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Impacts Of Cattail Management Techniques On Plant, Bird, Amphibian, And Invertebrate Communities In Shallow Wetlands Of Northwestern Minnesota

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IMPACTS OF CATTAIL MANAGEMENT TECHNIQUES ON PLANT, BIRD, AMPHIBIAN, AND INVERTEBRATE COMMUNITIES IN SHALLOW WETLANDS OF NORTHWESTERN MINNESOTA

by

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This thesis, submitted by Joshua J. Bruggman in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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ABSTRACT

Wetlands in the United States have been considered both an impediment to progress and a valuable asset for ecosystem services. As a result, rapid loss and degradation of wetlands has occurred and many attempts to protect and restore wetlands are now occurring. However, invasive species continue to challenge wetland management efforts. Cattails (*Typha* spp.) are invasive plants that can dominate a wetland once they become established. There are two species of cattails in the Northern Great Plains, broad-leaf (*Typha latifolia*) and narrow-leaf (*Typha angustifolia*) cattail. These two species can cross to produce a robust, hybrid cattail (*Typha x glauca*) that has become an increasing problem in wetlands. Over time, they can make the wetland become “cattail-choked”, excluding many native plant and wildlife species. Therefore, we sought to answer the question of what management techniques used to control cattails not only reduce them, but also which methods benefit both native plants and wildlife. Our study focused on 23 shallow wetlands at Glacial Ridge National Wildlife Refuge in northwestern Minnesota. We explored the effects of the treatments mowing, fire, chemicals, and the combination of chemical x fire on reducing cattails and promoting native flora and fauna. We collected baseline information in the summer of 2014 followed by management applications in the fall of 2014 and then two years of post-treatment data were collected in 2015 and 2016. We found that the use of chemicals (glyphosate) reduced the percentage of live cattail, while fire increased the percentage of live cattail. All other species of vegetation were impacted negatively by chemical x fire and little by the other treatments. Overall bird species richness was not influenced by the treatments, likely due to some species benefiting from the treatments, while others did not. We analyzed the response to treatments of five individual bird species, marsh wren (*Cistothorus palustris*), sedge wren (*Cistothorus platensis*), swamp sparrow (*Melospiza georgiana*), red-winged blackbird (*Agelaius phoeniceus*), and common yellowthroat (*Geothlypis trichas*). Marsh wren abundance decreased following the use of chemical and fire. Sedge wrens increased after fire. Swamp sparrows generally benefited from all of the treatments. Red-winged blackbird abundance decreased after the use of chemical, but increased after chemical x fire was applied. Common yellowthroats decreased one-year post-treatment followed by an increase two- years post-treatment. Amphibian species richness was not impacted by the treatments. Boreal chorus frog (*Pseudacris maculata*) abundance did not change relative to treatments; however, we did observe an increase from mowing. Dragonfly and damselfly abundance was not impacted by the treatments statistically. We did, however, observe a percent decrease after fire and chemical x fire for dragonflies. Our results show the best control method for reducing cattails is a combination of fire and chemical; however, the wetland system is complex with members of the community impacted differently by different treatments.

CHAPTER I

LITERATURE REVIEW OF CATTAIL (*TYPHA SPP.*) MANAGEMENT

INTRODUCTION

History of Wetlands

Wetlands are an integral part of North America's landscape, despite historical and current challenges that have diminished their extent. Over the years, wetlands have often been regarded as swamplands that served no purpose and were impediments to progress. Technological advancements took a toll on wetlands as they were drained, cleared, and farmed (Dahl and Allord 1996). During the 1930's, the United States government provided services to drain wetlands. By the 1960's, many financial, political, and institutional incentives to drain wetlands were in place (Dahl and Allord 1996). One example is the Watershed Protection and Flood Prevention Act of 1954 which in some ways contributed to the drainage of wetlands for flood control purposes. In the 1970's, awareness of ecosystem services provided by wetlands increased and laws to stop the conversion of wetlands, like the Federal Emergency Wetland Resources Act of 1986, helped slow this conversion. Dahl and Allord (1996) estimated that there were more than 40 million hectares of wetlands remaining in the U.S. as of 1996. In 2009, it was estimated that there were 44.6 million hectares of wetlands in the U.S. (Dahl 2010). Even though there have been gains in wetlands, an estimated 25,200 ha were lost from 2004–2009. The rate of wetland conversion has slowed, but losses continue even with wetland gains (Dahl and Allord 1996).

Soon after the implementation of the Federal Emergency Wetland Resources Act, states took their own actions to slow the alteration of wetlands (Dahl and Allord 1996). In Minnesota, losses are estimated to be over 52% of the original wetlands due to the development of roads, farmland, and housing (Minnesota Department of Natural Resources [MN DNR] 2016). Similar estimates occurred in North Dakota with approximately 45% of wetlands lost since the 1980's (USGS 2013). In both states, these losses are due, in part, to aforementioned advances in equipment and drainage for the purpose of agricultural development.

Prairie wetlands provide important ecological functions and ecosystem services. For example, wetlands filter excess nutrients and pollutants, provide erosion and flood control during heavy rain events, and are a groundwater re-charge source (McCauley et al. 2015). Moreover, wetlands provide wildlife and fish habitat during various life stages. These benefits, in combination with their ability to be used for recreation, income, and education, make wetlands a valuable resource (MN DNR 2016). These benefits can be diminished not only through human degradation, but with invasive species that reduce the function and quality of wetlands (Galatowitsch et al. 1999).

Invasive Species

What constitutes an invasive species? Alpert et al. (2000) defines "invasive species" as organisms that spread in space and have negative impacts in the new environment. Invasive species, under the right circumstances, can cause economic, environmental, or human harm (NRCS 2015). A species that is non-native may not be considered invasive if it does not negatively impact its new habitat (Boa 2013). Plants that are native to an ecosystem are considered native if found prior to European settlement (Brooks and Wardrop 2013). A native species can also become invasive if changes in an environment cause it to become a problem (Alpert et al. 2000). Cattails (*Typha spp*.) are a wetland plant that may be considered either native or non-native. In shallow wetlands, cattails (native and non-native) can destabilize local aquatic plant and animal diversity, reduce open water, and degrade habitat for many native plant and wildlife species (Murkin et al. 1982).

In Minnesota and North Dakota, there are two types of cattail; broad-leaf (*Typha latifolia*) and narrow-leaf (*Typha angustifolia*) cattail. Broad-leaf cattail is native to North America, whereas narrow-leaf cattail is usually considered non-native (Shih and Finkelstein 2008) with a European origin. However, early records, along with pollen and herbarium data, suggest that narrow-leaf cattail was present on the eastern seaboard during European settlement and from there it spread north and west with settler expansion (Shih and Finkelstein 2008). Thus, narrow-leaf cattail may be native to North America, but was not widespread at the time of settlement. Along with these two species, there is a cross between the two, hybrid cattail (*Typha x glauca*), that can occur. As narrow-leaf spread, hybrid cattail began to appear. Although initially considered sterile, Smith (1967) found hybrid cattail can produce functional pollen grains, allowing it to backcross with narrow-leaf cattail. These species not only can reproduce from seed, but by rhizomes as well, thus allowing these species to be invasive under favorable conditions (Shih and Finkelstein 2008). Hybrid cattail mainly reproduces from rhizomatous growth.

Restoration efforts informed by science have improved how we manage wetlands. A principal objective of the Clean Water Act (CWA) of 1972 is to restore and maintain the chemical, physical, and biological integrity of our nation's wetlands (Zedler 2004). The CWA established the basis for regulating pollutants that enter waters in the U.S. and regulates quality standards for surface waters (EPA 2016). There is a provision of "no net loss" to mitigate future wetland losses. In wetlands still intact, many techniques have been used to manage those dominated by stands of cattail. Water level manipulation, prescribed fire, and chemical treatment can all be effective means of cattail control (Murkin and Ward 1980, McWilliams et al. 2007). The use of cattle to graze stands of cattail was found to be an effective means of control in South Dakota wetlands (Schultz et al. 1994). Mowing and disking also has been used for cattail management. Of these techniques, a single management type alone may not be effective at controlling cattails. Resource managers are actively searching for the most effective combination of cattail control methods that include both economic and biotic response considerations. Due to anticipated climate and agricultural changes, the need to manage intact landscapes for healthy prairie wetland complexes that can provide a full host of life history needs is imminent and critical. Climate change will make future restoration and management efforts in wetlands difficult by altering hydrology (Erwin 2009). Research is needed to determine long-term effects of cattail removal or reduction treatments, especially how it relates to treatment timing, longevity, effectiveness, and cost. Effects of cattail control and responses of native plant and animal communities to these treatments must also be determined.

TYPES OF MANAGEMENT AND THEIR ECOLOGICAL IMPACTS

Chemical

Of the various types of management employed to control invasive cattails, chemicals are used most frequently (Table 1). Glyphosate and other herbicides were applied in Washington at three different rates and at three different growth stages of cattails (early July, mid-August, and mid-September) to assess which timing is best to spray (Comes and Kelley 1989). During mid-August, glyphosate, dalapon, and amitrole were applied to compare effects against glyphosate–only treatments. Chemicals were applied with an amphibious tracked vehicle. Glyphosate inhibited the emergence of cattails in the spring and early summer of the year following treatment. As the rate of glyphosate increased, the amount of cattails decreased. This was also affected by the different stages of cattail stand maturation. Chemicals applied at later stages of development had the greatest effect on cattails. The volumes at which glyphosate was applied did not matter, as all provided 90% reduction. Dalapon and amitrole both reduced cattails by 34–92%, but of the three chemicals, glyphosate controlled cattails the best. An application rate of 3.3 kg/ha of glyphosate was as good as or better than either dalapon (22 kg/ha) or amitrole (8.8 kg/ha) at reducing cattails (Comes and Kelley 1989).

In the Florida Everglades, Imazamox was used to control southern cattail (*Typha domingensis*) while trying to reduce harm to other native vegetation (Rodgers and Black 2012). This chemical was aerially applied at three different rates (0.28, 0.14, 0.07 kg/ha).

Twelve months after this chemical was applied at a rate of 0.28 kg/ha, it provided excellent control of southern cattail (99%) with little damage to desirable native vegetation (Rodgers and Black 2012).

Solberg and Higgins (1993) evaluated the use of Rodeo (glyphosate) to create openings in South Dakota wetlands. A fixed-wing aircraft was used to apply glyphosate at a rate of 2.8 L/ ha in July and August of 1985 and 1986. Wetlands ranging in size from 1.8–6.1 ha and classified as cattail dominant with 95–100% cattail coverage were selected (Solberg and Higgins 1993). In 1985, just the effects of glyphosate on cattails were measured while in 1986 the spray pattern was also assessed by comparing single-strip patterns and cross-strip patterns. The spray pattern influenced the degree of interspersion with the cross-strip pattern producing a greater cover to water ratio than the single-strip pattern. The number of live cattail stems was reduced by 99.7% one year after the application of Rodeo. Two years after the herbicide treatment, sprayed portions of the wetlands were dominated by bladderwort (*Utricularia vulgaris*). The total cost for using Rodeo in 1986 was $201.05/ha (Rodeo cost $25.10/L, surfactant cost $1.32/L) with $24.71/ha for the application (Solberg and Higgins 1993). The treatment reduced cattails with the effects lasting about two years. For maximum benefit, they recommended applying Rodeo during peak growth in mid-late summer (Solberg and Higgins 1993, Messersmith et al. 1992). Solberg and Higgins (1993) also looked at effects on waterfowl pairs. They found the total number of breeding pairs of waterfowl did not differ between treated and open water or cattail dominated control wetlands. However, wetlands with a cross-strip pattern of spraying had greater pair densities than the single-strip pattern with waterfowl pair densities greater in treatment wetlands than in the two control types (Solberg and Higgins 1993).

Linz et al. (1996a) compared densities of ducks in wetlands treated with various herbicide spray volumes and evaluated how this relationship differed between ducks and wetland variables in North Dakota. Three different spray volumes of glyphosate (50%, 70%, and 90%) were used to treat wetlands in mid-late July, 1990 and 1991 using a fixed-wing aircraft to spray a 15-m wide strip. A total of 17 wetlands were analyzed with an average wetland size of 11.4 ha. Wetlands were sprayed in mid-late July at a rate of 5.8 L/ha with glyphosate. Open water was increased in treatment wetlands compared to controls while dead vegetation was greater one year after the treatment was applied in treatment wetlands compared to the reference. By reducing the amount of live cattail, the number of ducks increased. Ducks favored the 50% sprayed wetlands more than other treatment levels. Diving ducks preferred wetlands with more open water. This ratio of open water to vegetation has been suggested to provide optimal habitat for invertebrates, which can then be related to waterfowl foraging (Murkin et al. 1982). In a shallow wetland with a lower spray volume, cattails can re-sprout in two years if there is no standing water covering dead stems. In this case using a higher spray volume can have longer lasting effects on the wetland.

A feature of cattail-dominated wetlands is the tendency for them to hold large numbers of migrating blackbirds (*Icteridae* spp.). This can be problematic for landowners who raise sunflowers as a crop because large flocks of blackbirds can have a devastating effect on these and other crops. Linz et al. (1992) assessed the use of Rodeo to disperse migrating blackbirds in cattail-choked wetlands. Between 1989 and 1990, eight wetlands were selected, four sprayed in August and September of 1989 and four in August of 1990. This treatment was applied with a fixed-wing aircraft that applied Rodeo at a rate of 5.8–7.0 L/ha in 1989 and a rate of 4.7 L/ha in 1990 (Linz et al. 1992).

Live cattail densities from quadrat surveys were 87% lower in 1991 than the pre-treatment densities in 1989 (Linz et al. 1992). Cattail densities in wetlands sprayed in 1990 were also significantly lower. As for effects on blackbirds (*Icteridae* spp.), densities were reduced from 12,720 prior to treatment to none one-year post treatment and to 12 birds two years post treatment (Linz et al. 1992). Other species such as marsh wren (*Cistothorus palustris*) and rails (sora, *Porzana carolina* and Virginia rail, *Rallus limicola*) also decreased significantly from wetlands treated in 1989. The use of Rodeo to fragment cattail dominated wetlands effectively reduced cattails for up to two years in northeastern North Dakota. After herbicide treatment the numbers of territorial males of red-winged blackbirds (*Agelaius phoeniceus*), yellow-headed blackbirds (*Xanthocephalus xanthocephalus*), and marsh wrens (*Cistothorus palustris*) were limited by reducing the live cattail density (Linz et al. 1996b). Managers should strive for equal amounts of open water, live, and dead vegetation which allows for various stages of regrowth to maximize avian diversity (Linz et al. 1996b).

Timing of applications can play a role in meeting management objectives. Additional research by Linz and Homan (2011) showed that cattails sprayed in July collapsed prior to the migration of blackbirds while cattails sprayed in August retained enough structure to host migrating blackbirds, suggesting an earlier application of glyphosate to cattail dominated wetlands reduced roosting attractiveness (Linz and Homan 2011).

Cutting/Disking

Mechanical control by cutting or disking has been used to control cattails (Table 1). At Delta Marsh, Manitoba in 1978, broad-leaf cattails were removed from a 4.2 ha stand during April 8–28 when the ground was still frozen with standing water over it (Murkin and Ward 1980). Using a seven-blade, one-way disc behind a tractor equipped with half-tracks, cattails were cut at ground level. To further test this method, a series of channels were cut in a crisscross pattern using a rake behind a tractor to remove the cut cattail material (Murkin and Ward 1980). Once the material was removed it created openings in the marsh. There was a significant negative correlation between water depth at the time of cutting and the final cattail densities (Murkin and Ward 1980). As water depth increased, the amount of cattail stems that re-sprouted was reduced. This was due to the oxygen supply being cut off to the rhizomes. With no available oxygen supply, the ability of cut cattail stems to grow back is diminished. One drawback to this method is the effectiveness of using heavy equipment in marshy areas (Murkin and Ward 1980). If the ground is too soft, the equipment can get stuck; costing time and labor. Overall, however, this technique still demonstrated an effective method to control dense cattail stands.

Concurrent with the previous study, the responses of waterfowl and invertebrates were measured. Using the same technique as described, aerial cattail cover was removed from April 8–28 with shallow water over frozen ground (Murkin et al. 1982). In order to determine if the ratio of cover removal influenced waterfowl and invertebrates, three main cover removal treatments (30%, 50%, and 70% removal of cattail) and a control (no removal) were assessed. The 50:50 ratio was an attempt to create a “hemi-marsh” state where there are equal parts of water and emergent vegetation thought to be best for both waterfowl and invertebrates (Weller and Spatcher 1965, Murkin et al, 1982). After treatment, invertebrate numbers increased after 4–6 weeks. In control blocks, invertebrate numbers were higher initially since the treatment blocks seemed to be delayed after treatment application (Murkin et al 1982). Following the increase in invertebrate numbers, waterfowl numbers increased as well. With warming temperatures 4–6 weeks after removal, invertebrate numbers increased. During this period, the greatest waterfowl pair densities were found in the 50% cover-removal plots (Murkin et al. 1982). The main conclusion from this work supported the hypothesis that the "hemi-marsh" phase of a wetland provides the maximum amount of use and production for certain wetland birds (Murkin et al. 1982).

Grazing

Cattle have been used to mimic natural disturbances created by bison (*Bison bison*) in wetlands (Table 1). Schultz et al. (1994) used cattle to experimentally graze a 0.81 ha plot in two cattail-dominated wetlands in South Dakota. A stocking rate of 10 crossbred beef steers per plot were used from 11 June 1984 and allowed to graze for 28 days. Grazing reduced both live and dead cattail stems in both grazed plots (Schultz et al. 1994). Following grazing, plots were used more by waterfowl pairs in 1985. This could be due to the increased interspersion or an abundance of aquatic invertebrates. After one year of grazing from 1985–1986 there was an increase in live cattail stems in both plots (Schultz et al. 1994). Two years after the grazing treatment, plots had returned to an un-grazed state. Knowing whether cattails can be used as a forage for cattle is another important consideration. Hubbard et al. (1988) looked into the chemical composition and digestibility of cattails during the growing season. This was conducted in order to see if cattails were a good forage and could be used to benefit management plans for waterfowl. The primary species evaluated was hybrid cattail in South Dakota wetlands. Plants were collected from 3 June to 23 September 1983. In the end the nutrient quality of hybrid cattail compared favorably with that of cool season grasses within the region (Hubbard et al. 1988). The best time to graze hybrid cattail was before spike emergence, when nutrient levels were at their highest. Stewart and Kantrud (1972) observed that during dry years, grazing by cattle largely eliminated cattails, while stands of hardstem bulrush (*Scirpus acutus*) developed. Grazing followed by another treatment may help to extend the control of dense cattail stands.

Fire

Fire is a management technique frequently used for multiple management applications (Table 1). Much of the information available is from burning of upland sites; however, literature pertaining to burning of wetlands is sparse. Conditions needed for a wetland to carry fire, fuel loading, fire intensity, and fire severity are variable and not completely understood (Robertson 1997). One consequence of burning cattail dominated wetlands is the smoke produced. It is a very thick black smoke that can create hazardous conditions for the public and workers on a fire (Robertson 1997). Cattail wetlands can be burned in the spring or fall. Saenz (1994) burned sites at Lacreek National Wildlife Refuge (NWR) in South Dakota. Two sites were burned in September and two in May 1992–1993. Above- ground biomass of cattail was 51–56% lower in burned sites compared to controls. Fire effectively reduced the above-ground biomass, but it is not known if these effects lasted longer than one year (Saenz 1994).

Miao et al. (2010) looked at the effects of fire to manage cattails in the Florida Everglades to assess the ecological effects of the nutrients released after a fire. A 447,000 ha wetland was burned by lighting all four corners of the plot and letting the fire burn towards the center. The fire consumed only dead cattail leaf litter and killed any live stems which then transitioned to standing dead stems (Miao et al. 2010). Nutrients released after the fire were measured, and dissolved inorganic phosphorus was the primary nutrient found. These nutrients released back into the ecosystem can have effects lasting long after the fire. Such an increase in nutrients warrants investigation of short-term responses of ecosystems (Miao et al. 2010).

Fire may also play a role in the expansion of *Typha* spp. Since *Typha* spp. is an early colonizer, it may disrupt wetlands dominated by native vegetation (Ponzio et al. 2004). A 265-ha area in the Everglades was burned using aerial ignition in June 1994 to simulate a natural lightning strike during that period. One year after the fire, *Typha* density at the burned sites more than doubled while control sites remained unchanged (Ponzio et al. 2004). The area remained continuously flooded, which could have helped *Typha* spread. Two years' post-burn there was still an increase in *Typha* expansion. After the third and fourth year, however, burned sites had *Typha* densities that were not significantly different from pre-burn levels. This study emphasizes the need for long-term monitoring of burned areas (Ponzio et al. 2004).

Water Level Manipulation

In many prairie wetlands, the ability to control water levels may not be feasible. Control structures to manage water, however, can aid wetland management (Table 1). Fredrickson and Taylor (1982) made recommendations for impoundments after some unwanted species, including cattails, took over. Cattails can become a problem once flooding in impoundments becomes regular. By either using an early or late drawdown, these techniques can help manage for desirable species depending upon the time of year. The timing of re-flooding can be an important consideration when trying to manage either desirable or undesirable vegetation (Fredrickson and Taylor 1982).

In a greenhouse study, cattails (*Typha spp.*) grew faster in 2.54 cm of water and equally as well in 15.24 cm of water (Bedish 1967). Asamoah and Bork (2010) looked at the drought tolerance of narrow-leaf cattail. Two greenhouse studies were conducted during fall-winter of 2002–2003 and 2003–2004. Treatments included continuously flooded, field capacity moisture, and various drying periods. Broad-leaf cattail had no mortality associated with continuously flooded and field capacity treatments (Asamoah and Bork 2010). Once the drying interval increased, the root mortality increased, reaching 50% when soil moisture was below 5% after 8 weeks (Asamoah and Bork 2010). Mortality increased to 100% by 12 weeks of drying when soil moisture decreased to 1.5%. Plant vigor decreased after 4 weeks of becoming dry and affected leaves first. Conditions necessary for soil moistures to control broad-leaf cattail in field conditions are unlikely, however, this information can be useful to manage narrow-leaf cattail.

The more problematic hybrid cattail can be abundant where water levels are stable. Boers and Zedler (2008) determined from aerial photographs that *Typha* expanded linearly over time and were at their highest where water levels were stable. The parent species of hybrid cattail were more abundant where water levels fluctuated (Boers and Zedler 2008). Hybrid cattail also produced more biomass when phosphorus was added along with stabilized water levels. These characteristics cause hybrid cattail to spread even where they normally would not. Boers et al. (2007) looked at eight constructed wetlands with varying water levels from May–October from 2001–2004. Wetlands plots were designated to measure the changes in vegetation. Plots flooded for a short time (35 days) had low hybrid cattail cover while plots flooded longer had higher hybrid cattail (Boers et al. 2007). Plots with a high abundance of hybrid cattail also were strongly correlated with low species richness. The main conclusion found was that extended hydroperiods favor hybrid cattail over native species. Stabilizing water levels should be avoided where possible to stop the spread of hybrid cattail.

Harris and Marshall (1963) looked at effects of water levels following five years of flooding and five years of drying at Agassiz National Wildlife Refuge in northwest Minnesota. Broad-leaf cattail was greatly reduced after three years of flooding and was completely eliminated after four years in water depths of 30–38 cm. During this study, hybrid cattail was suspected to be present. Hybrid cattail was not affected by water depths up to 61 cm deep with four years of re-flooding (Harris and Marshall 1963). Where other vegetative species died or natural openings occurred, hybrid cattail threatened to become a problem species.

Combination of Techniques

Research has been conducted using multiple techniques to manage cattails (Table 1). Corns and Gupta (1971) compared various chemical treatments and mowing to control broad-leaf cattail. Chemicals were either hand applied as a soil treatment or sprayed with a portable compressed air sprayer. Mowing was done when the cattails were flowering and cut at three week intervals for a total of seven cuttings (Corns and Gupta 1971). Spraying the chemical Tandex, at a rate of 22.4 kg/ha, controlled cattail in plots for a three-year period. Other chemicals that controlled cattail for two years were Amitrole at a rate of 16.8 kg/ha and Dalapon at a rate of 22.4 kg/ha. Mowing seven times between July 1968 and August 1969 reduced cattail stems by 90% in plots not in water (Corns and Gupta 1971). The soil-applied chemicals were as effective as long as there was no surface water. Lawrence et al. (2015) used a glyphosate-based herbicide and mowing to control cattails (*Typha* spp.). Chemicals were hand applied while mowed vegetation was either left on the soil surface or removed for comparison. All treatments reduced cattails one month after application, but only the chemical treatment had lasting effects. One year after chemical application, all species of vegetation, including cattails, remained killed. Mowing and removal of biomass did not reduce native plant species richness. The removal or harvesting of biomass was as effective as the chemical application after one year at reducing cattails (Lawrence et al. 2015). Czayka (2012) found that a wick application of glyphosate and cutting in early summer was the most effective treatments to reduce cattail stems. Humpert and Hubbard (1995) found that crushing and spray/crushing of cattails significantly increased avian species richness. These observations were mostly due to increased waterfowl use.

Smith and Kadlec (1985) compared cutting versus burning of marsh vegetation to control cattails (*Typha spp*.). Cutting reduced the production of cattails to levels comparable to burned plots. Fire was used on portions of the study area on 2 September 1981. Fire did not cause significant mortality to the cattail rhizomes in the soil. Without this, prescribed burning alone did not change the aboveground production of cattails (Smith and Kadlec 1985). A single treatment was not effective at reducing cattail in the plots. Ball (1990) evaluated fire and mowing to control cattails along with varying water levels. Burning cattails reduced shoot densities by 70% relative to controls while mowing reduced shoot densities 89%. Mowing cattails in shallow water was superior to burning (Ball 1990). However, in deeper water there was no difference between cattail shoot densities with either burning or mowing. If a single treatment did not produce adequate results, mowing a second time reduced cattail shoot densities by 99% (Ball 1990).

Mallik and Wein (1986) compared burning of a cattail community to either draining or flooding. Burns were conducted in either spring, summer, or fall in drained or flooded plots. The greatest decrease in cattail cover was obtained with a summer burn in drained plots (Mallik and Wein 1986). In flooded plots, the greatest increase in cattail cover was associated with a summer burn. To control cattails, draining followed by a summer burn was the best to reduce cattail cover and increase species diversity. On drained plots, overall species composition increased the most compared to the flooded plots (Mallik and Wein 1986). Krusi and Wein (1988) found that the standing crop density of the cattail mat was reduced the most with drainage followed by a summer burn. Their results were comparable to Mallik and Wein (1986) since a spring, summer, and autumn burn were used.

Burning and grazing can be an effective tool when combined to manage cattail. Smith (1989) compared the nutrient quality of broad-leaf cattail in burned, grazed, and control playa wetlands ranging in size from 5–40 ha. The burn treatment removed 90% of all above ground litter. Grazing knocked down all of the standing dead vegetation to less than 0.5 m. As for the nutrient quality of cattail as cattle forage, burning or grazing during winter did little to improve the quality of cattail (Smith 1989). Kostecke et al. (2005) compared macroinvertebrate (macro) responses to burning, disking, and grazing in cattail-dominated wetlands. After treatments were applied, the no-management control had greater macro biomass than the grazed wetlands. Of the three treatments, burning had the greatest macro invertebrate species richness (Kostecke et al. 2005). Treatments with more vegetation (control, burned) had greater macro invertebrate richness and biomass compared to disking and grazing. Even though controls had the greatest amount of macro invertebrate biomass, controlling cattails can still benefit wetland birds by opening dense vegetation (Kostecke et al. 2005).

STUDY APPROACHES

Of all the management actions described, there are still some gaps in information related to cattail management. In particular, vegetation assessments typically examined only changes in cattails with little focus on other emergent vegetation. The overall picture of how chemical applications on cattails affects wetland bird communities is still not complete. How secretive individual bird species are affected has not been fully determined, with most work focused on waterfowl use. Amphibian communities are often not considered when management is applied, although amphibians can be sensitive to chemical applications (Relyea 2005, Cauble and Wagner 2005). All of these components should be assessed to gain a complete ecosystem perspective of how cattail management methods affect species. In order to address these gaps in knowledge, I examined the current status of wildlife and vegetation in cattail-choked wetlands at Glacial Ridge National Wildlife Refuge (GRNWR). “Cattail-choked”, was defined as a wetland with over 90% cattail cover. I examined management influences on vegetation, birds, and amphibians. Evaluations of control methods will incorporate the costs and benefits of the various treatments.

Objectives

The study objectives were to evaluate effectiveness of management actions on wetlands based on a before-after-control-impact (BACI) study design to specifically:

1. Evaluate changes in overall wetland vegetation composition as a result of treatments.
2. Evaluate avian response to cattail management actions by measuring species richness and abundance of individual target species (e.g., marsh wren (*Cistothorus palustris*), sedge wren (*Cistothorus platensis*), and swamp sparrow (*Melospiza georgiana*).
3. Evaluate amphibian response to cattail management actions based upon changes in species richness.
4. Evaluate selected invertebrate (Odonata spp.) response to cattail management actions based upon changes in species richness.

Study Area

GRNWR is a 9,340 ha prairie and wetland restoration project located in northwest Minnesota, 24 km east of Crookston. It is located within the northern tallgrass prairie ecoregion. To date, GRNWR is one of the largest wetland and tallgrass prairie restoration projects in North America. It was implemented to restore habitat for native plants, wildlife, and to protect water quality. GRNWR is managed primarily by the U.S. Fish and Wildlife Service in cooperation with the Minnesota Department of Natural Resources, and The Nature Conservancy.

Historically, agricultural conversion of the glacial lake beach ridges in the region now encompassed by GRNWR was slow and fragmented due to the combination of dry, sandy ridges and perennially wet inter-ridge swales (Janke 2006). Large-scale drainage and cultivation of the property did not occur until the early 1980s, when an extensive network of private ditches was created to prepare the site for soybean, corn, and wheat production (Brown et al. 2005). An estimated 6,885 ha of the property were severely degraded by the end of the 1990s. In 2001, The Nature Conservancy purchased the property and began restoring 1,240 ha of wetland and 8,100 ha of tallgrass prairie (Gerla et al. 2012). After restoration efforts were complete, ownership of the property was transferred to the USFWS creating the official national wildlife refuge.

At GRNWR, a study was designed to test the effects of four methods of control: chemical, mowing, fire, chemical followed by fire (chemical x fire), and no management action (control) of invasive cattails. Twenty-three study wetlands were selected for monitoring as part of management efforts. Baseline data were collected in the summer of 2014 followed by treatment applications in the fall of 2014 by USFWS personnel and equipment. Mowing was conducted using conventional farm equipment. Custom work of applying Rodeo herbicide (Glyphosate active ingredient) at 3.79 L/ha with Activator 90 Surfactant at 4.73 cu/ha was conducted using fixed-wing aircraft in treatment wetlands. Fire, if permissible, was conducted by USFWS burn crews. The overall study follows a BACI study design with 2014 serving as a baseline for comparing pre- and post-treatments. Avian surveys were conducted from mid-May to early June in each sampling year. Amphibian surveys were conducted after avian surveys were complete, occurring from mid-June to early July. Vegetation surveys were conducted in August after amphibian surveys were completed and when vegetation was more easily identifiable.

Post-treatment surveys occurred in the summer of 2015 and 2016 to assess initial biotic changes to cattail management treatments.

STUDY SPECIES AS INDICATORS OF WILDLIFE RESPONSES

Birds

Several individual wetland bird species were chosen for analysis out of all the species recorded. Marsh wren (*Cistothorus palustris*), sedge wren (*Cistothorus platensis*), swamp sparrow (*Melospiza georgiana*), red-winged blackbird (*Agelaius phoeniceus*), and common yellowthroat (*Geothlypis trichas*) were all chosen based on specific habitat features used by these birds for nesting. All target species may utilize cattails for nesting, however, they differ in where they nest within a wetland. Marsh wrens nest in the interior, sedge wrens on the outer edge, and swamp sparrows can nest either in or along a wetland. Red-winged blackbirds and common yellowthroats were chosen since they both, like swamp sparrows, nest either in a wetland or in other habitat. Each of these bird species can be present together in an individual wetland.

Marsh Wren (*Cistothorus palustris*): The distribution of marsh wrens ranges from Mexico as their wintering habitat and as far north as British Columbia for their breeding habitat (Kroodsma and Verner 2013). Marsh wrens are found in wetlands with an array of vegetation consisting of cattails (*Typha* spp.) or bulrush (*Scirpus* spp.). Males arrive first on the breeding grounds where they make several nests within their territory. Some of the nests will be used and others will be simply used as decoy nests. Marsh wrens are polygynous, where the males attract a variable number of females (Kroodsma and Verner 2013, Leonard and Picman 1987). Nests are constructed in dense vegetation, primarily cattails, surrounded by deeper water and can be located near a wetlands center (Leonard and Picman 1987). For this reason, marsh wrens were chosen as a target species since they need dense vegetation for nesting.

Sedge Wren (*Cistothorus platensis*): Closely related to the marsh wren, sedge wrens are found as far north as Alberta and southern Saskatchewan for their breeding range. The wintering range of this species ranges from Texas to Florida along the southern United States (Herkert et al. 2001). Sedge wrens typically inhabit wet meadows, retired cropland, or upland margins of ponds or marshes (Walkinshaw 1935). The closely related marsh wren occurs in deep-water wetlands, sometimes dominated by cattails, which sedge wrens avoid (Bedell 1996). During the breeding season, male sedge wrens, like male marsh wrens, create multiple nests. Some will be used for brood rearing and others as decoy nests (Burns 1982). Nests are created in dense vegetation normally consisting of sedges or combinations of sedges and fine grasses. These are placed at the base of either a small bush or on the ground at the base of some sedges (Walkinshaw 1935). Since sedge wrens occur alongside marsh wrens in wetlands, this species was chosen to see any effects of wetland treatments on them.

Swamp Sparrow (*Melospiza georgiana*): This species has a broad breeding range extending from the Northwest Territories in Canada east to Maine. The wintering range of swamp sparrows is wide, ranging from southern Illinois to Louisiana, and into parts of Mexico (Mowbray 1997). The swamp sparrow inhabits areas that are not far from water during the breeding season. These areas can range from cattail marshes to brushy meadows (Erskine 1984, Greenberg 1988). Swamp sparrow females build nests with males assisting, but not helping in nest construction. Nests are made of grasses and sedges with coarser material woven in. They are placed either over ground or elevated directly above or near water (Reinert and Golet 1979). Nests can be built in wetlands or in slightly upland sites. For this reason, swamp sparrows were chosen for analysis since their habitat characteristics span that of both marsh and sedge wrens.

Red-winged Blackbird (*Agelaius phoeniceus*): Red-winged blackbirds are wide-ranging and considered year-round residents throughout much of the United States (Yasukawa and Searcy 1995). This species utilizes a variety of habitats from wetlands to sedge meadows (Bernstein and McLean 1980). Red-winged blackbirds can be a nuisance when they forage on crops such as sunflowers or corn (Yasukawa and Searcy 1995). Nests can be placed either in wetland or upland habitats. In wetlands, nests are commonly made of cattails, sedge, or willow (Bernstein and McLean 1980). Since red-winged blackbirds use both wetland and upland habitats, they were chosen for analysis as a generalist, but important species economically.

Common Yellowthroat (*Geothlypis trichas*): As their name implies, common yellowthroats range throughout all of the United States up to the Northwest Territories in Canada. The wintering range of this species encompasses Mexico, Cuba, and other South American countries (Guzy and Ritchison 1999). Common yellowthroats inhabit thick vegetation in their breeding range in habitats from wetlands to prairie (Lowther 1993). Nests are made of fine grasses or sedges placed on or near the ground (Stewart 1953). In wet areas, nests are built higher to prevent flooding during the nesting season. We chose common yellowthroats for analysis because they are easily identifiable and common in the region.

Amphibian

Boreal Chorus Frog (*Pseudacris maculata*): Boreal chorus frogs have a large range which includes areas of the Northwest Territories in Canada to the southern edge of Arizona and east to Indiana (IUCN 2015, Conant and Collins 1991). They inhabit a range of habitats from wetlands to meadows. Boreal chorus frogs can travel between wetlands that are a few hundred meters apart (Hammerson 1999). They breed in wetlands and marshy edges where there is still water. Breeding sites may be either temporary or permanent wetlands with a variety of aquatic emergent and submergent plants (Hammerson 1999). Adult boreal chorus frogs eat insects, whereas tadpoles feed on aquatic plants.

Northern Leopard Frog (*Lithobates pipiens*): This species ranges from as far north as Hudson Bay in Canada south to New Mexico (IUCN 2015, Conant and Collins 1991). Northern leopard frogs inhabit a wide variety of habitats, including streams, wetlands, and lakes. In summer, they inhabit wet meadows and fields (Hammerson et al. 2004, Karns 1992). This species breeds in shallow, still water that is usually permanent or semi-permanent, where eggs are attached to vegetation just below the water's surface. Northern leopard frogs are opportunistic, terrestrial foragers (Ohanjanian and Paige 2004). Their diet includes insects, worms, crustaceans, and other small prey (McAllister et al. 1999). Tadpoles feed primarily on algae, detritus, and phytoplankton.

Invertebrates (Odonata)

Dragonfly (*Anisoptera spp.*): There are a wide variety of dragonflies across much of North America. Dragonflies are part of the order Odonata with members in the sub-order Anisoptera (Johnson 1991). Most adult dragonflies inhabit permanent weedy ponds, wetlands, and littoral areas of lakes (Thorp and Covich 2001). Merritt and Cummins (1978) noted that eggs are deposited either on plant tissue or below the water's surface. Once the eggs hatch, the process of metamorphosis starts with a nymph immature stage. Since a nymph or adult dragonflies are carnivorous, they feed on other insects or even tadpoles at later stages of development (Merritt and Cummins 1978).

Damselfly (*Zygoptera spp.*): The range of damselflies is very similar to that of dragonflies in North America. Damselflies are part of the same order as dragonflies, but are in the sub-order Zygoptera (Johnson 1991). Adult damselflies deposit eggs in the same habitats as dragonflies and have the same immature stage of a nymph (Merritt and Cummins 1978). The larva of damselflies can be distinguished by three leaf-like extensions on the end of the abdomen (Johnson 1991). Damselflies are generalist feeders, using whatever prey are within the environment they inhabit.

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Table 1: List of sources for authors, treatment, timing, frequency, and outcome for various cattail management actions.

Treatment:	Timing:	Frequency:	Outcome:	Source:
Chemical				
Main Chemical Glyphosate Others Dalapon and Amitrole +T	Early July, mid-August, and mid-September 1983 and 1984.	Two sets of plots established; one treated in 1983 and the other in 1984 with a sprayer mounted on an amphibious tracked vehicle	• Of the three chemicals tested to control cattail, glyphosate controlled as well or better than dalapon and amitrole + T. Application in the fall was effective when seed was mature; earlier application at a higher rate can compensate for more precise timing of application.	Comes and Kelley 1989
Chemical: Glyphosate	August and September 1989; August 1990	Once using fixed-wing aircraft during years applied	• Fragmenting dense cattail stands eliminated the use by roosting blackbirds. Treatment did however reduce numbers of marsh wren and rail.	Linz et al. 1992
Chemical Glyphosate	Mid-late July 1990 and 1991	Once using fixed-wing aircraft	• Reduced cattail cover, increased open water, and increased duck densities.	Linz et al. 1996a
Chemical Glyphosate	Mid-late July 1990 and 1991	Once per year using fixed-wing aircraft	• Reduced cattail cover, reduced RWBL, YHBL, and MAWR densities in treated wetlands.	Linz et al. 1996b
Chemical Glyphosate	Mid-late July and late August 1998	Two different spraying periods during the same year	• Reduced cattail cover until the fourth post-treatment year.	Linz and Homan 2011
Chemical Glyphosate	June 19, July 27, and September 3, 1987.	Treatment applied once on each date using a backpack sprayer	• Cattail control was good to excellent using 2.5–3.4 kg/ha. Best application time was from late July to early September.	Messersmith et al. 1992
Chemical Imazamox	September 2009	Once by using a helicopter	• Cattail coverage was reduced at all three application rates.	Rodgers and Black 2012
Chemical Glyphosate	August 1985 and July 1986	Once per year using fixed-wing aircraft	• Duck pair densities increased in treated wetlands and reduced live cattail stems by 99.7% 1 year post-treatment.	Solberg and Higgins 1993

Cutting/Disking				
Cutting over frozen substrate	April 8–28 in 1978	Cut at ground level over frozen with standing water using at tractor with half-tracks	• Method of cutting shoots below the water surface does eliminate oxygen supply to rhizomes.	Murkin and Ward 1980
Cattail was cut below the water surface	April 8–28	Cut below water surface; tractor drawn rake removed cut cattail afterwards	• Increased invertebrate populations followed by an increase in waterfowl numbers.	Murkin et al. 1982
Grazing				
Grazed with 20 yearling crossbred beef steers; 10 per wetland enclosure	Started grazing on June 11, 1984 and continued for 28 days	Grazed only during the 28-day time period, which was chosen at random	• The presence of cattle reduced the amount of live and dead cattail stem frequencies in both grazed wetlands during July 1984; persisted through August 1984.	Schultz et al. 1994
Fire				
Fire	July 25, 2006	Once burning the plot towards the center	• Dead cattail leaf litter burned throughout the plot; live cattail stems died. Multiple variables were assessed to see the short-term effects of fire.	Miao et al. 2010
Fire	June 1, 1994	Once; chosen to simulate a natural lightning season burn in Florida	• Both burned sites had a significant increase in *Typha* density two years after the burn. The control had no change in *Typha* density.	Ponzio et al. 2004
Fire	N/A	N/A	• A review on prescribed burning as a management and restoration tool for wetlands.	Robertson, M. M. 1997
Fire	September 1992 and May 1993	Each site was burned once in September 1992 or May 1993	• Fire reduced above-ground biomass for both spring (56%) and fall (51%) sites; if these effects last more than one year is unknown.	Saenz, J. H. Jr. 1994
Water Level Manipulation				
Manage water level	Fall-winter 2002–2003	Different conditions were used,	• The tolerance of *T. latifolia* to wet and dry periods was reinforced. Root mortality	Asamoah and Bork

	and 2003–2004	continuous flooding and drying periods, in a greenhouse	increased with drying period length; 50% after 8 weeks at 5% soil moisture and 100% after 12 weeks at 1.5% soil moisture.	2010
Moisture requirement	Occurred from December 1962-August 1963; December 1963-March 1964	Occurred only once during the time periods used to experiment with.	• Optimum moisture requirements for hybrid cattail to germinate and grow are about 2.54 cm. of water. Drawing down water to less than 30 cm. increases the spread of hybrid cattail. The amount and timing of water level manipulation can be important to manage hybrid cattail; either for good or bad.	Bedish 1967
Water level stabilized	May-October 2001–2004	Water levels were recorded daily; average number of days flooded was 76	• Extended hydroperiod favored *Typha x glauca* over native species. Plots flooded for a short duration had low *T. x glauca* cover.	Boers et al. 2007
Stabilized water levels	June-October 2004	Water levels changed at 3 different times; duration held constant	• *Typha x glauca* expanded where water levels were stabilized and accumulated more P and biomass with stabilized water levels.	Boers and Zedler 2008
Manage water level	Winter, spring, summer and fall between 1968–1982	Variable depending on management goals	• A discussion of techniques that can be used to manage natural and man-made wetlands.	Fredrickson and Taylor 1982
Managed water levels	1949–1957	Pools drawn down in the summers of 1952 and 1953, followed by 5 years of drawdown and 5 years of re-flooding	• Hybrid cattail had little tendency to die out in water up to 61 cm. deep after 4 years of re-flooding. Different drawdown/re-flooding periods needed to maintain emergent marshes.	Harris and Marshall 1963
Combination of Techniques				
Burning, mowing, and flooding	Early April to mid-September	Burning and mowing came first, flooding was completed in early April,	• Plots were burned and mowed over ice in early spring and then flooded. If flooding was deep both burning and mowing killed cattail equally. In	Ball 1990

		depths ranged from 20-80 cm.	shallow water mowing kept cattail regrowth down much more than fire.	
Mowing and Chemicals Tandex, Amitrole, and Dalapon	1968–1970	Mowing was conducted 7 times, July, 1968 and August 1969. Chemicals were applied once in 1968 as either soil or spray treatments	• Mowing seven times between July, 1968 and August, 1969 reduced the cattail population by 90%. Sprayed Tandex at a rate of 22.4 kg/ha kept cattail regrowth down for a 3 year period. Amitrole (16.8 kg/ha) and Dalapon (22.4 kg/ha) sprayed controlled cattails for two years, but allowed other invasive weeds in. Soil treatments were as effective only if there was no surface water.	Corns and Gupta 1971
Cutting, Chemical Glyphosate, Tilling, and Wicking	2010–2011	Cutting was done on July 11, 2010 and June 31 2011, Tilling was done once in 2010, Chemical was applied in 2010.	• Wicking cattails in August by hand with Glyphosate after cutting reduced cattails the most.	Czayka 2012
Chemical Glyphosate and crushing	September to mid-January, May 28	Chemical was aerially sprayed once; crushing was done in mid-January and May 28 using a Bombardier tracked ATV.	• Avian species richness (waterfowl) was significantly higher in the crushed and crushed/sprayed treatments (88%) compared to control (47%) areas. Crushing should be used in combination with or an alternative to spraying.	Humpert and Hubbard 1995
Fire, disking, and grazing	1999	Burning was completed first, followed by grazing (stocking rate 5 and 20 head per 11 ha), disking completed	• Few differences were found in macroinvertebrates (macro) among treatments; the control and burned cattails had a greater diversity of macro's than the less vegetated treatments such as disking.	Kostecke et al. 2005

		after burning at a 15 cm. depth		
Burning and water level control, drained and flooded basins	Spring (May 30-June 4 1981), summer (July 20–22 1981), and September 26–27 1981) for burning	Burning was applied three times during 1981 and unburned plots were also kept.	• Drainage and burning of floating *Typha* mats reduced standing crop biomass the most. It was reduced to 20% of that in the flooded, unburned treatment. *Typha* mats mainly survived the treatments and no major shifts in species composition occurred.	Krusi and Wein 1988
Chemical Glyphosate	Early July 2013	Once using hand wicking	• Reduced *Typha* density and all other native species biomass.	Lawrence et al. 2015
Burning, flooding, and draining	Burning occurred in 1981 in spring (June 3 and 17), summer (July 1 and 15), and fall (August 12 and September 16)	Burning occurred once as well as flooding and drainage	• Treatments resulted in an increase in total numbers of other species after three years. Draining and summer burning produced the lowest cover and amount of *Typha*.	Mallik and Wein 1986
Cutting and burning	Burning was completed on September 2 1981	Both cutting and burning were used once in 1981	• Cutting reduced cattail (*Typha* spp.) more than levels found in burned plots. A single burn or cutting was not an effective management tool at reducing overall production of cattail.	Smith and Kadlec 1985
Grazing and burning	Cattle were grazed in winter (November to March), burns were completed from January to mid-March	Fire was used once as well as the cattle to graze study wetlands	• Prescribed burning and grazing during winter did little to improve cattail nutrient quality. As a forage for cattle and wildlife it is best in early spring.	Smith 1989

CHAPTER II: RESPONSES OF VEGETATION, BIRDS, AMPHIBIANS AND INVERTEBRATES TO CATTAIL MANAGEMENT TREAMENTS

INTRODUCTION

Cattails can be an invasive species, under certain circumstances, that threaten wetlands once they become established, posing a challenge to resource managers. Non-native cattails, such as narrow-leaf cattail and hybrid cattail in particular, can be problematic. Cattail-dominated wetlands often no longer support healthy migratory populations of breeding waterfowl and other wetland wildlife due to food and habitat loss (Smith and Kadlec 1985). For example, cattail invasion has been linked to a reduced capacity to support high densities of macroinvertebrates, the food source for some species of migratory waterfowl (Kostecke et al. 2005). A monotypic stand of non-native cattails can displace diverse native plant communities (Gleason et al. 2012). Murkin et al. (1982) suggested that wetlands with an abundance of cattails had reduced open water that is important for both native plant and animal communities. Cattail litter contributes to secondary negative impacts on wetlands since it smothers native plant communities and allows cattails to extend farther into wetland basins (Murkin and Ward 1980, Mallik and Wein 1986).

The invasion of cattails has been exacerbated by human disturbance. Agricultural drainage, for example, disturbs soils and creates deeper wetlands than those that historically occurred (Fredrickson and Taylor 1982). Once deeper wetlands are drained for the use of agriculture, the value of the wetland is lost (Zedler 2003). The ability of the wetland to hold water during flooding events is gone and soil erosion increases. Retaining and restoring wetlands to negate this effect may help to reduce problems caused by drainage. Within North American cattails, hybrid cattail (*Typha x glauca*), a cross between the native broad-leaf (*Typha latifolia*) cattail and narrow-leaf (*Typha angustifolia*) cattail, has become a focus of management efforts because of its ability to tolerate a wider range of conditions. For example, hybrid cattail thrives over other species during wetland conditions where water levels fluctuate (Smith 1967) and when there is an extended hydroperiod (Boers et al. 2007). Hybrid cattail can expand rapidly while accumulating biomass and nutrients (Boers and Zedler 2008). Once wetlands become dominated by cattails, especially hybrid, controlling them can be difficult.

Cattail Control Methods

Numerous studies have evaluated cattail control techniques such as use of chemicals, fire, and mowing, with various degrees of success. Studies relating to hybrid cattail management, however, are few. Hybrid cattail can tolerate deeper water levels, up to 100 cm, which makes management of this species difficult (Harris and Marshall 1963, Waters and Shay 1992, Bedish 1967). Linz and Homan (2011) found that glyphosate reduced the amount of hybrid cattail in a wetland. With this increase in dead cattail material, there can be secondary negative effects. Farrer and Goldberg (2014) found that adding hybrid cattail litter to a wetland decreases the amount of native plant richness and abundance. Once the litter was removed, the effects were reversed, showing that dead plant matter can be a barrier to wetland restoration. The application of various chemicals to control cattails have been used. Comes and Kelley (1989) used glyphosate, dalapon, and amitrole in sewage lagoons to compare cattail control effectiveness. These three chemicals were applied in early July, mid-August, and mid-September. Of these, glyphosate controlled cattail as well or better than dalapon or amitrole. The use of glyphosate in mid-late July was effective at reducing cattail cover and increasing open water in North Dakota (Linz et al. 1996a). This led to increased waterfowl densities; however, yellow-headed blackbird and marsh wren densities decreased (Linz et al. 1996b). Rodgers and Black (2012) found that applying Imazamox in September reduced cattail coverage at three application rates in the Florida Everglades.

Burning cattail-dominated wetlands is a common management tool; however, its effects on wetlands during and after a burn are unclear. Fire more than doubled *Typha* density one year after a burn in June in the Florida Everglades (Ponzio et al. 2004). Fire used in July removed dead cattail litter and reduced live cattail stems, but the subsequent effects of released dissolved phosphorus require further investigation (Miao et al. 2010).

Mechanical techniques such as cutting and mowing have also been used to manage cattail. Murkin and Ward (1980) cut cattail shoots below water level over frozen substrate in April, which reduced the number of shoots that re-sprouted in relation to water depth. One drawback to this technique, however, was the high cost of using heavy equipment in wet areas (Murkin and Ward 1980). If the cut cattail litter was removed, the number of invertebrates in the wetland increased, followed by an increase in waterfowl numbers (Murkin et al. 1982).

While research on various cattail management techniques and the effects on other plants and wildlife has been conducted, substantial variability with limited work on ecosystem interactions exist. Cattail-choked wetlands support fewer native species of vegetation (Boers et al. 2007, Asamoah and Bork 2010), decreased use by wildlife

(Kostecke et al. 2005, Linz et al. 1996a), and may exclude amphibian or invertebrate species (Solberg and Higgins 1993, Maerz et al. 2010). Best management practices and influences on meeting management goals for cattails are still lacking, especially relative to hybrid cattail. This study contributes to the gaps of knowledge by taking a community based approach of cattail management. Specifically, we evaluate responses of various cattail control methods including fire, chemicals, and mowing, on vegetation, birds, amphibians, and invertebrates one-year prior to and in the first two years after management actions were applied to the wetland.

METHODS

Study Area

Glacial Ridge National Wildlife Refuge (GRNWR) is a 9,340 ha prairie and wetland restoration project located in northwest Minnesota, 24 km east of Crookston, MN (Fig. 1). It is located within the northern tallgrass prairie ecoregion. To date, GRNWR is one of the largest wetland and tallgrass prairie restorations in North America. Implemented to restore habitat for native plants, wildlife, and protect water quality. In 2001, The Nature Conservancy (TNC) purchased the property and began restoring 1,240 ha of wetlands and 8,100 ha of tallgrass prairie (Gerla et al. 2012). Once restoration efforts were complete, ownership of the property was transferred to the U.S. Fish and Wildlife Service (USFWS), creating the national wildlife refuge. GRNWR is managed primarily by the USFWS in cooperation with the Minnesota Department of Natural Resources (MNDNR), and TNC.

Application of Management

We randomly selected 23 restored shallow wetlands 1–6 ha in size within GRNWR to examine the effectiveness of cattail reduction treatments (Fig. 1). We selected wetlands that were "cattail choked"; where >90% basin was covered in cattails. We selected cattail reduction treatments commonly employed in this region, which include mowing, prescribed fire, chemicals, and the combination of chemical x fire. Wetlands were randomly assigned to a single treatment or a treatment combination (Table 2). Management was applied from 12 September 2014 to 12 November 2014 (Table 2). A private contractor using conventional farm equipment completed mowing while the ground was frozen to take advantage of these conditions. The application of chemicals was conducted through a private contractor using a helicopter. Rodeo herbicide (Glyphosate active ingredient) was applied at 3.78 kg/ha with Activator 90 Surfactant at 0.076 kg/ha in early September while cattails were still storing nutrients in rhizomes. Prescribed fire was used in October once conditions were dry enough. Fire was applied after chemical application to utilize the combination of chemical x fire as a treatment.

Field Methods

Vegetation Surveys: We sampled vegetation from mid-July to mid-August in 2014–2016 and estimated vegetation with a combination of line intercepts and ¼ m^2 quadrats per wetland (Fig. 2). We used GIS to locate an approximate center in each wetland and oriented two, 25 m line intercepts along north-south and east-west cardinal directions. Wetland centers were located at the midpoint of the two intercepts (12.5 m mark). If the GIS-generated coordinates were not located within the wetland boundary, we relocated the point to the nearest cattail stand within the wetland. One, ¼ m^2 quadrat was placed on alternating sides every 5 m along each intercept, located 2 m from the line intercept, for a total of 12 quadrats per wetland. We measured quadrats at 0, 5, 10, 15, 20, and 25 m marks. If areas were trampled near the intersection of line intercepts, an equal number of meters were added to the end of the transect to account for those trampled (Fig. 2).

In each quadrat, we visually estimated percent cover of individual plant species, live and dead cattail cover, bare ground, and between-stem open water. Percent cover was constrained to 100% in quadrats because all vegetation and wetland characteristics were measured in a two-dimensional cross-section at ground or water level. We also took one measure of water depth, cattail litter depth, height of standing dead cattail stems, and height of living stems per quadrat. Average height of standing live and dead cattail stems were measured from ground level, even if the ground was submerged.

Avian Surveys: We used 50 m fixed-radius point counts to estimate avian species richness and abundance (Ralph et al. 1995). We randomly selected a point along each wetland edge such that half the area of the survey plot was inside the wetland perimeter (Reynolds et al. 1980, Fig. 3). We conducted 5-minute surveys that commenced after a 1-minute rest period upon arriving at the point. We surveyed birds between sunrise and 10:00 hours on days with winds ≤ 19 km/hr and no precipitation (North American Breeding Bird Survey 2011). We recorded all birds seen or heard within the survey plot Reynolds et al. 1980), including birds such as swallows and raptors that foraged over plots (Bryan and Best 1991). We repeated point counts three times during the breeding season (May-June) in order to estimate species richness and relative abundance and account for imperfect detection (MacKenzie et al. 2006, Conroy and Carroll 2009). We surveyed all wetlands before repeating surveys on previously visited wetlands to avoid timing effects by treatment on bird detectability as the breeding season progressed. Observers were rotated among treatments such that one observer did not survey all wetlands assigned to a single treatment.

We calculated relative abundance of a select number of bird species for each treatment across years. We selected marsh wrens (*Cistothorus palustris*), sedge wrens (*Cistothorus platensis*), swamp sparrows (*Melospiza georgiana*), red-winged blackbirds (*Agelaius phoeniceus*), and common yellowthroats (*Geothlypis trichas*) to assess how species abundance was affected by treatments. We selected marsh wrens because this is an obligate wetland species that uses cattails for nest building and foraging (Leonard and Picman 1987). Marsh wrens tend to nest in the center of wetlands in dead cattail cover. Sedge wrens use the edges of wetlands as habitat, either nesting in cattails or primarily sedges (Walkinshaw 1935). These two species are sensitive marsh birds, thus assessing how treatments affect them can be an indicator of how the wetland bird community is affected. Swamp sparrows, red-winged blackbirds, and common yellowthroats are habitat generalists. Swamp sparrows and common yellowthroats will nest in either wetlands or upland habitat (Erskine 1984, Lowther 1993). Red-winged blackbirds tend to nest in cattails, but can nest in other habitat types as well (Bernstein and McLean 1980).

Amphibian Surveys: Amphibian larvae were surveyed in mid to late June 2014, 2015, and 2016 using 20-minute dip-net surveys (Shaffer et al. 1994). Amphibian larvae traps were not used due to high Odonata nymph (dragonfly) depredation on trapped amphibian larvae experienced by a previous researcher at this study area (Larson 2007). Each wetland was walked for 20 minutes (20 for 1 surveyor, 10 for 2 surveyors) or shorter if the entire perimeter of the wetland was surveyed in less than 20 minutes. A 1 m sweep was taken approximately every minute (e.g., 20 dips total for a 20 minute survey). We recorded depth of water on the net frame, 30 cm W x 25 cm L, to the nearest quarter (i.e., ¼, ½, ¾, or full) to estimate sampled water volume to determine amphibian larvae density. Microhabitats within each wetland were relatively uniform due to the shallow nature of restored wetlands at GRNWR. We focused our sampling efforts in water depths of approximately 10–48 cm. Captured specimens were measured and immediately released into the same wetland.

All wetlands received three surveys from 2014–2016. Amphibian larvae were separated by species and counted, although toads (*Anaxyrus* spp.) and treefrogs (*Hyla* spp.) were evaluated to genus only. All chorus frog (*Pseudacris* spp.) larvae were assumed to be boreal chorus frogs (*Pseudacris maculata*) based upon recent genetic analysis that indicates western chorus frogs (*Pseudacris triseriata*) do not occur in Minnesota (Lemmon et al. 2007). We noted tadpole developmental stage and measured total length. Similar to bird surveys, we calculated amphibian species richness and evaluated boreal chorus frog and northern leopard frog abundance using the highest count data from the three repeat surveys.

Invertebrates: From our dip net surveys, we also estimated densities of predatory invertebrate larvae, mainly Odonata (dragonflies and damselflies). Previous studies indicated that Odonate larvae could strongly influence densities of amphibian larvae (Cecil and Just 1979, Morin et al. 1988). We examined relative abundance of dragonflies and damselflies.

Data Analysis

The study design followed a Before-After Control Impact (BACI) design for all treatments, with 2014 serving as a baseline, and 2015–2016 data serving as post-treatment. We calculated summary statistics, and reported number and species (family for invertebrates) of bird, amphibian, and invertebrate species. We analyzed data using a repeated measures regression SAS (Version 9.4) Proc Mixed Procedure. We tested whether treatment, year, or the interaction between treatment x year had an effect on vegetation, bird species richness, individual bird species, amphibian species, and invertebrates (Odonata). For vegetation, we evaluated the covariate of average water depth in cm. We evaluated the covariates of percent cover of live cattail, dead cattail, live stem, or dead stem heights for birds. Amphibian and invertebrates were evaluated with the covariates of average water depth (cm), percent live, and dead cattail cover. For avian, amphibian, and invertebrate abundance, we used maximum count data from the three repeated surveys each year for each survey season. This allowed us to take into account changes in detection over the three surveys since we did not have sufficient data to do a formal Royle-Repeat Count Analysis that directly incorporated detection. Given the BACI design, a significant effect of a treatment on the response variable (bird, vegetation, amphibian, or invertebrate) would be represented by a $p < 0.05$ in the treatment x year effect. We calculated parameter estimates to explore biological implications of treatments on response variables of interest and graphically represented these data. We also calculated percent change in response variables across from before to after treatment.

RESULTS

Vegetation Responses

We determined that cattail control treatment, year, and the treatment x year interaction had a significant influence on percent live cattail while average water depth did not (Table 3). Chemical treatment decreased the percentage of live cattail 73% after one year and 24% two years post-treatment (Table 4, Fig. 4). Chemical x fire decreased live cattail by 31% one year post-treatment (Table 4, Fig. 4). This decrease, however, did not last since live cattail increased 68% two years after treatment application. Fire increased the percentage of live cattail 68% one year and 54% two years post-treatment (Table 4, Fig. 4).

We found year had a significant influence on percent dead cattail while treatment and treatment x year did not (Table 3). Percent open water was influenced by year and average water depth (Table 3), while other species of vegetation were not influenced by any variable (Table 3). We found trends of increase in percent dead cattail of 57% one year and 45% two years following chemical treatments (Table 4, Fig. 5), and trends increased open water following chemical of 8% and chemical x fire of 16% (Table 4, Fig. 6). These increases did not last since two years post treatment, both chemical and chemical x fire both had decreases in open water. One year after chemical x fire, there was a trend towards a lower proportion of other vegetation species, decreasing by 57% (Table 4, Fig. 7).

Bird Responses

We observed a similar number of species (38–43) and individuals (656–838) across the three-year period (Appendix, Table 8). The six most abundant species across our study area, in order of decreasing abundance, were red-winged blackbird, common yellowthroat, marsh wren, bobolink (*Dolichonyx oryzivorus)*, sedge wren, and clay-colored sparrow (*Spizella pallida)*.

We did not observe a significant effect of treatment, year, or the interaction of treatment x year on avian species richness (Table 3). Although we found no significant effect, mowing had the greatest decrease in number of species detected from 2014–2016 (Table 5, Fig. 8). Species richness appeared to decrease 20% with the treatment combination of chemical x fire from 2014–2015, but then increased 4% in 2016 (Table 5). We did not find the covariates of percent live cattail or dead cattail to influence overall bird species richness.

We found that treatment, year, and treatment x year interaction did not influence marsh wrens (Table 3). While not significant, fire reduced marsh wren numbers the most from 2014–2016; 56% one year post-treatment and 74% two years after treatment application (Table 5, Fig. 9a). Chemical and chemical x fire reduced marsh wren numbers as well (Table 5, Fig. 9a). One year post-treatment chemical reduced marsh wren abundance by 70% and chemical x fire reduced marsh wrens by 59% (Table 5). We did not find that percent live or dead cattail influenced marsh wrens.

The treatment x year interaction significantly influenced sedge wren numbers (Table 3). Fire was associated with the greatest increase in sedge wren numbers from

2015–2016 (Table 5, Fig. 9b). We found that sedge wrens increased 22% one year and then 96% two years post-treatment following fire. Sedge wrens decreased with chemical and chemical x fire from 2014–2015, followed by a slight increase in 2016 (Fig. 9b).

Treatment alone affected swamp sparrow abundance, suggesting that perhaps wetlands differed in swamp sparrow use prior to the treatments (Table 3, Fig. 9c). Swamp sparrows increased following fire, chemical, and chemical x fire and decreased two years post-treatment with fire (Table 5, Fig. 9c). Year had a significant influence on common yellowthroat numbers, suggesting that factors such as weather may have affected common yellowthroats (Table 3). Fire decreased common yellowthroat abundance by 46% one year post-treatment, followed by an increase of 36% two years post-treatment (Table 5, Fig. 9e).

We found that year, the treatment x year interaction, average dead, and live stem heights all significantly influenced red-winged blackbirds, while treatment alone had no effect (Table 3). Chemical decreased red-winged blackbird abundance the most by 62% one year post-treatment, followed by an increase of 5% two years post-treatment (Table 5, Fig. 9d). Chemical x fire had an overall increase in red-winged blackbird abundance between 2014–2016. The presence or absence of dead and live cattail stems influenced whether red-winged blackbirds used a wetland. Once chemicals were applied live cattail stems died, which decreased overall red-winged blackbird use of the wetlands. However, with chemical x fire there was an increased use of wetlands by red-winged blackbirds. This could be due to the species changing how they utilize the wetlands, either for nesting or foraging.

Amphibian Responses: We captured five species of amphibians during the 2016 field season (Appendix, Table 9). We did not find a significant effect of treatment, year, or the treatment x year interaction on amphibian species richness (Table 3, Table 5, Fig. 10).

We did not find impacts of treatment, year, and the treatment x year interaction on boreal chorus frog or northern leopard frog abundance (Table 3). Average water depth was significant for boreal chorus frogs. We found that mowing was associated with an increasing trend in boreal chorus frog abundance (Table 6, Fig. 11), but no trends emerged for the northern leopard frogs (Table 6, Fig. 12).

Odonata Invertebrate Responses: Dragonfly abundance was only influenced by year and percent dead cattail (Table 3). We found that fire and chemical x fire showed a decreasing trend for dragonfly abundance (Table 6, Fig. 13). Damselfly abundance was not significantly impacted by treatment, year, or the treatment x year interaction (Table 3). Damselfly abundance had a declining trend from fire of 76% one year post-treatment followed by an increase of 2% two years post-treatment (Table 6, Fig. 14).

DISCUSSION

Vegetation:

Our results suggest that the percentage of live cattail decreases following the application of chemicals (glyphosate) and chemical x fire. Chemical application reduced the percentage of live cattail by 73% after one year and 24% two years post-treatment. These results are supported where the use of glyphosate fragmented dense cattail stands and reduced live cattail stems (Comes and Kelley 1989, Linz et al. 1992, Solberg and

Higgins 1993). The application rate we used, 3.78 kg/ha, was comparable to other studies that demonstrated similar control. Messersmith et al. (1992) found the use of glyphosate at 2.5–3.4 kg/ha was good to excellent to control cattails. An application rate of 3.3 kg/ha of glyphosate was better than two other chemicals used to control cattails (Comes and Kelley 1989). The timing of chemical application can be key in the success for cattail control. Our chemical treatment was applied in early September using a helicopter for aerial spraying. The application of glyphosate in late July to early September was the best application time for cattail control (Messersmith et al. 1992, Linz et al. 1992).

Literature on how fire affects wetlands is sparse, since much of the available information is from burning upland sites (Robertson 1997). Our result of the combination of chemical x fire reducing the percentage of live cattail is unique from other studies. Following one year after the application of chemical x fire, live cattails were reduced by 31%, which is similar to other studies. However, two years post-treatment the amount of live cattail increased by 68% from the original status in 2014. This could be due to the chemical killing the live cattail and fire only removing the dead material. We found that fire alone increased the percentage of live cattail 68% one year post-treatment. Ponzio et al. (2004) also found a significant increase in cattail density two years after fire was implemented. To reduce cattails, a single burn was not effective at reducing overall cattail production (Smith and Kadlec 1985). The timing of fire in wetlands is key to management objectives. Our timing for fire was an early October burn compared to other studies. Saenz (1994) found fire used in September reduced aboveground biomass by 51%. Whether this effect lasted more than one year is unknown. With, two years post-treatment, both the chemical and chemical x fire treated wetlands had an increase in percent live cattail. Linz and Homan (2011) found a similar result where cattail cover came back four years post-treatment; suggesting that a single fire application even coupled with chemical applications would likely only have limited impacts on cattail control efforts and may actually have an undesirable outcome for control efforts.

Although we did not find statistically significant impacts of management treatments or the interaction on percent dead cattail, open water, or other species of vegetation, there were trends for each. We found that the percent of dead cattail trended to increase after chemical application. One year after chemical applications, dead cattail increased by 57% and then 45% two years post-treatment. This makes sense since once chemicals are applied to a wetland, the live material dies, and there will be an increase in dead material. Linz et al. (1996a) found dead vegetation was greater one year after glyphosate was applied in treated wetlands. One of our management objectives was to increase the amount of open water. We found that chemical and chemical x fire trended to increase the amount of open water. With open water, chemical increased the amount by 8% one year post-treatment and 16% for chemical x fire. The use of Rodeo effectively reduced cattails and increased the amount of open water in treated wetlands (Linz et al. 1996a, Linz et al. 1996b). Our results of an increase in open water did not last more than one year. This could be from cattails re-colonizing wetlands two years post-treatment. Also in these shallow wetlands, water depths can vary from year to year. The amount of available water can either help or discourage an increase in open water. One year after chemical x fire was applied, we found a decreasing trend in the proportion of other species of vegetation. Once this treatment was applied, other species decreased by 57% and then 39% two years post-treatment. Lawrence et al. (2015) found a reduction in cattail density and all other native species biomass after glyphosate was applied. Burning followed by water level manipulation resulted in an increase in total numbers of other species of vegetation three years after application (Mallik and Wein 1986). Our results could mean that the combination of chemical x fire is not the best management tool combination to benefit other species of vegetation.

Birds:

Bird species richness was not impacted by our management actions, likely because either the vegetation was not changed enough to impact the bird community, or because some species benefitted while others did not, making changes in numbers of birds less apparent. Mowing showed the greatest decrease in number of species detected from 2014–2016. We observed that mowing decreased bird species richness by 13% after one year and then 27% two years post-treatment. Murkin et al. (1982) found cutting cattails below the water's surface increased both invertebrate and waterfowl numbers; however, our method of sampling for bird species differed in that it was better for detecting songbirds than waterfowl, which limited direct comparisons. Bird species richness decreased in 2015 by 20% followed by an increase in 2016 of 4% with chemical x fire. Humpert and Hubbard (1995) found increased avian species richness, mostly waterfowl, after wetlands were sprayed and crushed. We observed bird species richness decreased in 2015 in all of our treatments. In 2016, there was a slight increase in bird species richness for three treatments. This result could show that it may take longer than two years for birds to recolonize a wetland after a treatment was applied. Monitoring our wetlands over a longer period may have shown an increase.

We found trends in decreases of marsh wrens with fire, chemical, and chemical x fire followed by a slight increase in 2016. Specifically, with chemical application, marsh wren abundance declined 70% one year post-treatment and then 56% after two years. Linz et al. (1996b) found similar results where marsh wren and red-winged blackbird densities were reduced after glyphosate was applied. Post-burn sites had no nests of both marsh wrens and red-winged blackbirds the season after fire was applied (Saenz 1994). Both marsh wrens and red-winged blackbirds use cattails for nest building and foraging. With the removal of cattails in our wetlands, marsh wrens had no material to build nests. This result shows how some treatments adversely affected species. Considering this, managing cattails may be vital to the success or failure of marsh wrens.

We found that red-winged blackbirds were significantly impacted by the treatment x year interaction; there was also a significant interaction with live and dead cattail stem heights. This species uses a range of habitats from wetlands to uplands. Nests can vary in where they are built, in either wetlands or uplands. If nests are built in wetlands, they are commonly made from cattails (Bernstein and McLean 1980). Therefore, live and dead cattail stem heights affect whether red-winged blackbirds will exploit wetlands as habitat. This can have implications since this species can be a nuisance to certain crops, such as sunflowers (Linz and Homan 2011). With the use of chemicals, red-winged blackbird use of wetlands was decreased (Linz et al. 1996b). We found a similar result where chemical application reduced red-winged blackbirds 62% one year post-treatment. However, two years later, their numbers rebounded by 5% and use of wetlands treated with fire or chemical x fire saw increased use. If there was a goal to reduce red-winged blackbirds in wetlands, certain treatments like fire and chemical x fire may not be the best.

Common yellowthroat abundance was only impacted by year. This could be from differences in changes to the wetlands as vegetation regrows. The habitat that common yellowthroats inhabit is thick vegetation in wetlands or prairies (Lowther 1993). Here they build nests from fine grasses and sedges on or near ground level (Stewart 1953). We found that common yellowthroat use of the treated wetlands varied. In the first year after fire and mowing, the use of treated wetlands decreased by common yellowthroats. Fire reduced common yellowthroat use by 46% and mowing by 62%. Two years after treatment application the use of these wetlands increased by this species; chemical had an increased use in both 2015 by 81% and 120% in 2016. Two years after management is applied vegetation regrows and may suit common yellowthroats well.

We found impacts of our management actions on sedge wren abundance. Fire had the greatest increase in sedge wren abundance. After one year sedge wren use of wetlands increased by 22% and then by 96% after two years. Schramm et al. (1986) found sedge wrens preferred spring burned areas to other un-burned habitat. Although the timing of fire in our study was in the fall, this result shows sedge wrens may benefit from fire in both fall and spring burned wetlands. Sedge wren abundance decreased the first year after application of chemical and chemical x fire treatments and then rebounded slightly two years post-treatment. Sedge wrens make their nests out of sedges or fine grasses (Walkinshaw 1935). These treatments, along with fire, remove the vegetation sedge wrens use to build nests. The resulting rebound in sedge wren abundance could be in response to regrowth of new vegetation two years after treatment application.

We found that swamp sparrows were impacted by treatment alone, suggesting swamp sparrows may have used wetlands differently from the onset of the study. Swamp sparrows are a generalist wetland species, inhabiting areas not far from water (Erskine 1984). They utilize grasses and sedges to make their nests near wetlands or in upland sites (Reinert and Golet 1979). Even with the manipulations to the wetlands, swamp sparrow use of the treated wetlands increased. One example is after chemical application, swamp sparrow use increased by 18% one year post-treatment and then 57% after two years. This is an important result showing how species using the wetlands may benefit or respond differently to management.

Amphibian:

Similar to bird species richness, we did not find any statistically significant results in amphibian species richness. This result could be due to wetlands having differing conditions from the onset of sampling. Even though average water depth was not significant for amphibian species richness, water still plays a large role in amphibian life cycles. The amount of available water in our sample wetlands can be affected by annual variation in precipitation. Wetland size may play a role in amphibian species richness. Snodgrass et al. (2000) found that there was little or no relationship between wetland size, hydroperiod, or amphibian species richness. One recommendation they made is to consider smaller wetlands for conservation since these wetlands hold species only associated with small, shallow wetlands. Our wetlands ranged in size from 1–6 ha and even though we did not find statistically significant results, small shallow wetlands are still important for many amphibian species.

Recent research has demonstrated concerns of the use of chemicals on amphibian species. For example, Relyea (2005) found that Roundup eliminated two species of tadpoles, nearly exterminated a third, and resulted in a 70% decline in amphibian species richness. Our study used Roundup (glyphosate) and apparently did not change amphibian species richness or boreal chorus and northern leopard frog abundance. Boreal chorus frog use of wetlands treated with chemicals did decrease by 7% one year post-treatment, but then increased by 199% two-years post-treatment. This result may show short-term effects of chemical use on boreal chorus frogs. Boreal chorus frog abundance had an increasing trend associated with mowing. Use by boreal chorus frogs increased by 319% after one year and 296% two years after mowing. This was likely the result from increased vegetative cover and forage provided (Shulse 2011).

Invertebrate (Odonata):

Annual variation was the primary driver for dragonfly abundance. We expected the amount of available water would affect dragonfly abundance, but we did not observe this result. We found that fire and chemical x fire showed a decreasing trend in abundance for dragonflies. Fire reduced dragonflies by 23% after one year and then by 63% after two years. We expected to find increased invertebrate numbers as a result of mowing and fire (Murkin et al. 1982, Kostecke et al. 2005), but did not observe such trends. We found that percent dead cattail was a significant factor for dragonfly abundance. Mabry and Dettman (2010) compared dense monotypic stands of cattails to mixed structure vegetation in wetlands and observed Odonate species richness was greater in the mixed vegetation than in the monotypic stands. These results support the fact that dragonflies do better in wetlands not dominated by a single species. We saw a decreasing trend in dragonfly abundance in our treatments. Since percent dead cattail was a significant factor it could mean that changing the vegetative structure of the wetlands can benefit dragonflies. However, time lags of as much as three years can exist to see any responses from treatments and may be the rationale behind this lack of response (Elo et al. 2015).

MANAGEMENT IMPLICATIONS

We examined effects of chemical, mowing, fire, and a combination of chemical x fire on 23 small, shallow wetlands in northwestern Minnesota. Over a period of three field seasons, data collected both pre- and post-treatment elucidated varying results. We found that to control cattails, hybrid included, certain treatments were better than others. The application of glyphosate reduced cattails, fire increased cattails, and two years later many wetlands had as many or more cattails than our baseline year. Bird species richness was not affected overall; individual species results varied based upon how they use wetland habitat. Amphibian species richness was not affected overall, while individual species and invertebrates had similar results.

The results we found can help guide wetland management decisions regarding not only vegetation, but birds, amphibians, or invertebrates. We took a community based approach while surveying these wetlands. This approach looked at multiple levels of each wetland to assess the whole array of effects on wildlife. Many other studies look solely at one or two aspects of wetland management. Our study provides biological information on effects of the treatments we assessed. With this knowledge, plans to design wetland management plans can be better informed. Another aspect of management in its early stages is how cattails can be used as a biofuel source. Work on cattail litter has found that litter produced by cattails drives strong environmental and plant changes in wetlands dominated by cattails (Larkin et al. 2012). Treatments such as, chemicals or fire may kill or remove cattails, but the nutrients in the litter are still left behind. This continues the invasion cycle, which cattails readily seize. Lawrence et al. (2015) suggest that biomass harvesting of cattails could be a useful tool for managers aiming to reduce cattail abundance without eliminating native species richness. In addition, this approach has the dual function of using the harvested material to offset management costs and future research should explore its cost effectiveness.

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Table 2: Glacial Ridge National Wildlife Refuge cattail treatments, wetlands, average wetland size, timing, rate, and cost to conduct management.

Treatment	Number of Wetlands	Average Wetland Size	Timing	Rate	Cost
Mow	3	4.78 ha	11/12/14	Once	$5.81 per ha $300 per hr 14.33 ha total mowed
Fire	3	1.76 ha	10/8/14	Once	$990.58 per ha 5.27 ha burned $27,000 total along with chemical x fire wetlands
Chemical	7	5.47 ha	9/12/14	Rodeo herbicide (Glyphosate active ingredient) at 3.78 kg/ha with Activator 90 Surfactant at 0.076 kg/ha	$106.52 per ha 202 ha total sprayed total cost $21,518.53
Chemical x Fire	4	5.35 ha	9/12/14-10/8/14	Once for each treatment	$1,218.52 per ha 21.41 ha total sprayed and burned
Control	6	6.48 ha	-	-	-

Table 3: Results for vegetation, birds, amphibians, and invertebrates using a repeated measures regression SAS (Version 9.4) Proc Mixed Procedure. ** indicates a significant result. Note; perLCC means percent live cattail cover and perDCC means percent dead cattail cover.

Response Variable	**Covariates**	***F-value***	***D.F.***	***P-value***
% Live Cattail	Treatment	7.87	35	0.0001**
	Year	3.71	35	0.0345**
	Treatment*Year	4.49	35	0.0008**
	AvgWaterDepth	3.47	35	0.0711
% Dead Cattail	Treatment	0.95	35	0.4467
	Year	3.67	35	0.0358**
	Treatment*Year	0.94	35	0.4989
	AvgWaterDepth	3.78	35	0.0601
% Open Water	Treatment	1.51	35	0.2203
	Year	6.95	35	0.0029**
	Treatment*Year	1.52	35	0.1842
	AvgWaterDepth	34.00	35	<.0001**
% Other Vegetation Species	Treatment	0.69	35	0.6046
	Year	1.53	35	0.2313
	Treatment*Year	1.43	35	0.2207
	AvgWaterDepth	3.37	35	0.0751
Avian Species Richness	Treatment	1.36	34	0.2683
	Year	0.75	34	0.4804
	Treatment*Year	1.20	34	0.3309
	perLCC	1.61	34	0.2131
	perDCC	1.63	34	0.2102
Marsh Wren	Treatment	0.89	34	0.4777
	Year	2.86	34	0.0709
	Treatment*Year	0.38	34	0.9241
	perLCC	2.73	34	0.1080
	perDCC	1.65	34	0.2082
Sedge Wren	Treatment	2.22	34	0.0874
	Year	2.14	34	0.1329
	Treatment*Year	2.25	34	0.0473**
	perLCC	0.04	34	0.8399
	perDCC	0.59	34	0.4472
Swamp Sparrow	Treatment	4.35	34	0.0060**
	Year	0.51	34	0.6075

	Treatment*Year	0.61	34	0.7605
	perLCC	3.78	34	0.0601
	perDCC	0.32	34	0.5733
Red-winged Blackbird	Treatment	0.57	34	0.6859
	Year	3.13	34	0.0567**
	Treatment*Year	3.30	34	0.0067**
	AvgDCStems	4.71	34	0.0370**
	AvgLCStems	7.17	34	0.0114**
Common Yellowthroat	Treatment	0.99	34	0.4286
	Year	4.00	34	0.0274**
	Treatment*Year	1.23	34	0.3114
	perLCC	0.20	34	0.6596
	perDCC	1.73	34	0.1977
Amphibian Richness	Treatment	2.30	33	0.0796
	Year	0.16	33	0.8526
	Treatment*Year	0.83	33	0.5814
	perLCC	0.19	33	0.6627
	perDCC	1.72	33	0.1985
	AvgWaterDepth	0.00	33	0.9507
Boreal Chorus Frog	Treatment	0.68	33	0.6131
	Year	2.22	33	0.1244
	Treatment*Year	0.75	33	0.6462
	perLCC	0.54	33	0.4686
	perDCC	0.02	33	0.8769
	AvgWaterDepth	4.72	33	0.0372**
Northern Leopard Frog	Treatment	2.00	33	0.1180
	Year	0.17	33	0.8479
	Treatment*Year	0.03	33	1.0000
	perLCC	0.13	33	0.7245
	perDCC	0.89	33	0.3528
	AvgWaterDepth	0.97	33	0.3323
Dragonfly	Treatment	2.22	33	0.0882
	Year	5.93	33	0.0063**
	Treatment*Year	1.11	33	0.3847
	perLCC	2.12	33	0.1553
	perDCC	4.11	33	0.0507**
	AvgWaterDepth	0.01	33	0.9250

Damselfly	Treatment	0.58	33	0.6822
	Year	0.05	33	0.9507
	Treatment*Year	1.38	33	0.2417
	perLCC	0.83	33	0.3681
	perDCC	0.79	33	0.3814
	AvgWaterDepth	0.06	33	0.8011

Table 4: Average percent change in live cattail, dead cattail, open water, and other vegetation species after management methods were applied one (2015) and two year's (2016) post-treatment.

Treatment	**Year**	**Live Cattail**	**Dead Cattail**	**Open Water**	**Other Vegetation Spp.**
Chemical	2015	73% ↓	57% ↑	8 %↑	40% ↓
	2016	24% ↓	45% ↑	15% ↓	11% ↓
Chemical x Fire	2015	31% ↓	47% ↑	16% ↑	57% ↓
	2016	68% ↑	71% ↑	23% ↓	39% ↓
Fire	2015	68% ↑	8 % ↓	2 % ↓	41% ↓
	2016	54% ↑	3 % ↑	23% ↓	6 %↓
Mow	2015	12% ↑	33% ↓	14% ↓	15% ↑
	2016	4.65 ↓	45% ↑	43% ↓	57% ↑
Control	2015	79% ↑	26% ↑	52% ↓	31% ↑
	2016	87% ↑	47% ↑	55% ↓	1 % ↑

Table 5: Average percent change in bird species richness and individual species after management methods were applied one and two year's post-treatment.

Treatment	**Year**	**Bird Spp. Richness**	**Marsh Wren**	**Sedge Wren**	**Red-winged Blackbird**	**Swamp Sparrow**	**Common Yellowthroat**
Chemical	2015	3% ↓	70% ↓	35% ↓	62% ↓	18% ↑	81% ↑
	2016	1% ↑	56% ↓	27% ↓	5% ↑	57% ↑	120% ↑
Chemical x Fire	2015	20% ↓	59% ↓	38% ↓	90% ↑	4% ↑	31% ↓
	2016	4% ↑	12% ↓	28% ↓	157% ↑	17% ↑	14% ↓
Fire	2015	0.6% ↓	56% ↓	22% ↑	84% ↑	177% ↑	46% ↓
	2016	9% ↑	74% ↓	96% ↑	147% ↑	106% ↑	36% ↑
Mow	2015	13% ↓	0.5% ↑	92% ↓	9% ↓	118% ↑	62% ↓
	2016	27% ↓	35% ↓	93% ↑	34% ↓	431% ↑	693% ↑
Control	2015	2% ↑	28% ↓	33% ↓	16% ↑	2.57% ↑	32% ↑
	2016	17% ↓	32% ↓	63% ↓	38% ↑	108% ↓	18% ↑

Table 6: Average percent change in amphibian species richness, individual species, and invertebrates after management methods were applied one and two year's post-treatment.

Treatment	Year	Amphibian Spp. Richness	Boreal Chorus Frog	Northern Leopard Frog	Dragonfly	Damselfly
Chemical	2015	11% ↑	7% ↓	33% ↓	6% ↑	68% ↑
	2016	13% ↓	199% ↑	19% ↓	31% ↓	37% ↑
Chemical x Fire	2015	25% ↑	26% ↓	0.6%↑	45% ↓	23% ↓
	2016	14% ↑	32% ↑	30% ↓	54% ↓	45% ↓
Fire	2015	20% ↑	108% ↑	21% ↓	23% ↓	76% ↓
	2016	4% ↑	4% ↑	27%↓	63% ↓	2% ↑
Mow	2015	53% ↓	319% ↑	77% ↓	408% ↑	138% ↑
	2016	23% ↓	296% ↑	56% ↓	57% ↓	138% ↑
Control	2015	20% ↓	140% ↑	183% ↑	34% ↓	21% ↑
	2016	15% ↓	180% ↑	269% ↑	83% ↓	39% ↓

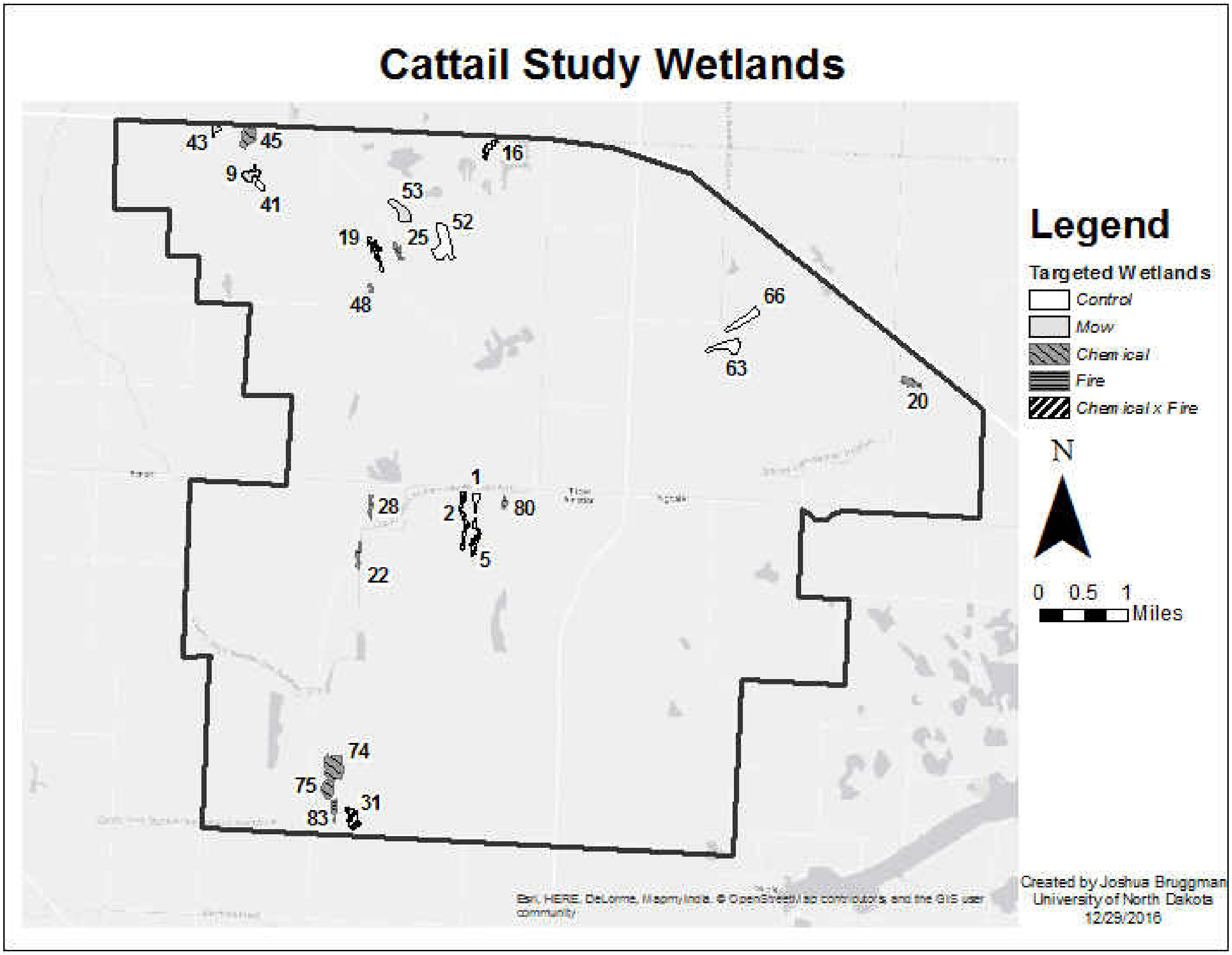


Figure 1: Glacial Ridge National Wildlife Refuge including study wetlands and cattail management.

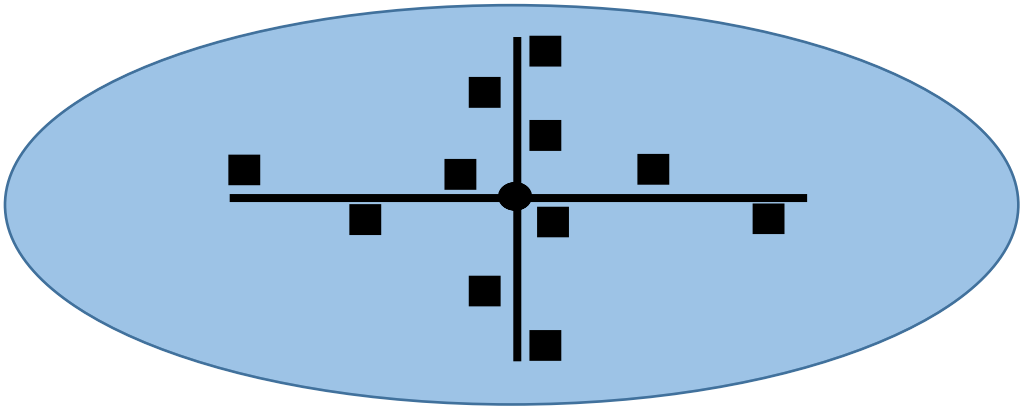


Figure 2: Vegetation survey diagram used for measuring vegetation at each wetland using a combination of 2 25-m line intercepts and 12 ¼-m^2 quadrats.

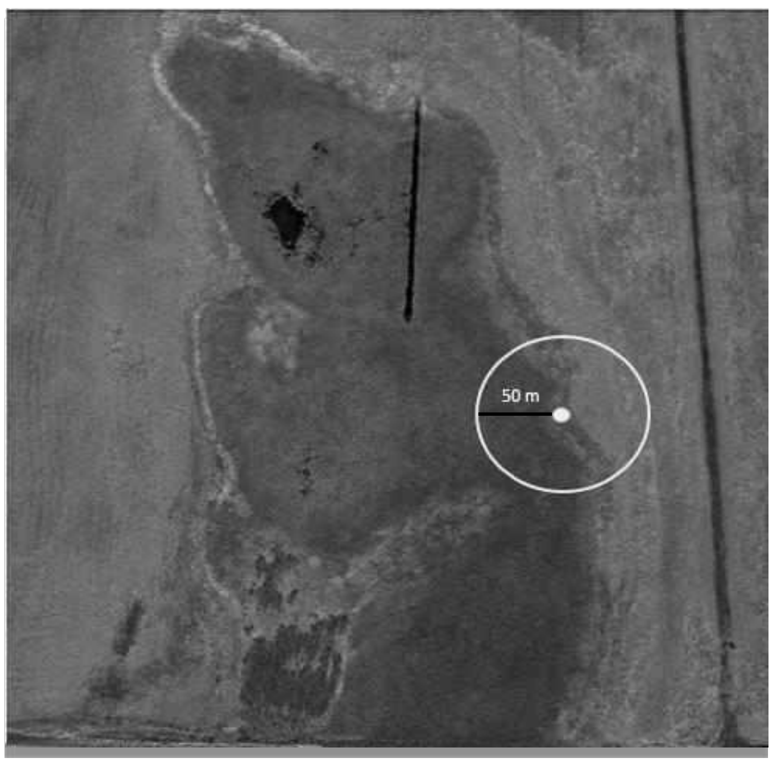


Figure 3: Example of a study wetland with a 50-m fixed-radius point count used to estimate avian species richness and abundance.

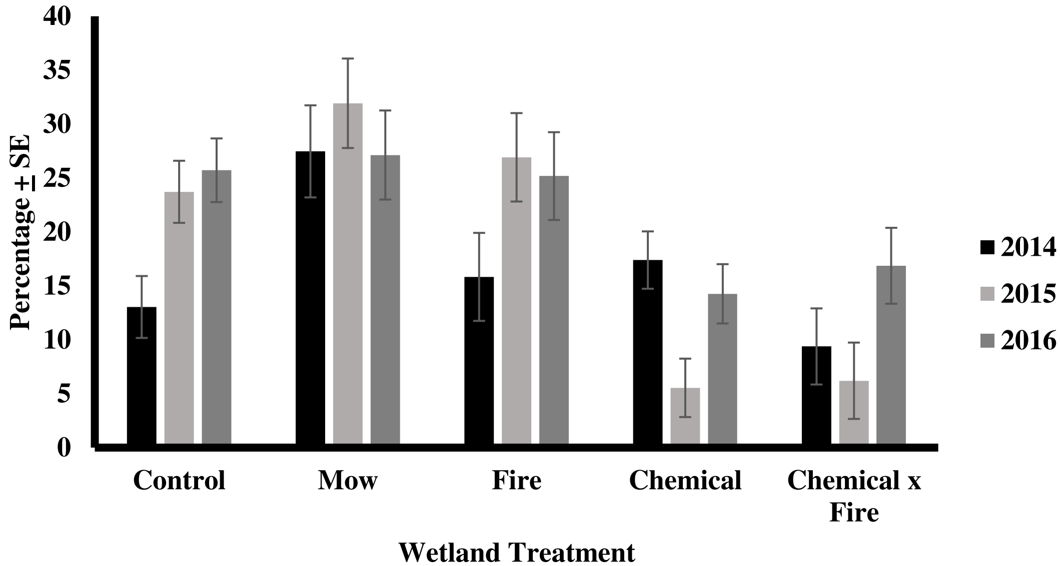


Figure 4: Proportion of live cattail relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

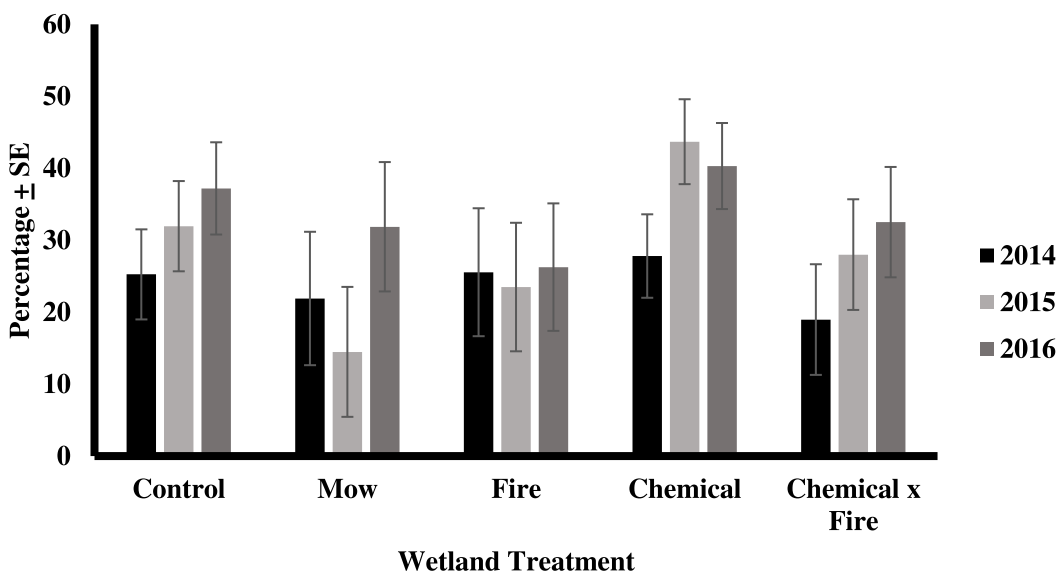


Figure 5: Proportion of dead cattail relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

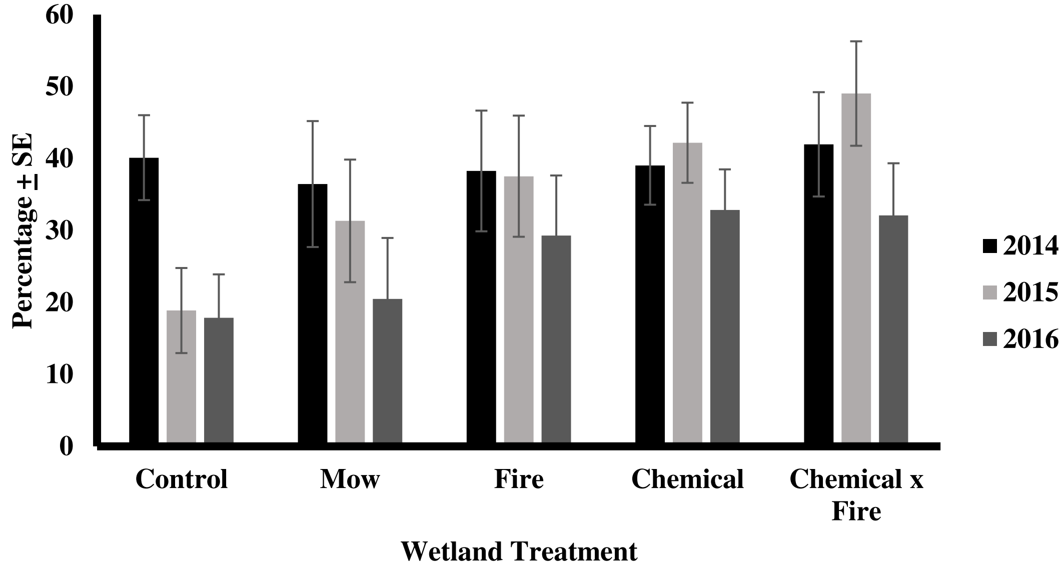


Figure 6: Proportion of open water relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

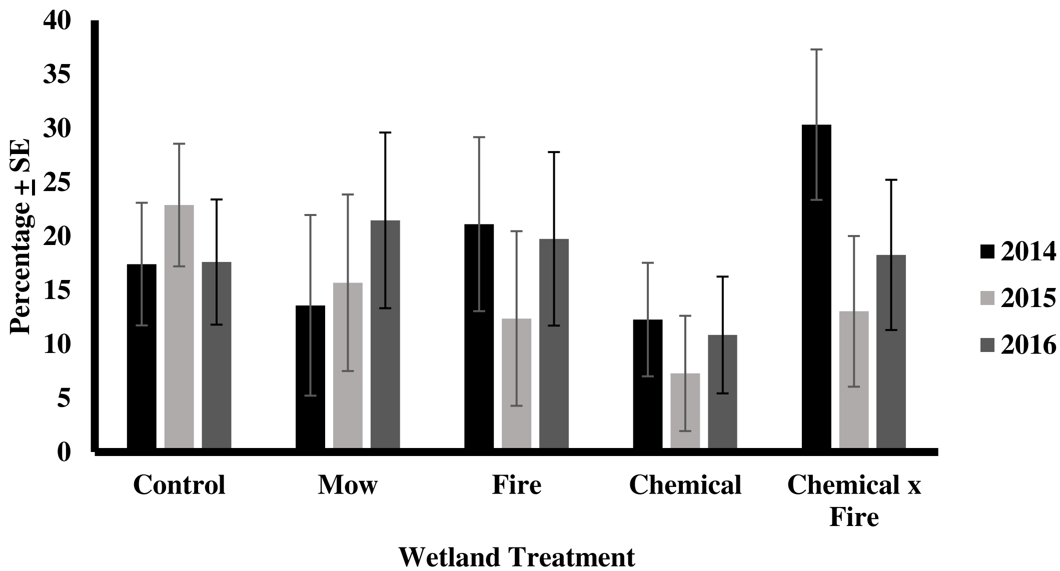


Figure 7: Proportion of other species of vegetation relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

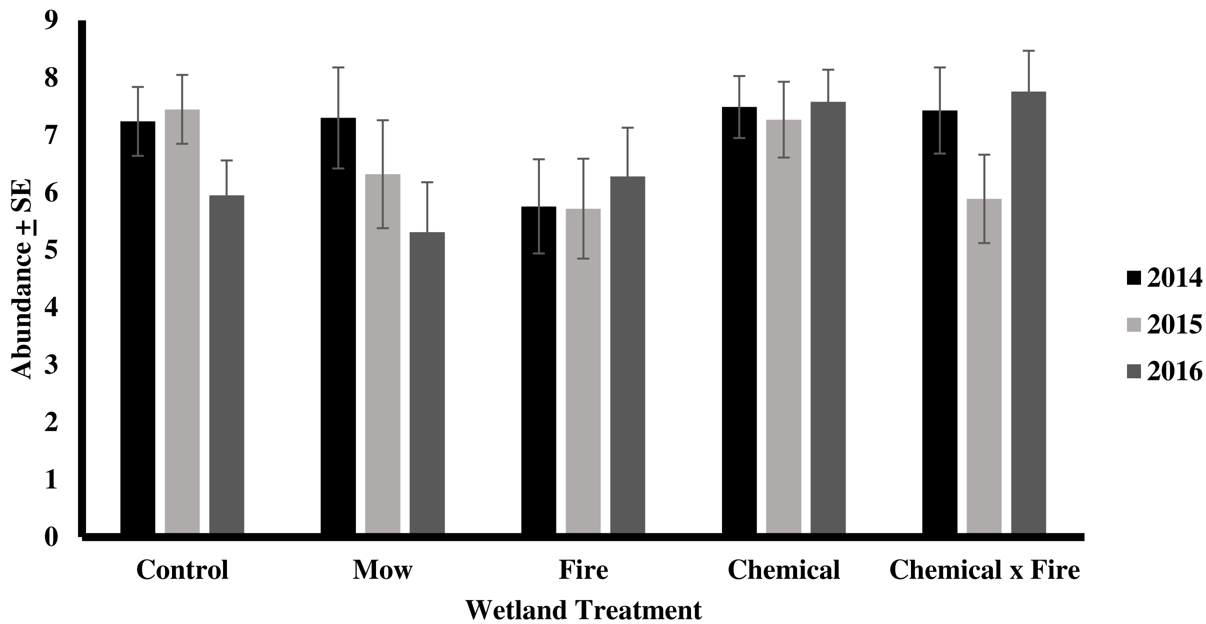


Figure 8: Bird species richness relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

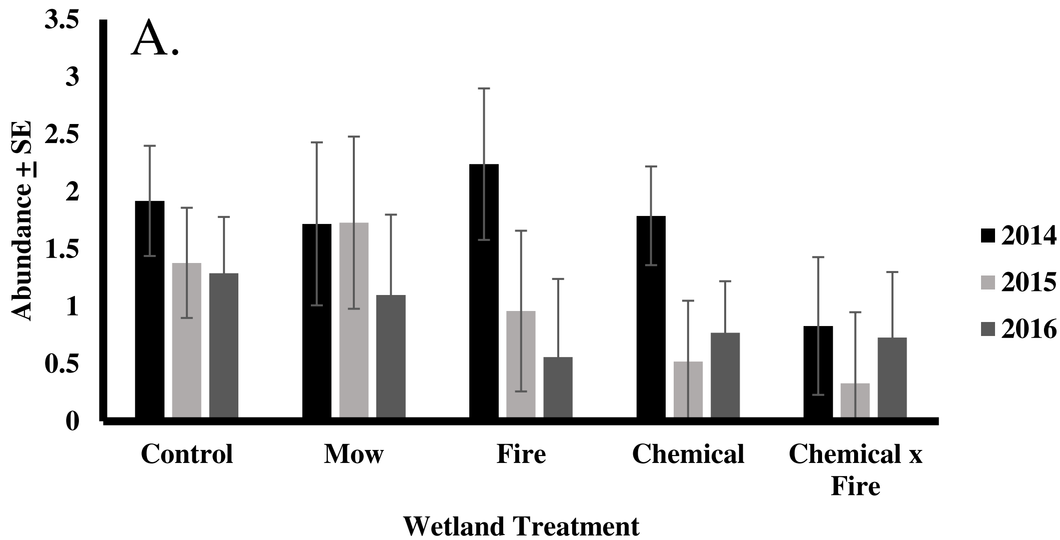
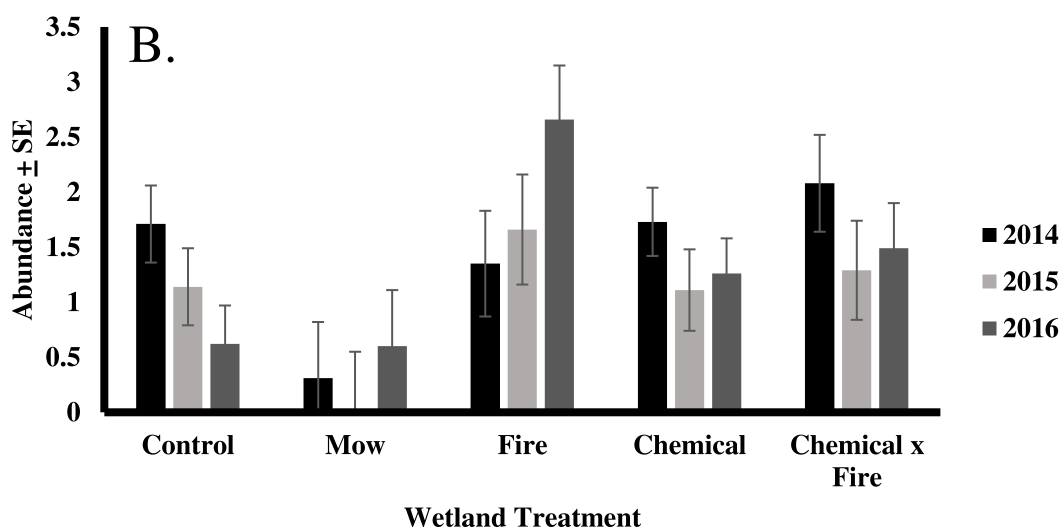


Figure 9: Abundance estimates of A. Marsh Wrens, B. Sedge Wrens, C. Swamp Sparrows, D. Red-winged Blackbirds, E. Common Yellowthroats relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).



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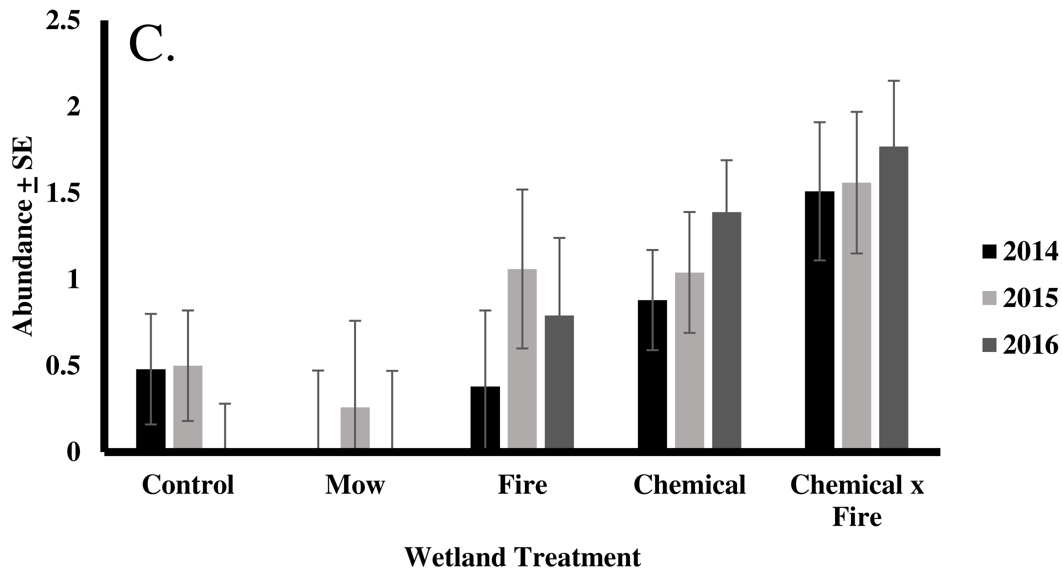

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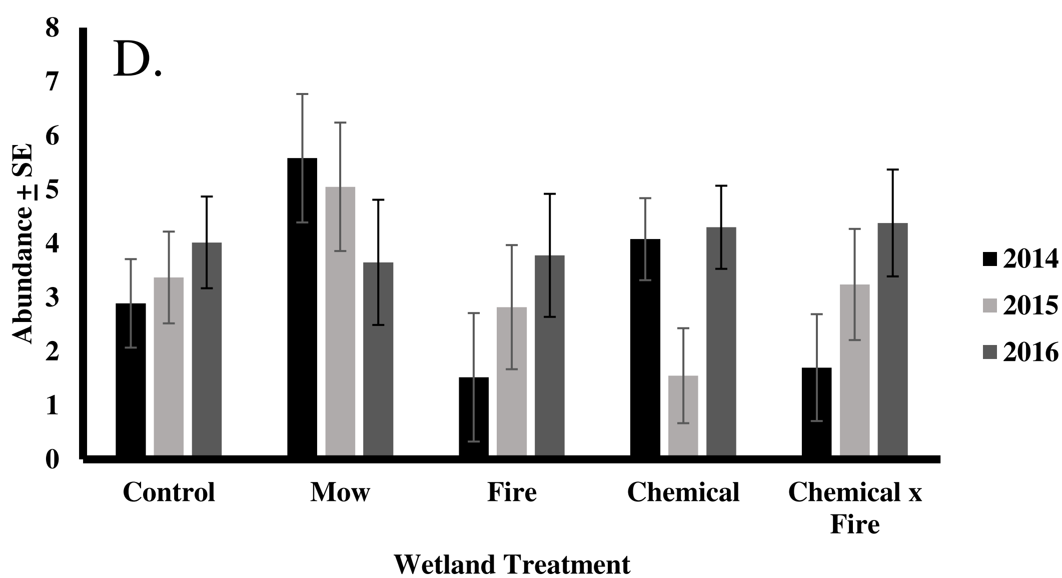

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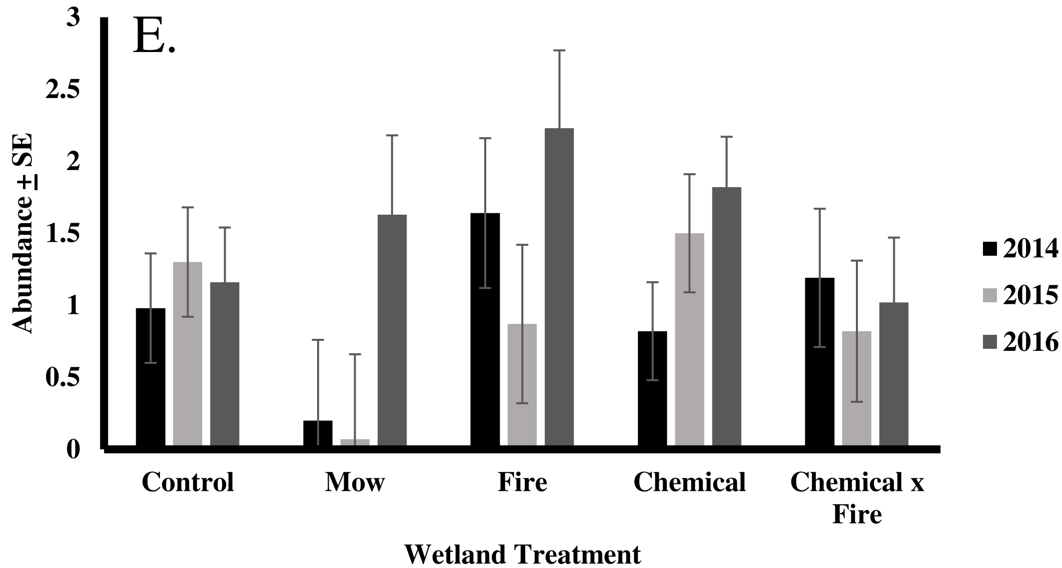

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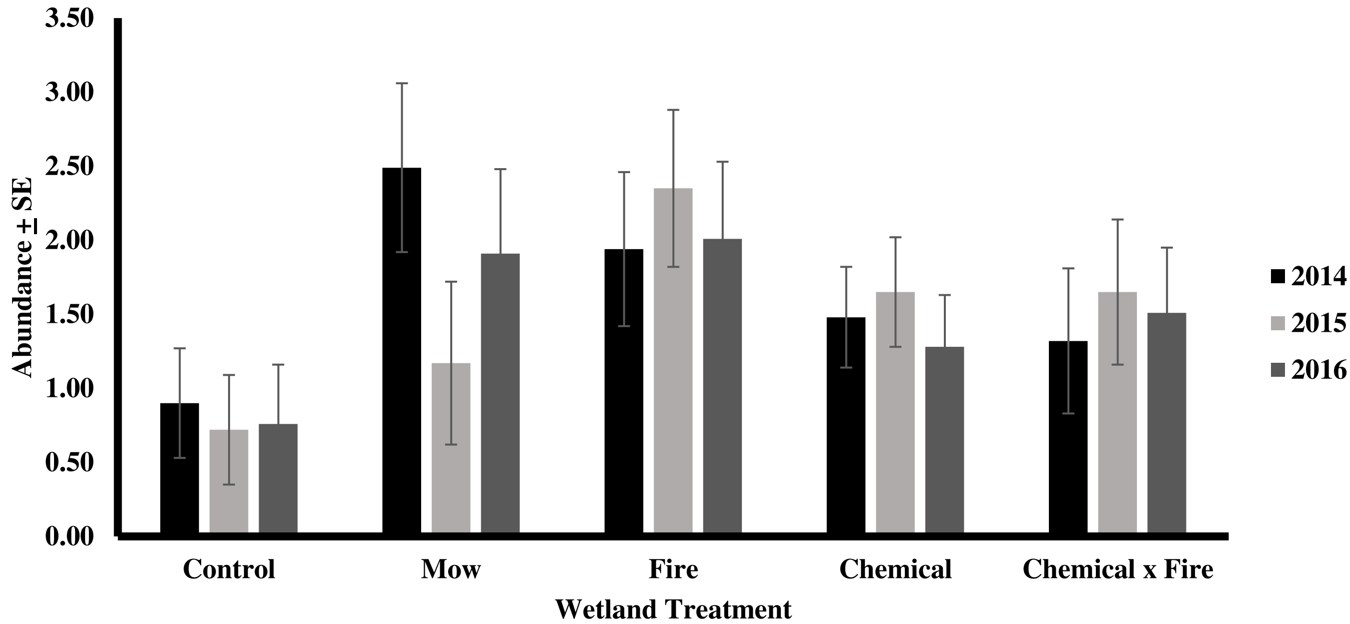

Figure 10: Amphibian species richness relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

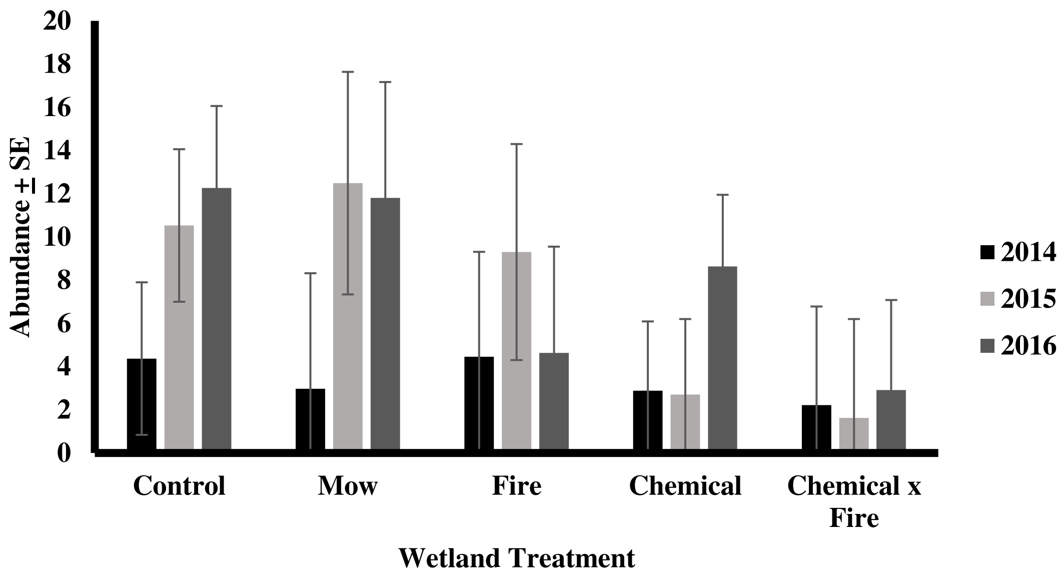

Figure 11: Boreal chorus frog abundance relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

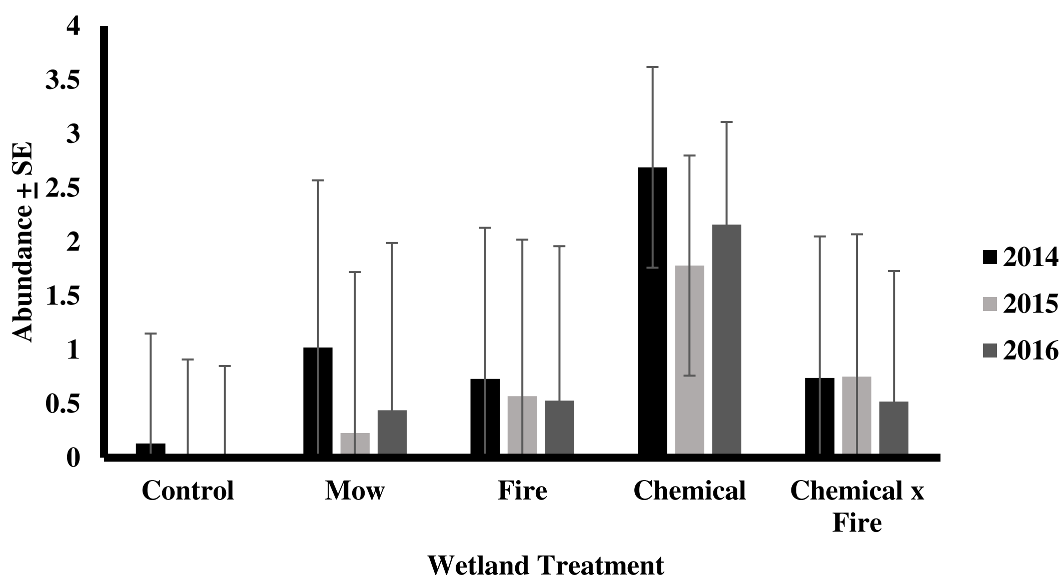

Figure 12: Northern leopard frog abundance relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

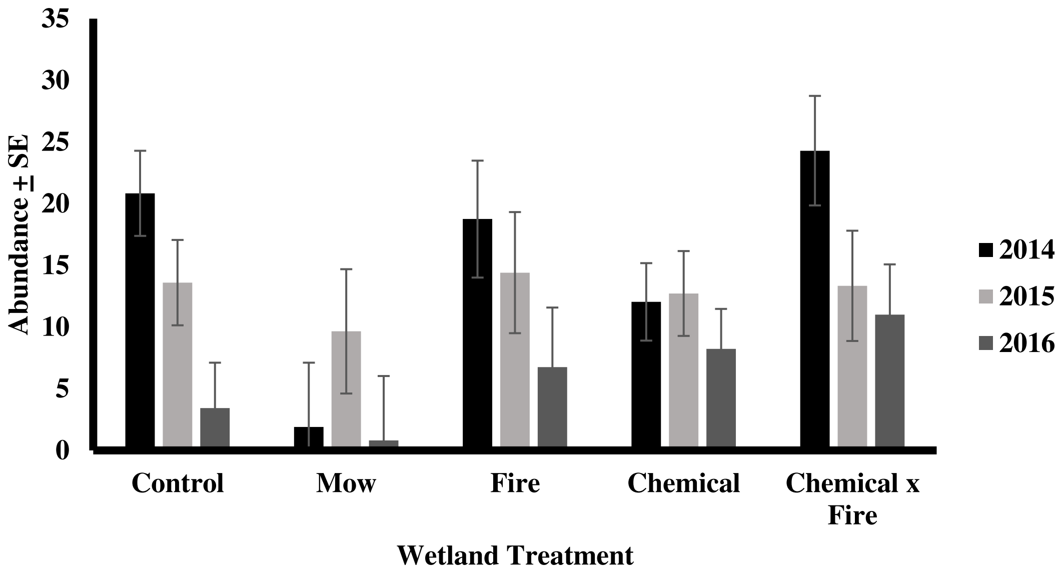

Figure 13: Dragonfly abundance relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

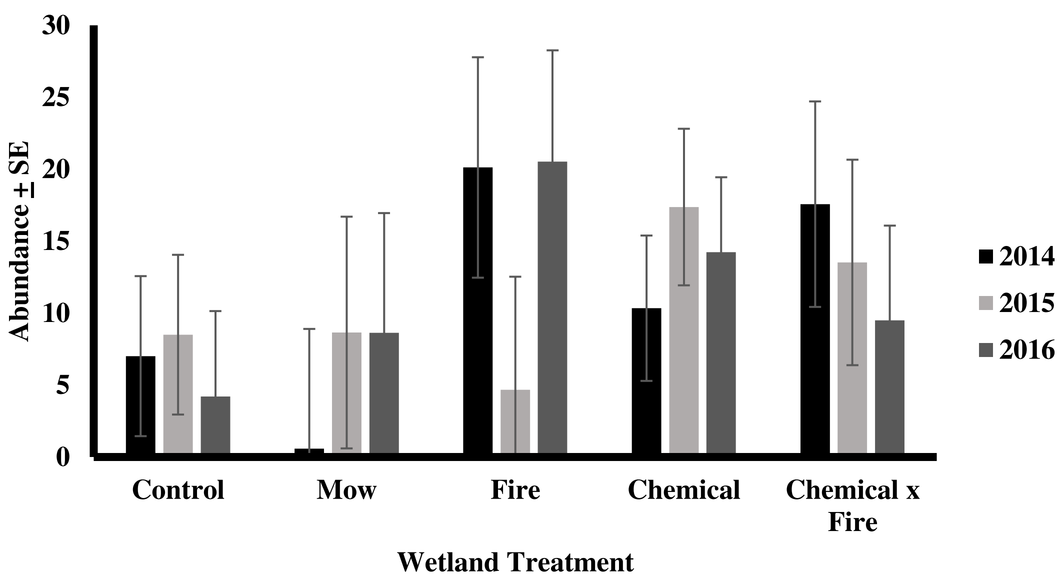

Figure 14: Damselfly abundance relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

CHAPTER III

SUMMARY AND CONCLUSIONS: WHAT SHOULD MANAGERS KNOW?

Wetlands are an integral part of North America's landscape. The benefits provided by wetlands include filtering nutrients and pollution, flood control, and a source for ground-water recharge (McCauley et al. 2015). These benefits also extend to wildlife and plants that utilize them as habitat. People derive income, recreation, and education from wetlands as well. However, wetland loss has been a concern with estimated losses in 1996 of more than 40 million hectares (Dahl and Allord 1996). In 2009, there was an estimated 44.6 million hectares of wetlands in the United States (Dahl 2010). From 2004–2009, there was also an estimated loss of 25,200 ha of wetlands. Wetland losses still happen today along with degradation in wetland quality. Wetlands can be diminished not only by human influence, but with invasive species such as cattails (Galatowitsch et al. 1999).

Cattails can destabilize local plant and animal diversity, create less open water, and degrade the overall habitat (Murkin et al. 1982). In the United States there are two species of cattail, broad-leaf (*Typha latifolia*) and narrow-leaf (*Typha angustifolia*). There is also a cross between broad-leaf and narrow-leaf cattail that has become an increasing problem (Shih and Finkelstein 2008). Hybrid cattail (*Typha x. glauca*), can spread to where both broad-leaf and narrow-leaf cannot (Smith 1967). Cattails can spread not only through seeds, but by rhizomes as well. Hybrid cattail produces mainly infertile seeds, but can also spread through rhizomes, making them especially difficult to control. The rapid spread and broad range of environmental tolerances of hybrid cattails has resulted in them excluding many native plant and animal species in wetlands. Consequently, many wetland managers are seeking ways to control the spread of cattails for a range of reasons.

We examined the impacts of cattail management on plant, bird, amphibian, and invertebrate communities in shallow wetlands in northwestern Minnesota. We assessed the effects of chemical, fire, mowing, and a no-management control on 23 study wetlands. Treatments were applied in the fall of 2014 after pre-treatment data were collected in the summer. We continued sampling in the summers of 2015 and 2016 to obtain two years of post-treatment data collection.

In summary, we found that percent live cattail decreased after chemical treatment (glyphosate) and chemical x fire. Other studies have found that glyphosate is effective at breaking up dense cattail stands (Comes and Kelley 1989, Linz et al. 1992, Solberg and Higgins 1993). Chemical application in our wetlands resulted in a 73% reduction one year after application and a 24% reduction two years after the pre-treatment year (Chapter 2). Although chemical x fire resulted in a decrease in live cattail one year after application, percent live cattail then increased 68% from the pre-treatment stage. Fire alone increased the amount of live cattail one year post-treatment (Chapter 2). According to Smith and Kadlec (1985), a single burn was not effective at reducing overall cattail production. There was a significant increase in cattail density two years after fire was used (Ponzio et al. 2004). We also observed increases in percent live cattail both one (68%) and two (54%) years post-treatment. These results suggest that a single management action may not be enough to control cattails. While fire may seem like an appropriate tool, it may actually promote cattail growth.

Murkin et al. (1982) proposed a hemi-marsh concept, a 50:50 ratio between vegetation and open water, as best for birds with a specific focus on waterfowl. Most cattail management seeks to open up wetlands; thus, increasing open water is often a key management objective. Similar to other studies, we found that chemical and chemical x fire trended to increase open water (Chapter 2; Linz et al. 1996a, Linz et al. 1996b). However, the percent change in open water after chemical application only increased 8% followed by a 15% decrease after two years from the baseline. Similarly, we observed a 16% increase in open water one year post-treatment, but this was rapidly reduced 23% from the baseline after two years. To increase the amount of open water in a wetland, repeated use of a cattail control method appears to be necessary. The proportion of other species in our wetlands trended to decrease with chemical, fire, and chemical x fire (Chapter 2). Like other research, the application of chemicals reduced other species of plants (Lawrence et al. 2015) even though it was beneficial in reducing cattails. Fire reduced the amount of other species of plants in our study. Although we did not manipulate water levels, draining a wetland followed by a summer burn can reduce cattail and increase species diversity (Mallik and Wein 1986). We only observed an increase in other species of vegetation following mowing for both years (Chapter 2). Therefore, to increase species diversity, the use of chemicals and fire may not promote this initially and may require longer periods of monitoring.

Frequently, management objectives focus on increased species richness for wildlife; however, bird species richness was not impacted by the treatments (Chapter 2).

Mowing had the greatest percent change, but not positively, in bird species richness with a decrease of 13% in 2015 and 27% in 2016 from the pre-treatment year. Research focused on waterfowl has found increases in waterfowl species numbers after cutting cattail stems (Murkin et al. 1982); however, our sampling methods were less appropriate for monitoring changes in waterfowl use. Further, we may not have been able to detect large changes in bird species richness due to individual species' responses to treatments. Some species, such as marsh wrens, need intact cattail cover specifically for nest building and foraging (Leonard and Picman 1987). As a result, management methods that reduce cattail and other wetland vegetation cover would negatively affect species like marsh wrens and was supported by our results. After chemical application, marsh wrens decreased 70% after one year and 56% after two years (Chapter 2). Fire also reduced marsh wren abundance 56% after one year and then 74% after two years. Similar results have been found where marsh wren densities were reduced after the application of chemicals (Linz et al. 1996b) and in post burned sites no nests were present one year after fire was used (Saenz 1994). Thus, species like marsh wrens may actually benefit from the dense stands of cattail in wetlands.

There were similar trends with red-winged blackbirds after chemical application (Chapter 2). One year after chemical application red-winged blackbirds were reduced 62% from their original status. The use of chemicals to disperse blackbirds has been done to fragment cattail-dominated wetlands near crops, such as sunflowers (Linz et al. 1996b, Linz and Homan 2011). We found red-winged blackbird abundance was related to the presence of dead cattail stems. This makes sense since they utilize cattails for building nests (Bernstein and McLean 1980). If there is a desire to decrease blackbirds in wetlands, chemicals can be an effective means. Interestingly, following chemical x fire and fire, there were large percent increases in red-winged blackbird abundance. Since fire removed all of the standing cattail material, there should have been a reduction in blackbird abundance. However, red-winged blackbirds could be using the wetlands for foraging instead of nesting if there was an increase in food availability.

Similar to marsh wrens and red-winged blackbirds, common yellowthroats and sedge wrens inhabit dense cover for nesting (Lowther 1993, Stewart 1953, Walkinshaw 1935). Sedge wrens and common yellowthroats both make their nests out of similar materials, placed on or near the ground (Stewart 1953, Reinert and Golet 1979). We found that fire and mowing reduced common yellowthroat abundance in the wetlands (Chapter 2). These results were followed by an increase in common yellowthroat abundance two years after fire and mowing were applied. Since common yellowthroats prefer dense cover, these treatments may have produced this cover two years post-treatment. Fire tended to increase sedge wren abundance overall, while mowing decreased it one year post-treatment. Like common yellowthroats, sedge wrens may have preferred the dense regrowth of vegetation caused by fire and mowing. Swamp sparrows are a generalist wetland species, inhabiting areas either with or not far from water (Erskine 1984). We found they increased after any management disturbance, while the control wetlands had simultaneous declines 2-years post treatment.

Treatments that increase cover, especially 2-years post treatment, were beneficial to common yellowthroats and sedge wrens. These treatments were important to note since fire increased the proportion of live cattail and mowing did slightly. Fire removed all of the live and dead material, allowing more dense vegetation to regrow two years later. Mowing created lots of litter, which in turn made denser cover. For a treatment to benefit common yellowthroats or sedge wrens, creating dense cover on the edges of wetlands will benefit these species. Swamp sparrows benefited from all of the treatment management actions; this could be due to their generalist habitat preferences.

Overall, the use of fire increased the abundance of four individual species while decreasing abundance for one, marsh wrens. The use of chemicals (glyphosate) benefited three species, while decreasing marsh wrens and sedge wrens. Mowing had variable results for individual species; chemical x fire decreased three species abundances while increasing swamp sparrows and red-winged blackbirds. Swamp sparrows and red-winged blackbirds share a common trait of being wetland generalist species. These two species may have taken advantage of the chemical x fire treatment by utilizing treated areas more. Knowing how these management actions affect individual wetland bird species can aid in better decisions when selecting treatments, especially considering the niche of sensitive or species of specific interest.

Similar to bird species richness, we found amphibian species richness was not impacted by the treatments (Chapter 2). The use of glyphosate in other studies resulted in a 70% decline in amphibian species richness (Relyea 2005). We did not find this in our study, even though chemicals may still play a role in amphibian species richness. For boreal chorus frogs, the greatest percent change was found after mowing (Chapter 2). One year after mowing, boreal chorus frog abundance increased 319% from the original status in the wetland. Mowing could benefit boreal chorus frogs by creating more cover for feeding or hiding in various developmental stages. Shulse (2011) found a positive relationship between more vegetative cover and forage provided by mowing for boreal chorus frogs. Dragonflies decreased in both post-treatment years with chemical x fire and fire. But we did not see a drastic decrease in dragonflies with chemical application (Chapter 2). These species can experience time lags for any effects to be detected from treatments so long-term monitoring of wetlands with Odonata are likely required to determine responses (Elo et al. 2015).

We used a community-based approach to sample wetlands that provides a more complete evaluation of how the various treatments used affect each ecological level in a wetland. The primary management objective, however, is to control the cattail coverage in the wetland. We observed chemicals reduced cattails and fire increased them. A single management approach may not be effective to control cattails. Using two treatments or a single treatment more frequently may better control cattails in wetlands, since we observed quick returns to pre-treatment levels two years after management actions were applied. Timing of treatment application is also critical to controlling cattails and must be considered when making management decisions. All of our treatments occurred in fall. Conducting a management effort in June when carbohydrate reserves in rhizomes are low may yield a more effective control (Linde et al. 1976). Further, cattail rhizomes need oxygen to survive. Cutting cattails below the water's surface to drown the stems can kill rhizomes (Murkin et al. 1982). However, challenges can arise with this since equipment can get stuck if conditions for cutting cattails are not right. When cattails are sprouting seed heads can be another good time to apply management. If you can combine phenological traits, like when the spike heads emerge, and when carbohydrate reserves are low, control of cattail will likely be more effective and efficient (Linde et al. 1976).

One area of emerging research focuses on removing cattails from a wetland by harvesting. Removal of cattail litter in the wetland reduces nutrients. Farrer and Goldberg (2014) found that adding hybrid cattail litter to a native marsh decreased native richness and abundance of plant species. Removing litter reversed these effects, suggesting this is a key component to restoring cattail-dominated wetlands. Litter also affects the amount of light, temperature, and plant biomass (Larkin et al. 2012). Live cattails can interact with the dead material to increase the rate of invasion (Tuchman et al. 2009). This is true for both hybrid cattail and narrow-leaf cattail.

Thus, in an effort to remove dead material, cutting of cattails followed by the removal of the material may improve a manager's ability to rejuvenate a wetland. One way to do this is by harvesting cattails; the nutrients captured by cattails are removed with the litter, helping to slow the cycle of invasion (Larkin et al. 2012, Tuchman et al. 2009, Lawrence et al. 2015). Once the harvested material is removed, there are multiple potential uses for cattails. Converting the harvested material into pellets or cubes for home heating stoves is one use (Grosshans 2014). Once the pellets are burned, the ash from the material could also be used as a soil amendment for cropland. Since cattails readily take up nutrients, such as phosphorus, it would be beneficial to not only people, but also wildlife. Developing a life cycle analysis of how to use cattails for multiple uses and benefits is essential. This concept could guide future management decisions, thus exploiting a full range of opportunities. We did not examine this management action; however, equipment was explored to facilitate the removal of cattail litter for harvest (Svedarsky et al. 2016). Finding the right approach to control cattail-choked wetlands is challenging and complex, making it difficult to meet multiple management objectives with a single treatment.

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APPENDIX

Table 7: Average percent cover of plant species encountered in line intercept (dominant plants) and quadrat (all species composition) vegetation surveys during the summers of 2014, 2015, and 2016 field seasons.

Species	2014 Intercept % Cover	2014 Quadrat % Cover	2015 Intercept % Cover	2015 Quadrat % Cover	2016 Intercept % Cover	2016 Quadrat % Cover
Agropyron smithii	0.00	0.00	0.00	0.00	0.00	0.00
Agrostis hyemalis	0.00	0.00	0.00	0.00	0.00	0.00
Alisma subcordatum	0.00	0.00	0.00	0.00	0.05	0.34
Alopecurus aequalis	0.19	0.13	0.24	1.18	0.05	0.20
Anemome canadensis	0.00	0.00	0.00	0.00	0.00	0.00
Apocynum cannabinum	0.00	0.00	0.00	0.00	0.00	0.00
Asclepias incarnata	0.05	0.14	0.02	0.05	0.00	0.00
Asclepias sullivantii	0.04	0.07	0.02	0.02	0.01	0.05
Asclepias syriaca	0.00	0.00	0.00	0.00	0.00	0.00
Beckmannia syzigachne	0.00	0.00	0.00	0.00	0.00	0.00
Cicuta maculata	0.00	0.00	0.00	0.00	0.03	0.09
Calamagrostis canadensis	0.05	0.04	0.00	0.00	0.01	0.00
Calamagrostis stricta	0.00	0.00	0.00	0.00	0.00	0.00
Carex amphibola	0.00	0.00	0.00	0.00	0.00	0.00
Carex aquatilis	0.10	0.00	0.02	0.05	0.00	0.00
Carex emori	0.00	0.00	0.00	0.00	0.00	0.00
Carex lacustris	2.23	0.54	0.43	1.54	0.00	0.00
Carex lurida	0.65	1.79	0.00	0.14	0.00	0.00
Carex sp.	0.00	0.00	0.00	0.00	0.00	0.00
Carex retrosa	1.58	1.16	0.07	0.27	0.36	1.70
Carex tenera	0.01	0.02	0.00	0.00	0.00	0.00
Carex utriculata	0.02	0.02	0.00	0.00	0.00	0.00
Carex viridula	0.37	0.34	0.00	0.00	0.00	0.00
Cinna latifolia	0.00	0.00	0.00	0.00	0.00	0.00
Cirsium arvense	0.00	0.00	0.00	0.00	0.00	0.00
Cirsium sp.	0.09	0.02	0.01	0.07	0.05	0.13
Deschampsia cespitosa	0.00	0.00	0.00	0.00	0.00	0.00
Echinochloa crusgalli	0.00	0.00	0.00	0.00	0.00	0.00
Eleocharis acicularis	0.00	0.00	0.00	0.00	0.00	0.00
Eleocharis compressa	0.00	0.00	0.00	0.00	0.00	0.00
Eleocharis palustris	0.00	0.00	0.00	0.00	0.00	0.00
Equisetum fluviatile	1.13	1.05	0.39	2.35	0.38	2.43
Equisetum hyemale	0.00	0.00	0.00	0.00	0.00	0.00
Equisetum palustre	0.00	0.00	0.00	0.00	0.00	0.00
Equisetum arvense	0.30	0.14	0.09	0.24	0.00	0.00
Erigeron philadelphicus	0.01	0.00	0.00	0.00	0.00	0.00
Galium trifidum	0.00	0.00	0.00	0.00	0.09	0.38

Poaceae sp.	0.00	0.00	0.00	0.00	0.00	0.00
Hordeum jubatum	0.00	0.00	0.00	0.00	0.00	0.00
Lathyrus palustris	0.00	0.00	0.00	0.00	0.01	0.00
Latuca sp.	0.00	0.00	0.00	0.00	0.01	0.00
Lemna trisulca	0.00	0.00	0.00	0.00	0.00	0.00
Lemna sp.	0.00	0.00	0.00	0.00	0.00	0.00
Leersia oryzoides	0.00	0.00	0.02	0.20	0.07	0.42
Lycopus americanus	0.00	0.00	0.07	0.54	0.00	0.00
Lycopus uniflorus	0.00	0.00	0.00	0.00	0.00	0.00
Juncus arcticus	0.13	0.14	0.04	0.14	0.02	0.18
Juncus balticus	0.00	0.00	0.00	0.00	0.00	0.00
Juncus brevicaudus	0.64	0.56	0.00	0.00	0.00	0.00
Juncus canadensis	0.00	0.00	0.16	0.58	0.11	1.07
Juncus torreyi	0.00	0.00	0.00	0.00	0.00	0.00
Juncus nodosus	0.01	0.00	0.00	0.00	0.00	0.00
Juncus sp.	0.00	0.00	0.00	0.00	0.00	0.00
Mentha arvensis	0.50	1.30	0.00	0.00	0.00	0.00
Menyanthes trifoliata	0.27	0.02	0.00	0.00	0.00	0.00
Muhlengbergia richardonis	0.06	0.11	0.00	0.00	0.01	0.00
Moss	0.00	0.00	0.00	0.00	0.01	0.04
Panicum virgatum	0.00	0.00	0.00	0.00	0.00	0.00
Phalaris arundinacea	3.89	7.03	0.25	3.19	0.48	2.50
Phragmites sp.	0.03	0.00	0.00	0.00	0.00	0.00
Plantago sp.	0.86	1.23	0.13	0.60	0.20	1.12
Poa pratensis	0.01	0.00	0.00	0.00	0.00	0.00
Poa palustris	0.00	0.00	0.00	0.00	0.00	0.00
Polygonum amphibia	0.00	0.00	0.00	0.00	0.00	0.00
Populus balsamifera	0.03	0.02	0.00	0.00	0.00	0.00
Populus deltoides	0.63	0.62	0.04	0.22	0.07	0.22
Potamogeton natans	0.00	0.00	0.00	0.00	0.00	0.00
Potamogeton pectinatus	0.08	0.00	0.02	0.00	0.05	0.00
Potamogeton sp.	0.07	0.02	0.00	0.00	0.00	0.00
Potamogeton strictifolius	0.17	0.09	0.00	0.00	0.00	0.00
Potentilla anserina	0.00	0.00	0.00	0.00	0.00	0.00
Ranunculus acris	0.00	0.00	0.00	0.00	0.00	0.00
Ranunculus cymbalarea	0.00	0.00	0.00	0.00	0.00	0.00
Ranunculus scleratus	0.00	0.00	0.00	0.00	0.00	0.00
Rorippa palustris	0.00	0.00	0.00	0.00	0.00	0.00
Rumex crispus	0.00	0.00	0.00	0.00	0.00	0.00
Rumex fueginus	0.00	0.00	0.00	0.00	0.00	0.00
Rumex stenophyllus	0.00	0.00	0.00	0.00	0.00	0.00

Sagittaria graminea	0.00	0.00	0.00	0.00	0.00	0.00
Salix amygdaloides	0.00	0.00	0.00	0.00	0.00	0.00
Salix bebbiana	0.02	0.00	0.00	0.00	0.00	0.00
Salix exigua	0.37	0.09	0.00	0.00	0.00	0.00
Salix petiolaris	0.00	0.00	0.00	0.00	0.00	0.00
Salix serissima	0.00	0.00	0.00	0.00	0.04	0.00
Salix discolor	0.10	0.00	0.00	0.00	0.00	0.00
Salix sp.	0.00	0.00	0.00	0.00	0.00	0.00
Scirpus sp.	0.13	0.05	0.03	0.00	0.20	0.49
Scirpus acutus	0.00	0.00	0.01	0.00	0.01	0.02
Scirpus atrovirens	0.04	0.00	0.00	0.00	0.00	0.00
Scirpus fluviatilis	0.00	0.00	0.00	0.05	0.23	0.72
Scirpus maritimus	0.01	0.02	0.02	0.00	0.00	0.00
Scirpus validus	0.13	0.04	0.08	0.13	0.05	0.09
Scolochloa festucacea	0.00	0.00	0.00	0.00	0.00	0.00
Silene latifolia	2.84	1.76	0.20	0.53	0.05	0.11
Sium suave	0.00	0.00	0.00	0.00	0.00	0.00
Sparganium eurycarpum	0.00	0.00	0.00	0.00	0.00	0.00
Spartina pectinata	0.00	0.00	0.00	0.00	0.00	0.00
Spirodela polyrhiza	0.00	0.00	0.00	0.00	0.00	0.00
Stuckenia pectinata	0.06	0.02	0.05	0.05	0.00	0.00
Unknown forb	0.03	0.07	0.00	0.00	0.13	1.00
Utricularia intermedia	0.08	0.02	0.00	0.00	0.00	0.00

In our vegetation data collection, we used line transects to assess dominant plant species cover. Figures 15–18 represent the results from the line transects, which are not used in the chapters. These figures are based on dominant species present.

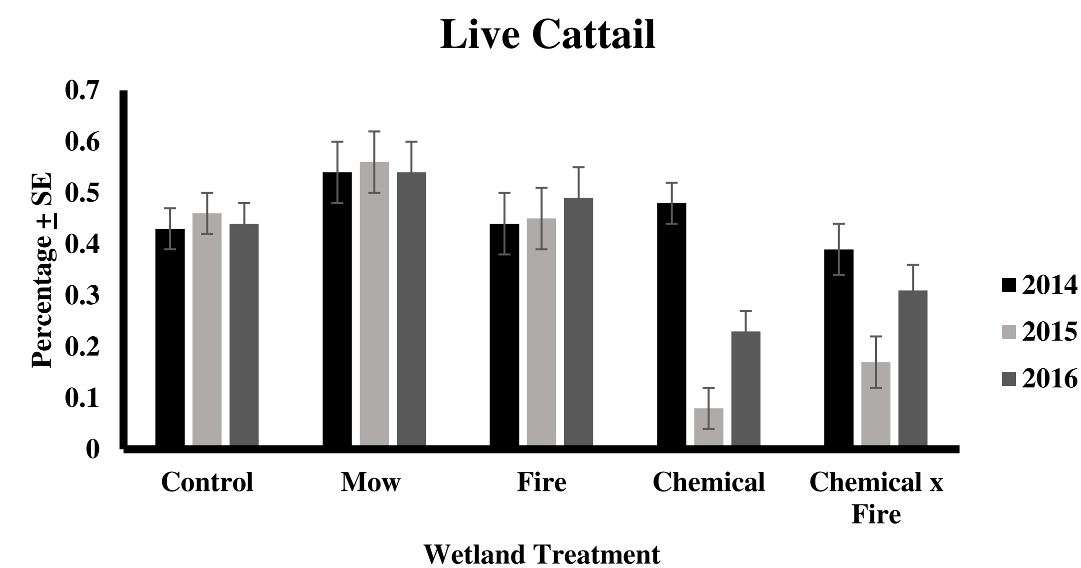

Figure 15: Live cattail relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

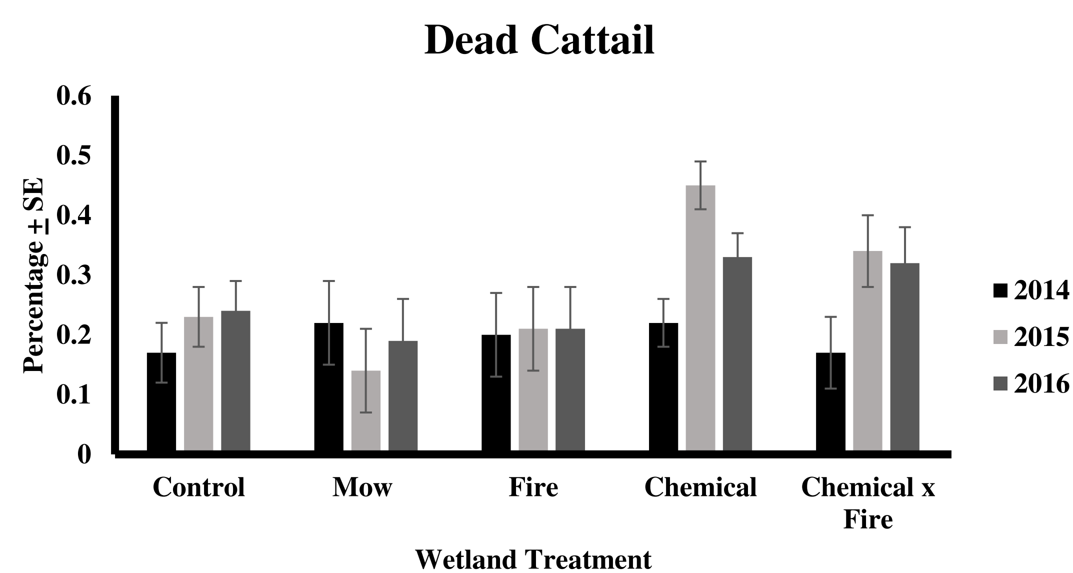

Figure 16: Dead cattail relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

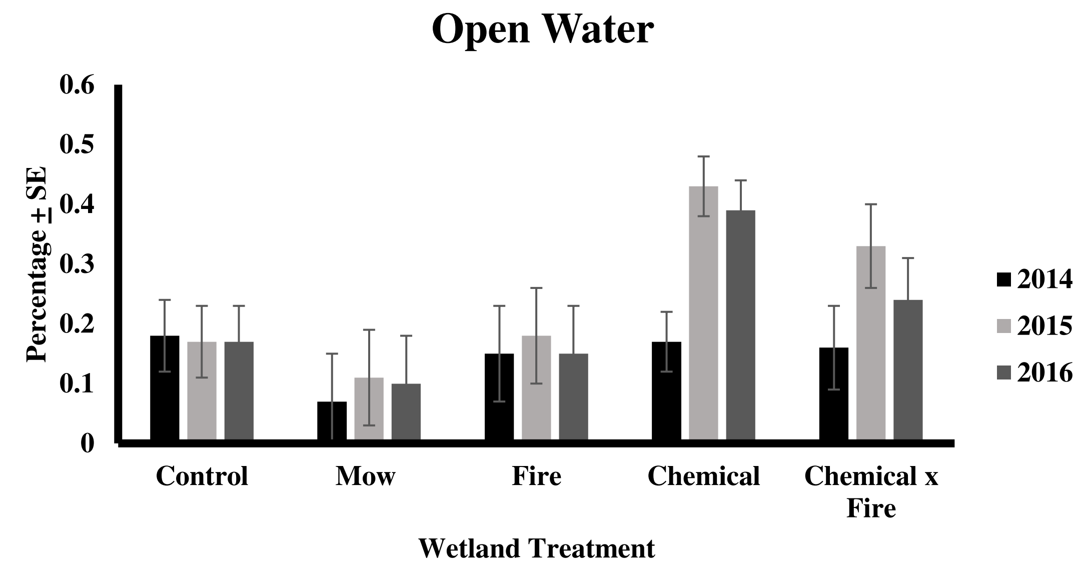

Figure 17: Open water relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

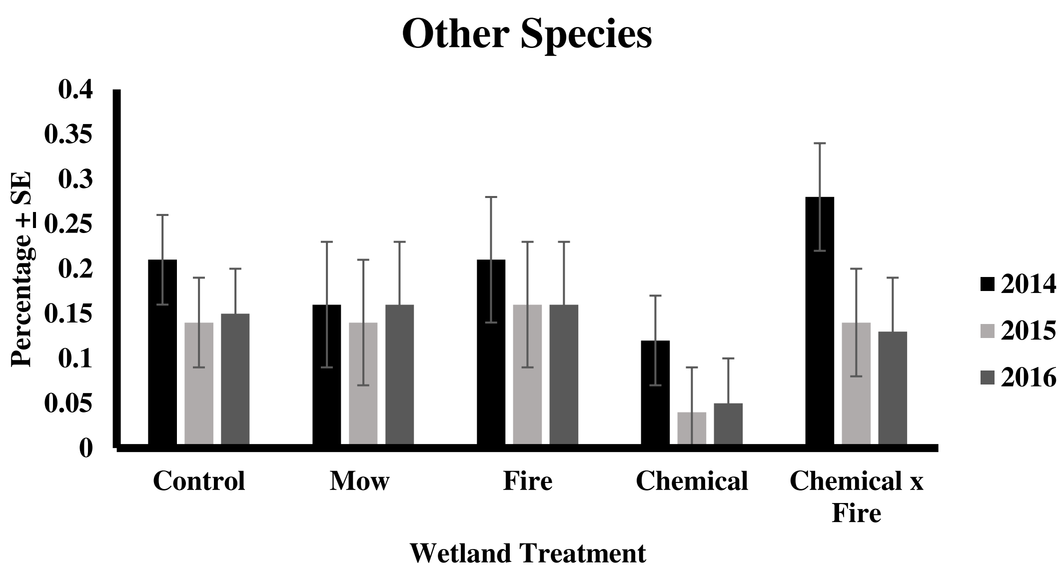

Figure 18: Other species of vegetation relative to each cattail management treatment between 2014 (pre-treatment) and 2015–2016 (post-treatment) at Glacial Ridge NWR (*n*=23).

Table 8: Bird species and number of individuals recorded in all wetlands during the field seasons of 2014, 2015, and 2016.

Common Name	**2014: Number of Individuals**	**2015: Number of Individuals**	**2016: Number of Individuals**
American Bittern	2	8	2
American Robin	0	5	0
American Goldfinch	5	8	23
Baltimore Oriole	0	0	1
Bank Swallow	3	0	4
Barn Swallow	4	13	5
Brown-headed Cowbird	0	6	9
Black Tern	5	20	25
Brewer’s Blackbird	0	2	11
Bobolink	58	33	57
Blue-winged Teal	5	2	4
Canada Goose	32	1	4
Canvasback	0	2	0
Clay-colored Sparrow	34	11	51
Cliff Swallow	12	0	0
Common Grackle	2	0	6
Chipping Sparrow	0	30	1
Common Yellowthroat	50	49	71
Eastern Kingbird	0	0	6
Gadwall	2	8	0
Gray Catbird	1	0	1
Green Heron	1	0	0
Green-winged Teal	0	0	2
Grasshopper Sparrow	9	13	0
Killdeer	1	7	7
Least Bittern	0	0	1
Le Conte's Sparrow	12	0	6
Mallard	19	12	22
Marsh Wren	54	25	62
Mourning Dove	5	0	7
Nelson’s Sparrow	0	0	2
Northern Harrier	3	1	3
Northern Shoveler	5	8	3
Northern Pintail	1	0	0
Northern Flicker	0	1	0
Greater Prairie Chicken	0	1	0
Red-winged Blackbird	177	194	219
Redhead	0	2	0
Sandhill Crane	1	1	6
Savannah Sparrow	44	21	43

Sedge Wren	69	41	53
Sora	16	18	3
Song Sparrow	1	7	11
Swamp Sparrow	26	31	37
Tree Swallow	1	4	6
Trumpeter Swan	1	7	14
Upland Sandpiper	2	0	0
Vesper Sparrow	0	0	1
Wilson’s Phalarope	5	2	0
Western Meadowlark	2	0	1
Wilson's Snipe	22	27	22
Wood Duck	0	0	3
Yellow-headed Blackbird	19	14	15
Yellow Warbler	8	17	4
Unknown	0	4	1
Total Species: 43	**Total Individuals: 727**	**Total Individuals: 656**	**Total Individuals: 838**

Table 9: Amphibian species and number captured in all wetlands during the summers of 2014, 2015, and 2016.

Species Captured	**2014: Number of Individuals Pre-treatment**	**2015: Number of Individuals 1-year post-treatment**	**2016: Number of Individuals 2-year post-treatment**
Boreal Chorus Frog	137	294	259
Northern Leopard Frog	41	34	33
Wood Frog	2	9	21
Hyla spp.	13	17	5
Toad spp.	9	23	5
Eastern Tiger Salamander	1	1	0
Total:	203	378	323