I. Introduction

Overview

Sandplain grasslands of the northeastern U.S. are iconic hotspots for biodiversity and important conservation priorities because of their relative rarity, limited geographical range, and the diversity of uncommon plant and animal species that they support. Sandplain grasslands reach their greatest extent on dry, sandy soils on coastal outwash deposits, which formed following the retreat of the southernmost extension of the Wisconsin ice sheets from Long Island to Cape Cod, including the Massachusetts islands of Martha's Vineyard and Nantucket (Fig. 1). Additional but generally smaller areas of grasslands that have vegetation similar to that on the coastal outwash plain occur in pockets of level, sandy soils farther inland in Rhode Island, southern New Hampshire, Albany, New York, the Connecticut River Valley and on some hillier and rocker soils near the coast in southeastern Massachusetts.

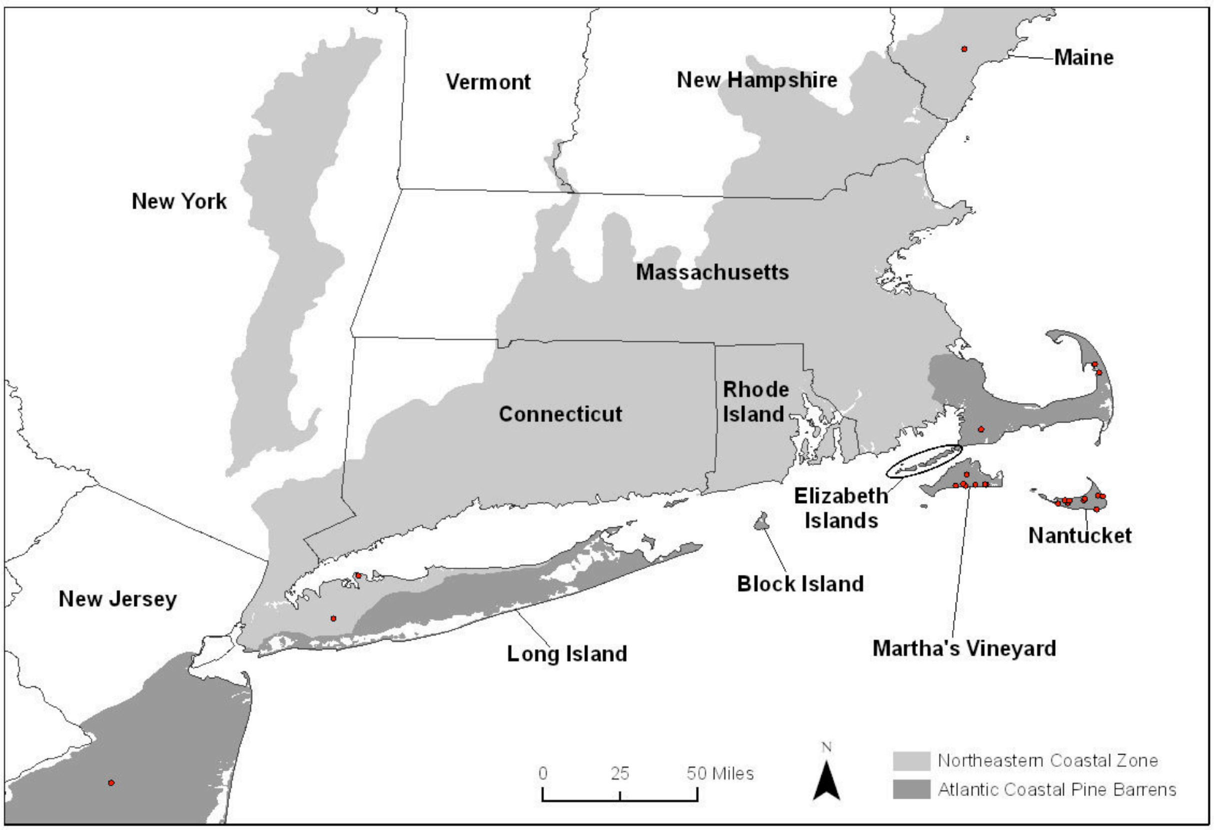

Figure 1. Map of the Atlantic Coastal Pine Barrens Region in which most sandplain grasslands occur, and the Northeastern Coastal Zone within which isolated pockets of sandplain grasslands also occur. Red dots indicate sites from which management experiences and case histories were drawn in this document.

Many widely-distributed plant species adapted to droughty, nutrient-poor soils attain their greatest abundance on open lands of the coastal sandplain. Examples of these species include little bluestem (*Schizachyrium scoparium*), Pennsylvania sedge (*Carex pensylvanica),* red fescue

(*Festuca rubra*), poverty grass (*Danthonia spicata*), wild indigo (*Baptisa tinctorum*), stiff aster (*Ionactis linariifolia*), and bearberry (*Arctostaphylos uva-ursi*), intermixed with widespread shrubs such as black huckleberry (*Gaylussacia baccata*), lowbush blueberry (*Vaccinium angustifolium)* and small bayberry (*Morella caroliniensis*). Sandplain grasslands contain more than 20 plant species that are listed as endangered, threatened, of special concern, or exist on state watch lists because they may become threatened. These include sandplain gerardia (*Agalinis acuta*), Nantucket shadbush (*Amalanchier nantucketensis*), sandplain blue-eyed grass (*Sisyrinchium fuscatum*), eastern silvery aster (*Symphyotrichum concolor*), purple needlegrass (*Aristida purpurascens*), purple milkweed (*Asclepias purpurascens*), and butterfly weed (*Asclepias tuberosa*). Sandplain grasslands support regionally uncommon grassland birds such as grasshopper sparrows (*Ammodramus savannarum*), savanna sparrows (*Passerculus sandwichensis*), eastern meadowlarks (*Sturnella magna*), American kestrels (*Falco sparverius*), northern harriers (*Circus hudsonius*), short-eared owls (*Asio flammeus*) and barn owls (*Tyto alba*). All of these species are uncommon or declining in the northeast. Sandplain grasslands also support a variety of moth and butterfly species such as the chain dot geometer (*Cingilla catenaria),* tiger moths (*Grammia oithona*, *G. phyllira*) and the frosted elfin (*Callophrys irus*).

Most sandplain grasslands owe their origin to land clearing and grazing that occurred in the northeast U.S. following European colonization. Smaller areas of land very near the coast probably formed a mosaic of shrubby or grassy vegetation patches, maintained in different stages of succession by the disturbances of wind, salt spray, and fires set by indigenous people, whose populations reached their greatest numbers near the coast. Grasslands expanded greatly during the expansion of agriculture and particularly animal grazing that followed European post-settlement and reached their greatest extent in the mid-1800s (Foster 2017). Frequent wildfires occurred during a period of abandonment of agriculture and subsequent forest regrowth, lasting until roughly the time of World War II, when the residential development for vacation homes began to increase (Foster and Motzkin 1999b). These fires helped prolong the existence of grasslands and associated disturbance-dependent shrublands.

While never the dominant coastal vegetation before European colonization, sandplain grasslands and interspersed shrublands were important reservoirs of the region's biodiversity. Grasslands reached their greatest extent on Cape Cod, and on the islands of Martha's Vineyard, Nantucket, and Long Island. Today, the area covered by grasslands is declining sharply as a result of residential development, fire suppression, abandonment of agriculture and widespread regrowth of woody vegetation. More than 90% of the coastal grasslands and related heathlands that were widespread in the northeastern U.S during the mid-19th century have been lost and this ecosystem now ranks among the northeast U.S.'s most imperiled.

Need for Active Management

Sandplain grasslands require active vegetation management by periodic disturbance to arrest secondary succession to shrublands and woodlands and to maintain, promote, or restore particular species of conservation concern. Managers concerned with the persistence of grasslands and biodiversity have two main challenges. One is to preserve and enhance existing grasslands in key places where they can be actively managed. The other is to develop approaches to creating new sandplain grasslands, either from places that supported them in the past, or from other types of ecosystems, such as woodlands or agricultural lands, in places where conditions are similar to those in extant grasslands. Such "new" sandplain grasslands could add to the total regional grassland area or replace previous grasslands lost to residential or other development, shoreline erosion, or succession to woodland in hard-to-manage locations. Both approaches are important, but different, and add to the complexity and challenge of regional sandplain grassland management.

Land managers have a number of potential options for managing for disturbances in existing sandplain grasslands. The main tools in sandplain grassland managers' collective toolbox are: prescribed fire, mowing, grazing, and vegetation removal (by either mechanical or chemical treatments). Each method has ecological benefits and potential drawbacks. Each also has different challenges for implementation, especially for the frequency at which disturbances are desired. Additionally, each method has a large number of potential associated influential variations that include seasonal timing, frequency, weather and climate conditions, composition and structure of existing vegetation, type of animals, and other factors. For example, prescribed burning can effectively prevent encroachment of woody plants and increase the density of some target, rare sandplain forbs. However, this method can be much less effective in restoring grassland and heathland vegetation to areas where second-growth oak and pine forests are well established, because many woody plants regrow vigorously from rootstocks. Mowing or chemical treatments can be alternatives to prescribed fire and can more predictably be used in cases where adjacent land use or local/regional concerns about fire risk and air pollution make use of fire less feasible. A return to a historic method, the use of grazing animals, could potentially play a greater role in grassland maintenance and management.

Options for creating new sandplain grasslands vary depending on whether exiting land is shrubland or woodland, or open and agricultural. Creating sandplain grasslands from shrublands and woodlands involves tree clearing, establishment of grassland vegetation, and managing aggressive woody regrowth. Creating grasslands from former agricultural land often requires eliminating or greatly reducing the existing predominantly non-native invasive weeds and cool season grasses, and potentially undoing soil conditions such as high pH, created by previous agricultural use that can favor non-native over native species.

Pathways to Better Management

While conservation ownership now protects a majority of the region's remaining large grasslands, many critical management challenges remain. One common challenge is that woody vegetation is expanding into grasslands across the region. A second is that many rare grassland-dependent plant and animal species continue to decline on many properties. A third challenge is the spread of non-native plant species into sandplain grasslands from surrounding lands. Lastly, all sandplain grasslands must now be managed in ways that consider the effects of rapid changes in and disruptions to climate. Most of these challenges occur widely and have common threads across the northeast region.

Although some sandplain grassland managers have experience from sandplain grasslands across a wide geographical region, there are also many that do not. Many managers have experience with some management tools, like fire, but have not attempted others, such as grazing. Although some of the information on the outcomes of sandplain grassland management actions or experiments is published in the scientific literature, much is either in other reports and "gray" literature. Some of this information is largely unwritten in any form, but resides in the experience of individual land managers and management practitioners. There could be great of value to managers and practitioners by the distribution of information on both the successes and failures of sandplain grassland management experiences.

These challenges and the desire to share lessons learned from management experiences motivated managers to meet in April 2016 and form a Sandplain Grassland Network. This meeting took place at the Marine Biological Laboratory in Woods Hole, MA. At that meeting, the Network committed to an activity designed to: (1) capture management experiences across the region, and (2) to disseminate this information. The group wanted the activity to review what we now know about different approaches to management and make available out-of-print and hard-to-get reports and other sources of detailed information. The activity would also point to management actions that might not have been previously tested—but should be. It would recommend approaches to improving monitoring of sites and management actions or experiments that are separated geographically and temporally. Lastly, it would recommend approaches to management that collective experience suggests will foster grasslands and the biodiversity they support in the face of continued pressures of expanding human land use and a changing climate.

This web-based document is the result of that activity. It was produced by assembling and evaluating dozens of publications and reports provided by managers and practitioners. It is based on that literature, but also on more than 40 in-person and phone interviews with managers.

Organization of this Document

This document is organized into five main sections, designed to help managers find and use information that helps them to sustain sandplain grasslands and their associated biodiversity (Fig. 2).

Section 1 addresses experiences with management that was designed to maintain or enhance current sandplain grassland areas. Chapter 1.1 in this section describes experiences with the use of prescribed fire in existing grasslands. Chapter 1.2 describes experiences with the use of mowing in existing grasslands. Chapter 1.3 covers experiences with vegetation removal of woody and non-native, invasive, or undesired vegetation in existing grasslands. Chapter 1.4 addresses experiences with the use of grazing animals to either maintain existing sandplain grasslands or reduce shrub cover in areas in which more grass- and forb-dominated vegetation is desired.

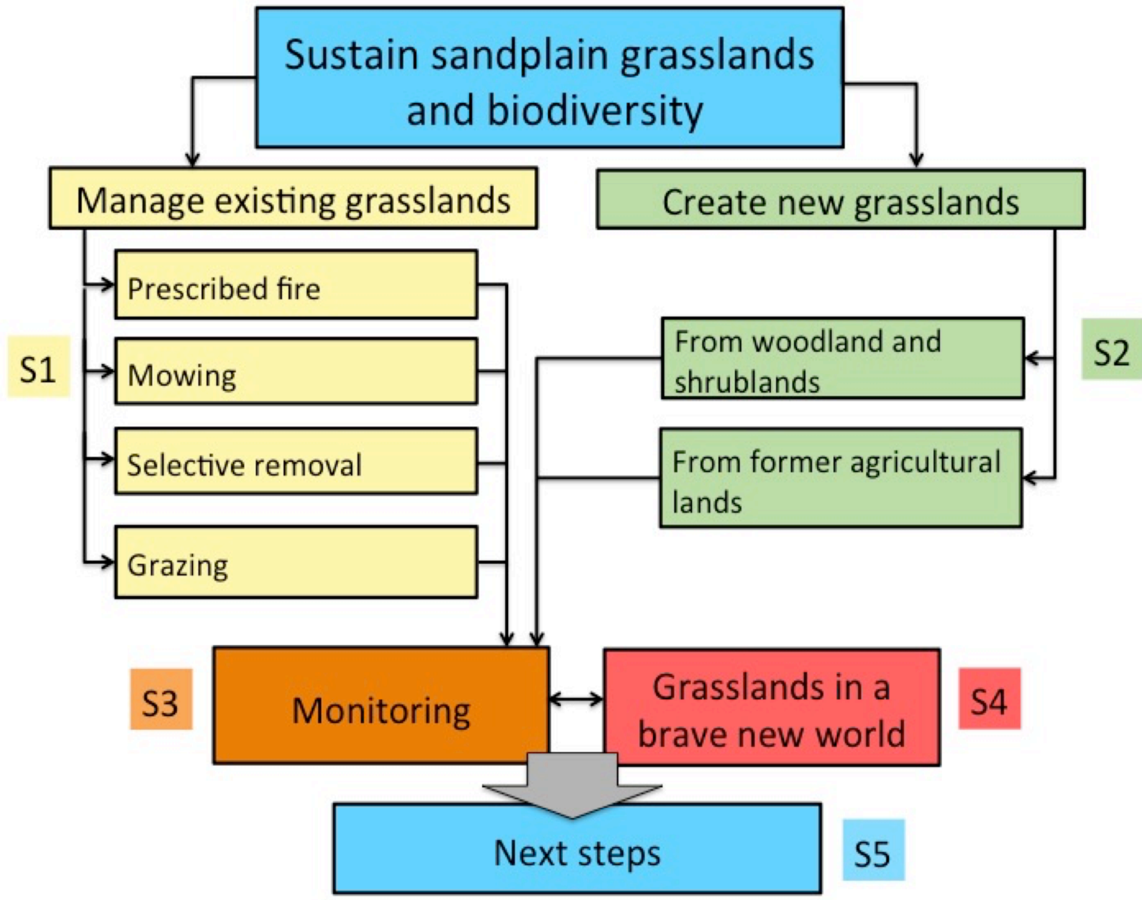

Figure 2. Organization of this document into sections (S1 to S5) that address management of existing grasslands, creation of new grasslands, monitoring, effects of future climate and land use, and next management steps.

Section 2 addresses experiences with actions designed to create or expand sandplain grasslands into areas that are currently not grasslands. Chapter 2.1 in this section covers experiences with forest or shrubland clearing to expand sandplain grasslands. Chapter 2.2 describes experiences with the creation of sandplain grasslands on former agricultural lands.

Section 3 outlines a regional approach to vegetation monitoring and improving the rigor with which grassland management actions are evaluated.

Section 4 describes the new issues that sandplain grassland managers now must contend with in the "brave new world," created by the combination of climate change, increased human population, and use of the landscapes in which sandplain grasslands are now embedded in the northeast U.S.

Section 5 describes new management approaches and experiments that this review suggests would allow more effective management of sandplain grasslands and their biodiversity in the future.

Figure 2. Organization of this document into sections (S1 to S5) that address management of existing grasslands, creation of new grasslands, monitoring, effects of future climate and land use, and next management steps.

Sections 1 and 2 contain detailed case histories. These are descriptions, from specific places, where lessons can be learned from particularly well-documented outcomes of past management.

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II. Regional History of Research and Conservation

Massachusetts

In Massachusetts, where the majority of sandplain grasslands now exist, early work focused on protecting key land parcels, starting in the 1960s. The major players in land protection and subsequent management included the Massachusetts Audubon Society (now Mass Audubon), Massachusetts Division of Fisheries and Wildlife, the Nantucket Conservation Foundation, the Nantucket Land Bank, The Nature Conservancy, The Trustees of Reservations, the Sheriff's Meadow Foundation, and the Martha's Vineyard Land Bank.

By the 1980s many of the key sandplain grassland and heathland parcels had been protected and the focus of conservation groups shifted to management. This change in focus was caused by concerns that sandplain grasslands were gradually succeeding to other community types in absence of the large-scale disturbances, such as fires and grazing, that had occurred in the past (Godfrey and Alpert 1985, Barbour et al. 1998). Shrub encroachment was identified as a major concern (Dunwiddie 1998, Dunwiddie et al. 1995, Dunwiddie and Caljouw 1990, Dunwiddie 1990). Early management efforts throughout the 1980s and early 1990s tested multiple potential techniques to determine their effectiveness at reducing shrub cover and promoting grassland diversity. Techniques tested included prescribed fire, mowing, grazing and herbicide applications.

Mass Audubon, the University of Massachusetts at Amherst, and William Patterson III started studies in 1981 on Nantucket to understand the composition, origins, extent and dynamics of sandplain grassland vegetation communities to develop methods for grassland maintenance and restoration. Fourteen test sites were established in six locations on Nantucket, Martha's Vineyard, and Cape Cod including Tom Nevers, Wellfleet Heathland, Sesachacha Heathlands, Ram Pasture, Wellfleet Grassland, Sanford Farm and Katama Plains (Dunwiddie 1998). By the late 1980s, results showed that merely maintaining present acreage of sandplain grasslands would be a challenge. Summer burning had logistical challenges and woody plants increased in cover with just only dormant season treatments. Recommendations were to explore management methods that more effectively limit shrub encroachment, including herbicide use, disk harrowing and spring burning followed by summer mowing (Dunwiddie 1998).

In 1982, four 0.25-ha permanent plots were established in Ram Pasture on Nantucket to measure cover and frequency before and after biennial treatments that included mowing, spring burning and summer burning. These studies continued for 13 years (P. Dunwiddie, W. Patterson III, Interviews.). The results showed that in untreated plots, the vegetation trended toward heathland species. Summer treatments were most successful t increasing herbaceous species and reducing shrubs (Dunwiddie et al. 1995, Dunwiddie et al. 1997).

On Nantucket, additional studies in the late 1980s and 1990 focused on sheep grazing. Twenty sheep were grazed in four areas in vegetation that ranged from scrub oak-dominated heath at Tom Nevers, to low shrub heath at Shawkemo, to grassy heath at Ram Pasture, and agricultural pasture at Squam. The results showed that heathland vegetation was adapted to moderate grazing pressure. Tall shrubs were not favored by sheep for grazing and it was challenging to predict the ideal balance of grasses, forbs and shrubs (Dunwiddie 1986). A study conducted in 1990 that compared un-grazed grasslands to adjacent sites grazed prior to 1948 showed that compositional differences were evident even 50 years after grazing. For example, shrubs were the dominant plant form in un-grazed areas while grazed areas had more bare soil patches and more of certain grassland-associated species (Dunwiddie 1997). The Nantucket Conservation Foundation compared the effects of growing season prescribed sheep grazing and mowing on promoting grassland habitat on former agricultural land at Squam Farm. This project from 2005-2008 documented that mowing and grazing were both effective at reducing shrub cover and increasing graminoid cover to some extent, but sheep grazing was more effective at creating patches of bare ground (Beattie et al. 2017).

In summary, this early research determined that various management techniques including burning, mowing, and grazing could be effective at maintaining sandplain grasslands. However, without implementation of aggressive management methods during the right season, shrub encroachment and loss of grass and forb diversity would be ongoing issues.

As a result of the above research, many organizations by the late 1990's attempted to initiate management techniques and particularly prescribed fire at a larger landscape scale. This goal was made challenging by a profession-wide trend towards requirements for increased training and certifications as well as concerns about liability associated with implementing prescribed fire. These challenges drove the formation of partnerships to share both information and fire professionals, with the goal of effectively applying prescribed fire to a larger landscape.

On Nantucket, the Partnership for Harrier Habitat Preservation (PHHP) was formed in 1997, in response to the issuing of the first Massachusetts Endangered Species Act (MESA) conservation permit, which required a partnership to fund more than 405 ha (1,000 acres) of habitat management for mitigation of development of a golf course. The PHHP provided funding for and oversaw the management of large-scale acreages of grassland, heathland and scrub oak barren on protected conservation land using prescribed fire and brush cutting to promote habitat for northern harriers, a species that was impacted by the development of the golf course. Most of the funding provided was spent during the first 10 to 15 years of the project and the management of these sites is now being undertaken by the landowners (the Nantucket Conservation Foundation and Mass Audubon).

On Martha's Vineyard, the premiere sandplain grassland site, Katama Plains, was protected in 1985 by the Town of Edgartown and The Nature Conservancy. Management at Katama started in 1986 and has continued to the present. In 1991, several conservation groups on Martha's Vineyard started a coalition called the Sandplain Restoration Project. The Project had wide ranging goals from inventory, research and prioritization, to mutual assistance during restoration, as well as public outreach and regulation change. The project ended when the main goal was achieved: making prescribed burning a publicly accepted, professionally delivered, and well-established practice. During the same time period, several conferences focused on sandplain habitat management and in conjunction, organizations and agencies on the Vineyard worked together to apply prescribed fire. Since 2010, fire management has once again shifted from staff and volunteers to the increased use of professional crews and contractors because of the challenges and costs of maintaining individual fire programs.

Despite these partnerships and an increased capacity to conduct management, and despite early research-based management recommendations for summer (growing season) prescribed fire, these recommendations have not been realized in part because greater development and tourism across Southeastern Massachusetts and the Islands has limited the seasons when managers can apply prescribed fire without large summer public impacts. Additionally, further research examining the influence of fire on sandplain grasslands indicated that fire alone may not be effective at maintaining many sandplain grassland sites (Motzkin and Foster 2002, Dunwiddie 1998, Niering and Dryer 1989) particularly if summer fire cannot be applied. Because these natural communities were likely created by a combination of plowing, harrowing and grazing, incorporating these techniques in rotation with prescribed fire may be helpful (Motzkin and Foster 2002). Staff at conservation organizations continue to experiment with these additional grassland management techniques. One of the goals of this guidance document is to capture lessons learned in those management actions.

In addition to the continued use of such management techniques as burning, mowing, and grazing to maintain existing grasslands, several new management projects and research experiments have focused on the creation of grasslands in Massachusetts since 2000. For example, from 2008 to 2013, methods of removing non-native species, soil alterations, tilling, and seeding were tested at Bamford Preserve, Martha's Vineyard to convert a non-native species-dominated agricultural grassland to a more native species-rich sandplain grassland community (Wheeler et al. 2015, Neill et al. 2015). Also, during 2001 at Job's Neck on Martha's Vineyard, about 20 hectares of oak forest were cut, mowed and seeded with grassland plant seeds to test methods for establishing native species-rich grassland (Lezberg et al. 2006, Chris Neill Interview). Since 2006, cattle grazing has been used on Naushon Island to restore coastal grasslands in former pastures that had been taken over by catbrier (*Smilax rotundifolia*)- and black huckleberry (*Gaylussacia baccata*)-dominated shrublands (C. Neill, Interview). Additionally, at the Truro and Marconi sites of Cape Cod National Seashore, burning and cutting of second growth pitch pine forest has been implemented to open the landscape and create a more diverse understory that includes grasses (D. Crary, Interview). Harrowing has also been used to encourage greater grass cover within previously managed scrub oak shrubland at the "Serengeti" on Nantucket (Omand et al. 2014). At the Francis Crane Wildlife Management Area, 138 hectares (341 acres) of second growth post-agricultural forest have been converted to grassland through mechanical tree removal, harrowing, and seeding since 1998 (J. Scanlon and C. Buelow, Interviews). Current management efforts focus both on refining the above techniques to maintain existing grassland diversity as well as to reclaim grasslands from agriculture, shrublands, or forest.

Maine

Kennebunk Plains in Maine has been conserved since the late 1980s and Wells Barrens has been conserved since 2000. In 1989 Kennebunk Plains was protected by the Land for Maine's Future Project by the State of Maine. A total of 421 hectares (1,041 acres) were initially purchased to protect sandplain grassland species. The Nature Conservancy bought an additional 50 hectares (123 acres) in the southeast corner of the Plains. Prior to being conserved, Kennebunk Plains and Wells Barrens were in blueberry production until the late

1980s. Prescribed fire was used until the mid-1980s to control woody vegetation and promote blueberries. For several years starting in 1985, the herbicide Velpar was employed to reduce species other than blueberries. The use of Velpar ceased when the property was purchased for conservation.

The Nature Conservancy re-implemented prescribed burning at Kennebunk Plains in 1990 (N. Sferra, Interview). Controlled burning occurs on 243 hectares (600 acres) in 16 units ranging from 13 to 20 hectares (32 to 49 acres) that are burned in the spring just after leaf-out or late summer to fall following the conclusion of bird nesting season. After fire management began, Peter Vickery initiated research at Kennebunk Plains, which was continued by Jeff Wells. This research focused on the frequency of controlled burning to maximize habitat for grassland nesting birds and promote rare plants such as northern blazing star (*Liatris novae-angliae)*. He found that burning increased rare northern blazing star seed production and reduced seed predation by microlepidoptera (Vickery 2002a, Vickery 2002b). To date, the burn program continues and is supplemented with periodic mowing to reduce shrub invasion on the grassland.

In 2007, 367 acres at the adjacent Wells Barrens was purchased by The Nature Conservancy for conservation. That site had not been actively managed since the late 1980s. In 2015, The Nature Conservancy cut the majority of the woody vegetation on the former grassland to prepare for restoration. In addition, The Nature Conservancy cut several stands of pitch pine woodland to create early successional habitat and plans to start implementing prescribed fire at the site.

New York Islands

Similar to other regions of the Northeastern Atlantic Coastal plain, a majority of the sandplain grasslands on Long Island either have been protected from development by land preservation, or are managed in association with commercial use (airports, roadways, communication towers, golf courses and agriculture). On Long Island, urbanization and population growth expanding east from New York City has increased grassland isolation, reduces connectivity and introduced non-native species. As a result, non-commercial grasslands are generally small remnants and relics of less than approximately 12 hectares (30 acres). Commercial or Native American-associated grasslands (Shinnecock and Montaukett Nations) are larger and range between 20 to 60 hectares (29 to 148 acres) (Weigand et al. 2017). A roughly equal portion of Long Island's grasslands are remnants of conventional agriculture that have converted to old fields since the 1950s. Regardless of past or current land use, grasslands of the New York Atlantic Coastal Plain are fragmented, and isolated and occur in a highly urban, agricultural and forested matrix. Like in the grasslands of Massachusetts and Maine, even when the boundaries of many of these grasslands are preserved, persistence of these disturbance-dependent ecosystems is not guaranteed because of woody succession and invasive species encroachment. On the New York islands, invasive species and increased woody succession are generally not being suppressed by mowing and/or burning at current return intervals. In addition, the high degree of fragmentation and high proximity to urban areas results in a large number of non-native and invasive species invading grasslands that must be managed.

In the New York region, the major land holders of grasslands include the U.S. Fish and Wildlife Service (Sayville and Conscience Point Grasslands), The Nature Conservancy (Shinnecock Hills, Mashomack), Suffolk County (Montauk County Park, Gabreski Airport), Nassau County (Hempstead Plains), Town of Riverhead (Enterprise Park at Calverton), New York State Office of Parks, Recreation and Historic Preservation (Montauk Downs), New York State Department of Environmental Conservation (Underhill), Green Tree Foundation, Henry Ferguson Museum and Land Trust (Middle Island Farms, Fishers Island), National Parks Service-Gateway (Floyd Bennett Field) and the Town of Easthampton (Easthampton Airport). Golf courses have also played an important role in maintaining and creating sandplain grassland habitat on Long Island. The National Links of America (Shinnecock Nation Historic Grassland) and Shinnecock Golf Course (Shinnecock Nation Historic Grassland) are adjacent golf courses in Southampton that were created on what was the historic Shinnecock Native American Nation's home range in the early 1900s (W. Salinetti, Interview) A majority of the holdings of the New York State Department of Environmental Conservation and the Town of Southampton are old-field grasslands. Unfortunately, however, not all these grasslands have been preserved and thus remain threatened by development. For example, Enterprise Park at Calverton (EPCAL) in Riverhead, the region's largest grassland, is slated for development, while the grasslands at Gabreski and Easthampton airports, which support a number of rare and unique flora, are being considered for solar array installations. Gardiners and Robin's Island grasslands, while owned privately, have the potential for development if the current owners develop or sell these properties.

Sandplain grasslands on Long Island share many aspects of their historical origin with those of Massachusetts. Fire has long been associated with grassland management on Long Island. Grasslands were maintained by Native Americans prior to European colonization, and the earliest evidence of the use of prescribed fire was by the Montaukett Native American tribe during the 1600s (Taylor 1923). Clear-cutting and deforestation increased the range of these grasslands to such an extent that Taylor (1923) in his Montauk Memoirs described a "sea of pink created by vast swaths of blooming sandplain gerardia (*Agalinus acuta*)*."* As in sandplain grasslands in coastal Massachusetts, grazing increased following colonization, especially in Montauk and associated coastal islands, through the end of the 1900s when it declined rapidly because of poor soils and pressures of residential development (Foster and Motzkin 2003). Early successional pitch pine stands established following the abandonment of grazing. Wildfires ignited in these sites resulted in many large and uncontrolled wildfires, which left a lasting legacy of fire suppression. As a result, applying prescribed fire has been and remains very challenging on many fronts and continues to be limited by the negative public perception of fire, lack of understanding of the ecological importance of fire, a high amount of grassland habitat directly adjacent to urban areas, and lack of regional experience in developing burn plans and allocating resources to conduct prescribed fires (Stack 1989).

Like in Massachusetts and Maine, prescribed fire has been and continues to be used in grassland management. Its use has been supported by the New York State Wildfire and Incident Management Academy, The Nature Conservancy, and New York State Department of Environmental Conservation since the late 1990s. Fire is most commonly used in the Town of

Southampton to manage grasslands at Shinnecock Golf Course, Shinnecock Hills and the Montauk grasslands. It continues to be used at National Links of America just to the north of Shinnecock golf course (W. Sallinetti, Interview).

The use of fire in grassland management was strongly encouraged in the 1990s by The Nature Conservancy. The Nature Conservancy developed numerous Fire Management Plans for Hempstead Plains, Big Reed, and Oyster Ponds Complex (Montauk), as well as monitoring and management plans for the endangered *Agalinis acuta* (Jordan and Parrish 2007, Kurtz 2008a, Kurtz 2008b, Horwith et al. 2009). The cancellation of The Nature Conservancy's prescribed fire programs in 2007 because of funding constraints resulted in the loss of specialized monitoring and management on upwards of 50 percent of the region's grasslands.

Across the region, the time between burns varies widely from 1 year (National Golf Links of America) to 50 years (Shinnecock Hills Preserve) with an average return interval of 8 years (Weigand et al. 2017). The New York State Department of Environmental Conservation plans to burn their grasslands on a three-year rotational basis, ideally in the spring to reduce cool season grasses and maximize impact on woody species, while the Henry Ferguson Museum and Land Trust burns on a biennial basis during the dormant season. Conversely, the U.S. Fish and Wildlife Service's Sayville grassland was burned for the first time in 2016 but previously had experienced small-scale arson fires in 1997, 2002, and 2007. Currently, old fields owned by the New York State Department of Environmental Conservation, Henry Ferguson Museum and Land Trust and National Links Golf Course frequently receive prescribed fire.

Land managers are currently attempting to maintain some capacity to conduct prescribed fires through contracted fire professionals. The Greentree Foundation successfully conducted its first grassland prescribed fire using a contracted burn boss in 2017. The Central Pine Barrens Joint Planning and Policy Commission also contracted the development of a prescribed burn plan for Pine Meadows County Park grassland and will implement the prescription using a contracted burn boss in partnership with Suffolk County Department of Parks and Recreation and NYS Department of Environmental Conservation. The U.S. Fish and Wildlife Service also re-initiated a burn program at Sayville in 2016.

Across Long Island, mowing is commonly utilized in place of fire when weather conditions or proximity to the urban interface prevents the use of fire. Mowing is most commonly conducted in the spring or dormant season. Mowing is also prescribed on a 3-year rotation but is utilized on average every 2.2 years (Weigand et al. 2017). Mowing frequency ranges from annually at airports, while the Shinnecock Hills Preserve has not been activity managed or mowed for the last 17 years.

The use of herbicides is not readily utilized or considered a management practice on Long Island because of concerns with non-target impacts to water quality, flora, fauna and soil.

Long Island lacks the diversity and history of sandplain grassland management research that occurs and has occurred in Massachusetts. Research focused predominantly on the iconic Hempstead Plains and within grasslands in Montauk, Conscience Point and Sayville because of the presence of the federally listed *Agalinus acuta* (Lamont and Fitzgerald 2000, Jordan and Parrish 2007, Edinger et al. 2014). This endemic species has a highly restricted range and only occurs in New York within Nassau and Suffolk Counties as well as Rhode Island, Connecticut, Massachusetts, and Maryland, with the largest population occurring in Suffolk County (New York Natural Heritage Program 2015).

The flora and fauna of the Hempstead Plains have been well studied, with floristic inventories conducted from the late 1800s nearly to the present (Hicks 1892, Harper 1911, Harper 1918, Ferguson 1925, Cain et al. 1937, Statler and Lamont 1987, Statler and Seyfert 1989, Statler et al. 1991). A recent study by Gulotta (2005) revealed that 54 percent of the flowering plants inventoried were native, providing an indication of the degree of non-native species encroachment on this grassland. Studies have been conducted on the control of mugwort (*Artemisia vulgaris*) using burning, mowing and herbicide treatments (Jordan et al. 2002). Lastly, in the 1990s The Nature Conservancy conducted monitoring on an *Agalinis acuta* population that was transplanted to a small section of the Hempstead Plains (Gulotta 2005, Jordan and Parrish 2007). The Friends of Hempstead Plains continue to monitor this population with support from the U.S. Fish and Wildlife Service and volunteers.

In addition to being an important research site, the Hempstead Plains provides an excellent example of the challenges the region faces. At its greatest extent, this site was estimated to cover upwards of 16,188 hectares (39,984 acres) of central Nassau County (Gulotta 2005, Neidich-Ryder and Kennelly 2014). The deep, well-drained soils of the plains are commonly thought to be a leading reason for the wide extent and long-term persistence of grasslands. The Hempstead Plains also has a long history of cultural use, including sheep grazing, home sites, and as the “Cradle of Aviation” that hosted airfields and flying schools that occurred during the early 1900s. While one of the most historically iconic and ecologically rich of the region’s grasslands, massive development extending eastward across Long Island from the boroughs of New York City has severely fragmented and reduced the Hempstead Plains to less than 2 percent of its historical range and less than 20 hectares (49 acres). The largest section of 7 hectares (17 acres) is preserved and managed by the Friends of Hempstead Plains at Nassau Community College (Gulotta 2005), while other, smaller fragments exist in isolated patches within an urban matrix in locations such as transportation rights of way, drainage retention basins, parklands, cemeteries and parks. The remaining grasslands contain many invasive species including sericea lespedeza (*Lespedeza cuneata*), cypress-spurge (*Euphorbia cyparissias*), mugwort (*Artemisia vulgaris*), and native and non-native species including apple species (*Malus* spp.), sumac species (*Rhus* spp.), small bayberry (*Morella caroliniensis)*, autumn olive *E. umbellata*, and honeysuckle species (*Lonicera spp.*).

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III.A. Prescribed Fire in Existing Grassland

Introduction

Prescribed fire can be used to maintain disturbance-adapted sandplain grasslands by manipulating ecological succession. The principal goals of grassland management with prescribed fire are to reduce woody vegetation cover, create conditions that maintain plant and animal species that rely on grassland habitat, alter soil conditions and microclimate, and reduce fuels and fire risk.

Figure 1. A 280-acre area of grassland managed by controlled burning at Camp Edwards in on Cape Cod. Photo from July 2016, two years after a fire treatment. Photo Credit: Jake McCumber.

Prescribed fire in sandplain grasslands typically aims to promote a diverse assemblage of target grassland species with a high proportion of warm-season grasses and native forbs, and a low proportion of cool season grasses and non-native invasive species, while reducing the regrowth of woody shrubs (Fig. 1). Prescribed fire can also maintain low fuel loads on a short-time basis, which can reduce fire hazards in some situations. Prescribed fire can also expose mineral soils, and maintain microclimates that foster germination and regeneration of fire-adapted or disturbance-dependent grassland species.

The behavior and consequences of prescribed fire for maintaining sandplain grassland vegetation can vary widely and depend on site conditions such as vegetation composition and structure, soils, climate, weather, fuel conditions, ignition patterns and techniques at the time of the fire, and applied fire variables such as seasonality and frequency at which prescribed fires are conducted. The use of prescribed fire exhibits logistical constraints that can hinder or prevent its use. Unpredictable weather, cost, manpower, local and regional regulations, smoke, health concerns, and perceived risk can all influence the effectiveness of burns by limiting options for applying prescribed fire. Management experience with fire and carefully planned experimental fire treatments during the last several decades provide rich information on fire effects in sandplain grasslands. Management of sandplain grasslands using fire can be complex and influenced by conditions that change on a daily or even hourly basis.

In this document, we evaluate the effects of prescribed fire in sandplain grassland compiled from published and unpublished studies and information obtained from Interviews with land managers. We focused on the following main questions relevant for sandplain grasslands management:

1) Does fire reduce woody growth?

2) Does fire maintain or increase grassland associated plant and animal species diversity?

3) Under which conditions is fire more or less effective at reducing woody species cover?

4) How can the effectiveness of prescribed fire be improved as a management tool to maintain sandplain grassland?

We focus on interpreting the main patterns that emerge from examining multiple experiences across multiple sites, with the understanding that responses to any one fire treatment under particular conditions may differ.

These studies represent only a portion of possible treatments and variables that could be tested. It is challenging to design and execute well-controlled studies to determine the impacts of management techniques on sandplain grassland when considering the combinations of individualistic species responses, treatments, short and long-term effects, and the number of replicates needed for sound investigations (Dunwiddie 1990).

Methods

We reviewed 75 sources that described or documented results of management actions in sandplain grasslands. Of these, 39 sources contained information on prescribed burning and 19 detailed specific management experiments or case studies. In addition, we Interviewed 13 professionals throughout the region about their experiences with prescribed fire in sandplain grasslands. Literature sources that tested active management treatments were classified by whether they: (A) reduced regrowth of woody vegetation and (B) increased biodiversity of plants or animals, or both (Fig. 2).

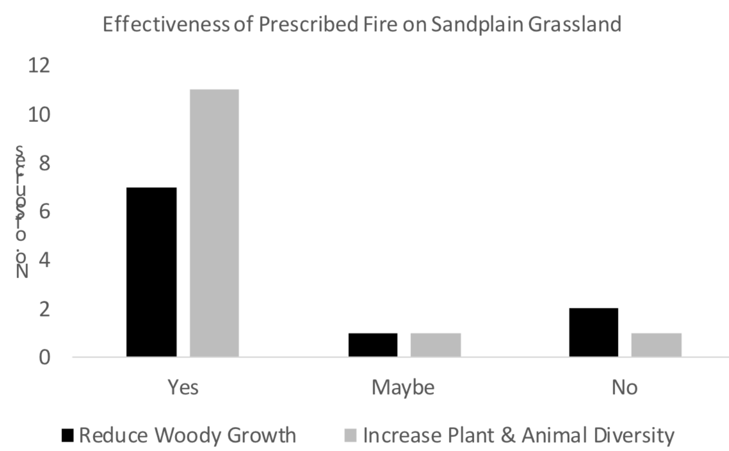

Figure 2. Number of sources that found prescribed fire in sandplain grasslands reduced woody shrub and tree regrowth.

This review of literature and interviews is used to summarize the state of current management understanding of fire regimes in sandplain grasslands and the effects of prescribed fire on: (1) fuels and soils, (2) vegetation composition, (3) vegetation structure, and (4) fauna in relation to seasonality and fire frequency. We then suggest ways that the use of fire could be improved to decrease woody cover, increase graminoid cover, and maintain and promote biodiversity in sandplain grasslands.

Results

Overall, a large majority of sources found that prescribed fire reduced the regrowth of woody vegetation and increased biodiversity in some manner (Fig. 2). However, no study found that fire alone was completely effective over the long term in reducing woody regrowth or increasing biodiversity. Rather, our review found that most sources concluded that pairing fire with other management practices will be needed to control woody regrowth and maintain sandplain grassland biodiversity over the long term.

Figure 3. A prescribed burn during summer in the Cape Cod National Seashore. Photo Credit: Lena Champlin.

Fire regime

Fire regime is the most influential fire-related factor (or family of factors) that influences the outcome of prescribed burning in sandplain grasslands, and calibration to current and antecedent site-specific conditions is essential to reach desired management outcomes. Traditionally, fire regime has been defined as fire frequency, seasonality, intensity and severity (Keeley et al. 2009), but may include size, pattern and other factors as well.

Fire intensity and severity are often confused. In fire ecology, fire severity is the degree to which a site has been altered or disrupted by fire; loosely, a product of fire intensity and residence time (NWCG). Intensity, or fireline intensity, is the product of the available heat of combustion per unit of ground and the rate of spread of the fire (NWCG).

In sandplain grassland habitat, fire frequency and seasonality are often more important than intensity in some situations (W. Patterson III, Interview, Dunwiddie et al. 1995) (as seen in Fig. 3). In sources we reviewed, fire frequency and seasonality were most common in experimental designs, while severity and intensity were typically not specifically tested, though sometimes discussed. Frequency ranged from annual single burns to multi-year burns at varying intervals. Seasonality is site-specific and depends largely on vegetation type, climate and weather. For this region, seasonality of prescribed fire applied to sandplain grassland is typically divided into spring, summer and fall/winter (Table 1). Spring fires are often divided between times of dormant or growing season vegetation.

Table 1. Fire seasons typically applied to sandplain grassland in the northeast US.

Season	Stage	Timeframe
Spring	Dormant	March to late April (sometimes to early May)
Spring	Growing	Mid to early June
Summer	Growing	Mid-June to late September (sometimes to October)
Fall/winter	Dormant	Between summer growing seasons (usually September to March)

Effects on fuels and soils

Fire can reduce fuels on a short-time basis (typically 1-2 years) in sandplain grasslands, including standing dead wood (coarse woody debris), standing dead grasses, forbs and plant litter (thatch), and recalcitrant organic material (duff). Combustion of these fuels exposes mineral soil, which then experiences increased soil radiation and soil temperature. This microclimate promotes seed recruitment of warm-season grasses and forbs. Without fire, an excess of plant litter can build up to favor cool-season grasses by increasing shade, water retention and nitrogen that could favor non-native or invasive species (C. Buelow, Interview).

There is some evidence that prescribed fire in sandplain grasslands raise rates of nitrogen mineralization in soil, nitrogen being the nutrient that has the most direct effect on plant growth. For example, Dudley and Lajtha (1993) found that burning annually in a sandplain grassland for two years during April increased nitrogen mineralization rates and the ecosystem did not return to pre-burn concentrations within three years following fire. Martin (2008) studied species responses in sandplain grasslands that had been burned at different periods, and suggested that there was an initial addition of nitrogen to the soil following fire. Higher mineralization rates likely occur because soil temperature is elevated immediately after fire (J. Carlson, Interview). However, fire effects on soils diminishes as vegetation regrows. It is hard to detect differences in major soil nutrients between sandplain grasslands and other typical coastal plain woodlands or shrublands, or between recently-burned and unburned woodlands, where more biomass is consumed and effects on soils would presumably be greater (Neill et al. 2007).

Effects of fire seasonality and frequency

Fire seasonality can influence fire intensity, and fire intensity and severity are often correlated (Keeley 2009). In observations on Martha's Vineyard and Nantucket, spring fires are typically most intense, summer fires are the least intense (but most severe in their effects on vegetation), and fall fires typically have medium intensity (Dunwiddie 1990). As for spring fires, Joel Carlson suggests that, a secondary effect would be to reduce future inputs into the fuel load due to severity but not from the first order effects. Given the right conditions, summer fires can have the most ecologically important impact on fuel, soil, and seed germination (W. Patterson III, Interview). Drought conditions can cause the duff layer to ignite, leading to longer smoldering burns in the soil (Raleigh et al. 2003a), which might have greater impacts on the shallow root systems of clonal woody plants in contrast with grasses that have deeper roots (J. McCumber, Interview). Karberg (2014) reported greater reduction of shrub cover in a more severe fall fire compared with less severe fall fires. Spring burns will generally not consume significant amounts of duff, though leaf litter accumulation may be reduced (Raleigh et al. 2003a). Further, although higher fire frequency can lead to greater amounts of bare mineral soil, fire intensity and severity can often, but not always, decrease if available fuels decrease with more frequent fires. This creates tradeoffs between the efforts involved in applying more frequent fires and their benefits, and these tradeoffs depend largely on site-specific conditions and overall management goals.

Effects on vegetation

In sandplain grasslands, initial species assemblages and their responses to fire can influence the effects of prescribed fire on vegetation composition (e.g. Karberg 2014). Life history characteristics of plants determine how they will respond to fire, making the seasonality crucial in determining species response (Raleigh et al. 2003a). As a general rule of thumb, early growing season burning in sandplain grasslands favors warm-season native grasses that are fire tolerant, and discourages non-native cool-season grasses that are fire intolerant (C. Buelow, J. Carlson, T. Simmons, Interview). Further, fall fires can promote forbs (Joel Carlson, Interview).

Figure 4. The rare New England silvery aster (*Symphyotrichum concolor*) only found on Nantucket Island, at Smooth Hummocks property. Credit: Chris Neill.

Little information on key aspects of life history exists for many of the infrequent species that are conservation targets of sandplain grasslands, such as the New England silvery aster (Symphyotrichum concolor) (Fig. 4). Farnsworth (2007) compared infrequent SPG species characteristics with those of close relatives and found that they typically experience distinct life-history traits such as (1) higher habitat specialization, (2) larger seed size, (3) smaller plant height, (4) less reliance on vegetative (colonial) reproduction, and (5) a tendency toward annual or biennial life history. However, there is no information on how many of these species respond to fire, though there is evidence that fire suppression could decrease species richness in grassland habitats. Leach and Givnish (1996) found that 8-60% of species were lost from prairie remnants in Wisconsin over a 32-52-year period most likely due to fire suppression, and that short, small-seeded, or nitrogen-fixing plants showed the heaviest losses.

Fire frequency depends on the available vegetation and fuels and should be tailored to overall objectives (J. Carlson, Interview). Typically, the necessary fire interval in sandplain grasslands is about four years (C. Buelow, N. Sferra, Interview), and can be as few as three years (J. McCumber, Interview) or up to 7 years (D. Crary, Interview). W. Patterson III (Interview) suggests that two years is possible under the right conditions and anything longer than three years can accelerate dominance of woody species, especially if burns occur in the dormant season.

We reviewed work related to the effects of prescribed burning on some target sandplain grassland plant species and found that frequency and seasonality were only reported in some studies but are important variables that should be considered (Fig. 5). Raleigh et al. (2003b) found that little bluestem (*Schizachyrium scoparium*), Pennsylvania sedge (*Carex pensylvanica*), and the northern blazing star (*Liatris novae-angliae*) responded positively to spring burns (typically mid-May). Freeman et al. (n.d.) found that a single annual April burn increased the number of flowering stems, enlarged weekly floral displays, and in some cases, increased flower production of the state-listed eastern silvery aster (*Symphyotrichum concolor*). Vickery (2002a) found that *L. novae-angliae* populations at the Kennebunk Plains in Maine benefited from fire and that the number of flowering plants, the number of seeds per flower, and seedling establishment were higher after fire, but seasonality was not reported. Vickery (2002b) found that fire dramatically decreased seed predation from microlepidoptera after one year, but predation rebounded to pre-burn numbers two years later. Martin (2008) found that *C. pensylvanica* increased after fire.

Figure 5. Head of the Plains, a 286-acre area on Nantucket managed by rotating burning in units in the fall (September to November) or spring (April to May) every five years to prevent woody growth. Photo Credit: Nantucket Conservation Foundation.

A key element to the use of fire for sandplain grassland management is that the frequency and severity of fires be sufficient to reduce—or at least restrain—woody growth. Historically, the consensus among land managers and ecologists was that growing season burns shifted vegetation away from woody plants and toward herbaceous grassland vegetation, while dormant season burns simply maintained grassland (e.g. Karberg 2013). However, Joel Carlson suggests that fire managers and fire ecologists have known that dormant season fires are not necessarily effective at maintenance of sandplain grassland over the long term, even with repeated burning. This point is also addressed in Karberg (2014).

Summer fires are typically most effective at reducing woody regrowth. Dunwiddie et al. (1995) sampled four plots – one burned in spring, one in summer, one that was mowed, and a control, and found that summer burns decreased frequency and/or cover of shrub species while spring burns had little to no effect. These findings indicate that if sandplain grasslands are to be managed exclusively with fire, summer burns are necessary at least at some frequency to

Figure 6. Grassland prescribed fire at Camp Edwards on Cape Cod in October 2013. Photo Credit: Jake McCumber.

reduce woody regrowth. The effects of fire on woody growth could likely be enhanced if fires took advantage of other co-occurring natural stressing factors such as defoliation by insect herbivores, droughts, and salt spray (J. Carlson, J. McCumber, Interview). A number of other sources have examined the effects of fire frequency. On Nantucket, one study found that a single spring burn was only enough to stop shrub encroachment in the year following the burn and did not reduce total woody shrub cover (Zuckerberg and Vickery 2006). In another study, a single burning treatment showed no long-term impact on shrub cover, but biennial burning or mowing over 12 years reduced shrub cover and/or frequency on Nantucket (Dunwiddie 1998).

There is also evidence that annual or biennial fires applied during the growing season (mid-June to October) both reduced shrub growth and increased plant diversity (Fig. 6). Karberg (2014) studied Units 5 and 8 at Head of the Plains on Nantucket (burned once during summer with high drought index values) and found a large decrease in shrubs and an increase in grassland species. Dunwiddie (1998) found similar results, where burning was more effective than mowing for reducing woody growth and increasing graminoid and forb cover, but the study also concluded that the addition of more aggressive methods, such as repeated treatments during the growing season, harrowing, and application of herbicide may be necessary for long-term control of shrub expansion.

Studies also examined the effects of annual and biennial fires applied during the spring dormant season (March to late April). Dunwiddie et al. (1995) burned biennially for 12 years during April at Ram pasture, Nantucket and found that spring burns were less effective than summer burns at decreasing shrub growth and increasing plant diversity. Dunwiddie and Caljouw (1990) burned biennially for six years during April on multiple sites and found that spring burns stimulated growth of herbs, while summer burns stimulated growth of warm season grasses.

During fall/winter dormant season fires (September to March), it seems that only annual single burns have been studied in sandplain grasslands. Karberg (2014) studied fall fires in Units 2 and 9 at Head of the Plains on Nantucket and found varying results based on site conditions and the applied fire regime. Fire in Unit 9 had led to no major changes to plant species composition with the lowest intensity recorded, while fire in Unit 2 led to higher plant species richness four years post-burn.

Although fire is an effective tool for promoting sandplain grassland vegetation under certain conditions, there has been no study that found fire alone to be a viable long-term management solution; rather, fire in combination with other tools is necessary, which applies to other grassland systems as well. Outside the northeast, Hesling and Grese (2010) burned annually in April on a remnant Michigan tallgrass prairie and found that frequent fire helped maintain prairie species and reduced non-native species and cool-season grasses, but fire alone did not produce a diverse prairie plant community.

Effects on fauna

The effects of prescribed fire on fauna are understudied and both the short- and long-term impacts to target species in sandplain grasslands need further research. Although fire can have negative effects on fauna, the short-term negative impacts must be balanced with the long-term creation of beneficial habitat (J. Scanlon, Interview).

There can be clear short-term effects on sandplain grassland animals that are management targets. At Camp Edwards, Grasshopper Sparrows (*Ammodramus savannarum*) declined in burned plots the year immediately following a fire (J. McCumber, Interview). At Katama Plains on Martha's Vineyard, meadow voles (*Microtus pennsylvanicus*), an important food source for Northern Harriers (*Circus cyaneus*), decreased for the two years following a burn (Buresch, reported in Revised Management Plan of Katama 2000). However, *M. pennsylvanicus* populations are quite cyclic and fire might easily not have had any effect there (R. Wernerehl, Interview). Fire can also harm larval stages of moths and butterflies in the short term (M. Mello, Interview), but create conditions for long term success (Fig. 7). Further, fire can kill long-lived rare animals like the box turtle (*Terrapene carolina*) (M. Jones, Interview). Many, insects, particularly herbivorous insects, are extremely sensitive to environmental change (P. Goldstein, Interview).

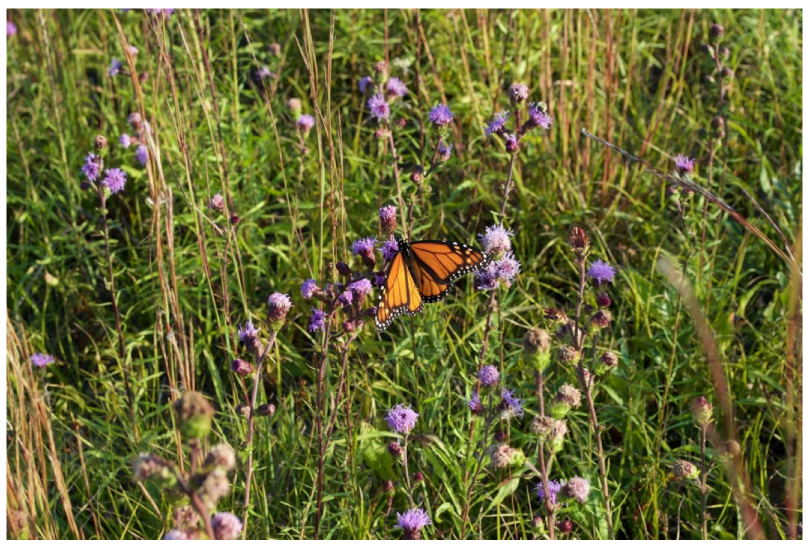

Figure 7. Monarch butterfly on northern blazing star at Kennebunk Plains in Maine. Photo Credit: Bob Wernerehl.

In the long term, the open grassland habitat created by fire supports many rare bird species and several insects including rare Lepidoptera (P. Goldstein, Interview). Though there was a decrease immediately after fire, at Katama Plains, Grasshopper Sparrows select nesting territories in sites that had been burned within the previous three years (Harris 1998, reported in Revised Management Plan of Katama 2000). Grasshopper sparrows require large open spaces and will not nest within about 75 meters of a forest edge (D. Vitz, Interview). Upland sandpipers (*Bartramia longicauda*), another target of sandplain grassland management, also require similar large open spaces (J. McCumber, Interview).

Seasonality is likely the most important factor that influences fire effects on fauna in sandplain grassland because lifecycles of animals and insects tend to make them vulnerable during the growing season when prescribed fires occur most. For example, on Nantucket, target grassland bird species nest primarily between May and June, but sometimes to mid-July (D. Vitz, T. Simmons, Interview). If burning occurs during this time, fire-caused mortality could affect populations of target species.

Dunwiddie (1991) conducted burns for two years in April biennially (1983-85) on Nantucket and found a decrease in Arthropod abundance and an increase in Orthopera.

Adjusting fire frequency and the proportion of area burned in any one year can limit the negative effects of prescribed fire on fauna. Maintaining a patchy mosaic of time since fire across a sandplain grassland can increase biodiversity and provide refuge for grassland fauna. For example, to protect animals, managers at the Frances Crane Wildlife Management Area on Cape Cod, burn only one-fourth to one-third of a 400-acre grassland during a single year (D. Vitz, Interview). Burning smaller patches during different years introduces heterogeneity into the grassland and potentially creates a mosaic of grass and heathland habitats for different animal species (J. McCumber, Interview). Further heterogeneity could potentially be created by stacking heterogeneous woody debris piles to vary the intensity and patchiness of burning (J. McCumber, Interview). We found no actual measurements of these potential spatial effects.

Logistical and Practical Constraints on the Use of Fire

While prescribed fire can often be effective for maintaining sandplain grasslands and species targeted for conservation, this management can also be complicated to implement. Implementing an ecologically effective fire regime can be constrained by costs, unpredictable weather, local regulations, smoke impacts, health issues, and perceived risk. Air quality can be affected in surrounding areas depending on atmospheric conditions. These constraints are exacerbated because sandplain grasslands are concentrated in coastal regions, which are tourist destinations and near the public. Smoke management typically limits the application of prescribed fire during summer, which is when ecological benefits of fire management can be greatest (J. Carlson, Interview). Burning when the drought index is high, which also enhances desired effects on vegetation, often requires increased monitoring and mop-up to mitigate smoldering and smoke impacts (J. Carlson, Interview). Smoldering combustion is influenced by on-site conditions and weather, is the most inefficient type of combustion, and produces the highest amounts of pollutants (J. Carlson, Interview).

Although applying fire during particular times of stress (e.g. droughts or outbreaks of herbivorous insects) could increase the effects of fire and reduce the frequency of fires required to obtain similar vegetation responses, being able to take advantage of these events in particular places will likely be challenging.

Summary and Pathways to More Effective Management

The effects of fire on vegetation structure in sandplain grassland and effects of fire frequency and seasonality have been studied in field management experiments. Summer fires during drought conditions most effectively reduce woody vegetation, woody debris, thatch, and duff, which exposes mineral soil and favors warm-season grasses and native forbs and discourages cool-season grasses and non-native invasive species. Spring fires can also promote warm season grasses. Summer fires consistently reduced woody growth only when they were conducted within a frequency every two to five years. Fire seasonality largely controls the effects on individual species and the resulting community. Early growing season fire typically favors warm-season, fire-tolerant native grasses and negatively affects fire-intolerant cool-season, and often non-native, grasses. Further, spring burns tend to stimulate growth of some forbs, while summer burns stimulate growth of warm season grasses. Much less is known about the effects of fire on fauna, but burning a mosaic of patches is recommended.

A major challenge for the use of fire for long-term management of sandplain grassland is the ability to apply it frequently enough, and to apply it in summer, or during conditions of drought, defoliation, or other stresses when its ecological effects are greatest.

This review identified several major ways to improve understanding of potential benefits of the use of fire for sandplain grassland management.

(1) Test combinations of fire with mowing or other management techniques. They should be designed and monitored as field experiments. This approach could potentially maintain the beneficial effects of fire in creating microclimate and soil conditions that promote target forb and warm-season grass species and limit growth of woody plants even when it its impractical to apply fire frequently enough during summer to restrict woody regrowth with fire alone. These combinations could be tested as sub-plots that are mowed or receive vegetation removal within larger areas that are currently being managed with prescribed fire at some intervals.

(2) Improve understanding of how infrequent or rare plants respond to different fire regime combinations. These rarer plants are some of the major targets for sandplain grassland management and often have life histories that differ from closely-related but more common species. There is currently almost no information on how these species respond to fire and the effects of fire seasonality, intensity or frequency applied to sandplain grassland.

(3) More work is needed to determine how prescribed fire affects the mortality and population dynamics of fauna in sandplain grassland. These effects may be particularly important for less common and conservation target species that have small, declining and dispersed populations. It is also important for higher-profile species such as birds and for more common species such as some invertebrates that are important prey of grassland birds.

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Case Study: Prescribed Burning at Kennebunk Plains

Site Description

Kennebunk Plains is located in a large continuous barren area that consists of more than 405 hectares (1,000 acres) of diverse sandplain communities including sandplain grasslands, pitch pine-heath barrens, pitch pine-scrub oak barrens, and red maple alluvial swamp forest (Fig. 1). This area has been protected since 1989 with funding from the Land for Maine's Future program. The property is located in the towns of Kennebunk and Sanford in southern Maine. Kennebunk Plains consists of over 243 hectares (600 acres) of open grassland (Fig. 2) with flat to rolling topography. The Maine Chapter of The Nature Conservancy conducts prescribed burning on grassland portions of Kennebunk Plains on behalf of the state. An additional 50 hectares (123 acres) of Kennebunk Plains adjacent to state land is owned and managed by The Nature Conservancy.

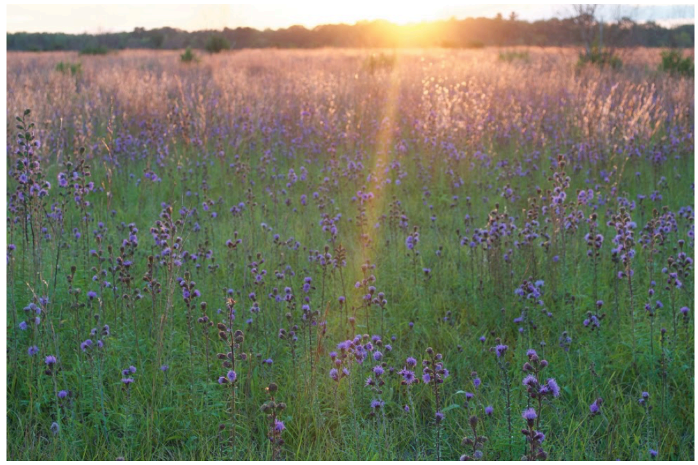

Figure 1. Purple flowers of northern blazing star (*Liatris novae-angliae)* population. Photo credit: Robert Wernerehl.

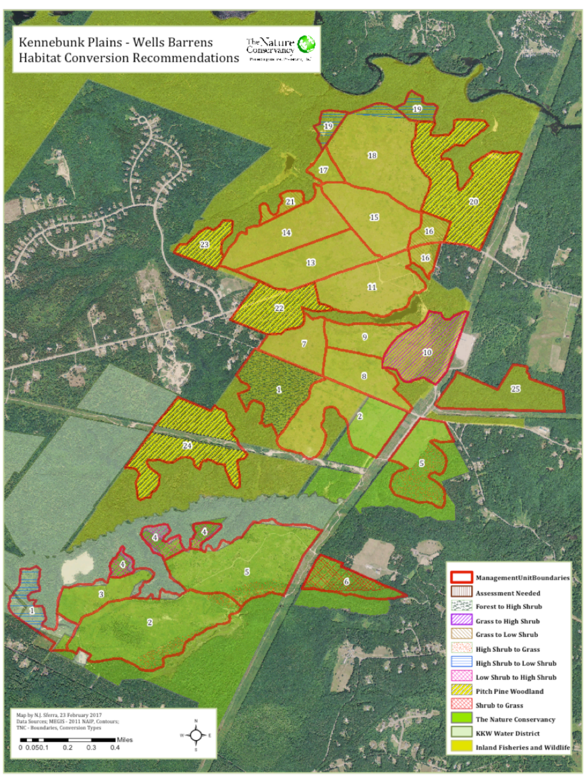

Figure 2. Map of Kennebunk Plains and Wells Barrens management units.

The Kennebunk Plains community is composed primarily of little bluestem (*Schizachyrium scoparium*), poverty grass (*Danthonia spicata*), Ericaceous shrubs, and supports 14 rare plant and animal species. The grasslands have the only viable population of the rare northern blazing star (*Liatris novae-angliae*) in Maine, the largest global population with over 1 million stems. Other rare plants include toothed white-topped aster (*Sericocarpus asteroides*) and upright bindweed (*Calystegia spithamaea ssp. spithamaea*). Kennebunk Plains also provides one of the best mainland sites for grasshopper sparrow (*Ammodramus savannarum*) nesting in New England. Other endangered birds include state-listed upland sandpipers (*Bartramia longicauda*), vesper sparrows (*Pooecetes gramineus*), and horned larks (*Eremophila alpestris*). The uncommon bobolink (*Dolichonyx oryzivorus*), eastern meadowlark (*Sturnella magna*), broad sallow moth (*Sympistis infixa*), and trembling sallow moth (*Chaetaglaea tremula*) exist in the Kennebunk Plains, as well as the state endangered black racer snake (*Coluber constrictor)* and the wood turtle (*Glyptemys insculpta*).

Kennebunk Plains exists in the northern-most range of sandplain grassland in North America. Kennebunk Plains differs from other sandplain grasslands for its existing further inland than other sites, lacking an influence of salt spray and salt tolerant species. In addition, plowing has never occurred there, resulting in high-quality habitat because it lacks any soil legacy effects from agriculture.

Like at other sandplain grassland sites, with a lack of consistent management, woody growth will increase through ecological succession.

Management Goals

1) Maintain native grasses and forbs by reducing woody growth and nonnative plants by use of prescribed fire and mowing;
2) Create conditions that promote fire-dependent plants, including the rare northern blazing-star (*Liatris novae-angliae*);
3) Provide habitat for grassland birds such as the rare grasshopper sparrow (*Ammodramus savannarum*), broad sallow moth (*Sympistis infixa*), and trembling sallow moth (*Chaetaglaea tremula*);
4) Decrease fire hazards by reducing litter and duff.

History of Management

The Kennebunk Plains have a long history of natural and anthropogenic fire disturbances. Archaeological evidence dating back approximately 5,000 years suggests that fire occurred intermittently (Roach 2005). Fire favors flora and fauna species with fire-adapted life history characteristics that aid in germination, regeneration, and reproduction. Evidence suggests that Native Americans and early European settlers used burning to manage flora and fauna at Kennebunk Plains. In the 1940s, the area was managed with prescribed fire for blueberry (Vaccinium spp.) production. During the 1980s, prescribed fire was replaced by herbicide application to exclude non-blueberry plants (Roach 2005).

In 1990, The Nature Conservancy introduced a regular fire regime in approximately 243 hectares (600 acres) of Kennebunk Plains to maintain sandplain grassland. Specifically, between 10 and 30 percent of grassland area is burned on an annual basis. Eighteen management units exist on the property of between13 to 20 hectares (32 and 49 acres). These are burned on a 4 to 5 year rotation. Mowing is sometimes also used to supplement fire to reduce the growth of shrubs. Prescribed fires face respectively low amounts of logistical and practical constraints at Kennebunk Plains. For example, smoke management is not typically a concern because the site is distant from residential areas.

Burning is the primary method of grassland maintenance at Kennebunk Plains because it shaped the communities historically and creates several effects that promote grassland plants.

Without fire, Kennebunk Plains would risk increased competition of non-fire adapted plant species such as nonnative and invasive species. Nancy Sferra (Interview) reports she prefers to burn in the spring because earlier burns tend to top-kill shrubs. Sferra (Interview) also reports that she also conducts prescribed burns in the fall, starting about August 1st to 15th, depending on the season. The preferred method for fall burning is to create some backing to the fire, rather than having a full head fire, to reduce the consumption of little bluestem (*Schizachyrium scoparium*) seeds.

Prescribed fire increases bare ground for grass germination, and temporally increases soil nutrients promoting plant growth, as well as removing litter and duff to reduce fire hazards. Compared with another sandplain grassland across the river (Wells Barrens) that has not been burned since the 1980s, Kennebunk Plains has noticeably less thatch, taller shrub cover, and higher cover of graminoids and native forbs (Nancy Sferra, Interview).

The average burn interval of about four years was initially determined by researchers, after studying the preferences of various grassland birds. While horned larks prefer recently disturbed areas, vesper sparrows are most common in areas that had not been burned for four years. Prescribed fire is usually applied during spring or fall to avoid bird nesting season. Rotating burn areas and not burning more than 25 percent of the area per year also protects nesting habitat. Grassland bird nesting areas are not mowed or burned between early May and August 15 to make habitat available and to allow birds to raise a second brood during late summer. Burns are conducted between the last week of April until about the 10th of May because, even though some birds are probably already setting up territory, there is still time for them to nest after fires (Nancy Sferra, Interview).

Research

Peter Vickery conducted several experiments in Kennebunk Plains from 1994 to 1996 to test the impacts of time since burning on northern blazing star (*Liatris novae-angliae)* growth and reproduction. Blazing star plants were examined in units, defined by months since previous burn. The following data were collected: (1) flowering northern blazing star plants were counted in 10 m2 units along two transects through four burn units, (2) 30 to 40 flower heads were collected and the number of seeds counted per flower head, (3) number of seedlings were counted in 0.25m2 quadrats. In addition, seeds were planted in each burning treatment and sprouts germinated were counted and survivorship of tagged seedlings was observed over time, and (4) the impact of predatory caterpillars, including two species of microlepidopteran moths (*Tortricidae*), were assessed by examining seeds. In addition, 20 stems were collected in various burn units and examined for predation.

Burning increased northern blazing star flowering, seed production, and reduced seed predation (Vickery 2002a, 2002b). Specifically, the following results were reported: (1) number of flowering plants was four times greater in recently burned units compared to units that were burned more than four years previous, (2) number of seeds produced in flowers on plants in recently burned units was greater, (3) seedling establishment and survival was greatest in units that were burned 20 months previous, as opposed to more recently burned units or units that had not been burned in over four years; and, (4) there was high predation of northern blazing star in Kennebunk Plains (approximately 62 to 87 percent of seeds affected).

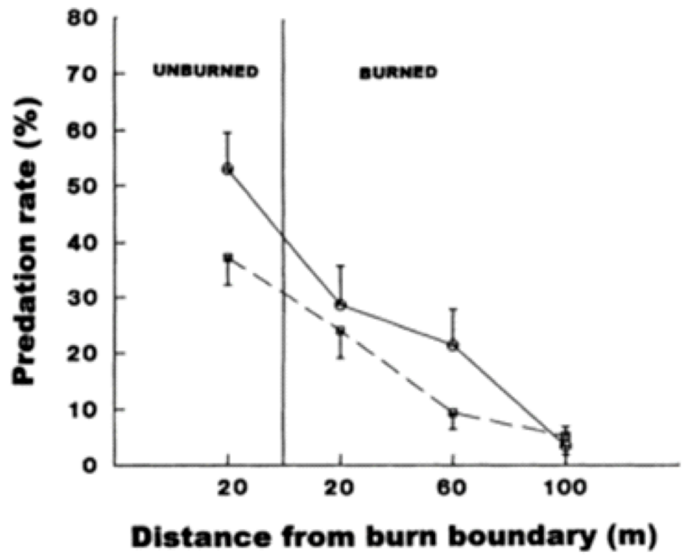

Figure 5. Predation of northern blazing star is greater in unburned units and spreads from the edge into recently-burned units (Vickery 2002b).

This research found that fire temporally removed predators from the flowers and that predation was lowered to 16 percent in units burned within a year. In locations that had not been burned in over five years, predation increased to 91 percent, indicating that increased frequency and repeated disturbance is necessary to reach desired results. Moreover, levels of predation were lower further from the edge of a burned unit next to unburned areas, suggesting that moths spread from unburned areas.

Ultimately, burning promoted northern blazing star populations by increasing seed production and survivorship and deceasing seed predation, but these effects were temporally and spatially linked. This research highlighted the need for experiments that apply more frequent burns over larger areas, as well as longer-term monitoring.

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III.B. Mowing in Existing Grassland

Introduction

Mowing can be used to maintain disturbance-adapted sandplain grasslands by manipulating ecological succession. The principal goals of management with mowing are to reduce woody vegetation cover, create conditions that maintain plant and animal species that rely on grassland habitat, and reduce fuels and fire risk.

Mowing in sandplain grasslands typically aims to promote a diverse assemblage of target grassland species with a high proportion of warm-season grasses and native forbs, a low proportion of cool season grasses and non-native invasive species, while reducing the regrowth of woody shrubs (Fig. 1). Mowing is used in grasslands to top-kill woody vegetation or other undesired vegetation.

Figure 1. At the Nantucket Land Bank's Smooth Hummocks Coastal Preserve on Nantucket, an area mowed annually during the growing season on the right side of the road is open grassland while an un-mowed area on the left side is a taller shrubland. Credit: Chris Neill.

The consequences of mowing for maintaining sandplain grasslands depend to a large degree on the structure of the pre-treatment vegetation, mowing timing and frequency, and to a lesser extent on the mechanics of mowing such as the height of cutting. Mowing can be less complicated and more predictable to apply than other management practices such as prescribed fire because its use depends primarily on the availability of equipment and operators rather than favorable weather or trained fire crews. The stage of succession and plant phenology can strongly influence the effectiveness of mowing. The experience of managers employing mowing and results of carefully planned experimental mowing treatments during the last several decades provide information on mowing effects in sandplain grasslands.

In this chapter, we evaluate the effects of mowing in sandplain grasslands compiled from published and unpublished studies and information obtained from interviews with land managers. We focused on the following main questions relevant to sandplain grassland management:

1) Does mowing slow woody growth?
2) Does mowing maintain or increase grassland associated plant and animal species diversity?
3) Under which conditions is mowing more or less effective at reducing woody species cover?
4) How can the effectiveness of mowing be improved as a management tool to maintain sandplain grasslands?

We focus on interpreting the main patterns that emerge from examining multiple experiences across multiple sites, with the understanding that responses in any one mowing treatment under particular conditions may differ.

These studies represent only a portion of possible treatments and variables that could be tested. It is challenging to design and execute well-controlled studies to determine the impacts of management techniques on sandplain grasslands when considering the combinations of individualistic species responses, treatments, short and long-term effects, and the number of replicates needed to detect trends in the face of variability (Dunwiddie 1990).

Methods

We reviewed 75 sources that described or documented results of management actions in sandplain grasslands. Of these, 24 sources contained information on mowing and 18 detailed specific management experiments or case studies. In addition, we interviewed 13 professionals throughout the region about their experiences with mowing in sandplain grassland. Literature sources that tested active management treatments were classified by whether they: (1) reduced regrowth of woody vegetation, and (2) increased biodiversity of plants or animals, or both (Fig. 2).

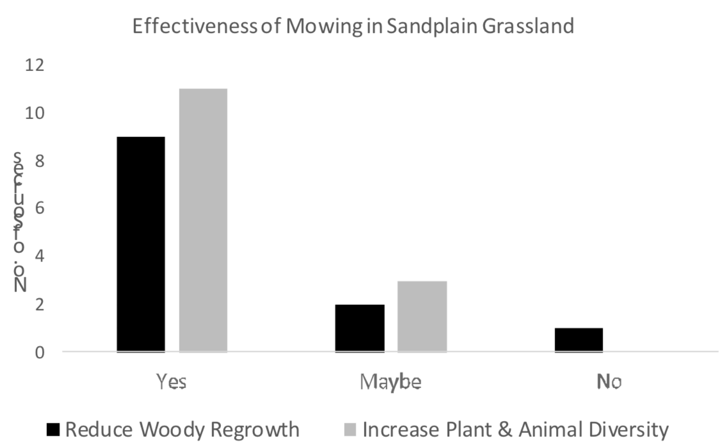

Figure 2. Number of sources that found mowing in sandplain grasslands slowed woody shrub and tree regrowth and increased plant and animal diversity.

This review was used to summarize the state of current management understanding of mowing combinations in sandplain grasslands and the effects of mowing on: (1) fuels and soils, (2) vegetation composition, (3) vegetation structure, and (4) fauna in response to seasonality and frequency of mowing. We then suggest ways that the use of mowing could be improved to decrease woody cover, increase graminoid cover and maintain and promote biodiversity in sandplain grasslands.

Results

A very large proportion of the total area of sandplain grasslands on public lands (and likely on private lands) are currently managed primarily by mowing (Oehler 2003). Overall, a large majority of sources found that mowing slowed the regrowth of woody vegetation and increased biodiversity in some manner (Fig. 2). However, no study found that mowing alone was effective at preventing woody species cover from continuing to increase over time. Rather, our review found that most sources suggested the pairing of mowing with other management practices as necessary to control woody regrowth and maintain sandplain grassland biodiversity over the long term.

Mowing regimes

Effects of mowing on vegetation largely depend on mowing seasonality and frequency. Mowing at a high frequency during the growing season reduces resource allocation to the roots and prevents regeneration of aboveground vegetation, which exhausts stored root energies (K. Fauteux, Interview). Some evidence shows that areas mowed at a high frequency over a long period of time exhibit an open structure compared with un-mowed areas (R. Freeman, Interview). However, too much mowing, and particularly mowing in a homogenous way (e.g., the same time and areas each year) could have undesirable consequences. While frequent mowing to reduce woody growth is necessary, implementing mowing annually or several times each year can have unintended consequences, such as creating a less biodiverse system. Such management could favor a few native species such as little bluestem (*Schizachyrium scoparium*) but reduce diversity of rarer forbs (Greller et al. 2000; M. Mello, Interview.). One suggested method to promote a more heterogeneous plant community is mowing irregular portions of the landscape over space and time to create a patchy mosaic that fosters higher biodiversity of flora and fauna. K. Beattie (Interview) suggested targeting only the portions of the landscape that have the highest shrub cover and leaving the grassy patches untreated. Further, mowing intensively multiple times per year and then relaxing management for several years to allow recovery of impacted rare species might be effective.

Mowing during the growing season and dormant season may reduce the abundance of rare plants by preventing seed set or burying seeds under mowing debris, inhibiting favorable germination conditions. Therefore, when managing for rare species, mowing is often conducted in the fall after seed production (Clarke and Patterson III 2007). Another practice to maintain habitat for rare species was implemented in Manuel F. Correllus State Forest, where annual or biennial fall mowing conducted in the grassy fire lanes created before 1938 was sufficient to maintain habitat for five rare grass and forb species. *Effect on soils and fuels*

Relatively little work has examined effects of mowing on soils and the relationships of soil characteristics to plants. However, increasing soil organic matter, nutrients and moisture are pretty major changes caused by mowing that could have potentially dramatic impacts on habitat suitability for different plant species (K. Beattie, Interview). While evidence from the northeast US is mostly anecdotal, effects on soils potentially include an increase in soil organic matter, slightly elevated soil nutrients, and higher soil moisture. A detrimental effect of mowing is that litter created by mowing serves as a mulch layer that reduces bare soil patches that are important sites for recruitment of desired plant species from seed (K. Beattie, Interview). The buildup of duff over time could change the microhabitat and potentially favor non-native or invasive species, or native species that are not affiliated with sandplain grassland habitats, but we found no studies highlighting this potential effect.

Even where soils have been studied in more detail, patterns are not especially clear. Martin (2008) compared an area of Nantucket heathland that was unmowed and burned with an area that had been mowed and burned and found different trends in nutrients and plant cover. For example, burned, unmowed areas were higher in soil nutrients and had a positive relationship with black huckleberry (*Gaylussacia baccata*) cover and a negative relationship with Pennsylvania sedge (*Carex pensylvanica*) cover.

The increase in litter associated with mowing increases the amount of fine fuel available to burn, likely increasing wildfire risk in sandplain grassland. However, we found no studies that quantified these effects.

Effects on vegetation

Initial species assemblages, their life history characteristics and timing determine how they will respond to mowing disturbance. For example, black huckleberry (*Gaylussacia baccata*) is fire-tolerant and clonal, therefore prescribed fire could stimulate growth more than mowing depending on the applied fire regime (Matlack 1997). Physical crushing, maceration, and mechanical impacts during the summer growing season have also been found to kill this species (T. Simmons, Interview).

Figure 3. At the Nantucket Land Bank's Smooth Hummocks Coastal Preserve, annual mowing leads to low woody cover but a limited diversity of forbs, mostly dense little bluestem (*Schizachyrium scoparium*) cover. Credit: Chris Neill.

There is evidence that mowing during the summer growing season is effective at reducing woody shrub cover and increasing plant biodiversity (Fig. 3). Dunwiddie (1998) studied various mow treatments at 14 sites across Cape Cod and the islands of Martha's Vineyard and Nantucket and found that cover decreased for some functional groups. With August mowing, frequency of forbs and graminoids increased but shrub growth was not reduced. Dunwiddie et al. (1995) found that frequency of forbs species increased 83 percent in a summer mowed treatment compared with an unmowed control and that small bayberry (*Morella caroliniensis*) declined eight-fold in frequency with mowing. The increase in the frequency of forbs with mowing was greater than the 62 percent increase in forbs documented in a paired fire treatment (Dunwiddie et al. 1995). Dunwiddie concluded that August burn and mow treatments reduced shrub cover and frequency and increased the frequency of graminoids and forbs compared with both spring burning and an unburned control. In a separate study, Dunwiddie and Caljouw (1990) found that mowing in August increased forb cover, decreased shrub cover, and increased graminoid cover. Dunwiddie (1990) found frequency of herbaceous species increased more after burning than mowing. There is additional evidence that dormant season mowing is not very effective at reducing cover of woody plants compared with summer mowing. Dunwiddie (1998) examined mowing during the dormant season at Katama on Martha's Vineyard and found that frequency of shrubs was not reduced and forb frequency decreased, but there was an increase in graminoid frequency.

On Naushon Island, C. Neill (Interview) found that mowing grassland edges once per year in June for three successive years during summer had relatively small effects on the cover of common greenbrier (*Smilax rotundifolia*) and black huckleberry (*Gaylussacia baccata*) but mowing twice per year in June and August reduced shrub cover and increased graminoid cover.

Overall, there is consistent evidence that dormant season mowing increases graminoid cover but does not necessarily achieve other goals such as reducing woody shrub cover, increasing forbs, or affect the frequency of target plant species. Summer mowing, in contrast, increases the number of species and cover of forbs and reduces cover of woody shrubs, although it appears that even more aggressive measures are needed to completely remove shrubs.

Figure 4. A recently-mowed dense huckleberry stand on a portion of Nantucket Land Bank's Smooth Hummocks Coastal Preserve property. A "drunken mowing" technique left a mosaic of mowed areas and un-mowed shrub patches. Credit Chris Neill.

Mowing can select for some plants over others (Raleigh et al. 2003), especially when mowing is repeatedly applied at the same time of year. Mower blades do not typically cut low-lying vegetation. For this reason, seasonality is important to consider (Raleigh et al. 2003). For example, late-flowering species are less susceptible to mowing during spring when most of the biomass is in short basal rosettes or underground. In contrast, mowing in the late growing season would negatively impact these same species considerably, as they are typically tall and flowering (Raleigh et al. 2003). Chris Buelow (Interview) suggested that mowing works well for converting an area from woody vegetation or clonal herbs such as some goldenrod species (*Solidago* spp.) to grassland when mowing is conducted during summer.

We found two key gaps in understanding the effects of mowing on existing northeastern U.S. sandplain grassland vegetation. First, little information on key aspects of life history exists for many of the infrequent species that are sandplain grassland conservation targets that might be managed by mowing. This parallels the lack of similar information about effects of burning. Farnsworth (2007) compared the characteristics of infrequent sandplain grassland species with their more abundant close relatives and found that they typically have distinct life-history traits such as: (1) higher habitat specialization, (2) larger seed size, (3) smaller plant height, (4) less reliance on vegetative (colonial) reproduction, and (5) tendency toward annual or biennial life history. There is very little information on how the phenology and abundance of most of these infrequent species respond to mowing. Second, despite the potential importance of the invasion of non-native woody shrubs and vines in existing northeastern U.S. sandplain grasslands, widespread concerns by managers about their control, and the potential of mowing as a management method, we found no studies that specifically examined invasive species responses to mowing within areas of existing sandplain grasslands. There is the strong perception by managers that the list of potentially important non-native and invasive species that now threaten northeastern U.S. sandplain grasslands is growing. For example, Amur peppervine (*Ampelopsis glandulosa*) and black swallow-wort (*Cynanchum louiseae*) appear to be spreading rapidly on both Long Island and southeastern Massachusetts (P. Weigand and C. Neill, Interviews).

Effects on fauna

The mechanical disturbance of mowing can be harmful to nesting birds and immobile animals. Atwood et al. (2017) suggest that mowing hay during breeding season is the leading threat to grassland-nesting birds in New England, and that adjusting mowing schedules could have drastic effects. Rather, they suggest avoiding mowing in New England from May 15 to August 15, and to collect and cut hay at least every three years.

Mowing blades and tractor tires can crush and injure some animals (M. Jones, Interview). Long-lived species such as box turtles (*Terrapene carolina*) can be especially vulnerable. To combat turtle mortality due to mowing, it is recommended that mowing should be rotated on a multi-year basis, and that no more than 25 to 50 percent of areas greater than 4 hectares (10 acres) should be mowed in any given year (Mowing Advisory Guidelines 2009).

Mowing can also kill larval stages of invertebrates such as moths and butterflies (M. Mello, Interview). In addition, thatch build up can negatively affect grassland birds that require bare patches between vegetation for travel corridors and nesting (Rudnickey et al. 1997). Zuckerberg and Vickery (2006) compared the effects of burning and mowing on the response of bird species. They found that mowing was more effective than burning for restoring grassland bird habitat in shrublands and affecting abundances of shrubland birds and vegetation structure. However, the effects were species-specific: Eastern Towhee (*Pipilo erythrophthalmus*) and Common Yellowthroat (*Geothlypis trichas*) abundance decreased as the frequency of mowing increased at sites on Nantucket, mowed several times throughout the season. Further, Savannah Sparrow (*Passerculus sandwichensis*) abundance showed no response to mowing, while Song Sparrows (*Melospiza melodia*) preferred unmanaged habitat.

The effects of mowing on grassland animals can be reduced by limiting the size of the area mowed and by leaving patches of un-mowed habitat each year as refugia. One method, "drunken mowing," leaves a mosaic of mowed and un-mowed patches. Avoiding mowing between May 15 and July 15, when birds are nesting, can limit the negative impact of mowing on birds (D. Vitz, Interview). In many cases, mowing patterns can more easily be controlled than fire, and properly staged management can provide escape routes for mobile wildlife. For example, instead of mowing from the outer edge and spiraling inward, mowing which is initiated in the middle of a field and travels in an outward spiral pattern may allow mobile animals to escape (Raleigh et al. 2003). Increasing the height of the mowing blade can also help protect wildlife especially turtles, snakes and ground-dwelling insects and reptiles (M. Jones and P. Goldstein, Interviews). Lower invasion by non-native invasive species may be a secondary benefit associated with the ability to raise the mower deck and reduce soil disturbance in places where invasive species occur and can spread. Regardless, it is important to thoroughly clean mowing equipment each time it is transported between sites to prevent spread (K. Beattie, Interview).

Because reducing the spread of shrubs and trees, especially non-native invasive plants, is most effective when mowing is done frequently and during the growing season, the timing of management needs to be carefully planned to minimize conflicts with nesting birds and other wildlife. Woody growth should be mowed immediately following the nesting season, which generally concludes around July 15 in this region. Mowing during late summer (July 15 to August 30) will affect woody species just after flowering or seed drop.

The nesting season is shifted (to about 2 weeks later) on the coastal Massachusetts islands and perhaps even Long Island) as the maritime influence results in cool and damp springs; thus, August 1 is a better date to aim for at these sites (K. Beattie, Interview) (Fig. 5).

Figure 5. Tractor mowing of shrubs at grassland edges on Naushon Island in August 2016. Credit: Lena Champlin.

These timeframes are likely to achieve the greatest reduction in woody plant biomass because it is the time when woody plants have lowest belowground energy reserves. Mowing during fall will reduce the impact to nesting birds but will be less effective at reducing woody regrowth because plants have greater belowground reserves at this time. A second mowing during March following a late summer mowing can reduce additional shrub growth that occurred after the initial cut during fall.

Logistical and Practical Constraints on the Use of Mowing in Existing Grassland

Mowing is one of the most practical techniques for managing sandplain grassland because it requires a low amount of training, manpower, and equipment and fewer variables and less complexity associated with its implementation. To be effective, mowing requires short- and long-term strategies. For example, higher frequency mowing might be effective at initially reducing woody growth. In subsequent years, mowing frequency and seasonality can be adjusted to maximize richness of herbaceous species.

Figure 6. Typical mowing and light brush-cutting equipment used by the Nantucket Conservation Foundation. Photo Credit: Nantucket Conservation Foundation.

Because mowing does not result in mortality to undesirable woody plants in many cases, it requires frequent application and therefore can be time-consuming. Another constraint is that if there is a lapse in management, re-growth can quickly outpace the capacity of the mowing equipment and make follow-up treatments difficult or impossible. Therefore, if a mowing cycle is missed because of time or financial constraints, mowing in subsequent years will be more challenging and costly.

Figure 7. Heavier brush-cutting equipment used by the Nantucket Conservation Foundation to expand grasslands invaded by shrubs and reduce wildfire risk. Photo Credit: Nantucket Conservation Foundation.

The type of mowing equipment and mower settings influence the effects on vegetation (Fig. 6 and 7). The height of the mow deck will determine the cut height of the vegetation. The time of year at which mowing commences will determine how seed set and maturation of particular species will commence and be impacted. In addition, very low mower blades have a higher propensity to disturb the organic layer of the soil (D. Crary, Interview; Greller et al. 2000) and thereby might increase risk of invasive species establishment. It is important to be able to adjust the height of the mower deck to target different plants depending on the site conditions and the desired grassland management goals (C. Politan, Interview).

Access and site conditions, such the presence of rocks, larger trees, tree stumps, fence posts or waterways create physical barriers that can make mowing more challenging because it is difficult to operate a tractor safely in those conditions. However, compared with prescribed fire, mowing is logistically easier for several reasons. There are fewer constraints on mowing based on time of year and fewer regulatory restrictions. In coastal regions, mowing is not as influenced by the summer tourist season and therefore can be more easily conducted during summer when disturbance to woody shrub growth is more effective. Because the timing of mowing is flexible, it may be easier to align with timing of funding available for management, and mowing is not spatially limited by proximity to houses. In addition, mowing can be much less expensive than prescribed fire depending on the duration and the desired impact (K. Fauteux, Interview). Therefore, mowing is often used in properties where burning cannot be conducted because of the location, the time of year, and lack of funding (C. Buelow, Interview). Risk management is also an important consideration with any management practice. Compared to fire, mowing is a much less risky alternative (K. Beattie, Interview).

While mowing can simulate many effects of burning, the differing mechanisms (maceration vs. incineration) have different long-term effects on grassland communities. Management that depends solely on mowing may create high amounts of litter and thereby potentially alter soil characteristics and result in a more uniform treatment. This may not create mineral soil niches, reduce seed pests, create other conditions that favor target grassland plants, or create conditions for species that require bare patches for travel corridors and nesting (Dunwiddie, reported in Revised Management for Katama 2000).

Although mowing during particular times of stress (e.g., droughts or outbreaks of herbivorous insects) could increase its effects and reduce the frequency of management required to obtain similar vegetation responses, being able to take advantage of these events in particular places will likely be challenging.

Summary and Pathways to More Effective Management

The effects of frequency and seasonality of mowing on vegetation structure in sandplain grasslands have been studied in field management experiments. Summer mowing most effectively reduced woody vegetation cover and increased forbs and graminoids compared with spring and fall mowing. Mowing has low logistical constraints compared with fire, but it also creates higher amounts of litter that may reduce diversity of target plants and animals. These factors suggest that combinations of summer mowing and occasional prescribed fire could potentially be effective. This approach may take advantage of the ease of use of mowing in most years while maintaining the benefits of fire applied less frequently. Further, mowing first can reduce the complexity and risk of follow-up fire management, perhaps making fire more feasible or likely to be implemented (K. Beattie, Interview).

This review identified several major ways to improve understanding and potential benefits of the use of mowing for sandplain grassland management:

(1) Test more combinations of mowing with fire or vegetation removal of woody vegetation. These tests should be designed and monitored as field experiments. Combinations could be tested as sub-plots within large areas that are currently being managed by mowing. Areas of fire or vegetation removal could be applied as plots within the larger mowed area.

(2) Improve understanding of how infrequent or rare plants respond to different mowing combinations. There is currently almost no information on how these species respond to mowing and the effects of mowing seasonality and frequency.

(3) Determine how mowing affects the mortality and population dynamics of insects, birds, mammals and reptiles in sandplain grassland. These effects may be particularly important for less mobile reptiles and insects that might be killed by mowing.

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Case Study: Mowing and Burning at Katama Plains

Site Description

Figure 1. Katama Plains landscape. Photo credit: Chris Neill.

Katama Plains Conservation Area is a 77-hectare (190-acre) property managed by The Nature Conservancy located in southeastern region of Martha's Vineyard. It is one of the largest areas of high-quality and diverse sandplain grassland remaining on Martha's Vineyard and in New England.

Prior to European settlement, this area likely had primarily low oak and pine woodland similar to other uncultivated areas of Martha's Vineyard. Since the mid-1600s this area was used as pasture for sheep and cattle with occasional burning for management and grazed regularly up until the 1900s. Based on soil horizons there was likely soil tilling for crop agriculture before 1900, but the land has been protected since then. Aerial images and records show that Katama Airfield has been grassland since the 1920s and likely even earlier. In 1938 aerial photos, the Katama property was continuous grassland. Regular burning for management was implemented up until 1962. In 1988 the Department of Environmental Management acquired parts of Katama Plains and more recently the property has been managed with a combination of mowing and burning.

In 2008, monitoring observed 43 plant species and 98 percent of plant cover was native species including low sweet blueberry (*Vaccinium angustifolium*), Pennsylvania sedge (*Carex pensylvanica*), yellow wild indigo (*Baptisia tinctoria*), little bluestem (*Schizachyrium scoparium*), stiff aster (*Lonactis linariifolia*), small bayberry (*Morella caroliniensis*), and northern dewberry (*Rubus flagellaris*). There is a strong focus on conservation of rare plants at Katama Plains including Nantucket shadbush (*Amelanchier nantucketensis),* bushy frostweed (*Crocanthemum dumosum*), and others. There are also rare birds and butterflies, including Northern Harriers (*Circus cyaneus*) and occasionally Short-eared Owls (*Asio flammeus*).

Management Goals

1) Reduce growth of woody vegetation.
2) Increase native graminoid and forb species.
3) Increase diversity of grassland animal species.

History of Management

Figure 2. The red outlined areas are the three large management units established in 2000. Smaller yellow unites were established in the 1980s.

In 2000, The Nature Conservancy developed a management plan to apply prescribed fire and mowing during the same year. Specifically, they burned in spring (March to May) and mowed in summer (mid-August to fall) on a three-year rotation for six years among three large management units. A similar management regime is continued today. Prescribed fire applied every three to four years, and mowing every six years per unit. The interval of repeated management was selected to keep shrubs below 1.5 m height. A "control" unit is also mowed when shrubs are above 2 m tall. Pitch pines (*Pinus rigida*) are selectively cut when they appear, including in the control unit (Revised Management for Katama 2000).

Mowing at Katama Plains is designed to produce effects similar to those of growing season fires. Prescribed fires are applied during the dormant season in combination with mowing during the growing. Growing season mowing reduces shrubs more than dormant season mowing, which often reduces the timeframe and logistical and practical constraints of management. W. Patterson III (Interview) estimated that annual summer mowing at Katama significantly reduces shrub abundance in 5 to 6 years, while annual mowing in both June and August has the same effect in only 2 to 3 years.

Nantucket shadbush (*Amelanchier nantucketensis*) is a rare shrub that grows in the Katama Plains grasslands. Frequent mowing will have a negative impact on this rare plant, therefore the plants are marked and mowing specifically avoids them.

The mowing regime is designed to minimize effects on the nesting of birds including Northern Harriers (*Circus cyaneus*) and Grasshopper Sparrows (*Ammodramus savannarum*) by disturbing only one third of the area at a time. August mowing maintains potential Grasshopper Sparrow habitat. Grasshopper Sparrows formerly nested at Katama but do not nest there currently, and their absence is a cause for concern. It is also important for maintaining habitat for Northern Harriers not to mow grass or all shrubs directly to the ground. A mowing at a height of 0.5 m promotes quick vegetation recovery in some locations that are necessary to allow some shrub habitat for Northern Harrier nesting.

Research

Dudley and Lajtha (1993) examined effects of burning at Katama Plains on soil nutrients and vegetation biomass. Results showed that available nitrogen increased immediately following a spring burn, but subsequently declined during the few years following a burn until the available nitrogen was lower than pre-burn conditions (Fig. 3). Further, above-ground shrub biomass was reduced after fire. Burning also decreased graminoid biomass compared with an unburned control area (Dudley and Lajtha 1993).

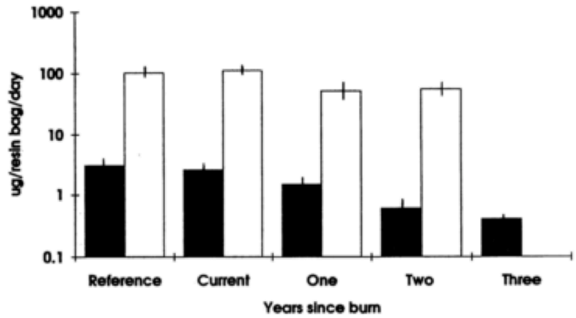

Figure 3. Available nitrogen in plots over in time since controlled burn. Black bar is average resin-bound nitrate and open bar is ammonium (Dudley and Lajtha 1993).

Wheeler (2015) analyzed species composition and cover data at Katama Plains. In this study, vegetation was monitored in 1 m^2 plots in burn Unit F (Unit 3) and Unit G (Unit 1) from 1999 to 2014. Vegetation was monitored in 1999 or 2000, 2003 to 2008 and 2014. Burning occurred in the spring in 1989, 1994, 2000, 2005, and 2009 in unit F and in 1988, 1992, 1999, 2002, 2006, and 2010 in Unit G. Wheeler found that vegetation diversity did not change significantly over this time period in response to burning management. Total cover of all species increased slightly during the entire period. Further, forb cover increased slightly in the year following a burn, and shrub cover has increased over time. Thus, the burning treatments in this study have not stopped shrub growth. Shrub cover may be slightly reduced in the first year following a burn, but increasing burn frequency by one to two years would likely be impractical because of low fuel availability and potentially logistical constraints (Wheeler 2015). At Katama, the burning and mowing regime keeps the vegetation at a fairly steady state by reducing shrub growth, but a continuous application of fire in combination with other management techniques would likely be necessary to reduce existing shrub cover.

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III.C. Grazing in Existing Grassland

Introduction

Grazing can be used to maintain disturbance-adapted sandplain grasslands by manipulating ecological succession. The principal goals of management with grazing are to reduce woody vegetation cover, create conditions that maintain plant and animal species that rely on grassland habitat, alter soil conditions, and reduce fuels and fire risk.

Grazing in sandplain grasslands typically aims to promote a diverse assemblage of target grassland species with a high proportion of warm-season grasses and native forbs, a low proportion of cool season grasses and non-native invasive species, while reducing the growth of woody shrubs (Fig. 1). Grazing is used in grassland management to affect vegetation composition and structure by top-killing vegetation. Grazing can also maintain low fuel loads that reduce fire hazards by consumption and expose mineral soils and maintain microclimates by compaction that fosters germination and regeneration of disturbance-dependent grassland species.

Figure 1. Sheep grazing shrubs at Squam Farm, Nantucket. Credit: Gregory Stroud.

The consequences of grazing on sandplain grassland vegetation largely depend on pre-treatment vegetation and grazing variables such as type of animal, seasonality, and grazing intensity, which can influence the effectiveness of grazing, as well as palatability of pre-treatment species. Grazing is equipment-intensive, complicated, costly and requires the availability of staff that are knowledgeable about grazing, ecology and overall management goals. These factors influence the effectiveness of grazing for maintaining sandplain grasslands. Management experience with grazing and carefully planned experimental grazing treatments during the last several decades provide information on grazing effects in sandplain grasslands. Management of sandplain grasslands using grazing can be complex and is influenced by conditions that change on a short-term basis, even where the effects of grazing are tested in planned experiments.

In this document, we evaluate the effects of grazing in sandplain grasslands compiled from published and unpublished studies and information obtained from interviews with land managers. We focused on the following main questions relevant for sandplain grassland management:

1) Does grazing limit woody growth?

2) Does grazing maintain or increase grassland associated plant and animal species diversity?

3) Under which conditions is grazing more or less effective at reducing woody species cover?

4) How can the effectiveness of grazing be improved as a management tool to maintain sandplain grasslands?

We focus on interpreting the main patterns that emerge from examining multiple experiences across multiple sites, with the understanding that responses in any one grazing treatment under particular conditions may differ.

These studies represent only a portion of possible treatments and variables that could be tested. It is challenging to design and execute well-controlled studies to determine the impacts of management techniques on sandplain grassland when considering the combinations of individualistic species responses, treatments, short and long-term effects, and the number of replicates needed for sound investigations (Dunwiddie 1990).

Methods

We reviewed 75 sources that described or documented results of management actions in sandplain grassland. Of these, eight sources contained information on grazing and two detailed a specific management experiments or case studies (Fig. 2). In addition, we interviewed 3 professionals in the region about their experiences with grazing in sandplain grasslands. Literature sources that tested active management treatments were classified by whether they: (1) reduced regrowth of woody vegetation and (2) increased biodiversity of plants or animals, or both (Fig. 2).

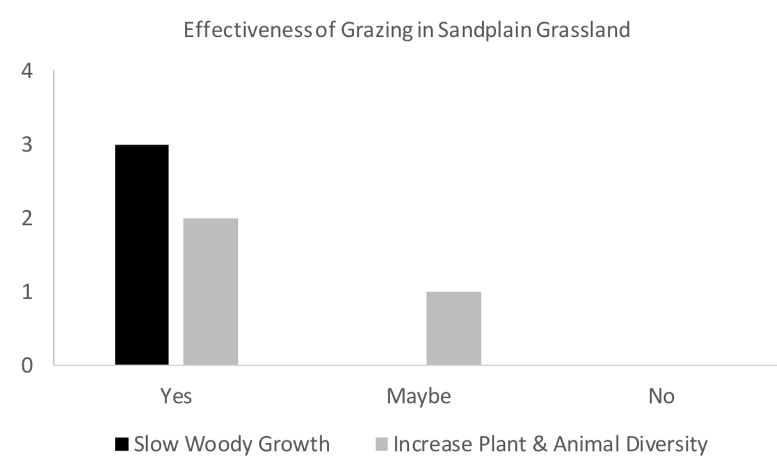

Figure 2. Number of sources that found prescribed fire in sandplain grassland reduced woody shrub and tree regrowth.

We used this review and interviews to summarize the state of current management understanding grazing combinations in sandplain grasslands and the effects of grazing on: (1) soils and fuels, (2) vegetation composition, (3) vegetation structure, and (4) fauna in relation to important grazing variables. We then suggest ways that the use of grazing could be improved to decrease woody cover, increase graminoid cover, and maintain and promote biodiversity in sandplain grassland.

Results

Overall, the majority of sources found that grazing reduced the regrowth of woody vegetation and increased biodiversity in some manner (Fig. 2). However, no study found that grazing alone was completely effective over the long term in reducing woody regrowth or increasing biodiversity. Rather, our review found that pairing grazing with other management practices will be needed to control woody regrowth and maintain sandplain grassland biodiversity over the long term.

Grazing regime

Grazing regime is the most influential grazing-related factor that influences the outcome of prescribed grazing in sandplain grasslands and calibration to current and antecedent site-specific conditions is essential to reach desired management outcomes. Targeted grazing is defined as "the application of a specific kind of livestock at a determined season, duration, and intensity to accomplish defined vegetation or landscape goals" (Launchbaugh and Walker 2006). In sandplain grasslands, type of animal (goat, sheep, or cattle), season, and grazing intensity are important variables that influence the outcome of grazing in sandplain grasslands, and are largely depend on pre-treatment vegetation.

Effects on Soils and Fuels

Livestock are capable of modifying plant biomass, structure, and floral composition by removing vegetation through consumption and disturbing soil and ground cover with their movement patterns. These actions can create bare ground that facilitates colonization of grass and forb vegetation through seed germination (Bullock et al. 1994, 1995; Silvertown et al. 1988). Therefore, while grazers may consume grass biomass in the short term (Fig. 2), they may create soil conditions that promote grass survival and reproduction over the long term.

Figure 2. Cattle enclosure experiment on Naushon Island testing stocking rates of cattle. Credit: Lena Champlin.

Effects of grazing variables

Animal type largely determines the effects to sandplain grassland ecology. Large-scale historic livestock grazing in New England was primarily done by sheep.

Sheep are intermediate feeders capable of both grazing on herbaceous vegetation and browsing on woody vegetation. In contrast, cattle are grazers that predominantly consume grass, while goats are browsers that feed predominantly on the branches and leaves of woody plants (Burritt and Frost 2006). C. Neill (Interview) studied the effects of cattle grazing on grassland, edge, and shrub habitats and found that cattle did not decrease shrub and tree cover. Therefore, the choice of livestock suitable for ecological management should be based on pre-treatment vegetation at the site (Table 1).

Table 1. Choice of livestock based on pre-treatment vegetation.

Pre-Existing Vegetation	**Type of Animal**
Woody vegetation (shrubs and vines)	Goat
Mix of woody and herbaceous species	Sheep
High proportion of graminoids	Cattle
Mix of shrubs, graminoids and forbs	Combination treatments

Sheep and cows can be effectively contained using a solar-powered fence system with fiberglass posts supporting several strands of electrified wire, which is cost effective and easily deployed. In contrast, goats are jumpers and can be aggressive and territorial, making them difficult to contain. Goats typically require tightly woven electric net fencing, which is significantly more expensive than electric wire fencing systems (Kott et al. 2006). Pre-treatment vegetation, overall goals, and cost are important factors for deciding which animal to use in any potential management.

Seasonality also impacts the effects grazing could have on sandplain grasslands. Seasonality influences the amount of time, care and cost needed to maintain livestock. Because of relatively short growing seasons in the northeast U.S., grazing cannot typically be sustained without supplemental feed. Therefore, animals must be overwintered and fed grain and hay, sold at the end of each season, or transported for winter. Hendrickson and Olson (2006) suggest that grazing effectiveness relies on target plant species phenology. To reach maximum success in reducing woody growth, grazing should coincide with the period between bud and flower to increase stress on target plant species. Because most plants (including woody plants) are typically most palatable during leaf-out stage, animals that might otherwise avoid these species can be encouraged to graze on them during spring (Kott et al. 2006). Increasing concentrations of toxic secondary compounds, such as tannins in oaks (Quercus spp.) that increase with age, contribute to a decline in palatability (Makkar et al. 1991, Makkar 2003). Timing grazing to the time of maximum palatability when grazing can have the greatest grassland-promoting benefits is a management challenge.

Winter season grazing is a potential option at grassland management sites where multiple target species could be negatively affected by growing season treatments. Experimentation with this type of management is currently under consideration for property owned by The Trustees of Reservations on Martha's Vineyard, MA (R. Hopping, Interview). During dormant seasons, forb species are dormant while apical meristems of graminoid species are at or below the soil surface and less likely to be grazed. In contrast, the axillary and apical buds and stems of shrubs are exposed and vulnerable to grazing (Hendrickson and Olson 2006). However, one issue that needs to be carefully considered for winter grazing is the need for supplemental feed and the origin of any supplemental feed. Grain and hay can be sources of seeds of non-native invasive pasture weeds that could potentially do more harm than good. Therefore, to reach optimal results, it is recommended to introduce livestock immediately after spring leaf-out or soon after re-sprouting occurs in response to grazing or other treatment (R. Hopping, Interview).

The intensity of grazing is also important to consider, and depends on the size of treatment area, the number of animals per unit area (stocking rate), daily and seasonal weather patterns, and pre-treatment vegetation composition. Historic grazing patterns were likely very different than what can be replicated today in a managed setting because of the difficulty in providing large, continuous free-range areas without introduced predators like coyotes and dogs. Today, fencing is required to keep predators out, and livestock are confined to treatment areas (Fig. 3). Stocking rates, livestock residency period (rotation), and treatment area should be calibrated to balance degradation of grasslands by overgrazing with aims to reduce the dominance of a small number of species. For example, increased grazing intensity due to trampling and consumption could result in bare ground conditions that open niches for native forbs or graminoids. However, there is a threshold at which intensity reaches a point when the area and condition of bare ground stops being beneficial to disturbance-dependent target species, and even might favor non-native invasive species or cause erosion.

Figure 3. Naushon cattle selectively graze in a mosaic of grass and shrub landscape. Credit: Lena Champlin.

Today, sandplain grasslands are the result of many decades of intense grazing and other disturbances, followed by a long release period. To mimic a historic grazing regime, one option could be to graze a small flock long-term within a large area, resulting in less intense grazing pressure as animals can graze across a large area and select preferred forage. Therefore, they are less likely to deplete most of the available vegetation. Though, at the same time, grazing in this manner may not be effective at removing less palatable species such as woody shrubs. As a result, this type of grazing may be more suitable for grassland maintenance rather than restoration. Low intensity grazing can result in a mosaic of grazed and un-grazed vegetation that is beneficial to the persistence of rare plants and insects. It also requires less set-up, management and staff time.

Effects on vegetation

Little information on key aspects of life history exists for many of the infrequent species target for sandplain grassland conservation. There is almost no information on how many of these species respond to grazing. Some evidence suggests that a legacy of historic grazing could promote long-term grass and forb target species following a release from grazing. Dunwiddie (1997) studied patterns in land-use history of historically grazed pasture on Nantucket and found a high abundance of graminoid and target forb cover compared to adjacent ungrazed land. Ungrazed plots contained a high cover or frequency of non-target species such as small bayberry (*Morella caroliniensis*), while grazed plots included little bluestem (*Schizachyrium scoparium*), sweet-fern (*Comptonia peregrina*), and the rare forb, bushy frostweed (*Crocanthemum dumosum*). These findings indicated that historic grazing benefited some infrequent sandplain grassland species.

Further, evidence suggests grazing could negatively affect sandplain grassland vegetation in the short-term (Fig. 4) and that such a release from grazing over some period of time can be favorable. On Naushon Island, C. Neill (Interview), studied the response of vegetation to cattle grazing and found that native graminoid and forb cover decreased in the short term. Forbes (2011) also found that graminoid and forb cover decreased following grazing, but no long-term monitoring data exists on trends during subsequent post-treatment recovery growing seasons.

Figure 4. Grassland vegetation plot before (left) and after (right) after one week of high intensive cattle grazing. Credit: Lena Champlin.

When using sheep or cattle, the timing of grazing treatments in an existing grassland is important because both desirable and undesirable plant species can be equally targeted by grazers. Early season grazing would have minimal effects on late-season maturing target species such as northern blazing-star (*Liatris novae-angliae*) and little bluestem grass. The reverse would be true for desirable early season bloomers such as sandplain blue-eyed grass (*Sisyrinchium fuscatum*) and bushy frostweed. Similarly, management can be timed to maximize negative impacts to undesirable non-native invasive species such as velvet-grass (*Holcus lanatus*) and cypress-spurge (*Euphorbia cyparissias*) by grazing just prior to flowering and seed set. Therefore, it is important to thoroughly inventory the management area prior to treatment to identify potential forage and make decisions about the timing and effect of graze treatments on both desirable and undesirable target species.

A concern about grazing management is that intensive grazing may eradicate existing rare native plants. For example, lion's-foot rattlesnake-root (*Nabalus serpentarius*) is highly selected by deer (Patterson III et al. 2005) and is therefore likely to be selectively grazed by livestock. But studies have shown that other rare plant species persist despite grazing, and that undesirable consequences could be mitigated by understanding and applying grazing variables correctly. Dunwiddie et al. (1986) found that grazing had no negative effects on desirable plants and no introduction of non-native species. Karberg and Beattie (2009) found healthy populations of rare plant species after years of grazing, including St. Andrew's cross (*Hypericum stragulum)*, bushy frostweed, and purple needle-grass (*Aristida purpurescens)*. Further, several species of rare plants now absent from Nantucket were common on the island in the early 1900s, including purple cudweed (*Gamochaeta purpurea*) and sandplain gerardia (*Agalinis acuta*). This timeframe is concurrent with the cessation of historic sheep grazing, indicating that some rare species thrived in release periods after large-scale grazing occurred (P. Dunwiddie, Interview). Modern vegetation studies show that rare plants that are not preferentially grazed thrive under grazing management, and non-native invasive plants can be targeted (Fig. 5). Needle-grass indirectly benefitted from grazing because it is likely unpalatable to sheep on Martha's Vineyard, MA (Patterson III et al. 2005). Sandplain flax (*Linum intercursum*) may also be unpalatable to grazing animals, as all members of the genus are known to produce toxic or acidic compounds (Zaremba 2003; Patterson et al. 2005). Therefore, grazing impacts each rare plant species differently but many of the rare sandplain plants likely survived and thrived after high intensity historic livestock grazing.

Figure 5. Goats are brought over by boat to Sheriff's Meadow's Cedar Tree Neck Sanctuary to eat invasive bittersweet and poison ivy, because a tractor mower cannot be used. Credit: Alison Meed.

There is some evidence that combinations of grazing and other management practices could reach desired goals. The Nantucket Conservation Foundation conducted four seasons of sheep grazing and mowing management research at Squam Farm on Nantucket starting in 2005 and found that grazing combined with mowing significantly reduced the growth of woody species. Forbes (2011) compared mowing with grazing on Naushon Island, MA and found that grazing had a significantly greater impact than mowing on reducing woody growth and varied cover with gaps and increased areas of bare soil. Dunwiddie et al. (1986) found that in heathland habitat overgrown by scrub oak (*Quercus ilicifolia*) and dwarf chinkapin oak (*Q. prinoides*) treated with brush-cutting prior to grazing, all species (both desirable and undesirable) showed a four- to six-fold decrease in cover, indicating possible over-stocking of sheep. Brush cutting alone appeared to be more effective at increasing desirable heath species and was almost as effective at reducing oak species as brush-cutting combined with grazing. These results were based on only one growing season.

Applying grazing during particular times of stress (e.g., droughts or outbreaks of herbivorous insects) could increase the effects of grazing and reduce the frequency of grazing required to obtain similar vegetation responses. However, being able to take advantage of these events by having animals available in particular places will likely be challenging.

Effects on fauna

The effects of grazing on the response of fauna are understudied and the short- and long-term impacts to target species in sandplain grasslands need further research. Most of the information available on how grazing affects rare sandplain grassland associated fauna is anecdotal and theoretical, as there have been no detailed studies focusing on fauna in this region. Concerns for wildlife include physical crushing or exclusion by the presence of large grazing livestock. This type of disturbance is likely less of a concern in grazing management than disruptive burning and mowing treatments. For example, nesting birds may not be negatively impacted by the presence of grazing livestock during the growing season, and might actually benefit in some ways (Fig. 6). At Squam Farm on Nantucket, the Nantucket Conservation Foundation observed several spotted turtles (*Clemmys guttata*)—including one that was radio-tracked—traversing areas actively grazed by sheep with no observable negative impacts. Another concern about introducing livestock to grassland habitats is the potential impacts on animal communities throughout the food web and their interactions. Mesopredators might increase in the presence of livestock, which would detrimentally impact small mammals and birds, although evidence for this comes from outside the northeast U.S. (Coates et al. 2016). Effects of grazing on fauna are understudied, and should be the focus of future research.

Figure 6. Bird nest made with sheep wool, near Naushon Island farmhouse and small modern sheep herd. Credit: Lena Champlin.

Logistical and Practical Constraints on the Use of Grazing

Based on ten years of targeted sheep grazing experience at Squam Farm on Nantucket, the Nantucket Conservation Foundation concluded that managing live animals in a humane and sustainable manner is equipment-intensive, complicated, costly and requires the constant availability of staff. Maintaining a year-round core breeding flock is an integral part of a targeted grazing program. During the winter, it is necessary to provide high-quality hay and grain supplement to optimize breeding and nutrition, maintain sheep in permanent fencing capable of withstanding snow, and have the capacity to provide water during below-freezing conditions. Hay purchased for livestock grazing typically contains a mixture of native and non-native (often invasive) species seed that can add undesirable consequences to sandplain grassland. Annual vaccinations for rabies, intestinal parasites, and others are costly but necessary to maintain flock health. The availability of highly trained staff with the interdisciplinary skills necessary to oversee both sheep flock health and land management goals is one of the most important elements of a targeted grazing program and the highest financial cost.

Expanding grazing on existing new, local, commercial, or non-profit farms has been suggested as a way to increase regional food production (Donahue et al. 2014). While most of this grazing would presumably occur on managed agricultural grasslands that do not have the typical flora of sandplain grasslands, there could be potential to incorporate some animal use on existing sandplain grasslands, or to use grazing animals in efforts to either expand sandplain grasslands from woodlands or to transition agricultural grasslands to sandplain grasslands. Partnership farms would reduce the responsibility of land management organizations for animal husbandry, and potentially costs. However, any use of animals on existing high-quality sandplain grasslands would require further study to examine potential effects on target species and require carefully-constructed management plans to ensure that conservation management rather than food production remains the primary objective on these lands.

Summary and Pathways to More Effective Management

The effects of grazing on vegetation composition in sandplain grasslands and effects of grazing variables have been studied in field management experiments. The types of animals, seasonality, and grazing intensity are the most important variables that control the outcome of grazing management. Goats are recommended to control woody vegetation, sheep for a mix of woody growth and forbs, and cattle if there is a high proportion of graminoids. Evidence suggests that grazing could have long-term positive effects to maintain sandplain grasslands, but a release period seems to be important over some interval. Logistical and practical constraints are high for this practice. Ultimately, there has been little work on the effects of grazing in sandplain grasslands. Future research should incorporate different animal, seasonality and grazing intensity treatments into experiments and examine grazing in combination with other management practices. A major challenge for the use of grazing for long-term management of sandplain grasslands is the ability to apply it effectively given the complexity of logistical constraints.

This review identified several major ways to improve understanding and potential benefits of the use of grazing for sandplain grassland management.

(1) Test combinations of grazing with other management techniques. They should be designed and monitored as field experiments. Treatments should be designed in sites with well-understood land-use histories to factor in pre-existing conditions;

(2) Improve understanding of how infrequent or rare plants respond to different grazing treatments. These rarer plants are some of the major targets for sandplain grassland management and often have life histories that differ from closely-related but more common species. There is currently almost no information on how these species respond to grazing and the effects of seasonality, grazing intensity or type of animal.

(3) More work is needed to determine how grazing affects population dynamics of fauna in sandplain grassland. These effects may be particularly important for less common and conservation target species that have small and dispersed populations. It is also important for higher-profile species such as birds and for more common species such as some invertebrates.

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Case Study: Grazing at Squam Farm

Site Description

Squam Farm is a 34-hectare (85-acre) property owned by Nantucket Conservation Foundation (NCF), located on the glacial moraine in the northeastern section of Nantucket. Squam Farm provided an ideal location for a long-term sheep grazing project because it had regulated vehicle access, an accessible water source, and an NCF staff member living on-site year-round.

Figure 1. Squam Farm sheep grazing experiment. Photo Credit: Nantucket Conservation Foundation.

The cessation of agriculture in the 1800s initiated ecological succession on Squam Farm. Today, the property contains a high level of habitat heterogeneity, including coastal shrubland, managed grassland, deciduous hardwood swamp, mixed deciduous forest, and shrub swamp. Prior to NCF purchasing the land, some upland areas were mowed and grazed with heritage breed livestock during the 1980s and 1990s. As a result, some areas remain open and contain a diverse mixture of graminoids, forbs, vines, and shrubs. After purchasing the land, NCF mowed annually to maintain grassland habitat in these areas.

Prior to this sheep grazing project, vegetation communities contained an assemblage of native sandplain grassland-associated species including little bluestem (*Schizachyrium scoparium*), Pennsylvania sedge (*Carex pensylvanica*) and poverty-grass (*Danthonia spicata*), as well as non-native, cool-season grasses such as velvet-grass (*Holcus lanatus*), sweet vernalgrass (*Anthoxanthum odoratum*), and sheep-fescue (*Festuca ovina*). Common forbs included grass-leaf flat-topped goldenrod (*Euthamia graminifolia*), common St. Johns-wort (*Hypericum perforatum*), oxeye-daisy (*Leucanthemum vulgare*), common sheep sorrel (*Rumex acetosella*) and dwarf cinquefoil (*Potentilla canadensis*). These grasslands were interspersed with both native and non-native shrub and vines, including scrub oak (*Quercus ilicifolia*), small bayberry (*Morella caroliniensis*), black cherry (*Prunus serotina*), winged sumac (*Rhus copallinum*), Japanese honeysuckle (*Lonicera japonica*), fox-grape (*Vitis labrusca*) and poison-ivy (*Toxicodendron radicans*). Further, high population densities of turtles and snakes were observed in upland areas on the property, including rare spotted turtle (*Clemmys guttata*). Thus, sheep grazing was initiated at this site as an alternative to mowing during the growing season because of potentially less impact on wildlife.

Management Goals

1) Maintain open grassland structure;
2) Increase sandplain grassland target species;
3) Reduce woody shrub and vine cover;
4) Reduce non-native invasive species cover;
5) Minimize negative impacts to key wildlife species;
6) Test the feasibility of implementing a long-term grazing program.

History of Management

Targeted grazing management occurred at Squam Farm from 2005 to 2015 on approximately 31 hectares (75 acres) of previously-mowed uplands on the property. A targeted research project (Schlimme 2006) occurred within a 0.69 hectareha (1.7 acre) area in 2005 to 2008. At this time, grazing was the primary management tool.

During a ten-year period, a variety of sheep breeds were managed year-round at Squam Farm. During the winter, sheep were kept in permanent fenced pastures in the southern section of the property and fed both grain and purchased or locally-grown hay. Selected ewes were bred in the late fall to produce lambs in mid-April. The initial sheep flock consisted of Cotswold, Romney, and Romney/Cotswold crossbreeds and was supplemented in 2010 with 15 North Country Cheviot/Scottish Blackface crossbreeds.

Uplands formerly maintained by annual mowing received repeated grazing each year, beginning in early spring (as soon as green-up occurred) and continuing until the first killing frost of late fall. Anecdotal observations and photo monitoring conducted in these areas showed a marked decrease in woody species and a corresponding increase in graminoids over time with this management. In addition to these managed grassland sites, areas containing dense shrubland habitat with non-native, invasive woody species such as Japanese honeysuckle, autumn-olive (*Elaeagnus umbellata)*, privet (*Ligustrum* spp.), oriental bittersweet (*Celastrus orbiculatus*) and Amur peppervine (*Ampelopsis glandulosa*) were also intensely grazed. This treatment was effective at removing the dense shrub understory and facilitating access for follow-up invasive species management.

Grazing at Squam Farm was discontinued in 2015 primarily because of lack of funding, and because of difficulties in maintaining animals year-round.

Research

A research project took place within a 0.69 ha (1.7 acre) section of the North Pastures section of Squam Farm from 2005 to 2008. The experiment examined the effects of repeated grazing and mowing on early successional vegetation composition over a four-year period (3 years of treatment and 1 year of recovery), and compared that treatment to unmanaged control areas (Beattie et al. 2017, Schlimme 2006).

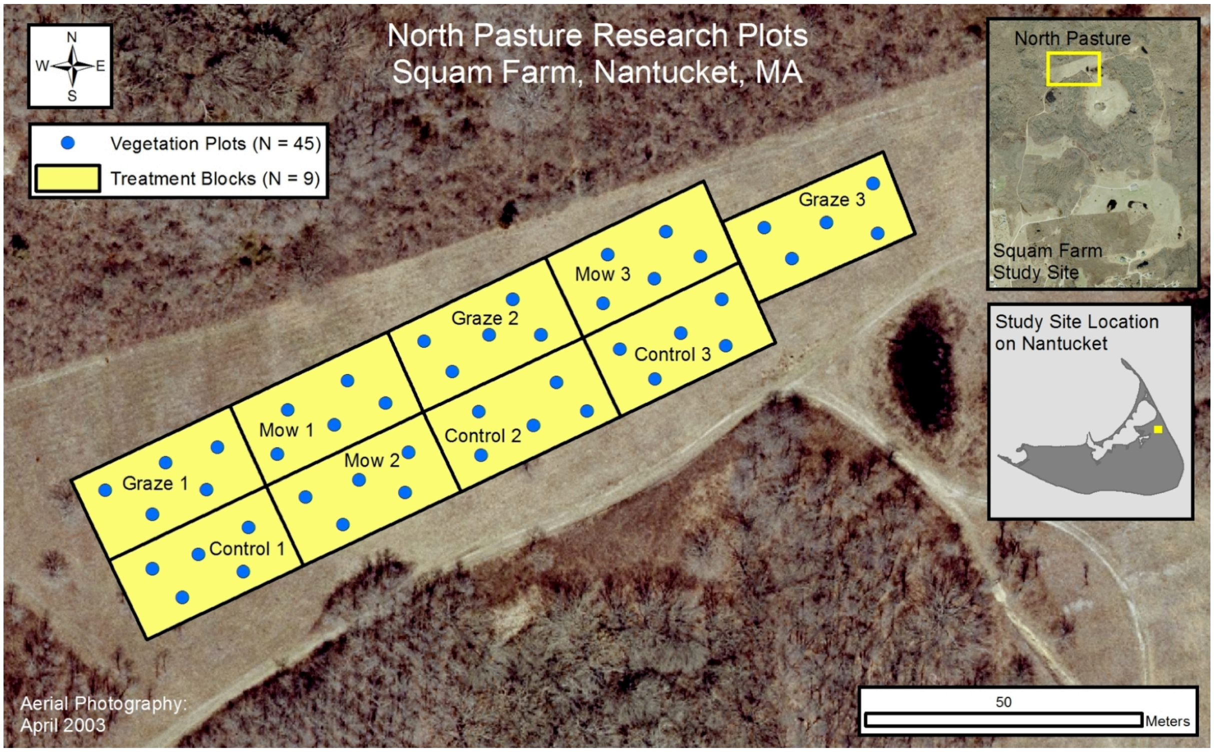

Figure 2. Experimental design of the research pasture at Squam Farm.

The North Pasture research area was divided into nine research blocks (each 33 m x 21 m) and included 3 Graze, 3 Mow and 3 Control treatments (the Control provided an example of currently unmanaged vegetation as influenced by previous management). Vegetation community composition was sampled within 45 permanently marked $1m^2$ research plots (5 plots per research block; 15 plots per treatment type) using a 1 m^2 inclined point quadrat sampling frame. Sheep used for the project included 28 adult Cotswold sheep during the first (2005) season and a mixed, reduced sized flock of Cotswolds and Romneys during 2006 and 2007.

During each Graze treatment, the sheep remained within the first research block until they had consumed almost all available forage, then were moved to the second and third blocks and allowed to graze for the same period of time. The Mow treatment was performed within 1 to 2 days from when the sheep were removed from the Graze treatment blocks. The number (2 or 3) and timing (month) of treatments varied between each treatment year because of variations in vegetation response. No treatments were conducted during 2008 but post-project vegetation monitoring was done.

Vegetation composition was classified by functional group (graminoid, forb, woody species), and ground cover (bare ground, litter), and quantified using cover classes. Prior to treatments, no significant difference was observed between cover of functional groups and ground cover, allowing comparison of functional groups between treatment blocks.

After three consecutive years of treatment, shifts in functional group and ground cover dominance were evident in the initial year of recovery (2008) in both graze and Mow treatments compared with the control treatment and with pre-treatment. Graze and mow treatments significantly reduced cover of woody species. The Mow treatment showed significantly greater reduction in woody species compared with the Graze treatment. Graminoid occurrence was significantly greater in the Graze and Mow treatments compared with the Control, although only the mow treatment was significantly higher as compared with pre-treatment.

Overall forb species decreased in both the Graze and Mow treatments, although there was no significance between the treatments or pre-treatment forb occurrence.

Both Graze and Mow treatments significantly increased the presence of bare ground in the sampled plots, as compared to the Control and pre-treatment sampling. In the Graze treatment, bare ground was significantly higher at the end of the study compared with the mow treatment. Treatments had little impact on the occurrence of litter, although the Graze treatment showed a non-significant trend of decreased litter.

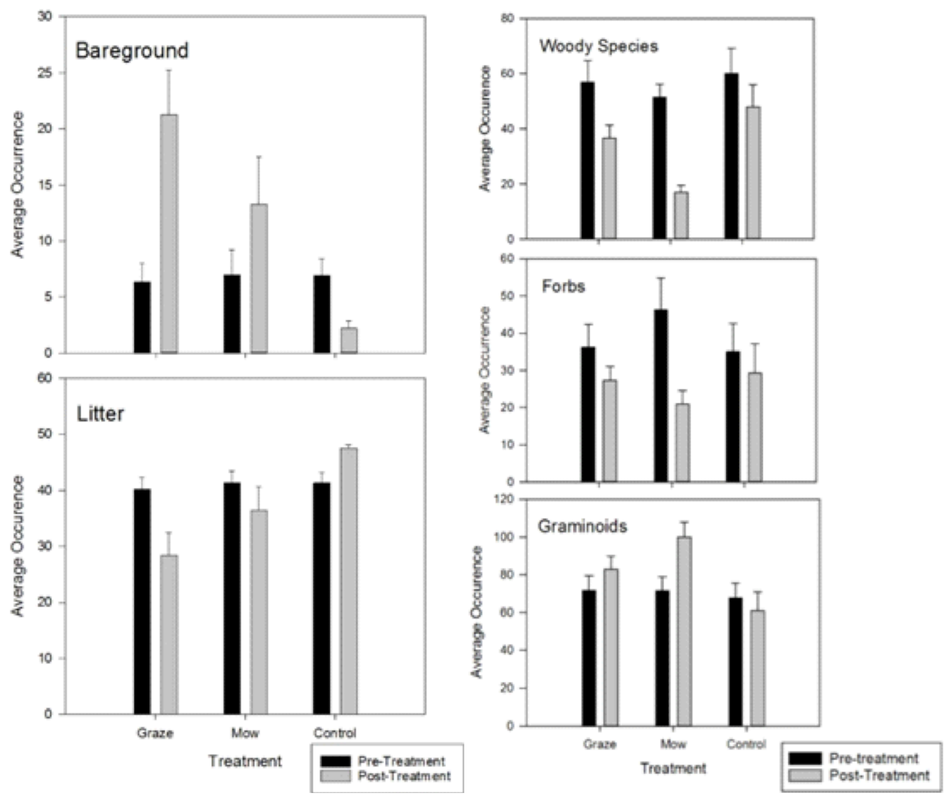

Figure 3. Pre- and post-treatment results of ground cover and cover of vegetation by functional group.

Individual species of management interest (including three sandplain grassland-indicative species, three weedy/agricultural species, and two woody species) were analyzed separately for trends in response to treatment. Significant changes in three of the eight species were detected after three consecutive years of management. Grassleaf flat-topped goldenrod (*Euthamia graminifolia*), a sandplain grassland-indicative species, decreased significantly in both the Mow and Graze treatments compared with the control and pre-treatment. The occurrence of sweet vernalgrass, a non-native pasture grass—significantly increased in the Mow treatment compared with both the Graze and Control treatments. Velvet-grass (a non-native, invasive grass) occurrence significantly increased in both the mow and graze treatments compared to the control and pretreatment. The other species examined were ox-eye daisy (*Leucanthemum vulgare*), Pennsylvania sedge (*Carex pensylvanica*), little bluestem (*Schizachyrium scoparium*), scrub-oak (*Quercus ilicifolia*), and Japanese honeysuckle (Lonicera japonica), and all showed no significant changes between treatments.

Three consecutive years of sheep grazing or mowing treatments significantly decreased the woody species and increased graminoid species. Grazing alone significantly increased patches of bare ground within the landscape, providing areas for seed germination and species recruitment in the grasslands.

Although mowing and grazing had similar effects on reducing woody species occurrence and increasing graminoid cover, the ecological impacts of each treatment varied. Mowing reduced all vegetation to a uniform height, including new leaf and shoot growth as well as older woody stems. In contrast, grazing was selective and sheep tended to prefer newer growth and prune the younger foliage and stems. In this study, the Graze treatment created a patchy mosaic effect, and the amount of time spent in each grazing treatment block influenced the efficiency of treatment.

Ultimately, disturbance by both grazing and mowing treatments increased weedy species in the treatment area. Mowing increasing sweet vernal grass (*Anthoxanthum odoratum*) significantly more than grazing. Management treatments implemented in areas that have not been recently mowed or grazed should be monitored for the establishment and spread of these weedy species. Mowing and grazing treatments significantly reduced the occurrence of grass-leaf flat-topped goldenrod, a native perennial forb. Management resulting in a mosaic of treatment time and intensity may be more effective at maintaining the suite of native forb species.

The overall conclusions from this study and experiences at Squam Farm were that: (1) sheep grazing reduced clonal shrub and vine cover, (2) grazing also introduced seeds of weedy agricultural plant species, and that grazing alone will not likely result in habitat restoration over a relatively short period of time. Constraints of costs and the difficulty of managing animals year-round led NCF to end the sheep grazing program.

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III.D. Vegetation Removal in Existing Grasslands

Introduction

Removal of select plants or communities can be used to maintain disturbance-adapted sandplain grassland by manipulating ecological succession. The principal goals of management with vegetation removal are to reduce woody vegetation cover, create conditions that maintain plant and animal species that rely on grassland habitat, and promote recruitment and establishment of native grassland species.

Vegetation removal activities in sandplain grassland typically aim to promote a diverse assemblage of target grassland species with a high proportion of warm-season grasses and native forbs, and a low proportion of cool season grasses and nonnative invasive species through the removal of undesirable species. In existing grassland, undesirable species include nonnative and aggressive native and non-native woody plants. Vegetation removal can be mechanical such as hand-pulling, digging, cutting, select mowing, or shading (Fig. 1). It can be by chemical treatment with herbicides, or by a combination of mechanical and chemical methods. The most commonly used and effective method is direct herbicide application to undesirable species. Recent experience shows that this can be an effective, targeted tool to remove unwanted plants from existing sandplain grasslands.

Figure 1. Invasive grass removal using plastic covering at the Bamford Preserve, Martha's Vineyard. Photo: Chris Neill

In this document, we evaluate the effects of vegetation removal management techniques in sandplain grassland compiled from published and unpublished studies and information obtained from interviews with land managers. We focused on the following main questions relevant for sandplain grassland management:

1) Does vegetation removal reduce woody growth?
2) Does vegetation removal maintain or increase grassland associated plant and animal species diversity?
3) Under which conditions is vegetation removal more or less effective at reducing woody species cover?
4) How can the effectiveness of vegetation removal be improved as a management tool to maintain sandplain grassland?

We focus on interpreting the main patterns that emerge from examining multiple experiences across multiple sites, with the understanding that responses in any one vegetation removal treatment under particular conditions may differ.

Methods

We reviewed 75 sources that described or documented results of management actions in sandplain grassland. Of these, only seven sources contained information on vegetation removal and one detailed a specific management experiment. In addition, we interviewed nine professionals throughout the region about their experiences with prescribed vegetation removal in sandplain grassland (Fig. 2).

This review and interviews is used to summarize the state of current management understanding using vegetation removal in sandplain grassland and the effects of vegetation removal on: (1) vegetation composition, (2) vegetation structure, and (3) fauna in relation to different techniques. We then suggest ways that the use of vegetation removal could be improved to decrease woody cover, increase graminoid cover, and maintain and promote biodiversity in sandplain grassland.

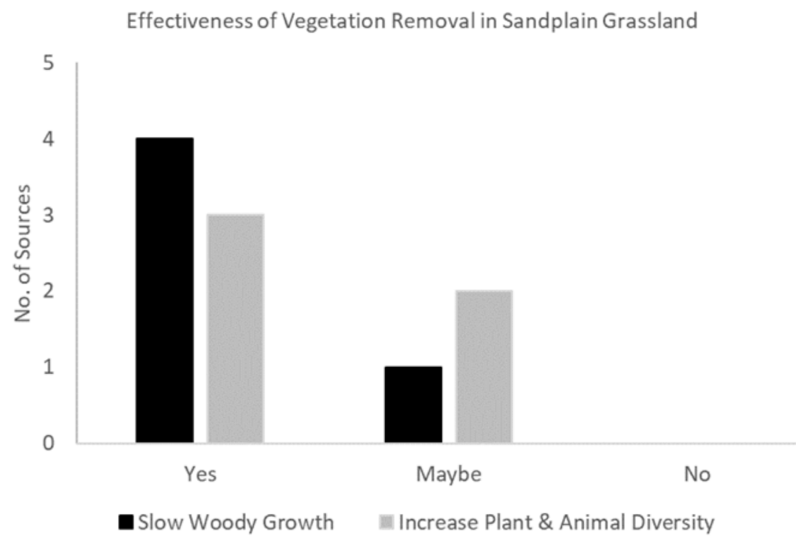

Figure 2. A small number of sources found that selective removal of vegetation in sandplain grasslands slowed growth of woody species and increased plant and animal diversity.

Results

Four sources highlight that vegetation removal can decrease woody growth and/or increase plant and animal diversity (Dunwiddie n.d., Raleigh et al. 2003, Ecological management of grasslands 2009, and Wheeler et al. 2015). More work is needed to understand vegetation removal and its effects on sandplain grasslands, especially in relation to individual responses of target species.

The primary goal of vegetation removal in sandplain grassland is to control woody species and non-native invasive vegetation growth, which can compete with desired sandplain grassland species. Vegetation removal has the ability to target specific individual plants or potentially larger patches of individual plants. Vegetation removal is intended to quickly and efficiently remove undesirable vegetation to allow desirable vegetation a chance to establish and is not considered a management technique that will be utilized long term. Vegetation removal can also be applied mechanically by hand digging or pulling of target species prior to seed set. This can be both time- and labor-intensive and often depends on the availability of staff and/or volunteers. Manual pulling can also disturb the soil and surrounding native plants (D. Vitz, Interview). Other methods of vegetation removal include mowing, flooding, grazing, smothering, and hot foam application. Mechanical methods are often used prior to the application of herbicide.

The undesirable consequences of herbicide for sandplain grassland vegetation include mistakenly killing native desirable plant species, potential negative effects on animals such as insects, and negative effects on soils. Use of herbicides faces few technical constraints that would hinder or prevent its use, but public objections to its use often arise. Temperature, wind, and improper application can cause undesirable consequences, and training is required to maximize its effectiveness. Experiences of managers with herbicide and carefully planned experimental herbicide treatments during the last several decades provide information on herbicide effects in sandplain grasslands.

Effects of seasonality and frequency

The seasonal timing and frequency of vegetation removal has been understudied, and understanding of the most effective methods for uses herbicide come mostly from the experience of managers. A benefit of using herbicide to reduce cover of woody shrubs is that only one application is often needed in the summer (C. Politan, Interview). There is also a greater interval between treatments with herbicides compared with mechanical removal, because herbicides can kill vegetation completely, rather than leaving live root systems for regrowth (J. Scanlon, Interview). For that reason, herbicide could be a very important tool for killing prolific clonal woody species that have historically been a leading challenge for managing sandplain grasslands.

Herbicide treatments are timed based on the phenology of vegetation to be controlled (Raleigh et al. 2003, D.Vitz, Interview). For locations with a variety of invasive species, treatments may occur several times throughout summer to target different plants and with different techniques (C. Politan, Interview). For example, foliar application of growth inhibitors in early spring is used to control cool-season grasses (C. Buelow, Interview). Foliar herbicide applications to kill woody invasive species can be conducted in the summer, even when prescribed burning is not possible (J. McCumber, Interview). Stump cut treatments typically occur in fall and winter for large woody species (C. Buelow, Interview.). In sandplain grasslands, herbicides are typically applied during one season to kill invasive species, followed by mowing or other practices repeated over time (J. McCumber, Interview). If herbicides are not used, the frequency and period of mowing, burning, or grazing would need to be much greater to achieve similar reductions of non-native, invasive species and woody growth (Raleigh et al. 2003).

Effects on vegetation

When applied correctly, herbicides can be very effective for removing or reducing cover of undesirable species. Woody species and large areas of invasive forbs and graminoids can often be effectively treated through the direct application of herbicides, often following mechanical treatment such as mowing (J. Karberg, Interview). Use of herbicides is a common practice used by the Massachusetts Division of Fish and Wildlife to restore and maintain grassland systems with minimal issues or public concern, and can effectively eliminate common generalist woody species that threaten sandplain grassland (C. Buelow, Interview).

Application of herbicides alone is in existing sandplain grasslands should be restricted to spot treatments of problematic species rather than widespread treatments, and should be used in conjunction with other standard grassland maintenance techniques such as mowing and prescribed fire (TTOR 2009). When used together, the total amount of herbicide applied can be reduced. In addition, while mechanical treatments may only reduce the growth of woody species, the addition of herbicide often succeeds in killing undesirable graminoids and forbs. Top-kill disturbances such as burning and mechanical cutting (Fig. 3) or mowing alone may not successful remove aggressive species such as autumn-olive (*Elaeagnus umbellata*) and honeysuckle (*Lonicera spp.*) (C. Buelow, Interview). The Nantucket Conservation Foundation removes encroaching pitch pines (a native but undesirable species in sandplain grassland) through cutting, followed by direct application of herbicide to cut stems. Black huckleberry (*Gaylussacia baccata*)—a common and prolific coastal woody species—is clonal and fire tolerant, and the addition of herbicide treatment could work to reduce shrub growth (J. McCumber, Interview) and allow establishment of early successional grassland species. Species life history characteristics are important to consider when planning vegetation removal applications.

Figure 3. Mechanical cutting of experimental plots in an agricultural grassland dominated by cool-season, European grasses at the Bamford Preserve on Martha's Vineyard. Photo Credit: Chris Neill.

In sandplain grasslands, Krenite (Fossamine ammonium) is used to reduce the growth of woody species, and for broad-spectrum glyphosate-based herbicides are used to kill non-native grasses and broadleaf plant removal. On Nantucket, Krenite was used in combination with burning to reduce scrub oaks (P. Dunwiddie, Interview). At the Bamford Preserve on Martha's Vineyard, Rodeo concentrate (0.8% glyphosate) was used to remove non-native cool-season grasses on small experimental plots (Wheeler et al. 2015).

Herbicide can often be the most practical means to effectively control non-native invasive species. Although invasive species often have a difficult time invading sandplain grasslands on very nutrient poor soils (C. Neill, Interview), J. Karberg (Interview) suggested that occurrences of spotted knapweed (*Centaurea stoebe*) and silvergrass (*Miscanthus spp.)* are increasing in some coastal areas of high quality sandplain grasslands. Early and aggressive removal of non-native grasses or invasive woody species are recommended during attempts at sandplain grassland creation especially before native grasses and forbs become well established (C. Neill, Interview). In established sandplain grasslands some cover of cool-season grasses often occurs mixed with a greater cover of warm-season grasses and does not necessarily merit as aggressive treatment. In some places, like Nantucket, non-native plants are not typically a significant problem in established sandplain grasslands (J. Karberg, Interview).

Wheeler et al. (2015) tested the efficacy of tilling, herbicide, hot foam, and plastic cover for removing initial non-native vegetation and found that herbicide, plastic cover, and repeated tilling were about equally effective in reducing non-native species cover and promoting native species cover. Tilling was intended to disturb the roots of non-native species but is not typically used in existing sandplain grassland because of its negative effects on existing desirable species.

Hand pulling and cutting can effectively treat small areas or in grasslands where the density of undesired species is very low, but they are impractical for larger grasslands and are limited in their effectiveness by the difficulty of removing the rootstocks of woody plants ad all fragments of spreading clonal plants (C. Neill, Interview).

Effects on fauna

The effects of vegetation removal on fauna have not been studied in sandplain grasslands and need further study.

Logistical and Practical Constraints on the Use of Vegetation Removal

Historically there has been concern about the use of herbicides, particularly regionally in coastal Massachusetts (J. McCumber, Interview). In the past, public opinion has limited the use of herbicides in grassland maintenance, especially to control native and non-native invasive species (P. Dunwiddie, Interview). Public concerns about chemical herbicides are focused on potential environmental impacts on non-target plants and animals.

Training and licensure is required to apply herbicide at the management level and managers with experience with herbicides in sandplain grasslands make a number of the following recommendations for safe herbicide use. While most modern herbicides are not typically toxic to non-target plants, wildlife, or humans when used appropriately (Raleigh et al. 2003, P. Dunwiddie, Interview), restrictions for specific chemicals need to be followed. For example, Krenite application should not be applied to standing water, but should be applied directly to brushy plants typically by ground sprayers. Glyphosate should not be applied near surface waters or to bare soil. Herbicides that are not problematic for groundwater or soil should be chosen for managing sandplain grassland (J. McCumber, Interview).

Impacts of herbicides to non-target species can be reduced by adjusting application methods. Broadcast spray from airplane or tractor can be useful but also raises the most concerns. For example, at Westover Air Force Base in Chicopee, Massachusetts, both aerial and boom spray techniques (Fig. 4) were used in one of the largest and most successful grassland restoration projects in the northeast. But application of herbicides by broadcast spraying has been identified by other managers as potentially most problematic because of effects on insect populations (TTOR 2009), and others suggest that selected spot treatment is safer (G. Motzkin, Interview).

One of the most localized methods for herbicide application is mechanical cutting and painting of herbicide on stems. In addition, foliar spray can be applied with equipment that sprays individual plants (Drew Vitz, Interview). Such targeted application methods reduce the impacts of herbicide on other plants or animals (J. McCumber, Interview). The weather conditions when herbicides are applied should be carefully considered (Raleigh et al. 2003).

Figure 4. An example boom-broadcast of herbicide for conversion from agricultural lands to exclude perennial grasses. Credit: Paul Rothbart, Connecticut Department of Environmental Protection.

Although removing vegetation during particular times of stress such as during droughts or outbreaks of herbivorous insects could increase its effectiveness and reduce the frequency of management required to obtain similar vegetation responses, being able to take advantage of these events in particular places will likely be challenging.

Hand pulling and cutting are typically limited by a combination of the large amount of labor required to treat large areas, the ineffectiveness of hand removal in completely removing plants and rootstocks, and the frequency with which hand treatments need to be repeated.

Summary and Pathways to More Effective Management

Experience of sandplain grassland mangers shows that applications of herbicides have been effective to reduce non-native invasive species and increase diversity and cover of native target species in sandplain grasslands.

Research on the effects of herbicides on vegetation, fauna, and soils in sandplain grasslands is nearly non-existent. Although herbicide and other vegetation removal techniques are commonly used there has been no research related to the specific response of target species in relation to specific herbicides, timing and frequency of application or combinations of mechanical and chemical application. In addition, no research has examined effects on non-target sandplain grassland plant species, fauna, or soils.

This review identified several major ways to improve understanding and the potential benefits of the use of vegetation removal for sandplain grassland management.

(1) Test combinations of use of herbicides in combination with other practices to control woody vegetation and non-native invasive species. Tests should be designed and monitored as field experiments, and ideally applied in sub-plots that receive other forms of management within larger areas that receive regular prescribed fire, mowing, and/or grazing.

(2) Improve understanding of how infrequent or rare plants respond to different vegetation removal combinations. These rarer plants are some of the major targets for sandplain grassland management and often have life history characteristics that differ from closely-related but more common species, and could be sensitive to timing, frequency and chemical differences of herbicide treatments. There is currently almost no information on how these species respond to vegetation removal and the effects of these treatments to non-target species.

(3) More work is needed to determine how prescribed vegetation removal affects the mortality and population dynamics of fauna in sandplain grassland. These effects may be particularly important for less common and conservation target species that have small and dispersed populations. It is also important for uncommon species of grassland birds and for more common species such as some invertebrates that are important prey species.

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Case Study: Vegetation Removal at Hempstead Plains

Site Description

Hempstead Plains is the most iconic and historic grassland of the northeast (Edinger et al 2014). A total of 24 fragmented acres (10 hectares) is all that remains of the larger grassland area that once covered about 40,000 acres in Nassau County, New York (Edinger and Young 2018). The largest continuous extant area of Hempstead Plains consists of 19 acres (8 hectares) and is located on the campus of Nassau Community College (formally Mitchel Field Air Force Base) and is managed by the Friends of Hempstead Plains at Nassau Community College (Fig. 2). This non-profit organization was established in 2001 to preserve and restore the Hempstead Plains and offer educational programs at this unique area (Gulotta 2005).

Figure 1. Hempstead Plains during the growing season. Photo: Friends of Hempstead Plains.

Figure 2. Extent of the Hempstead Plains with soils. Map credit: Carole Ryder.

In 1909, the Hempstead Plains remained largely unplowed and had a grassland community composition with a large proportion of native plants (Harper 1912). At that time, the four most abundant tree species, gray birch (*Betula populifolia*), blackjack oak (*Quercus marilandica*), post oak (*Quercus stellata*), and pitch pine (*Pinus rigida*), were stunted and scattered sparsely throughout the barren landscape (Harper 1912). In addition, a dozen shrub species, sixty herb species, and a few moss, lichen and fungi species were recorded at the time (Harper 1912). Common shrubs including scrub oak (*Quercus ilicifolia*) and dwarf chinquapin oak (*Quercus prinoides*) that grew roughly at knee height. Little bluestem (*Schizachyrium scoparium*) was the most common grass.

Figure 3. Hempstead Plains in 1902. Photo in Harper (1912).

However, over time, floristic inventories document the encroachment of non-native species into the Hempstead Plains. In 1987, Lamont and Stalter observed 171 species of which 62 percent were native, while a subsequent survey in 2004 by Eric Lamont documented 185 species with only 54 percent being native (B. Gulotta, Interview). This indicates that the higher numbers of species documented in the Plains are attributed to non-native encroachment. A 2017 complete community plant survey of the Hempstead Plains, including the Purcell parcel south of the highway, conducted by New York Natural Heritage Program identified that the plains now support an estimated 294 plant species (Edinger and Young 2018). An alarming trend of invasive species encroachment was further identified by a comparison of the 1999 and 2017 community surveys, which revealed that the number of invasive species increased from six in the 1980s to 34 in 2017 (Edinger and Young 2018). Collectively, these trends identify nonnative and invasive species as a critical management challenge that threatens the ability of the Plains to provide habitat to globally- and state-rare species.

Sandplain gerardia (*Agalinis acuta*) is a federally endangered plant that is known from about a dozen populations in five states, with the Hempstead Plains containing the second largest population in New York (S. Sinkevich, Interview). Monitoring of sandplain gerardia in 2000, 2006 and 2007 (Fig. 4) by The Nature Conservancy showed large fluctuations in the populations throughout Long Island (M. Jordan, Interview). For example, in 2006, the average number was at 8,400 plants. In 2007, the number of plants dropped to 3,081 which was the lowest recorded since 1997. It is unclear why populations have fluctuated so drastically. The Hempstead Plains supports 13 other rare species (Table 1).

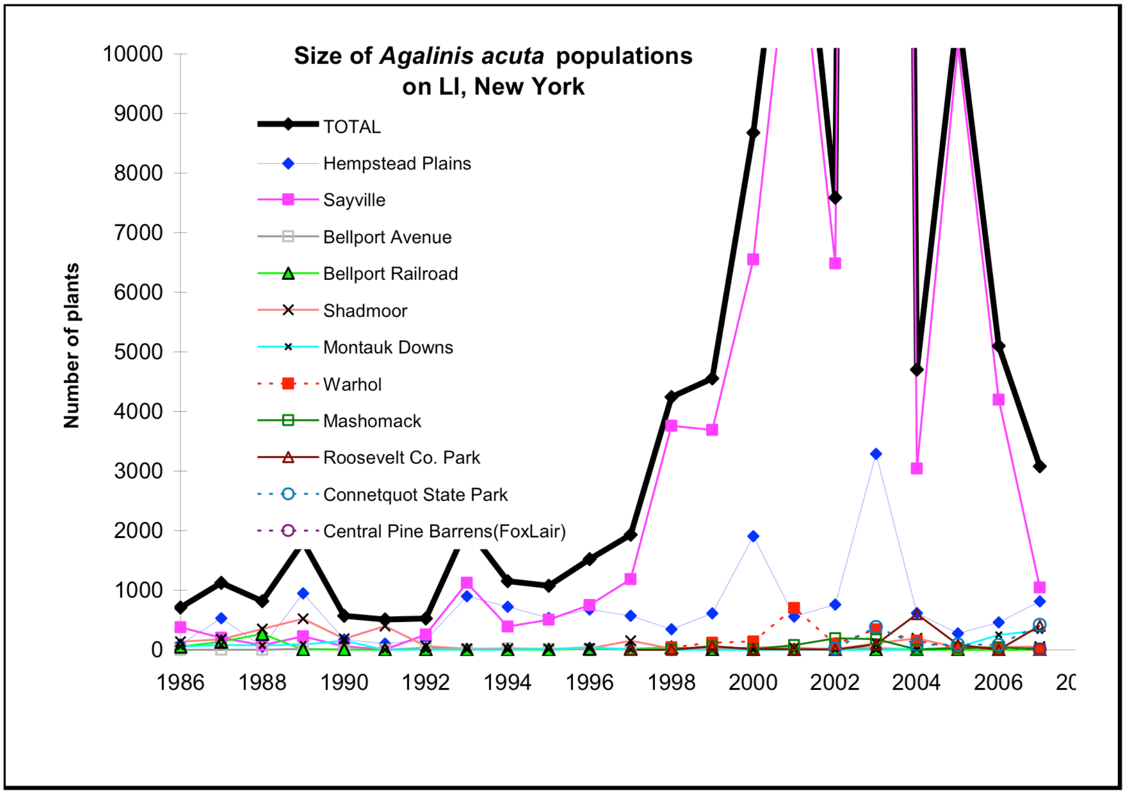

Figure 3. Sandplain gerardia (*Agalinis acuta*) population trends in Long Island, New York between 1986 and 2007 (M. Jordan).

Table 1. Rare plant survey history and ranking for species documented in the Hempstead Plains (Young 2017, Edinger and Young 2018).

Scientific Name	Common Name	Year First Surveyed	Year Last Surveyed	Heritage and Protected Rank
Agalinis acuta	Sandplain gerardia	1984	2016	G1S1 E
Aletris farinosa	Stargrass	1990	2010	G5 S2 T
Asclepias viridiflora	Green Milkweed	1984	2010	G5 S2 T
Carex mesochorea	Midland Sedge	1985	1985	G4G5 S2 T
Crocanthemum dumosum	Bushy Frostweed	1983	2003	G3 S2 T
Crocanthemum propinquum	Low Frostweed	2010	2010	G4 S2 T
Cuscuta pentagona	Five-angled Dodder	1991	1991	G4G5 S3 R
Desmodium ciliare	Hairy Small-leaved Tick-trefoil	1991	1997	G5 S2S3 T
Lespedeza angustifolia	Narrow-leaved Bush Clover	1985	1992	G5 S2 T
Polygala nuttallii	Nuttall's Milkwort	1985	1985	G5 S2 T
Scleria pauciflora	Few-flowered Nut Sedge	1983	1997	G5 S1 E
Sericocarpus linifolius	Narrow-leaved White-topped aster	1992	1997	G5 S2 T
Stachys hyssopifolia var. *hyssopifolia*	Rough Hedge Nettle	1984	1991	G5T4T5 S2 T
Viola pedata	Birds-foot Violet	1984	1984	G5 S3 R

History of Management

The Friends of Hempstead Plains has been the primary manager of the Hempstead Plains since its inception in 2001. It managed the Hempstead Plains in partnership with The Nature Conservancy from 2001 to 2005. The goals of the management have been to: (1) protect endangered species, (2) remove non-native invasive plant species, (3) improve and restore native habitat and (4) decrease woody shrub growth.

Experimental Studies

Susan Antenen and Robert Zaremba of The Nature Conservancy conducted prescribed burns at Hempstead Plains from 1991 to 1995 (Antenen et al. 1991). A research study was also conducted to evaluate effects of mechanical, chemical, and fire treatments on three invasive plant species. A total of 18 10 x 10 m plots were established in 1991 and 1992 in areas of mugwort (*Artemisia vulgaris*), Chinese lespedeza (*Lespedeza cuneata*), and cypress spurge (*Euphorbia cyparissias*) (Jordan, et al. 2002). Treatments included: (1) mowing one to three times annually, (2) one application of the herbicide Roundup (6 oz/gal;) at 0.10 oz/m^2 in 1992 or 1993, (3) one herbicide application in both 1992 and 1993, (4) prescribed burn in spring or fall in one or two years from 1991 to 1995, and (5) combination treatments of prescribed fire and herbicide application (Jordan et al. 2002). Species cover was estimated prior to mowing and herbicide for every plot in 1992 to 1995 and 2001 (Jordan et al. 2002).

Results

Jordan, et al. (2002) found that mugwort was nearly eliminated by mowing two to three times per year for three years, and limited regrowth occurred after applying herbicide two years in a row. However, the abundance of mugwort remained unchanged with dormant season burns and burn-herbicide treatments. Mugwort is a clump-forming rhizomatous perennial that reproduces primarily by vegetative spread (Jordan et al. 2002). Reduction by repeated herbicide or mowing application likely occurred because of exhaustion of stored reserves in the rhizomes.

Chinese lezpedeza cover was only temporarily reduced in the mowed plots, and showed variable change in burn only plots. In plots in which burn-herbicide combination treatments were applied, Chinese lespedeza was nearly eliminated within two years, but subsequently regrew to cover levels that equaled or exceeded initial abundance. Chinese lespedeza spreads primarily by seeds, and its rapid expansion following herbicide application was likely a result of the presence of a persistent soil seedbank. Mowing was largely ineffective at controlling this species most likely because of root sprouting or recruitment from the seedbank.

Cypress spurge was present in only three plots in 1992. However, it invaded four other plots between 1992 and 1995 and increased in cover during that time. Cypress spurge appears to reproduce only vegetatively at this site, and mowing, fire and herbicide were all ineffective at its control. Removal of taller competitors by mowing or herbicide may have facilitated the dramatic increase of this species.

Copper leafy spurge flea beetles (*Aphthona flava*) were also introduced in some areas of Hempstead Plains in 2002 as a biocontrol effort for cypress spurge. While the beetles do not directly kill this forb, the combined effects of foraging of adult beetles and larvae on foliage in mid-June and July, and feeding on roots in the spring weaken the plants. Monitoring documented the abundance of adult beetles and a negative effect on the cypress spurge cover overtime, (B. Gulotta, Interview).

An inadvertent response to the reduced abundance of cypress spurge has been an increase in mugwort (B. Gulotta, Interview). Constant mowing seemed to weaken and reduce the abundance of mugwort. However, a 10 x 10 ft (3 x 3 m) canvas that was used to cover two mugwort patches in early spring for two to three months reduced mugwort and allowed rapid regrowth of forbs dominated by common milkweed (*Asclepias syracia*) and Indian hemp (*Apocynum cannabinum*).

Ultimately, this study found that the effects of invasive plant control at Hempstead Plains varied by species and was a function of interrelated management variables. Species reproductive attributes, growth form, and competitive ability were all important species characteristics (M. Jordan, Interview). Specifically, mugwort was eliminated by repeated mowing and herbicide. Chinese lespedeza was not affected by dormant season burning, by repeated mowing, and effects of fire varied (M. Jordan, Interview). Herbicide nearly eliminated Chinese lespedeza, but it rebounded close to its pretreatment levels within 2 to 6 years, likely from a persistent seedbank (M. Jordan, Interview). Finally, cypress spurge was not controlled by mowing, herbicide, or fire and it greatly increased in cover and extent under these treatments, because of elimination of competing species (M. Jordan, Interview).

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IV.A. Conversion from Agriculture

Introduction

Creating or expanding sandplain grasslands from recently-cultivated land or from agricultural grasslands that are typically pastures or hayfields (Fig. 1) is an important potential mechanism that could increase the limited area of current sandplain grasslands. Opportunities for conversion of agricultural grasslands exist because the area of these grasslands can be larger than the area of sandplain grasslands in many places (Fig. 2).

Figure 1. Agricultural grassland, Peterson Farm, Falmouth, MA. Photo: Chris Neill.

Conversion of agricultural lands or agricultural grasslands to sandplain grassland habitat aims to promote a diverse assemblage of grassland species with a high proportion of warm-season grasses and native forbs, and a low proportion of cool-season grasses and non-native invasive species. Conversion also aims to combat soil legacy effects from years of agriculture and maintain microhabitats that foster germination and regeneration of disturbance-dependent native grassland plants.

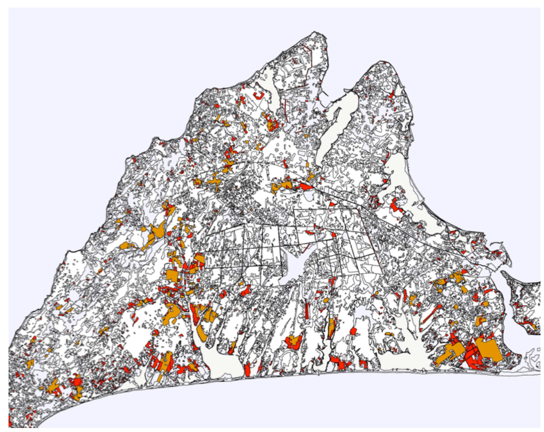

Figure 2. Area of existing sandplain grassland compared with agricultural grassland on Martha's Vineyard. Red is high quality sandplain grassland; orange is agricultural grassland. Based on map by The Nature Conservancy (2002).

In this document, we evaluate results compiled from published and unpublished studies and information obtained from interviews with land managers. We focused on the following main questions relevant for sandplain grassland management:

1) What are the phases needed to restore sandplain grasslands on agricultural land or agricultural grasslands?

2) What management techniques have been studied?

3) What are the results of different management techniques?

4) How can the effectiveness of management techniques be improved?

We focus on interpreting the main patterns that emerge from examining multiple experiences across multiple sites, with the understanding that responses to any one treatment of a management practice under particular conditions may differ.

Methods

We reviewed 75 sources that described or documented results of management actions in sandplain grasslands. Of these, eight sources contained information on conversion of agriculture to sandplain grasslands, and four detailed specific management experiments and case studies. In addition, we interviewed three professionals throughout the region about their experiences with conversion from agricultural land to sandplain grasslands. Literature sources that tested active management treatments were classified by whether they: (1) decreased non-native species, and (2) increased native biodiversity of plants or animals. We also used the review and interviews to summarize the state of current management practices and phases used to convert agricultural land to sandplain grasslands and their effects on: (1) fuels and soils, (2) vegetation composition, (3) vegetation structure, and (4) fauna in relation to important variables. We then suggest ways that the use of these management practices could be improved to increase warm-season graminoid cover, increase sandplain grassland forbs, and promote fauna in converted agricultural lands.

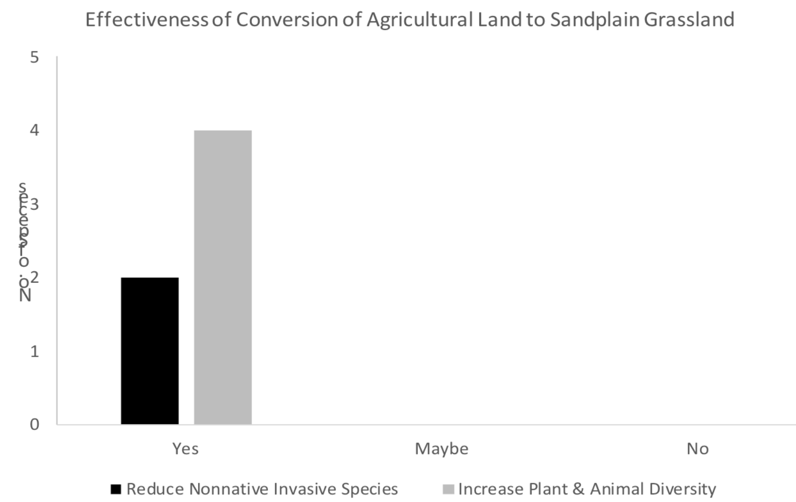

Figure 3. Number of sources that found results that suggest a decrease of non-native invasive species and/or an increase in plant and animal diversity.

Results

Few studies have examined this conversion (Fig. 3). Well-documented regional attempts at converting recently-tilled lands or agricultural grasslands to native species-rich sandplain grasslands is limited primarily to work done on Bamford Preserve on Martha's Vineyard and we draw heavily on those results here (Wheeler et al. 2015, Neill et al. 2015).

Conversion phases and management practices

Conversion of agricultural grasslands to sandplain grasslands typically involves three phases: (1) removal of existing non-native plants, (2) soil disturbance and/or soil amendments, and (3) seeding.

Bamford Preserve is a 25-ha property located in southeastern Martha's Vineyard, Massachusetts owned and managed by The Nature Conservancy. The property was tilled for crops until 1992 and subsequently maintained for pasture and hay. Existing grassland was dominated by sweet vernalgrass (*Anthoxanthum odoratum*), orchard-grass (*Dactylis glomerata*), smooth brome (*Bromus inermis*), and non-native forbs such as ribgrass plantain (*Plantago lanceolata*) and Queen Anne's lace (*Daucus carota*).

Existing vegetation in agricultural grasslands

Agricultural grasslands were identified as a community distinct from sandplain grasslands and heathlands by Dunwiddie et al. (1996), but can contain some plants more typical of sandplain grasslands and often include some cover of native warm-season grasses such as little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), or other species. However, predominant existing plant cover in recently cultivated agricultural grassland in the northeastern U.S. typically consists of non-native cool-season grasses such as *A. odoratum*, *D. glomerata*, tall rye grass (*Schedonorus arundinaceus*), sheep fescue (*Festuca ovina*), velvet-grass (*Holcus lanatus*), brome (*Bromus* spp), timothy (*Phleum pretense*), bentgrasses (*Agrostis* spp), and quack-grass (*Elymus repens*) (C. Neill, interview). Recently-cultivated agricultural grasslands also typically contain predominantly non-native forbs including plantains (*Plantago* spp.), spotted cats-ear (*Hypochaeris radicata*), dandelion (*Taraxacum officinale*), vetch (*Vicia* spp.), yarrow (*Achillea millefolium*), common sheep sorrel (*Rumex acetosella*), and others (C. Neill, interview). These lands are also often invaded by non-native shrubs and vines including Morrow honeysuckle (*Lonicera morrowii*), multiflora rose (*Rosa multiflora*), autumn-olive (*Elaeagnus umbellata*), oriental bittersweet (*Celastrus orbiculatus*), and increasingly in the Northeast U.S., Amur pepperbush (*Ampelopsis glandulosa*), and black swallow-wort (*Cynanchum louiseae*) (C. Neill, interview).

Phase 1: Vegetation removal

Vegetation removal can be implemented mechanically or chemically by application of herbicide. Wheeler et al. (2015) tested five methods of removing existing vegetation at Bamford Preserve in 5 x 5-meter plots on Martha's Vineyard: (1) tilling twice during the growing season, (2) tilling tree times during the growing season, (3) glyphosate herbicide, (4) black plastic, and (5) a Waipuna® hot foam machine designed for organic weed management of golf courses. Wheeler et al. found that tilling twice, tilling three times, black plastic and the broad-spectrum herbicide glyphosate were all roughly equally effective at reducing the formerly-established plant species and increasing the richness of native species after planting with a native seed mix. Hot foam was less effective at reducing the former species and the elimination of formerly-established plant species by herbicide resulted in slightly higher cover of native plants after five years compared with tilling and black plastic.

Phase 2: Soil disturbance and/or amendment

Wheeler et al. (2015) also examined the effects of soil characteristics on plant recruitment and survival by testing three levels of elemental sulfur additions (to lower soil pH), three levels of wood chip additions and two levels of sawdust additions (to immobilize soil nitrogen and reduce soil available nitrogen), three levels of urea nitrogen additions (to raise soil available N to test the idea that cover of native species and native species diversity decrease with higher N), and supplemental water (to test the effect of drought stress for germination and seedling establishment) (Fig. 4).

Figure 4. Soil amendment plots after tilling and treatment. Photo: Chris Neill.

The justifications for these treatments were: (1) lowering soil pH by adding elemental sulfur (S) has been successful in other places (Owen et al. 1999) and may improve soil conditions for restoring communities adapted to acidic soils (Walker et al. 2007); (2) the addition of organic matter with a high carbon to nitrogen ratio (C:N) has been used successfully in restoration efforts to decrease soil nitrogen because it stimulates microbial nitrogen immobilization and thereby reduces the amount of plant-available nitrogen (Morgan 1994, Blumenthal et al. 2003, Perry et al. 2010); (3) the general finding that nitrogen decreases species richness and native species abundance in many grasslands worldwide (Suding et al. 2005, Seabloom et al. 2015); and (4) the fact that even fairly dry-tolerant coastal sandplain species experienced reduced growth when water availability is very low (Griffiths and Orians 2003).

Wheeler et al. (2015) found that additions of carbon as sawdust or wood chips did not change soil nitrogen availability and had no effect on native cover or richness. This indicated that the amounts of these amendments that would be practical to apply as restoration management treatments had little effect on plant establishment or persistence over five years. Even high levels of nitrogen additions had little effect on soil nitrogen availability and did not affect the richness and cover of target native plant species. Additions of elemental sulfur of 91 g S/m^2 reduced soil pH from 6.2 to 5.0, a level typical of existing sandplain grassland. Sulfur additions of 182 g S/m^2 and 273 g S/m^2 were also applied. All three levels dramatically increased native species cover, but this effect decreased somewhat over time (Fig. 5).

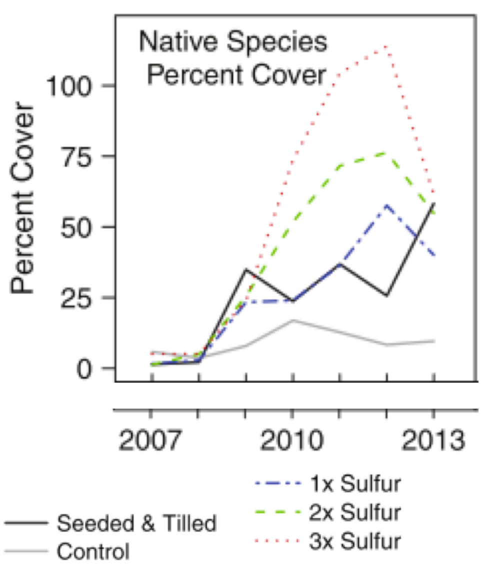

Figure 5. Response of vegetation to sulfur additions over a seven-year period. From Wheeler et al. (2015).

Wheeler et al. (2015) found that most of this increase in sulfur caused a large increase in the cover of little bluestem (*Schizachyrium scoparium*) three and four years post tilling and seeding. Sulfur additions also increased the cover of hairy pinweed

(*Lechea mucronata*), Greene's rush (*Juncus greenei*), common hairgrass (*Deschampsia flexuosa*), big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*) and frostweeds (*Crocanthemum* spp.). Sulfur additions reduced the abundance of ribgrass plantain (*Plantago lanceolata*) and smooth brome (*Bromus inermis*). Water additions had no effect on species richness or cover, likely because the summer in which the seeding and supplemental watering were conducted were slightly wetter than average and soil moisture was probably adequate for germination and establishment without supplemental watering.

Another important finding from Wheeler et al. (2015) was that nitrogen supply, either as increased by fertilizer additions or decreased by sawdust or wood chip additions, had no measurable effect on target species richness or cover. This indicated that nitrogen does not play a major role in structuring plant competition or causing the competitive exclusion of poorer competitors. While elevated levels of soil nitrogen are associated with declines in species richness in many grasslands (Marrs 1993, Bakker and Berendse 1999, Stevens et al. 2004, Clark and Patterson III 2007, Simkin et al. 2016), soils in coastal Northeastern grasslands may have insufficient native nitrogen for elevated nitrogen levels to cause the same kinds of effects. This would also explain why the addition of sawdust or wood chips, which have reduced non-native, invasive species abundance in other grasslands (Blumenthal et al. 2003, Burke et al. 2013), had no effect.

This conclusion in Wheeler et al. (2015) was supported by two other studies in Northeast sandplain grasslands. In one study, Weiler (2011) planted three native plant species that are targets for sandplain grassland restoration—orange milkweed (*Asclepias tuberosa)*, little bluestem (*Schizachyrium scoparium*), and downy goldenrod (*Solidago puberula*)—into the Bamford Preserve soil treatments that included three levels of carbon addition, three levels of nitrogen addition, a control that was tilled with no amendments, and an untilled, un-manipulated control.

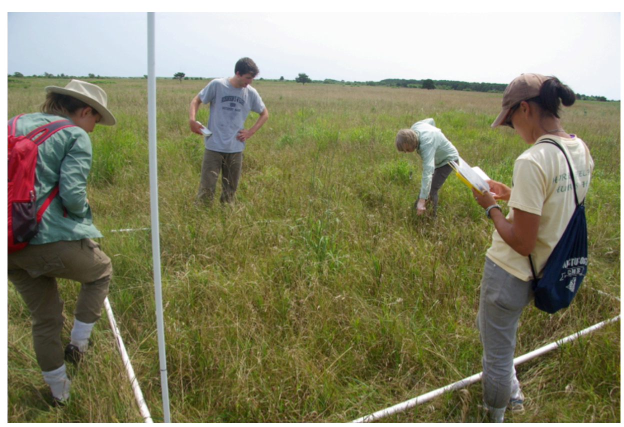

Figure 6. Vegetation cover monitoring at Bamford Preserve. Photo: Chris Neill.

The native species were seeded into plots that had either: (1) regenerating non-native vegetation, or (2) regenerating vegetation that was removed by clipping (as seen in Fig. 6). Clipping of surrounding vegetation increased downy goldenrod and little bluestem grass biomass within all treatments. Sulfur significantly reduced soil pH and increased the biomass of downy goldenrod and little bluestem grass. Some soil amendments increased planted native biomass somewhat compared with the control, but there were no significant differences among these treatments and the tilled control, indicating that it was tilling alone that increased native species establishment. The major conclusion of the clipping experiment was that efforts to reduce non-native species biomass will lead to more rapid establishment of native species on agricultural grasslands than will manipulation of soil properties. In a second, related study, Kinnebrew (2016) found very weak associations between soil extractable nitrogen and species richness in grassland plots on Naushon Island, MA.

Seeding

Wheeler et al. (2015) also tested three variations of seeding with locally-collected seeds: (1) no seeding, (2) seeding in autumn in one year, and (3) seeding in autumn of two successive years. Results suggested that removal of the established plant community in combination with addition of seeds of desired species was required to increase the cover and richness of desired native sandplain grasses and forbs after five years (Fig. 7). Related experience establishing sandplain grasslands on areas cleared from forest showed that seeding led to high species richness at Job's Neck on Martha's Vineyard (Lezberg et al. 2006), and higher cover of native grassland species and lower cover of non-native species in coastal Connecticut (Jones et al. 2013).

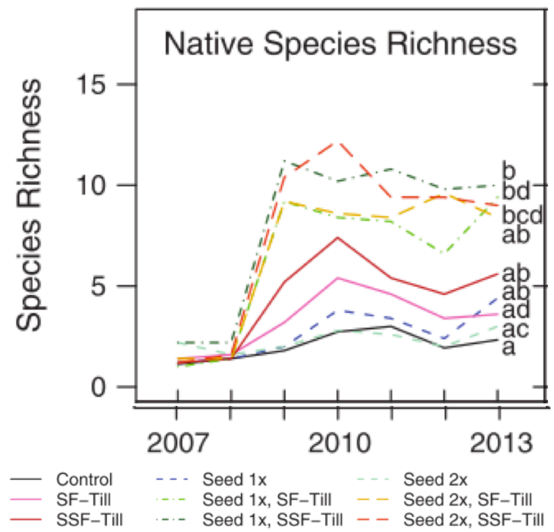

Figure 7. Tilling and seeding together increased native species richness at Bamford Preserve. From Wheeler et al. (2015).

A number of species appeared in main treatment plots, including in the tilled and unseeded controls that were not present in the former vegetation, the planted seed mix, or nearby surrounding lands, strongly indicating that they germinated from a soil seedbank that was established during former cultivation. The two most abundant species in this category were black mustard (*Brassica nigra*) and nut flatsedge (*Cyperus esculentus*). The presence of these plants was ephemeral and they were not present four years post-treatment.

Wheeler et al. (2015) also found that the recruitment of native species from the seedbank was not sufficient for establishing more than a small number of native species, and seeding with target plants was required. Seedbanks of native species in other agricultural grasslands are also suspected to be low although this has not been quantified. This differs from the seedbank that was found under existing species-rich sandplain grasslands on Nantucket, which were relatively rich and higher than in woodland or scrub oak shrubland (Omand et al. 2014).

Weigand (2017) studied seed limitations in the Atlantic Coastal Pine Barrens ecoregion and found that sources of seeds of desired grasses and forbs, either from a seedbank or from adjacent lands, are typically limited because of past agricultural use or habitat isolation. Thus, Weigand (2017) also argues that supplemental seeding especially of grassland specialist species is almost certainly necessary to ensure enrichment and diversification of old fields with desired species that are characteristic of regional grasslands.

The Bamford Preserve experiment used a uniform seed source to eliminate variation. However, the availability and quality of seeds, particularly local native seeds, will likely vary across years, and limit the area that can be converted and planted at one time or in one year (E. Loucks, Interview). While supplemental water did not have an effect in this experiment, drier conditions in some years may reduce germination and seedling survival.

The findings in the small plots at Bamford Preserve were used to guide the treatment of larger areas of the existing agricultural grasslands. One subsequent attempt (Fig. 8) applied combinations of tilling and elemental sulfur additions, and was successful in 2010 (E. Loucks, Interview). Further attempts to treat larger areas in a similar manner in subsequent years (2012 and 2014) were less successful, potentially because of poor seed quality, insufficient soil-to-seed contact, seeds sinking too deep into the soil, dry conditions following seeding, or a combination of factors (E. Loucks, Interview). These attempts indicate that year-to-year variations in seed production, seed quality, and conditions during key periods of seed germination may strongly influence outcomes, even when management methods are similar.

Figure 8. Creation of warm-season grass dominated sandplain grassland at Bamford Preserve on Martha's Vineyard. This large area was treated after evaluation of the results of multiple treatments in small plots. Photo: Chris Neill.

One important unanswered question from Wheeler et al. (2015) is how the vegetation will evolve over time. There was evidence five years post-treatment that the cover of native species that had become established started to decline, and it is unknown whether these declines may influence the long-term future of plant diversity in this converted sandplain grassland. Given the history of a number of existing sandplain grasslands that occur today on formerly-tilled sites, a richer mix of native species could increase over time. This appears to have been the history at Katama Airfield and the Crane Wildlife Management Area in Falmouth, MA. The elevated pH caused by former liming declines over several decades and becomes very small after about 60 years (Neill et al. 2007), and this should favor native over non-native species. After conversion from agricultural grasslands, newly-created sandplain grasslands will require a maintenance management regime to limit regrowth of woody species and other undesirable species.

Even though the lack of a native shrub component makes sandplain grasslands created on agricultural lands different from most older, well-established grasslands, we suspect that shrub cover at Bamford Preserve will increase over time. Methods for encouraging the colonization of native shrubs but not non-native shrubs are not well known. It is not clear that acceleration even of native shrubs is desirable, given that continued expansion of shrub cover is a major management concern. Once sandplain grasslands are established, regular management of the grassland through mowing, burning, herbicide application, or other methods will almost certainly be required.

Logistical and Practical Constraints

Because agricultural lands and agricultural grasslands are already cleared and treated with conventional practices such as tilling and hay cutting, conversion of these lands to sandplain grasslands does not typically raise the same concerns as clearing of woody vegetation or disturbing former woodland to create sandplain grasslands from woodlands may. In some cases, soil disturbance can raise objections. E. Steinauer (Interview) suggests that tilling or harrowing could cause public concern in some areas on Nantucket. Use of herbicides or black plastic for vegetation removal may be controversial or undesirable in some locations. The availability of tractors and tillers to remove vegetation and prepare soils may be limited. Loss of farmland for growing local food is an increasing concern (Donahue et al. 2014).

The availability of sufficient, high-quality, native seed will likely limit future efforts to construct sandplain grasslands on formerly tilled lands or agricultural grasslands. The commercial supply of seed remains limited even with a swell of grassroot organizations and business efforts to produce local sources of genetically appropriate species for grassland restorations. Restorations now often depend on low diversity seed mixes dominated by native grass cultivars from other regions. Use of these standard seed mixes rather than local ecotypes, appears in New York to be causing the development of novel grasslands dominated by warm-season grasses and with lower grassland plant species richness (Miller 2013, Weigand 2017). Use of ecotypic, local plant materials would address this concern, but increasing the availability of local seed for sandplain grassland creation projects remains a challenge.

Another concern about the future vegetation of sandplain grasslands created on former agricultural lands is the potential invasion by a range of non-native species that are present in the landscape today but that were likely not as abundant when native grasses and forbs became established on current, but formerly-cultivated, sandplain grasslands. In addition to traditional old-field invading shrub species such as multiflora rose, Oriental bittersweet, and bush honeysuckles, new invasive shrubs and vines that are today common invaders of agricultural fields include black swallow-wort (*Cynanchum louiseae*), Amur pepperbush (*Ampelopsis glandulosa*), and spotted knapweed (*Centaurea stoebe*). Experience with these species in other sandplain grasslands suggests that they can be controlled in sandplain grasslands purposefully created from agricultural lands using mowing, burning, and selective removal with herbicides if a dense cover of native species is established.

Summary and Pathways to More Effective Management

This review indicated that vegetation removal and seeding are both required to establish sandplain grassland vegetation on former agricultural lands. The addition of seed alone, or removal of the formerly-established plant species alone, resulted in much lower recruitment of target plant species. Native sandplain grassland associated species increased in richness and cover after one season of tilling and seeding with native seeds. There was no clear advantage to seeding in multiple years. Tilling and seeding with native species did not eliminate formerly dominant non-native grasses and forbs, although non-native species greatly decreased in cover. The success of herbicide treatment, which did not experience soil disturbance, clearly showed that the elimination of competition with formerly-established plants, and not solely the act of physical soil disturbance by tilling, promoted germination and establishment of target plant species.

Soil amendment experiments concluded that additions of elemental sulfur of more than 91 g S/m^2 reduced soil pH and dramatically increased native plant species cover, but this effect decreased somewhat over time. Additions of carbon as sawdust or wood chips also did not change soil nitrogen availability and had no effect on native cover or richness. This indicated that that amounts of these amendments that would be practical to apply as restoration management treatments had little effect on plant establishment or persistence over five years. Even high levels of nitrogen additions had little effect on soil N availability and did not affect the richness and cover of target native plant species. Lastly, nitrogen supply, either as increased by fertilizer additions or decreased by sawdust or wood chip additions, had no measurable effect on target species richness or cover. This indicated that nitrogen did not play a major role in structuring plant competition or causing the competitive exclusion of poorer competitors.

We found no research that specifically examined abundance and composition of fauna in response to creation of sandplain grasslands from agricultural lands or agricultural grasslands.

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IV.B. Conversion from Forest or Shrubland

Introduction

Conversion of forest or shrubland to sandplain grassland aims to promote a diverse assemblage of target grassland species with a high proportion of warm-season grasses and native forbs, and a low proportion of cool-season grasses and non-native species. This conversion focuses on removing all or most trees and shrubs, disturbing soils to eliminate built up organic material that does not promote grassland plants, and sometimes seeding to promote recruitment of disturbance-dependent grassland species that were not present in the original woodland or shrubland. Conversion of forest or shrubland is the most aggressive and potentially intensive pathway to creating sandplain grassland. However, extensive areas of second-growth forest, now present in the northeast US, create numerous opportunities for conversion to grassland habitats (Raleigh et al. 2003a).

Figure 1. Frances Crane Wildlife Area, 2017. Photo credit: Michael Whittemore.

Conversion of forest or shrubland to sandplain grassland requires a variety of techniques to be employed in several phases, and results might vary widely depending on site conditions such as existing vegetation composition and structure, soil legacy effects, weather after restoration, and important management variables, and whether treatments are applied in combination.

Local experience converting forest or shrubland to native species-rich sandplain grassland is limited. Evidence from Frances Crane Wildlife Area in Falmouth, MA offers the most comprehensive case study detailing a full conversion using a variety of management techniques. In addition, Lezberg et al. (2006) report results from mechanically removing overstory oak, combined with planting grassland plant species seeds on Martha's Vineyard, and Omand et al. (2014) highlight experimental results testing the composition of existing seedbank in forest or shrubland on Nantucket. In this document, we evaluate results compiled from published and unpublished studies and information obtained from interviews with land managers. We focused on the following main questions relevant for sandplain grassland management:

1) What are the necessary phases needed to create grassland from forest or shrubland?

2) What management techniques have been studied?

3) What are the results of management techniques in relation to the goal of creating native species-rich grassland?

4) How can the effectiveness of such management techniques be improved to convert forest or shrubland to sandplain grassland?

We focused on interpreting the main patterns that emerged from examining multiple experiences across multiple sites, with the understanding that responses to any one treatment of a management practice under particular conditions may differ.

Methods

We reviewed 75 sources that described or documented results of management actions in sandplain grasslands. Of these, 32 sources contained information on conversion of forest or shrubland to sandplain grassland, and 11 detailed specific management experiments and case studies. In addition, we interviewed 8 professionals throughout the region about their experiences with conversion agricultural land to sandplain grassland. Literature sources that tested active management treatments were classified by whether they: (A) reduce woody growth, and (B) increased native biodiversity of plants or animals.

We also used the review and interviews to summarize the state of current management practices used to convert forest or shrubland to sandplain grasslands and their effects on: (1) fuels and soils, (2) vegetation composition, (3) vegetation structure, and (4) fauna in relation to important variables. We then suggest ways that the use of such management practices could be improved to decrease woody cover, increase graminoid cover, and maintain and promote biodiversity in sandplain grasslands.

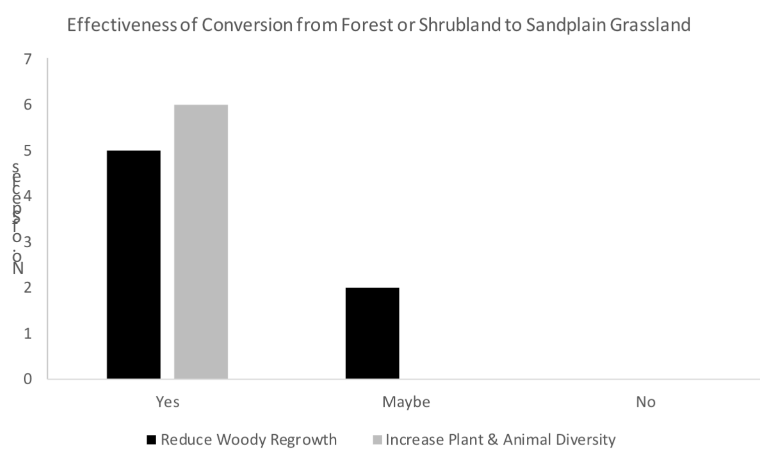

Figure 2. Number of sources that found results that suggest a decrease in woody growth and/or an increase in plant and animal diversity.

Results

Overall, the majority of sources found that most of the management practices reported in the literature achieved desired results (Fig. 2).

Conversion phases and management practices

Conversion of forest or shrubland to grassland involves a removal of woody plants to promote grassland composition and structure—a process of tearing down and rebuilding (C. Buelow, Interview). Conversion of forest or shrubland to sandplain grassland should be conducted in the following three phases: (1) tree removal, (2) soil disturbance and seeding, and

(3) return to maintenance regime. We reviewed five management examples in which techniques used to convert forest or shrubland to sandplain grassland were studies. The examples included variations of vegetation removal, burning, wood removal, soil disturbance, and seeding.

Preexisting vegetation

Predominant existing plant cover in forest or shrubland in northeast coastal upland areas is composed of pitch pine (*Pinus rigida*), eastern white pine (*Pinus strobus*), American beech (*Fagus grandifolia*), and oak species (*Quercus spp.).* One of those oak species, scrub oak (*Quercus ilicifolia*) is a fast-growing and tall shrub and that can quickly invade grassland and heathland. It can be expensive to continually manage (Raleigh et al. 2003a), although areas of scrub oak are themselves high-priority targets for conservation management (Swain 2016, NYNHP 2018).

Phase 1: Tree and Shrub Removal

Vegetation removal

Mechanical vegetation removal is the most common practice for removing trees and shrubs during the conversion to sandplain grassland. Vegetation removal may then be followed by herbicide application. Typically, large trees are logged and tree saplings and woody shrubs are mowed and/or treated with herbicide.

At Frances Crane Wildlife Area, tree shears were used for large trees and Brontosaurus mulchers and Hydro Ax flail mowers were used to remove invading saplings and shrubs.

Lezberg et al. (2006) mechanically removed overstory oak. They harvested overstory trees at ground level in clear-cut and savannah areas using a feller-buncher, while shrubs and small trees were mowed with a mechanical brush mower. Oak stump sprouts were cut with a mechanical weed brush cutter in summer to delay regrowth of oak trees. Mechanical removal of trees and shrubs, in combination with seeding increased cover of native forbs and ed minimal increase in non-native forb cover.

Combining herbicide application with other management methods can reduce the amount of herbicide used and allow very targeted application on non-native or disturbance-tolerant shrubs that persist after other management practices (J. McCumber, Interview). Some herbicides prevent shrub re-sprouting. For trees and shrubs, a phenoxy-based herbicide is often used. For non-native invasive trees and shrubs, 268 Picloram or glyphosate will typically kill the whole root system (Raleigh et al. 2003a). Krenite herbicide has been used to target scrub-oak (*Quercus ilicifolia*) (Dunwiddie 1990). One of the greatest challenges of using herbicide is public concern, especially when applied to native species, which can limit this technique in native shrub conversions (G. Motzkin, Interview). At the Frances Crane Wildlife Area, herbicide was applied to select areas after mechanical removal to control non-native invasive species.

Prescribed fire

Figure 3. Cut-and-burn of pitch pine forest at the Cape Cod National Seashore Marconi Area to create more open lands. Photo credit: Lena Champlin.

Prescribed fire has been used at some locations on the Cape Cod National Seashore (CCNS) to convert second-growth forest to grassland (Fig. 3). In the Marconi area, burning was applied with some success. Prescribed burning is most effective for conversion when paired with other management. D. Crary (Interview) suggests that mechanical cutting prior to burning expedites the conversion timeline. Further, some forests with dense understories need brush cutting before burning to reduce fuel loads to ensure a safe burn (Raleigh et al. 2003b). Even with the successful removal of trees, grassland might not always establish. For example, grassland did not become established in research plots at the CCNS in Truro that were repeatedly burned because of the lack of seed sources (D. Crary, Interview).

Prescribed burning can also be applied to help convert shrubland to sandplain grassland. Some shrub species are fire-tolerant and burning in the summer can be challenging, so burning alone is not usually an effective method to convert shrublands to grasslands (J. McCumber, Interview). Combining burning with other tools such as mowing will increase the speed and potential success of restoration to grassland (D. Crary, Interview).

Figure 4. Fire during the fall of 2015 in the Pohoganut section of the Manuel F. Correllus State Forest on Martha's Vineyard. Photo credit: Chris Buelow.

A growing season burn is often applied if the ecological goal is to change the system, while a dormant season burn (Fig. 4) or management is often used to maintain the system (C. Buelow, Interview). For conversion, summer burns can be the most effective management option to control woody growth because plants have high biomass allocated above ground (D. Crary, W. Patterson III, T. Simmons, Interviews). Dormant season burns can help remove excess thatch and fuels (T. Simmons, W. Patterson III, interviews). When mowing is done before burning in a woody shrubland, the fire can be very intense and shrub cuttings will carry the fire and create a large amount of smoke (J. McCumber, Interview). Depending on location and personnel restrictions, burning post-mowing may need to wait a year to allow some regrowth and therefore reduce the flame lengths, smoke, and fire intensity (P. Dunwiddie, Interview).

Frequency of prescribed fire application can influence fire's effectiveness in removing tree and shrubs. The first burn top-kills shrubs, making it important that this burn occurs during the growing season, to have the greatest impact (P. Dunwiddie, Interview). Once initiated, burning should continue over time to reduce shrub cover and maintain recruitment of native grasses and shrubs (P. Dunwiddie, Interview). Prescribed burning in shrubland can occur more frequently than grassland because there is more biomass fuel to burn (D. Crary, Interview).

Mowing

Figure 5. Shrub edge mowing with a DR Field and Brush Mower on Naushon Island. Photo credit: Lena Champlin.

No solid evidence exists that mowing alone effectively removes woody growth in the conversion of forest or shrubland to sandplain grassland. However, when combined with other practices, mowing is often the first step to successful shrub management (P. Dunwiddie, Interview) (Fig. 5). In recently-logged areas, mowing has been used to control residual woody regrowth. At the Frances Crane Wildlife Management Area, deforested areas were mowed two years after logging to help maintain woody growth after conversion. In contrast, however, research in the Middle Moors on Nantucket found that scrub oak had not decreased over time after 20 years of repeated mowing.

Grazing

There is no evidence from recent decades that grazing alone can effectively remove woody growth from forests or shrublands. Research experience on Naushon Island showed that livestock species will not reduce shrub cover in dense shrub patches (C. Neill, Interview). However, varying livestock types can be used for specific components of conversion of forest or shrubland to sandplain grassland, because different grazing animals have differing preferences and tolerances. For example, cattle prefer non-woody species, while sheep will eat more woody plants including poison-ivy (*Toxicodendron radicans*) and invasive Oriental bittersweet (*Celastrus orbiculatus*) (Raleigh et al. 2003a). Success in vegetation control by livestock is best achieved when the livestock have been conditioned to graze on plants such as woody species that are not generally recognized as standard forage species. For example, observations have shown that sheep raised in shrubbier areas are more likely to graze shrubs, making it important to maintain local sheep flocks if they will be used to targeted grazing management (K. Beattie, Interview). Goats eat many woody plants and have even grazed on woody bark (Raleigh et al. 2003a). At the Manuel F. Correllus State Forest, sheep sometimes grazed pitch pine (*Pinus rigida*) slash and also ate scrub-oak (*Querus ilicifolia*), dwarf chinquapin-oak (Quercus prinoides), and blueberry (*Vaccinium spp.*) sprouts (Patterson III et al. 2005). Sheep grazing has also been effective at clearing out dense understories of invasive species such as honeysuckles (*Lonicera spp.*), which in-turn allowed for more effective herbicide treatment and native species seeding (K. Omand, Interview). Grazing of forest dominated by scrub oak at Squam Farm on Nantucket (Karberg and Beattie 2009) and Tom Nevers (Dunwiddie 1986) suggests that sheep can reduce cover, and combining grazing with mowing can further reduce woody growth (Dunwiddie 1986).

The season in which grazing occurs is also an important consideration because vegetation palatability changes, as seasonable and young leaves and shoots produced in the spring can be more palatable to grazing, making spring grazing management important for impacting shrub growth (C. Neill, Interview). Additionally, winter grazing will likely affect shrubs more greatly than herbaceous vegetation because grasses and forbs are already dormant. (C. Neill, Interview).

The stocking rate can influence the effectiveness of shrub grazing. On Naushon Island, however, a high density of grazing cattle in summer had relatively little post-grazing effect on the proportion of shrubs within 0.25-hectare (0.6-acre) enclosures. Rotational grazing is a common method in which grazers are stocked at a defined density and in a confined area, and then rotated into new areas, depending on the rate of defoliation desired. A high stocking rotational grazing technique, with a rest period for previously grazed areas, would facilitate high intensity grazing over a short time frame and therefore may have the largest effect on vegetation structure by encouraging grazers to eat less favorable plants, while reducing the likelihood of over grazing (Raleigh et al. 2003a). On Squam Farm on Nantucket Island, sheep consumed scrub oak, particularly earlier in the season when grazed at higher intensities (K. Beattie, Interview). In that study, 17 sheep were turned out into 33 m x 21 m pastures for 48-hour rotations (Karberg and Beattie 2009). On Tom Nevers Nantucket, 20 sheep were stocked in a 20 m x 20 m pasture for 5-day periods, totaling 70 grazing days (Dunwiddie 1986).

Grazing preference can also vary among individuals within a species and between different breeding lines within a species. Several experiments have found that while introduced livestock are unlikely to graze shrubs, offspring born into native grazing will graze more

Figure 6. Naushon Island cow reluctantly grazing tips of short *Silmax rotundifolua* in the shade. Photo credit: Lena Champlin.

readily on woody plants. The propensity of Naushon-born animals to graze shrubs was observed with cattle grazing catbrier (*Smilax rotundifolia*) on Naushon Island (Fig. 6, C. Neill, Interview) and with sheep grazing on scrub oak at Squam Farm Nantucket (Karberg and Beattie 2009). Livestock grazing on shrubs can also be a learned behavior achieved by watching others, training through rewards, and increased stocking density to encourage them to consume new plants (T. Simmons, Interview). In addition, differing breeds of livestock have varying preferences and tolerances and thus will graze on different plants (P. Dunwiddie, Interview). On Nantucket, sheep breeds selected to more effectively graze shrubby areas increased the effectiveness of grazing on scrub oak (K. Beattie, Interview). Other factors such as weight, age, stage of breeding, individual health and environmental conditions can influence the efficacy of shrub grazing. For example, after sheering, sheep forage more heavily to compensate for lost heat (Raleigh et al. 2003a), which can influence forage preference and intensity. Because many factors influence how an individual animal grazes, accurately predicting how a particular flock or herd will affect shrub composition can be challenging.

Figure 7. Enclosure experiment on Naushon Island: Red square outlines a plot that has been mowed last 3 years and blue is un-mowed. Both plots start with about 50% shrub area cover and 50% grass along a shrub edge. Mowing makes a significant difference on shrub cover and height. Photo credit: Lena Champlin.

Grazing may be most effective at removing shrubs in combination with other management treatments, particularly mowing (Fig. 7). There are some woody plants that are just not palatable to livestock, or that they will not graze intensively enough to impact composition (T. Simmons, Interview). At Lost Farm Sanctuary on Martha's Vineyard, the shrub species that sheep did not preferentially graze persisted following extended targeted grazing management (E. Steinauer, Interview). In some cases, after grazing management, the remaining undesirable shrubs can be selectively removed by mechanical cutting or herbicide (D. Foster, Interview). In addition, mowing prior to targeted grazing can increase livestock access to target areas as well as increase the palatability of shrubs. In Tom Nevers on Nantucket, scrub oak that reached 10 to 12-feet (3.0 to 3.6 m) tall was impassable to sheep flocks, so brush cutting was applied to provide access for grazing (P. Dunwiddie, Interview). Mowing and thinning at the Manuel F. Correllus State Forest on Martha's Vineyard also preceded the introduction of sheep to graze forest dominated by scrub oak. Though grazing may leave some woody plants, when combined with mowing, shrub loads were reduced to a tenth of the initial measurements (Patterson III et al. 2005). In addition, shrubs tend to produce palatable new-growth after mowing, increasing the likeliness that livestock will graze as well as increasing the effect on shrubs by the combination treatments.

Woody debris removal

Some forestry practices leave behind woody debris, which could promote undesirable consequences. Therefore, a removal phase is required after cutting to remove stumps and branches (J. Scanlon, Interview). Removal of woody debris, chipping, and mulching are suggested to avoid adding nutrients to the soil, which can suppress grass establishment and growth (Raleigh et al. 2003b). Excess lumber could be sold for profit, but delivery might not be economical in many places (C. Neill, Interview). Or, lumber piles or mulch could be burned to expose mineral soil for grass establishment (D. Crary, Interview).

At the Frances Crane Wildlife Management Area, stumps were ground to two-inches below the surface two years after logging to promote grassland establishment (Fig. 8). At Job's Neck on Martha's Vineyard, wood was chipped and removed from the site (Lezberg et al. 2006). Stumps of tree oaks (*Quercus velutina* and *Quercus alba*) had to be removed after mowing because they re-sprouted vigorously (C. Neill, Interview). Pitch pine eradication is particularly difficult because the pitch pine is a prolific disturbance-dependent species that produces stump sprouts and epicormic branching when cut. To ensure mortality, D. Crary (Interview) recommends cutting trees three feet above the ground and reburning at a later time. This practice will lead to trunk buds sprouting rather than root buds, and another burn thereafter will often kill the tree, because of the second episode of stress.

Figure 8. Wood chipping at Job's Neck forest conversion. Photo credit: Chris Neill.

Phase 2: Soil Disturbance and Seeding

Soil disturbance

After removal of trees, saplings, shrubs and woody debris during creation of sandplain grassland to woodland, there is a phase of soil disturbance to prepare for seeding (C. Neill, Interview). Two options have been applied in similar conversions: harrowing and tilling. Harrowing or tilling can both reduce and break up clonal shrub roots and stumps, disturb the duff and soil substrates, and prepare the soil for growth of seeds in the seedbank or new recruitment (Omand et al. 2014). Soil disturbance can remove recalcitrant organic duff layers and expose mineral soil that is important for native grass germination (T. Chase, Interview). Depending on the management practice and equipment used, vegetation removal may also cause some soil disturbance. For example, skid tracks cause more disturbance than rubber wheels (Raleigh et al. 2003b).


Figures 9 and 10. Harrowing for the Middle Moors project. Photo credit: Karen Beattie.

Disc harrowing (Fig. 9 and 10) can be very effective in shrub removal because it breaks up clonal shrub rootstock and destroys the roots of shrubs like oak and ericaceous species (Dunwiddie 1990, Wagner et al. 2003). Harrowing to create fire breaks in 1993, 1994, and 2002 at the Manuel F. Correllus State Forest on Martha's Vineyard was effective for removing scrub oak by destroying rootstocks (Patterson III et al. 2005, Mouw 2002). Disc harrowing has been shown to achieve similar outcomes in closed-canopy forests. At the Frances Crane Wildlife Management Area, harrowing was effectively applied in an area of second-growth forest that was cleared of trees and shrubs prior to seeding.

There are some concerns about introducing soil disturbance to areas that in some cases were not previously used for agriculture. Concerns about soil disturbance include potential disruption of the soil integrity and microbiota, and the unpredictability of plant recruitment (J. McCumber, Interview) and the potential for soil disturbance to allow recruitment of weeds and non-native plants (Wagner et al. 2003, E. Loucks, Interview). At the Francis Crane Wildlife Management Area, harrowing promoted fast-growing herbaceous non-native invasive species including Japanese stiltgrass (*Microstegium vimineum*) and mile-a-minute vine (*Persicaria perfoliata*) in areas converted from forest (C. Buelow, Interview). Recruitment of non-native species might be reduced by soil harrowing right before seeds are added (C. Buelow, Interview), or by carefully selecting sites with a low chance for non-native species recruitment (K. Omand, Interview).

Growing season mowing of non-native species prior to seed set might help eliminate weedy species in the seedbank and encourage native grass and forb recruitment and establishment (K. Omand, Interview). In areas that recently succeeded to shrubs, soil disturbance can expose seedbanks and allow recruitment of native species. For example, harrowing in a mowed shrubland dominated by scrub oak at Middle Moors on Nantucket allowed recruitment of many grassland species from the seedbank (K. Omand, Interview, Figs. 11 & 12). In the year immediately following soil disturbance, native plant recruitment may be slowed by the competing establishment of weedy annual species before giving way to native, desirable perennial species (Clarke and Patterson III 2007, Omand, Interview).

Figures 11 and 12. Harrowing for the Middle Moors project. Photo credit: Karen Beattie.

Seeding

Seeding of target species is the best way to create or reestablish grasslands into cleared areas (C. Buelow, Interview). Tree removal and soil disturbance in places that lack a seedbank or seed rain will likely result in regrowth of tree and shrubs or even recruitment of non-native invasive species (C. Neill, Interview). The benefits of seeding depend on the available seedbank and/or the potential of seed rain from adjacent grasslands. Without a native seed source, seeding is required to jumpstart native graminoids (C. Buelow, Interview). The presence of a native seedbank has the benefit of having genetics that more closely resemble those from native populations (J. Scanlon, Interview). One major factor that controls the quality and availability of the seedbank is site history, which varies widely (C. Neill, Interview). Sites with previious soil tillage have higher numbers of non-native species (Neill et al. 2007, VonHolle and Motzkin 2007). Diversity in the seedbank declines with succession from grassland to shrubland or forest (Omand et al. 2014). Existing vegetation type also controls seedbank attributes. For example, scrub oak barrens tend to have low diversity in the seedbank and lack some native forbs that are characteristic of grassland (Omand et al. 2014). Some research has been done on seedbank composition in some forest types. In plots at Middle Moors on Nantucket, Omand (Interview) tested the seedbank in land that was mowed for 20 years and recently harrowed. She found that hand seeding patches of native species showed similar species diversity compared with unseeded patches. However, for most forest-to-grassland conversions, no seedbank exists because of seed viability limitations of some species over time (C. Buelow, Interview). Therefore, seeding is typically necessary in forest conversion sites (C. Neill, Interview). Ultimately, more research is needed to understand the extent of grass and forb seed survival as well as length of persistence in the seedbank.

Seed rain occurs from travel of seeds from adjacent land, and the abundance of seed rain depends on connectivity with nearby grassland and the overall area of grassland. When forest was cleared for grassland at Frances Crane Wildlife Management Area, the area of forest cleared was twice as large as the existing grassland so recruitment alone would not have been a successful method of reseeding (C. Buelow, Interview). After tree removal at Job's Neck on

Martha's Vineyard, some seeds were planted and some graminoid recruitment likely occurred likely because of the proximity to adjacent grassland areas (C. Neill, Interview).

There are two sources for seeds that could be planted during sandplain grassland creation from forest or shrubland: (1) commercial sources, and (2) seed collected from other grasslands. Commercially grown seed mixes typically consist of common warm-season graminoids, such as little bluestem (*Schizachyrium scoparium*). Commercially grown fast-growing seed helps create a grassy ecosystem in a short time period (Jones et al. 2013). Commercial sources of local seed are limited (C. Polatin, Interview), with the closest seed sources to coastal areas in the northeast US being from New York (J. Scanlon, Interview), and none currently from Massachusetts. This limits the use of local seeds in the creation of grasslands (C. Polatin, Interview). In addition, northeastern grasslands are globally rare with regionally specific species assemblages, making it especially important to expand seed that has close genetic origin to local populations (P. Wiegand & C. Buelow, Interviews).

Some organizations, including the Nature Conservancy on Martha's Vineyard, gather seeds locally with a mechanical seed stripper (Prairie Habitats, Inc., Argile, Manitoba, Model 410i) behind a tractor (Lezberg et al., 2006). Challenges to gathering local seed include labor, having enough sites to collect from, and storing seed (E. Loucks, Interview). In addition, the life history characteristics of some plants make collecting difficult or nearly impossible. If seed collection is possible, priority should focus on collecting forbs as well as graminoids, especially rare forb species. Wheeler et al. (2015) found that forb recruitment is very low without seeding, and G. Motzkin (Interview) highlights the need to not only plant rare species, but also maintain them over time.

Figures 13 and 14. Little bluestem seed harvest on Nantucket. Photo credit: Karen Beattie.

Planting methods and equipment can influence the success and rate of establishment, and come in many forms (Fig. 13 and 14). At Francis Crane Wildlife Area, warm-season graminoid seeds were coated and planted individually using a Brillion seeder, which limits wind transport and improves the proportion of seeds that establish at the site (J. Scanlon, Interview). In grasslands in Massachusetts, a Truex® warm season grass drill can also be used (C. Polatin,

Figure 15. Truax seeder is a no-till drill for warm-season grass seeding. Photo credit: Paul Rothbart.

Interview) (Fig. 15). Hand seeding is also done for small properties, but can be labor intensive (Lezberg et al., 2006).

Seasonality and frequency are also important variables that influence planting. Precipitation and wind impact the recruitment of seeding (E. Loucks, Interview). Typically, only one season of seeding is needed. Cold and wet conditions are best for seeding for little bluestem grass, so it is often planted early in the growing season. In contrast, it is not as successful to seed warm season grasses in the middle of the growing season (J. Scanlon, interview). Some species have seeds that must overwinter before emerging, so the diversity of plants that grow the following year will fully represent all potential species that could be established (P. Wiegand, Interview).

Phase 3: Return to Maintenance Regime

After the creation of grassland, it is necessary to apply a maintenance regime in a timely manner to limit regrowth from stumps or woody tree and shrub seeds and sprouts, which may be a recurrent problem in areas converted from forest or shrubland. Grazing, prescribed burning, mowing, and vegetation removal are common management practices for maintaining grasslands, and their effectiveness hinges on existing site conditions, management variables, and whether they are applied in combination. These management tools are covered extensively in other chapters.

Figure 16. Camp Edwards burning in October 2013, pitch pine tree torching. Photo Credit: Jake McCumber.

Logistical and Practical Constraints

Conversion from forest or shrubland to sandplain grassland has specific constraints. This conversion type is the most intensive, making cost a limiting factor. Because machinery to remove trees can be expensive, it may be more cost-effective on larger properties, and to clear one large area at once rather than smaller areas over multiple times (Raleigh et al. 2003b).

Management proposals for conversion of forest to grasslands can face strong public dissent over concerns about cutting down trees. Conversion from forest to grassland requires more of a visual landscape change and has a longer phase of recovery than restoration of native grassland in previously open lands (C. Neill, Interview). Harrowing and other soil disturbance, especially in areas that have undisturbed soil, can be controversial (E. Steinauer, Interview). Seeding is often necessary, especially in second-growth forest conversions, but local commercial seed sources do not exist. Local seed collection can provide a source, but collection takes a long time and storing seeds can be logistically difficult.

The constraints on the use of prescribed fires in the post-clearing phase may be exacerbated in forest and shrubland conversions. The higher fuel content in shrublands leads to greater production of smoke makes planning and safety concerns logistically challenging and particularly for summer burns. Burning in shrublands requires more experienced prescribed fire crew due to increased burn complexity which can increase the cost and limit the window of burn application.

Summary of Outstanding Questions

This review indicated that no management practice alone can accomplish a conversion of forest or shrubland to sandplain grassland, and that the successful sandplain grassland creation hinges on the interaction of site conditions (such as presence of a seedbank) and the effectiveness of tree removal and post-clearing management of woody regrowth. The first and most intensive phase of conversion is tree and shrub removal. This can be effectively done using mechanical tree clearing in combination with other management practices such as prescribed fire, mowing, and grazing. Woody debris removal is important to avoid adding nutrients to the soil, and to lower fuel hazards. Large-scale soil disturbance such as harrowing or tilling seems to be vital to transform forest systems to grassland by breaking up root systems of undesirable clonal woody species, and create conditions that encourage germination of disturbance-dependent target species but it is best conducted in places where it will minimize recruitment of non-native plants. Seeding is generally necessary in old, closed-canopy second growth forests that are not close to other grasslands, or that might have never been open-land habitat. The first step of shrub removal should be mechanical cutting to open dense shrub thickets. Mowing, burning and other disturbance management will most effectively reduce woody shrubs when applied during the growing season.

This review identified several major ways to improve understanding of techniques commonly applied to convert forest or shrubland to sandplain grassland.

(1) Test combinations of mechanical removal of trees and shrubs with other management techniques such as prescribed fire, herbicide application, grazing, and mowing. These should be designed and monitored as field experiments;

(2) Improve understanding of how infrequent or rare plants respond to different conversion combinations. There is currently almost no information on how these species respond to management practices associated with sandplain creation from forest or shrublands;

3) Further research about conversion of forest and shrubland to sandplain grassland could involve a more detailed examination of large-scale soil disturbance in land that has been previously cleared. Experiments should compare the response of vegetation composition over time in sandplain grasslands created from woodlands on formerly-cleared areas in which the soil is harrowed compared with areas where the soil is not disturbed.

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Case study: Conversion from Forest or Shrubland at Middle Moors

Site Description

Figure 1. Middle Moors, Nantucket, MA. Photo credit: Iris Clearwater.

The Middle Moors is the largest undeveloped open space on Nantucket and totals more than 4,000 acres (1,620 hectares) of protected lands (Fig. 1). The majority of this area is owned and managed by the Nantucket Conservation Foundation (NCF), including the portion that is commonly called Nantucket's "Serengeti." This area contains more than 400 acres (162 hectares) of a savanna-like habitat that contains mostly shrubland, patches of grassland and occasional trees. The Serengeti is located in the center of the island on morainal soils, more inland than other open-land habitats. Historically, this area had large expanses of open grasslands created by sheep grazing during the 1700 and 1800s. Between the cessation of grazing and the advent of mowing management in 1998, the vegetation cover was described as "closed shrub oak" with greater than 75 percent cover of scrub oak (*Quercus illicifolia*).

The Middle Moors consists of a mosaic of shrubland, heathland and grassland, but predominately shrubland. Omand et al. (2014) described this habitat as a monoculture of scrub oak shrubland dominated by scrub oak and dwarf chinquapin oak (*Quercus prinoides*) 3-6 m tall. This habitat-type is less diverse than heathland and grassland.

Management Goals

1) Reduce woody cover to create sandplain grassland;
2) Disturb soil to increase the removal of scrub oak by breaking up scrub oak roots and soil, removing woody debris on the ground, and exposing mineral soil to encourage the germination of seeds of native warm season grasses and forbs;
3) Plant a mix of native seeds to establish sandplain grassland.

History of Management

The NCF's management goal in the Serengeti was to restore the areas of grasslands and heathlands that existed about a century ago. Historically sheep grazing reduced taller shrubs and promoted grasses and forbs. But grazing was removed completely from this area by late 1800s and scrub oak and pitch pine (*Pinus rigida*) grew back rapidly.

Nantucket Golf Club provided the initial funding for restoration and maintenance of open habitat in the Middle Moors on property owned by NCF and Mass Audubon. Follow-up management is now the responsibility of these current property owners. Restoration methods including brush cutting and prescribed burning to reduce cover of scrub oak and other tree species. Begun in 1998, annual dormant season mowing (with some summer mowing at the initiation of the project) has been the primary management technique utilized in the Serengeti. Mowing was selected because of the challenges of burning large expanses of scrub oak. Annual mowing reduced the height of scrub oak, but not much establishment of grass species was observed. Scrub oak resprouted quickly after cutting and mowing over time was repeated to attempt to keep up with the rapid scrub oak regrowth.

Experimental disc harrowing of the soil was implemented in a small area of the Serengeti to test effects of more complete scrub oak removal. The goal of harrowing was to increase the removal of scrub oak by breaking up roots and soil, removing woody debris on the ground, and exposing mineral soil, which supports the germination of grass and forbs. Initially just harrowing was tested, and then harrowing and combined seeding of native grasses was tested.

Research

Seedbank Composition in Early Successional Communities

Based on the results of the initial Harrowing Project research, Omand et al. (2014) completed a seedbank study that compared seedbanks in grasslands, heathlands, and scrub oak shrublands on Nantucket, including the Middle Moors. This study was done to determine the potential need for seed addition during restoration projects in these areas. Soil samples collected in September 2007 were cold stratified and planted in a greenhouse where seedling emergence was recorded and seedlings were identified weekly from April 1 until September 30, 2008 (germination of new seedlings slowed after six months).

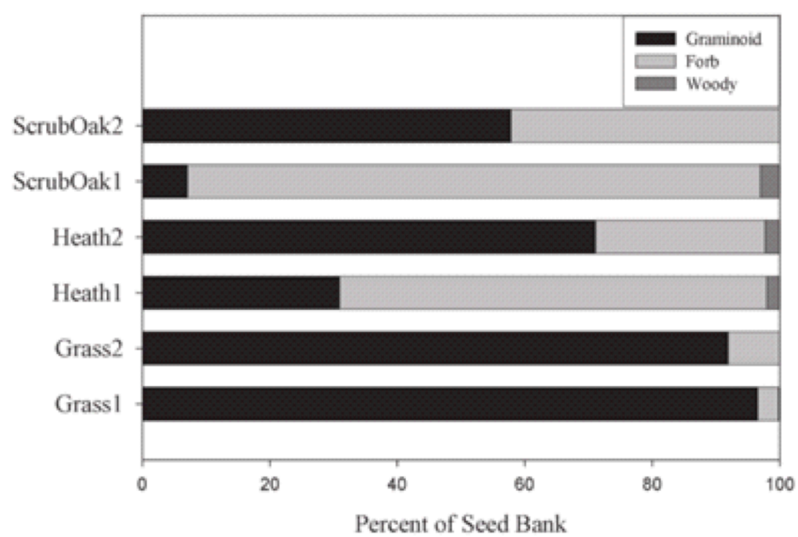

Figure 3. Percent composition of species in seedbank (ScrubOak1= Middle Moors).

The frequency of grass seedling germination was much lower in the Middle Moors sample than in other locations (Fig. 3). The shrubland Middle Moors seedbank contained predominantly woody species and weedy species such as horseweed (*Erigeron canadensis*). The diversity of native forbs and grasses contained in the seedbank of the grasslands was not present in the shrublands. The limited diversity of grasses and forbs in the scrub oak shrublands indicates that seeding with native seeds may be very important for conversion from forest and shrubland to sandplain grasslands. Omand et al. (2014) suggested: (1) further study of the effect of duff and mineral substrates on the post-seeding germination of important grassland species, and (2) tests of the effects of duff removal or mixing of soil layers (i.e., by harrowing) when combined with native seed addition.

Large Scale Harrowing and Native Seed Addition

The results of the initial Harrowing Project and the Seedbank research indicated that small-scale soil disturbance led to a short-term increase in grass and forbs but a quick return to woody species dominance and that the soil seedbank in these scrub oak-dominated areas lacked key native grassland species. In 2011, the NCF initiated a final experiment to examine larger-scale soil disturbance (disc harrowing) combined with seed addition of native species to effectively reduce woody cover and increase grassland habitat.

One unit of 3.1 acres (1.25 hectares) was treated with disk harrowing in late autumn of 2010; the second unit of 2.9 acres (1.16 hectares) was left undisturbed with the exception of continued annual brush-cutting. Thirty 1.0 m^2 plots of each treatment (Harrow, Harrow & Seed, Control and Seed Only) were located randomly and monitored pre-treatment and annually for three years post-treatment for vegetation percent cover by growth form (woody, forb, and graminoid), species composition, and substrate type. In addition, permanent photomonitoring points were established along the perimeter of the study site and visited each year to visually document change over time.

Large-scale soil disturbance from disc harrowing effectively reduced woody cover, particularly of aggressive native species such as scrub oak and black huckleberry. Rebounds in woody species cover in the third year of monitoring within Harrowed and Harrowed & Seeded plots were primarily caused by vigorous regrowth of bristly dewberry (*Rubus hispidus*), a low-growing and desirable component of grasslands and heathlands. Scrub oak, black huckleberry and low-bush blueberry had very little cover three years post-harrowing. Harrowing alone boosted both graminoid and forb cover, but the harrowed plots lacked little bluestem grass (*Schizachyriuim scroparium*) and other key grassland and heathland species. Harrowing strongly decreased the aggressive clonal native graminoid Pennsylvania sedge (*Carex pensylvanica*) and combined harrowing and seed addition further slowed recolonization by this species, presumably due to the rapid establishment of sown little bluestem grass. Combined harrowing and seeding also shifted the vegetation composition more strongly toward that of grassland than harrowing alone, mainly by establishing the key little bluestem grass grassland dominant species. However, the rapid germination and expansion of little bluestem grass appeared to limit the success of other sown species as well as those emerging from the seedbank. The composition of plots without soil disturbance, with or without seed addition, remained nearly the same.

Conclusions and Management Implications

Ultimately, annual mowing alone reduces shrub height but does not eliminate shrub cover or increase grasses and forb dominance within scrub oak dominated shrublands. Harrowing or other large-scale soil disturbance can help promote conversion to early successional grassland by breaking up shrub roots and removing duff to expose mineral soil for seed germination. Shrubland seedbanks contain a smaller component of grass and forb seeds than do grasslands, so seeding with native grasses and forbs after harrowing is important for increasing grassland plant diversity after initial mowing of scrub oak. Combining soil disturbance and native seed addition in scrub oak dominated shrublands appears to be a valuable tool for expanding grassland habitat.

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V. Monitoring Management Impacts in Sandplain Grasslands

Introduction

This review by the Sandplain Grassland Network focuses on using information gathered from previous management experience to improve future conservation management in ways that both maintain existing grasslands and create new areas of sandplain grasslands. The ability to adapt management over time relies on effective monitoring to assess management success. This section will address *why* you should monitor, w*hat* you should monitor, and *options* for monitoring.

Adaptive management requires setting management goals and monitoring of success and failure so the management can be altered in the future. Goals will differ by location but can include maintaining diverse plant and animal communities, and eliminating or reducing cover of non-native and invasive plants. Criteria for success will vary from project to project and property to property. The following list details some important considerations for establishing a useful monitoring protocol.

- A clear definition of management goals;
- determine what and how often to monitor to evaluate if management is successful;
- assess what resources are available for monitoring and design a monitoring scheme that is achievable;
- determine the kind of data you want to collect. Quantitative data, such as regular counts or surveys, can be time consuming and expensive to collect, but provide a depth of information over time. Qualitative data are typically faster and less expensive to collect but can provide useful and repeatable information;
- when possible, baseline monitoring prior to management will help to determine the effects of management.

What to monitor depends upon the management goals for a particular location, as well as by the resources available for monitoring. One of the stumbling blocks to successful monitoring is selection a monitoring plan that is either too little to detect changes in the face of natural variability, or too ambitious to be implemented successfully or sustained. Below we describe various types of monitoring with different goals in mind, and when one method might be more appropriate than another. Many of these methods may be used in combination to have the greatest effect.

Options for monitoring include landscape photomonitoring, vegetation monitoring (both of the plant community and of key individual species), wildlife monitoring (particularly birds, small mammals or other species of key interest), insect diversity monitoring, soil monitoring, water quality monitoring, or others. Because grasses and forbs create the structure of sandplain grassland habitats, and because reduction of woody plants is so important for grassland management, most sandplain grassland monitoring involves some assessment of vegetation and vegetation change over time.

Prior to designing a monitoring plan, asking certain questions will help define and design a monitoring approach. For example, what are key management objectives? Are there particular species that are of high interest? Are there particular landscape-level issues that require assessment (such as spread of invasive species, or impacts of human visitation)? Clear identification of monitoring goals can help define the kinds of data needed and whether qualitative or quantitative data are needed. In addition, this will help to define the time frame of monitoring, such as whether it can occur every three years, every 10 years, or whether it is needed every year. All of these questions will help to develop a monitoring plan that will not be over- or under-designed, and one that can effectively inform future management.

Qualitative Vegetation Monitoring

Qualitative monitoring of vegetation is the most common way that sandplain grassland management is monitored and it is typically the most practical and cost-effective monitoring to implement. Qualitative vegetation monitoring techniques can be used as part of a larger quantitative vegetation monitoring plan, but they can also stand alone to provide basic information.

Photomonitoring

Photomonitoring involves identifying permanent locations to take photos of a site in a way that can be easily replicated over time to track change in vegetation composition, structure, and land use. Photomonitoring can be simple, rapid and extremely reproducible. Photomonitoring is useful to show change over time or to compare pre to post management. Photos, while they do not tell a complete quantitative story of vegetation change, are important for presentations and reports to boards, administrators and the public because the visual results of management. Photomonitoring is an important tool that can be included as a part of all monitoring plans.

Individual photopoints (locations of reproducible photos) must be permanently marked to allow resampling over time. Photopoints can be marked with rebar in the ground (detectable with a metal detector), wooden posts, flagging, or existing landmarks such as large rocks or fence posts. A compass is used to document the direction a photo is taken and to allow future reproduction. A camera or phone is held at a standard elevation (dbh, or diameter at breast height, is a good reference). The digital photos must then be well labeled and stored. Because these photopoints are revisited over time, a photographic record of change over time can be created.

Table 1. Examples of sandplain grassland sites where photomonitoring has been used.

Name of project	Location	Citation
Peter Dunwiddie land history	Nantucket, MA	Dunwiddie 1992
Camp Edwards	Cape Cod, MA	Jake McCumber, personal communication
NCF Property Monitoring	Nantucket, MA	NCF 2017
Middle Moors	Nantucket, MA	Middle Moors Case Study

Species Presence/Absence

The occurrence of individual plants at a site can indicate management effects, particularly when management is intended to affect rare or invasive plants or a particular suite of plants, such as shrubs. Monitoring species presence/absence at a site consists of using a systematic way to document whether a particular species is located on the site during a particular sampling time. By systematically exploring a particular property or management unit, and documenting all plants observed, a species list is created for that time. Repeating this method can generate additional species lists that can be compared over time. Monitoring can also focus only on one particular plant or group of plants. Examples could be documenting the presence/absence of rare plants, non-native, invasive plants, or functional groups of plants such as shrubs. The presence/absence of these plants can be tracked over time and can be used to signal the need to manage. Presence/absence surveys can be conducted in combination with the quantitative surveys discussed below and can be particularly useful at documenting rare species, which often get missed in more randomly structured sampling protocols that cover less total land area.

Species presence/absence examples

Table 2. Examples of sandplain grasslands where presence/absence of plant species have been collected over time.

Name of project	**Location**	**Citation**
Trustees of Reservations	Multiple sites	Russ Hopping, Interview
Hempstead Plains	Nassau, NY	Hempstead Plains Case Study

Vegetation Mapping

Vegetation can be mapped on the ground or aerially. On the ground, a handheld GPS unit can be used to document the extent of an individual species population or of a defined plant community. In addition, locations of individual plants can be documented with points. This method can be particularly useful for documenting the extent of non-native plants targeted for control or rare species targeted for management designed to increase occurrence. Handheld computers with GPS units can also be used to document other information about the location of mapped vegetation such as slope, dominant surrounding vegetation, hydrology, or disturbance.

Remote Sensing

Mapping of plant communities or population can be done using aerial photos from planes or drones, or from satellite images. Remote sensing data can be very useful for looking at change over time in relation to management or climate, and for tracking phenology (Nagendra et al. 2012). The choice of method depends on the resolution available, area of required coverage, image availability, and cost. Aerial photo interpretation can delineate broad vegetation communities by defining grassy areas, evergreen trees, and shrublands, for example. This method should be used in conjunction with ground truthing, visiting sites in the field to verify aerial photo interpretation. Older and historical aerial photos can be interpreted and compared with more current photos to document vegetation community change over time.

The Nature Conservancy used a combination of aerial photos and ground truthing methods to map the vegetation communities of Nantucket and Martha's Vineyard in the late 1990s (Lundgren et al. 2000). Targeted aerial photos of a management area taken before and after management can be used to investigate coarse-scale change in vegetation. For example, it may be easier to quantify changes in grassland versus woody vegetation from such images. Google Earth images can be used in this way to observe changes over time. The growth over time of patches of black huckleberry (*Gaylussacia baccata*) at a site on Nantucket was tracked using both aerial photos and quadrats along the edge of the huckleberry patches (Harper 1995). Changes to the area of black huckleberry and catbrier (*Smilax rotundifolia*) on Naushon Island were quantified using aerial images from 1932 to 2014 (Champlin 2016). Several products from satellite images are also widely available. Nagendra et al. (2012) discuss a wide range of remote sensing data sources that are used for ecological monitoring in a variety of research projects and programs. The need for high-resolution spatial information that allows mapping of plant species or at least functional groups often limits the utility of even the highest resolution data from satellite images.

Unmanned Aerial Vehicles

Unmanned aerial vehicles, or drones, have been used for a number of survey applications including mapping non-native, invasive plants. On Nantucket, drones were used in 2016 to survey several pond edges for occurrence of the invasive common reed (*Phragmites australis*). While not a sandplain grassland, this demonstrated potential to use drones in these habitats. Drones can be programmed to fly straight transects and so may be ideal for ecological surveys. In post-processing, individual photos taken by the drone are stitched together into photomosaics using computer software to create a high definition image of the survey area. This image is georeferenced and ready to use in any GIS software. The high resolution of the resulting images can be used to observe vegetative change over time. Drone flight requires a licensed operator, the appropriate technology, and the necessary permitting, especially when flying close to an airport. However, the high resolution georeferenced images produced will likely allow users to quantify the areas of certain sandplain grassland vegetation features of high interest, such as shrubs.

Quantitative Vegetation Monitoring

Quantitative methods of monitoring vegetation allow managers and researchers to use summary and statistical data from monitoring to describe trends and responses of vegetation to management over time. Quantitative monitoring can also be used to identify vegetation community thresholds that prompt the use of management to maintain more open sandplain grassland habitats. For example, quantitative vegetation monitoring can indicate that, over time shrubs recover to pre-management dominance three years after a fall burn so management should be performed every three to four. Quantitative vegetation monitoring is more time consuming than most qualitative methods. Quantitative monitoring can be performed on a multi-year rotation and potentially combined with annual qualitative monitoring. Two of the most common quantitative measures of the plant community in sandplain grasslands are plant cover and species richness or species diversity.

Percent Cover Estimation

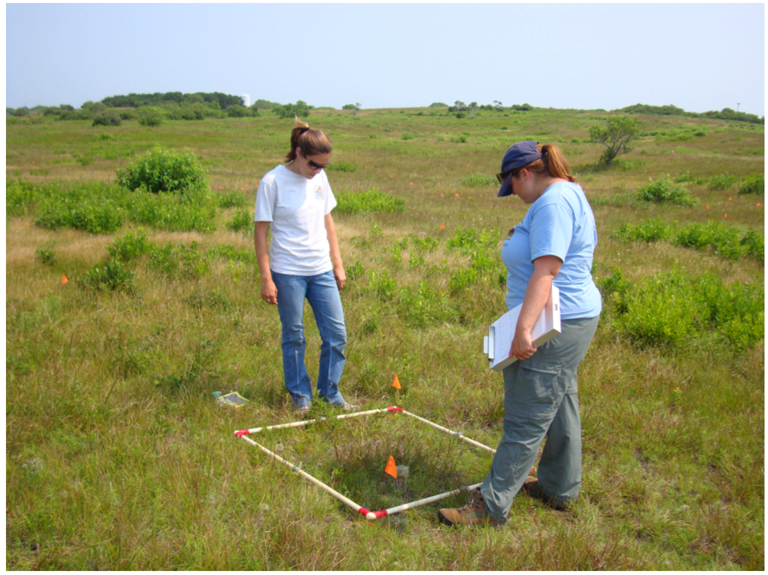

Figure 1. A one square meter plot frame used to assess percent cover within a sandplain grassland on Nantucket. Photo Credit: Nantucket Conservation Foundation.

Plant cover monitoring in sandplain grassland is typically conducted using visual estimation of percent cover of individual species and/or functional groups (woody species, graminoids, forbs, scrub oak, etc.). In this method, permanently-marked plots or quadrats are located throughout the management area and visited on a set schedule to record cover (Fig. 1). The plot is visually assessed for the percent cover of each plant species and/or functional group within each plot, where visual assessment is typically a birds-eye view from above the plot. This method can include measures of every plant identified to the species level, groupings of plants such as cover of all oak species, and measures of bare ground or litter. Cover values are typically recorded within ranges of percent cover and percent cover ranges are converted to cover range midpoints for statistical analysis (Lezberg et al. 2007). The method can be used in grasslands, shrublands, and woodlands and has been widely used across the northeast US sandplain grassland region (Motzkin et al. 2002, Eberhardt et al. 2003, Wheeler et al. 2015). Percent cover estimates of plants and functional group can be used to examine species composition and also statistically to compare effects of management both over time and between sites. Advantages of this method include its nondestructive nature, its repeatability in the same location, and the large number of plots that can be measured in comparison to methods that require harvesting. Drawbacks of this method include the difficulty of reliably assessing patterns of change for species with consistently low cover values, difficulties identifying all plants at one time of year, and subjective variability of cover estimates if different people record cover in different years.

Permanent plots can also be used to collect other information including evidence for herbivory, individual stem counts, vegetation height, soils and other environmental variables. Plot size depends on the stature of the vegetation and the time required to identify and record all species. Open grassland and low shrubland habitats can be estimated using $1m^2$ plots. Denser woody areas typically will require larger plots up to 9 m^2. Information from the cover quadrats can determine the proportion of each species or functional group relative to the entire plant community. Elzinga et al. (1998) provide useful specifics for determining quadrat size, number of quadrats needed per area, and percent cover categories.

Table 3. Examples of sites that used vegetation cover in quadrats to monitor plant community change.

Name of Project	**Location**	**Citation**
Katama Plains	Martha's Vineyard, MA	Katama Case Study
Squam Farm	Nantucket, MA	Squam Farm Case Study
Herring Creek	Martha's Vineyard, MA	Wheeler et al. 2015
Middle Moors	Nantucket, MA	Middle Moors Case Study

Point-intercept Method

Figure 2. Transect set up at a site for the point intercept method. Photo Credit: Nantucket Conservation Foundation.

The point-intercept method is another way to estimate plant species cover that is often used in grasslands and shrublands (Fig. 2). Multiple transects are randomly established across the site. A sampling dowel, laser, or pin flag is lowered to the ground at particular regular intervals along the transect (e.g., on a 50 m transect, the pin could be placed at every meter mark to create 50 sample points per transect). At each sample point, every plant species that touches the pin is recorded as present. In addition, plants that touch can be recorded as well as ground cover. At each sampling point, a plant species is recorded only once, even if it touches the pin more than once. Percent cover of plant species and/or functional group can then be estimated as the percentage of sample points at which species occurs along the transect (e.g., on a 50 m transect, little bluestem might be encountered at 30 points, so its cover is 60%).

This method is particularly useful for sampling variation and quantifying changes in plant species cover over time. Cover can be estimated at different heights, and canopy cover can also be estimated. The point-intercept sampling is often less time consuming than plot percent cover estimates. This method does under estimate rare species and is recommended to be combined with presence/absence searches.

Point intercept examples

Table 4. Examples of sandplain grasslands where point intercept methods have been used.

Name of Project	Location	Citation
Frances Crane Wildlife Management Area	Falmouth, MA	Calijouw, Interview
Property Management Monitoring	Nantucket, MA	NCF 2017

Frequency

Assessing how frequently a particular species is encountered in a specific plot or unit is another method for documenting species response to management. This method is most often used for targeted surveys of rare species, non-native species, or key target species. Frequency is best estimated at the plot level, and plot establishment is typically targeted, not random. The rare eastern silvery aster (*Symphyotrichum concolor*), located in the Smooth Hummocks Coastal Preserve on Nantucket, was surveyed over time within several targeted quadrats. In addition to plant stem number, this method also recorded plant height, flowering, and seed output before and after burning and mowing treatments (Freeman et al. 2005). Individual species frequency surveys can often be used in combination with point-intercept, or percent cover assessments to look for additional species not detected in either sampling scheme. This method can be used to document changes in individual species occurrence over time, and in response to management.

Frequency examples

Name of Project	**Location**	**Citation**
Symphyotrichum concolor targeted monitoring	Nantucket, MA	Freeman et al. 2005
Agalinis acuta monitoring by TNC	Martha's Vineyard, MA	Tom Chase, personal communication

Monitoring Considerations

Number and size of quadrats or transects

The appropriate size and number of quadrats, number and location of photopoints, and number and length of transects per area are other things to consider when establishing a monitoring program. These depend on: (1) the size of the area to be sampled, (2) the uniformity of the area to be sampled, (3) the money and person-power that can be devoted to monitoring, and (4) the sample size needed for sufficient statistical power. Simple pilot studies can be used to determine a sampling design that can be applied to other similar management areas. Good explanations of sampling design can be found in Elzinga et al. (1998) and Gotelli and Ellison (2013). Often, successful monitoring programs in similar or nearby areas can be used as guides to determine a monitoring design and the sampling effort needed. This saves time and can provide the additional advantage of creating an opportunity to compare results.

Frequency of monitoring

The frequency of monitoring depends on the goals of monitoring and management, as well as available resources. Short-term monitoring is often used to assess success of a particular management treatment or regime and may not need to be repeated long term. This can be valuable information, but long-term monitoring provides additional valuable information. Long-term monitoring plots allows the collection of quantitative data on the effects of different management techniques. With changing climate, permanent long-term monitoring plots may detect longer-term changes: climate-caused impacts of management on vegetation communities. For example, some managers argue they are starting to see longer-term impacts of management on mycorrhiza and plant associations (R. Lombardi, Interview).

One option to sustain long-term monitoring would be to sample more intensively just prior to and after management, and then less frequently at other times. For example, the direct impacts of prescribed fire on vegetation communities are thought to be less important three to five years post-management. Sampling every year up to five years after management, and then transitioning to sampling every two to three years may be an effective long-term monitoring protocol. In this instance, it would be appropriate for high frequency monitoring during the treatment phase of management, with a transition from project monitoring to long-term, follow up monitoring (C. Neill, Interview).

Monumenting

Whatever type of monitoring is chosen for the property or project, it is important to properly mark, or monument, each plot, transect end, or photo point locations. This will allow for repeated sampling at the same location. Methods of monumenting vary, but will depend on whether they need to withstand mowing or fire, visual aesthetics, or potential disturbance by animals or people. The answer to these questions can be very site-specific. Some examples include survey flags for temporary markers, rebar with labeled caps for more permanent markers (height above ground based on height of mower deck), or nails and washers flush to the ground. All points should be georeferenced with a GPS unit or related to some other permanent marker. Flagging tape can additionally mark survey points for ease of visibility, but it rarely lasts longer than one season, can attract herbivorous activities of deer, and may be removed by people.

Monitoring Results

Whether the data are quantitative or qualitative, it is important to summarize, visualize, and analyze results where possible (Elzinga et al. 1998, Gotelli and Ellison 2013). These results will likely inform the kind and frequency of future management. It is also extremely important to share results. The effort of monitoring results by the Sandplain Grassland Network aims to help share information and knowledge derived from a variety of locations and monitoring efforts.

Use of Citizen Science

Depending on project goals and locations, monitoring projects may be an excellent way to incorporate citizen scientists into data collection. With a simplified protocol and some training, much qualitative and quantitative data might be collected on a larger scale with volunteers. This monitoring method would be more successful if tapping into an already-established citizen science program. Another option would be to coordinate before and after data collection with a regional university or college course, high school science class, or local master naturalist program. While the availability of such programs is location-specific, they can be very useful resources and add an education or outreach component to a management project.

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Lombardi, Roberta. Interviewed by Lena Champlin on February 1, 2017

Monitoring for other species and environmental conditions

Vegetation tends to be the most commonly monitored component of ecosystem response to restoration and/or management but, depending on your goals and resources, there are many other categories that can be monitored.

Other species of Interest

Birds

Sandplain grasslands edged with coastal shrublands provide habitat for several bird species, many of which are special concern, threatened, or endangered due to loss of habitat. Concern may exist to track recovery of bird populations, or guarantee that management does not negatively impact bird populations. Birds can often be a good charismatic symbol for changes in grassland habitat but can potentially hide changes if the bird populations are slow to change in response to changing habitat (J. McCumber, Interview).

Sampling Methods

Various methods exist for monitoring bird populations and range from extremely time intensive to the use of occasional citizen scientists. Point counts involving observations and call identifications as well as using electronics to monitor calls over set periods of time can collect quantitative data for analysis on bird diversity at a site. Mark recapture and telemetry studies can document target bird movement patterns over an area in a season and over time. Nest location surveys and opportunistic observation can help document bird presence at a site. Using citizen scientists to document bird sightings using programs such as eBird can collect long-term qualitative data on bird use of a location.

Examples in Sandplain Grasslands

- At Francis Crane, bird populations are monitored yearly, with general surveys every year and standardized surveys every three years to track potential changes in bird populations (D. Vitz, Interview).
- Camp Edwards has 26+ years of bird monitoring data conducted by the same individual and focused on occurrence of state-listed birds (J. McCumber, Interview).
    - On Martha's Vineyard, annual counts of grasshopper sparrows are conducted at Katama Plains to track population (Revised management plan for the Katama Plains Conservation Area 2000).
- On Nantucket Island, long term surveys for Northern Harrier populations includes locations of nest sites to inform burn timing and locations in an effort to avoid impacting populations (Massey et al. 2008).
- On Nantucket, grassland bird surveys have been conducted in different projects to document bird populations. Surveys were conducted in 50m circular plots in early morning (typically between 6am-9am) but all species visually or auditorily identified during the sampling period were recorded. (Zuckerberg and Vickery 2006; NCF 2018).

Protocols and Resources

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Invertebrates

Sandplain grasslands serve as strongly associated habitat for a variety of invertebrates including many species of conservation concern. The American Burying Beetle, the purple tiger Beetle, and multiple moth and butterfly species of special concern are all dependent on these grasslands in some way. Monitoring at a particular site may be geared to directly detect populations of these species due to localized concerns.

Sampling Methods

All sampling methods for invertebrates need to consider that invertebrates can experience large population fluctuations between years, often making sampling necessary over multiple years to document species occurrences (P. Goldstein, Interview, M. Mello Interview). Standardized invertebrate monitoring methods within sandplain grasslands are not common.

Typical monitoring methods include conducting presence/absence inventories of individual species or a suite of species. Pitfall traps and sweep netting for insects are common as well as light traps to document moth species. Becoming more common in grasslands is the use of modified garden leaf-blowers to 'vacuum' sample invertebrates (Cherril et al 2017).

Examples in Sandplain Grasslands

- Dunwiddie (1991) collected arthropods using sweep nets along 50m transects during 3 sampling days in summer 1985, representing monitoring pre- and post-burn management.

- Bee populations were catalogued on Nantucket and Martha's Vineyard by using bee bowls placed along transects and filled with soapy water. Insects attracted to the color of the bowls would be captured, collected and processed for identification (P. Goldstein, Interview).
- On Nantucket, pitfall traps consisting of pyrex test tubes fitted into a PVC sleeve and placed flush with the soil surface allowed sampling of ground-dwelling/leaf litter insects and other invertebrates in a management site (NCF 2017).
- Many of these sampling methods are broad range and lead to bycatch, depending on your sampling goals. Additionally, the biggest limit to sampling invertebrates is the ability to accurately and quickly identify the species you have sampled.

Protocols and Resources

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Small Mammals

Small mammal populations can often be used as indicators of an ecosystem's response to management and can provide a measurement of biodiversity. Small mammals serve as the prey sources for larger mammals and birds of prey while remaining fairly sensitive to microclimate changes in habitat. Additionally, small mammals tend to be relatively abundant, making sampling easy to conduct, particularly in grasslands and low shrublands.

Sampling Methods

Live trapping of small mammals using Sherman live traps is the most common sampling method due to its efficiency and ease. Sherman traps are available in various sizes and trapping success does depend on appropriate trap size for the targeted mammals. Some protocols vary trap size optimize sampling. Trapping often occurs during the breeding season, but can be conducted year-round depending on your monitoring questions. Trapping during extreme weather can cause stress for animals and lead to mortality, so take care to follow standard protocols for establishing, checking, and insulating traps. Traps are typically placed along established transects and baited as appropriate. Traps are typically opened in the evening and checked and rechecked the next morning and at regular intervals to prevent animals being in the traps for too long.

Pitfall traps can be used to detect smaller small mammals such as shrews and gophers. Pitfall traps often can be lethal unlike correctly deployed Sherman live traps. Wildlife cameras placed at bait stations can also be used to sample mammals, particularly larger wildlife species not able to be sampled using the Sherman live traps.

*Staff should be sufficiently trained in handling small mammals. Rabies vaccinations may be required to handle small mammals, and permits for sampling may be necessary.

Examples in Sandplain Grasslands

- On Nantucket Island, small mammals are being sampled as part of a sandplain grassland restoration project involving harrowing and brushcutting relative to reference grasslands. Sherman live traps are deployed relative to random vegetation sampling plots. Each sampling session involves five trap nights and with traps opened and baited in the evening and checked prior to 8am the following morning. (NCF 2017)

Protocols and Resources

Nantucket Conservation Foundation (NCF). 2017b. Head of the Plains reset project: Small mammal trapping protocol. Science and Stewardship Department, Nantucket MA.

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If you are interested in monitoring the response of a particular species to management, check the literature or reach out to other managers in the area. Chances are someone has already done the work of creating a monitoring protocol or plan you can adopt at your site. This box indicates a number of locations at which studies have occurred and are good resources for finding protocols.

VI. Managing Sandplain Grasslands in a Brave New World

The Sandplain Grassland Network compiled and reviewed lessons learned from the past several decades of sandplain grassland science and management. While the lessons from previous experiences are important, future management to maintain sandplain grasslands as regional biodiversity hotspots will likely involve new challenges. This is because sandplain grasslands within northeastern U.S. coastal landscapes will increasingly be influenced by climate change, spread of new or different non-native and invasive species, changing patterns of land use, herbivore populations, and attitudes toward land conservation and land management. Recognizing these challenges—and facing up to what we do and do not know about how this "brave new world" will influence sandplain grasslands—will help to guide future management and research, and improve the success of future sandplain grassland management.

Climate change

Although climate change already affects the northeast U.S., in the upcoming decades these impacts will be severe and will increasingly influence sandplain grassland biota. The climate of the region has warmed 1.3 ^{o}C (2.4 ^{o}F) since 1895, and the annual mean temperature exceeded the 20th-century average every year since 1993 (Bradley et al. 2018). Between now and about 2065, the average summer and winter temperatures in Massachusetts will likely increase more than 3.3 ^{o}C (6 ^{o}F) relative to pre-industrial levels. The coldest winters of the future will be like the warmest winters of recent years and the coolest future summers will be like our hottest summers of today. Summer in the northeast U.S. by the end of the century will feel like a present-day typical summer in South Carolina. Annual rain and snow has already increased about 200 mm (7.8 in) since 1900 and the amount of precipitation falling during intense multi-day events increased by 71% between 1958 and 2012—a greater increase in intense precipitation than anywhere else in the U.S. The future will bring more winter rain and less winter snow. The future of summer rainfall is less certain but summer rain will likely become more variable so that more intense summer droughts may occur even while total yearly precipitation rises (Horton et al. 2014). We currently know relatively little about how these climate changes will affect most of the important plant and animal species that sandplain grasslands support.

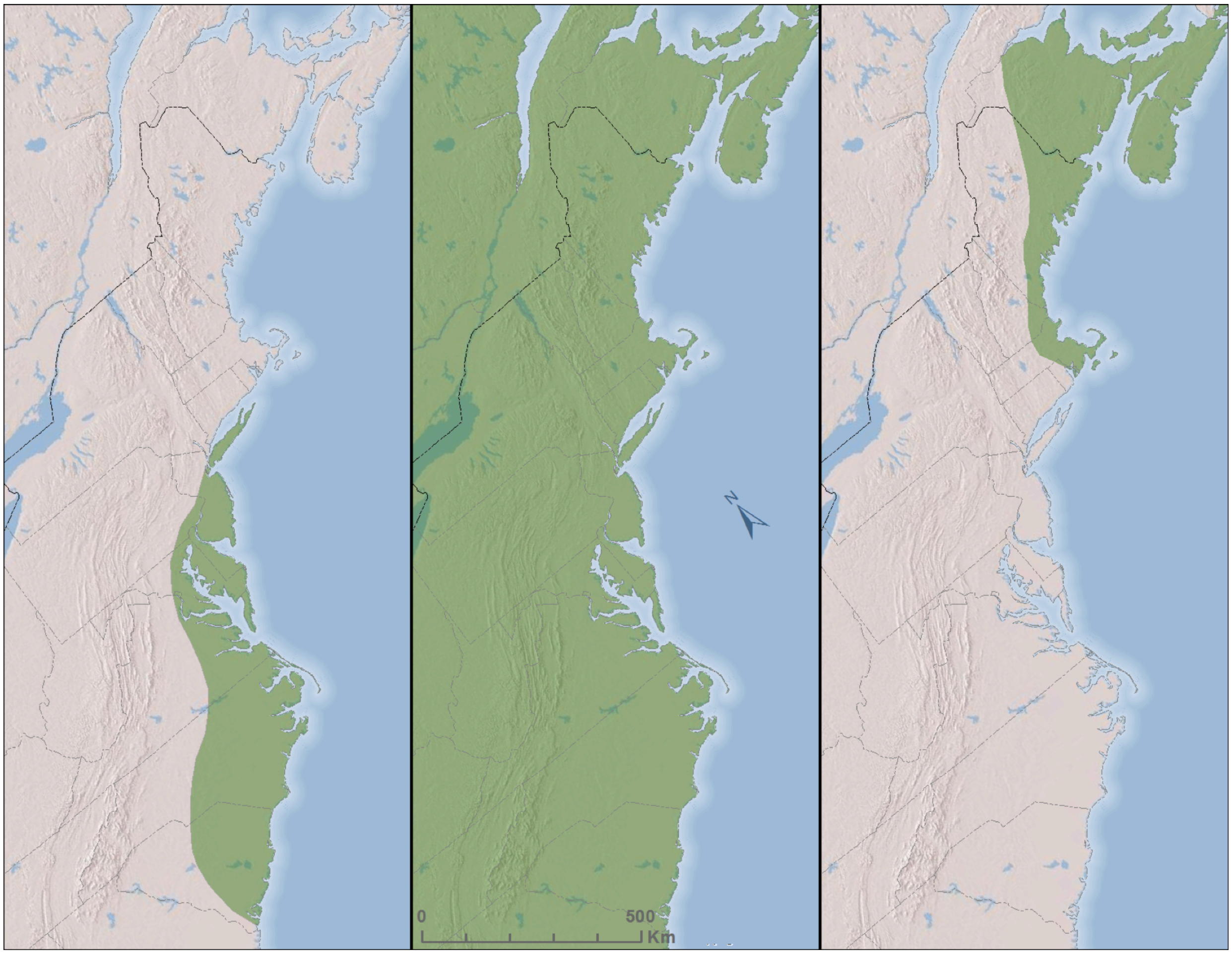

Figure 1. Hypothetical examples of sandplain grassland species with southerly (left), widespread (middle) or northerly (right) current ranges.

Warmer temperatures alone will likely shift the distributions of many sandplain grassland species over time. This may make it harder or easier to manage for different species depending on the north-south position of their current ranges (Fig. 1). Species near the current northern edge of their range may increase and may become easier to manage for in the future. For example, Blue Grosbeak (*Passerina caerulea*) is a grassland and shrubland bird species with a current southerly North American distribution. It is increasing in the northeast and was first successfully bred in Massachusettsetts in 2017 (Neill 2017). In contrast, grassland species now at the southerly edge of their range may become harder to manage for and face greater risk of regional extirpation. Broom crowberry (*Cormea conradii*) is an Ericaceous shrub that has a restricted current coastal range from New Jersey north to Newfoundland. Management of broom crowberry could become much more challenging in the future especially within the southern part of its range. How climate change influences the management of other important common sandplain grassland species that have very broad ranges may be less pronounced. The ranges of foundational sandplain grassland species such as little bluestem grass (*Schizachyrium scoparium*) or Pennsylvania sedge (*Carex pensylvanica*) extend well to the north and south of the northeast U.S., so their future ranges will almost certainly continue to include this region under the projected near-term future climate. These potential range shifts will almost certainly not be restricted to sandplain grassland species of conservation interest, but will potentially occur also for woody or invasive species that create persistent challenges for sandplain grassland managers. A comprehensive evaluation of current and potential future ranges of target and problem species, which could provide information on the potential importance of these shifts, has not been conducted.

Future climate changes that bring more variable precipitation and more severe occasional summer droughts could affect the ecological dynamics and management of sandplain grasslands in several important ways. Because sandplain grasslands occur on well-drained soils, effects of flooding caused by more extreme rainfall will likely be minor. However, drought might decrease seed set and increase the years in which many sandplain grassland plants either produce fewer seeds or lower quality seed. This could influence approaches to restoration actions that depend on seed collections from existing grassland-associated plants. If the frequency and severity of droughts and dry summers increases, it could also reduce seed germination or the survival of seedlings of plants planted into restoration projects. More frequent or severe droughts will likely make predictable management by prescribed fire more difficult by creating more "red flag warning" days, and fewer days when fire can be used during the growing season, when fire is most effective for controlling growth of woody plants in sandplain grasslands. In contrast, increased frequency of dry summers might increase the effectiveness of fire during the growing season, at the times when it can be used, because the combined stress of fire and drought could reduce the survival and re-sprouting of the remaining root stocks of woody plants.

Shifts toward earlier flowering because of warming temperatures are well documented in the northeast U.S. (Miller-Rushing and Primack 2008). These changes are a concern because they could disconnect the time of flowering from the time in which pollinators are active, thus disrupting both plant and pollinator reproduction and their long-term viability (Scaven and Rafferty 2013). These changes have not been investigated specifically in sandplain grasslands. Warming temperatures could also change conditions in locations in the coastal sandplain grassland region where microtopographic features influence the occurrence and timing of low temperatures, and the relative balance between trees and a shrubbier community that contains a larger grassy component. On sandy and drought-prone soils, topographic lows can result in "frost pockets" where nighttime below-freezing temperatures occur into early summer (Aizen and Patterson 1995). Because these late frosts typically occur before scrub oak (*Quercus illicifolia*) but after tree oak (*Q. alba*, *Q. velutina*) leaf out, they can cause greater tree oak mortality and maintain scrub oak barrens (Motzkin et al. 2002). Warmer springs or cloudier conditions that prevent radiative nighttime cooling would potentially eliminate this phenomenon and increase the presence of woodland at the expense of scrub oak shrubland that frequently harbors at least some plant species more typical of sandplain grasslands.

Rising sea levels already influence the conservation management of sandplain grasslands and the effects of rising sea levels will increase in the future. Many excellent examples of native species-rich sandplain grasslands occur directly behind the open Atlantic Ocean coastal dunes or adjacent to coastal salt and freshwater ponds, particularly on Long Island, the mainland coast of Massachusetts, Nantucket, and Martha's Vineyard. In these locations, frequent disturbance by wind and salt spray helps to limit tree growth and maintain grass cover (Griffiths et al. 2006). This aids management because less aggressive efforts will be needed to maintain grass and prevent tree regrowth in strictly coastal sites compared with sites farther inland. Sea level rise already threatens these coastal sandplain grasslands that lie very near the coast. Sea level in the northeast has risen approximately 20 cm since 1900 and the rate of sea level rise is increasing. Recent studies indicate that Massachusetts will likely see 100 cm of additional sea level rise by 2100 and nuisance flooding of low-lying areas along the U.S. east coast is increasing (Sweet et al. 2018). This means that some of best current examples of sandplain coastal grasslands will likely experience more extreme storm surges and the accompanying effects of salt spray, temporary flooding, and wind damage during this period.

Imminent and accelerating sea level rise means that maintaining the most coastal sandplain grasslands in the northeastern U.S. will require the ability to: (1) allow current coastal sandplain grasslands to gradually migrate inland, or (2) create sandplain grasslands at locations farther inland in places that are currently other habitats. Both strategies will likely be necessary to sustain even the current area of high quality grasslands and the implementation of these strategies can benefit from lessons learned in this review. Although relatively few locations exist in the populated northeast U.S. coastal region where corridors of undeveloped lands exist in contiguous swaths that connect large, inland protected areas directly to the coast, some of the areas where this landscape connectivity exists are already important locations of sandplain grasslands. Large central portions of the island of Nantucket that include the Sanford Farm/Ram Pasture, Head of the Plains, Trots Hills, and Smooth Hummocks properties, contain excellent examples of coastal sandplain grasslands in locations that are contiguous with protected lands farther inland. There are other examples of these landscapes at the Katama Plains and the Long Point Wildlife Refuge on Martha's Vineyard, and surrounding Allens Pond in southeastern Massachusetts. Even in these locations, the loss of sandplain grasslands at the coast will not necessarily be compensated for by expansion of sandplain grasslands inland into what are currently more shrub- or tree-dominated areas. A high long-term management priority for these still-contiguous properties to adapt to sea level rise might be to aggressively enlarge patches of existing sandplain grassland near the coast into these more wooded areas farther inland. In some instances, these contiguous inland areas are themselves highly-valued, terrestrial habitats such as scrub oak woodlands or pitch pine barrens that are conservation priorities. This will require careful assessment of tradeoffs by land managers. In many cases, more landscape-scale plans for maintaining or creating sandplain grasslands farther inland can draw on the experiences gained from managing woody regrowth in existing grasslands or converting existing shrublands or woodlands to grassland.

There is a much larger number of, typically smaller, examples of existing, highly coastal sandplain grassland patches, for which such protected migration pathways on protected lands do not exist. To compensate for the future loss of these areas to rising sea levels, managers should consider opportunities to create new sandplain grasslands on existing woodlands or existing anthropogenic grasslands in more inland locations.

Species Invasions

Many areas of current extent of sandplain grasslands were used for agriculture for some time between European settlement and the early- to mid-20th century (Motzkin and Foster 2002). Most sandplain grasslands have a component of their flora composed of non-native species because of this land use legacy. Compared with sites that were never tilled, grasslands that were formerly tilled generally have in their floras a number of non-native, widespread, weedy plants (Von Holle and Motzkin 2007).

Today, sandplain grasslands face increasing pressures from invasion by non-native and invasive species for several reasons. First, sandplain grasslands in the northeast U.S. now exist within a landscape, highly fragmented by residential development (Reinmann and Hutyra 2017) in which the proximity of grasslands to residential lands has greatly increased. The floras of residential yards in the northeast and elsewhere in the U.S. contain high numbers and proportions of non-native species and species that can easily colonize surrounding lands. Many of the invasive species that currently cause management concerns in sandplain grasslands, such as oriental bittersweet (*Celastus orbiculatus*), bush honeysuckles (*Lonicera* spp.), autumn olive (*Elaeagnus umbellata*) and multiflora rose (*Rosa multiflora*), have been present to various extents in some sandplain grasslands for many decades. However, persistent re-invasion of these species is more likely today that it was in the past because of increased dispersal of seeds that originate in the edge-rich residential landscapes in which sandplain grasslands are now embedded.

Second, the abundances of some invasive species that are relative newcomers in sandplain grasslands appear to be increasing rapidly in the northeast U.S. Three examples are Amur peppervine (*Ampelopsis glandulosa*), spotted knapweed (*Centaurea stoebe*), and black swallow-wort (*Cynanchum louiseae*). Reasons for the recent increase are not entirely clear, but it appears to be occurring in New York (including Long Island) and Massachusetts. Warmer temperatures and especially warmer winters may be factors, as well as the increase of carbon dioxide concentrations in the global atmosphere. Most vines, including poison ivy (*Toxicodendron radicans*), increase their growth rates faster than other plants in the presence of elevated carbon dioxide (Mohan et al. 2006).

Many sandplain grasslands also have a number of native species of vines and shrubs that persisted through periods of agricultural use, but then increased when lands were released from grazing or tilling. Some species likely persisted because they were protected from grazing by thorns (such as catbrier, *Smilax rotundifolia*; or brambles, *Rubus* spp.) or because they were unpalatable (such as black huckleberry, *Gaylussacia baccata*). Sandplain grasslands that were released from grazing relatively recently are likely undergoing a current rapid expansion of these species because spread occurs largely by clonal reproduction, and accelerates after an initial, relatively slow increase in the ratio of edges to open areas. The spread of these species into remaining grasslands on Naushon Island is an example of this recent rapid expansion of native shrub species into grasslands (Champlin 2016).

In unusual cases, the introduction or spread of an invasive species may create new opportunities for creating sandplain grasslands or shrublands in new places. The spread of the southern pine beetle (*Dendroctonus frontalis*) across the New Jersey Pine Barrens in 2001 and onto Long Island in 2014 threatens the region's pitch pine (*Pinus rigida*) forests because of the beetle's effectiveness in killing trees usually within several months of infestation (Dodds et al. 2018). This range expansion will almost certainly continue in the northeast U.S. in coming years. The inevitable loss of pitch pine forests results in areas that could be considered for sandplain grassland creation and expansion.

Trophic Interactions

The proximity of sandplain grasslands to fragmented residential landscapes has consequences for many sandplain grassland-associated animal species. High densities of medium sized predators like skunks and raccoons occur in residential landscapes (DeStafano and DeGraf 2003) and are associated with sources of food, availability of denning sites in residential landscapes, and the loss of apex predators. Some of these predators, like crows, are highly mobile and can key in on specific habitats at certain times of year. The abundance of generalist predators in adjacent residential lands can influence sandplain grassland birds and reptiles, even when these predators do not specifically target grassland species of high conservation concern (Vickery et al. 1992). Domestic cats are likely the number one anthropogenic cause of wildlife mortality in the U.S. (Loss et al. 2013) and grassland birds nesting on or close to the ground are particularly vulnerable to predation (Isaksson et al. 2007). Because many sandplain grasslands are popular places for people in increasingly populated surrounding areas to walk, disturbances by dogs, particularly during the nesting season, are an increasing concern. Roads increase mortality of reptiles (Foreman 2002) and a higher density of roads near sandplain grasslands today compared with in the past almost certainly threatens box turtles (*Terrapene carolina*), black racers (*Coluber constrictor*), and eastern hognose snakes (*Heterodon platirhinos*) that use sandplain grasslands. These trophic interactions created by adjacent residential landscapes create new and persistent challenges for sandplain grassland management. Predator control is typically publicly unacceptable and highly controversial. Management of vegetation both in and around grasslands to promote target species, coupled with education targeted at surrounding residential landowners (Lutter et al. 2018), may be the best alternative approach to managing higher predation rates.

The populations of herbivorous white-tailed deer (*Odocoileus virginianus*) have also increased throughout the northeastern U.S. sandplain grassland region. Deer populations on Long Island, in Massachusetts, and other places are now above estimated carrying capacity and various approaches to reducing deer numbers are being considered. Deer herbivory can threaten sandplain grassland plants that are conservation targets. Some species such as lion's foot (*Nabalus serpentarius*), are highly affected by deer browse and occur in numbers only in places like the Nantucket Airport that are fenced and where deer are controlled. Deer and rabbits also graze heavily on New England blazing star (*Liatris scariosa* var. *novae-angliae*) and damage to plants is greatest when grazing occurs during the middle of the growing season.

More of the current debate about high deer populations in the coastal sandplain region focuses on the role that deer play as hosts to the ticks that transmit Lyme disease, erlichiosis, anaplasmosis, babesiosis, rocky Mountain spotted fever, and other vector-borne diseases. Insect-borne diseases reported to the Center for Disease Control in the U.S. Mosquito and tick-borne diseases increased three-fold between 2004 and 2016 and are spreading rapidly in the northeastern U.S. While the increase in Lyme and other diseases has been attributed to an increase in deer populations (Wilson et al. 1988), this link is not straightforward above relatively low deer densities and may be more closely associated with the reductions in the numbers of predators that prey on the small mammals that are primarily responsible for transmitting the bacteria (*Borrelia burgdorferi*) that cause Lyme disease (Levi et al. 2012). Forested areas generally support higher abundances of deer ticks (*Ixodes scapularis*) than grasslands and shrublands but patches of little bluestem (*Schizachyrium scoparium*) supported small mammals with high tick burdens despite low numbers of host-seeking ticks (Ostfeld et al. 1995). It is still not clear exactly how the landscape configurations of grasslands, shrublands, and woodlands in important sandplain grassland areas influences risk of Lyme and other tick-borne diseases. One new feature of the presence of new vector-borne diseases may be the ways that landowners choose to manage their properties to reduce exposure risk. Some agencies recommend management that promotes lawns, tree removal, wood chip borders and other features to reduce tick abundance (Stafford 2002). The extent to which these land conversions from more to less natural habitat structures influence the region is not clear, but the diseases, which are the root cause of the underlying motivation to modify yards and other areas of high human contact, were not present to nearly the current extent before the significant expansion of the area of Lyme disease risk in the northeastern U.S. that occurred since Lyme disease was first described from Lyme, Connecticut in 1976.

There are other ways that managing sandplain grasslands into the future could be more difficult compared with in past decades. Vegetation management with prescribed fire today faces many challenges that include regulations under the Clean Air Act, the Endangered Species Act, other state and local regulations, and public acceptance, including perceived risks to property (Ryan et al 2013). In the densely populated northeastern U.S., and particularly in coastal locations where tourism is a major driver of local economies, burning in summer is not allowed by local fire departments. Attitudes toward prescribed fire vary widely within towns within the sandplain grassland region, adding to the challenge of applying fire when and where it would be most useful. One effect of these restrictions is that current prescribed fires, even when they can be conducted, now occur at more restricted times of the year. In the northeast, prescribed fires are conducted primarily in the spring and fall (Carlson 2013) and rarely in the summer, when the benefits to sandplain grasslands of reducing woody vegetation would be greater. Maintaining prescribed fire programs is also costly, and the unpredictability of weather, the narrowing of allowed fire windows, and greater requirements for insurance when grasslands lie adjacent to valuable coastal properties, can all add to the cost. In the future, greater precipitation—and particularly greater precipitation in late winter—may increase the difficulty of conducting prescribed fires in grasslands even during the spring and fall seasons when they typically now occur. Implementing recommendations of this review and increasing the amount of burning that occurs in sandplain grasslands during the growing season will take investments in education of both local fire departments and the public. While mowing in existing grasslands is widely accepted and faces many fewer logistical constraints, mowing does not provide some of the habitat heterogeneity and exposed soil that are benefits of prescribed burning. Mechanical clearing of forest or shrubland to expand grasslands in priority locations can also meet some public resistance. In contrast to burning, however, mechanical clearing faces fewer regulatory hurdles caused by air quality or risk to property. Objections are largely aesthetic and will likely continue to be manageable. Both prescribed fire and mowing cause some direct mortality to sandplain grassland plants and animals, including some species of conservation priority. This will continue to be a concern in the future. Applying management to only portions of conservation properties at any one time—while leaving a portion as an unburned or unmowed refuge—will remain the best strategy for managing for populations of sandplain grassland species over time.

Other Land Use Trends

New suburban residences will continue to expand onto existing unprotected open space throughout the region where sandplain grasslands occur. The rate of expansion has slowed in Massachusetts, on the Islands, and Cape Cod in recent years because of increases in land protected for conservation. The success of the local land trust movement (National Land Trust Alliance 2015) has contributed to the protection of open space that in the northeast U.S. that includes both sandplain grasslands and anthropogenic grasslands, that may have potential as sites for future sandplain grassland conversion and expansion. However, rapid expansion still continues on Long Island and in places like the interior southern counties of Massachusetts (Lautenheiser et al. 2014). Understanding and managing the multiple effects of residential development on multiple ecosystem services is a major national challenge (Groffman et al. 2017). One approach to influencing how homeowners manage residential properties is through programs such as the Habitat Network that encourages people to map and manage properties with native species to provide increased wildlife habitat and other services such as pollination. Engaging property owners around key sandplain grassland reserves could potentially reduce the harmful effects of habitat fragmentation.

There is strong interest in expanding the production of local foods across the northeast U.S. and reversing the pattern of long-term decline in the region's farmland that has occurred since the mid nineteenth century. The recent *A New England Food Vision* (Donahue et al. 2014) calls for a three-fold increase in the area of agricultural land in New England (from 2 to 6 million acres) to meet a goal of producing half of New England's food by 2060 food while leaving 70% of the region forested. A trend in land use to accommodate greater food production could have important influences on grassland conservation and management. Because current agricultural grasslands not currently protected for conservation in the sandplain region are already cleared and because they have been in previous agricultural use, they will likely be perceived as lands onto which food production could easily be expanded. Increasing interest in use of these lands for agriculture could make it harder to expand or restore more native species-rich, sandplain grassland vegetation onto these existing grasslands in the future. If existing agricultural grasslands are maintained for grazing with a greater emphasis on food production, there is potential to make future grazing compatible with some objectives of sandplain grassland conservation, such as development of grazing systems that would promote greater cover of warm season compared with cool season grasses. Much more work needs to be conducted with local producers of grazing animals to examine the values and effects of different grazing strategies. Expanded cultivation of current agricultural grasslands would remove most of the potential for conserving the species that are sandplain grassland conservation targets in at least in the short run.

Another potential intersection of local food production and expanded local agriculture could be increased interest in using grazing animals for management of existing higher-quality conservation lands, which include currently high-quality sandplain grasslands, or sandplain grasslands into which woody vegetation is expanding. There could be both benefits and impacts of the introduction of grazing animals into conservation lands. We currently know relatively little about how grazing animals influence sandplain grassland vegetation structure, the spread of non-native species, animal habitat, or the direct disturbance effects on many important sandplain grassland species. More carefully designed and monitored experiments that examine the responses to different animals, and use of animals at different densities and different times of year, are needed.

Moving Management into the Future

The management of sandplain grasslands will have to adapt to future conditions in a number of ways. Key issues that emerge from this review that are likely to confront sandplain grassland managers in the future include the following:

(1) More aggressive approaches to controlling the regrowth of undesired woody vegetation and a wider variety of exotic and invasive species will be needed. This will require applying more treatments such as mowing, burning, soil disturbance, or herbicide applications during the growing season or applying combinations of treatments, and applying them more frequently. Many of the same approaches to woody plant management can be adapted for invasive plant management.

(2) Emphasis on conservation of larger landscapes that include sandplain grasslands as a component will be required to conserve grasslands and their associated biodiversity in the face of rapid climate change. At the scale of small regions, these landscapes should connect current grasslands near the coast with protected lands that contain grasslands, shrublands or woodlands farther inland in places that could eventually replace grasslands nearer the shore that will be lost as sea level rises and coastal flooding increase.

(3) Develop strategies for accommodating larger future variations in climate by adapting management programs, such as prescribed burning, to both allow for the flexibility of foregoing treatment in very wet years and expanding the areas treated in very dry years, when management benefits are likely to be greater. In addition, accommodation should be made to spread restoration management actions like seed collections and seeding out over different years to avoid failures during more likely but less predictable future periods of intense weather events such as rainy periods and droughts.

(4) Partnerships should be developed to test the effects of grazing animals on sandplain grasslands. This information could be used potentially to develop strategies by which grazing of animals for food production might be consistent with sandplain grassland biodiversity conservation management.

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VII. Summary

We have been managing and creating grasslands in globally rare sandplain habitats for nearly 40 years. Our review of the state of management of sandplain habitats demonstrates that while we have made good progress in the short term and have learned a great deal about these habitats, our management is currently not adequate to maintain this system over the long term. Unless we make progress with management of woody species, many species will not persist due to the incremental degradation of this community type.

In existing sandplain grasslands, we have had good success at promoting warm season grasses with aggressive mowing and burning, and moderate success at reducing unwanted species with herbicide. However, we have had less success with restricting the growth of woody plants and at maintaining plant and animal diversity. The challenges are numerous, but implementing prescribed fire in the growing season and limited success with grazing are among the most important. Both tools are expensive and logistically complicated, limiting widespread use. Due to our use of frequent mowing and infrequent burning and grazing, we are in danger of homogenizing our management approaches and increasing coordinated risk across the system.

Creating new grasslands is harder than maintaining existing grasslands and land use history is an important factor that can impact success. Although we have had some successes with clearing, disturbing soil, and planting in forested or shrubby systems, dealing with persistent woody vegetation remains a challenge. In agricultural systems, we need to improve our ability to remove existing vegetation and to deal with persistent non-native species. Additionally, access to a local seed supply remains an ongoing challenge. As with existing grasslands, we need to test very aggressive combinations of management or be prepared for the process to take a long time. We also encounter within a few years the same challenges of maintaining existing grasslands.

The challenge moving forward is not only to maintain these systems using similar methods that created them, but to test new aggressive combinations as the application of no one management practice can accomplish what we need. For example, we need to mow at different intensities within burned areas, use herbicides at different frequencies within other management areas and to spot control shrubs, or use grazing combined with other management. We also need to address the issue of woody debris left by mowing which impedes seedling germination and enriches soil.

We also need to address new threats such as new and existing invasive species, habitat fragmentation, increased nitrogen deposition, mesopredators, and climate change. The achievement of overall goals hinges on existing ecology, available seedbank and/or proximity to seed rain, management practices, important management variables, and whether they are applied in combination. We also need to focus more on responses of individual target species as there is little known about how to manage for individual species.

We are recommending the next steps below regarding management:

Management Recommendations

Fire

Do a summer research burn and then do and compare other management techniques to see if we can find replacement for summer burning.

Grazing

1. Develop a group position paper on grazing in conservation lands
2. Do work on anthropogenic lands with animals to get conservation outcomes (Farm Institute and Bamford Preserve on Martha's Vineyard, new Dartmouth, MA land).

Combination Treatments

1. Create Truro like plots in sandplain system and test various combinations of treatments.
2. Piggy back on top of management already happening to do research. Push smaller areas within larger area harder as experiments by introducing combinations of management to the mix.
3. Work with Heritage to develop soil disturbance protocol.
4. Research different mowing/forestry equipment to see if we can find tool to break up mowing debris.
5. Implement one-acre research project on Nantucket in area where soil disturbance is not an issue to determine method for breaking up mowing debris.

Monitoring

Review monitoring chapter before writing.

New Research Needed

1) There is a need to test combinations of management techniques both for creating and maintaining sandplain grasslands as field experiments. These combinations could be set up as sub-plots that receive different mechanical removal techniques to test the response desirable and non-desirable species.
2) Further research about conversion of forest and shrubland to sandplain grassland could involve a more detailed examination of large-scale soil disturbance in land that has been deforested. Experiments might focus on comparing the response of vegetation composition over time in deforested areas that have been harrowed versus undisturbed soil.

3) Improve understanding of how infrequent or rare plants respond to different conversion combinations. These rarer plants are some of the major targets for sandplain grassland management and often have life histories that differ from closely-related but more common species. There is currently almost no information on how these species respond to management practices associated with conversion, whether via seedbank or seeding.
4) Test combinations of mechanical and chemical removal of non-desirable plant species with other management techniques such as prescribed fire, grazing, and/or mowing. These combinations should be designed and monitored as field experiments. These combinations could be set up as sub-plots that receive different mechanical removal techniques to test the response desirable and non-desirable species. Specifically, prescribed fire should be researched as a potential first stem for removal of exotic, cool-season grasses.
5) More work is needed to determine how such a conversion or management affects the mortality and population dynamics of animals that use agricultural lands. These effects may be particularly important for less common and conservation target species that have small and dispersed populations. It is also important for higher-profile species such as birds and for more common species such as some invertebrates or meadow voles that are important prey of grassland birds.

Areas for Future Discussion

This guidance document did not address several issues that are important to managing sandplain grasslands across the range of these grasslands. These issues include:

1. Should we do a regional scale conservation plan for this habitat?
2. What is the best use of each grassland site?
3. How important is connectivity across the system and should we do anything different to facilitate connectivity?
4. What policies could be changed or created to facilitate creation and maintenance of these systems?