primary objective of prescribed fires, such that MN DNR's prescribed burns often have little impact on live cattail (Appendix 1.2). Water level control (flooding and drawdown) were also commonly reported (each by 57% of respondents) (Table 1). Drawdown and flooding are often used as part of larger treatment process, i.e., draw down water levels (or take advantage of seasonal low water levels) to apply a treatment for cattail (e.g., cutting, mowing, disking, roller-chopping), followed by flooding (or reliance on high seasonal water levels) over cut or smashed stems to enhance plant kill. Some respondents also discussed use of drawdown and flooding cycles to promote muskrat herbivory, i.e., drawdowns to regenerate emergent vegetation forage (including cattails), followed by high water levels to promote muskrat breeding and overwintering.

Wildlife staff treat different types of water bodies for cattail (Table 2). Most respondents reported conducting treatments in shallow lakes (90% of respondents) and small wetlands (84% respondents), with smaller proportions also treating large lakes (16% respondents) and rivers (14%). Twenty-nine percent of respondents reported treatments on other types of water bodies, specified in text boxes. In particular, several (10%) of respondents listed impoundments. One person clarified that impoundments could be classified as small wetlands or shallow lakes based on size but are quite different systems due to their extremely altered hydrology and soils. Additionally, 8% of respondents listed small areas treated with the goal of maintaining waterflow: creeks, ditches, and/or outlets/drainages of lakes, shallow lakes, and wetlands. Additional waterbody/wetland types listed less commonly included moist soil units, wet meadow/sedge meadows/floodplains, bogs/fens, areas surrounding water control structures (for facilities maintenance purposes), borrow ditches (with goal of creating fire breaks), and large wetland complexes (i.e., 30-5,000 acres).

TABLE 1. PERCENT OF RESPONDENTS WHO USE VARIOUS TREATMENT METHODS FOR NON-NATIVE CATTAIL, FROM A SURVEY OF MN DNR WILDLIFE SECTION STAFF WHO MANAGE NON-NATIVE CATTAIL AS PART OF THEIR WORK (N=51 RESPONDENTS). VALUES SUM TO GREATER THAN 100% BECAUSE RESPONDENTS COULD SELECT MULTIPLE ANSWER CHOICES.

Treatment	Percent respondents
Herbicide - aerial application	82%
Herbicide - applied from ground equipment (e.g. Marsh Master)	78%
Prescribed fire	69%
Water level control - flooding (for example, flooding cattail after cutting)	57%
Water level control - drawdown	57%
'Cookie cutter' or other amphibious vehicle to remove floating cattail	45%
Herbicide - applied by hand (e.g. with backpack sprayer)	41%
Mowing	37%
Roller-chopper	26%
Cattle grazing	20%
Disking	18%
Scraping	16%
Planting native wetland vegetation on restorations before cattail establishment[a]	2%
Herbicide – applied by boat with ATV-type sprayer[a]	2%
Removal of floating cattail-dominated bogs by hand and equipment[a]	2%
Muskrat grazing[a]	2%
Nutrient management[a]	2%

[a]Listed as an "other" treatment that was not covered by the provided answer choices.

Wildlife staff use different types of cattail treatments in different types of water bodies (Table 2), and reasons for the differences were described in free response (Appendix 1.2). For example, in shallow lakes, aerial herbicide application was listed more commonly than ground-equipment herbicide application, whereas ground equipment application was more common than aerial application in small wetlands, for logistical reasons relating to wetland size, hydroperiod, and floating vs. rooted state of cattail (Table 2, Appendix 1.2). Respondents indicated via free response (Appendix 1.2) and write-in water body types that herbicide applied by hand (e.g. backpack sprayer) is generally limited to small areas to improve water flow (outlets, drainages, creeks, ditches) and/or small areas around water control structures (for facilities maintenance). Treatments that are only possible in dry or low water conditions, or whose outcomes are improved by such conditions, were more common in small wetlands than shallow lakes, and were not applied in larger/deeper lakes (e.g. herbicide applied via ground equipment, mowing, roller-chopping, disking, scraping) (Table 2, Appendix 1.2). On the other hand, amphibious vehicles that target floating mats (i.e. Cookie Cutters, Swamp Devils®) require deep water and a developed access (or a crane) to get in and out of wetlands, and they were reported most commonly among respondents treating larger/deeper water bodies.

Table 2. Percent of respondents who use various non-native cattail treatment methods for various water body types. For each row, percentages are percent of the total number of respondents who conduct cattail treatments in that type of wetland. Percent of respondents who treat the wetland type (out of n=51 respondents total) are shown in the last (right) column. Non-zero values are shaded to facilitate comparison across water body types

Type of water body	Herbicide - aerial application	Herbicide - from ground eqpt. (e.g. Marsh Master)	Prescribed fire	Water level control - flooding (for example, flooding cattail after cutting)	Water level control - drawdown	'Cookie cutter' or other amphibious vehicle to remove floating cattail	Herbicide - applied by hand (e.g. with backpack sprayer)	Mowing	Roller-chopper	Cattle grazing	Disking	Scraping	Planting native wetland vegetation on restorations before cattail establishment[a]	Herbicide – applied by boat with ATV-type sprayer[a]	Removal of floating cattail-dominated bogs by hand and [illegible]	Muskrat grazing[a]	Nutrient management[a]	Percent of respondents who treat this type of waterbody
Small/shallow wetlands	70	84	65	47	49	12	33	40	23	23	19	19	2		2	2	2	84
Shallow lakes	72	30	35	52	50	43	13	9	9	2	2			2		2	2	90
Larger/deeper lakes	38		38	13	13	50											13	16
Rivers	14	29	57	14		14	14								14		14	14
Impoundments[a]	80	60	40	20	60	20												10
Creeks, ditches, outlets/drainages[a]		50					25	25						25				8
Wet meadow, sedge meadow, floodplain[a]			100							50								4
Moist soil unit[a]		50						50										4
Around water control structures[a]							100											4
Borrow ditch[a]		1																2
Wetland complexes[a]			100	100	100													2
Bog/fen[a]	100	100	100				100											2

[a]Listed as an “other” treatment that was not covered by the provided answer choices.

Which treatment is most effective?

We asked respondents which of their treatments or regimens they found to be most effective for controlling non-native cattail, stating that we were interested in both short-term and long-term effectiveness. Some respondents indicated that they did not have enough experience or observations to answer this question yet, but 41 respondents described the effectiveness of treatments.

Most (30) respondents indicated that herbicide, sometimes in combination with another treatment, was the most or one of the most effective of their treatments/regimens for controlling non-native cattail. Several respondents commented that herbicide results were short-term, and a few commented that outcomes were variable (longer-lasting impacts in some wetlands, short-term impacts in others). One respondent observed that herbicide has longer-lasting impacts in newly established basins, and one respondent observed longer impacts in areas with flowing water. Some respondents indicated that repeating herbicide treatment in later years (after observing results of the initial treatment) improved overall outcomes. Some treatment combinations that improved outcomes were herbicide followed by flooding (water level control or precipitation), and herbicide followed by mechanical treatment, with disking and roller-chopping mentioned specifically.

Some additional effective treatments listed by smaller numbers of respondents included repeated annual cattle grazing in small wetlands (with on-going treatment required to keep subsequent invasion of reed canarygrass under control), drawdown and tillage, roller-chopping (short term results), scraping, winter burning (short-term results), and a combination of treatments (unspecified, as opposed to a single type of treatment). Another effective treatment was managing for muskrat herbivory (e.g., drawdown to allow germination of emergent vegetation, followed by gradual transition to high water levels to support muskrat reproduction and overwintering habitat.

Some respondents specifically discussed which treatments tended to last the longest. Observed treatments with longest-lasting impacts were scrapes, aerial herbicide followed by roller chopping (preferably preceded by drawdown and followed by flooding), and prescribed burning followed by flooding.

Some respondents discussed most-effective treatments for floating cattail mats specifically. Aerial herbicide was usually listed as the most effective treatment in this case, sometimes in combination with other follow-up treatments for best outcomes. A common goal was to both kill the floating cattail plants and sink or otherwise destroy the mats, which interfere with water level control and may eventually be recolonized by live cattails, and a few respondents mentioned variable results regarding whether cattail mats sink after herbicide treatment. One respondent commented that floating mats can eventually sink if the water is deep enough and the area treated with aerial herbicide is large enough. Other respondents observed that follow-up treatment with an amphibious vehicle (i.e. Cookie Cutter or Swamp Devil®) to chop up the mat, flooding after herbicide treatment, or repeated herbicide treatments promoted mat sinking/destruction. One respondent observed that prescribed fire improved outcomes of aerial herbicide on cattail mats, but another observed that prescribed fire made outcomes worse. One respondent reported good results from aerial spraying, followed by flooding to put cattail in a floating state such that mats would gather at the basin outlet, followed by removal with a backhoe.

Role of dead cattail

The effect of removing dead cattail (dead, standing cattail and cattail litter) via prescribed burns was a topic that appeared sporadically among different question responses, and was interesting because different respondents had differing observations. Respondents commented that prescribed fire does not usually kill live cattail, but can be used to remove dead, dry cattail litter, or to create openings in dead stands following herbicide treatment. Respondents have tried burning to remove litter before herbicide treatment, after herbicide treatment, and after mowing. Three respondents observed that removing biomass after herbicide treatment simply allows cattail to recolonize the area faster. Another respondent was undecided, given the role that dead cattail may play in suppressing both new cattail growth and native vegetation with potential to compete with new cattail: "Post herbicide treatment thatch is either a blessing or a curse and I don't have enough data to decide. It doesn't lay down and so the native seed bank doesn't express itself for up to 2 years. On the other hand, it may be delaying the germination of cattail seed. Where the thatch is removed or leveled the natives come in much faster and provide cover and competition."

Challenges to implementing the most effective treatments

We asked, "What is the biggest challenge to implementing the most effective treatment(s) for non-native cattail?" The question was multiple choice with multiple selections possible, and an option to write in another challenge not covered by the provided answer choices. Response options included the most effective treatments being time consuming for staff, being expensive compared to less effective treatments, requiring particular field/weather conditions, and requiring equipment that is difficult to access. Of the 43 respondents who answered the question, most (75%) indicated that need for particular field/weather conditions was one of the biggest challenges (Fig. 3). Similar numbers of respondents (around 40%) indicated the most effective treatment was time-consuming, expensive, and required equipment that was difficult to access (Fig. 3). "Other" challenges included inability to apply herbicide on large-scale projects that involve tribal partners (in the context of herbicide being observed as the most effective treatment for larger scale treatments); scheduling challenges when trying to apply multiple treatments in combination; reviews and permits for herbicide application and for Swamp Devil® treatments; and avoiding herbicide safety/exposure issues with herbicide applied via ground equipment (e.g. Marsh Master®).

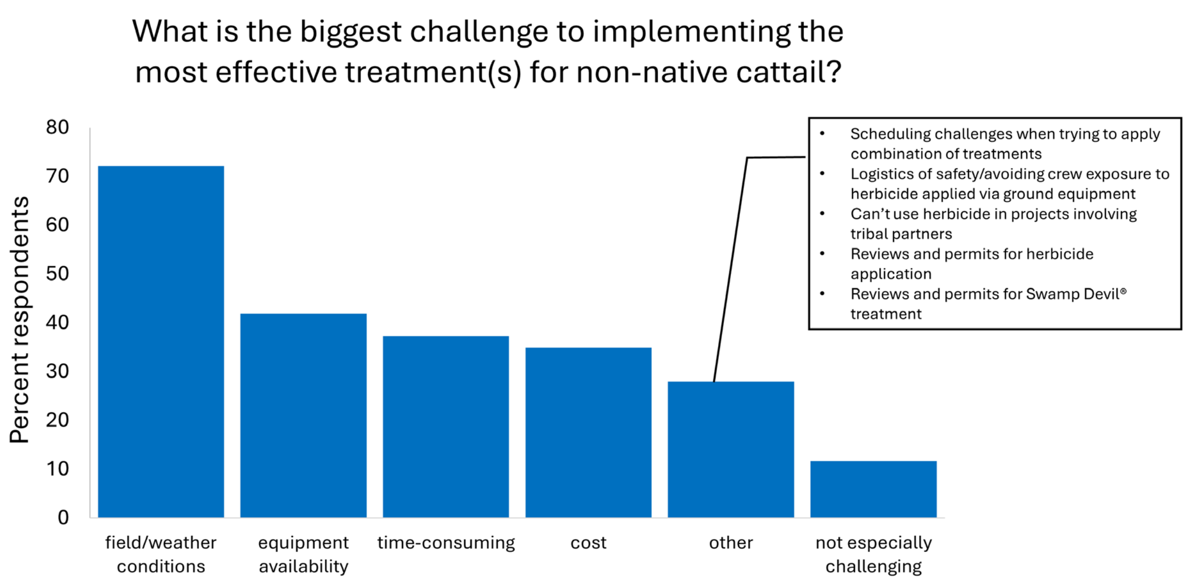


FIGURE 3. PERCENT RESPONSES TO THE MULTIPLE-CHOICE QUESTION, "WHAT IS THE BIGGEST CHALLENGE TO IMPLEMENTING THE MOST EFFECTIVE TREATMENT(S) FOR NON-NATIVE CATTAIL?" IN A SURVEY OF MN DNR WILDLIFE SECTION STAFF WHO MANAGE NON-NATIVE CATTAIL AS PART OF THEIR WORK (N=43 RESPONDENTS ANSWERED THE QUESTION). VALUES ADD TO GREATER THAN 100% BECAUSE RESPONDENTS COULD SELECT MULTIPLE ANSWER CHOICES. DATA UNDERLYING THIS FIGURE ARE IN TABLE S4. FREE RESPONSE DESCRIPTIONS SPECIFYING "OTHER" CHALLENGES ARE SHOWN IN THE TEXT BOX (OR REFER TO MAIN TEXT OR CAPTION OF TABLE S4).

Information needs

We asked respondents about information needs related to research and monitoring of non-native cattails and cattail management. Respondents described a variety of topics, ranging from general (e.g., effective methods for treating cattail) to specific (Table 3). Respondents indicated need for information about most effective cattail treatments in various types of wetlands/situations, including temporary wetlands, seasonal wetlands, semi-permanent wetlands, shallow lakes, impoundments, shallow wetlands with managed water levels, outlets, floating cattail mats, and varying wetland shoreline ownership situations. Treatment longevity and vegetative, invertebrate, waterfowl, and other wildlife responses to treatment were also listed as information needs. Respondents described need for information about whether various factors influence wetland susceptibility to invasion and/or treatment outcomes, including soil chemistry, water chemistry, nutrient enrichment, pesticide from agricultural run-off, and potential gaps in native plant communities. Some respondents wondered about the effectiveness of removing the duff layer (via e.g. burning or scraping) in releasing native vegetation seed bed versus promoting faster recolonization of cattail. One respondent indicated that it would be useful to investigate what tools MN DNR should invest in to treat cattail successfully, including on remote sites. Respondents described information needs about several different treatments and combination treatments (e.g. herbicide followed by Swamp Devil®/Cookie Cutter, fire, or roller-chopping in shallow lakes; physical barriers to floating mats at outlets; and prescribed burning of cattail bogs). There were numerous questions about herbicide, including evaluation of results of MN DNR's large-scale aerial spraying program, effectiveness of glyphosate versus imazapyr, and potential for impacts of pesticide and/or surfactants on ecosystem health, wetland hydrology, water quality, wetland wildlife, vegetation communities, amphibians, and pollinators. Respondents also described information needs pertaining to the role of muskrats in setting back cattail, including whether muskrats help maintain openings in cattail, whether populations have declined to the extent that some wetlands are no longer within reach of population cores, and whether transplanting muskrats would extend the benefits of other cattail treatments.

One respondent made the important point that most-effective treatments will ultimately vary with the specific conditions of individuals wetlands and require adaptive management with manager insight. However, research can provide support by looking for patterns or "guidelines" that managers can work from: "Again, for best results, I think we'll need to work out combinations/regimes, and those are likely going to need to vary from basin to basin. I'm not sure how many times I've mentioned this to folks, but if you take Dr. Leigh Fredrickson's wetland ecology and management workshops, the main take home lesson will be that there are no silver bullets to wetland management as every basin is it's own system. There's no recipe card. You have to look at the conditions of that specific basin, try something and then adapt as needed. That said, there's definitely room for guidelines, and we need to start trying new approaches and building those guidelines."

TABLE 3. INFORMATION NEEDS IDENTIFIED BY WILDLIFE SECTION STAFF WHO MANAGE NON-NATIVE CATTAIL AS PART OF THEIR WORK (N=31 RESPONDENTS ANSWERED THE SURVEY QUESTION).

Information need	Notes
Methods to effectively treat cattail in wetlands	Variations on this topic were: -methods that are cost-effect and timely -methods that lend to long-term effectiveness -cost-benefit information -impacts on wildlife and wildlife responses to various treatments

Information need	Notes
	-effective methods of treatment and follow-up treatment -effectiveness and costs of treatment with respect to various types of sites (e.g., WMA vs. private shoreline on a shallow lake)
What tools do we need to invest in to treat cattail successfully, including on remote sites?	
How does soil and water chemistry affect non-native cattail?	
Role of nutrient enrichment in cattail invasion, and methods/impacts of N and P reduction before cattail treatment	
Role of pesticides from run-off in cattail invasion	
Are we losing or missing aspects of the plant community that are allowing non-native cattail to invade?	
Long-term effectiveness of different treatments in cattail-choked seasonal wetlands	
Most effective cattail management methods in temporary, seasonal, and semi-permanent basins	Specific topics include: -how long do treatments last? -how do treatments differ in terms of vegetative responses, invertebrate responses, and wetland use by waterfowl and other wildlife?
Most effective methods to treat floating cattail mats (which may differ from rooted cattail in terms of treatment effectiveness and longevity)	Variations on this topic included: -effective approaches in floating bog wetlands where flooding is not possible -effective approaches for large floating mat complexes -effectiveness of burning cattail bogs during drawdown, allowing the bog to smolder such that roots are consumed. (Respondent commented that bog would likely burn similar to peat, and that such burns in the past likely created some

Information need	Notes
	of the open water areas in their region, but that policy would prohibit allowing the burn to smolder.) -Effectiveness of reseeding dead cattail mats with native marsh forbs and grasses Note: variations on this question came from respondents in various areas of the state, and appropriate treatments/treatment effectiveness may vary in different geographical regions, e.g., cattail bogs in the northwest region of Minnesota versus floating mats farther south
Most effective treatments and treatment timing in shallow wetlands with managed water levels?	
What treatments or combination of treatments work best in shallow lakes, given different lake characteristics?	Respondent commented that documentation of treatment results is difficult to acquire and has been minimal
Does physical disturbance following herbicide treatment improve outcomes in shallow lakes?	Particular physical disturbances mentioned included Swamp Devil®/Cookie Cutter on floating mats, and fire and roller-chopping during drawdown, possibly combined with water level rise to drown cattail afterward
Effective treatment methods at wetland/lake outlets to maintain water flow	Variations on this topic included: -treatments besides herbicide -treatments for floating mats (bog poles, floating barriers, structures with different fish-finger designs) Respondent commented that most effective outlet treatments might be largely site-specific
How to manage cattails for wetland wildlife in impoundments?	Respondents commented that many MN DNR wildlife impoundments were constructed over 50 years ago, often on organic soils, and that impoundments are highly altered wetlands with different ecological and successional processes taking place compared to other wetlands. In the northwest region, floating sedge peat mats in particular make impoundments different from other cattail-dominated wetland system.

Information need	Notes
	Impoundment-related topics: -What unique ecological processes are taking place as impoundments age and succession occurs? (This information can be used to figure out how to best work with those processes to manage for wetland wildlife.) -Longevity of cattail treatments -Vegetative responses to cattail treatments -Wildlife use in relation to cattail treatment -Water chemistry changes in response to treatment. (In particular, does killing large amounts of cattail in a short time period send large amounts of nutrients downstream?)
What problems does non-native cattail create in southeast areas of the state with more rivers and streams (as opposed to lakes and wetlands)?	
Information relating to herbicide application	Specific variations on this topic included: - Evaluation of DNR aerial herbicide spraying program results. A respondent noted that DNR has been conducted aerial spraying for 10 years, and that managers need to know if they should continue aerial spraying. -effects of wetland condition and timing of application on herbicide treatment outcomes -effectiveness of glyphosate vs. imazapyr -long-term (e.g. 10-year) results of herbicide treatment -impacts of herbicide application on ecosystem health -impacts of herbicide application on wetland hydrology -impacts of herbicide treatment on water quality -impacts of herbicide treatment on wildlife/animals -impacts of herbicide treatment on non-cattail plants and vegetation communities. (Example: information about vegetation community pre-spraying, immediately post-spraying, and 3 years post-spraying) -impacts of surfactants on amphibians and pollinators
Effectiveness of removing duff layer (burning or scraping) in releasing native vegetation seed	

Information need	Notes
bed versus promoting faster recolonization of cattail	
Can fire be an effective tool with proper timing?	
Muskrat population dynamics and management related to muskrats	Variations on this topic included: -Have muskrat populations declined to the extent that some wetlands are no longer within reach of population cores? -Does transplanting muskrats help outcomes last longer post-treatment? -Do muskrats help maintain openings in cattail?
Effectiveness of treatment combinations	
Literature review of cattail treatments	This is part of research staff's usual process when designing research projects. A different format might be more usable for managers.

Discussion/Conclusions

Survey responses indicated that research pertaining to cattail treatment methods would be helpful to MN DNR wetland management work. Over 80% of survey respondents viewed non-cattail treatment as an important management priority due to the problems that non-native cattail creates for wildlife habitat, native plant diversity, water level management, and wetland accessibility for recreationists. Respondents frequently mentioned concerns for waterfowl and wild rice, but also mentioned other wetland taxa. Respondents described a variety of information needs regarding effectiveness of treatments on various types of water bodies, ranging from temporary and seasonal wetlands to larger/deeper shallow lakes and impoundments; a need to evaluate effectiveness of on-going treatments (e.g. DNR aerial herbicide spraying program); and underlying factors impacting treatment effectiveness (such as nutrient enrichment or gaps in native plant communities).

MN DNR Wildlife staff currently use a variety of treatments for non-native cattail, with herbicide (applied via helicopter or amphibious ground equipment like Marsh Masters®) being the most commonly reported treatment. Responses to the question of which treatment(s) is/are most successful varied considerably. Herbicide was commonly listed as the most effective or one of the most effective treatments, but respondents indicated variably longevity of herbicide impacts. Respondents who specifically discussed longevity of treatment impacts said that they observed longest-term results from scrapes, aerial herbicide followed by roller chopping (preferably preceded by drawdown and followed by flooding), and prescribed burning followed by flooding. A wide variety of other most-effective treatments and treatment combinations was reported, possibly in part because staff work on a variety of different water body types in different ecoregions.

Importantly, responses reflected that different treatment types are possible in different water body types. Research studies of treatment effectiveness and cost-benefit analyses in one type of water body (e.g., small seasonal wetlands) would not necessarily be applicable to other types of water bodies (e.g., shallow lakes with floating cattail mats). Information provided by managers in the report was extremely valuable for understanding the benefits and limitations of various treatments in various contexts. Research staff unfamiliar with cattail treatments may find Appendix 1.2 helpful for considering the practicality of various cattail treatments in various wetland types, though updated information specific to study areas of interest should also be sought during study conception.

Knowing management goals is helpful for designing studies that meet management needs and for interpreting research results regarding cattail treatment “success” or “effectiveness”. Reported management goals usually involved increasing open water coverage and decreasing cattail coverage. Respondents also looked for increasing abundance and diversity of native plants (with particular interest in wild rice) and animals (with particular interest waterfowl) as indicators of treatment success. Incorporating response variables measuring these factors into study designs would help produce research results useful to managers. However, survey respondents’ specific goals varied based on starting wetland condition and treatment being applied, such that future researchers will need to the consider the particular wetland types, conditions, and treatments being studied when interpreting study results in terms of “treatment effectiveness”. Overall, respondents indicated that wetlands tend to need retreatment about every six years or more frequently, such that studies following wetlands for at least 4-6 years will likely be needed to compare treatment longevity.

Information about wetland conditions that trigger respondents to treat wetlands for cattail also provides context for planning research. Triggers for treating cattail generally had themes corresponding to management goals (declining open water, high coverage of cattail monocultures), but specifics varied among respondents (e.g. cattail coverage ranging from 50-100%, observed impacts to wild rice, outlet blockage, or wetland bird use). Given this variation, and because wetland starting conditions may impact research outcomes, researchers should ask managers about typical pre-treatment wetland conditions for specific study areas, wetland types, and treatment regimes of interest when planning new studies.

In addition to describing biological “triggers”, respondents pointed out that time, funding, equipment availability, and weather/ground conditions were all limiting practical factors, such that they needed to prioritize which wetlands received treatment. Field/weather conditions for treatment application was the most frequently listed challenge to applying most-effective treatments, followed by equipment availability, staff time required to apply treatments, and cost. Consideration of whether various treatments are realistic to apply at broad scale, or what types of financial investment (equipment purchases, increased staffing) would be necessary for broad-scale application, would help ground study results in a practical context. However, more challenging or costly treatments might still be useful for select priority wetland if results are long-lasting.

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Literature Cited

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. E. Klug, D. J. Larkin, B. A. Lawrence, G. Linz, J. Marburger, G. Noe, C. Otto, N. Reo, J. Richards, C. Richardson, L. R. 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, Ecosystem Services, and Management. Wetlands 39:645–684.

Fitzpatrick, M., E. Zlonis, J. Maile, A. Kleinschmidt, S. Kvidt, J. Rambow, S. Vacek, S. Salvevold, D. Larkin. T. Arnold, S. Ellis-Felege. 2024. Ecological responses and efficacy of cattail treatment methods. Minnesota Department of Natural Resources Phase II Wildlife Research Proposal. 58 pp.

Kantrud, H. A. 1986. Effects of vegetation manipulation on breeding waterfowl in prairie wetlands - a literature review. Fish and Wildlife Technical Report 3. Washington, D.C. 15 pp.

Appendix 1.1 Survey Questions

Introduction

The survey was organized into blocks by topic, designated here by blue text at Heading Level 3. Survey questions are in **bold text** and coded parenthetically as followed: f = free response; m1 = multiple choice, one selection possible; mm = multiple choice, multiple selections possible; yn = yes/no. Additional regular font text describes survey flow.

For multiple choice questions, the response options are shown under the question in bold text. Where “Other” was listed as an answer choice, a follow-up free response question asked the respondent to specify further.

Questions

Respondent Information

1. What is your name? (f)

2. What group/program do you work for? (m1)

- **Area Wildlife staff**
- **Shallow Lakes Habitat Program**
- **Wetlands Habitat Program**
- **Other**

3. May we contact you (via work e-mail) if we want to learn more about your non-native cattail treatment observations? (yn)

Where is cattail management important?

4. In which Wildlife Area do you usually work? (Select more than one if you work regularly in multiple Wildlife Areas.) (m/m)

5. Is non-native cattail control an important management priority in the Area(s) where you regularly work? (m1)

- **Yes - very important**
- **Yes - moderately important**
- **Yes - minimally important**
- **No - not important**
- **Not sure**

What cattail treatments do you use?

Question 6 was a multi-part question. Respondents were first asked to which cattail treatments they use, with allowance for up to three “other” treatments to be specified in text boxes. Then, for each treatment selected, two follow-up questions appeared, asking about the type of water body and time of year when the respondent typically applied the treatment. An optional free response text box was also provided for any additional comments that respondents wanted to make about the treatment.

6a. What cattail treatment methods do you use? (m/m)

- **Scraping**
- **Herbicide - aerial application**

- **Herbicide - applied from ground equipment (e.g. Marsh Master)**
- **Herbicide - applied by hand (e.g. with backpack sprayer)**
- **Prescribed fire**
- **Cattle grazing**
- **Mowing**
- **Disking**
- **Roller-chopper**
- **"Cookie cutter" or other amphibious vehicle to remove floating cattail**
- **Water level control - flooding (for example, flooding cattail after cutting)**
- **Water level control - drawdown**
- **Other (Please specify)**
- **Another "other" treatment (Please specify)**
- **Yet another "other" treatment (Please specify)**

6b. In what types of water bodies do you typically apply [SELECTION] treatment? (m/m)

- **Small/shallow wetlands (less than approximately 50 acres)**
- **Shallow Lakes (greater than 50 acres but less than 15 feet deep)**
- **Larger/deeper lakes**
- **Rivers**
- **Other**

6c. At what time(s) of year do you typically apply [SELECTION]? (m/m)

- **January**
- **February**
- **March**
- **April**
- **May**
- **June**
- **July**
- **August**
- **September**
- **October**
- **November**
- **December**

6d. Here is an optional space to provide any additional information you want to share about [TREATMENT]. Note, we'll ask which treatment works best in the next section. (f)

7. Do you often conduct multiple repeated treatments or combinations of treatments on the same wetland? If so, please tell us about the most common ways you combine or repeat treatments.

Examples: herbicide in summer, followed by a burn in winter; herbicide two years in a row (f)

Which treatments work best?

8. Which of your treatments or regimens are most effective for controlling non-native cattail?

We are interested in both short-term and long-term effectiveness. (f)

9. What is the biggest challenge to implementing the most effective treatment(s) for non-native cattail? (m/m)

- **The most effective treatment is not especially challenging**
- **The most effective treatment is time-consuming for staff compared to less effective treatments**
- **The most effective treatment is expensive compared to less effective treatments**
- **The most effective treatment requires particular field/weather conditions to apply**
- **The most effective treatment requires equipment that is difficult to get access to**
- **Other**

Management goals

10. What are the biggest problems that non-native cattail creates in your work area?

Examples: wild rice competition, wetland accessibility for waterfowl hunters, habitat for amphibians, waterfowl, marshbirds, fish nursery... (f)

11. What conditions trigger you to treat a wetland for cattail?

Examples: wetland is 95% covered in cattail, particular plant species have disappeared? (f)

12. What are your goals when treating cattail? That is, what do you consider a "successful" outcome?

Examples: 50% open water area and 50% emergent vegetation, particular plant or animal species in the wetland... (f)

13. How often do you find you need to re-treat wetlands to meet management goals? (m/m)

- **About every 1-2 years**
- **About every 3-4 years**
- **About every 5-6 years**
- **About every 7-8 years**
- **About every 10 years**
- **Less frequently than every 10 years**
- **Don't need to re-treat wetlands - results are fairly permanent**

Future studies

14. Do you have any specific information needs related to research and monitoring of cattail management? For example, research questions that you feel should be addressed? (f)

Anything else?

15. Here is a space for any other feedback or information you would like to share with the cattail treatment project research team. (f)

Appendix 1.2 Timing and context for each treatment

Introduction

This appendix includes contextual information cattail treatments, which respondents provided in free-response follow-up questions about each treatment, as well as information about seasonal timing of each treatment.

Treatments

Scraping

Respondents indicated that scraping is conducted in all months except April-May, but June through November were the most commonly listed months (Table A.2.2). Respondents commented that scraping is done at any time of year that conditions allow (e.g., thawed ground, low water levels, and contractors available), but late summer or fall is the preferred timeframe. Respondent comments included that scraping is typically associated with new wetland restorations on former agricultural fields, and that it is typically conducted on very small wetlands (<1 acre). A challenge associated with scraping is finding something to do with the scraped material, which is laden with nutrients. One respondent commented that scraping tends to be the most effective treatment for cattail, but that it is expensive and time-consuming.

Aerial herbicide

Aerial herbicide is applied in June through September (Table A.2.2). Respondents commented that timing of herbicide is dependent on when plant uptake of chemical will be most effective and is largely determined by the statewide coordinator for aerial (helicopter) spraying. Observed best phenology for herbicide application varies annually and varies across the state - a respondent in far northern Minnesota mentioned that bog mats remain frozen until early July in some years, and that later spraying (i.e., after frost in early September) has yielded best results for their Area. One respondent commented that effectiveness varies, and that results last longer with water level control (e.g., flooding in spring and fall following application).

Respondents described some drawbacks of aerial herbicide, including more overspray and impacts on non-target species compared to herbicide applied via ground equipment. Some respondents mentioned tactics to avoid impacting wild rice, including stopping treatment in September and creating odd-shaped spray polygons to work around wild rice interspersed with cattail. Another drawback was being restricted to spraying a large polygon in the middle of a basin as opposed to spraying a more random mosaic to emulate hemi-marsh. Some respondents also mentioned that aerial herbicide treatments are not possible on projects involving tribal partners.

Benefits of aerial spraying included not needing to clean ground equipment (Marsh Master®, etc.) to prevent invasive species spread, which is a difficult task (Table A2.1). Another respondent pointed out that aerial application is the only way to treat floating cattail mats with herbicide, though several respondents mentioned variable results regarding whether floating mats sink following herbicide application.

Table A2.1. Comparative benefits of herbicide application via aerial versus ground equipment

Benefit of aerial application	Benefit of ground application
Can be feasibly applied over large areas	Can target areas too small for the helicopter (e.g. outlets)
Easier to keep ground crews from being exposed to herbicide	Requires less paperwork and coordination
Effective in wet conditions and can be used on floating cattail mats	Can spray irregular shapes to create hemi-marsh conditions
Avoids difficult task of cleaning ground equipment to avoid prevent invasive species transfer	Easier to avoid nontarget species; less overspray

Herbicide application from ground-based equipment (e.g., via Marsh Master®)

Similarly to aerial herbicide, ground-based application is conducted in June through October (Table A.2.2), and respondents wrote that timing is determined by when plant uptake of chemical will be most effective in killing cattail.

Some respondents reported drawbacks of ground-based herbicide application, including safety issues pertaining to crew exposure to chemicals. Marsh Masters® and similar equipment also must be cleaned to avoid invasive species transfer, and the cleaning process is difficult. Another challenge of ground equipment use is that it tends to leave strips of live cattail. That is, herbicide is sprayed off the back of the equipment, and cattail that is crushed by the vehicle treads immediately prior to receiving the spray is not as thoroughly killed as standing cattail. This is particularly true when wetlands have standing water, such that cattails are crushed below water level (which largely shields them from the herbicide), or partially stand back up but remain wet (such that the herbicide is diluted and/or drips quickly off the stems). Outcomes are better in dry wetlands, but kill is still not as thorough as it is in uncrushed areas outside the vehicle tracks. The remaining living cattail in tracks is a source for quicker respread of cattail through the wetland in the years following treatment. Respondents suggested waiting for dry conditions and/or treating wetlands multiple years in a row (with different track lines) to improve outcomes. Finally, treatment with ground equipment is also not efficient at large scales (compared to aerial herbicide) and requires fairly even terrain.

On the other hand, reported benefits of ground-based herbicide application were that it can target more precise areas and smaller wetlands than aerial application. Thus, it can be used to keep outlets clear and create hemi-marsh conditions. Additionally, ground-based application requires less paperwork and coordination than aerial applications.

Herbicide application on foot/by hand (e.g., backpack sprayer)

Similarly to other aerial applied-herbicide and herbicide applied from ground equipment (e.g., Marsh Master®), herbicide applied by hand (e.g., backpack sprayer) is applied in June through October (Table A2.2).

Several respondents noted that hand application is limited to very small areas, and sometimes more focused on facility maintenance than habitat enhancements. Common applications included treatment in small areas around water level control structures, treatments to maintain water flow (small drainages, wetland/shallow lake outlets, culverts, and narrow channels), follow-up spot treatments after other cattail control treatments have been applied, "small pocket" treatments, and preparing bait sites for MN DNR waterfowl banding.

Prescribed fire

April and May were the most commonly listed months for prescribed fire treatment (>80% of respondents), but respondents overall reported use of prescribed fire year-round (Table A2.2).

Several respondents indicated that cattail control is not a primary objective of prescribed fire, especially in the common April-May timeframe, when conditions are typically wet and fire does not effectively burn live cattail in wetlands. Rather, prescribed fire is often focused on prairie enhancement or woody vegetation control, with cattail control a secondary objective at most. One respondent observed that spring burns can have the benefit of creating temporary openings, temporarily improving wildlife habitat. Additionally, the regenerating cattail that grows in the openings which may be more attractive to muskrats than mature stalks, and lead to increased muskrat predation later in the year.

Respondents commented that prescribed fire in fall or winter, when water levels are lower, would be more effective for controlling cattail, especially if fire could be followed by spring flooding. Another respondent described a different approach, summer burns (June-July) in sedge meadows to target cattail while heads are forming. However, respondents indicated that they did not commonly conduct these winter or summer burns to target live cattail.

Though live cattail control is often not a primary objective of prescribed fire, respondents indicated that fire could be useful to remove dead cattail. This can be beneficial in reducing fire fuel load on the landscape. Respondents also suggested that prescribed fire could be applied prior to herbicide treatment to improve herbicide effectiveness, or after herbicide treatment to create openings in the dead stand. Respondents had varying observations about the utility of fire post-herbicide. Three respondents observed that fire after herbicide treatment simply tended to promote faster recolonization of new cattail. Another respondent was undecided, given the role that dead cattail may play in suppressing both new cattail growth and native vegetation with potential to compete with new cattail: "Post herbicide treatment thatch is either a blessing or a curse and I don't have enough data to decide. It doesn't lay down and so the native seed bank doesn't express itself for up to 2 years. On the other hand, it may be delaying the germination of cattail seed. Where the thatch is removed or leveled the natives come in much faster and provide cover and competition."

Another proposed (though not yet implemented) use of prescribed fire was burning herbicide-treated floating cattail mats prior to chopping the mat via Swamp Devil®, to reduce the amount of biomass requiring chopping.

Grazing

Grazing is commonly conducted in June through September but may start as early as April (Table A2.2).

Grazing treatment may be applied to wetlands with varying levels of intensity. One respondent indicated that grazing treatment typically happens in small wetlands that happen to be part of a larger upland grazing unit, as the forage value of cattail alone is not sufficient for farmers to want to graze cattle exclusively on cattail. However, another respondent indicated that fencing could be used to focus grazing pressure on cattail, if using breeds of cattle that will eat cattail. The respondent cautioned that older cattail stalks cause eye hazards and are less palatable to cattle than newer cattail growth.

Other respondents indicated that cattle grazing creates only temporary openings in cattail, and must be done each year, or followed by flooding of grazed stalks, for effective outcomes. One respondent also cautioned that cattle damage wetlands significantly.

Mowing

August and September were the most commonly listed months for mowing (79% and 58% of respondents), but mowing occurs in June through February (Table A2.2). Respondents highlighted the necessity of dry wetland conditions, or solid ice in winter, to prevent mowing equipment from getting stuck.

Respondents shared several approaches to mowing. Some respondents discussed use of fall and winter mowing to set up development of open water areas with rising water levels the following spring, with the aim of benefiting migrating and breeding waterfowl and shorebirds. Results are temporary, with cattail regrowing in the openings as the year progresses. Respondents also indicated that mowing or haying may also be conducted in summer, especially in dry years, with goals of creating waterfowl and shorebird habitat or maintaining wetland access points.

Respondents shared that water levels following mowing influence outcomes, with potential to drown cattail for longer-term results if the cut stems are flooded after mowing. However, they reported varying success with drowning cattail in practice. One respondent indicated that haying consistently over multiple years improved outcomes. One respondent reported that mowing in their area was primarily conducted to keep trees out of newly restored wetlands, with a side benefit of mild setbacks to young cattail.

Disking

Respondents reported disking in July-December, with August being the most commonly reported month (Table A2.2). Respondents emphasized that disking can only occur during dry conditions to prevent equipment from getting stuck and may be conducted opportunistically when dry conditions occur. Disking is usually conducted on small/shallow wetlands, but one respondent reported an experimental disking treatment following a drawdown on a shallow lake, with the intent of disking up buried seeds of native vegetation. Disked plots were the only areas where cattail didn't grow following reflooding.

Roller chopping

Respondents reported roller-chopping in June through October, with September being the most commonly reported month (Table A2.2). Respondents indicated that roller chopping requires drier conditions or appropriate equipment to pull the roller chopper in wet conditions (e.g., a Marsh Master®). Some respondents indicated that this is a newer treatment for them (i.e., tried on one or a few wetlands), with one respondent describing positive results in terms of opening habitat for blue-winged teal

Amphibious vehicle to remove floating cattail (e.g., "Cookie Cutter")

Respondents reported using amphibious vehicles (Cookie Cutter, Swamp Devil®) to remove floating cattail mats in April through October, with June through August being the most commonly listed months (Table A2.2). Respondents reported that there is one shared Swamp Devil® used statewide, so machine availability heavily impacts frequency and timing of this treatment. Additional challenges to using the Swamp Devil® included the need for either a developed access site or support from a crane (which is logistically challenging and expensive) to get the machine in and out of the water body, and the need for water deep enough to float the machine. One respondent commented that they found the cost to benefit ratio impractical.

Several respondents commented that they typically target or plan to target floating mats of dead cattail that fail to sink following aerial glyphosate treatment. Respondents commented mechanical treatment is needed because mats of floating cattail mats often don't sink after herbicide treatment and thus continue clogging outlets, covering open water habitat, damaging wild rice, and serving as a substrate for cattail re-invasion. Some respondents focus Swamp Devil® treatments on smaller areas, like outlets rivers, and ditches (to maintain water flow), water control structures, or boat access areas. Another respondent discussed treating bog mats to create hemi-marsh conditions in former open water areas.

One respondent discussed options for managing the "dead cattail slurry" left behind after chopping herbicide-treated floating mats. In the context of treating outlets, their preferred option was to chop mats in spring following a winter with high snowpack, such that high water would flush away some of the dead material. Alternately, they suggested use of a harvester to collect chopped material behind the Swamp Devil®, with material to be deposited in existing spoil banks or other areas (which would need to be identified in the permitting process).

Drawdown and flooding

Drawdown and flooding were often discussed in reference to each other in free response questions, so we describe them together here.

Flooding and drawdown were reported in all months of the year; however, flooding was most frequently listed in April-June, and drawdown was most frequently listed in Jun through November (Table A2.2). For some wetlands, respondents manage water levels artificially. For other wetlands, they take advantage of seasonal low (summer-fall-winter) and high (spring) water levels. A common comment was that water level control of cattails can be thwarted by weather/precipitation conditions.

Many respondents discussed drawdown and flooding together as part of a process: drawdown (or reliance on seasonal low water levels) to apply a treatment for cattail (e.g., cutting, mowing, disking, roller-chopping), followed by flooding (or reliance on high seasonal water levels) over cut or smashed stems to drown the plants. Some respondents also discussed use of drawdown and flooding cycles to promote muskrat herbivory, i.e., drawdowns to regenerate emergent vegetation forage (including cattails), followed by high water levels to promote muskrat breeding and overwintering.

Flooding in and of itself was not discussed as a cattail control measure, but one respondent reported flooding cattail mats after they lose buoyance due to herbicide treatment.

A few respondents mentioned that drawdown in and of itself tends to promote cattail growth. In fact, one respondent described the use of drawdown to encourage emergent vegetation growth (which is often cattail) to stabilize lake shorelines. Typically, drawdowns are conducted for management purposes not directly related to cattail, such as fish (e.g. carp) kill, sediment consolidation, and germination/rooting of vegetation. On the other hand, two respondents pointed out that drawdowns create appropriate conditions for other aquatic plants that may compete with cattails.

Table A2. 2. Months of the year in which respondents report conducting cattail treatments, from a survey of MN DNR Wildlife section staff who manage non-native cattail as part of their work. Values are percent of respondents reporting each month, out of the total number of respondents who report conducting that type of treatment (last column).

Treatment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	number respondents conducting treatment
Scraping	13	13	13			38	63	75	50	38	50	25	8
Herbicide - aerial application						10	62	88	24				42
Herbicide - applied from ground equipment (e.g. Marsh Master)						15	70	88	28	3			40
Herbicide - applied by hand (e.g. with backpack sprayer)						33	81	86	19	5			21
Prescribed fire	6	3	20	80	91	43	17	34	40	29	14	14	35
Cattle grazing				10	60	90	100	100	80				10
Mowing	11	11				16	37	79	58	37	32	21	19
Disking							44	78	67	56	33	22	9
Roller-chopper						31	62	69	92	23			13
'Cookie cutter' or other amphibious vehicle to remove floating cattail				22	52	70	70	70	48	22			23
Water level control - flooding (for example, flooding cattail after cutting)	7	10	38	66	69	66	48	38	41	34	17	7	29
Water level control - drawdown	34	38	45	41	48	59	59	52	59	62	52	45	29

Supplemental Tables

Table S1. Percent respondent responses to the multiple-choice question, ““Is non-native cattail control an important management priority in the Areas where you regularly work?” in a survey of MN DNR Wildlife Section staff who manage non-native cattail as part of their work (n=51 respondents).

Answer choice	Percent respondents
Yes – very important	43%
Yes – moderately important	45%
Yes – minimally important	10%
No – not important	2%

Table S2. How often practitioners need to re-treat wetlands for non-native to meet management goals, from a survey of MN DNR Wildlife Section staff who manage non-native cattail as part of their work (multiple choice question). Table shows the percent of respondents (n=43) who selected each individual answer choice. Values sum to greater than 100% because respondents could select more than one answer choice.

How often wetlands need to be retreated	Percent respondents
About every 1-2 years	33%
About every 3-4 years	72%
About every 5-6 years	44%
About every 7-8 years	12%
About every 10 years	7%
Less frequently than every 10 years	5%
Don’t need to re-treat wetlands - results are fairly permanent	2%

Table S3. How often practitioners need to re-treat wetlands for non-native to meet management goals, from a survey of MN DNR Wildlife Section staff who manage non-native cattail as part of their work (multiple choice question). Table shows the percentage of respondents (n=43) who selected each combination of answer choices. Where respondents chose several consecutive options, combination labels are abbreviated. For example, if a respondent chose “about every 1-2 years” and “about every 3 to 4 years”, the combination is labeled “1-4 years”.

How often wetlands need to be retreated	Percent respondents
Every 3-4 years	23
Every 1-4 years	19
Every 3-6 years	16
Every 5-6 years	16
Every 1-2 years	7
Every 3-8 years	5
Every 1-8 years	2
Every 1-10 years	2
Every 1-2 years to less frequently than every 10 years	2
Every 3-4 years or every 10 years	2
Less frequently than every 10 years	2
Don't need to re-treat wetlands - results fairly permanent	2

Table S4. Percent responses to the multiple-choice question, “What is the biggest challenge to implementing the most effective treatment(s) for non-native cattail?” in a survey of MN DNR Wildlife Section staff who manage non-native cattail as part of their work (n=43 respondents answered the question). Values add to greater than 100% because respondents could select multiple answer choices. Respondents added free-response descriptions when they selected the “other” option. “Other” challenges included inability to apply herbicide on projects involving tribal partners (in the context of herbicide being observed as the most effective treatment for larger scale treatments); scheduling challenges when trying to apply multiple treatments in combination; reviews and permits for herbicide application and for Swamp Devil® treatments; and herbicide safety/exposure issues with herbicide applied via ground equipment (e.g. Marsh Master®).

Challenge	Percent respondents
Field/weather conditions	72
Equipment availability	42
Time-consuming	37
Cost	35
Other	28
Treatment is not especially challenging	12