Best Management Practices For Rainwater Basin Wetlands

A contribution to the

Rainwater Basin Joint Venture Implementation Plan

By the Rainwater Basin Joint Venture

Public Lands Workgroup

July 2016

CONTENTS

HANDBOOK PURPOSE

This handbook updates the "Best Management Practices for Rainwater Basin Wetlands Handbook" (RWBJV 1994). The recommendations presented in this update are a product of the habitat assessments, management tracking, and vegetation monitoring completed by the Rainwater Basin Joint Venture Vegetation Management and Monitoring Workgroup from 2004 through 2013.

Specific Goals

1. Describe the basic ecology of the Rainwater Basin as it relates to wetland habitat management for migratory wetland dependent birds.
2. Highlight philosophies behind setting wetland management goals, objectives, and selecting management practices.
3. Provide public land managers, private lands biologists, and private landowners with information to make informed decisions regarding management techniques that can be used to promote desired habitat conditions with a primary focus on improving vegetative conditions for wetland-dependent migratory birds.

ACKNOWLEDGEMENTS

The Rainwater Basin Joint Venture Management Board would like to commend the efforts of the numerous partner staff that developed this Best Management Plan for Rainwater Basin Wetlands. The Vegetation Management and Monitoring Workgroup was comprised of Heidi Hillhouse, eTech Consulting, Jeff Hoffman and Richard Souerdyke, Nebraska Game and Parks Commission, Andy Bishop, Roger Grosse, Christopher Jorgensen, Ryan Reker, and Dana Varner, Rainwater Basin Joint Venture, Rich Walters, The Nature Conservancy, and representatives from the U.S. Fish and Wildlife Service. Special thanks to Laurel Badura, Dustin Casady, Ele Nugent, Mark Pfost, Tim Smith, Shon Thelen, and to the numerous technicians that collected the field data required to evaluate management actions and develop this document. Doreen Pfost, Rainwater Basin Joint Venture, provided and compiled technical edits. Bill Kendal, U.S. Geological Survey, and Scott Boomer, U.S. Fish and Wildlife Service were an invaluable resource to develop the structured decision framework that allowed us to construct the probability tables presented in this document. Thanks to Lisa Webb, U.S. Geological Survey Missouri Cooperative Fish and Wildlife Research Unit, and Nate Walker, Nebraska Game and Parks Commission, for reviewing and providing comments to previous versions of this document.

Suggested Citation:

Rainwater Basin Joint Venture Public Lands Workgroup. 2016. Best management practices for Rainwater Basin wetlands. Rainwater Basin Joint Venture Report, Grand Island, NE, USA.

EXECUTIVE SUMMARY

The Rainwater Basin Joint Venture partnership (RWBJV) was formed with the intent of protecting, restoring, and enhancing wetland habitat for millions of wetland-dependent birds during spring migration in the Rainwater Basin wetland complex (RWB). In 1994, RWB public land managers developed the first version of the "Best Management Practices for Rainwater Basin Wetlands" document (RWBJV 1994). Since then, RWBJV partners have supported directed research and monitoring projects to better understand the impacts of a variety of land management practices and strategies used to improve habitat conditions for migratory birds.

The 2013 RWBJV Implementation Plan update emphasized the importance of hydrologic function and vegetation management to maximize habitat conditions. Monitoring data collected on public lands in the RWB from 2009-2013 were used to learn more about the effects of several wetland management treatments on vegetation communities. The data presented here is not intended to be prescriptive, but rather to be a source of information for public land managers, private lands biologists, and private landowners interested in helping to achieve wetland habitat and migratory bird objectives using efficient and effective vegetation management tools.

For wetland habitat in the RWB, the objective is to obtain moist-soil dominated plant communities because of the large amount of seeds produced, which are a high-quality waterfowl food. Bare soil, which may include mudflat and shallow open water areas, also is desired as it is an early successional state that typically develops into a productive moist-soil vegetation community. Late successional plant communities that are dominated by cattail, river bulrush, or reed canarygrass provide fewer seeds for waterfowl or may even preclude wetland use.

Management treatments were more effective at promoting moist-soil vegetation and increasing moist-soil seed production when applied in multiple, consecutive years. Treatments led to a higher percentage of points in a desirable community if applied when invasive plant communities were at a lower density (i.e., 26% - 50%) and not yet dominant (i.e., >75%). Grazing was used on a large proportion (38.6%) of public lands because it is effective at reducing stand height, creating structural and species diversity, increasing ponding frequency and it also generates income. Results indicate that grazing was more effective at promoting a desirable vegetative state than rest, except in bare soil patches. Grazing in multiple, consecutive years increased its effectiveness. Spraying reduced undesirable species after the first year of a multi-year treatment plan, but the full effects were often not realized until the 3rd year after two consecutive years of chemical treatment. Spraying treatments were needed in consecutive years because the seed bank of invasive species can only be reduced by spraying newly emergent plants each year before additional seeds can be produced. While spraying appeared to be very effective at producing or maintaining a moist-soil vegetative state, it was only used on a small proportion (4.6%) of public lands, primarily due to its financial costs. Costs could be mitigated by using grazing on the same sprayed areas in the same year. Prescribed fire was applied to 7.5% of public lands, but appeared to produce marginal changes in wetland plant communities when used alone, and, in some cases, resulted in a high percentage of undesirable plant communities. The effectiveness of fire may be delayed one or more years but using grazing in conjunction with fire produced better results and offset the costs. Disking was applied to 4.6%

of the public land areas and was particularly effective at converting reed canarygrass and river bulrush/cattail communities at high densities (i.e., >75%) to a more desirable state when combined with grazing and/or spraying. Disking also was very effective at converting an area to a bare soil (non-plant) state. While disking had a high initial monetary expense, it may not need to be repeated for several years if used in conjunction with less costly methods in a long-term plan.

Long-term planning and implementation can greatly improve the effectiveness of vegetation management, as within-year and across-year treatment interactions have clear effects on outcomes. Additionally, it is more efficient to manage undesirable species before they become the dominant plant community, because less costly methods were more effective at low densities of river bulrush/cattail and reed canarygrass. Haying (1.6%), removal of culturally-accelerated sediment (0.2%), and roto-tilling (0.1%) were rarely applied within our experimental units and could not be evaluated. Evaluation of the effects of water level changes also was not conducted. Further research or monitoring is needed to determine how these methods could be used to manage wetlands for the benefit of waterfowl and other waterbirds in the RWB.

INTRODUCTION

Rainwater Basin Wetland Complex

The Rainwater Basin wetland complex (RWB) in south-central Nebraska encompasses 6,100 square miles distributed across 21 counties. Historically, the gently rolling topography of this region contained over 11,000 shallow playa wetlands covering over 204,000 acres, or approximately 5% of the landscape (Bishop and Vrtiska 2008). Playa wetlands are isolated wetlands not connected to natural drainages. Each wetland has a unique watershed that funnels runoff from precipitation and snowmelt to the wetland at the terminus of the watershed (Smith 2003). Within each playa, a thick clay layer in the soil slows water percolation, and therefore the majority of water loss occurs through evaporation or plant transpiration (Smith 2003). Water levels of playas within the RWB tend to draw down partially or entirely during dry periods, and smaller wetlands may remain dry for months, or years depending on precipitation patterns (Gersib et al. 1990). Before agricultural development, the uplands surrounding these wetlands were dominated by tall-grass or mixed-grass prairie (Smith 2003).

Due to their small size and ephemeral hydrology, playas in the region are relatively easy to drain, fill, and/or plow, and the adjacent uplands are highly productive cropland (Gersib et al. 1990). Today, the RWB landscape is dominated by row-crop agriculture with nearly 65% of the RWB landscape in cultivation for agricultural production. Nineteen percent remains in upland grasslands, and only 40,000 acres, or 20%, of the historic wetlands remain (Bishop and Vrtiska 2008, Raines et al. 1990, Schildman and Hurt 1984). Currently, the remaining wetlands in the RWB account for less than 1% of the landscape.

The remaining wetlands in the RWB face many challenges. Conversion attempts, including surface drains, dikes, and concentration pits remain, negatively impacting wetland function (LaGrange 2005, Schildman and Hurt 1984). In addition, irrigation reuse pits and road ditches within the watershed divert water and negatively impact hydrologic functions, including ponding duration, magnitude, and occurrence (Bishop and Grosse 2012, Bishop and Vrtiska 2008). Both wetland and watershed impediments negatively impact wetland function and at times promote conditions that allow colonization by undesirable plant species (LaGrange 2005, LaGrange et al. 2011). Reed canarygrass (*Phalaris arundinacea*), cattail (*Typha latifolia*), and river bulrush (*Bolboschoenus fluviatilis*) are the primary undesirable species in the RWB. If unmanaged, these species can outcompete desired annual plant species, including smartweed (*Polygonum* spp.), barnyard grass (*Echinochloa crusgalli*), and sedges (*Carex* spp.; Pederson et al. 1989). Given the ecological importance of this region for migratory waterfowl, shorebirds, and waterbirds, including the federally endangered Whooping Crane (*Grus americana*), effective management and promotion of desired vegetation communities that benefit wildlife is critically important (Gersib et al. 1992, LaGrange 2005, Pederson et al. 1989). Both public land managers and private landowners actively and passively implement management actions in an attempt to provide the necessary foraging resources (Drahota and Reichart 2015) and wetland conditions used by these priority species (LaGrange and Stutheit 2011).

Every spring, an estimated 9.8 million migrating waterfowl use RWB wetlands to rest and replenish their lipid reserves before completing their migrations (Bishop and Vrtiska 2008). This concentration of migrating waterfowl deplete the food resources within the few remaining wetlands (Drahota 2012), and overcrowding increases the risk of disease outbreaks (Smith and

Higgins 1990, Stutheit 1988). Webb et al. (2010) found that directing conservation resources toward clusters of wetlands, or micro-complexes, provides greater benefit to wetland-dependent migratory species when compared to isolated wetlands (Webb et al. 2010). In addition, waterfowl may acquire lipid resources more efficiently in a localized landscape containing a high density of wetlands (Tidwell et al. 2013). Higher numbers of ponded wetlands in a complex also reduces potential for intra- and interspecific competition for space and foraging resources, mitigating crowding and the risk of a disease outbreak (Smith 2003). However, recent research suggests that, because seed resources needed by spring-migrating waterfowl are a limiting factor in the RWB, restoration or management of any additional wetlands acres would be beneficial, regardless of proximity to existing habitat (Drahota 2012). Furthermore, a wider distribution of wetland habitats across the RWB landscape increases the probability that at least some of the wetlands will intercept a storm path and thus, provide flooded habitat conditions for migrating waterfowl (Robichaux 2010). Bishop and Vrtiska (2008) estimate that 90% of waterfowl-use of the RWB occurs during spring migration, so management in the region tends to focus on providing habitat and food for migrating waterfowl.

North American Waterfowl Management Plan (NAWMP)

Waterfowl are the most prominent and economically important group of migratory birds in North America (North American Waterfowl Management Plan, Plan Committee 2012). In the 1970s and 1980s, despite prior efforts to preserve and manage waterfowl habitat, widespread habitat loss resulted in alarming population declines of many waterfowl species (United States Fish and Wildlife Service (USFWS) and Canadian Wildlife Service (CWS) 1986). These declines prompted the governments of the United States and Canada to adopt the North American Waterfowl Management Plan (NAWMP) in 1986. This plan, which now includes Mexico, serves as a challenge and a logical guide to the protection of waterfowl habitats in North America. Since its inception, the NAWMP has served as a broad policy framework that describes the overall scope of requirements for management of migratory waterfowl in Canada, the United States, and Mexico. The NAWMP has been revised five times, continually integrating new science. As new information is integrated, population and habitat objectives are refined. The recently revised NAWMP not only addresses waterfowl populations and habitat, but expands the goals to include various stakeholder groups (e.g., hunters, viewers).

To achieve waterfowl conservation, the NAWMP established partnerships called "Joint Ventures," the primary goal of which is to conserve habitats necessary to sustain waterfowl populations at target levels, with an emphasis on using sound science to inform decision-making. Joint Ventures are partnerships including representatives from state, federal, and municipal governments, non-government organizations, private companies, and private individuals working together to protect, restore, and enhance important waterfowl habitat. Each Joint Venture develops and implements region-specific habitat protection, restoration, and enhancement conservation actions that contribute to the NAWMP goal.

The Joint Ventures have made significant strides in protecting, restoring, and enhancing habitat needed to support population objectives outlined in the NAWMP, and as a result, current populations of most duck and goose species have rebounded to levels above the long-term average (USFWS 2012). However, ongoing work is needed to ensure continuing healthy populations of waterfowl during periods of drought and in recognition that wetland habitat loss continues despite the millions of acres impacted by Joint Ventures.

Rainwater Basin Joint Venture (RWBJV)

Nebraska's RWB provides essential mid-latitude stopover habitat for waterfowl, shorebirds, and other wetland-dependent species. In 1991, the NAWMP Committee officially recognized the RWB as the eighth area in North America to merit Joint Venture status. The goal of the Rainwater Basin Joint Venture (RWBJV) is to restore and maintain sufficient wetland habitat in the RWB to assist in meeting population objectives identified in the NAWMP (RWBJV 2013*a*) and in the three other national bird plans (North American Landbird Conservation Plan (Rich et al. 2004), North American Waterbird Conservation Plan (Kushlan et al. 2002), and the United States Shorebird Conservation Plan (Brown et al. 2001)).

The RWBJV was initially focused strictly on the RWB, and was tasked with protecting 9,000 existing wetland acres and restoring or creating an additional 15,000 acres (Gersib et al. 1992). In 2013, the RWBJV revised its Implementation Plan. This revision employed a bioenergetics model to refine habitat objectives necessary to support the estimated 8.6 million waterfowl (RWBJV 2013*b*) and 500,000 shorebirds (RWBJV 2013*c*) that are predicted to use this region at population goals outlined in the NAWMP (NAWMP 2012) and United States Shorebird Conservation Plan (Brown et al. 2001). These energetics models indicated that wetlands in the RWB would need to provide 4.4 billion kcals of wetland foraging resources for waterfowl (RWBJV 2013*a,* RWBJV 2013*b*) and 210 million kcals from invertebrates for shorebirds (RWBJV 2013*c*). In order to provide sufficient wetland habitat to meet these foraging objectives, the RWBJV developed strategies for both public and private lands that would result in a sufficient wetland base (i.e., 62,000 acres) containing suitable habitat. To meet these goals wetland hydrology should be restored by removing on-site wetland modifications and off-site modifications from the surrounding watersheds. Active management needs to be implemented on at least 5,000 acres annually to promote desired vegetation communities (RWBJV 2013*a*, RWBJV 2013*b*, RWBJV 2013*c*).

Education and information transfer will be critical if the RWBJV is to achieve its ambitious goals over the next 20 years. This handbook was prepared by the RWBJV Vegetation Management and Monitoring Workgroup (hereafter referred to as the Workgroup), a subset of the Public Lands Workgroup, to provide insights into how the RWBJV partnership can most successfully implement management treatments that result in desired vegetation communities and achieve the active management goal outlined in the RWBJV Implementation Plan (RWBJV 2013*a*).

IMPORTANCE OF RAINWATER BASIN WETLANDS

Waterfowl

The RWB is recognized as an essential spring staging area for millions of migrating ducks and geese in the Central Flyway (Bishop and Vrtiska 2008, Gersib et al. 1989, Gersib et al. 1992, NAWMP 2012, RWBJV 2013*a*). Spring migration is an energetically demanding period for migratory bird species (Newton 2008). In addition to maintaining body condition, waterfowl must also accumulate sufficient lipid reserves to complete migration and successfully initiate the reproductive cycle (Devries et al. 2008, LaGrange and Dinsmore 1988). While waste corn (*Zea mays*) comprises a significant portion of the diet of geese and some ducks in Nebraska during spring migration (Pearse et al. 2010, Pearse et al. 2011*b*), it lacks certain amino acids required for tissue maintenance and follicle development (Baldassarre and Bolen 2006, Krapu et al. 2004, Loesch and Kaminski 1989). Additionally, depletion of natural wetland seed foods may drive ducks to supplement their diets with agricultural foods (Drahota 2012). Loesch and Kaminski (1989) and Reid et al. (1989) found that naturally occurring wetland plant seeds were a necessary component of duck diets that can offset protein and mineral deficiencies associated with agricultural food sources. This highlights the importance of providing wetland-derived food resources for waterfowl. Some species of duck, such as Blue-winged Teal (*Anas discors*) and American Green-winged Teal (*A. crecca*), rely heavily on wetlands to provide nearly all of their foraging resources (RWBJV 2013*b*). The most recent RWBJV Waterfowl Plan established a goal of ensuring that there are adequate wetland seed foods available to meet the caloric needs of spring-migrating waterfowl (RWBJV 2013*b*). Because moist-soil vegetation produces the largest biomass and density of wetland seed foods (Drahota and Reichart 2015), any efforts to manage waterfowl habitat should be directed towards promoting the growth of moist-soil vegetation. The seeds produced by invasive reed canarygrass, cattails, and bulrush are generally not consumed by waterfowl or do not contain sufficient caloric content and these plant communities can reduce the area of resting and loafing habitat.

Shorebirds

The diversity of water regimes (i.e., semi-permanent, seasonal, and temporary) exhibited by RWB wetlands attract a variety of shorebird species during spring migration, including a significant proportion of the world's population of Buff-breasted Sandpiper (*Tryngites subruficollis*; Jorgensen 2008, Jorgensen et al. 2008). For shorebirds, as with other long-distance migrants, spring passage is energetically expensive and has the potential to impact recruitment on the breeding grounds. In the Central Plains/Playa Lakes Shorebird Planning Region, shorebirds key in on shallow wetlands with an abundance of mudflats (Brown et al. 2001, Fellows et al. 2001). Playa wetlands, like those found in the RWB, attract higher densities of shorebirds compared to other habitats (Fellows et al. 2001, Skagen 1997, USGS 2008). Based on inventories conducted in the RWB, there is currently a deficit of available habitat for migrating shorebirds (RWBJV 2013*c*). Inventories indicate that there are sufficient historic wetland acres in the RWB; however ponding frequency and duration are limited so hydrology must be improved to ensure ponded acres. In addition, active wetland management is necessary to ensure desired vegetation communities, maintain hemi-marsh conditions, and facilitate large expanses of mudflats as water levels draw down during shorebird migration. Invasive reed canarygrass, cattails, or bulrushes reduce preferred shorebird habitats, so reduction or elimination of those species should be used to increase the amount of shorebird habitat.

Waterbirds

Wetland habitats also benefit at least 52 species of waterbirds that have been documented using RWB wetlands (RWBJV 2013*d*). A primary waterbird conservation objective in the RWB is to provide adequate stopover habitat for the federally endangered Whooping Crane. Several studies have found that the RWB is a critical mid-latitude stopover site (Austin and Reichert 2001, CWS and USFWS 2007, Tacha et al. 2010, USFWS 2009). RWB wetlands are especially important because little or no suitable habitat exists in the 120 miles between the heavily used Cheyenne Bottoms Wildlife Management Area and Quivira National Wildlife Refuge in Kansas and the RWB in Nebraska (Chavez-Ramirez et al. 2008). The risk posed by this Kansas-Nebraska gap prompted Chavez-Ramirez et al. (2008) to argue for protection, restoration, and intensive management of wetland habitat on a landscape scale within and south of the RWB. To contribute to Whooping Crane recovery, the RWBJV established a preliminary goal of protecting, restoring, and enhancing at least 70% of the high-priority wetland footprints identified by the Whooping Crane Habitat Suitability Index Model (Bishop et al. 2010). Three strategies were developed to maximize the habitat values of these properties for Whooping Cranes. The first two strategies involve acquiring new wetland acres and restoring the hydrology of existing wetlands and the third involves continuation of active management on public lands to promote desired habitat conditions. Management of wetland habitats for the benefit of Whooping Cranes may involve reducing or eliminating invasive plant species and reducing stand height while promoting moist-soil vegetation, mudflat, and open water habitats.

CHARACTERIZATION OF RAINWATER BASIN WETLANDS

Formation, Soils, and Hydrology

Formation

Playa wetlands in the RWB were formed approximately 25,000 years ago (Krueger 1986, Kuzila 1994). It is hypothesized that ancient paleobasins underlie the contemporary RWB wetlands (Kuzila 1994). Like the contemporary basins, these paleobasins were formed through deflation, a wind-driven process (Kuzila 1994). Prevailing winds, blowing northwest to southeast, likely picked up and transported lighter silt loam soil, creating depressions and associated lunettes (Starks 1984), while the heavier clay particles remained. As water accumulated in each depression, the clay particles were transported into the subsoil, creating a clay pan (Gersib et al. 1990). Clay pans in the RWB range in depth from 12 to 72 inches over the permeable silt loam parental material (Gersib et al. 1990). Under saturated conditions, clay pans are nearly impermeable to water (Smith 2003).

Soils

Soils associated with RWB wetlands are often described according to water regime (Gilbert 1989). Hydric wetland soils develop under conditions of constant to occasional flooding that result in different physical and chemical properties than those of upland soils (Erickson and Leslie 1987). The frequency of flooding determines the hydric properties of the soils, and also influences plant communities typically found on each soil type (Gilbert et al 1989, Soil Survey Staff). There are three primary hydric soil series found in RWB wetlands: Massie, Scott, and Fillmore (Gersib et al. 1990, Gilbert 1989). The Butler soil series are often described as the transitional soils between the hydric and upland sites (Gersib et al. 1990). In a given wetland, any combination of the four soil types may be found depending on the depth and complexity of the wetland (Gilbert 1989).

Massie soils, which only occur under semi-permanent water regimes, are the least common in the RWB. Massie soils are generally flooded year round with only occasional dry-downs. The plant communities associated with these semi-permanently flooded areas include cattails, bur reed (*Sparganium eurycarpum*), and softstem bulrush (*Scirpus validus*). When dry, these areas can provide moist soil or mudflat habitats (Soil Survey Staff).

Scott soils often occur where land is seasonally flooded. They may surround Massie soils, or they may represent the deepest part of a wetland that is only seasonally inundated. Scott soils are usually flooded for part or most of each year; water levels on these soils usually draw down for a portion of each year. Wetlands associated with Scott soils often support a plant community dominated by desirable plant species such as, annual smartweeds, barnyard grass, and other annual plants (Soil Survey Staff).

Less frequently flooded than Scott soils, Fillmore soils occur in areas that flood temporarily, but for most of the year lack standing water. Fillmore soils generally support plant communities that contain barnyard grass, smartweed, rushes (family *Juncaceae*), and small sedges (family *Cyperaceae*). When dry, these soils may also support communities of upland annual weeds including ragweed (*Ambrosia* spp.), pigweed (*Amaranthus* spp.), and sunflower (*Helianthus* spp.; Soil Survey Staff).

The least frequently flooded wetland soils found in the RWB are the Butler soils. These soils are generally inundated only in high water events and then only for short periods. Butler soils are dry enough in nearly all years to allow cropping (Gersib et al. 1990).

Hydrology

RWB wetlands frequently cycle between ponded and dry conditions (Erickson and Leslie 1987) and historically only received water from precipitation and runoff (Smith 2003). As a wetland dries, large fissures or cracks form, which are commonly termed macropores. Macropores may be inches across and extend several feet through the clay pan, characteristics that cause RWB wetlands to contribute to groundwater recharge. Most groundwater recharge occurs quickly through the macropores during the first influx of water into the basin (Mullican et al. 1994, Wilson 2010). As a basin fills, the clay swells and the macropores close, but recharge, at a much reduced rate, continues between the clay particles through micropores contained in the clay pan (Smith 2003). Gardak and Roe (2009) postulated that because of the recharge through the macro- and micropores playas play an important role in recharging groundwater levels in the Ogallala Aquifer.

RWB wetlands often operate at a water deficit, meaning that evaporative water losses exceed water income (Stutheit et al. 2004, USFWS 2007), especially during the growing season. As a result, water levels vary substantially both within and across years (Erickson and Leslie 1987). Each wetland is contained within a unique watershed that funnels overland flow from precipitation events or snowmelt to the wetland that lies at the watershed's lowest point (Smith 2003). RWB wetlands are depressions on the landscape that fill as a result of precipitation or snowmelt and then lose water gradually as a result of groundwater recharge, and evaporation and transpiration by the wetland vegetation communities. Only deep wetlands with extensive watersheds are likely to hold water year round, and it is common for RWB wetlands to be largely or entirely dry for part of the year. In some RWB wetlands, habitat managers may, in times of drought, supplement water with canal deliveries derived from the Platte River or with groundwater pumping

RWB Wetland Vegetation Communities

Plant communities in playa wetlands are largely determined by two factors: topography and disturbance (Gilbert 1989, Haukos and Smith 2003, LaGrange and Stutheit 2011). Topographic location generally determines how much water is available to the plant and duration of inundation (Gilbert 1989). The pool of potential species in a location is related to their ability to germinate and grow in standing water or saturated soils and their ability to tolerate dry periods when water levels decrease (Gilbert 1989). Disturbance also influences species distribution and abundance (Gersib et al. 1989, LaGrange and Stutheit 2011, LaGrange et al. 2011). For example, managers often use a combination of natural disturbances like grazing and prescribed fire to promote desired germination conditions. In highly modified systems like the RWB, mechanical disturbance including disking, haying, and rototilling is also used to promote desired vegetation communities. Weather patterns also create disturbance within the system with the reoccurrence of periods of drought and deluge.

In general, plant communities within wetlands are distributed according to water depth (Gilbert 1989, Smith 2003). Many species in RWB wetlands germinate most successfully in open vegetated conditions with damp or saturated soils, but with no standing water (Gilbert 1989). The depth and timing of standing water in a wetland strongly influences which seeds germinate in a given year (Haukos and Smith 1993, Haukos and Smith 2003). The presence of standing water or anything that blocks light from reaching the seed (e.g., standing or dead plant material, sediment) can decrease germination rates (LaGrange et al. 2011). Also, growing in standing water can be challenging to plants, as the oxygen levels in water and saturated soil are relatively low (Jackson and Drew 1984). Plants that regularly germinate or grow in these anaerobic conditions tend to be specially adapted to them and often do poorly when water levels decrease.

In RWB wetlands, areas with the deepest water, which rarely draw down completely, can be referred to as "inner marsh" areas. Plants in the inner marsh are those that can tolerate near-continuous standing water. Perennials are often able to withstand low germination rates in any given year, and may not need dry-down conditions to germinate. Once germinated, inner marsh species are able to grow and spread in standing water (Gilbert 1989). Examples of species found in inner marsh plant communities include cattails, bur reed, river bulrush, water plantain (*Alisma plantago*), pondweed (*Potamogeton crispus*), and duckweed (family *Lemnaceae*). Many of these species do not tolerate extended periods of dry conditions (Gilbert 1989).

Areas of RWB wetlands that often hold standing water, but have a draw-down period in most years, can be referred to as "outer marsh". These areas tend to include species that require dry conditions to germinate, but tolerate both wet and dry growing conditions. The outer marsh portions of RWB wetlands can be very diverse, and can include a wide number of both annual and perennial species. Annual and perennial smartweeds, barnyard grass, spikerushes (*Eleocharis* spp.), annual grasses (family *Poaceae*), sedges, and plains coreopsis (*Corepsis tinctoria)* are among the more dominant species found in these areas, and are considered to be desirable, high seed-producing species utilized by waterfowl (Gilbert 1989). Unfortunately, the invasive species reed canarygrass is also found in outer marsh areas (LaGrange 2005, LaGrange and Stutheit 2011, LaGrange et al. 2011). Established stands of reed canarygrass suppress the germination of annual plants. Reed canarygrass produces abundant above-ground growth and a thick litter layer that blocks sunlight, reducing seed germination rates of annual plants. This species, with time, can also suppress perennial species through shading and crowding. Unlike many perennials, reed canarygrass produces substantial numbers of seeds in addition to abundant above-ground and below-ground growth, allowing it to spread vigorously (Walters 2003).

In the absence of disturbance, the plant communities in RWB wetlands tend towards dense stands of woody and/or perennial species, including sedges, spikerushes, bur reed, reed canarygrass, river bulrush, or cattails, depending on the water depth. Perennial plant communities often generate abundant growth during the year, resulting in thick litter layers that provide poor growing conditions for annual plants. However, because of poor germination conditions, wetlands with dense stands of desirable perennial plants may be better able to resist invasion by annual or perennial invasive species (LaGrange and Stutheit 2011).

Disturbances can reset successional patterns and cause wetland plant communities to shift from perennial-dominant to annual-dominant plant communities (Anderson and Smith 1999, LaGrange and Stutheit 2011, Reid et al. 1989, Smith and Haukos 1993). Disturbances such as disking, fire, flooding, grazing, and wetland restoration usually result in more exposed soil, increasing light penetration, and therefore providing excellent germination conditions for many annual species (Hillhouse et al. 2010, LaGrange and Stutheit 2011, Pederson et al. 1989, Smith and Haukos 2003). However, disturbance may also inhibit or delay seed germination if those seeds become buried under an organic layer, covered with sediment, or are underwater during the time of year when germination usually takes place (LaGrange et al. 2011, Beas et al. 2013a). Because annual plants usually produce more seeds than perennial plants, disturbances that stimulate seed germination tend to favor annual plant growth. An exception is reed canarygrass, which has seeds that are less sensitive to the timing of germination than those of many annuals, allowing the species to germinate more vigorously than annual plants when suitable conditions occur in the mid to late summer (Walters 2003).

WETLAND MANAGEMENT

Wetland Assessment

Prior to implementation of any management actions, both an on-site wetland assessment and off-site watershed evaluation should be completed. The assessment and planning phase allows the public land manager, private lands biologist, or landowners to identify management objectives as well as restoration opportunities that exist within the wetland and watershed. The RWBJV partners have developed many landscape habitat assessments and geospatial datasets that can provide a foundation, however a thorough on-site assessment is needed to fully develop a management plan. The RWBJV Implementation Plan identifies several potential actions that may be part of these management plans including:

1. Strategic acquisitions that should be pursued to maximize restoration and management potential of the existing publicly owned wetlands.

2. On-site wetland restorations and enhancements that will increase hydrologic function on public wetlands and private wetlands enrolled in conservation programs.
3. Watershed restorations and enhancements that increase water conveyance to the wetland and increase the extent and duration of wetland ponding during critical periods for wetland dependent migratory birds.
4. Active management (e.g., grazing, mechanical, herbicide, fire) that results in desired vegetation and habitat conditions for wetland dependent migratory birds.

Some wetlands are owned by a single landowner while others have multiple owners. This can create challenges with management, but by strategically implementing conservation strategies outlined in the RWBJV Implementation Plan, the RWBJV partners can better address wetland and watershed modifications, both on-site and off-site. As wetlands are evaluated, a mechanism to prioritize conservation will need to be developed by the RWBJV partners. This hierarchy should prioritize restoration and enhancement actions that reduce the time and effort required to achieve and maintain suitable habitat in these wetlands (LaGrange and Stutheit 2011).

Wetland projects are usually placed into one of three categories: 1) restoration, 2) enhancement, or 3) management. Along the gradient from restoration to enhancement to management, project needs, costs, and time involvement generally decreases (LaGrange and Stutheit 2011). Following is a brief description of each category:

1. **Restoration** - Generally defined as restoring hydrology by undoing modifications in the wetland (e.g., pits, drainage ditches, dikes, tile lines, land leveling, severe sedimentation) and within the watershed (e.g., filling upland pits, re-establishing water delivery). Hydrology modifications have an effect on wetland vegetation and, over a long period of time, the soils. Restoration usually requires engineered solutions and input from other specialists, including soil scientists, civil engineers, and biologists.
2. **Enhancement** - Actions that improve existing wetland functions by changing the plant community and/or water management capabilities in the wetland (e.g., well or water control structure installation or replacement). Enhancement actions may be used when there are no major issues with the hydrology of a wetland, but the plant community may consist of less desirable species, due to a long period of management inactivity (e.g., the presence of trees, reed canarygrass, dense cattails, river bulrush).
3. **Management** - The application of vegetation management actions that keep the plant communities in desirable conditions. Nothing is *seriously* wrong with hydrology or the vegetative community. Management tools such as prescribed fire, grazing, disking, water manipulations, or herbicide treatments are used to maintain the vegetation in its desired condition.

Many wetland restorations and some enhancement projects can be complex and usually require expertise in biology, engineering, permitting, hydrology, and soils. More complex projects require the expertise of various partners. The RWBJV partners provide technical expertise and resources that can be shared and leveraged to develop management plans. Recognizing that completion of some of these restorations may take years, depending on funding, management plans should still be developed at the outset. Ideally, management plans would identify desired vegetative communities and prioritize management techniques to be implemented in the near term (i.e., one year) and in the extended management horizon (i.e., five years). This management framework should be flexible, recognizing that annual climatic patterns, precipitation events, and funding may influence habitat conditions, and in some cases, limit management opportunities. It should also be recognized that new opportunities may arise that previously were not feasible. Without this flexibility, it is difficult for land managers to respond to changing conditions or to leverage resources to implement secondary or tertiary follow-up management actions. Methodical planning also allows an appropriate monitoring system to be developed to evaluate management success.

Management Objectives

Wetland management is continual, but some management objectives, such as modifying vegetation structure, can be accomplished in the short-term. A set of strategies should be outlined to accomplish both short- and long-term objectives under different climatic and financial scenarios. Management regimes should be designed to mimic the natural processes that originally formed and maintained wetlands, to provide conditions that will promote native species, and to maximize foraging resources for wetland-dependent migratory birds. However, management regimes must also take into consideration that conditions have changed substantially from historic conditions, and mimicking natural processes may not be sufficient to achieve management goals.

Established, well-defined objectives are critical to successful implementation of the management framework. Management success and effectiveness can only be measured if objectives have been established. Management objectives should be quantifiable and time-based, for example "reduce reed canarygrass by 50% in five years" or "increase the distribution and abundance of annual species by 25% within two years." An Adaptive Resource Management (ARM) framework should be instituted to facilitate a process of "learning by doing." The ARM framework centers on setting objectives, taking action (i.e., implementing different management strategies) based on a flexible management plan, measuring success of the strategies implemented, and then, based on observations, adjusting strategies to maximize future outcomes.

Wetlands are dynamic systems, so it is seldom feasible to "fix" a problem and walk away. For example, spraying invasive species with herbicide may remove existing plants, but the seed bank often remains. Left unmanaged, the invasive species may reoccur rapidly. As noted previously, no single management treatment or prescription can achieve success, especially in the highly variable RWB landscape, but with a commitment to well-established management objectives and implementation of multiple complementary treatments, RWB wetlands can be managed to promote desired vegetative communities and biological states. The following descriptions provide an overview of the management tools commonly used in the RWB to eliminate and reduce the distribution and abundance of undesirable species and to promote the vegetation communities necessary to provide foraging resources for wetland-dependent migratory birds.

Since 2004, the RWBJV partners have worked collaboratively to implement various management practices and evaluate vegetative response to these actions. The response tables presented in this document can be a source of information to develop strategies for achieving both short- and long-term management objectives developed in wetland management plans.

Common Management Tools

Rest

Taking no action is the easiest management treatment to implement. As with any other management, taking no action has many advantages and disadvantages. No action is often selected for one of two reasons: either the desired plant community is relatively stable or management resources are limited (LaGrange and Stutheit 2011), or the ability to implement a treatment is limited. Generally, being satisfied with the wetland condition means that invasive plant species are rare or absent, seed producing plants are abundant, and water levels are sufficient to provide foraging, loafing and/or roosting habitats. These are wetlands where the conditions are not expected to change substantially within the management year and many are dominated by native perennial and annual plant species, providing competition to invasive species (LaGrange and Stutheit 2011).

If a moist-soil vegetative area is repeatedly rested, ecological succession will occur which leads to a transition from primarily annual plant species to a perennial-dominated community. Previous research in the RWB has indicated that early successional annual species provide a greater seed biomass than late successional perennial species (Drahota 2012). Additionally, a buildup of detrital litter (i.e., dead plant material) may occur after multiple years of resting, which can suppress seed production of perennial plants and reduce germination rates of annual plants. However, litter buildup also tends to slow the spread of invasive species, so this may not be a negative condition (LaGrange and Stutheit 2011).

A decision to manage through no action can also occur when an area is sufficiently degraded that it will take a substantial resource investment to restore desired functionality. In this type of situation, the area is usually in such poor condition that it is unlikely to degrade further without treatment. If the area has excessive culturally-accelerated sediment and/or is completely dominated by invasive species, choosing to not manage the area may not cause substantial changes in the condition. However, if this area is in close proximity to a better quality wetland, then a no action decision should be made with caution, as an unmanaged source of seeds from invasive species could accelerate degradation, or increase the management requirements, of nearby wetlands.

Grazing

Before European settlement, large herds of bison and elk were the primary grazers found across Nebraska's landscape. Today, under several management scenarios, cattle can be used as a substitute for native grazers to attain vegetation management objectives. Use of species other than cattle (e.g., goats, horses, hogs) may also be feasible for management (Pederson et al. 1989), but currently land managers in Nebraska have little experience with these species and herds of these alternative livestock are not large enough to be used effectively. Cattle can be used to alter wetland species composition (LaGrange and Stutheit 2011), diversify vegetative structure

(USFWS 2007), increase the amount of bare ground, mudflats, and open water (Hillhouse et al. 2010), reduce invasive species (USFWS 2007), increase the productivity of selected species (LaGrange and Stutheit 2011), and increase the nutritive quality of the forage (LaGrange and Stutheit 2011). Grazing is a tool that allows for flexibility with regard to timing, frequency, and intensity of plant defoliation and trampling.

There are many ways to use grazing as a management tool in wetlands. One is to use cattle infrequently and for a limited period of time to address a particular management objective. Another scenario is to use cattle as part of a permanent grazing system, such as rotational grazing. Grazing can also be used annually as a tool to maintain the vegetation community. The best grazing management system for a specific wetland depends on the land management objectives, the existing plant community, wetland area, grazing infrastructure, and other factors (LaGrange and Stutheit 2011, USFWS 2007). It is important to explicitly identify the specific management objective, as this will dictate timing, duration, and stocking rate necessary to achieve desired results (Drahota and Casady 2011, Drahota and Casady 2012).

Season of grazing is critical, and depending on management objectives, growing dates will dictate the periods in which grazing will be most beneficial. Invasive plant species often require season-long grazing to hinder plant development. In wetlands with severe invasive plant problems, grazing should begin as soon as the plants start to emerge in early spring, as this is the time when the plants are most palatable (LaGrange and Stutheit 2011). It may be necessary to graze twice per season, resting the site during growth of annual plants, and then resuming grazing during the second growing phase of the invasive species in wetlands that have a combination of native and invasive species,. If the goal is to provide more open water or bare ground and annual plants in wetlands, spring and early-summer grazing may be sufficient. In these cases, cessation of grazing by mid-summer will allow for growth of annual plant species that usually produce large volume of seeds and are important source of wildlife food. The last optimal date to remove grazers to allow for seed development by annual plant species generally has been recommended at 10 August (USFWS 2007).

The stocking rate, expressed in animal unit months (AUM)/acre, influences the overall intensity of herbivory and the physical impacts of grazing on wetland plants. Stocking rates on areas we sampled varied from 0.01 to 8.18 AUM/acre, with an average of 0.33 AUM/acre. More than 90% of points, however, had stocking rates between 0.1 and 1.0 AUM/acre. Light stocking rates allow cattle to select favored grazing species or areas. Heavy stocking rates force cattle to consume more plant species, including undesirable plants, and the hoof action can help to compact wetland soils, shred stems and tubers, and create more bare ground (LaGrange and Stutheit 2011, Pederson et al. 1989). The USFWS (2007) noted that a stocking rate of two to four animals per acre reduced river bulrush and cattail cover by 25%. Often, stocking rates are dependent on the number of animals an individual producer has or the number of different grazers within the local vicinity. In situations when local producers do not have sufficient animals to achieve the desired stocking rate, temporary cross fences can be used to confine the animals to smaller paddocks and achieve desired grazing intensity. This may require moving animals between paddocks to achieve management objectives across the entire site. Another solution is to have multiple producers graze the same site.

The RWBJV partners are actively developing grazing infrastructure on both public and private wetlands to increase opportunities. It is hoped that by having more access to grazing opportunities more producers will incorporate livestock into their operations. This should increase opportunities for both public land managers and private lands biologists to integrate grazing as a management tool. Ideally, sites will have a perimeter fence to keep livestock out of adjacent cropland, a livestock well to provide clean water, and an access point that allows cooperators to use semitrailers or large stock trailers to transport livestock to the site. This infrastructure will allow cooperators to more efficiently move livestock to and from the site and increase the likelihood of achieving desired stocking rates.

Unlike most management treatments, grazing is a cost-positive option for land managers. Both the USFWS and Nebraska Game and Parks Commission (NGPC) collect fees or in-kind services for grazing on public lands. These fees are reinvested by the agencies to increase habitat values on their properties (e.g., perimeter fencing, invasive species control, supplemental water). The USFWS and NGPC recognize that producers are integral to achieving effective grazing as a management tool. To compensate producers for the issues associated with grazing public wetlands the USFWS and NGPC each have agency-specific deductions from the standard average grazing fee established by University of Nebraska – Lincoln (UNL) Extension (http://farm.unl.edu/). Grazing on private lands is based on a negotiated contract between the landowner and the livestock operator, but often closely follows the averages reported by the UNL extension.

Burning

Fires, caused by lightning or set by Native Americans, were a primary disturbance in pre-settlement Nebraska prairies and wetlands (LaGrange and Stutheit 2011, USFWS 2007). The pre-settlement fire return interval was estimated to be 3 to 5 years for tall-grass prairie, 5 to 10 years for moist mixed-grass prairie, and 25 years for dry mixed-grass prairie (Samson and Knopf 1996). Fires initiated by Native Americans occurred primarily in late summer and autumn (Higgins 1986). Fires caused by lightning occurred generally during summer and early fall, with most in July and August (Higgins 1986).

Managers do not need to exactly mimic pre-settlement fire return intervals, as more frequent or infrequent fire intervals may be needed to manage habitats in modern-day altered ecosystems (Lagrange and Stutheit 2011). Today, most prescribed fires are conducted during late winter through green up (USFWS 2011). Spring represents the best opportunity to acquire burn permits since temperatures are low and humidity is high, making prescribed fires easier to control on days with light wind (USFWS 2007). However, burning can be justified for any season of the year as long as management objectives are met. For example, late spring fires can be used to reduce exotic cool-season grasses, such as reed canarygrass; late-summer fires can be used to reduce bulrush and cattail stands in wetlands; winter or early spring fires can be used to open up wetlands for the spring migration (LaGrange and Stutheit 2011).

The impacts of prescribed fire on vegetation communities are often short-lived (Pederson et al. 1989). Most of the native and invasive vegetative communities found in the RWB evolved with fire and are only impacted if high temperatures are able to penetrate the soil and impact the root zone. Brennan et al. (2005) noted that prescribed fire also did not influence the abundance, species richness, or community composition of wetland-dependent migratory birds using the RWB during spring migration. Although prescribed fire alone does not cause significant long-term habitat alteration, it is a critically important catalyst for successful implementation of other management treatments, like grazing and spring herbicide treatments. Fire also can be an important management tool to help control woody species.

If wetlands have been left unmanaged for a significant time, prescribed burning may be used in conjunction with grazing as a management strategy. In these situations, burning is typically implemented in late winter or early spring prior to grazing. Prescribed fire implemented in this timeframe will remove detrital litter and stimulate earlier and better regrowth (USFWS 2007). Although the new regrowth is highly nutritious and palatable for large ungulates and other wildlife (LaGrange and Stutheit 2011), nutritive qualities decline rapidly as the plant matures and grazing should begin as soon as post-fire green up occurs (Smith 1989).

Implementing prescribed fire is relatively inexpensive for public land managers who typically already have equipment and trained staff. There are also local burn associations that allow private landowners to work together to implement prescribed fire on their lands. When these resources are not available, private contractors can be hired. Costs vary widely, depending on the site and complexity of the burn plan. In 2013, bids from private contractors ranged from $25.00/acre to $75.00/acre.

Herbicide

Depending on the chemical, herbicide applications can significantly impact both desired and undesired vegetation communities. Pederson et al. (1989) recognized the effectiveness of chemical applications, but noted their potential negative effects as well. For example, most research indicates that the glyphosate-based herbicides do not cause direct mortality in invertebrates, but may induce changes in vegetation structure that have a negative impact (Henry et al. 1994, Solberg and Higgins 1993). Due to the challenges of moving heavy equipment to and within ponded wetlands, herbicide treatments have become a necessary alternative to methods such as haying, shredding, mowing, and disking, particularly when managing some of the more aggressive species such as river bulrush, *Phragmites*, cattails, and reed canarygrass. There are several strategies for applying herbicide treatments in wetlands:

1. **Broadcast Application Using a Floater** - Because temporary and seasonal wetlands dry more frequently during the year, it is often possible to apply the herbicide using a floater, which is a tractor with wide tires that are less likely to damage the soil surface of the wetland.
2. **Broadcast Application Using a Spray Plane -** On larger and/or semi-permanent or permanent wetlands, it is often necessary and more economical to hire a spray plane for aerial application of the herbicide.
3. **Spot Treatment Using a Pickup Truck, Tractor, Boat, or ATV** - Wetlands that have scattered patches of the vegetation being treated do not need to be broadcast-sprayed, but should instead be spot-treated with application of the herbicide directly to the target plants.

As previously discussed, herbicide applications are most effective when implemented in conjunction with other management techniques. In conjunction with fire, mowing, haying, shredding, or disking, secondary herbicide applications can significantly increase the impact of these primary treatments to reduce the distribution and abundance of undesired perennial vegetation. In addition, Walters (2003) documented that back to back annual herbicide treatments were an effective treatment to reduce the abundance of reed canarygrass.

New herbicides are continually put on the market with some approved for over-water applications and others not. As availability of herbicides changes, labels are subject to change, thus managers and applicators should always ensure they are following label directions, as required by law. Like all other management treatments, application timing is critical. Spraying bulrush, cattail, or reed canarygrass with glyphosate in late August or early September controls these plants while having minimal effect on desirable wetland plants. Walters (2003) documented that a glyphosate treatment after the first freeze provided better results than alternative treatment periods. After the first freeze, perennial plants are actively transferring resources to the root system in preparation for winter, which allows systemic herbicides to kill both the aboveground and underground plant growth. This significantly increases the effectiveness of the herbicide treatment (USFWS 2007) and the seeds of annual moist-soil plants are unaffected and able to germinate in the spring.

With the increased variety of new herbicide products, costs of this treatment have been significantly reduced. In 2013, it cost the RWBJV $13.00/acre to apply glyphosate at recommended rates to manage undesired perennial vegetation (i.e., cattail, bulrush, reed canarygrass).

Haying, Shredding, Mowing

Haying, shredding, or mowing temporarily opens wetlands and can result in increased waterfowl and shorebird use. Although Davis and Bidwell (2008) found an increase in vertebrate biomass in shredded wetlands, these treatments generally do not cause long-term changes to plant communities (Pederson et al. 1989, USFWS 2007). Like burning, these methods are nonselective management practices. Haying, shredding, or mowing affect both actively growing desirable and undesirable plants species equally from a vegetative standpoint. If properly timed, however, these methods can place more stress on the undesirable species being targeted (LaGrange and Stutheit 2011). For example, summer haying can be effective in controlling some woody species and late spring haying or mowing can stress reed canarygrass.

Timing of haying is often dictated by the forage quality of the hay. Producers prefer to hay when forage quality is high and many Nebraska producers prefer to hay in July to maximize forage quality and quantity. Despite the benefits, early- or mid-summer haying may destroy many ground-nesting bird nests (Sargeant and Raveling 1992), and often these species do not complete hatching until late June or mid-July. July 15 is the earliest haying date allowed on NGPC public lands. In addition, mid-summer haying in multiple, consecutive years stresses native warm-season plants and promotes exotic cool-season species, such as reed canarygrass (Foster et al. 2009).

Like prescribed fire, the impacts that haying, shredding, and mowing treatments have on vegetative community composition are limited, but may significantly increase the effects of secondary treatments. For example, the NGPC has successfully treated reed canarygrass through a combination of mowing and prescribed fire. This was accomplished by mowing the reed canarygrass in late spring before it went to seed. The mowed reed canarygrass clippings were allowed to dry and were then burned. The additional fuel load created by the clippings produced a hotter fire, which likely damaged the roots and seed bank of the reed canarygrass. Most plants are low in below-ground energy reserves (i.e., carbohydrates) just prior to and during flowering. Mowing them at that time is the best way to stress them and, over time, potentially reduce their abundance. Haying has also been used by the USFWS to prepare reed canarygrass stands for late fall herbicide treatments. In this case, reed canarygrass was hayed in late summer, after which it began actively growing. Following the first freeze, stands were sprayed with glyphosate. Mowing and grazing interactions have also been observed. An early spring mowing can result in a rapid re-growth of vegetation that grazing animals will find very palatable (LaGrange and Stutheit 2011), thus increasing the grazing intensity on the actively growing species.

On public lands these management practices are often completed by the grazing tenant. Typically, managers determine haying, shredding, and mowing fees from University of Nebraska - Lincoln Extension publications (http://farm.unl.edu/).

Disking and Rototilling

Disking and rototilling are among the most aggressive mechanical management treatments within wetlands. These actions are non-selective, significantly impacting all species in the treated area. A heavy construction disk or rototiller is designed to mechanically turn over the first eight to twelve inches of soil and cut the root masses of plants into pieces. This equipment can be effective in reducing the population of unwanted vegetation on a site. Experience has shown that for disking alone to be effective, especially on species such as reed canarygrass, a minimum of 3 passes with a heavy disk must be made. Rototilling is more effective in a single pass because the tiller blades cut the roots, rhizomes, and tubers and bring them to the soil surface where they die more quickly by drying in the heat of summer or by freezing during the winter (LaGrange and Stutheit 2011). However, most rototillers are narrow and require the tractor operator to go very slowly which greatly limits the number of acres that can be treated in a day. Rototilling is a good technique to use for smaller stands of undesirable vegetation or to create small openings (LaGrange and Stutheit 2011).

The effects of disking and rototilling are greater when used in combination with other treatments. Walters (2003) documented that the most effective treatment to reduce abundance of reed canarygrass was a spray-disk-spray combination of treatments within the same year. Disking 10-14 days after a summer herbicide application can further destroy vegetation and open the seedbed for new reed canarygrass plants to sprout from the seed bank. Once seedlings have reached a sufficient size, treating with the herbicide again will kill the new vegetation. Recently, the RWBJV partners have followed with an additional pass with a finish disk 10-14 days after the second herbicide treatment. This works by leveling out the soil surface to prepare the seed bank for germination of annuals the following growing season.

It should be noted that mechanical methods can destroy desirable vegetation along with the invasive species, so care should be taken when using this technique. The positive aspect of mechanical management is that it opens the wetland up for annual vegetation to quickly grow and become established (LaGrange and Stutheit 2011).

Costs vary, depending on the number of passes. A typical treatment may include three passes with a disk and and a final pass with a finish disk. In 2013, the average cost per disking pass (i.e., heavy construction disk) was $30.00/acre (desired three pass treatment, $90.00/acre).

A final, single pass with the finish disk costs approximately $10.00/ acre. No current estimates are available for the cost of implementing a roto-tilling treatment.

Water Level Manipulation

Drought and deluge were historically natural drivers of wetland vegetation communities in prairie ecosystems (Euliss et al. 2004). Watershed conditions have changed considerably from the early 20th century. Water inputs to wetlands have been reduced as a result of altered drainage from roads, construction of irrigation reuse pits within the watershed, terraces within the watershed that shortstop runoff, no-till farming practices that reduce overland flow, and conversion away from gravity irrigation to pivot irrigation. All of these changes have reduced the volume of water that reaches wetlands.

Active management of water levels via supplementation or drawdown, also referred to as moist-soil management, has been documented to significantly increase seed production (Anderson and Smith 1999, Bolen et al. 1989, Haukos and Smith 1993) and invertebrate density (Anderson and Smith 1999, Davis and Smith 1998). Playa wetlands that were managed using moist-soil management techniques had significantly more waterfowl (Anderson and Smith 1999, Haukos and Smith 1993) and shorebird (Anderson and Smith 1999, Davis and Smith 1998) use compared to unmanaged sites. Although water-level manipulation infrastructure exists in some form at most public wetlands, water has not been extensively used as a management tool in the RWB. Reliable funding to operate high-capacity wells or to pay for surface water deliveries is not currently available for all of areas with pumping capabilities. Additionally, public managers do not currently have pumps or water control structures to remove excess water and most private wetlands have limited infrastructure for water-level manipulation. Therefore, we were not able to evaluate the effects of these management tools.

Common Restoration Tools

Removal of Culturally-accelerated Sediment

Sediment removal often requires heavy equipment (e.g., paddle scrappers, pan scrappers, excavators, bull dozers) to excavate culturally accelerated sediment or fill material from the wetland footprint (LaGrange et al. 2011). Sediment removal is not considered a management practice, but rather a wetland enhancement or restoration action (LaGrange et al. 2011, LaGrange and Stutheit 2011). Although this activity can have a profound impact on wetland vegetation, the primary goal of sediment removal is to restore wetland hydrology by removing built-up organic materials and sediment that has been deposited in the wetland from adjacent croplands (LaGrange et al. 2011).

Prior to European settlement the uplands surrounding RWB wetlands were dominated by mixed-grass and tall-grass prairie species. Sod-forming prairie vegetative communities have extensive root systems that provide soil structure and significantly reduce movement of upland material into the wetlands. Before agricultural conversion of the RWB uplands most soil movement was out of the wetlands when wind scoured the dry mudflats (Gilbert 1989). Today though, a majority of uplands are cultivated for row-crop agriculture production, primarily corn and soybeans (*Glycine max*; Bishop and Vrtiska 2008). This high degree of agriculture production has resulted in a reversed landscape; the wetlands now contain relatively permanent vegetation, while the cultivated agriculture fields lack permanent vegetation (LaGrange et al. 2011). Agriculture fields tend to have a large amount of exposed soil, which is vulnerable to both wind and water erosion. Particles from the exposed soil tend to be carried downhill and deposited in the wetlands. The deposited sediments have many impacts on RWB wetlands, including lower water level, reduced micro-topography as sediment creates smooth surfaces, reduced surface water area (LaGrange et al. 2011), burial of plant seeds (Beas et al. 2013) and invertebrates (Riens et al. 2013), and an increase in nutrient levels. Collectively, these changes can lead to alteration of playa ecosystem functions, including increased exotic species, decreases in water availability, and a reduction in the ability of the wetland to serve as wildlife habitat (LaGrange et al. 2011).

Once a wetland restoration or enhancement has been completed, measures should be taken to reduce the amount of sediment entering the wetlands. Control of sediment accumulation is most effectively accomplished by three methods. First, proper watershed management can help reduce erosion. Upland sources of sediment within the watershed, which may be more than a km away from the wetland, can be planted with grass to reduce erosions. However, if management of these areas is not possible, the wetland edge should be vegetated with permanent, well-managed grassland species to stop shoreline erosion and reduce sheet erosion from adjacent uplands. In addition, Riens et al. (2013) found that wetlands with at least a 25 meter upland buffer had both improved water quality and invertebrate abundance and diversity. The third method entails construction of small retention cells at major water delivery points. The purpose of the cells is to slow the flow of water, causing sediments to drop out. These cells must be periodically cleaned out. Retention cells are usually 20'-x-20' areas that are three to four feet deep at the point where the water reaches the wetland edge. A series of silt basins can be built if sedimentation is severe. These retention cells should be placed in the upland portion of the waterway, adjacent to the wetland in order to avoid damaging the clay pan.

Since sediment removal uses heavy equipment to mechanically remove sediment and re-shape the wetland topography it has greater initial costs than other restoration activities. Total cost is variable, depending on the size of the project and the amount of sediment to be removed. Sediment removal should be done with the guidance of a soil scientist who can determine the location and amount of current soil that is a result of recent sedimentation (LaGrange et al. 2011, Tang et al. 2015). Average costs in 2013 ranged from $1,650 to $2,420/acre to remove six inches of material.

METHODS

Implementation of a Structured Decision Framework

The Workgroup collaborated with both academics and land managers to develop a structured decision framework that could be used to update the Best Management Practices document. This framework was designed to provide habitat managers with a set of tools to evaluate the current vegetative conditions and determine the influence management treatments have on changing the plant communities and therefore how much energy can be provided (kcals) in consideration of financial constraints. The foundation of this structured decision making (SDM) framework is a set of response tables that were developed from five years of management tracking and vegetation monitoring. These tables outline the shifts in vegetation state that occurred in response to one or more management actions. These tables also depict the cost-benefit trade-offs to aid in decision making. Information regarding duration of benefit of treatments is presented in a series of graphs. Transition probabilities for the most common management techniques are also reported. The following section describes the background and methods used to define vegetation states, vegetation monitoring, data storage, data analysis, and the methods used to create the transition probability tables.

Methods: Vegetation States

The first step to develop the structured decision framework was to effectively describe vegetation states in a way that is relevant to wetland management. The Workgroup worked directly with the RWBJV Public Lands Workgroup, including representation from all of the NGPC and USFWS land managers, to create a management-based hierarchical classification to describe vegetation states. This hierarchy was based on species of concern, primarily reed canarygrass, river bulrush, and cattail. The species composition used to describe the different vegetation states were directly tied to potential management trigger points based on input from the Public Lands Workgroup. Currently, these undesirable species may not be specifically targeted if they make up <50% of vegetative cover. Thus, we included a 26-50% category to test whether earlier management may be warranted.

Nine vegetative states with amount of vegetation were identified (Table 1). Three of the vegetative states are based on the relative abundance of reed canarygrass, three are based on the relative abundance of cattails and/or river bulrush combined, and the remaining three include a moist-soil vegetation community, bare soil, and an "other" vegetation community (Table 1). This hierarchy classifies undesired species communities based on their presence over the dominant species or community. For example, a vegetative stand described as being composed of 70% annual moist-soil vegetation with 30% reed canarygrass would be classified as reed canarygrass 26-50%, rather than moist-soil. The most common species and the vegetation states with which these species are associated are described in Appendix A.

Table 1. Hierarchical classification of vegetation states identified by the Rainwater Basin Joint Venture Vegetation Management and Monitoring Workgroup to evaluate best management practices in the Rainwater Basin wetland complex, Nebraska.

Vegetation	Percent Cover	Value
Reed Canarygrass	>75	Undesirable
Reed Canarygrass	51-75	Undesirable
Reed Canarygrass	26-50	Undesirable
River Bulrush/Cattail	>75	Undesirable
River Bulrush/Cattail	51-75	Undesirable
River Bulrush/Cattail	26-50	Undesirable
Moist-Soil	≥25	Desireable
Bare Soil		Desireable
Other		Undesirable

Reed Canarygrass

Reed canarygrass is one of the most difficult to manage invasive wetland species in the RWB (Walters 2003). This species often invades the seasonal and temporary outer marsh zones (Gilbert 1989), displacing desired annual hydrophytes (Walters 2003). Managers often try to manage against reed canarygrass before it becomes established (Walters 2003). Based on past management experience, three vegetation states were defined for reed canarygrass. The first is a mixed vegetation community with reed canarygrass ranging between 26% and 50% of the overall vegetative cover. At this range of cover, reed canarygrass has not yet established the thick litter layer that tends to prevent germination of other wetland vegetation (Walters 2003) and managers have good success applying active management treatments to significantly reduce its presence. The next vegetation state was defined as reed canarygrass coverage 51-75%. At this coverage, reed canarygrass is actively colonizing the site through spread of rhizomes and seed germination. At this point, multiple treatments are generally necessary to reduce reed canarygrass because the seed bank must be eliminated in addition to the adult plants. The final vegetation state used to describe reed canarygrass is >75%. At this level reed canarygrass is the dominant species, generally a thick rhizome layer exists, and a viable seed bank is present. To reduce reed canarygrass at this level is a multi-treatment, multi-year endeavor.

River Bulrush and/or Cattail

The river bulrush and cattail vegetation states are also described using three categories. These are native species within the RWB; however, if left undisturbed, these species form dense stands that limit the available habitat for migratory wetland-dependent birds. Additionally, most of the cattails found in Nebraska are a hybrid between the native broad-leafed cattail and the introduced narrow-leafed cattail. River bulrush and cattails are often present in the seasonal, semi-permanent, and permanent zones of the wetland (Gilbert 1989, Reid et al. 1989). Dense stands of river bulrush and/or cattail can displace more desirable vegetation, reduce hemi-marsh conditions, and eliminate mudflats that provide shorebird habitat during drawdown (Reid et al. 1989, Sojda and Solberg 1993). As with reed canarygrass, managers often try to reduce bulrush and cattails before they become monocultures within a wetland. Since these two species occur within similar water regimes and are managed with the same techniques, three vegetation states were defined for both species combined. The first is a mixed vegetation community with river bulrush and/or cattails in combination ranging between 26% and 50%. At this density, target species are manageable through a variety of mechanical and chemical treatments (Sojda and Solberg 1993). The next vegetation state described for river bulrush and/or cattails was 51-75%. At this point, multiple treatments are generally necessary to reduce these species since both adult plants and seedlings from the seed bank may need to be managed. The final vegetation state used to describe river bulrush and/or cattails is >75% (Table 1). At this level, these two species are dominant, and may require intensive multi-treatment, multi-year actions.

Moist-Soil Vegetation

The moist-soil vegetative community is made up of a combination of annual and perennial hydrophytes that have been grouped together. Common species in this vegetative community include sedges, rushes, smartweeds, and other native annual hydrophytes. This vegetation state represents the most desired condition for RWB wetlands, because the goal is to provide optimal foraging conditions for waterfowl and shorebirds (RWBJV 2013*a*). Numerous research projects have described the management techniques that promote this vegetation state (Anderson and Smith 1999, Haukos and Smith 1993, Haukos and Smith 2003) and its value to waterfowl (Anderson and Smith 1999, Haukos and Smith 1993, Reinecke et al. 1989). Many of the highest seed-producing species associated with this vegetation state are annuals. Disturbance is essential to set back ecological succession to promote the bare ground and germination conditions that many of these annual species favor.

Bare Soil State

This state is not defined by a single species or vegetative community, but rather consists of exposed soil, mudflats (i.e., water less than 3 inches deep), or open water (i.e., water over three inches deep) with little or no vegetative cover (Table 1). The bare soil state is important to managers, as it typically appears during transitions between wetland vegetation states. These open conditions can provide ideal germination areas when ponded water recedes, providing exposed mudflats or dry open soil for germination of the desired moist-soil vegetative plants during subsequent growing seasons. Mudflats and shallow water also provide important foraging habitat for shorebirds and waterbirds.

Other Vegetative State

Noxious weeds, upland grasses (e.g., smooth brome (*Bromus inermis*), Kentucky bluegrass (*Poa pratensis*), big bluestem (*Andropogon gerardii*), and cultivated crops (i.e., corn, soybeans) were lumped into a catch-all category called "other". A list of the most common species in the other vegetative state category is in Appendix A.

Methods: Vegetation Monitoring

Vegetation monitoring is most effective when it is adaptive and designed with consideration to defined objectives (Brownstein et al. 2015, Legg and Nagy 2006). With this in mind, the Workgroup adopted a modified 1-m x 1-m Daubenmire (1959) cover class monitoring protocol to evaluate percent vegetative cover. This protocol allowed annual data collection, analyses to evaluate effects of management on different vegetative states, and development of probability tables that outlined potential management success by different treatments. Additionally, several researchers have recommended the use of a large number of small sample plots for vegetation monitoring, rather than a smaller number of larger plots (Brownstein et al. 2015). Therefore, we collected data from more than 3,159 sample plots each year. Target sampling dates were 15 September through 15 October, with additional sampling occurring until the first snowfall, if necessary. At each sample point a 1-m^2 quadrat was placed on the ground. Presence and associated cover class of each plant species, as well as the presence of bare soil, mudflat, or open water was described using one of six cover class categories (Table 2).

Table 2. Daubenmire Cover Classes (Daubenmire 1959) used to evaluate percent vegetative cover at sample points on public lands in the Rainwater Basin.

Cover Class	Range of Coverage (%)	Midpoint of Range (%)
1	0-5	2.5
2	6-25	15
3	26-50	37.5
4	51-75	62.5
5	76-95	85
6	96-100	97.5

An analysis of a subset of points (n = 64) that were sampled by two different observers in 2013 found that observer agreement may be as low as 72%. Points were relocated each year using a hand-held GPS unit. While this may lead to differences in plot placement between surveys due to GPS error, Johns et al. (2015) found that the power to detect change increased greatly as replication increased. Multiple observers were used to collect data so differences in plant identification skills or biases may have also led to observer errors (Morrison 2015). To avoid these types of errors, many researchers recommend a process to train and test observers during a pilot study year. While we did have a small amount of double sampled data to test for error, the subset only accounted for 0.2% of the total dataset. These data cannot be used to make inferences about how errors may affect results at this time. Instead, we used a large set of sample points to reduce the impacts of errors, as recommended by Johns et al. (2015). We do, however, suggest that future vegetation monitoring projects make efforts to measure and control for GPS or observer errors.

The 2009 sample points were located at the midpoint of transects developed as part of a prior monitoring effort. The Workgroup agreed on these initial sample points since the distribution of the original number of transects reflected the total area of the dominant vegetation communities. In 2010, a more spatially balanced set of sample points was developed to ensure sampling across the extent of the historic hydric soil footprint, regardless of current hydrology, and to adequately assess management actions that occurred during the 2010 management year.

To establish this new sample set, the vegetation map that was used to develop the original sample set was spatially joined with the historic wetland mask using GIS. The historic wetland mask used in this analysis was generated by intersecting the wetland features identified in the United States Department of Agriculture Bureau of Chemistry and Soils (1910-1934), National Wetland Inventory (1980-1982; Cowardin et al. 1978), and the hydric soils delineated in the Soil Survey Geographic Database (Soil Survey Staff 1961-2004). This analysis resulted in a new wetland sample unit, which included both the inventoried areas used in the prior assessment and the portions of historic wetlands not previously catalogued. Based on the area of the non-sampled historic hydric footprint at each property, additional sample points were established following the area ratio outlined in Bishop et al. (2004).

Over 75% of the sample points collected in 2009 received no management or a grazing treatment (Table 3). In 2010, 2011, and 2012, additional survey points were generated to increase sampling effort within vegetative states that had received different management treatments. The sample points developed in 2012 were also revisited in 2013. No additional points were added in 2013 because of the large sample size and lack of staff resources.

Because many of the management treatments were used less frequently (Table 4), there was a low sample size for these treatments. The additional points added in 2010, 2011, and 2012 allowed more observations of these different treatments across the diversity of vegetation states. This increased the opportunity to evaluate treatment effects when applied to the different vegetation states.

Table 3. Number of sample points undergoing one of 31 management treatments or treatment combinations in each year on public lands in the Rainwater Basin, 2009-2013.

	2009	2010	2011	2012	2013
Disk	111	15	5	222	9
Disk/Fire	0	0	1	0	0
Disk/Fire/Sediment Removal	0	0	1	0	0
Disk/Sediment Removal	1	0	8	0	0
Disk/Spray	0	0	1	23	0
Fire	245	192	56	293	25
Fire/Hay	10	7	0	0	0
Fire/Sediment Removal	0	0	3	0	0
Fire/Spray	0	0	0	49	0
Graze	1,310	1,798	2,113	3,027	4,916
Graze/Disk	97	81	53	116	1
Graze/Disk/Hay	8	0	0	62	0
Graze/Disk/Spray	0	0	52	33	9
Graze/Fire	219	170	73	156	78
Graze/Fire/Hay	7	0	0	0	0
Graze/Fire/Spray	0	0	32	0	0
Graze/Hay	60	28	12	100	0
Graze/Hay/Sediment Removal	0	0	0	2	0
Graze/Hay/Spray	0	18	5	4	0
Graze/Fire/Spray	0	0	0	0	48
Graze/Sediment Removal	0	18	0	2	13
Graze/Spray	0	114	716	923	275
Graze/Roto-Till	33	0	0	0	0
Hay	77	22	11	159	18
Hay/Sediment Removal	0	0	0	1	0
Hay/Sediment Removal/Spray	0	0	0	4	0
Hay/Spray	0	13	12	8	0
Rest	1,485	1,947	2,549	3,716	4,042
Sediment Removal	11	50	7	3	25
Spray	6	100	377	681	159
Roto-Till	10	0	35	14	5

Table 4. Combined size in acres of sampled plots undergoing eight different management treatments each year from 2009-2013 on public lands in the Rainwater Basin. Some plots received more than one treatment per year.

	Year	Resting	Grazing	Burning	Disking	Spraying	Haying	Sediment Removal	Rototilling
Number of acres	2009	16,001	14,230	4,778	1,624	19	995	68	94
	2010	15,207	15,589	3,883	867	928	525	168	0
	2011	17,262	16,934	1,377	824	2,989	219	39	58
	2012	17,808	12,916	1,641	3,772	3,116	713	60	13
	2013	18,492	13,876	478	68	831	201	96	8

To increase sampling effort within under-sampled management treatments, the Workgroup coordinated with public land managers to acquire management plan maps prior to the 15 September –15 October sample period. These management plan maps described the spatial extent of the projected management action, type of management action, and details of the management action (e.g., grazing intensity, grazing timeframe, herbicide treatment, herbicide application date). This information was catalogued in a GIS database that allowed management actions to be intersected with the wetland sample unit layer. The intersection of the wetland sample unit layer and management data resulted in new polygons that represented vegetation communities that were similar, but managed differently. Every polygon within the intersected layer was analyzed to ensure that all polygons between 0.5 – 5.0 acres had at least two sample points. Larger polygons were apportioned additional points following the same ratio outlined in Bishop et al. (2004). From 2009 to 2013, the number of sample points tripled. For the most part, sampling increased proportionally across all vegetation states (Table 5). All treatments were confirmed by the land managers each year to correct for differences between planned and actual management actions.

Because this was a passive ARM effort, the Workgroup did not seek to influence management activities in any way. The Workgroup recognized that public land managers have to make decisions, work with local producers, respond to climatic events, and react to potential opportunities. The goal of this monitoring effort was strictly to monitor the response of vegetation to routine management actions.

The Workgroup recognized that precipitation events impact vegetation communities. However, the highly variable precipitation patterns led the Workgroup to exclude impacts of ponded area from the analysis. In addition, sampling occurred across the precipitation gradient from West to East (e.g., Gosper to Seward counties), which theoretically could have reduced the measured impacts of precipitation on vegetation response as both ponded and dry sites were sampled across this gradient.

Because the Daubenmire (1959) cover classes were descriptive and not quantitative, raw data collected at each point had to be transformed and relativized. This was a two-step process that included converting cover class observations for each species to the midpoint of the cover class range (Table 2). When the cover class midpoints of the different species observed at a single monitoring point were summed, the total was rarely 100%. To account for this variation,

Table 5. Number of sample points in each of nine vegetation states sampled each year from 2009-2013 in the Rainwater Basin.

Vegetation state	2009	2010	2011	2012	2013
Moist-soil ≥25%	1,739	2,033	3,049	5,047	5,493
River Bulrush/Cattail 26% - 50%	87	197	332	303	275
River Bulrush/Cattail 51% - 75%	77	143	159	153	251
River Bulrush/Cattail >75%	175	316	408	542	162
Bare soil	238	488	616	719	637
Other	154	371	408	1,078	1,034
Reed Canarygrass 26% - 50%	120	199	294	509	766
Reed Canarygrass 51% - 75%	123	132	246	288	459
Reed Canarygrass >75%	446	507	527	776	338
Total	3,159	4,386	6,039	9,415	9,415

the observations at each point were relativized by taking the midpoint for each observation anddividing by the sum of the midpoints within that point. For example, a plot with reed canarygrass cover class 5, smartweed cover class 2, and barnyard grass cover class 2, would be assigned midpoints of 85%, 15%, and 15% respectively. These would total 115% total cover, so the midpoint of each observation would be divided by 115. As a result, the relativized percent covers were 74% reed canarygrass, 13% smartweed, and 13% barnyard grass. This ensured that each of the points was equally weighted in the analysis.

Once each point had been transformed and relativized, species were aggregated by vegetation community associated with the different vegetation states (e.g., reed canarygrass, bulrush/cattail, moist-soil; see Appendix A). Following hierarchical protocols, the most invasive species, reed canarygrass, was given highest priority while bulrush/cattail was given second priority (Table 1). For example, any point with >25% reed canarygrass was assigned to one of the three reed canarygrass vegetative states (i.e., 26-50%, 51-75%, or >75%). Points with ≤25% reed canarygrass but >25% bulrush/cattail were assigned to one of the three bulrush/cattail vegetative states. Points with ≤25% reed canarygrass and/or bulrush/cattail and ≥25% moist-soil plants were assigned to the moist-soil vegetative state. Points with ≤25% reed canarygrass, bulrush/cattail, and/or moist-soil vegetation were assigned to either the bare soil or other vegetative state, depending on majority cover type. Following this protocol, the example point from above would be assigned to the reed canarygrass 51-75% vegetation state, since 74% of the aggregated community would be described as reed canarygrass while moist-soil vegetation would constitute 26% of the community (13% smartweed + 13% barnyard grass).

Methods: Transition Probabilities

A goal of this project was to provide public land managers, private lands biologists, and private landowners with information to make informed decisions regarding management techniques that can be used to promote desired habitat conditions in the RWB. To help better direct limited resources, we completed this analysis to describe the probability of achieving a particular outcome when the five most common management treatments are applied to either undesirable (i.e. bulrush/cattail, reed canarygrass) or desirable (i.e. bare soil, moist-soil) communities.

We used the methods described by Breininger et al. (2010) to estimate transition probabilities (ψ) and their associated errors using the multi-state model in Program MARK (version 8.0; White and Burnham 1999). This modeling method is typically used to estimate survival, detection, and transition probabilities for a population of animals after capture-recapture data has been collected. However, it can also be used to estimate the probabilities of transition among habitat types by substituting habitat point data for animal capture-recapture data. Survival and detection probabilities were fixed at 1.0, because unlike animals, geographic points cannot experience mortality and are always able to be detected using GPS data. Each encounter history indicated the initial habitat state, the treatment applied, and the resulting habitat state. This analysis measures the effects of one year of management action(s) without accounting for treatments that may have occurred in prior years. For transitions that did not occur in the dataset, ψ was constrained to 0.0. Due to small sample sizes, all three reed canarygrass categories (i.e., 26-50%, 51-75%, and >75%) were combined into one, and likewise for bulrush/cattail. Points that transitioned to or from the “other” vegetative state were excluded from this analysis. This analysis includes the five most frequently observed treatments: graze (n = 8,419), rest (n = 7,534), graze/spray (n = 1,403), spray (n = 920), and fire (n = 283). The full dataset, including all treatments and "other" plant communities, included 22,999 individual transitions. The data used in this analysis included 18,559 individual transitions (81% of the full data set). We also estimated 95% confidence intervals (CI) for each transition probability. This is a range of values that has a 95% chance of containing the true probability of transition.

Methods: Response Tables

The Workgroup developed response tables to provide a more detailed account of the frequency with which vegetation states remained the same or shifted to another vegetation state as a result of a single in-year treatment, a combination of treatments within a single season, or multiyear treatments. The response values described in the tables are based on the vegetation monitoring data and management practices implemented in publicly owned RWB wetlands from 2009 through 2013. Although the tables themselves are not predictive, these tables describe the results of past management and can be used to make management decisions based on current and desired vegetative states. These tables also allow assessment of the outcomes of less frequently used management techniques, in-year treatment combinations, and up to 4 years of treatment.

All response tables presented in this document are arranged in the same manner. A table is given for each initial vegetative state, except for bare soil and other, and for 1-, 2-, or 3-year evaluation intervals. Rows within the table are labeled with the management treatment(s) being evaluated. Columns are labeled with the nine possible vegetation states and represent the vegetation at the end of the interval. The percentages within the table are calculated separately for each row, so each row should sum to 100%, representing all of the possible vegetation outcomes based on the initial vegetation and management received. The number of points receiving each type of management is listed in light grey in the far right column. Higher numbers of points are associated with greater certainty. Only treatment combinations with ≥ 20 observations are presented in this section. The complete set of response tables are provided in Appendix C, which includes all treatment combinations regardless of sample size. Higher percentages were assigned darker shading to assist in identifying the most frequent outcome. Blue shading was used for the one-year treatment regime(s), orange shading was used for the two-year treatment regimes, purple shading was used for the three-year treatment regimes, and green shading was used for the four-year treatment assessments.

Cost-Benefit Analysis

The cost-benefit estimates use the data presented in the response tables to estimate changes in the amount of energy available in the form of moist-soil seed production following treatment(s) based on the frequency of each resulting vegetation state and the estimated moist-soil seed production of that state. Dominant vegetation stands (i.e., those >75%) are used to estimate the transitional stands (i.e., 26-50% and 51-75%) by using the midpoint of that group multiplied by the estimated energy availability of the dominant stand, and by assuming the rest of the vegetation is moist-soil (Table 6). For example, the mean percentage of reed canarygrass at reed canarygrass 26-50% points was 37.5% (i.e. the midpoint of 26% and 50%) while assuming the remaining 62.5% was made up of moist-soil plants. If moist-soil plants contain 250,000 kcals/acre and reed canarygrass contains 25,000 kcal/acre, the amount of energy available at reed canarygrass 26-50% points would be 165,625 (i.e. 250,000*0.625 + 25,000*0.375 = 165,625). Bare soil seed production is set equal to moist-soil vegetation seed production because that is the expected production the following year. Seed production for the "Other" vegetative state is set equal to zero because these seeds are generally inaccessible to waterfowl. The kcal/acre estimates used for this analysis are the same as those used in the RWBJV Waterfowl Plan (RWBJV 2013b). These estimates were primarily derived from data reported by Rabbe et al. (2004). While researchers in other regions have generated lower spring wetland food production estimates (Brasher et al. 2010, Hagy and Kaminski 2012, Straub et al. 2012), recent RWB research suggests they may be much higher (Drahota 2012) than those used for this document. However, because we seek to compare changes in seed production, the actual number of kcal/acre in each community is less important than the ratios among communities. Here, we assumed moist-soil ≥25% communities contain 10 times more seed food energy than reed canarygrass >75% and bulrush/cattail >75%. This is consistent with results comparing managed and unmanaged playas in Texas (Haukos and Smith (1993). To simplify the tables, kcal values are presented as thousands of kcals. Management costs used in the cost-benefit tables were gathered from public lands contracts (Table 7). Combinations of treatments within a year and/or across years are the sum of management costs for the represented management activities. For example, grazing and spraying within a single year would result in a $40/acre income, because grazing provides an income of $55/acre while spraying carries a cost of $15/acre. Disking one year followed by grazing the second year would result in a $40/acre cost, because disking carries a cost of $95/acre while grazing provides an income of $55/acre. Cost-benefit tables present the changes in kcal production in response to management relative to areas that are rested.

Table 6. Estimated kilocalories (kcal) per acre for each of the nine vegetative states on public lands in the Rainwater Basin.

Vegetative State	kcals/acre
Moist soil ≥25%	250,000
River Bulrush /Cattail 26% - 50%	165,625
River Bulrush/Cattail 51% - 75%	109,375
River Bulrush/Cattail >75%	25,000
Bare soil[a]	250,000
Other	0
Reed Canarygrass 26% - 50%	165,625
Reed Canarygrass 51% - 75%	109,375
Reed Canarygrass >75%	25,000

[a] Bare soil seed production is set equal to moist-soil vegetation seed production because that is the expected production the following year.

Table 7. Estimated cost (dollars/acre) for one year of seven individual management actions on public lands in the Rainwater Basin.

Management Action	Estimated Cost ($/acre)
Rest	0
Graze	+55
Spray	- 15
Fire	-50
Disk (3 passes)	-95
Hay	+60

Methods: Duration of Benefit

The data presented in the duration of benefit charts indicate how long an effect can be observed after an application of one or more treatments in a single year. These graphs provide a visual evaluation of vegetation community responses to an active management action when no action is taken in one or more subsequent years. These charts include data from points where active management (i.e., not rest) was applied in the first year, followed by at least one year of rest. Only treatment combinations with 20 or more observations are included. Results are reported as "before treatment" (i.e., the previous fall), treatment year (i.e., the fall of the year treatment is applied), year 2 (i.e., the fall of the year after treatment year), and where available, year 3 (i.e., the fall of the second year following treatment).

RESULTS

Moist-Soil Vegetation: Transition Probabilities

The probabilities that a moist-soil vegetative community will transition to reed canarygrass (6-10%), bulrush/cattail (2-7%), or bare soil (5-9%) are relatively low for all five management techniques (Table 8). However, the combined probabilities of transition to either reed canarygrass or bulrush/cattail are similar for grazing and spraying combined (12%), grazing (14%), resting (14%), and spraying (17%), but lowest when fire (9%) is applied. These results indicate that once a healthy moist-soil vegetation community has been established, it is likely to remain in a moist-soil state, regardless of management. The effects of grazing and spraying are greater when used in combination, rather than individually. If a land manager would like to implement active management to avoid a transition from moist-soil vegetation to either reed canarygrass or bulrush/cattail, fire may be slightly more effective than other methods. This makes sense because native moist-soil communities in the Great Plains evolved with fire and research has indicated that appropriately timed prescribed burning can have positive short-term effects on moist-soil vegetation communities (Laubhan 1995).

Table 8. Probabilities and their associated 95% confidence intervals for transitions from a moist-soil habitat to a bare soil, reed canarygrass, or bulrush/cattail habitat after one year of one of the five most frequent management treatment(s) in the Rainwater Basin region of Nebraska, 2009-13.

Initial	Treatment	Result	Transition Probability* (%)	95% Confidence Intervals	
				Lower (%)	Upper (%)
Moist-Soil	Fire	Bulrush/Cattail	2.0	0.8	5.3
Moist-Soil	Fire	Bare Soil	6.1	3.5	10.4
Moist-Soil	Fire	Reed Canarygrass	6.6	3.9	11.0
Moist-Soil	Graze	Bulrush/Cattail	4.7	4.2	5.4
Moist-Soil	Graze	Bare Soil	7.8	7.1	8.6
Moist-Soil	Graze	Reed Canarygrass	8.9	8.1	9.8
Moist-Soil	Graze/Spray	Bulrush/Cattail	5.6	4.0	7.8
Moist-Soil	Graze/Spray	Bare Soil	8.6	6.5	11.1
Moist-Soil	Graze/Spray	Reed Canarygrass	5.9	4.3	8.2
Moist-Soil	Rest	Bulrush/Cattail	4.0	3.5	4.6
Moist-Soil	Rest	Bare Soil	5.1	4.5	5.7
Moist-Soil	Rest	Reed Canarygrass	9.8	9.0	10.7
Moist-Soil	Spray	Bulrush/Cattail	7.4	5.3	10.4
Moist-Soil	Spray	Bare Soil	8.6	6.3	11.7
Moist-Soil	Spray	Reed Canarygrass	9.1	6.7	12.2

* This number indicates the probability that each resulting vegetation state will occur following the indicated treatment.

Moist-soil ≥25%: Response Tables and Cost-Benefit Analyses

The annual plant species associated with this community can produce seed biomass between 70 and 809 pounds/acre prior to spring migration ((Haukos and Smith 1993, Drahota and Reichert 2015). Managers often try to maintain these communities through less extreme management treatments, such as grazing. Unfortunately, more extreme management treatments are sometimes required to reduce the amount of perennial species and improve germination and growing conditions for annual moist-soil vegetation species (Haukos and Smith 2003, Reid et al. 1989, Reinecke et al. 1989). Disking and herbicide treatments are sometimes used to set back succession in moist-soil plant communities.

Because bare soil areas are likely to become moist-soil vegetation in subsequent years, both moist-soil vegetation and bare soil states are considered desired states. Therefore, all management actions presented here result in desired states most of the time (Table 9). Rest is the most common management choice in moist-soil vegetation, while grazing is the most common active management. Although grazing accomplished management goals of maintaining moist-soil vegetation, the combination of grazing with other treatments was usually more effective than grazing alone. Similarly, evaluation of the combined moist soil and bare soil states suggest rest and haying are the least effective maintenance tools, with the highest probability of infestation by reed canarygrass being found after haying (Table 9).

Moist-soil ≥25% is the most productive vegetation class, so any change away from that class leads to decreased seed production. However, nearly all active management options resulted in greater energy availability when compared to rest. Although increases in energy availability can be most efficiently accomplished (by a slim margin) with sediment removal, it is mostly a tool intended for restoring hydrology and has the highest initial cost. Multiple combinations of grazing, disking, and spraying resulted in similar predicted changes in areas with moist-soil ≥25% vegetation. Grazing or grazing and spraying combined both appear to be viable ways to maintain predominantly moist-soil vegetation while providing a modest income per acre.

Table 9. Percentage of moist-soil ≥25% sample points in each of nine vegetation states following one year of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

		Vegetation outcome after management (%)									Cost-benefit evaluation	
Treatment	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Disk+Spray	34	55.9	2.9	0.0	0.0	38.2	2.9	0.0	0.0	0.0	+37	$ (55)
Graze+Disk	68	41.2	0.0	0.0	1.5	48.5	0.0	4.4	0.0	4.4	+30	$ (40)
Disk	104	41.3	1.0	0.0	1.0	47.1	1.9	1.9	1.9	3.8	+26	$ (95)
Graze+Spray	591	77.5	3.6	1.4	0.5	8.3	3.0	2.4	2.0	1.4	+25	$ 40
Spray	424	73.8	2.1	2.1	3.1	8.5	1.4	2.6	2.1	4.2	+17	$ (15)
Graze	4991	74.1	2.1	1.1	1.3	7.4	5.7	3.7	2.3	2.4	+15	$ 55
Graze+Fire	194	66.5	1.0	1.0	1.0	14.4	9.8	3.1	1.5	1.5	+10	$ 5
Rest	5058	72.1	1.5	0.7	1.3	4.5	11.2	3.0	1.8	3.9	0	$ -
Fire	244	68.9	0.4	0.0	1.2	4.9	19.3	2.9	1.2	1.2	-11	$ (50)
Hay	44	45.5	2.3	0.0	2.3	15.9	6.8	15.9	4.5	6.8	-12	$ 60

Many management actions had a high probability of maintaining moist-soil vegetation or bare soil after two years of treatment (Table 10). Two years of rest was the most common management treatment applied to moist-soil vegetation, followed by back-to-back years of grazing. Grazing treatments were implemented alone, or in conjunction with, other treatments in 16 of the 25 two-year treatments combinations. When moist-soil and bare soil outcomes are combined, grazing in combination with other treatments (including grazing the subsequent year) resulted in a desired vegetation state 77.5% of the time. However, the effects of grazing were strongly dependent on the other treatments it was combined with, and resulted in a desired vegetation state between 51.2 - 100% of the time. When applying grazing to a moist-soil vegetation state, it is important to have the livestock removed by August 10th, so plants can recover and produce seeds (USFWS 2007). Disking followed by rest and disking followed by grazing both generated desirable conditions at 100% of sample points. The year-one graze/fire treatment followed by a year-two rest treatment was the least effective (51.2%) at maintaining a desired state, but year-one graze/fire followed by grazing in the second year was among the most effective (90.5%) treatments. This highlights the importance of a management plan that identifies follow-up treatments and/or the combination of additional treatments in a long-term framework.

Most management treatment plans result in increased moist-soil seed production when compared to two years of rest. From a seed production perspective, the four most effective treatments include disking in the first year. However, this can be both expensive and hard to implement. A combination of grazing in both years and either burning or spraying in one or both years can also provide good results while being easier to implement and less costly. Grazing alone, even two years in a row, is substantially less effective at increasing moist-soil seed production than grazing in combination with other treatments. In general, less intensive management treatments (i.e., rest, fire only, graze only) in the first year result in lower seed production than more intensive management efforts after two years of management.

Table 10. Percentage of moist-soil ≥25% sample points in each of nine vegetation states following two years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment			Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Disk+Spray	Disk	20	40.0	0.0	0.0	0.0	60.0	0.0	0.0	0.0	0.0	+101	$ (150)
Disk	Rest	60	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+90	$ (95)
Disk	Graze	41	85.4	0.0	0.0	0.0	14.6	0.0	0.0	0.0	0.0	+90	$ (40)
Graze+Disk	Graze	34	64.7	2.9	0.0	0.0	23.5	0.0	5.9	2.9	0.0	+82	$ 15
Graze+Fire	Graze	115	87.0	3.5	0.9	0.9	3.5	1.7	1.7	0.0	0.9	+76	$ 60
Graze+Spray	Graze+Spray	99	80.8	1.0	1.0	3.0	12.1	1.0	0.0	0.0	1.0	+75	$ 80
Graze+Spray	Graze	262	79.8	1.1	1.1	0.4	5.7	4.6	2.7	1.1	3.4	+63	$ 95
Graze+Spray	Rest	71	78.9	2.8	0.0	1.4	0.0	4.2	7.0	2.8	2.8	+57	$ 40
Spray	Spray	75	81.3	2.7	2.7	1.3	2.7	2.7	1.3	4.0	1.3	+56	$ (30)
Spray	Graze	129	79.8	3.1	0.0	0.0	2.3	2.3	5.4	2.3	4.7	+54	$ 40
Graze	Graze+Spray	215	69.8	5.1	1.4	2.8	9.8	2.3	4.2	2.8	1.9	+49	$ 95
Spray	Rest	104	75.0	1.0	1.9	2.9	8.7	3.8	1.0	1.0	4.8	+49	$ (15)
Graze	Graze	1408	70.9	2.8	0.9	1.5	7.8	7.3	3.9	2.4	2.5	+41	$ 110
Rest	Disk	80	51.3	1.3	1.3	5.0	33.8	3.8	2.5	0.0	1.3	+36	$ (95)
Graze	Rest	655	68.7	1.4	0.9	1.2	4.9	13.0	3.1	2.1	4.7	+25	$ 55
Graze	Spray	25	68.0	0.0	0.0	0.0	0.0	4.0	8.0	8.0	12.0	+24	$ 40
Rest	Graze+Spray	25	68.0	0.0	4.0	0.0	8.0	8.0	4.0	4.0	4.0	+20	$ 40
Rest	Spray	106	52.8	0.9	6.6	10.4	19.8	2.8	1.9	3.8	0.9	+14	$ (15)
Rest	Graze	726	65.6	1.2	0.4	0.7	7.9	11.7	4.3	2.9	5.4	+12	$ 55
Rest	Rest	1885	67.6	1.2	0.5	1.3	2.5	17.2	2.6	2.4	4.7	0	$ -
Fire	Rest	184	68.5	4.3	1.6	2.2	2.2	14.1	3.3	1.1	2.7	-4	$ (50)
Rest	Fire	70	65.7	0.0	0.0	2.9	2.9	18.6	2.9	0.0	7.1	-7	$ (50)
Rest	Graze+Fire	56	55.4	3.6	0.0	0.0	7.1	16.1	3.6	1.8	12.5	-13	$ 5
Graze+Fire	Rest	43	37.2	7.0	2.3	4.7	14.0	25.6	4.7	2.3	2.3	-22	$ 5
Fire	Graze	26	50.0	0.0	0.0	0.0	7.7	38.5	3.8	0.0	0.0	-47	$ 5

Most evaluated 3-year management treatment combinations had a high probability of maintaining the moist-soil or bare soil states (Table 11). Three consecutive years of grazing and three consecutive years of rest were the most common management combinations, and generated marginal results compared to the other management options evaluated. Grazing or rest was included at some point in all of the three-year treatment combinations. To allow moist soil vegetation sufficient time to recover and produce seeds, grazing should cease on moist soil species by 10 August (USFWS 2007). Integration of herbicide treatment (i.e., spraying) or fire in the same year as a grazing treatment increased the probability of maintaining a moist-soil vegetative state relative to grazing alone. This highlights the importance of a management plan that proposes a multiyear set of treatments and/or the combination of treatments to prevent the establishment of undesired species.

Consecutive years of grazing, grazing and burning, and grazing and spraying are the most effective at increasing moist-soil seed production across the three years, and are simultaneously some of the least costly options. Including a year of rest at any point seems to greatly decrease the effectiveness of the other years of treatment except when rest occurred in the third year following two years of more intensive treatments.

Table 11. Percentage of moist-soil ≥25% sample points in each of nine vegetation states following three years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment				Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	Year 3	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Spray	Graze+Spray	Graze	55	81.8	1.8	0.0	3.6	10.9	0.0	0.0	0.0	1.8	+126	$ 135
Graze+Spray	Graze	Graze	40	87.5	2.5	5.0	0.0	2.5	0.0	2.5	0.0	0.0	+116	$ 150
Graze+Fire	Graze	Graze	61	90.2	1.6	0.0	1.6	3.3	0.0	1.6	0.0	1.6	+115	$ 115
Spray	Spray	Rest	29	86.2	0.0	0.0	0.0	6.9	0.0	3.4	3.4	0.0	+113	$ (30)
Graze+Fire	Graze	Rest	29	86.2	6.9	0.0	0.0	0.0	3.4	3.4	0.0	0.0	+108	$ 115
Spray	Spray	Graze	26	84.6	0.0	0.0	3.8	0.0	3.8	0.0	3.8	3.8	+88	$ 25
Graze	Graze+Spray	Graze	70	70.0	2.9	1.4	1.4	11.4	2.9	5.7	0.0	4.3	+85	$ 150
Spray	Rest	Rest	34	79.4	2.9	2.9	0.0	2.9	8.8	0.0	0.0	2.9	+78	$ (15)
Rest	Disk	Rest	76	51.3	1.3	1.3	5.3	35.5	2.6	1.3	0.0	1.3	+76	$ (95)
Graze	Graze+Spray	Graze+Spray	45	46.7	13.3	4.4	8.9	22.2	0.0	2.2	2.2	0.0	+71	$ 135
Graze	Graze	Rest	204	71.1	1.0	0.5	1.5	6.4	4.9	7.8	2.0	4.9	+69	$ 110
Graze	Graze	Graze	516	65.5	4.7	1.9	2.1	9.3	8.1	4.1	2.3	1.9	+63	$ 165
Graze	Graze	Graze+Spray	43	69.8	2.3	0.0	4.7	4.7	7.0	2.3	7.0	2.3	+59	$ 150
Rest	Spray	Rest	24	62.5	0.0	0.0	0.0	25.0	12.5	0.0	0.0	0.0	+48	$ (15)
Graze	Rest	Graze	193	75.6	0.0	1.0	0.5	3.1	12.4	1.0	2.1	4.1	+43	$ 110
Rest	Spray	Spray	56	55.4	0.0	5.4	12.5	16.1	0.0	3.6	5.4	1.8	+29	$ (30)
Graze	Rest	Rest	141	60.3	5.0	0.0	0.7	5.0	17.7	4.3	4.3	2.8	+24	$ 110
Rest	Graze	Rest	158	53.8	2.5	0.0	1.9	20.9	14.6	0.6	2.5	3.2	+23	$ 55
Rest	Graze	Graze	127	59.8	0.0	0.8	1.6	9.4	13.4	7.1	1.6	6.3	+17	$ 110
Fire	Rest	Rest	96	68.8	5.2	3.1	4.2	4.2	9.4	4.2	0.0	1.0	+14	$ (50)
Rest	Rest	Graze	193	64.8	4.1	1.0	2.6	5.7	8.3	3.6	3.6	6.2	+12	$ 55
Rest	Rest	Fire	46	63.0	2.2	0.0	0.0	6.5	13.0	0.0	4.3	10.9	0	$ (50)
Rest	Rest	Rest	743	67.3	1.3	0.3	1.5	2.3	17.9	2.0	2.7	4.7	0	$ -
Rest	Graze+Fire	Graze	39	66.7	5.1	0.0	0.0	2.6	7.7	5.1	2.6	10.3	-2	$ 60
Rest	Fire	Rest	48	72.9	0.0	0.0	4.2	0.0	16.7	2.1	0.0	4.2	-4	$ (50)
Graze+Fire	Rest	Graze	24	54.2	12.5	4.2	8.3	4.2	12.5	0.0	4.2	0.0	-29	$ 60
Rest	Rest	Graze+Fire	35	42.9	0.0	5.7	14.3	2.9	11.4	8.6	5.7	8.6	-38	$ 5

Grazing and fire combined, followed up by grazing in three subsequent years, resulted in the greatest percentage of points remaining in the moist-soil state and the greatest increase in moist-soil seed production (Table 12). Persistent grazing, with or without spraying in the same year, also produced large increases in moist-soil seed production, when compared to rest. The treatment plans that were most effective also produced the greatest financial returns.

Table 12. Percentage of moist-soil ≥25% sample points in each of nine vegetation states following four years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment					Vegetation outcome after management (%)										Cost-benefit evaluation	
Year 1	Year 2	Year 3	Year 4	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Fire	Graze	Graze	Graze	30	90.0	0.0	0.0	0.0	3.3	3.3	0.0	3.3	0.0	201	$ 170
Graze	Graze+Spray	Graze+Spray	Graze	35	57.1	5.7	2.9	11.4	11.4	0.0	5.7	5.7	0.0	124	$ 190
Graze	Graze	Graze	Graze	190	72.6	4.2	1.1	2.6	4.7	7.9	2.6	1.1	3.2	120	$ 220
Graze	Graze	Graze+Spray	Graze	20	70.0	0.0	0.0	0.0	10.0	5.0	0.0	5.0	10.0	116	$ 205
Graze	Graze	Rest	Graze	100	71.0	0.0	0.0	0.0	1.0	13.0	6.0	1.0	8.0	111	$ 165
Graze	Rest	Graze	Rest	24	70.8	0.0	0.0	0.0	12.5	8.3	0.0	0.0	8.3	102	$ 110
Graze	Graze	Graze	Rest	40	72.5	0.0	0.0	2.5	2.5	15.0	0.0	0.0	7.5	102	$ 165
Rest	Graze	Rest	Graze	48	79.2	0.0	0.0	0.0	10.4	6.3	2.1	2.1	0.0	102	$ 110
Rest	Spray	Spray	Rest	35	54.3	2.9	0.0	14.3	20.0	0.0	0.0	2.9	5.7	77	$ (30)
Graze	Rest	Rest	Rest	26	80.8	0.0	0.0	0.0	0.0	19.2	0.0	0.0	0.0	75	$ 55
Rest	Graze	Graze	Graze	60	75.0	0.0	0.0	0.0	5.0	10.0	3.3	1.7	5.0	75	$ 165
Graze	Rest	Rest	Graze	29	55.2	0.0	3.5	6.9	20.7	6.9	0.0	0.0	6.9	70	$ 110
Rest	Rest	Graze	Rest	48	76.6	4.3	2.1	2.1	0.0	6.4	2.1	2.1	4.3	68	$ 55
Fire	Rest	Rest	Rest	69	79.7	0.0	0.0	0.0	1.5	18.8	0.0	0.0	0.0	67	$ (50)
Rest	Graze	Rest	Rest	38	63.2	2.6	2.6	0.0	0.0	13.2	10.5	5.3	2.6	61	$ 55
Rest	Rest	Graze	Graze	22	72.7	0.0	0.0	9.1	0.0	9.1	4.6	0.0	4.6	53	$ 55
Rest	Rest	Rest	Graze	44	75.0	0.0	0.0	0.0	0.0	20.5	2.3	0.0	2.3	40	$ 55
Rest	Rest	Fire	Rest	40	70.0	0.0	0.0	2.5	0.0	15.0	5.0	2.5	5.0	37	$ (50)
Rest	Rest	Graze+Fire	Graze	22	63.6	0.0	0.0	0.0	13.6	0.0	4.6	9.1	9.1	24	$ 60
Rest	Rest	Rest	Rest	175	54.9	0.6	0.6	0.6	2.3	28.6	1.7	2.3	8.6	0	$ -

Moist-Soil ≥25%: Duration of Benefit

Figure 1A: Vegetation outcomes (%) for moist-soil ≥25% points following one combined grazing and spraying treatment and one year of rest.

More than 75% of points remained in moist-soil ≥25% following grazing and spraying treatments in the same year. The combined treatment also was fairly successful at preventing the spread of bulrush/cattail in the year of rest following treatment. The number of points in reed canarygrass, however, more than doubled in the year of rest following treatment.

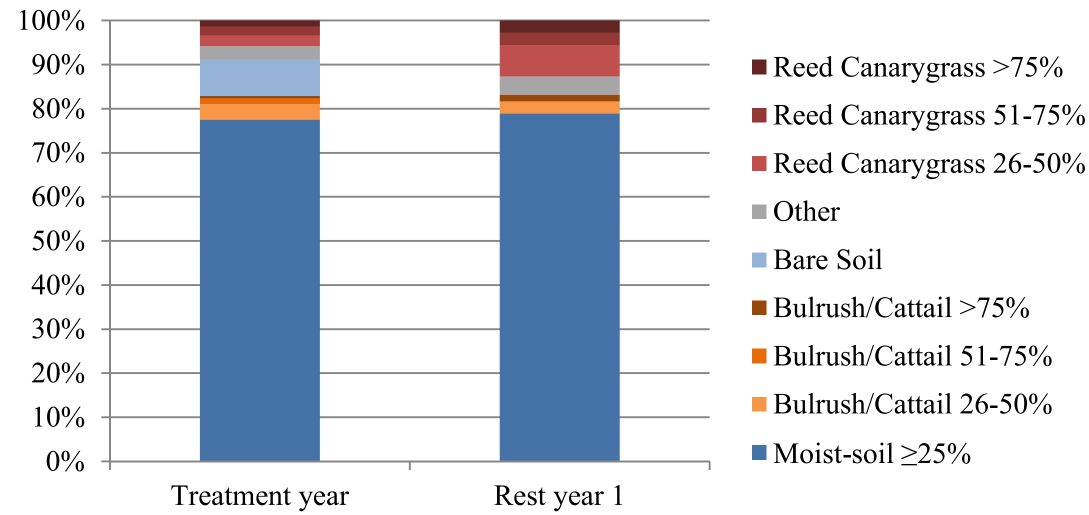


Figure 1B: Vegetation outcomes (%) for moist-soil ≥25% points following a single grazing treatment and two years of rest.

The effect of a single year of grazing on moist soil vegetation declines over time if no other active management is used. Moist-soil vegetation decreases and reed canarygrass and other vegetation increase steadily in the ensuing year.

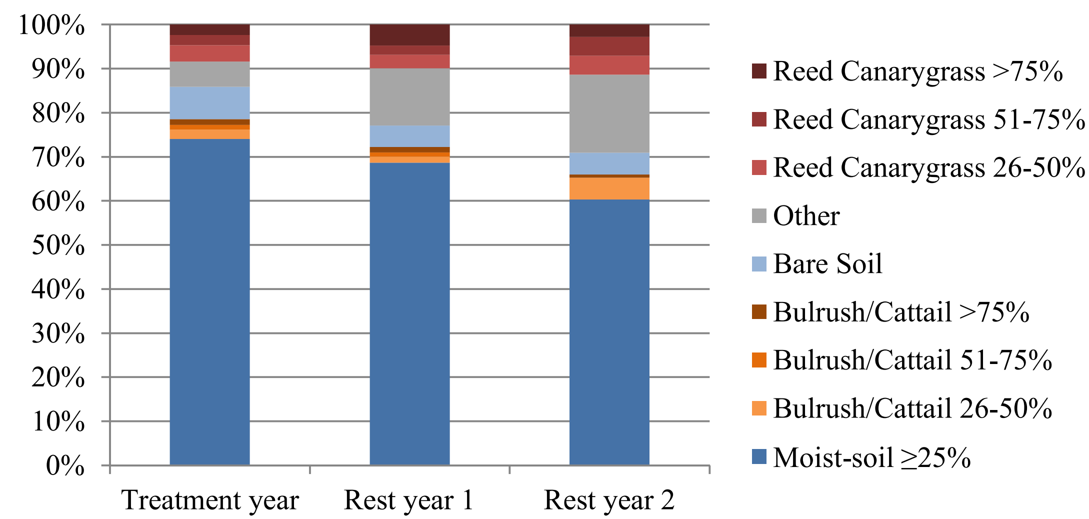


Figure 1C: Vegetation outcomes (%) for moist-soil ≥25% points following a single spraying treatment and two years of rest.

One year of herbicide application on moist soil vegetation followed by rest resulted in increasing proportions of moist soil vegetation in the two years following treatment. The effects of spraying on invasive species also seem to be long-lasting as the percentage of points in bulrush/cattail or reed canarygrass continued to decrease over both years of rest.

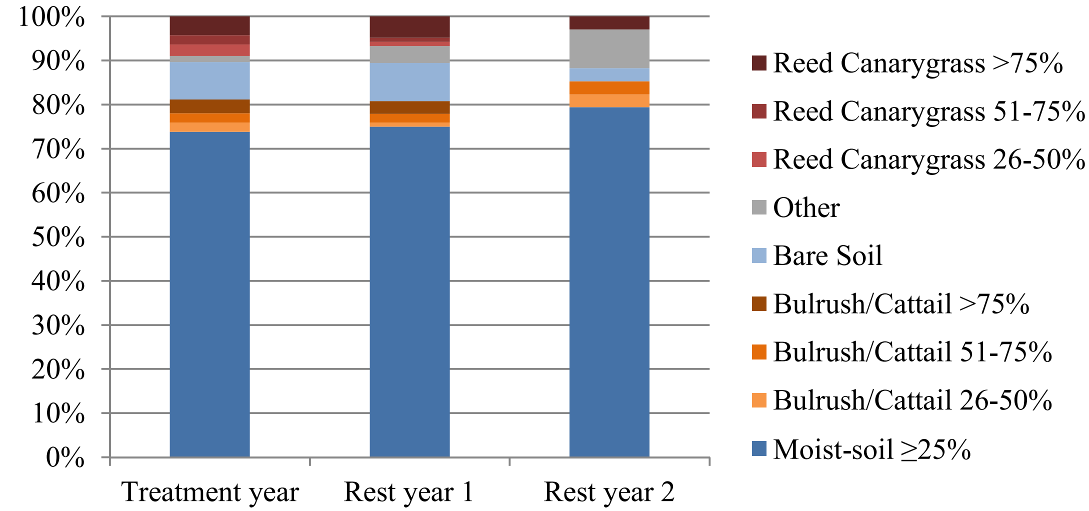


Figure 1D: Vegetation outcomes (%) for moist-soil ≥25% points following a single fire treatment and three years of rest.

One year of burning moist-soil vegetation followed by rest resulted in relatively stable proportions of moist soil vegetation, but steadily increasing proportions of bulrush/cattail in years 2 and 3. Reed canarygrass, however, does not appear to increase substantially in the two years following treatment.

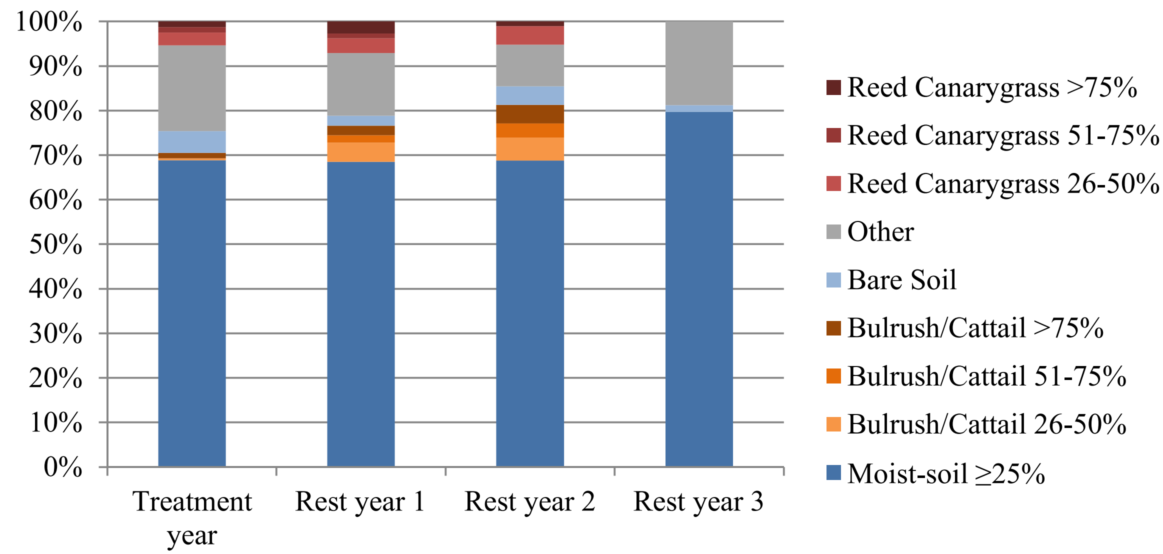


Figure 1E: Vegetation outcomes (%) for moist-soil ≥25% points following a combined grazing and fire treatment and one year of rest.

Grazing and burning moist soil vegetation within a single year seemed to stimulate the growth of invasive and other species during the year of rest following treatment. Allowing a year of rest following this treatment also resulted in a substantial decrease in moist-soil vegetation.

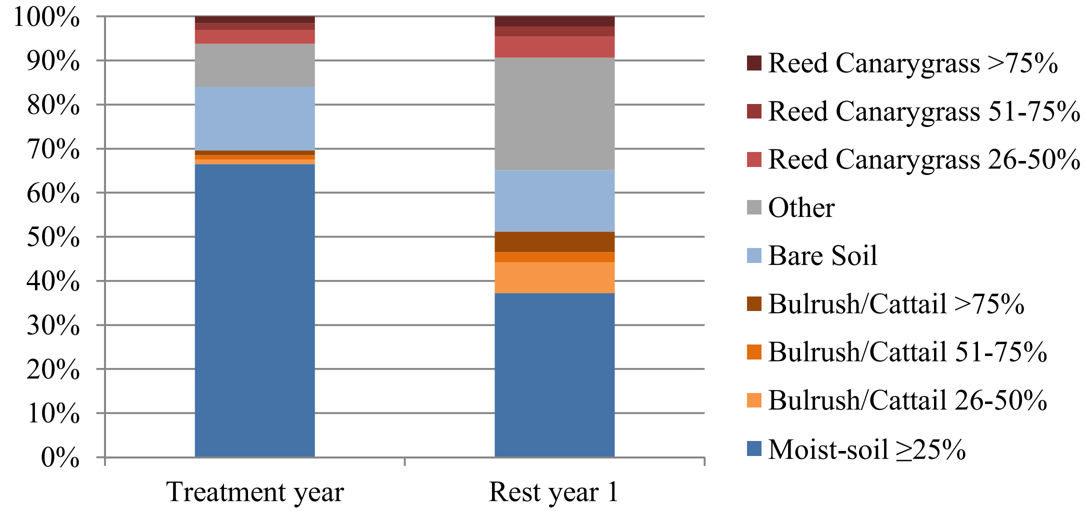


Figure 1F: Vegetation outcomes (%) for moist-soil ≥25% points following a single disking treatment and one year of rest.

Immediately following disking, bare soil conditions replaced at least half of the moist-soil community. However, during the subsequent year of rest, there is a full return of moist-soil vegetation.

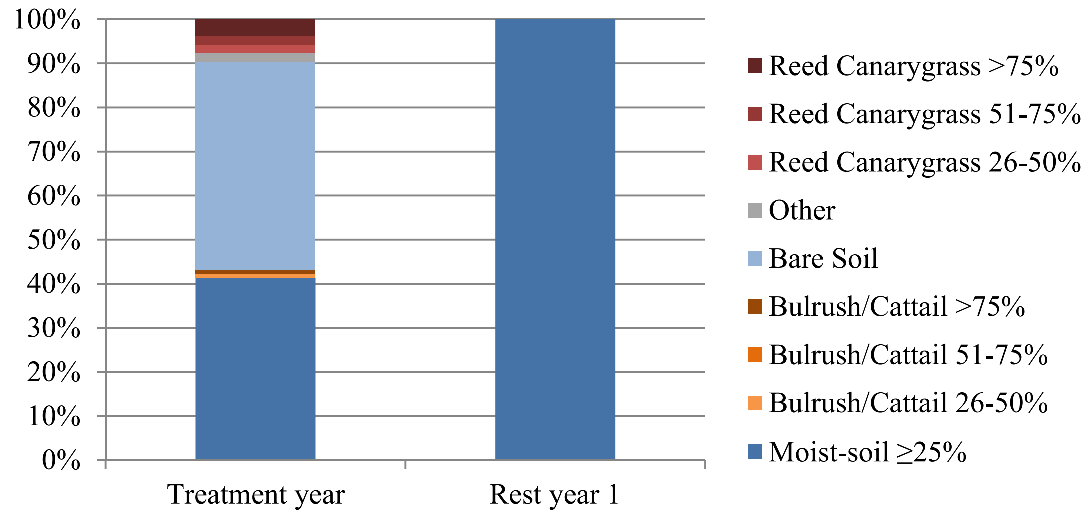
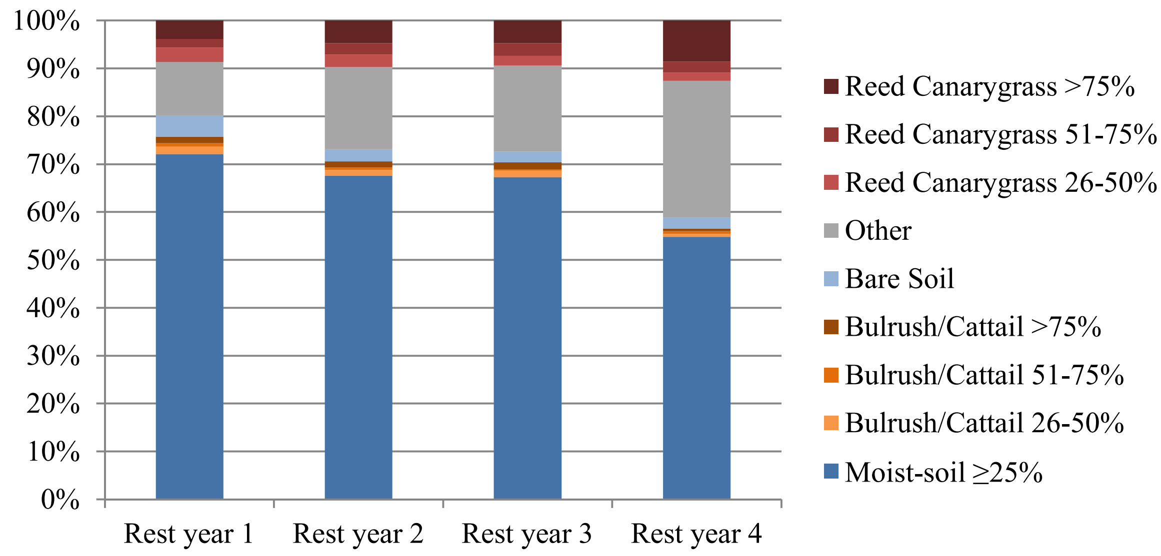


Figure 1G: Vegetation outcomes (%) for moist-soil ≥25% points following four years of rest.

Following four consecutive years of rest, more than 45% of points transitioned out of the moist-soil state. Almost 15% of points transitioned to an invasive plant community.



Reed Canarygrass: Transition Probabilities

A single year of spraying (48%; CI: 42 - 55%) or the combined treatment of grazing and spraying (42%; CI: 37-48%) were most effective at transitioning reed canarygrass to moist-soil vegetation (Table 13). If both of the desirable vegetation states (i.e., moist-soil and bare soil categories) are considered, grazing and spraying combined are more effective (57%) than spraying alone (50%). The probabilities are low that reed canarygrass will transition to bulrush/cattail (0-7%) following any of the five treatments. Data that were not included in this analysis seem to suggest that use of more aggressive treatments (e.g. disking, sediment removal, haying) or use of more than two treatments in the same year may be more effective at eliminating reed canarygrass (Appendix C). Additionally, use of spraying, either alone or combined with grazing, in two consecutive years produced a higher percentage of points (65-75%; Table 15, Table 16) that transitioned to moist-soil vegetation.

These results indicate that a single management technique likely will not be effective at eliminating reed canarygrass in one year. It may not be efficient or effective to use high-cost management treatments on reed canarygrass unless a multi-year plan is in place. Low-cost treatments are more effective if reed canarygrass is not yet the dominant species. For example, if only grazing or resting are used in two consecutive years the percentage of points that transitioned to either moist-soil vegetation or bare soil was much higher for areas where reed canarygrass made up 26-50% of the ground cover (48%) as compared to areas where reed canarygrass made up >75% of the ground cover (23%; Appendix C).

Table 13. Probabilities and their associated 95% confidence intervals for transitions from a reed canarygrass habitat to a moist-soil, bare soil, or bulrush/cattail habitat after one year of one of the five most frequent management treatment(s) in the Rainwater Basin region of Nebraska, 2009-13.

Initial	Treatment	Result	Transition Probability (%)	95% Confidence Intervals	
				Lower (%)	Upper (%)
Reed Canarygrass	Fire	Bulrush/Cattail	0.0	0.0	0.0
Reed Canarygrass	Fire	Moist-Soil	8.7	3.3	21.0
Reed Canarygrass	Fire	Bare Soil	2.2	0.3	13.9
Reed Canarygrass	Graze	Bulrush/Cattail	3.9	3.1	5.1
Reed Canarygrass	Graze	Moist-Soil	27.0	24.8	29.3
Reed Canarygrass	Graze	Bare Soil	4.1	3.2	5.3
Reed Canarygrass	Graze/Spray	Bulrush/Cattail	2.2	1.1	4.3
Reed Canarygrass	Graze/Spray	Moist-Soil	42.4	37.4	47.5
Reed Canarygrass	Graze/Spray	Bare Soil	14.4	11.2	18.4
Reed Canarygrass	Rest	Bulrush/Cattail	2.6	1.9	3.5
Reed Canarygrass	Rest	Moist-Soil	30.0	27.8	32.4
Reed Canarygrass	Rest	Bare Soil	2.6	1.9	3.5
Reed Canarygrass	Spray	Bulrush/Cattail	7.4	4.6	11.7
Reed Canarygrass	Spray	Moist-Soil	48.1	41.6	54.8
Reed Canarygrass	Spray	Bare Soil	1.9	0.7	4.8

Reed Canarygrass >75%: Response Tables and Cost-Benefit Analyses

Encroachment of reed canarygrass is among the greatest challenges for managers, especially in the outer marsh and transition zones described by Gilbert (1989). This species annually produces large quantities of seeds and expands its distribution asexually through rhizomes (Walters 2003). Dense stands of reed canarygrass produce significant amounts of above-and below-ground biomass. This growth results in a thick litter layer that can bury moist-soil plant seeds and/or reduce moist-soil seed germination. Reduction of this species is typically a multi-year, multi-treatment endeavor (Walters 2003), and complete eradication is exceedingly difficult. Successfully managing a site dominated by reed canarygrass requires multiple intensive treatments to reduce distribution and abundance of the species and cultivate germination and growing conditions for annual moist-soil vegetation species (Walters 2003).

Herbicide applications, alone or in combination with other treatments, resulted in the greatest transition to the moist-soil vegetation state within a single year (Table 14). Consistent with Walters (2003), the combination of disking, spraying, and grazing in the same year had the greatest impact; shifting vegetation from >75% reed canarygrass to moist-soil vegetation at 58% of points, and shifting an additional 15% of the points to bare soil, which generally transitions to moist-soil vegetation during the following year. Only 19% of the points remained reed canarygrass >75% after this combination of treatments. In contrast, a single year of disking alone only reduced the probability of reed canarygrass >75% to 53%, again highlighting the importance of combining multiple treatments. Similarly, the combination of grazing and spraying was more effective than grazing alone at reducing the percentage of reed canarygrass.

Grazing and prescribed fire, alone or in conjunction, converted reed canarygrass >75% to moist-soil vegetation at less than 18% of points. Hillhouse et al. (2010) noted that typical grazing practices had no effect on the basal cover of reed canarygrass, but could improve germination conditions for annual species. Haying had functionally zero impact on reed canarygrass dominance since all points remained in one of the three reed canarygrass states in hayed sites. However, haying may still be a useful management tool when used to remove the above ground growth and significantly increase chemical contact from an herbicide application. Unfortunately, insufficient data points were available to fully evaluate this effect.

A combination of grazing, disking and spraying in the same year yielded the greatest increase in moist-soil seed production, but is relatively expensive. In contrast, a combination of grazing and spraying was also quite effective and results in at least modest income. Disking and grazing alone have minimal benefits relative to rest, while fire and haying actually led to a decrease in kcals when applied to reed canarygrass >75%.

Table 14. Percentage of reed canarygrass >75% sample points in each of nine vegetation states following one year of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

		Vegetation outcome after management (%)									**Cost-benefit evaluation**	
Treatment	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail > 75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass > 75%	**Change in moist-soil seed production relative to rest (thousands of kcals)**	**Cost/acre**
Graze+Disk+Spray	26	57.7	0.0	3.8	0.0	15.4	0.0	3.8	0.0	19.2	**+106**	$ (55)
Graze+Spray	195	33.3	0.0	1.0	0.0	15.9	1.0	13.8	11.3	23.6	**+73**	$ 40
Spray	118	39.8	0.8	2.5	2.5	2.5	1.7	16.1	9.3	24.6	**+62**	$ (15)
Graze+Disk	23	8.7	4.3	0.0	0.0	34.8	0.0	17.4	0.0	34.8	**+61**	$ (40)
Disk	30	20.0	0.0	0.0	0.0	16.7	0.0	3.3	6.7	53.3	**+26**	$ (95)
Graze+Fire	39	17.9	0.0	0.0	0.0	7.7	2.6	15.4	5.1	51.3	**+16**	$ 5
Graze	757	17.7	0.5	0.1	1.3	2.8	4.5	14.4	9.2	49.4	**+7**	$ 55
Rest	930	18.9	0.2	0.1	1.3	2.3	5.5	8.6	10.1	53.0	**0**	$ -
Fire	37	5.4	0.0	0.0	0.0	2.7	10.8	5.4	5.4	70.3	**-39**	$ (50)
Hay	33	0.0	0.0	0.0	0.0	0.0	0.0	12.1	12.1	75.8	**-40**	$ 60

Control of reed canarygrass is often a multi-year, multi-treatment process. Spraying alone or in combination with grazing in back-to-back years resulted in the greatest percentage of points transitioning to a moist-soil vegetative state (Table 15). This response is likely a result of the first herbicide application killing adult plants, while the subsequent herbicide treatment kills the newly germinated seedlings. Grazing may contribute to the impact of spraying by weakening plants and reducing standing dead biomass, leading to increased herbicide to leaf contact. When treatment plans included grazing and spraying in the first year, the mean percentage of points that transitioned to moist-soil vegetation was much higher if spraying was repeated in the second year (70%) as compared to using only grazing or resting in year two (47%). In contrast to spraying, less aggressive management plans that included only grazing or rest resulted in moist-soil vegetation <25% of the time, with >65% of points remaining in a reed canarygrass vegetative state. A single year of disking was not very effective at eliminating reed canarygrass. This may indicate regrowth from seed and/or rhizomes, again emphasizing the need for either previous year or following year treatments to maximize effects.

Although very effective, the combination of grazing, disking, and spraying in the first year followed by disking in the second year is also the most expensive management combination reported here. In contrast, grazing and spraying in consecutive years is the second most effective management combination for increasing moist-soil seed production and is cost positive. However, risk of reinvasion by reed canarygrass is slightly higher with this strategy, with nearly 20% of the vegetation remaining in one of the reed canarygrass categories. Spraying alone, without grazing, is both more expensive and less effective than some treatments that included both spraying and grazing. One or two years of grazing alone resulted in only slightly greater moist-soil seed production than rest, but did provide additional income that could be used for more aggressive treatments in the following years. However, given that spraying costs are relatively low; grazing without spraying seems a poor choice in reed canarygrass dominated areas.

Table 15. Percentage of reed canarygrass >75% sample points in each of nine vegetation states following two year of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment			Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Disk+Spray	Disk	20	40.0	0.0	0.0	0.0	50.0	0.0	5.0	0.0	5.0	+250	$ (150)
Graze+Spray	Graze+Spray	40	75.0	0.0	0.0	0.0	7.5	0.0	5.0	7.5	5.0	+206	$ 80
Graze+Spray	Spray	26	65.4	0.0	0.0	0.0	3.8	0.0	23.1	0.0	7.7	+195	$ 25
Spray	Spray	33	66.7	3.0	6.1	0.0	0.0	0.0	12.1	3.0	9.1	+175	$ (30)
Spray	Rest	28	64.3	0.0	0.0	3.6	3.6	0.0	10.7	7.1	10.7	+170	$ (15)
Graze+Spray	Graze	75	49.3	0.0	1.3	0.0	5.3	4.0	4.0	14.7	21.3	+148	$ 95
Graze+Spray	Rest	35	45.7	0.0	0.0	5.7	5.7	8.6	14.3	8.6	11.4	+148	$ 40
Spray	Graze	39	43.6	2.6	0.0	0.0	2.6	5.1	17.9	5.1	23.1	+132	$ 40
Graze	Graze+Spray	92	38.0	0.0	1.1	1.1	14.1	2.2	9.8	14.1	19.6	+84	$ 95
Disk	Rest	20	35.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	60.0	+43	$ (95)
Graze	Rest	146	23.3	1.4	0.0	0.0	0.7	4.8	16.4	9.6	43.8	+27	$ 55
Graze	Graze	174	19.5	2.9	0.0	0.6	2.3	5.7	10.9	13.8	44.3	+20	$ 110
Rest	Graze	114	16.7	0.9	0.0	0.9	5.3	4.4	17.5	10.5	43.9	+17	$ 55
Rest	Rest	313	21.7	0.6	0.6	0.3	1.6	8.9	6.1	6.7	53.4	0	$ -
Rest	Fire	20	5.0	0.0	0.0	0.0	10.0	0.0	10.0	5.0	70.0	-14	$ (50)
Fire	Rest	22	36.4	0.0	0.0	0.0	0.0	13.6	0.0	13.6	36.4	-15	$ (50)
Rest	Disk	20	5.0	0.0	0.0	0.0	10.0	0.0	0.0	10.0	75.0	-24	$ (95)

When back to back herbicide treatments were combined with grazing in years one and two, followed by grazing in year three, less than 9% of points remained in reed canarygrass >75% (Table 16). However, an otherwise similar treatment with only one year of spraying had nearly 30% of the points remaining in reed canarygrass >75%, highlighting the importance of multiple years of aggressive management to reduce reed canarygrass abundance. Plans that included only grazing and/or rest resulted in between 60 and 70% of their points remaining in a reed canarygrass state and were less effective at increasing native plant seed production than most of the more aggressive management strategies. Contrary to expectations, there is no evidence that three years of grazing resulted in a higher percentage of points in moist-soil vegetation than three years of rest.

A single year of disking with rest before and after was the only management plan that had a negative energy available outcome compared to resting only. This may be because of uncontrolled regeneration from the seed bank following disking. All combinations of treatments that included only rest or grazing resulted in only very small increases in energy available relative to rest alone. Only when more aggressive combinations of treatments were applied was energy substantially increased. Grazing and spraying in combination, especially when applied in consecutive years, provide the best cost-benefit return by resulting in substantially improved moist-soil seed production while also generating income via grazing leases.

Table 16. Percentage of reed canarygrass >75% sample points in each of nine vegetation states following three years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment				Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	Year 3	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Disk+Spray	Disk	Graze	20	40.0	0.0	0.0	0.0	50.0	0.0	5.0	0.0	5.0	+381	$ (95)
Graze+Spray	Graze+Spray	Graze	23	69.6	0.0	0.0	0.0	4.3	0.0	4.3	13.0	8.7	+310	$ 135
Graze	Graze+Spray	Graze	37	43.2	0.0	0.0	0.0	16.2	5.4	0.0	5.4	29.7	+264	$ 150
Graze	Graze+Spray	Spray	20	30.0	0.0	0.0	5.0	10.0	0.0	10.0	25.0	20.0	+252	$ 80
Graze	Rest	Graze	55	25.5	1.8	0.0	0.0	0.0	5.5	12.7	7.3	47.3	+31	$ 110
Graze	Graze	Rest	25	16.0	8.0	0.0	0.0	8.0	8.0	12.0	8.0	40.0	+28	$ 110
Graze	Graze	Graze	66	22.7	4.5	0.0	1.5	1.5	4.5	9.1	16.7	39.4	+28	$ 165
Rest	Graze	Rest	26	19.2	3.8	0.0	3.8	3.8	7.7	11.5	7.7	42.3	+16	$ 55
Rest	Rest	Graze	29	27.6	0.0	3.4	0.0	0.0	0.0	6.9	6.9	55.2	+1	$ 55
Rest	Rest	Rest	138	26.1	0.7	0.7	0.0	0.7	9.4	8.7	8.0	45.7	0	$ -
Rest	Disk	Rest	20	5.0	0.0	0.0	0.0	10.0	0.0	0.0	10.0	75.0	-61	$ (95)

Four consecutive years of rest resulted in a greater percentage of points transitioning to the moist-soil state (Table 17). While four years of grazing eliminated all reed canarygrass points, 77% of points transitioned to a bulrush/cattail state, suggesting the changes may be at least partially related to water level changes. However, both of these four-year treatment assessments had relatively few observations.

Table 17. Percentage of reed canarygrass >75% sample points in each of nine vegetation states following four years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment					Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	Year 3	Year 4	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Rest	Rest	Rest	Rest	37	43.2	0.0	0.0	0.0	0.0	29.7	5.4	5.4	16.2	0	$ -
Graze	Graze	Graze	Graze	22	22.7	0.0	18.2	59.1	0.0	0.0	0.0	0.0	0.0	-8	$ 220

Reed Canarygrass >75%: Duration of Benefit

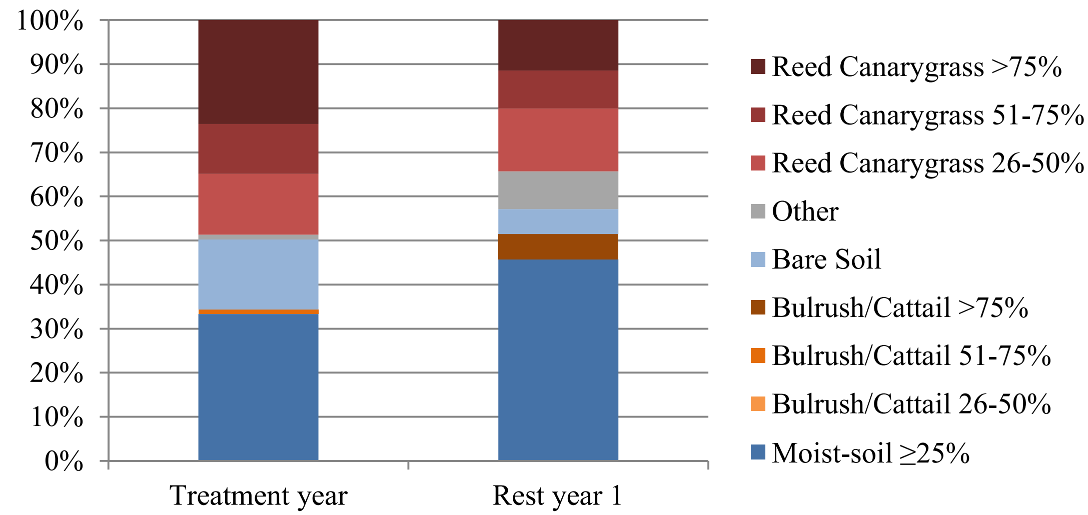


Figure 2A: Vegetation outcomes (%) for reed canarygrass >75% points following a combined grazing and spraying treatment and one year of rest.

The percentage of points in reed canarygrass continued to decrease in the year of rest following treatment. The percentage of points in either moist-soil vegetation or bare soil, however, only increased slightly during that time.

Figure 2B: Vegetation outcomes (%) for reed canarygrass >75% points following a single grazing treatment and one year of rest.

The effects of grazing on reed canarygrass >75% is relatively similar in the treatment year and the year following treatment. The percentage of points in moist-soil vegetation increased by 5% in year 2 while those in a reed canarygrass state decreased slightly.

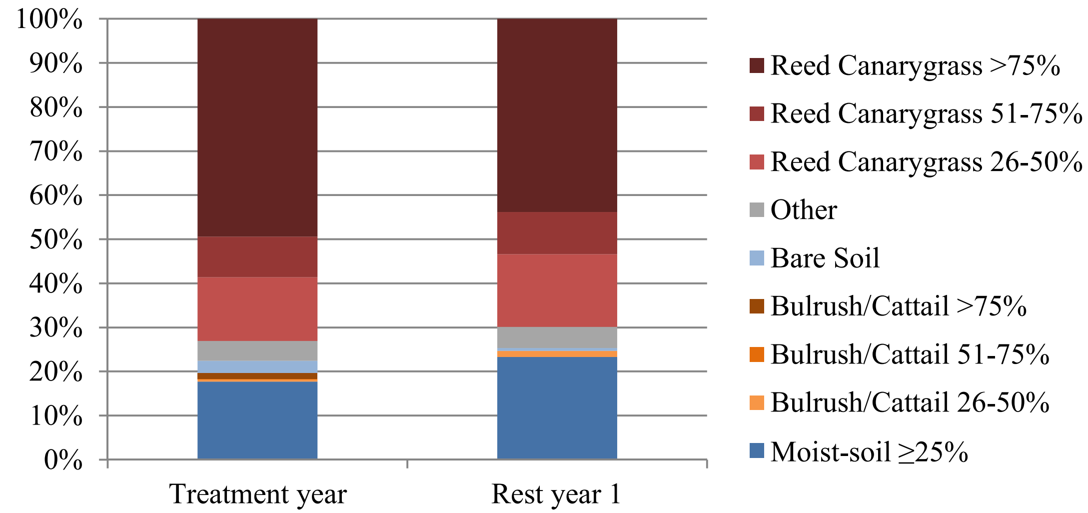


Figure 2C: Vegetation outcomes (%) for reed canarygrass >75% points following a single spraying treatment and one year of rest.

One year of spraying reed canarygrass >75% substantially reduced reed canarygrass in the treatment year, and the effect was not only sustained but magnified in the second year. The percentage of points in moist soil vegetation also continued to increase during the second year.

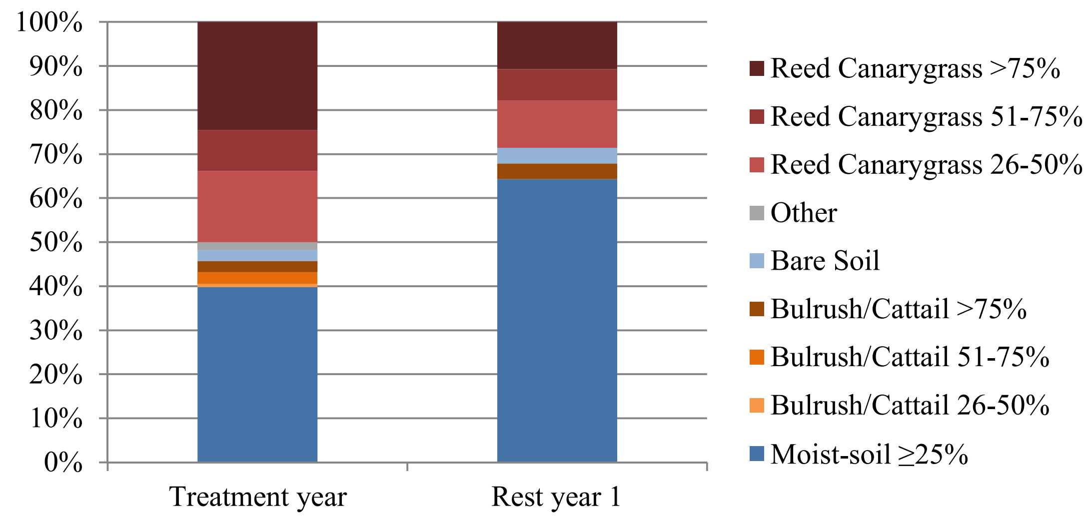


Figure 2D: Vegetation outcomes (%) for reed canarygrass >75% points following a single fire treatment and one year of rest.

For the most part, the effects of burning on reed canarygrass >75% do not appear until the year following treatment. The percentage of points in moist-soil was six times greater in the Year 2.

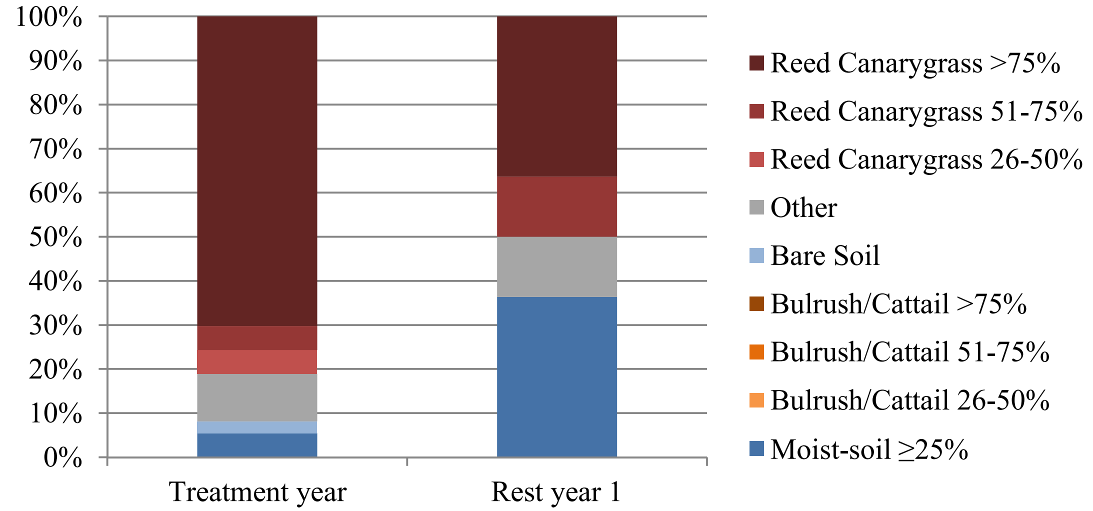


Figure 2E: Vegetation outcomes (%) for reed canarygrass >75% points following a single disking treatment and one year of rest.

When one year of disking reed canarygrass >75% was followed by a year of rest, the treatment effects did not extend into the second year. Bare soil points that resulted from the disking treatment likely transitioned to moist-soil vegetation during the subsequent year, but the combined amount of bare soil and moist soil points did not increase.

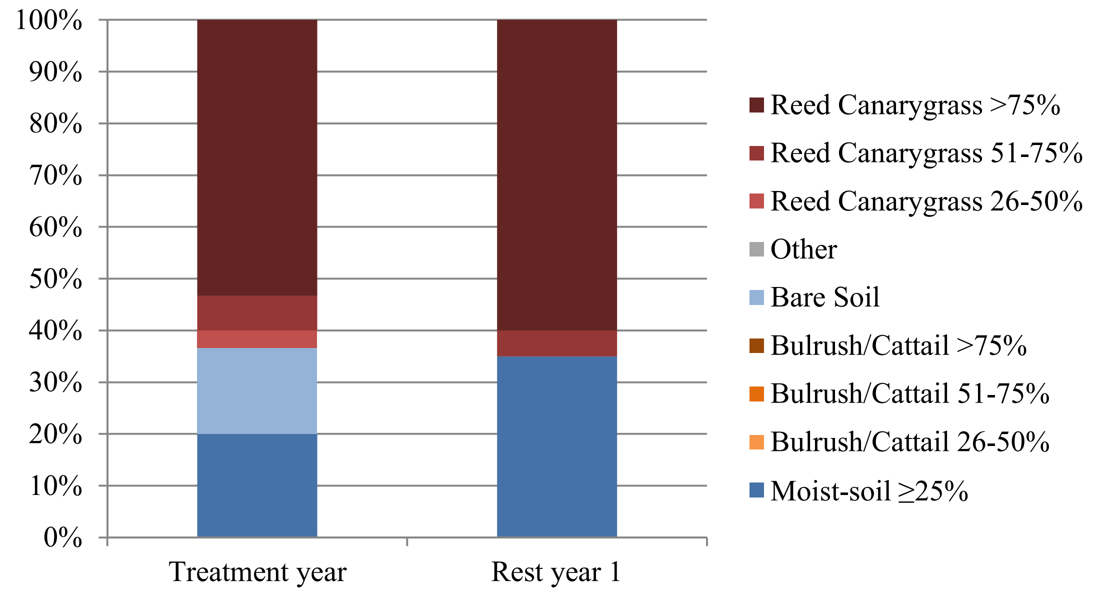
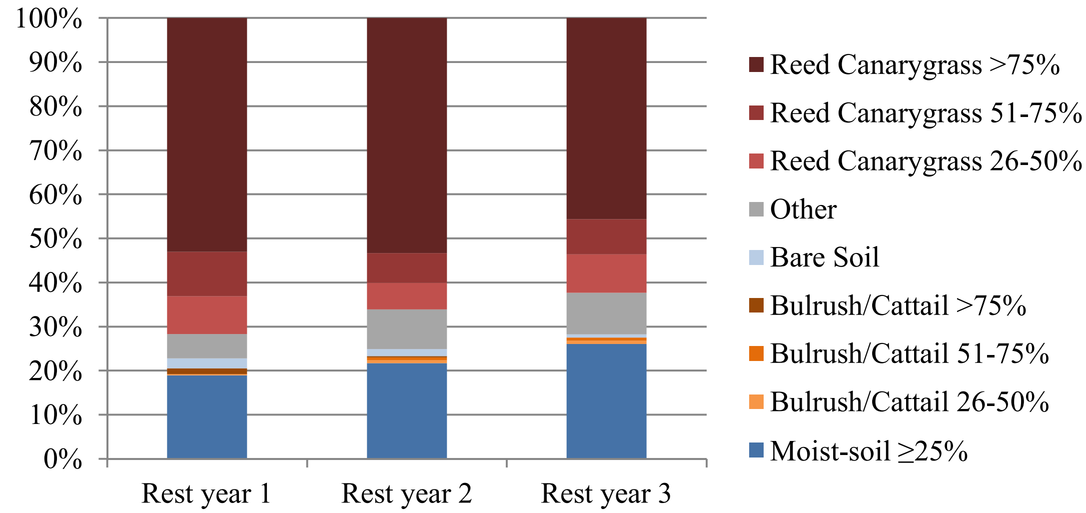


Figure 2F: Vegetation outcomes (%) for reed canarygrass >75% points following three years of rest.

Even with no active treatment, a small proportion of reed canarygrass >75% points transitioned to moist-soil vegetation every year. This may be caused by residual effects of previous treatments or natural or human-caused changes in water level, which we did not measure.



Reed Canarygrass 51-75%: Response Tables and Cost-Benefit Analysis

This vegetative state represents the period when reed canarygrass is actively colonizing a site. Colonization is occurring through rhizomes, tillers, and seed germination. It is much more cost effective to manage against reed canarygrass at the 51 - 75% density, before coverage exceeds 75%, although it is still a multi-year, multi-treatment, process since both the adult plants and seed bank must be managed. In general, points that were initially in the reed canarygrass 51-75% state tended to be dynamic, with only a small proportion of points remaining in this state regardless of management.

As with the reed canarygrass >75% state, herbicide applications alone or in combination with grazing were most effective at shifting reed canarygrass to a moist-soil community (Table 18). Grazing and spraying combined resulted in a shift to either the moist-soil or the bare soil state 60% of the time, while grazing alone left 59% of points in a reed canarygrass state. Resting resulted in slightly more moist-soil vegetation than grazing, however, one third of points shifted to a reed canarygrass >75% state after resting. All management actions resulted in increased moist-soil seed production compared to resting. The results of spraying alone or grazing and spraying combined were similar to those seen in reed canarygrass >75%. The increases in seed production are less in this case because the estimated initial seed production of reed canarygrass 51-75% is higher than reed canarygrass >75%. As seen previously, a combination of grazing and spraying results in both good increases in moist-soil seed production and income. Grazing alone or with fire are both less useful in terms of moist-soil seed production.

Table 18. Percentage of reed canarygrass 51-75% sample points in each of nine vegetation states following one year of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

		Vegetation outcome after management (%)									Cost-benefit evaluation	
Treatment	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Spray	48	58.3	12.5	0.0	0.0	0.0	2.1	18.8	6.3	2.1	+74	$ (15)
Graze+Spray	86	48.8	2.3	1.2	1.2	11.6	1.2	7.0	11.6	15.1	+54	$ 40
Graze+Fire	21	38.1	0.0	0.0	0.0	4.8	0.0	14.3	14.3	28.6	+23	$ 5
Graze	288	27.4	2.8	1.0	0.7	5.6	3.8	13.5	17.7	27.4	+6	$ 55
Rest	296	35.1	1.0	0.7	1.0	2.0	7.4	9.8	9.5	33.4	0	$ -

Consistent with the one-year treatment and reed canarygrass >75% results, any two-year treatment regime that included spraying was more successful at shifting vegetation to moist-soil states than those that used grazing or rest alone (Table 19). Management combinations that included grazing and spraying at least once each shifted an average of 57% of the points to moist-soil vegetation and only 10% to reed canarygrass >75%. In contrast, management combinations that included only grazing and/or rest resulted in an average of 33% moist-soil points and 33% reed canarygrass >75% points. All two-year treatment plans resulted in greater moist-soil seed production when compared to two years of rest. Any management plan that included spraying resulted in greater energy available than treatments including only rest or grazing. However, in contrast to the reed canarygrass >75% results, for points that received grazing and spraying in the first year, there was little difference in moist-soil seed production between points that were grazed or rested in the second year.

Table 19. Percentage of reed canarygrass 51-75% sample points in each of nine vegetation states following two years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment			Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Spray	Graze	37	64.9	0.0	0.0	0.0	13.5	0.0	8.1	5.4	8.1	+157	$ 95
Graze+Spray	Rest	22	63.6	0.0	0.0	0.0	18.2	9.1	0.0	0.0	9.1	+147	$ 40
Spray	Graze	25	48.0	0.0	4.0	0.0	0.0	4.0	24.0	12.0	8.0	+139	$ 40
Graze	Graze+Spray	23	52.2	4.3	0.0	0.0	8.7	0.0	13.0	8.7	13.0	+86	$ 95
Graze	Rest	43	41.9	0.0	0.0	2.3	4.7	2.3	9.3	4.7	34.9	+38	$ 55
Graze	Graze	79	30.4	3.8	1.3	1.3	1.3	3.8	19.0	7.6	31.6	+27	$ 110
Rest	Graze	40	30.0	0.0	0.0	2.5	5.0	5.0	12.5	12.5	32.5	+17	$ 55
Rest	Rest	108	29.6	1.9	0.0	1.9	1.9	15.7	7.4	10.2	31.5	0	$ -

Only one three-year treatment combination occurred at 20 or more points in reed canarygrass 51-75%, so comparisons across three-year treatments are impossible. Relative to the two-year rest plan, three consecutive years of rest results in slight increase in the percentage of points in moist-soil vegetation and a small decrease in the percentage of points in a reed canarygrass state (Table 20). This may occur because of human-caused or natural changes in water level that kill or stress reed canarygrass while promoting moist-soil vegetation or some other disturbance factor(s) that were not measured, such as freezing temperatures, insect herbivory, or disease. No cost-benefit analysis is possible for this set of response tables.

Table 20. Percentage of reed canarygrass 51 - 75% sample points in each of nine vegetation states following three years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment				Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	Year 3	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Rest	Rest	Rest	39	35.9	2.6	0.0	2.6	2.6	15.4	12.8	5.1	23.1	0	$ -

Reed Canarygrass 51% - 75%: Duration of Benefit

Figure 3A: Vegetation outcomes (%) for reed canarygrass 51-75% points following a combined grazing and spraying treatment and one year of rest.

The full effects of grazing and spraying on reed canarygrass 51-75% were not apparent until year 2. After two years, 82% of points were in a moist-soil or bare soil state, while only 9% remained in a reed canarygrass state.

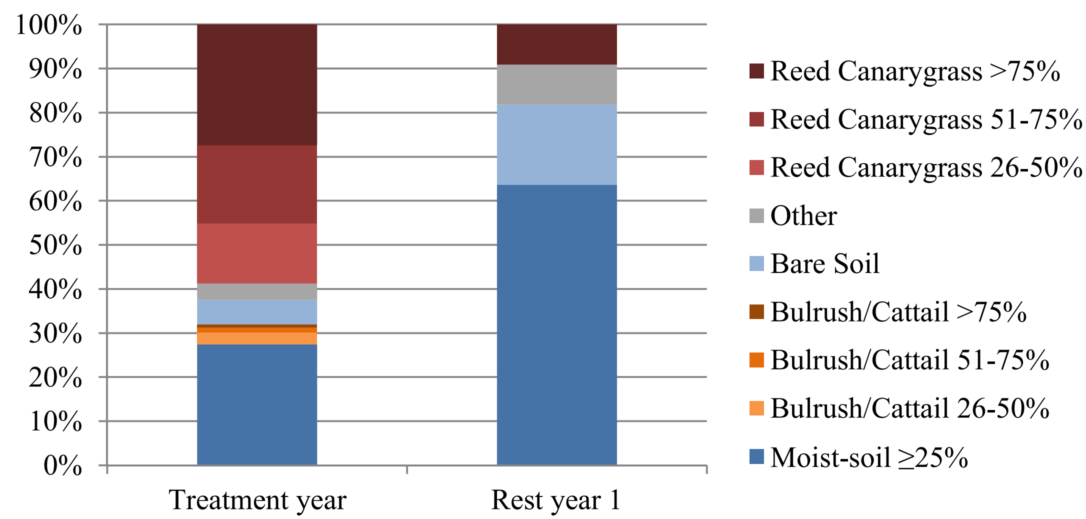


Figure 3B: Vegetation outcomes (%) for reed canarygrass 51-75% points following a single grazing treatment and one year of rest.

While grazing reduced the percentage of points in reed canarygrass 51% - 75% substantially in the year of treatment, these effects were greatly reduced during the subsequent year of rest.

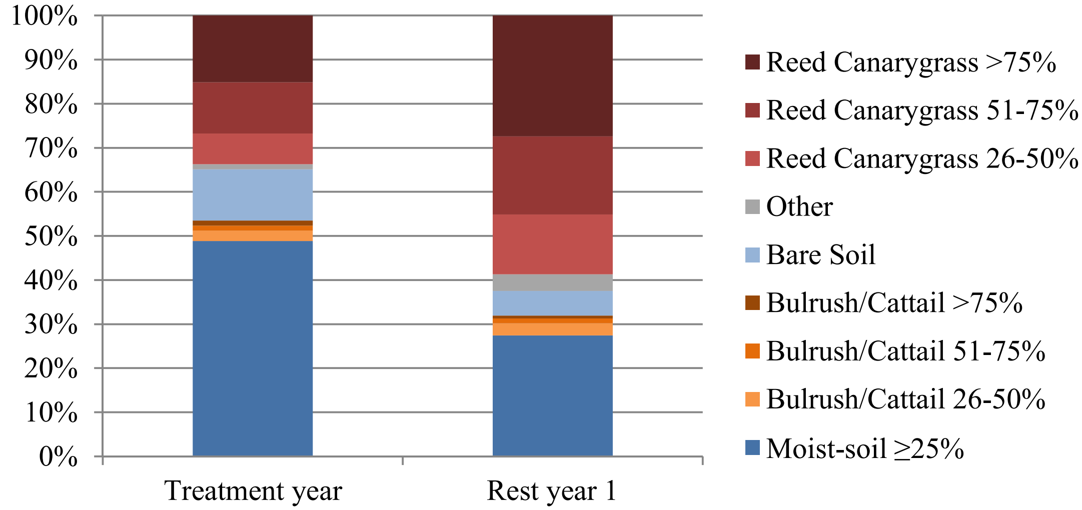
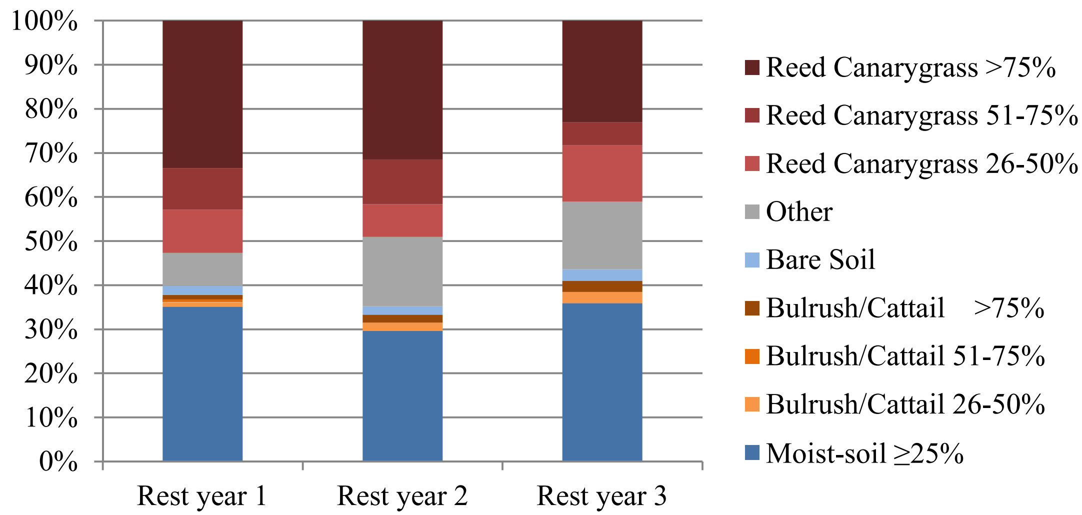


Figure 3C. Vegetation outcomes (%) for reed canarygrass 51-75% points following 3 years of rest.

Without one or more active management treatments, few points remained in the reed canarygrass 51-75% state. While one-third of points transitioned to a higher density reed canarygrass state, approximately one-third of points transitioned to a moist-soil state.



Reed Canarygrass 26% - 50%: Response Tables and Cost-benefit Analyses

In this vegetative state, reed canarygrass is not the dominant species and can often be reduced through a combination of treatments. It may be advantageous to actively manage against reed canarygrass at this stage before it becomes more established, even with the risk of damage to more desirable vegetation. Depending on the growth pattern, spot spraying or rototilling the isolated patches can be an effective treatment.

As with other reed canarygrass vegetative states, herbicide treatments, alone or in combination with grazing, resulted in the highest transition rates from reed canarygrass to moist-soil vegetation (Table 21). Grazing and rest treatments resulted in lower probabilities of transitioning to moist soil vegetation and higher probabilities of shifting to more dominant stands of reed canarygrass. Grazing and spraying did a better job of increasing moist-soil seed production than spraying alone, and produced the greatest increases in seed foods while also generating income. Grazing resulted in only slightly greater moist- soil seed production than rest.

Table 21. Percentage of reed canarygrass 26 - 50% sample points in each of nine vegetation states following one year of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

		Vegetation outcome after management (%)									Cost-benefit evaluation	
Treatment	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	**Change in moist-soil seed production relative to rest (thousands of kcals)**	**Cost/acre**
Graze+Spray	90	54.4	2.2	0.0	0.0	13.3	0.0	15.6	3.3	11.1	**+55**	$ 40
Spray	53	54.7	1.9	1.9	1.9	1.9	0.0	20.8	7.5	9.4	**+42**	$ (15)
Graze	502	36.9	2.2	1.4	2.4	4.8	5.8	15.9	13.1	17.5	**+5**	$ 55
Rest	405	43.5	1.7	0.5	1.7	3.0	10.4	10.1	7.4	21.7	**0**	$ -

Reed canarygrass 26% - 50% points tend to be dynamic, with relatively few staying in the same vegetation class from year to year, which emphasizes the importance of encouraging shifts to occur in ways that help accomplish management goals. Year one treatments of spraying alone or in combination with grazing, when followed by an additional year of grazing, were most effective at shifting plots from reed canarygrass 26% - 50% to moist-soil vegetative states (Table 22). Combined grazing and spraying treatments in year two were less effective, perhaps because of reed canarygrass seedling growth that had not been adequately controlled by grazing alone during year one. Additionally, the effects of spraying may be delayed, not becoming fully apparent until a year after treatment. Plots that received treatment combinations including only grazing or rest were less effective at increasing moist-soil vegetation. Plans that included only resting and grazing led to an increase in reed canarygrass density as 25-39% of points entered the reed canarygrass 51% - 75% or >75% states. Also, note that in comparison to reed canarygrass 51% - 75% points, similar management applied to reed canarygrass 26% - 50% points tended to result in greater shifts to moist-soil vegetation. This emphasizes the importance of being proactive in managing areas with low levels of reed canarygrass, as it is more difficult to achieve a moist-soil result after it reaches a >50% density. As with reed canarygrass 51% - 75%, one year of grazing and spraying combined or spraying alone followed by grazing in the second year resulted in substantially better moist-soil seed production than any treatment plans. Any combination of treatments that included only grazing and rest tended to result in little change in moist-soil seed production relative to two years of rest.

Table 22. Percentage of reed canarygrass 26 - 50% sample points in each of nine vegetation states following two years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment			Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Spray	Graze	42	71.4	2.4	0.0	0.0	7.1	2.4	9.5	7.1	0.0	+119	$ 95
Spray	Graze	21	66.7	4.8	0.0	0.0	4.8	4.8	9.5	4.8	4.8	+94	$ 40
Graze	Graze+Spray	27	29.6	3.7	0.0	11.1	14.8	0.0	25.9	3.7	11.1	+15	$ 95
Graze	Graze	129	42.6	1.6	3.9	2.3	4.7	7.8	11.6	8.5	17.1	+3	$ 110
Rest	Rest	118	50.0	1.7	0.8	1.7	3.4	11.9	5.1	9.3	16.1	0	$ -
Rest	Graze	62	45.2	1.6	1.6	0.0	0.0	11.3	12.9	11.3	16.1	-5	$ 55
Graze	Rest	54	33.3	0.0	0.0	1.9	3.7	11.1	11.1	11.1	27.8	-24	$ 55

Of all the three-year combinations of treatments on reed canarygrass 26% - 50%, only two occurred at 20 or more points (Table 23). Of those, three consecutive years of rest resulted in slightly higher moist-soil vegetation and slightly lower total probabilities of reed canarygrass compared to grazing. Although moist-soil seed production decreased slightly after three years of grazing, income was produced that may be used for management in other areas or in the future.

Table 23. Percentage of reed canarygrass 26 - 50% sample points in each of nine vegetation states following three years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment				Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	Year 3	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Rest	Rest	Rest	46	45.7	2.2	0.0	0.0	2.2	10.9	8.7	15.2	15.2	0	$ -
Graze	Graze	Graze	40	32.5	0.0	12.5	5.0	5.0	2.5	17.5	5.0	20.0	-7	$ 165

Reed Canarygrass 26% - 50%: Duration of Benefit

Figure 4A. Vegetation outcomes (%) for reed canarygrass 26-50% points following a single grazing treatment and two years of rest.

The effect of one year of grazing on reed canarygrass 26% - 50% did not extend into the years of rest following treatment. The percentage of points in moist-soil vegetation decreased in the years following treatment while the percentage of points in reed canarygrass or bulrush/cattail increased.

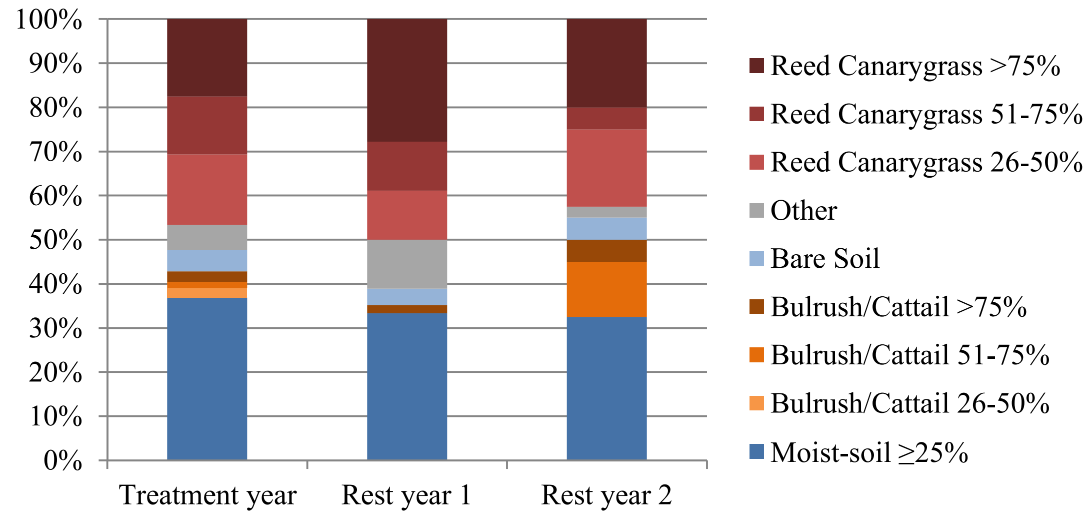
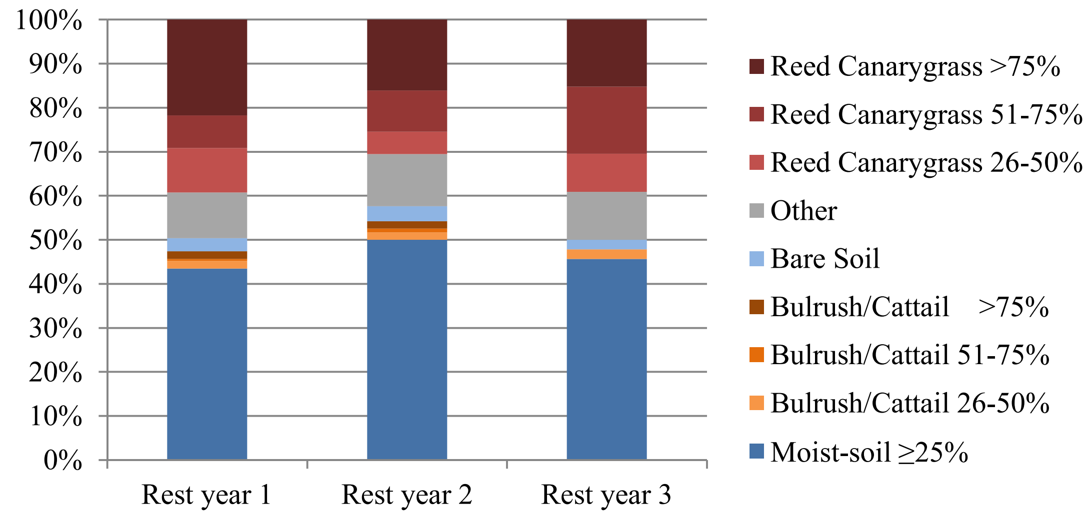


Figure 4B. Vegetation outcomes (%) for reed canarygrass 26-50% points following three years of rest.

After three years of rest, almost half of these reed canarygrass 26% - 50% points transitioned to a moist-soil state. This is likely caused by changes in hydrology, either natural or human-caused, or residual effects from treatments that occurred in prior years.



River Bulrush/Cattail: Transition Probabilities

The probability of transition from bulrush/cattail to moist-soil vegetation is 40% (CI: 34 - 47%) if spraying is used and 38% (CI: 32 - 43%) when grazing and spraying are used together (Table 24). This is more effective at converting bulrush/cattail to moist-soil vegetation than grazing (30%; CI: 28 - 33%) or fire (24%; CI: 12 - 43%) alone. If a bulrush/cattail area is rested, the probability of transition to moist-soil vegetation is 31% (CI: 27 - 34%). This may occur because of residual effects from management actions that occurred in previous years or natural processes, such as changes in water levels caused by precipitation. These results suggest that if a land manager has resources available and would like to eliminate bulrush/cattail from an area and ensure a moist-soil community, herbicide spraying should be applied. Grazing may also be used in conjunction with spraying, as revenues from the grazing may provide funds for spraying and grazing does not seem to negatively influence the impacts of the herbicide treatment. Additionally, there is a 7% (CI: 4 - 11%) probability of transition to reed canarygrass if spraying is applied alone, while that probability is reduced to 3% (CI: 2 - 6%) if spraying and grazing are combined. Fire is a high-cost treatment that is not particularly effective at producing moist-soil (24%) or bare soil (3%) habitats.

If resources are limited and only low- or no-cost options can be used, resting (31%) and grazing (30%) are similarly effective at producing a moist-soil community. Conversely, it is very difficult to convert bulrush/cattail to bare soil as none of these 5 management techniques result in a transition probability higher than 11%. If a land manager would like to convert bulrush/cattail to bare soil, more aggressive methods, such as disking (Table 25), will likely be needed. The probability that bulrush/cattail will transition to reed canarygrass is 7% or less for all treatments. As detailed in the Response Tables, the percentage of points that transitioned from bulrush/cattail to moist-soil vegetation never exceeded 60%, even after more aggressive, multi-year treatment plans and in areas where bulrush/cattail was not yet dominant (i.e., 26% - 50%). A more successful method of reducing bulrush/cattail may be through sediment removal or water level manipulation, which we did not measure.

Table 24. Probabilities and their associated 95% confidence intervals for transitions from a bulrush/cattail habitat to a moist-soil, bare soil, or reed canarygrass habitat after one year of one of the five most frequent management treatment(s) in the Rainwater Basin region of Nebraska, 2009-13.

Initial	Treatment	Result	Transition Probability (%)	95% Confidence Intervals	
				Lower (%)	Upper (%)
Bulrush/Cattail	Fire	Moist-Soil	24.1	12.0	42.7
Bulrush/Cattail	Fire	Bare Soil	3.4	0.5	20.8
Bulrush/Cattail	Fire	Reed Canarygrass	0.0	0.0	0.0
Bulrush/Cattail	Graze	Moist-Soil	30.3	27.8	32.9
Bulrush/Cattail	Graze	Bare Soil	7.4	6.1	9.0
Bulrush/Cattail	Graze	Reed Canarygrass	5.7	4.6	7.1
Bulrush/Cattail	Graze/Spray	Moist-Soil	37.5	32.4	42.9
Bulrush/Cattail	Graze/Spray	Bare Soil	10.9	8.0	14.9
Bulrush/Cattail	Graze/Spray	Reed Canarygrass	3.1	1.7	5.7
Bulrush/Cattail	Rest	Moist-Soil	30.5	27.4	33.7
Bulrush/Cattail	Rest	Bare Soil	4.0	2.9	5.6
Bulrush/Cattail	Rest	Reed Canarygrass	7.0	5.5	9.0
Bulrush/Cattail	Spray	Moist-Soil	40.2	33.8	46.9
Bulrush/Cattail	Spray	Bare Soil	9.8	6.5	14.6
Bulrush/Cattail	Spray	Reed Canarygrass	7.0	4.3	11.3

River Bulrush/Cattail >75%: Response Tables and Cost-Benefit Analyses

River bulrush and cattails often occur in the emergent zone described by Gilbert (1989). Since these two species occur in the deeper portions of wetlands, management can be extremely challenging. The saturated conditions within the persistent emergent zone often reduce opportunities to complete management activities, as the ability to access these areas with large equipment is limited. Both species expand in distribution and abundance through rhizomatous growth, produce a significant seed source, and, at times, cause a buildup of thick detrital litter, and shade out other emergent species. As with reed canarygrass, the combination of litter and organic material degrades germination conditions (i.e., sunlight and bare ground) and buries seeds of more desirable species, this can result in a persistent marsh zone dominated by a monoculture of river bulrush or cattails. Thus, managers often try to manage against river bulrush and cattails before they become monocultures (Reid et al. 1989). Also similar to reed canarygrass, managers must use significant resources to reduce the distribution of the bulrush/cattail >75% vegetative state so it is more efficient to manage the transitional stands when possible.

Since river bulrush and cattail commonly grow in standing water and/or saturated soils, managers have to be opportunistic when utilizing management treatments that require the use of heavy equipment, such as rototilling and disking. Fortunately, aerial herbicide applications can be applied even under saturated or inundated conditions. Herbicide treatments alone or in combination with a grazing treatment resulted in the greatest reductions in bulrush/cattail vegetation and transition to moist-soil vegetation (Table 25). The grazing and resting treatments resulted in reductions in bulrush/cattail >75% similar to those seen with herbicide treatments. Grazing and disking in a single year was most likely to shift vegetation to the bare soil state, and when combined with moist-soil vegetation, produces the most favorable total outcome.

Most management treatments shown here increased seed production and resulted in either modest income or modest expenses. Grazing and disking together were the most effective at increasing moist-soil seed production but also the most costly. Spraying, either alone or with grazing, led to an increase in energy available and defrayed costs when grazing was also used. Ultimately, single year of any of the treatments listed here appears relatively ineffective at substantially increasing available energy, regardless of cost.

Table 25. Percentage of bulrush/cattail >75% sample points in each of nine vegetation states following one year of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

		Vegetation outcome after management (%)									Cost-benefit evaluation	
Treatment	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Disk	26	11.5	19.2	11.5	26.9	30.8	0.0	0.0	0.0	0.0	+28	$ (40)
Spray	122	31.1	13.1	9.8	29.5	6.6	0.0	4.1	4.1	1.6	+17	$ (15)
Graze+Spray	133	30.1	12.8	11.3	32.3	7.5	1.5	1.5	0.8	2.3	+10	$ 40
Graze	651	23.0	18.0	11.5	35.6	7.5	0.0	2.3	0.6	1.4	+4	$ 55
Rest	389	24.4	18.8	12.1	32.6	2.8	0.8	3.3	1.5	3.6	0	$ -
Graze+Fire	40	22.5	17.5	2.5	47.5	2.5	0.0	0.0	0.0	7.5	-21	$ 5

The combination of grazing and disking in year one, followed by grazing in year two, produced the greatest percentage of points that shifted to moist-soil vegetation, and also the greatest reduction in bulrush/cattail vegetative states (Table 26). Herbicide treatments alone or in conjunction with other in-year treatments in the first year usually provided strong probabilities of transition to a moist soil community. Although many treatments show promise for reducing bulrush/cattail plant communities, all treatment combinations reported here resulted in at least 31% of points remaining in a bulrush/cattail state. Alternating resting and grazing treatments had the lowest percentage of points shifting to the moist-soil vegetation state, and 55-69% of points remaining in one of the bulrush/cattail vegetation states. Grazing and disking, followed by grazing, resulted in the greatest energy increase of any two-year management combination tested by a substantial margin. However, disking is often difficult to accomplish in relatively wet areas like those dominated by bulrush/cattail plant communities. Repeated spraying or graze and spray combination treatments perform similarly when spraying occurs in the first year, but spray followed by rest in the second year or spraying in the second year only is less effective at increasing moist-soil seed production within the two year period. There is little benefit seen for burning or single year grazing treatments when compared to resting.

Table 26. Percentage of bulrush/cattail >75% sample points in each of nine vegetation states following two years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment			Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Disk	Graze	26	57.7	15.4	7.7	7.7	11.5	0.0	0.0	0.0	0.0	+90	$ 15
Spray	Spray	54	44.4	20.4	7.4	14.8	0.0	0.0	11.1	1.9	0.0	+47	$ (30)
Graze+Spray	Graze+Spray	38	44.7	15.8	7.9	15.8	5.3	0.0	5.3	2.6	2.6	+39	$ 80
Graze+Spray	Graze	50	48.0	16.0	8.0	18.0	4.0	2.0	0.0	0.0	4.0	+34	$ 95
Graze	Graze	183	39.9	14.8	10.4	21.3	5.5	0.0	3.3	3.3	1.6	+21	$ 110
Spray	Rest	32	46.9	6.3	3.1	21.9	3.1	3.1	0.0	0.0	15.6	+18	$ (15)
Rest	Spray	27	44.4	11.1	3.7	33.3	3.7	0.0	0.0	3.7	0.0	+8	$ (15)
Graze	Rest	56	33.9	21.4	7.1	26.8	3.6	1.8	0.0	0.0	5.4	+2	$ 55
Graze+Fire	Graze	34	38.2	11.8	5.9	26.5	14.7	0.0	2.9	0.0	0.0	+2	$ 60
Rest	Rest	126	38.9	11.9	7.1	23.8	3.2	2.4	2.4	2.4	7.9	0	$ -
Graze	Graze+Spray	35	34.3	5.7	5.7	40.0	8.6	2.9	0.0	2.9	0.0	-7	$ 95
Rest	Graze	68	22.1	19.1	19.1	30.9	1.5	0.0	4.4	1.5	1.5	-19	$ 55

All three year treatment plans were similarly effective at reducing percentage of points in the bulrush/cattail >75% vegetative state, but those that included grazing were slightly more effective at generating moist-soil vegetation (Table 27). While spraying or grazing were fairly effective at reducing the density of bulrush/cattail when used alone, they did a better job eliminating bulrush/cattail and producing moist-soil vegetation when used in combination. Relative to rest, all other management treatments resulted in similar modest increases in seed production. Given these results, there is little to differentiate between treatments besides cost. Spraying alone was more costly than grazing or grazing and spraying, but produced similar results.

Table 27. Percentage of bulrush/cattail >75% sample points in each of nine vegetation states following three years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment				Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	Year 3	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Spray	Graze+Spray	Graze	25	52.0	12.0	8.0	16.0	0.0	0.0	4.0	4.0	4.0	+55	$ 135
Spray	Spray	Rest	22	31.8	31.8	9.1	13.6	0.0	0.0	9.1	4.5	0.0	+54	$ (30)
Graze	Graze	Graze	63	41.3	19.0	14.3	19.0	4.8	0.0	0.0	1.6	0.0	+31	$ 165
Rest	Rest	Rest	36	38.9	11.1	5.6	16.7	8.3	2.8	5.6	0.0	11.1	0	$ -

River Bulrush/Cattail >75%: Duration of Benefit

Figure 5A: Vegetation outcomes (%) for bulrush/cattail >75% points following a single grazing treatment and one year of rest.

When one year of grazing was followed up with a year of rest, new moist-soil areas continued to appear during the second year. With this treatment plan, however, more than half of all points remained in bulrush/cattail and reed canarygrass was able to invade some areas.

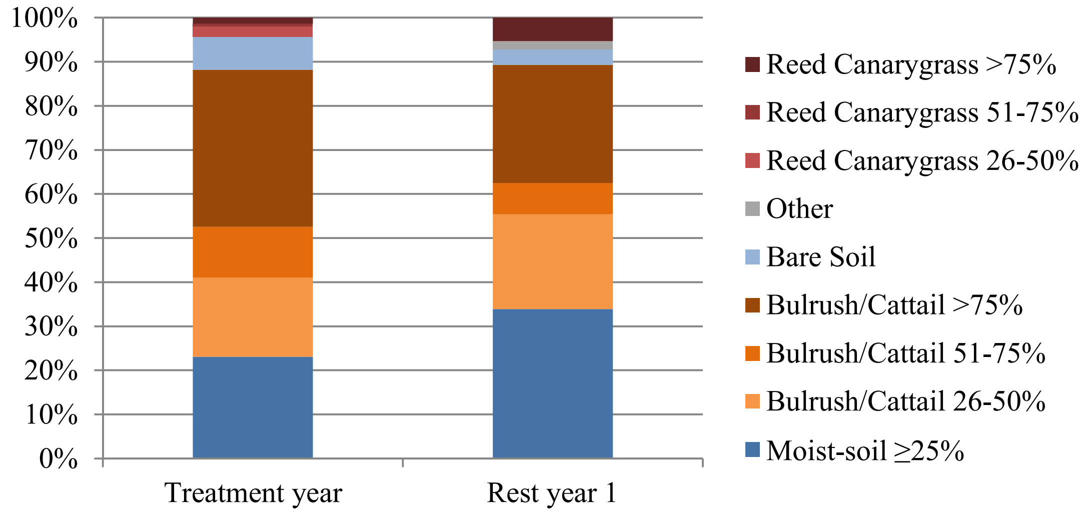


Figure 5B: Vegetation outcomes (%) for bulrush/cattail >75% points following a single spraying treatment and one year of rest.

The effects of spraying on bulrush/cattail >75% were not only sustained but magnified in the second year. Moist-soil vegetation increased and bulrush/cattail decreased during the year of rest following treatment. There was, however, a noticeable increase in reed canarygrass >75% in year 2.

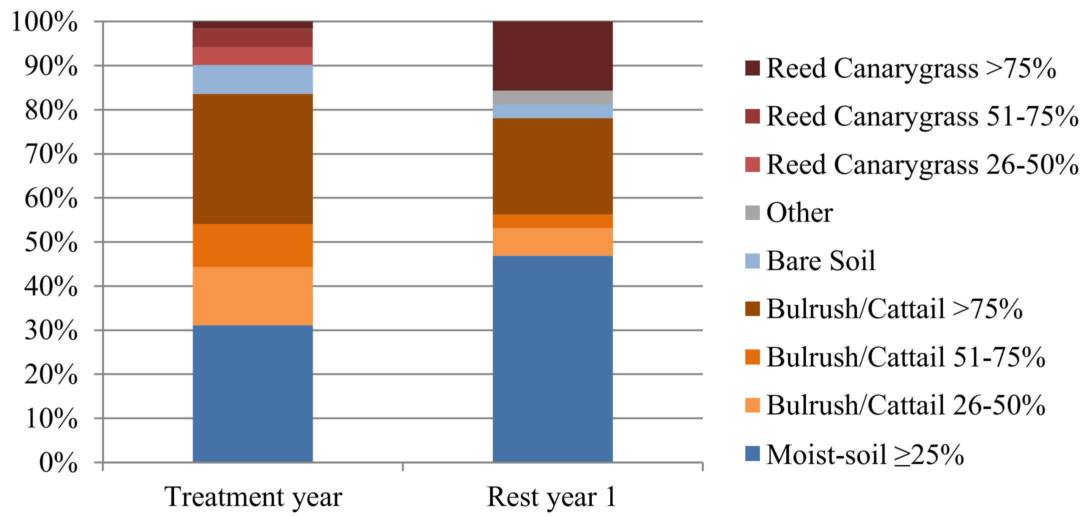
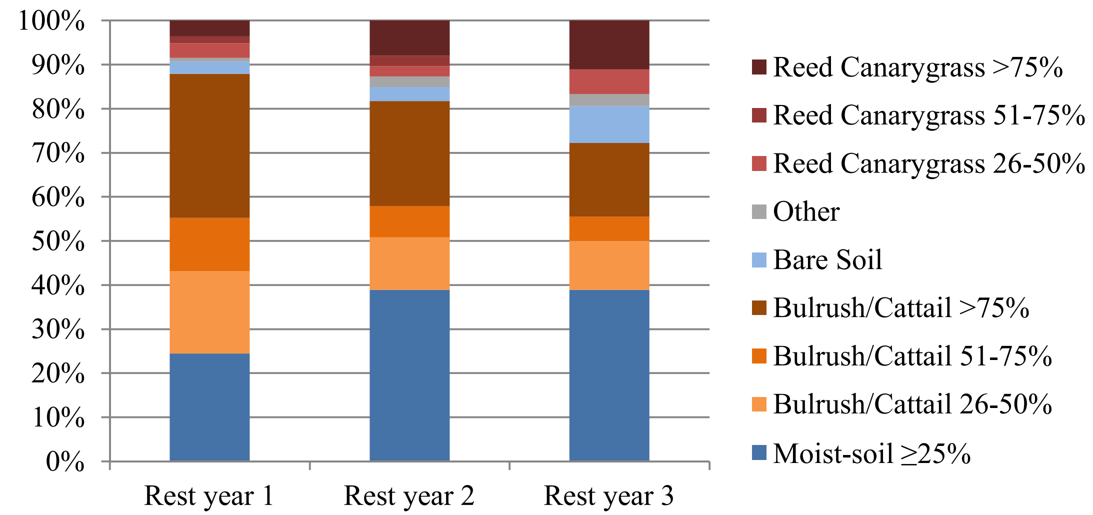


Figure 5C. Vegetation outcomes (%) for bulrush/cattail >75% points following three years of rest.

When left untreated, the total percentage of points in bulrush/cattail decreased slightly each year. Some of those points, however, transitioned to a reed canarygrass state. Hydrology is likely the driver of these changes, as cattails and river bulrush are both sensitive to prolonged drought and flooding.



River Bulrush/Cattail 51-75%: Response Tables and Cost-Benefit Analyses

In this vegetative state, river bulrush and/or cattails are the dominant species and are often managed through a combination of treatments. It is often more efficient to actively manage against river bulrush and cattail before they colonize a site and form a monotypic stand, so this is a potentially critical stage for targeted management. Since the persistent marsh zone is typically saturated, mechanical treatments can only be implemented opportunistically. As a result, aerial herbicide treatments and grazing are the most common management treatments used to manage these species. To increase the effects of grazing on these sites, late spring burns are recommended to open up the canopy, remove detrital litter and/or organic layers, and stimulate new plant growth that provide better forage quality (Drahota 2008) that cattle find palatable.

Bulrush/cattail 51-75% was the least common of any vegetative state, and as a result had a very limited number of treatments that occurred at 20 or more points. Relative to points that started out as bulrush/cattail >75% (Table 25), all treatment combinations applied to bulrush/cattail 51-75% points resulted in a higher percentage of moist-soil vegetation (Table 28), emphasizing the importance of managing these stands before they reach >75% cover of river bulrush and/or cattail. Herbicide applications applied alone resulted in the highest shift to moist-soil vegetation and the lowest total percentage of points in bulrush/cattail vegetative states, while other treatments resulted in similar increases in moist-soil vegetation. However, all treatments also had similar percentages of vegetation shifting to bulrush/cattail >75%, suggesting that single year treatments are not sufficient to cause predictable vegetation shifts in this plant community.

Although herbicide application was the most costly, it delivered an increase in moist-soil seed production more than three times greater than other treatments. All other management options reported here resulted in similar seed production. Ultimately, all changes in seed production that occurred following management were quite low, emphasizing the difficulty in mitigating the damage and loss of food resources for wetland-dependent birds that these invasive species cause.

Table 28. Percentage of bulrush/cattail 51-75% sample points in each of nine vegetation states following one year of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

		Vegetation outcome after management (%)									Cost-benefit evaluation	
Treatment	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	**Change in moist-soil seed production relative to rest (thousands of kcals)**	**Cost/acre**
Spray	41	53.7	7.3	2.4	22.0	7.3	0.0	2.4	2.4	2.4	**+31**	$ (15)
Graze+Spray	68	39.7	11.8	10.3	27.9	8.8	0.0	0.0	0.0	1.5	**+10**	$ 40
Graze	242	33.9	15.7	12.0	24.4	4.1	0.8	3.3	3.3	2.5	**+1**	$ 55
Rest	140	35.7	16.4	11.4	27.1	2.9	0.0	2.1	2.1	2.1	**0**	$ -

In contrast to the reed canarygrass states, two years of rest in bulrush/cattail 51-75% produced a greater increase in moist-soil vegetation and a lower percentage of remaining bulrush/cattail vegetation than either grazing or a single year of grazing and spraying followed by grazing (Table 29). The only treatment scenario that resulted in an increase in moist-soil seed production was two consecutive years of grazing and spraying combined. The relatively high probability of transitioning to bulrush/cattail >75% vegetative state (25-35%) or remaining in any of the three bulrush/cattail states (35-61%) highlights that none of these treatment regimens are ideal for eliminating bulrush/cattail.

Only grazing and spraying in two consecutive years resulted in higher seed production than rest, and that difference was modest. While all management treatments besides rest resulted in the generation of income from grazing leases, most of these plans led to a decrease in moist-soil seed production. While the most aggressive treatment plan may result in less income, that trade-off may be necessary if an increase in seed production is the goal.

Table 29. Percentage of bulrush/cattail 51 - 75% sample points in each of nine vegetation states following two years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment			Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Spray	Graze+Spray	20	55.0	5.0	10.0	30.0	0.0	0.0	0.0	0.0	0.0	+14	$ 80
Rest	Rest	60	46.7	6.7	3.3	25.0	5.0	1.7	5.0	0.0	6.7	0	$ -
Graze+Spray	Graze	33	27.3	18.2	9.1	33.3	6.1	0.0	3.0	0.0	3.0	-13	$ 95
Graze	Rest	20	25.0	20.0	10.0	35.0	5.0	0.0	5.0	0.0	0.0	-23	$ 55
Graze	Graze	104	29.8	11.5	4.8	34.6	5.8	0.0	5.8	1.9	5.8	-24	$ 110

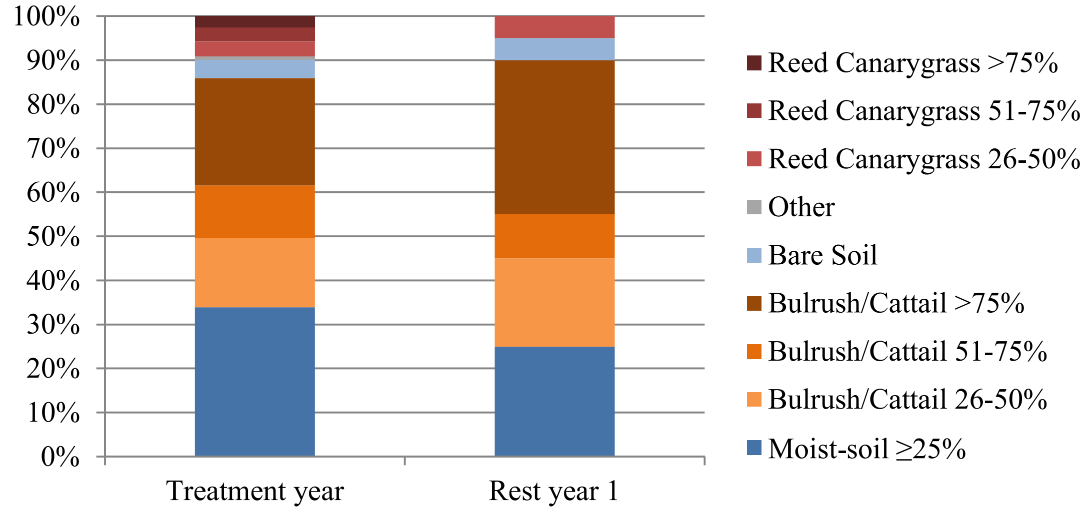
Only two management combinations occurred frequently enough to be included in the three-year results tables (Table 30). Of these, three years of rest seems to be more effective at converting bulrush/cattail to moist-soil vegetation, but neither consecutive years of rest nor consecutive years of grazing are very effective at shifting plots completely out of bulrush/cattail states. In particular, note that rest and grazing both result in at least 32% of points shifting to the bulrush/cattail ≥75% vegetative state. After three consecutive years of treatment, rest resulted in better moist-soil seed production than grazing. However, the reasons for this are unclear.

Table 30. Percentage of bulrush/cattail 51 - 75% sample points in each of nine vegetation states following three years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment				Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	Year 3	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Rest	Rest	Rest	22	40.9	4.5	9.1	31.8	4.5	4.5	0.0	0.0	4.5	0	$ -
Graze	Graze	Graze	56	23.2	12.5	5.4	41.1	5.4	0.0	5.4	1.8	5.4	-44	$ 165

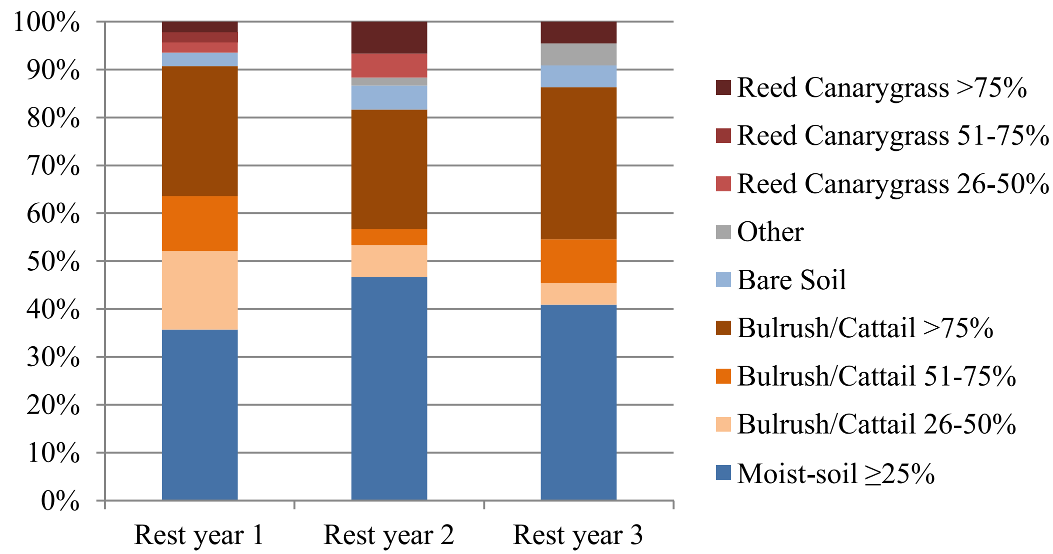
River Bulrush/Cattail 51% - 75%: Duration of Benefit

Figure 6A. Vegetation outcomes (%) for bulrush/cattail 51-75% points following a single grazing treatment and one year of rest.



While one year of grazing bulrush/cattail 51-75% reduced the total percentage of points in bulrush/cattail in the treatment year, bulrush/cattail increased and moist-soil vegetation declined in the second year after treatment. Nearly two-thirds of points remained in a bulrush/cattail state following a year of rest.

Figure 6B. Vegetation outcomes (%) for bulrush/cattail 51-75% points following three years of rest.



When no active management was used, nearly one-third of the bulrush/cattail 51-75% points transitioned to the bulrush/cattail >75% state. However, more than 40% of points transitioned to moist-soil vegetation despite receiving no management.

River Bulrush/Cattail 26 - 50%: Response Tables and Cost-Benefit Analyses

In this vegetation state, river bulrush and/or cattail have not yet become the dominant species, but the risk of invasion is high as these species are prone to vigorous spreading through rhizomatous growth and germination from an abundant seed bank. It is recommended to treat these stands aggressively using a combination of management activities within a single year in order to prevent the rapid development of monotypic stands.

Herbicide applications used alone or in combination with grazing resulted in relatively high percentage of points shifting to moist-soil and/or bare soil vegetative states (Table 31). Bare soil states are important because they are likely to transition to moist-soil vegetation the following year, but are also at risk for colonization by bulrush/cattail seedlings. Spraying with grazing resulted in a less moist-soil vegetative state and more bulrush/cattail vegetation than spraying alone. Grazing and rest resulted in the greater shifts to the bulrush/cattail >75% vegetative state than other treatments, and both resulted in >44% of points being in one of the bulrush/cattail vegetation states.

Spraying was the most effective way to increase both seed production and moist-soil vegetation, but also carried a net cost. A combination of grazing and spraying generated an increase in seed production while also producing a modest income. Rest resulted in the lowest seed production. Note that the predicted seed production after management is higher in points starting as bulrush/cattail 26% - 50% than those starting as bulrush/cattail 51% - 75% or bulrush/cattail >75%, highlighting the importance of managing these stands before they become dense monocultures.

Table 31. Percentage of bulrush/cattail 26 - 50% sample points in each of nine vegetation states following one year of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

		Vegetation outcome after management (%)									Cost-benefit evaluation	
Treatment	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass > 5%	**Change in moist-soil seed production relative to rest (thousands of kcals)**	**Cost/acre**
Spray	51	51.0	11.8	7.8	9.8	19.6	0.0	0.0	0.0	0.0	**+55**	$ (15)
Graze+Spray	121	43.8	16.5	11.6	9.9	15.7	0.0	0.0	1.7	0.8	**+41**	$ 40
Graze	387	40.1	17.3	10.9	16.3	9.3	0.3	3.4	1.8	0.8	**+24**	$ 55
Rest	300	35.3	17.3	7.3	27.7	6.0	1.0	1.7	1.7	2.0	**0**	$ -

Alternating years of grazing and spraying and grazing alone were most effective at shifting points to a moist-soil vegetative state (Table 32). However, consecutive years of grazing and spraying combined were less effective, and were instead similar to less aggressive treatments such as two consecutive years of rest or grazing in terms of outcomes. Alternating grazing and rest treatments seem to have been particularly ineffective at shifting vegetation out of a bulrush/cattail states.

Nearly all management combinations resulted in an increase in seed production compared to rest. Combinations of grazing and spraying, either in consecutive years or paired with a single year of grazing, were more effective at increasing seed production than any less aggressive treatment that was evaluated. Interestingly, in contrast to points starting as bulrush/cattail 51% - 75% or bulrush/cattail >75%, combining a year of grazing and spraying with a year of grazing only was more effective at promoting seed production than two consecutive years of grazing and spraying.

Table 32. Percentage of bulrush/cattail 26 - 50% sample points in each of nine vegetation states following two years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment			Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Spray	Graze	56	57.1	8.9	3.6	14.3	8.9	0.0	3.6	3.6	0.0	+79	$ 95
Graze	Graze+Spray	26	57.7	3.8	3.8	15.4	19.2	0.0	0.0	0.0	0.0	+72	$ 95
Graze+Spray	Graze+Spray	40	40.0	7.5	7.5	27.5	15.0	0.0	2.5	0.0	0.0	+51	$ 80
Graze	Graze	129	39.5	11.6	6.2	23.3	14.0	0.8	0.8	1.6	2.3	+34	$ 110
Graze	Rest	27	33.3	18.5	11.1	18.5	3.7	0.0	11.1	0.0	3.7	+24	$ 55
Rest	Rest	104	42.3	9.6	9.6	21.2	3.8	1.9	3.8	4.8	2.9	0	$ -
Rest	Graze	78	26.9	15.4	16.7	21.8	9.0	0.0	3.8	5.1	1.3	-8	$ 55

Three consecutive years of rest was the most effective way to increase moist-soil vegetation and decrease bulrush/cattail states at the end of the interval (Table 33). This is particularly surprising when comparing three years of rest with two years of rest followed by grazing the treatment that resulted in the strongest shift to bulrush/cattail ≥75%. However, all 3-year treatment intervals shown here represent a relatively low number of points and should be viewed with some caution.

Two years of rest followed by grazing resulted in a large decrease in seed production. The increases in seed production that followed two of the treatment plans were quite small, however, all management treatments reported here resulted in greater seed production than was seen in bulrush/cattail 51% - 75% or bulrush/cattail >75% points. This further highlights the importance of managing bulrush/cattail stands before they become too dense.

Table 33. Percentage of bulrush/cattail 26 - 50% sample points in each of nine vegetation states following three years of management action(s) and results of cost-benefit evaluation from 2009-2013 in the Rainwater Basin region of Nebraska. Only management actions with >20 sample points are included.

Treatment				Vegetation outcome after management (%)									Cost-benefit evaluation	
Year 1	Year 2	Year 3	# of points	Moist-soil ≥25%	River Bulrush/ Cattail 26-50%	River Bulrush/ Cattail 51-75%	River Bulrush/ Cattail >75%	Bare Soil	Other	Reed Canarygrass 26-50%	Reed Canarygrass 51-75%	Reed Canarygrass >75%	Change in moist-soil seed production relative to rest (thousands of kcals)	Cost/acre
Graze+Spray	Graze+Spray	Graze	31	35.5	9.7	6.5	35.5	9.7	0.0	3.2	0.0	0.0	+39	$ 135
Graze	Graze	Graze	41	31.7	17.1	7.3	26.8	9.8	0.0	2.4	2.4	2.4	+26	$ 165
Rest	Rest	Rest	20	50.0	5.0	5.0	20.0	0.0	5.0	10.0	0.0	5.0	0	$ -
Rest	Rest	Graze	26	15.4	7.7	11.5	53.8	3.8	3.8	3.8	0.0	0.0	-69	$ 55

River Bulrush/Cattail 26% - 50: Duration of Benefit

Figure 7A. Vegetation outcomes (%) for bulrush/cattail 26-50% points following a single grazing treatment and one year of rest.

The effects of grazing bulrush/cattail 26% - 50% did not carry over into the year of rest following treatment. The percentage of points and the density of bulrush/cattail on those points both increased following rest. Moist soil vegetation declined in year 2, while the percentage of points in a reed canarygrass state more than doubled.

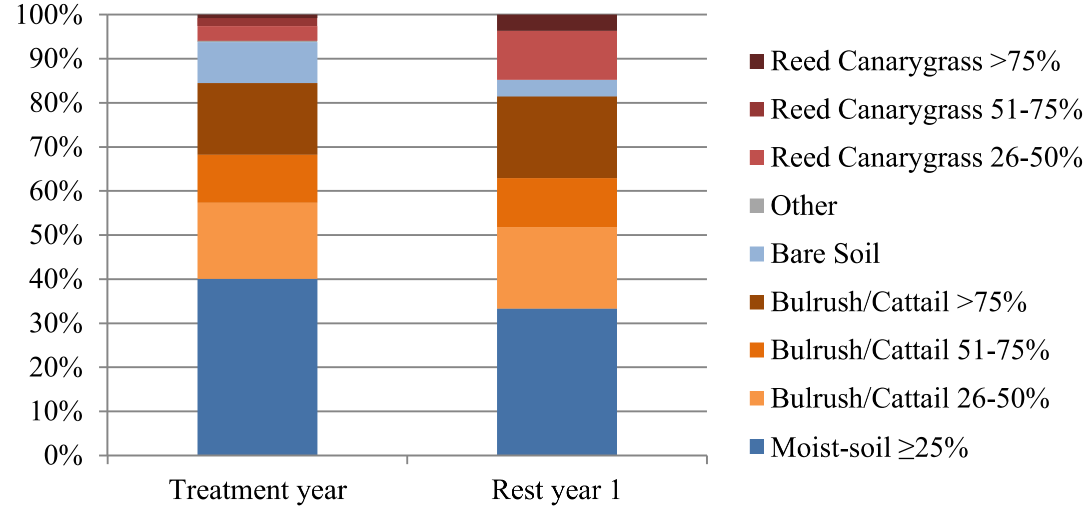
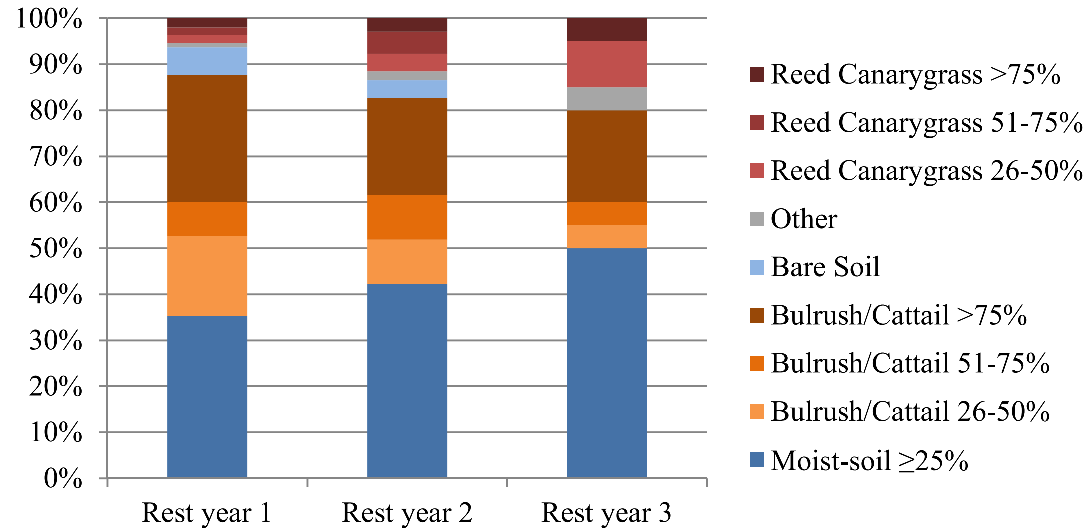


Figure 7B. Vegetation outcomes (%) for bulrush/cattail 26-50% points following three years of rest.

When points with a low density of bulrush/cattail were rested, 40% transitioned to a higher density bulrush/cattail state or reed canarygrass after 3 years. The percentage of points that transitioned to moist-soil vegetation, however, was even higher (50%).



CONCLUSIONS

Waterfowl and other wetland-dependent birds evolved to survive in a constantly changing environment. Grazing by native ungulates, drought and deluge weather events, annual hydrological cycles, and frequent fire caused changes across the landscape that resulted in optimal conditions for spring-migrating waterfowl in the RWB. Modern development, however, has altered many of these natural processes. Wetlands are particularly vulnerable to plant invasions because of their landscape sink position (Zedler and Kercher 2004) and, for the most part, intervention is needed to restore or maintain historical disturbance patterns that support native wetland plant communities.

Some vegetation management methods attempt to mimic natural processes, such as prescribed fire and cattle grazing. Research has indicated that grazing can greatly reduce cover of some invasive plants (Sillman et al. 2014). We also found that, generally, grazing produced better outcomes than resting. Compared to other management techniques, however, the increases in moist-soil seed production following grazing were small. In reed canarygrass communities, one year of grazing always resulted in fewer points dominated (i.e. >75%) by reed canarygrass when compared to the results of no management. The percentage of points containing moist-soil vegetation, however, was always higher after resting than after grazing. While grazers successfully reduced or prevented the spread of reed canarygrass, they did not appear to facilitate the establishment of moist-soil plants. When applied to an existing moist-soil area, grazing always performed better than resting and effects were magnified in multiple consecutive years. Grazing seemed to produce mixed results when applied to river bulrush/cattail communities. This may be due to wide variations in cattle stocking rates among areas, as high intensity grazing is likely more effective than low intensity (Kostecke et al. 2004, Drahota and Casady 2012). Stocking rates at >90% of our sample points were <1.0 AUM/acre, which is lower than those recommended by USFWS (20007). The duration of grazing likely also has an effect on the plant community. Additional research is needed to determine ideal stocking rates and grazing duration to promote or maintain moist-soil plant communities in the RWB.

We found that prescribed fire, when used alone, usually did not produce good outcomes, which is consistent with prior research (Kostecke et al. 2004). Results were mixed when fire and grazing were used in the same year, which may be due to differences in grazing intensity (Kostecke et al. 2004). Our results also suggest that the full effects of prescribed fire may not be realized until a year or more following treatment. Burning seems to produce the best results when combined with grazing, followed up by grazing in one or more subsequent years, and applied to a moist-soil community, a management regime that mirrors historic patterns. Although fire can also be a tool to help control woody invasion, we did not measure those effects in this project.

More aggressive management, like spraying or disking, kills most of the vegetation and can produce bare ground, creating an opportunity for a more desirable community to supplant an undesirable community. We found that spraying usually resulted in greater moist-soil seed production when compared to other solo treatments. The positive effects of spraying were often magnified in subsequent years. Additionally, spraying and grazing often worked better in combination than individually. Our results agree with previous research that indicated that spraying in multiple consecutive years may be needed in areas where an invasive plant seed bank is present (Lavergne and Molofsky 2006). Disking also works well in combination with spraying because the herbicide kills the growing plants while disking may cause some of the seeds to be buried too deep to allow germination. In general, disking works well alone or in combination with other methods because it creates an early successional “blank slate” where moist-soil vegetation can be reestablished without competition from more hardy invasives. However, if the invasive seed bank is not managed, the positive effects of disking may be temporary (Lavergne and Molofsky 2006).

We generally found that any management at all resulted in a greater amount of moist-soil seed energy available compared to no management. No management or resting may be used intentionally if a land manager does not anticipate a negative outcome. For example, a land manager may be aware of other variables that we were unable to measure, such as natural or human-made water flows, that can help shift an area towards a more productive plant community. In other cases, resting may be used if there are no resources available for management activities, even in areas where intervention is clearly needed. We may be more likely to see a negative outcome in this scenario. We were not able to determine the intentions or objectives of land managers making management decisions, even though these variables may be correlated with outcomes. A randomized treatment study may be needed to control for these factors.

We were not able to fully evaluate all vegetation management treatments or combinations of treatments used in the RWB due to small sample sizes (Table 3). For example, mowing could not be assessed, although it may be an effective management technique (Hagy and Kaminski 2012) and would likely mimic intensive grazing treatments (Drahota and Casady 2012). Additionally, water level manipulation, a common moist-soil management activity in some regions, is rarely used in the RWB. Changes in water levels due to precipitation or drought may have affected vegetation communities in this study, as we frequently observed transitions away from a late successional state in areas that received no management. It is unlikely that a dominant reed canarygrass, river bulrush, or cattail community would shift back to a moist-soil state without some form of disturbance including inundation for extended periods of time or prolonged drought. Further study is needed to evaluate treatment intensity, duration, and hydrology to determine whether alternative management methods should be considered in the RWB.

LITERATURE CITED

Adams, C.R., and S.M. Galatowitsch. 2006. Increasing effectiveness of reed canary grass (*Phalaris arundinacea* L.) control in wet meadow restorations. Restoration Ecology 14:441 – 451.

Anderson, J.T., and L.M. Smith. 1999. Carrying capacity and diel use of managed playa wetlands by nonbreeding waterbirds. Wildlife Society Bulletin 27:281 – 291.

Austin, J.E., and A.L. Richert. 2001. A comprehensive review of the observational and site evaluation data of migrant whooping cranes in the United States, 1943-99. U.S. Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, North Dakota, and State Museum, University of Nebraska, Lincoln, Nebraska, USA.

Bahm, M.A., T.G. Barnes, and K.C. Jensen. 2014. Evaluation of herbicides for control of reed canarygrass (*Phalaris arundinacea*). Natural Areas Journal 34:459 – 464.

Baldassarre, G.A., and E.G. Bolen. 2006. Waterfowl ecology and management, 2nd edition. Krieger Publishing Company, Malabar, Florida, USA.

Beas, B.J., L.M. Smith, T.G. LaGrange, and R. Stutheit. 2013a. Effects of sediment removal on vegetation communities in Rainwater Basin playa wetlands. Journal of Environmental Management 128:371 – 379.

Beas, J.B., L.M. Smith, K.R. Hickman, T.G. LaGrange, and R. Stutheit. 2013b. Seed bank responses to wetland restoration: Do restored wetlands resemble reference conditions following sediment removal? Aquatic Botany 108:7 – 15.

Bishop, A.A, J. Liske-Clarke, M. Tacha, and R. Reker. 2010. Whooping Crane Conservation Plan for the Rainwater Basin Region of south central Nebraska. http://rwbjv.org/rainwater2012/wp-content/uploads/2013/04/RWB-Whooping-Crane-Conservation-2010.pdf. Rainwater Basin Joint Venture, Grand Island, Nebraska, USA.

Bishop, A.A., and R. Grosse. 2012. Scoring criteria and ranking for wildlife habitat incentive program, Rainwater Basin Public Wetland Watershed Special Initiative. http://rwbjv.org/rainwater2012/wp-content/uploads/2012/02/RWB-Pit-Fill-Model-for-2012-WHIP-SI.pdf. Rainwater Basin Joint Venture, Grand Island, Nebraska, USA.

Bishop, A.A., and M. Vrtiska. 2008. Effects of the Wetlands Reserve Program on waterfowl carrying capacity in the Rainwater Basin region of south-central Nebraska. USDA NRCS. ftp://ftpfc.sc.egov.usda.gov/NHQ/nri/ceap/RWB_WRP_Final percent20Report.pdf. Rainwater Basin Joint Venture, Grand Island, Nebraska, USA

Bolen, E.G., G.A. Baldassarre, and F.S. Guthery. 1989. Playa Lakes. Pages 341-366 *in* L.M. Smith, R.L. Pederson, R.M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Technological University Press, Lubbock, Texas, USA.

Breininger, D.R., J.D. Nichols, B.W. Duncan, E.D. Stolen, G.M. Carter, D.K. Hunt, and J.H. Drese. 2010. Multistate modeling of habitat dynamics: factors affecting Florida scrub transition probabilities. Ecology 91:3354 – 3364.

Brennan, E.K. 2006. Local and landscape level variables influencing migratory bird abundance, diversity, behavior, and community structure in Rainwater Basin wetlands. Doctoral dissertation, Texas Tech University, Lubbock, Texas, USA. Available electronically from http://hdl.handle.net/2346/985.

Brennan, E.K., L.M. Smith, D.A. Haukos, and T.G. LaGrange. 2005. Short-term response of wetland birds to prescribed burning in Rainwater Basin wetlands. Wetlands 25:667 – 674.

Brown, S.B., C. Hickey, B. Harrington, and R. Gill (Editors). 2001. United States Shorebird Conservation Plan. Manomet Center for Conservation Sciences, Manomet, Massachusetts, USA.

Brownstein, G., R. Blick, C. Johns, P. Bricher, A. Fletcher. and P.D. Erskine. 2015. Optimising a sampling design for endangered wetland plant communities: another call for adaptive management in monitoring. Wetlands 35:105 – 113.

Canadian Wildlife Service and U.S. Fish and Wildlife Service. 2007. International recovery plan for the whooping crane. Ottawa: Recovery of National Endangered Wildlife (RENEW), and U.S. Fish and Wildlife Service, Albuquerque, New Mexico, USA.

Chavez-Ramirez, F., C. Helzer, and P. Tebbel. 2008. A landscape perspective of whooping crane migration through Nebraska: conservation and management implications. Proceedings of the International Crane Workshop in Zacatecas, Mexico.

Davis, C.A., and J.R. Bidwell. 2008. Response of aquatic invertebrates to vegetation management and agriculture. Wetlands 28:793 – 805.

Davis, C.A., and L.M. Smith. 1998. Ecology and management of migrant shorebirds in the playa lakes region of Texas. Wildlife Monographs 140.

Daubenmire, R.F. 1959. Canopy coverage method of vegetation analysis. Northwest Science 33:43 – 64.

Devries, J.H., R.W. Brook, D.W. Howerter, and M.G. Anderson. 2008. Effects of spring body condition and age on reproduction in Mallards (*Anas platyrhynchos*). Auk 125:618 – 628.

Drahota, J.D. 2009. Rainwater Bain wetland grazing, forage quality, and wildlife habitat [unpublished report]. On file at Rainwater Basin Wetland Management District, Funk, Nebraska, USA.

Drahota, J.D. 2012. Rainwater Basin seed availability, depletion, and waterfowl response during spring migration. M.S. Thesis, University of Nebraska-Kearney, Kearney, Nebraska, USA.

Drahota, J.D., and D. Casady. 2011. Review of grazing treatments on WPAs in the RWB 2009 [unpublished report]. On file at Rainwater Basin Wetland Management District, Funk, Nebraska, USA.

Drahota, J.D., and D. Casady. 2012. Review of grazing treatments on WPAs in the RWB 2011 [unpublished report]. On file at Rainwater Basin Wetland Management District, Funk, Nebraska, USA.

Drahota, J.D., and L.M. Reichart. 2015. Wetland seed availability for waterfowl in annual and perennial emergent plant communities of the Rainwater Basin. Wetlands: DOI 10.1007/s13157-015-0698-3.

Erickson, N.E., and D.M. Leslie, Jr. 1987. Soil-vegetation correlations in the Sandhills and Rainwater Basin wetlands of Nebraska. U.S. Fish and Wildlife Service Biological Report 87(11), Stillwater, Oklahoma, USA.

Fellows, S., K. Stone, S. Jones, N. Damude, and S. Brown. 2001. Central Plains/Playa Lakes conservation plan, version 1.0. http://www.shorebirdplan.org/wpcontent/uploads/ 2013/01/CPPLR.pdf accessed August 2003.

Foster, L.B., K. Kindschier, G.R. Houseman, and C.A. Murphy. 2009. Effects on hay management and native species sowing on grassland structure, biomass, and restoration. Ecological Applications 19:1884 – 1896.

Fuhlendorf, S.D. and D.M. Engle. 2001. Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns. Bioscience 51:625 – 32.

Gersib, R.A., B. Elder, K.F. Dinan, and T.H. Hupf. 1989. Waterfowl values by wetland type within Rainwater Basin wetlands with special emphasis on activity time budget and census data. Nebraska Game and Parks Commission. Lincoln, Nebraska and U.S. Fish and Wildlife Service, Grand Island, Nebraska, USA.

Gersib, D., J. Cornely, A. Trout, J. Hyland, and P.J. Gabig. 1990. Concept plan for waterfowl habitat protection, Rainwater Basin area of Nebraska. Nebraska Game and Parks Commission, Lincoln, Nebraska, USA.

Gersib, R.A., K.F. Dinan, J.D. Kauffeld, M.D. Onnen, P.J. Gabig, J.E. Cornely, G.E. Jasmer, J.M. Hyland, and K.J. Strom. 1992. Looking to the future: an implementation plan for the Rainwater Basin Joint Venture. Nebraska Game and Parks Commission, Lincoln, Nebraska, USA.

Gilbert, M.C. 1989. Ordination and mapping of wetland communities in Nebraska's Rainwater Basin region. CEMRO Environmental Report 89-1. U.S. Army Corps of Engineers, Omaha District, Omaha, Nebraska, USA.

Hagy, H.M., and R.M. Kaminski. 2012. Winter waterbird and food dynamics in autumn - managed moist-soil wetlands in the Mississippi Alluvial Valley. Wildlife Society Bulletin 36:512 – 523.

Haukos, D.A., and L.M. Smith. 1993. Seed bank composition and predictive ability of field vegetation in playa lakes. Wetlands 13:32 – 40.

Haukos, D.A., and L.M. Smith. 2003. Past and future impacts of wetland regulations on playa ecology in the Southern Great Plains. Wetlands 23:577 – 589.

Henry, C. J., K.F. Higgins, and K.J. Buhl. 1994. Acute toxicity and hazard assessment of Rodeo®, X-77 Spreader®, and Chem-Trol® to aquatic invertebrates. Archives of Environmental Contamination and Toxicology 27:392 – 399.

Higgins, K.F. 1986. Interpretation and compendium of historical fire accounts in the Northern Great Plains, Resource Publication No. 161. U.S. Fish and Wildlife Service, Washington, D.C., USA.

Hillhouse H.L., S.J. Tunnell, and J. Stubbendieck. 2010. Spring grazing impacts on the vegetation of reed canarygrass in invaded wetlands. Rangeland Ecology and Management 63:581 – 587.

Jackson, M.B., and M.C. Drew. 1984. Effects of flooding on growth and metabolism of herbaceous plants. Pages 47-111 *in* T.T. Kozlowski, editor. Flooding and plant growth. Academic Press, San Francisco, California, USA.

Johns, C.V., G. Brownstein, R.A. Blick, P.D. Erskine, and A.T. Fletcher. 2015. Testing the power of wetland vegetation monitoring survey design to detect change based on visual cover estimates. Wetlands 35:1055 – 1064.

Jorde, D.G., G.L. Krapu and R.D. Crawford. 1983. Feeding ecology of Mallards wintering in Nebraska. Journal of Wildlife Management 47:1044 – 1053.

Jorgensen, J.G. 2008. 2008 update to an overview of shorebird migration in the eastern Rainwater Basin, Nebraska. Published by author. Lincoln, Nebraska, USA.

Jorgensen, J.G., J.P. McCarty, and L.L. Wolfenbarger. 2008. Buff-breasted sandpiper density and numbers during migratory stopover in the Rainwater Basin, Nebraska. Condor 110:63 – 69.

Kostecke, R.M., L.M. Smith, and H.M. Hands. 2004. Vegetation response to cattail management at Cheyenne Bottoms, Kansas. Journal of Aquatic Plant Management 42:39 – 45.

Krapu, G.L., D.A. Brandt, and R.R. Cox, Jr. 2004. Less waste corn, more land in soybeans, and the switch to genetically modified crops: trends with important implications for wildlife management. Wildlife Society Bulletin 32:127 – 136.

Krueger, J.P. 1986. Development of oriented lakes in the Eastern Rainbasin region of south central Nebraska. M.S. Thesis, University of Nebraska- Lincoln, Lincoln, Nebraska, USA

Kushlan, J.A., M.J. Steinkamp, K. Parsons, J. Capp, M.A. Cruz, M. Coulter, I. Davison, L. Dickson, N. Edelson, R. Elliott, R.M. Ervin, S. Hatch, S. Kress, R. Milko, S. Miller, K. Mills, R. Paul, R. Phillips, J.E. Saliva, B. Sydeman, J. Trapp, J. Wheeler, and K. Wohl. 2002. Waterbird Conservation for the Americas, Version 1. North America Waterbird Conservation Initiative, Washington, D.C., USA.

Kuzila, M.S. 1994. Inherited morphologies of two large basins in Clay County, Nebraska. Great Plains Research 4:51 – 63.

LaGrange, T.G. 1985. Habitat use and nutrient reserves dynamics of spring migratory mallards in central Iowa. M.S. Thesis, Iowa State University, Ames, Iowa, USA.

LaGrange, T.G. 2005. Guide to Nebraska's wetlands and their conservation needs. Nebraska Game and Parks Commission, Lincoln, Nebraska, USA.

LaGrange, T.G., and J.J. Dinsmore. 1988. Nutrient reserve dynamics of female mallards during spring migration through central Iowa. Pages 287-297 *in* M. W. Weller, editor. Waterfowl in Winter. University of Minnesota Press, Minneapolis, Minnesota, USA.

LaGrange, T.G., and R. Stutheit. 2011. Wetland Management Guidelines for Nebraska's wildlife management areas. Nebraska Game and Parks Commission, Lincoln, Nebraska, USA.

LaGrange, T.G., R. Stutheit, M. Gilbert, D. Shurtliff, and P.M. Whited. 2011. Sedimentation of Nebraska's playa wetlands: a review of current knowledge and issues. Nebraska Game and Parks Commission, Lincoln, Nebraska, USA.

Laubhan, M.K. 1995. Effects of prescribed fire on moist-soil vegetation and soil macronutrients. Wetlands 15:159 – 166.

Lavergne, S., and J. Molofsky. 2006. Control strategies for the invasive reed canarygrass (*Phalaris arundinacea L.*) in North American wetlands: the need for an integrated management plan. Natural Areas Journal 26:208 – 214.

Legg, C.J., and L. Nagy. 2006. Why most conservation monitoring is, but need not be, a waste of time. Journal of Environmental Management 78:194 – 199.

Loesch, C.R., and R.M. Kaminski. 1989. Winter body-weight patterns of female mallards fed agricultural seeds. Journal of Wildlife Management 53:1080 – 1087.

Marty, J.T. 2005. Effects of cattle grazing on diversity in ephemeral wetlands. Conservation Biology 19:1626 – 1632.

Morrison, L.W. 2015. Observer error in vegetation surveys: a review. Journal of Plant Ecology p.rtv077.

Mullican, III, W.F., N.D. Johns, and A. Fryar. 1994. What a difference a playa lake can make: Defining recharge scenarios, rates, and contaminant transport to the Ogallala (High Plains) Aquifer. Pages 97-106 *in* L.V. Urban and A.W. Wyatt, editors. Proceedings of the Playa Basin Symposium, Texas Tech University Lubbock, Texas, USA.

Newton, I. 2008. The migration ecology of birds. Academic Press, London, United Kingdom.

North American Waterfowl Management Plan, Plan Committee. 2012. North American Waterfowl Management Plan: People Conserving Waterfowl and Wetlands. U.S. Department of Interior, Fish and Wildlife Service, Canadian Wildlife Service, Secretaria de Medio Ambiente y Recursos Naturales. Washington D.C., USA.

Pearse, A.T., G.L. Krapu, D.A. Brandt, and P.J. Kinzel. 2010. Changes in agriculture and abundance of snow geese affect carrying capacity of sandhill cranes in Nebraska. Journal of Wildlife Management 74:479 – 488.

Pearse, A.T., R.T. Alisauskas, G.L. Krapu, and R.R. Cox. 2011*a*. Changes in nutrient dynamics of midcontinent greater white-fronted geese during spring migration. Journal of Wildlife Management 75:1716 – 1723.

Pearse, A.T., G.L. Krapu, R.R. Cox, and B.E. Davis. 2011*b*. Spring-migration ecology of Northern Pintails in south-central Nebraska. Waterbirds 34:10 – 18.

Pederson, R.L., D.G. Jorde, S.G. Simpson. 1989. Northern Great Plains. Pages 281-310 *in* L.M. Smith, R.L.Pederson, R.M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Technological University Press, Lubbock, Texas, USA.

Rabbe, M., J. Drahota, and A.A. Bishop. 2004. Estimating duck use-days in the Rainwater Basin wetlands—a baseline model for management implications. Unpublished report. Rainwater Basin Wetland Management District, Funk, Nebraska, USA.

Raines, R.R., M.C. Gilbert, R.A. Gersib, W.S. Rosier, and K.E. Dinan. 1990. Regulatory planning for Nebraska's Rainwater Basin wetlands (advanced identification of disposal areas). Prepared for the Rainwater Basin Advanced Identification Study. U.S.

Environmental Protection Agency, Region VII, Kansas City, Kansas and U.S. Army Engineer District, Omaha, Omaha, Nebraska, USA.

Rainwater Basin Joint Venture. 1994. Best management practices for Rainwater Basin wetlands. Rainwater Basin Joint Venture, Grand Island, Nebraska, USA.

Rainwater Basin Joint Venture. 2013*a*. The Rainwater Basin Joint Venture Implementation Plan. Rainwater Basin Joint Venture, Grand Island, Nebraska, USA.

Rainwater Basin Joint Venture. 2013*b*. Rainwater Basin Joint Venture Waterfowl Plan. Rainwater Basin Joint Venture, Grand Island, Nebraska, USA.

Rainwater Basin Joint Venture. 2013*c*. Rainwater Basin Joint Venture Shorebird Plan. Rainwater Basin Joint Venture, Grand Island, Nebraska, USA.Rainwater Basin Joint Venture. 2013*d*. Rainwater Basin Joint Venture Waterbird Plan. Rainwater Basin Joint Venture, Grand Island, Nebraska, USA.

Riens, J., M. Schwarz, F. Mustafa, W.W. Hoback. 2013. Aquatic macroinvertebrate communities and water quality at buffered and non-buffered wetland sites on federal waterfowl production areas in the Rainwater Basin, Nebraska. Wetlands 33:1025 – 1036.

Reid, F.R., J.R. Kelley, Jr., and T.S. Taylor. 1989. Upper Mississippi Valley wetlands: refuges and moist-soil impoundments. Pages 181-202 *in* L.M. Smith, R.L.Pederson, R.M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Technological University Press, Lubbock, Texas, USA.

Reinecke, K.J., R.M. Kaminski, and D.J. Moorehead. 1989. Mississippi Alluvial Valley. Pages 203-248 *in* L.M. Smith, R.L.Pederson, R.M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Technological University Press, Lubbock, Texas, USA.

Rich, T.D., C.J. Beardmore, H. Berlanga, P.J. Blancher, M.S.W. Bradstreet, G.S. Butcher, D.W. Demarest, E.H. Dunn, W.C. Hunter, E.E. Iñigo-Elias, J.A. Kennedy, A.M. Martell, A.O. Panjabi, D.N. Pashley, K.V. Rosenberg, C.M. Rustay, J.S. Wendt, and T.C. Will. 2004. Partners in Flight North American Landbird Conservation Plan. Cornell Laboratory of Ornithology, Ithaca, New York, USA.

Robichaux, R.M. 2010. Correlating climate with late-winter wetland habitat in the Rainwater Basin, south central Nebraska. M.S. Thesis, Kansas State University, Manhattan Kansas, USA.

Samson, F., and F. Knopf. 1996. Prairie Conservation: Preserving North America's most endangered ecosystem. Island Press, Washington, D.C., USA.

Sargeant, A.B., and D.G. Raveling. 1992. Mortality during the breeding season. Pages 396-422 *in* B.D.J. Batt, A. Afton, M. Anderson, editors. Ecology and management of breeding waterfowl. University of Minnesota Press, Minneapolis, USA.

Schildman, G., and J. Hurt. 1984. Wildlife diseases and mortality summary (1950-1983). Nebraska Game and Parks Commission, Lincoln, Nebraska, USA.

Skagen, S.K. 1997. Stopover ecology of transitory populations: the case of migrant shorebirds. Pages 244–269 *in* F.L. Knopf, F.B. Samsom, editors. Ecology and conservation of Great Plains vertebrates. Springer-Verlag, New York, New York, USA.

Silliman, B. R., T. Mozdzer, C. Angelini, J.E. Brundage, P. Esselink, J.P. Bakker, K.B. Geden, J. van de Koppel, A.H. Baldwin. 2014. Livestock as a potential biological control agent for an invasive wetland plant. PeerJ 2: e567.

Smith, B.J., and K.F. Higgins. 1990. Avian cholera and temporal changes in wetland numbers and densities in Nebraska's Rainwater Basin area. Wetlands 10:1 – 5.

Smith, L.M., 1989. Effects of grazing and burning on nutritive quality of cattails in playas. Journal of Aquatic Plant Management 27:51 – 53.

Smith, L.M. 2003. Playas of the Great Plains. University of Texas Press, Austin Texas, USA.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed [10/09/2001 – 10/09/2010].

Sojda, R.S., and K.L. Solberg. 1993. Management and control of cattails. U.S. Department of the Interior, Fish and Wildlife Service. U.S. Fish and Wildlife Service Leaflet No. 13.4.13.

Solberg, K.L., and K.F. Higgins. 1993. Effects of glyphosate herbicide on cattails, invertebrates, and waterfowl in South Dakota wetlands. Wildlife Society Bulletin 21:299 – 307.

Stutheit, R.G. 1988. Mortality and disease investigations. Nebraska Game and Parks Commission, Pitman-Robertson Report W-15-R-44, Lincoln, Nebraska, USA.

Stutheit, R.G., M.C. Gilbert, P.M. Whited, and K.L. Lawrence. 2004. A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of Rainwater Basin depressional wetlands in Nebraska. ERDC/EL TR-04-4, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi, USA.

Tacha, M.C., A.A. Bishop, and J. Brei. 2010. Development of the whooping crane tracking project Geographic Information System. Proceedings North American Crane Workshop 11:2010.

Tidwell, P.R., E.B. Webb, M.P. Vrtiska, and A.A. Bishop. 2013. Diets and food selection of female mallards and blue-winged teal during spring migration. Journal of Fish and Wildlife Management 4:63 – 74.

U. S. Fish and Wildlife Service and Canadian Wildlife Service. 1986. North American Waterfowl Management Plan. U. S. Fish and Wildlife Service, Washington D.C., USA.

U.S. Fish and Wildlife Service. 2007. Comprehensive Conservation Plan: Rainwater Basin Wetland Management District. U.S. Fish and Wildlife Service-Rainwater Basin Wetland Management District, Kearney, Nebraska and U.S. Fish and Wildlife Service-Region 6, Mountain-Prairie Region, Lakewood, Colorado, USA.

U.S. Fish and Wildlife Service. 2009. Biological opinion on the effects to whooping cranes from the construction and operation of personnel facility at Funk Waterfowl Production Area (FWS# 66412-2009-F-0466) Grand Island, Nebraska, USA.

U.S. Fish and Wildlife Service. 2011. Rainwater Basin Wetland Management District Land Protection Plan. Denver, Colorado, USA.

U.S. Fish and Wildlife Service. 2012. Waterfowl population status, 2012. U.S. Department of the Interior, Washington, D.C., USA.

Walters, R.A. 2003. Evaluation of chemical and mechanical soil disturbance for controlling reed canarygrass in south central Nebraska. M.S. Thesis, University of Nebraska-Kearney, Kearney, Nebraska, USA.

Webb, E.B., L.M. Smith, M.P. Vrtiska, and T.G. LaGrange. 2010. Effects of local and landscape variables on wetland bird habitat use during migration through the Rainwater Basin. Journal of Wildlife Management 74:109 – 119.

White G.C., and K.P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46:120 – 138.

Wilson, R.D. 2010. Evaluating hydroperiod response in the Rainwater Basin wetlands of south-central Nebraska. M.S. Thesis, University of Nebraska-Lincoln, Lincoln, Nebraska, USA.

Zedler, J.B., and S. Kercher. 2004. Causes and consequences of invasive plants in wetlands: opportunities, opportunists, and outcomes. Critical Reviews in Plant Sciences 23:431 – 452.