
Zhi (Richard) Li

Advisor:
Professor Brian Donahue

BRANDEIS UNIVERSITY

Senior Thesis
for
Undergraduate Program in Environmental Studies

Committee:
Professor Brian Donahue
Professor Colleen Hitchcock
Professor Eric Olson

May 2017
Abstract

Open lands, including agricultural lands, grasslands, shrublands, non-forested wetlands, and other early successional habitats, have shown a substantial decline in New England over the past 150 years. Many open land species depending on these habitats are now in a dangerous situation. This study examines the open lands and open land species in southwest Lincoln, Massachusetts. This research answers five questions regarding Lincoln’s open lands: (1) What role does history play in creating the current landscape? (2) What are the natural communities and land use in southwest Lincoln? (3) What species depend on open lands as habitats and which parts of the open land ecosystem do the species of concern play? (4) What are some existing management regimes and conservation conflicts? (5) What are some potential management measures to conserve open lands and open land species? Recognition of the cultural, biological, and social values of these early successional habitats emphasizes that in this region of New England, open lands are predominantly artificial and intimately related to the history and interests of humans. The decreasing biodiversity in open lands and the uncertainty of management effects underscore the urgency of adopting proactive and adaptive conservation regimes.
# Table of Content

## Chapter I. Introduction

I.1. The Transformation of Open Lands  
I.2. Background of the Town of Lincoln, MA  
I.3. The Definition of “Open Lands”  
I.4. The Objectives of This Study

## Chapter II. The History of Open Lands in New England and Lincoln

II.1. The Reasons of Studying History  
II.2. Overview of the Open Land History in New England  
II.3. Glacial Dynamics and Legacies  
II.4. Prehistory, Before 1600  
II.5. Colonial Period, 1600-1775  
II.6. The Market Revolution, 1775-1850  
II.7. Concentrated Production, 1850-1920  
II.8. Suburbanization and Agricultural Decline, 1920 to Present

## Chapter III. Current Natural Communities and Land Use in Lincoln

III.1. Overall Description of the Study Area  
III.2. The Physical Features and Ecology of Each Field  
III.3. Types of Natural Communities/Land Use and Ecology

## Chapter IV. Species of Concern in the Study Area

IV.1. Introduction  
IV.2. Grassland Species  
IV.3. Grassland Birds  
IV.4. The Bobolink (*Dolichonyx oryzivorus*)  
IV.5. The American Kestrel (*Falco sparverius*)  
IV.6. The Eastern Bluebird (*Sialia sialis*)  
IV.7. The Eastern Spadefoot Toad (*Scaphiopus holbrookii*)  
IV.8. Pollinators  
IV.9. The American Black Duck (*Anas rubripes*)  
IV.10. The Northern Leopard Frog (*Lithobates pipins*)  
IV.11. The Spotted Turtle (*Clemmys guttata*)  
IV.12. The Eastern Ribbon Snake (*Thamnophis sauritus*)  
IV.13. Beavers (*Castor Canadensis*)  
IV.14. Winter Moth (*Operophtera brumata*)/Gypsy Moth (*Lymantria dispar*)  
IV.15. Invasive Plant Species

## Chapter V. Existing Management

V.1. Introduction  
V.2. Management at the National Level  
V.3. Management Practices in Massachusetts  
V.4. Management at the Local Level  
V.5. Other Local Stakeholders  
V.6. Management of Each Parcel  
V.7. Challenges to Open Land Managements in Lincoln
Chapter VI. New Management Measures

VI.1. Introduction
VI.2. Re-examining the Objectives of Land Conservation and Management
VI.3. Convene Partners to Create an Inventory of Species and Establish Monitoring Programs
VI.4. Monitor and Modify Current Agricultural Practices to Ensure the Compatibility of Agriculture and Conservation
VI.5. Research and Experiment the Effects of Prescribed fire on Managing Grasslands
VI.6. Continue to Protect Wetlands and Identify Critical Wildlife Habitat within Wetlands
VI.7. Educate Local Farmers and Residents to Raise Awareness of Environmental Issues and Increase Engagement in Conservation Activities
VI.8 Conclusion

Chapter VII. Conclusion

VII.1. The Philosophy of Open Land Conservation
VII.2. Limitations of this Study and Future Direction
VII.3. Conclusion

Acknowledgement

Works Cited
Chapter I. Introduction

I.1. The Transformation of Open Lands

New England is the most forested region in the United States today, with over 75 percent of forest coverage in some regions (Foster, et al., 2010). However, most of the land currently dominated by trees were tilled lands, hayfields, pastures, shrublands, and other types of early-successional lands over a century and a half ago. For example, farmland represented over 70 percent of all land in Massachusetts (Foster & Amber, 2004, p75). Since the 1850s, open lands have decreased at a precipitous rate. Many species which Henry David Thoreau commonly observed in Concord’s open lands such as upland sandpipers (*Bartramia longicauda*), eastern meadowlarks (*Sturnella magna*) among others are now rare, some of which are listed as Massachusetts’s endangered, threaten, or rare species (Foster, 1999).

The massive and rapid change of the open lands in New England was due to humans. The transformation of land-use practices in northeastern America resulted in the rise and fall of these open lands over the last 300 to 400 years. The peak of open land abundance was the result of forest clearance and gradual increase of agrarian landscapes (Foster & Motzkin, 1998). This trend was followed by agricultural abandonment and reforestation.

Today’s scarcity of open lands reflects the lack of disturbance by humans. The imperiled open land species and habitats today lead to a philosophical argument: whether we should protect open lands for their biodiversity and ecological services, given that they are mostly created by humans. The feasibility and effectiveness of conservation practices add another layer to the challenge.
I.2. Background of the Town of Lincoln, MA

As a historical town located in the outskirts of Boston, Lincoln, MA had an analogous transformation of open lands. The broad variety of natural communities, diverse types of land use, and rich literature legacies make Lincoln the perfect place to study open lands. Today there are 29 types of natural community and 5 types of agricultural production in Lincoln (Town of Lincoln, 2017). Henry David Thoreau’s rich records of Walden Pond and its surrounding area also provide insightful information to study the open lands Lincoln. Additionally, the town’s strong support for conservation serves as a model to analyze the management of open lands.

Before the town was established in 1754, the area that became Lincoln was owned by three adjacent towns: Concord, Lexington (once part of Cambridge), and Weston (once part of Watertown) (MacLean, 1988, p1). The focused area of this research is located in the southwest side of Lincoln, a section which dominantly belonged to Concord prior to 1754. It is now mainly composed of four sections: Baker Bridge Fields, Codman North, Codman South, and Codman East.

The study of Lincoln’s history before 1754 can be conducted through the historical records of Concord. Moreover, given the adjacency of two towns and the shared agricultural tradition, the transformation of Concord’s landscape is parallel to Lincoln’s after 1754. This study partly relies on Concord’s historical transformation to reflect the history of Lincoln.

I.3. The Definition of “Open Lands”

This study distinguishes between the two terms “open space” and “open lands.” The term “open space” is typically used in the realm of land use planning. It refers to undeveloped areas that are accessible to the public. Woodland is normally included in this definition of open space.
On the contrary, “open lands” typically refers to farmlands, including hayfields, pastures, and tilled lands, and natural communities such as barrens, heathlands, shrublands, grasslands, and other non-forested uplands (MNHESP, 2010). Besides uplands, this study also broadens the definition to include non-forested wetlands because they played a critical role in the history of land use in New England and because they support a large number of open land species. All these lands experience periodic disturbances that maintain their openness. Otherwise, in most cases these early successional communities would go through succession and will be replaced by woods (Bazzaz, 1996).

I.4. The Objectives of This Study

Identifying scales, rates, and causes of historical transformation is the prerequisite for sustainable open land management. Any effective open land policy requires the consideration of the history and the dynamic nature of the landscape. The knowledge of forests’ and open land’s composition and their likely ecological trajectory can help guide decision making. In addition, not only are land managers required to create an inventory of flora and fauna species of concern, but it is necessary for them to understand each species’ role in the ecosystem. Management of open lands also integrates environmental concerns with socioeconomic interests. Besides maintaining open land for biodiversity, the interests of different groups should be balanced and satisfied to achieve successful conservation. Economic, social and cultural factors can either support or hinder land management.

The current study desires to accomplish five objectives regarding the open lands in southwest Lincoln, MA:
1. Study the historical transformation of landscapes in southwest Lincoln and human interactions in the framework of New England history;

2. Categorize natural communities and land use within the study area and analyze their ecological roles in supporting open land species;

3. Create an inventory of flora and fauna species of concern in southwest Lincoln and interpret their biology and ecology

4. Understand current management practices associated with open lands along with open land species and identify conflicts as well as opportunities regarding Lincoln’s open lands;

5. Propose future management regimes to conserve open lands and open land species in the study area.

Each chapter from Chapter II to Chapter VI is designed to accomplish one of the objectives. The final chapter reflects the relationship between human and nature and concludes the need of open land management.
Chapter II. The History of Open Lands in New England and Lincoln

II.1. The Reasons for Studying History

No piece of landscape comes into existence suddenly. The way a piece of landscape forms is determined by the joint forces of nature and human throughout the course of thousands of years. Studying landscapes and species requires knowledge from multiple disciplines (Whitney, 1994). Historians and geographers have traditionally contributed to the temporal and spatial elements of the picture (Sauer 1938). Aldo Leopold once emphasized the need to interpret history through the lens of ecology (Whitney, 1994, P4). Previous patterns of land use and disturbances are difficult to discount (Foster et al., 2008) because they are revealed in the contemporary landscapes. The integration of history and science helps for understanding the change of landscapes, recognizing species of concern, determining objectives of policy and management, and generating adaptive techniques (Foster & Motzkin, 2003). The study of a type of land would never be comprehensive without an understanding of the past.

II.2. Overview of the Open Land History in New England

One should keep in mind that the landscape of New England has been dynamic, going through a number of substantial ecological transformations (Foster, 1999). It is not unrealistic to construct a timeline marking the alteration of open lands. Many researchers believe that grasslands and heathlands existed before humans entered the stage (Whitney, 1994; Askins, 2000). The prehistorical landscape was gradually shaped by climate as well as natural disturbances such as wind, fire, ice, and pathogen (Foster & Motzkin, 1998). In terms of the range of prehistorical open lands, limited paleoecological, archaeological, or historical evidence
was found to support that natural disturbances reached a sufficient level to maintain open lands (Foster & Motzkin, 2003).

*Homo sapiens* have been intentionally and unintentionally caused the transformation of landscapes to various degrees. Humans arrived in North America as the ice sheet retreated, and gradually aggregated influences on the land. Native Americans used fire for facilitating agriculture, horticulture, and hunting (Whitney, 1994; Donahue, 2004; Foster & Motzkin, 2003). Although some researchers believe that prehistorical fire set by Native Americans created open lands, reliable evidence supporting the extent of open lands is limited.

The massive transformation began with the arrival of European settlers through the creation of agricultural fields, pastures, and hayfields. Due to agriculture, forested wilderness transformed into open lands. This process reached its peak during the mid-19th century (Foster, 1999) when farmlands constituted more than 50% of all land in New England. The increase of open fields provided habitats for many open-land plants and animals. Many species, such as Eastern meadowlarks, grasshopper sparrows and so on, have migrated from the Midwest and “naturalized” into New England. On the other hand, the generation of forest fragmentation accompanied by the decline in species that rely on forests, including vultures, eagles, herons, etc. The transformation from wild and forested lands to fruitful gardens also involved fighting against carnivores including bears and wolves (Whitney, 1994, p300). Hunting further decreased the population of deer, turkey, elk, and buffalo and other game at an unprecedented rate. Yet this situation did not last more than a century. Changes to markets economy and technological revolutions substantially altered farming tradition and resulted in farmland abandonment. The consequence of this trend was the regeneration of woody plants and the decline of open lands.
However, suburban sprawl has resulted in more forest fragmentation since 1950. Today, there is a widespread recognition of the abundance of forests throughout New England, containing 33 million forest acres of 42 million total acres (Motzkin & Foster, 2002; Foster et al., 2010). On the other hand, the notable decline of bobolinks, meadowlarks, grasshopper sparrows, and woodcock reflects the dramatic decrease of open grasslands, shrublands, and pastures (Foster, 1999). The forest and grasslands in New England have been through a substantial change in their fauna and flora that not many places in the world can compare (Haggett 1979, Klopatek et al. 1979).

Before 1754, the land that became Lincoln belonged to Concord, Cambridge, and Watertown. Like other towns in New England, Lincoln experienced first the depletion and then the regeneration of forests, as well as the disappearance of once-abundant hayfields, pastures, and shrublands. The historical stone walls and old barns marks its farming legacy. During the heyday of agriculture in the 1850s, the town of Lincoln reached 90% of open land coverage (Town of Lincoln, 2017). Investigating the history of colonial Concord gives a picture of nowadays Lincoln. Given the parallel of agricultural practices and development, the history of Concord after 1754 also serves as a reflection of Lincoln’s. It was a critical moment when the railroad came through in 1844. From then on, Lincoln’s emphasis gradually transformed from agriculture to residential. The transformation of Lincoln fits perfectly into the model of landscape alteration in New England through the history.

II.3. Glacial Dynamics and Legacies

The picture would not be complete without investigating the movement of glaciers and the melting of them before humans entering this area. During the past two and a half million
years, a number of cold glacial periods have been followed by shorter and warmer interglacial periods (Donahue, 2004, p25). Since the last interglacial period, a glacier gradually expanded southward as the temperature dropped in the recent ice age. The Laurentide ice sheet which was as high as one mile covered most of New England at the peak of the last glaciation period over 15,000 years ago (Foster et al. 1998, p21; Whitney, 1994, p42).

The glacial movement left unique features on the landscape (Town of Lincoln, 2017), and contributed to the diverse assortment of soil (Donahue, 2004, p32). One of the surface characteristics created by this movement was drumlins. Created by drifting of ice over compacted boulders and other glacial sediment, these mounds of till have served as ideal locations for pastures or orchards (Millington, 1930, Winer, 1955). Another way that the glacier shaped the land was through depositional landforms. During the glacier’s expansion southward through New England, it scraped away pieces of bedrocks and deposited them as it melted. These diverse sizes of deposits formed glacial till which is mostly found in upland Concord (Donahue, 2004, 27). The flow of streams produced by the melted glacier carried sands and gravel and deposited them as the water slowed (Strahler 1966).

The deposits left by meltwater consists of two types. One type is composed of finer sands and silt and the other is coarser and more droughty. The former was suitable for agricultural uses, whereas the latter was not conventionally as valuable (Donahue, 2004, p30). Much of south Lincoln was created by the deposition of fine till and silt that forms a delta-shaped outwash (MacLean, 1988, p5).

As climate continued to influence the formation of soil, and as organic matter accumulated in deposits, the resulting soil in the town of Concord, MA consists of 75% of
upland soils mainly developing in glacial till and 25% of mucks and peats (Donahue, 2004, p30-31).

The focused area of this study encompasses of three types of soils: sand and gravel, floodplain deposits, and till or bedrock. Most of the Baker Bridge Fields contains sand and gravel, while the wet areas on the east were dominated with floodplain deposits. Floodplain deposits extend to the northeast side of Codman North. The rest soils of Codman North and Codman East have developed on glacial sand and gravel. Codman South has the combination of sand and gravel till and bedrock, with the latter only outcropping in areas around the west pasture (“Walden Woods Webmap”).

The climate has been relatively stable from 1500 to present in Northeastern United States (Whitney, 1994, P5). The climate in Eastern North America has more continental characteristics (Whitney, 1994, p48). Warm and humid flow from the Gulf of Mexico and maritime tropical air collectively determine the hot summer in New England. In winter, dry and cold air from north-central Canada continues to affect New England (Whitney, 1994, p48-49). Winters during the time of settlement were described as having “deep snows and bitter frosts” (Josselyn, 1675). The fluctuation of temperature is more extreme compared to Old England’s throughout the year. The climate and soil in New England have been the primary determinants of New Englanders’ agricultural practices since the seventeenth century.

Many pieces of evidence have confirmed the high coverage of original forests in New England prior to the arrival of Europeans in the seventeenth and eighteenth centuries (Whitney, 1994). Since the retreat of the ice sheet, different tree species arrived in New England as the climate started to warm (Foster, 1998, p21-22). The oak forest dominating southern New England was regularly disturbed by fire. Burning often kills northern hardwoods and Eastern
hemlocks, whereas fire and sandy soils are beneficial to pitch pine’s establishment. Thus, this natural disturbance contributed to a diverse forest composition with northern hardwoods, hemlock, and white pine. Wet areas including ponds formed by beaver tend to form wet meadows and forested swamps (Donahue, 2004, 37-38).

It is agreed that chronic and intense disturbance is also the primary factor allowing the development of grasslands and shrublands, either caused by human or not (Raup, 1937; Whitney, 1994). Tracing the size, pattern, and persistence of these open lands requires the understanding of the scale of these disturbances.

II.4. Prehistory, Before 1600

Native Americans

In addition to natural disturbance, native populations modified the habitat composition both intentionally and unintentionally. Native Americans were challenged by the predisposition of the forest-dominant landscape, yet they managed the fauna and flora and obtained resources from diverse ways. Native Americans in New England were mobile as food sources shifted among different seasons (Donahue, 2004, p38). There are also indications to suggest they modified the breeding of certain weedy plants which provided oily and starchy seeds (Smith, 1992). Horticulture was further advanced in the Late Woodland period.

Archaeological reconstructions suggest that fire was a tool for the Native Americans to manage their forest during Woodland period (3000-500 BP) (Johnson, 1996; McWeeney, 1994, 2003). Fire was useful in increasing acorn and nut and berry production, and generating grasses and new leaves for deer browsing (Donahue, 2004, p38). Other uses of fire also included the facilitation of traveling, and the improvement of game habitats (Whitney, 1994, p108). In general,
vegetation on the finer soils was burned to develop horticulture and agriculture. Since 1,000 years ago, tilled lands with the combination of corn, beans, and squash became more popular among the Native Americans (Donahue, 2004, p40). The cultivation of this combination was achieved through slash-and-burn (Donahue, 2004, p43). Cutting trees left debris on the surface. Fire turned the debris into a rich coating of wood ashes which are beneficial for planting (Whitney & Davis, 1986). Since their fields faced the problem of depletion of fertility, the sites for maize plantation were mobile and short-termed (Foster et al., 2008).

The resulting landscape from prehistorical residents’ activities was mosaic in vegetation types and ages (Whitney, 1994). The prevalence of pitch pine and white oak in Concord prior to European Settlement indicates that fire used by Native Americans was a force modifying vegetation compositions (Whitney & David, 1986). Certain species such as quail, turkeys, ruffed grouse, and deer benefited from the edges and open fields (Thompson & Smith 1971).

An Unresolved Question

In heavily wooded environments, disturbance, either natural or man-made, is always the prerequisite for clearing forests and creating open space habitats. With such disturbance from nature and Native Americans, did European settlers start with a considerable amount of open lands when they settled down? Was the fire used by indigenous people substantial enough to prevent forest succession? One of the most controversial arguments of New England’s open land history is the abundance and distribution of grasslands and shrublands before the arrival of European settlers. Several issues need to be resolved before reaching a conclusion about the abundance of prehistorical open lands.
First of all, the population and agricultural demands of Native Americans need to be evaluated because their use of fire might be closely related to the abundance of open lands. Since most of the fire was set by Native Americans, the impacts of fire on creating open lands were shaped by the agricultural and hunting needs of the local population (Cronon, 1983). Given the absence of cattle, it is dubious that they had incentives to maintain the openness of grasslands, and that their land use practices created persistence of these habitats (Motzkin & Foster, 2002).

Some extent of openness was created by slash and burn. However, the majority of the historical records of burning refer woodlands, but little is related to burning in open lands (Foster & Motzkin, 2003). Fire in New England landscapes was useful for maintaining cover types and understory in woodlands. It was not conducive to the development of grassland and heathland vegetation (Dunwiddie & Caljouw, 1990; Patterson et al., 1983; Foster & Motzkin, 2003). Even if Native population started much pre-European fire, the effect of fire on modifying vegetation also depends on climate and original vegetation (Parshall & Foster, 2002). Comparing to coastal areas of southern New England, upland areas of southern New England have less fire because the latter are cooler, moister, and were more sparsely populated (Whitney & Davis, 1986).

Moreover, the credibility of early account of open lands should be closely examined. Ethno-historical records have a trend of supporting the existence of open lands (Motzkin & Foster, 2002). Yet Motzkin and Foster (2002) call attention to the inaccuracy and exaggeration in such records from earlier explorers, traders, and settlers. A lot of the historical evidence on fire used by Native Americans are based on second-hand information or rely on undetermined sources (Whitney, 1994, p109).

The debate of biological evidence should be carefully studied before inferring the existence of prehistorical open lands. Some researchers attempt to draw indications from
biological evidence to support the abundance of pre-historical grasslands. The fact that current endemic species relying on open land habitats tolerate fire has been used to argue for the influence of such habitats (Schweitzer & Rawinski, 1987; Dirig, 1990; Askins, 1997, 2000). However, there should be more caution while using certain species as indicators of open space habitats, since they might not be specific to such habitats (Dirig, 1990). Evidence for pollen does not support the persistence of grasslands in New England, besides wet meadow in a substantial scale (Donahue, 2004, p 45).

Lacking significant amount of palaeoecological document to support the occurrence of grasslands and heathlands increases the difficulty in studying the abundance of open lands before the arrival of Europeans (Dunwiddie, 1990; Stevens, 1996; Parshall et al., 2003). The reliability of evidence supporting open land habitats should be carefully examined. However, it is reasonable to assume that some extent of open lands existed in the pre-European landscape. Forests were cleared as Native Americans used slash and burn to create tillage lands. Other uses of fire by Native Americans and natural fire could also create periodic open habitats. In order to estimate the distribution and abundance of open land prior colonization, the following questions need to be answered:

- What is some evidence to support the parcel-wise distribution and population of Native Americans?
- To what extent did Native Americans’ activities, including hunting, horticulture, and fire, affect the natural environment?
- How does the understanding of prehistorical patterns of open lands help guide current management and conservation practices?
Unlike upland grassland, wetlands were considered to be common along rivers and brooks during the pre-European age. Grassy meadow, forested swamp, marsh, and bog were the main types of wetlands in Concord, MA (Donahue, 2004, p48). These habitats were created not only by climate and topography but also by beavers and humans who actively managed them (Donahue, 2004, p49). Beavers created dams and knocked down trees, generating ponds and open habitats which supported diverse types of species. Wetlands were resourceful fields for foraging food, e.g. fish, mussels, turtles, snakes, and berries. Donahue (2004, p49) suspects that Native Americans might have been using fire to prevent woods from growing in these areas.

During this period, there were small fragmentations of meadow and swamp in our focused areas. The west of Codman North contained a swamp by the stream. However, given that forest spanned across 95% of the original Concord boundary, the majority of the study area was covered by forest (Donahue, 2004, p42).

II.5. Colonial Period, 1600-1775

In 1620, William Bradford described eastern Massachusetts as a land that had “a weather-beaten face, and the whole country, full of woods and thickets, represented a wild and savage hue" (Bradford, 1620). The Northeastern part of the country was first dominated by large trees, but widely scattered populations of American Indians. The early settlers who landed in the country were always amazed by the size and density of the trees. They soon realized that the climate, soils, and vegetation in New England, substantially different from the ones in England, posed various challenges. These new settlers gradually evolved a practice of mixed husbandry that has been sustainably supporting their living in the following centuries (Donahue, 2004, p87).
**Tilled Lands**

The management of tillage lands by early settlers was similar to Native Americans’. The first few generations of settlers actively transformed the forests to agricultural lands through slash and burn. What challenged them was the sandy soil with a lot of rocks in the fields left by glacial movement. These rocks were removed by early generations from the fields and became the material for stonewalls used to enclose private property. It did not take a long time for the colonists to realize that wheat and other grains from England did not perform well in New England’s long winter and coarse sand, and Indian corn and rye, which were more suitable, became the primary crops planted in the seventeenth and eighteenth centuries (Donahue, 2004, p89). Vegetables and herbs were planted in gardens to provide supplementary nutrients (Foster et al., 2008). As New Englanders grew rye, barley, potatoes, corn, beans, and squash in different soil types, and used orchards to grow apples, their diet became more diverse and nutritious over generations (McMahon, 1985).

The major issue posed by arable fields was the lack of organic matter. The acidic and thin soil was far from being fertile (Donahue, 2004, p90). Even though the fields created by fire were fertilized by ash, the depletion of nutrients over several years of cropping demanded a solution for sustainable farming. General tilled lands did not constitute a large portion of the agricultural fields for most of the town, and most towns had less than 10% of tilled land in a year (Foster et al., 2008). The upland sandy and droughty soils were not ideal for tillage. The reason that Concord farmers’ favored them might be because they were relatively easy to plow (Donahue, 2004, p158).
To maintain the fertility of the soil, New England farmers applied manure to the fields. Cattle were a critical part in their stock. Integrating tilled lands with livestock, early generations adapted the system of farming in England to New England’s soil and climate.

**Pastures**

Cattle were the primary source of dairy, meat, locomotion, and manure. One way that colonists raised their cattle was by grazing. During this period, different lands were grazed: mowed lands, fallow lands, tilled lands, and unsettled outlands (Foster et al., 2008). Tilled fields were grazed once the crops were harvested. Farmers brought their stock to graze in upland forests too. Rocky and steep upland areas that were inferior to be plowed were transformed into pastures (Whitney, 1994, p253). Gradually, New England farmers expanded areas suitable for grazing by clearing forests.

However, there were several challenges for grazing during the early colonial period. First, because a limited percentage of common area was open, not many uplands were available for grazing (Donahue, 2004, p95). Second, the climate in New England led to numerous problems. Grass and legumes were not available for over five months because of New England’s cold winters (Winthrop, 1976). The dry summer and sandy soil further lowered the quality of pasture during midsummer (Donahue, 2004, p96). Third, the grasses native to New England were not desirable for grazing.

Grasses grew in New England uplands before European settlement include little bluestem (*Andropogon scoparius*), poverty grass (*Sporobolus vaginiflorus*, *Aristida dichotoma*, and *Danthonia spicata*), hairgrass (*Agrostis scabra*) and panic grass (*Panicum ssp.*) (Giuliano & Daves, 2002; Donahue, 2004, p95). Not only were they harsh and coarse once matured, but they
were not resistant to trampling and grazing (Kalm, 1972, Sauer, 1941). Furthermore, they contained little nutrient as feed for livestock (Edwards 1948).

One way of solving the problems of grazing was by planting European species. These species include white clover (*Trifolium repens*), Kentucky bluegrass (*Poa pratensis*), redtop (*Agrostis gigantea*), Timothy (*Phleum pretense*), and red clover (*Trifolium pretense*) (Whitney, 1994; Foster et al., 2008). They were preferable by New England farmers because they provided earlier forage and because they were more productive. Some of them, such as white clover and Kentucky bluegrass were brought unintentionally by early settlers (Russell, 1976), whereas others were deliberately introduced (Whitney, 1994, p251-252). European cool-season grasses and legumes soon replaced native grasses to dominate New England uplands (Whitney, 1994, p250-253). Apart from the introduction of European grasses, other reasons for the decrease of native grasses include unfamiliarity with the species, heavy grazing by early settlers, and repeated spring mowing (Jung et al., 1985; Askins, 1999; US Department of Agriculture; Giuliano & Daves, 2002). As a result, native New England upland grasses were never important in the northeastern agricultural system through history.

In addition, turning to wet meadows for grass compensated the dearth of high-quality pastures. Wet Meadows provided palatable grasses intermixed with coarse vegetation (Donahue, 2004, p96). The vegetation in freshwater meadows were predominantly native grasses and sedges (Lowell, 1831; Foster, 2001, p48); in saltwater meadows, black grass (*Juncus gerardi*) and *Spartina patens* were two important native species (Smith et al., 1981). These grasses became valuable feed for cattle. Since the colonial period, wet meadows have been critical to New England livestock industry.
Hayfields

However, pastures were unable to provide sufficient feed all year around. New England’s cold climate required a supply of hay and fodder for five months (Winthrop 1976). Upland hayfields and lowland wet meadows together provided forage during winters. Not only were they valuable for yielding hay, but manure collected from them was used to fertilize tilled lands.

There were three strategies to manipulate the productivity of meadows. First, drainage ditches were dug and dams were built to raise water level so that forests and shrubs from wetlands were converted to grasses and sedges (Foster, 1999). Second, grasses and herbs were mowed every year to improve harvests. Also, the colonists adopted the same tool used by Native Americans, fire, to prevent the growth of trees (Foster, 2001).

Managing hayfields was challenging. Since there were many types of wetlands, a broad variety of vegetation was found in Concord grasses, sedges, wildflowers, and young shoots of woody plants (Foster, 2001, p49). However, not all of them were suitable for feed. Some of the patches were vulnerable to flooding and too wet to be mowed.

In addition, manual mowing was very labor-intensive. The process involves cutting, drying the hay in hot sun and wind, raking it into rows or piles, bundling it into haycocks, and loading the hay onto wagons (Foster, 2001, p49). Furthermore, farmers were worried about having wet, moldy, or musty hay (Foster, 2001, p49). Therefore, farmers only mowed the fields once annually. Mowing did not occur until July and August (USDA, 1984).

Through generations of systematic management and harvesting, meadows were able to provide more reliable resources. Throughout the colonial period, more desirable English sedges and grasses were planted to replace native species and meet the increasing demand for hay.
Species include redtop, Timothy, and red clover were more abundant in uplands where wet meadows were scarce (Motzkin & Foster, 2002).

**Wood and Timber**

Another key element in the colonial livelihood was wood. New Englanders required substantial amounts of fuel to sustain them through the cold winter in New England. Timber was also harvested to build houses, barns, bridges, poles, furniture, carts, etc. Farmers would spend much of the winter in woodlands, either in private properties or common (Donahue, 2004, 97-98). The process of tree cutting corresponded with the creation of open lands.

**The Study Area during the Colonial Period**

Early towns like Concord, Cambridge, and Watertown held land in common through the form of communal farming. As the village of Concord was established along a stretch of fine silt loam that supports grassy meadow (Donahue, 2004, p78), agricultural fields clustered at the center of old Concord. The southwest part of Lincoln, the study area, was barely utilized by Concord’s farmers during the first generation of migrants (Donahue, 2004, Plate 3). However, after 1650, the land was granted to a variety of individuals during the Second Division (MacLean, 1988, p66-67). Tomas Flint and Reverend Peter Bulkeley were two of the immigrants in Concord. Bulkeley acquired 1050 acres of lands within Lincoln’s boundary during his lifetime, and Flint owned Flint Pond by the mid-17th century. Eventually, the Bulkeley and Flint families would own approximately one-sixth of Lincoln’s lands (MacLean, 1988, p14-19).

The majority of the land, including Codman North, Codman East, and Baker Bridges’s Fields, was among the 750-acre-land granted to Bulkeley. Part of Codman South was among the
Biggs-Stow family’s grant of 666 acres, and the rest belonged to Oliver Barrett (MacLean, 1988, p66-71). These areas, converted to farmlands, were either passed down to heirs or leased to other farmers in the following generations.

*A Self-Sustainable System*

New England farmers set the tone for the following centuries by establishing a self-sustainable and mixed-husbandry farming system. The same self-sustainable model had been adopted for several generations. With an appreciation for labor, farmers in New England celebrated this bucolic aspiration. Their reliance on open farmlands and resources continued to shape the landscapes and impact species relying on these areas. Forests continued to be converted into agricultural lands. The pressure of having enough agricultural lands emerged as the population grew. For instance, by the end of the colonial period, every possible area that could be tilled by applying manure was occupied in Concord. The agricultural system in Concord was pushed to the limit of sustainability (Donahue, 2004, p203, p226).

**II.6. The Market Revolution, 1775-1850**

At the turn of the century, maritime trading expanded when more and more trading occurred along New England rivers. The urban population increased dramatically (Foster et al., 2008). These factors led to an unprecedentedly high demand for farm produce. The development of transportation, including roads, bridges, railroads, and canals brought connections to inland areas, facilitating the exchange of goods and money.

As more agricultural produce was required in the market, farmers’ aspirations changed. Rather than farming for their own family, they became market-oriented and started to grow cash
crops. The lands were pushed to a greater productivity to meet the demand of the market. The development of transportation, especially the construction of the railroad, allowed different regions to specialize in growing crops that best suited their local conditions. Throughout southern New England, profits from livestock business overshadowed profits from crops and other labor-intensive productions (Bushman, 1967). Farmers increased beef and dairy production by extending pastures and hayfields (Foster et al., 2008).

The output of upland English hay doubled during this period (Donahue, 2004, p228). Farmers reduced tilled lands to concentrate on the production of fodder and hay. By the second half of the eighteenth century, European cool-season grasses filled into the new open lands created by massive forest clearing by farmers (Whitney, 1994, p252). They gain advantages through the initial flush of nutrients (Steward, 1933; Colby, 1941). White clover came spontaneously (Colby, 1941). Hayfields were mostly dominant with Timothy and red clover, while Kentucky bluegrass and white clover prevailed in pastures (Welles, 1824, Cutler and Cutler 1888; Russell, 1976, p131). The dominance of alfalfa, clover, and cool-season grasses would continue to compose most of the New England’s agricultural grasslands until the end of the early nineteenth century (Dwight, 1969).

Swamps and wet meadows continued to produce hay as the number of ditches and drains grew. The expansion of hayfield could be exemplified by the grassland resources of Worcester Country, MA from 1771 to 1860. The total acreage of mowing had increased from 82,421 acres to 171,325 acres, and the areas of pasture had tripled during this time (Whitney, 1994, p254).

Schedule of farming also began to change with the help of technology by the 1850s. As a labor-intensive activity, mowing by hand was conducted once in July prior to the invention of mechanical hay harvesting equipment. However, when tedders and rakes became available in the
mid-19th century, farmers began to mow their fields twice, one time in April to late June, and another one in late summer and fall (Giuliano & Daves, 2002). Mowing two times annually allowed farmers to obtain maximum yield. Furthermore, forage mowed in early growing season contained high protein (Cherney et al., 1993), which led to higher milk production (Bosworth & Stringer, 1985). The second mowing was also desirable because the hay contained more leaves than stems.

Furthermore, wood and timber were extensively harvested as woodland areas shrank dramatically. Wooden products and firewood were in high demand. Extensive exploitation of forested resources and land clearing caused the dramatic decline of forest cover in Northeastern US. For example, there was about 25% of forest coverage by 1850 in Massachusetts (Donahue, 2004; Hall et al., 2002). The decrease of forested areas accompanied the rise of grasslands. There were up to 20 million acres of farmlands in the mid-nineteenth century across New England, producing feeds that sustained this economy.

The Towns of Concord and Lincoln

The town of Concord did not majorly convert to commercial production until the second quarter of the century (Donahue, 2004, p227-228). Farmers specialized in raising cattle to produce beef, butter, cheese, and milk for the market with some alteration in farming practices (Donahue, 2004, p228). During the 19th century, there were more pastures than hayfields in Massachusetts, even though there were some overlapping of the two. At the end of 1830, Concord was dominated with open agricultural lands, and forests were restricted to the least fertile and least accessible places (Foster, 2001, p210). The coverage of farmlands in Concord peaked at 89% in 1850.
In Lincoln, market-oriented farming was made possible by the urbanization of Boston. The advancement of technology and reduced cost of production were additional factors that contributed to a change of agricultural patterns in Lincoln. Since the service of the railroad in 1844, farmers continued to ship produce to the Boston market (MacLean, 1988, p418). The acreage of tillage lands increased by two-thirds from 1830 to 1850. Additionally, 450 acres of land were turned into hay production between 1830 to 1860 (MacLean, 1988, p439). At the same time, the areas devoted to grazing shrank from 2,900 acres to 1,700 acres during this period as pastures were converted to tilled lands and hayfields (MacLean, 1988, p441).

During winter, Lincoln farmers spent most of their time preparing wood and transporting it to meet the demand of the Boston market. For example, in the year of 1855, Lincoln farmers sold 1,173 cords of firewood for $4,994 (MacLean, 1988, p444).

*Environmental Responses*

The overall productivity of hayfield and pasture was greater than the earlier era’s, but these lands were in a vulnerable state. Without fertilizers, the acidic soils of New England undermined legumes’ ability to restore nitrogen. Many hayfields with European grasses suffered a decrease in yield. The export of nutrients, including calcium, potassium, and phosphorus, from soil was compensated by limited manuring (Whitney, 1994, p253). New England farmers increasingly suffered from the declining productivity of the fields caused by soil erosion and degradation.

In addition, cattle selectively ate palatable grasses over coarser grasses. Even though the fields were dominated by native plants including red cedar, white pine, juniper, steeplebush, meadowsweet, and huckleberries in this period, non-native brushy plants, including bracken fern
(Pteridium aquilinum), mosses (Polytrichum spp.), etc., and other unpalatable species become more and more abundant. They would eventually replace prime grasses in the fields (Donahue, 1999; Foster, 2001, Whiteney, 1994, p254).

Throughout the course of this period, New Englanders witnessed the disappearance of large animals such as lynx, bear, beaver, moose, deer, and wolf due to hunting (Foster, 2001, p213). Species with low productive rate (elk and bison) were killed because of the ease of hunting them (Silver, 1974; Genoways, 1986). Some carnivores like bear and wolf were intentionally eliminated because they were incompatible with the livestock-based economy in New England (Whitney, 1994, p306). Deer were extirpated by the mid-1800s, and beavers were absent by the 1700s (Foster, 1998).

On the contrary, grassland wildlife species were the beneficiaries due to the expansion of grassland habitats. During Thoreau’s age, grassland birds including bobolink, bluebird, meadowlark, field sparrow, and song sparrow were abundant in Concord (Foster, 2001, p15).

II.7. Concentrated Production, 1850-1920

With the introduction and advancement of steam power during the mid-19th century, industrialized revolution altered the landscapes, the social structure, and the way of living across the country. Shifting the focus to manufacture, many towns in Massachusetts moved downhill to access water-power (Foster, 1998). Factories that produced textiles and wooden products aggregated in cities, attracting the influx of labors from rural areas (Botts 1934). This period was marked by the increase in urban population during the early 20th century.

The rise of economic opportunities in cities coincided with the decline of agriculture (Foster, 1998, p38). Migration to cities correlated with the loss of population and farmland
abandonment in rural hill towns, yet this trend depended on regional geography (Foster 1998, p38). Towns closer to industrial cities, such as Worcester and Fitchburg, produced commodities to meet the demand of these densely populated areas, whereas remote towns waned faster (Pabst, 1941; Baker & Patterson, 1986).

Some New England farmers continued to specialize in producing commodities, vegetables, fruit, poultry, and hay, for other regions and urban areas. They succeeded in producing milk in 1900 four times as efficiently as in 1850 but significantly reducing the use of pasture. While yield per acre significantly increased, less agricultural fields were required to meet the demand. Farmers relied more on grains purchased from western states to feed their cattle. Their main concentration was on productive hayfields with heavy manure application where located in broad valley bottoms or gentle, rolling terrains (Foster et al., 2008; Foster, 2001, p9).

As fewer fields were required for agricultural purposes, the succession of trees appeared in old fields. White pine was one of the early colonizers. Numerous white pines were harvested for timber by the end of the nineteenth century. This trend reached its peak in 1910-1911 and continued to rise through the 1940s (Foster, 1998, p42). Simultaneously, hardwoods such as oaks, red maple, cherry, etc. gained advantages in succession from the opening of resources and constituted mixed hardwood forests (Foster, 1998, p43). Trees had returned to New England, with a coverage of about 50% of the landscapes by 1920, even though they were younger (Foster, 2008). During this same period, forest disturbances became more common due to human introduced pests or pathogens (Foster, 1998, p50). Some of the examples include gypsy moths, chestnut blight fungus, and Dutch elm disease.
The transformation of the landscape during this period significantly altered the composition of species that previously thrived in grassland habitats. The populations of bobolinks, meadowlarks, grasshopper sparrows, and woodcocks began to decline, and they continue to decline till today (Foster, 1998, p10).

Lincoln’s Development

In the 1850s, Lincoln was one of the least populated cities in Massachusetts (MacLean, 1988, p457). Nonetheless, the town which advocated agriculture gradually turned into an urbanized and industrialized society. Along with the development of transportation, more commuters from Boston chose to spend their summer in Lincoln. These summer residents helped boost the real estate in Lincoln and attracted many businessmen and professionals (P529-532). Because land became more valuable for real estate, farming was increasingly specialized (MacLean, 1988, p501). Milk and hay were two of the leading produce in larger farms, whereas smaller farms concentrated in producing cucumbers, eggs, poultry, etc. (MacLean, 1988, p525).

II.8. Suburbanization and Agricultural Decline, 1920 to Present

Southern New England suffered an economic decline from the 1930s to 1970s (Harrison & Kluver, 1989). Many factories and industries were closed during this period. Traditional agricultural produce was outcompeted by mass-production achieved through advanced technology and low-cost transportation. As a result, the total agricultural area declined steadily, constituting just 7% of the Massachusetts landscape today (Hall et al. 2002), while forests continued to grow back. However, there has been a resurgence of organic farms in recent years (Foster et al., 2008). As Massachusetts’s economics rose again after the 1970s, residential
development became a major force transforming the landscape. Since people desired to live in places where is accessible to major cities relatively easily, houses were built along major highway junctions in suburban areas. The low-density house-lots are dispersed in rural areas, creating fragmentation within forests. From 1971 to 1999, 164,837 acres of forest and 28,782 acres of cropland in Massachusetts were lost mostly due to suburban sprawl (Foster et al., 2008).

Lincoln after World War I

There was an influx of population to Lincoln in the twentieth century. The growth in population became more substantial after World War II (MacLean, 1988, p573). During the 1920s, the town established zoning to limit the growth of commercial and industrial activities (MacLean, 1988, p565). Lincoln continued to regulate zoning by-law and subdivide large properties. These regulations have transformed Lincoln as a single-family residential community today (MacLean, 1988, p567-568). The growth of residential area correlated with the decline of farmlands. Farmer numbers shrank from 63 people in 1950 to just seven individuals in 1970 (MacLean, 1988, p579-581).

The town started to emphasize conservation in the 1950s through the establishment of the Lincoln Land Conservation Trust in 1957 and the Conservation Commission in 1958. They work cooperatively to acquire land, monitor, and protect the environmental, historical, and aesthetic values in Lincoln. The non-profit farm established in 1973, Codman Community Farm, has been working on restoring the agricultural heritage of the town. Today, there are 547 acres of farmland in Lincoln.
Chapter III. Current Natural Communities and Land Use in Lincoln

III.1. Overall Description of the Study Area Today

Town of Lincoln is located in the east of Massachusetts, with a total area of 15.0 square miles. It is a commuting town 18 miles west of Boston. Paul Brooks refers to it as “a hill town, a wet town and a forest town” (Brook, 1976). Represented by Mt. Misery, Pine Hill, Pigeon Hill, and other high points, the hills reach 380 feet above sea level. In between the hills, wetland composes about 30% of the town’s landscape (Town of Lincoln, 2017). The stone walls and old barns surrounding most of the fields indicate the agricultural heritage of the town. Six hundred and thirty-eight acres were used for agriculture in 1976, yet the number has declined to its current 547 acres (Town of Lincoln, 2017).

This study focuses on open lands in southwest Lincoln (Figure 1). The north side of the study area reaches as far as the south of Pine Hill, the south ends at the south border of Codman South. The west boundary borders Route 126, and the east covers the red maple swamp at Codman East. This area encompasses a rich diversity of land use, including multiple types of agricultural fields and natural communities including wetlands and forests. Even though the study concentrates on open lands, it is critical to mark out forests, forested wetlands, and developed units, given that open lands and species among them are also influenced by the surrounding environment. The location of woodlands and residential units might also affect the features of adjacent open lands. Identifying other land uses also helps to understand the incentives and effects of open land management. The shrubby edges located between forests and agricultural fields are of particular concern because some edges are dominated by invasive species. Previous researchers have discovered that predator species are more prevalent in edges
between forests and pastures (Chalfoun, Ratnaswamy, & Thompson III, 2002). Nesting grassland birds also tend to nest away from edges (Renfrew, Ribic, & Nack, 2005).

This study follows the classification of Massachusetts Natural Heritage & Endangered Species Program (NHESP) to identify natural communities in the study area (MASSWILDLIFE, n.d.). They define natural communities as “assemblages of species that recur together in particular environmental conditions” (MASSWILDLIFE, n.d.). Natural communities are identified by dominant physical and biological features that classify groups of plants and associated animals. The type of natural communities reveals the structure, dominant species and characteristic species in these areas. All kinds of farmland are categorized as “cultural grassland” by NHESP, but this study further specifies land use in the study area. It is also necessary to indicate the presence of shrubs dominated by invasive plants and differentiate them with native shrubs. This study uses “>80% native shrub”, “>80% mixed invasive shrub”, “>70% buckthorn shrub” to represent the presence of shrubs in the maps. There are thirteen kinds of natural community/land use applied to identify the landscapes of the study area. They are tilled field, hayfield, pasture, non-agricultural grassland, >80% native shrub, >80% mixed invasive shrub, >70% buckthorn shrub, forest, open water, shallow emergent shrub, deep emergent shrub, and red maple swamp.
Figure 1. Natural Communities and Current Land Use of the Study Area. Created by: Li Z. (2017, April). This map identifies the range of the current study area in southwest Lincoln.

III.2. The Physical Features and Ecology of Each Field

*Baker Bridge Fields*

The first area is Baker Bridge Fields and their surrounding areas (Figure 2). The Baker Bridge Fields property is located south of Pine Hill and divided in the middle by Baker Bridge road. It is composed of 39 acres of open lands and about 63 acres of woodlands including forest swamp surrounding the brook and pond. Twenty-one acres of the field, including both north and south parts, are currently managed by The Food Project, a non-profit organization growing organic produce (LLCT, 2004). The tilled lands are surrounded by a belt of non-agricultural grassland.
The southeast side of the property contains a belt of tree species intermixed with dense understory dominated by glossy buckthorn (*Frangula alnus*). The tree canopy reaches as much as 25% cover so that it is categorized as “forest” in the study. Trees composing the canopy include red maple (*Acer ruburm*), Norway maple (*Acer platanoides*), and white pine (*Pinus strobus*). Invasive species including Japanese honeysuckle (*Lonicera japonica*) and multiflora rose (*Rosa multiflora*) also occur. Winterberry (*Ilex verticillata*) and these invasive species form a dense shrub layer that is less than 4 meters high. Deer trails can be spotted within this patch, indicating that white-tailed deer (*Odocoileus virginianus*) are actively using the surrounding habitats.

Further southeast lies a deep emergent marsh which was transformed from a red maple swamp through beaver activity. In the Lincoln Land Conservation Trust’s report in 2004, it was still a red maple swamp with a canopy coverage of over 25%. Understory used to have a variety of saplings: swamp white oak (*Quercus bicolor*), pin oak (*Quercus palustris*), American elm (*Ulmus Americana*), and white pine (*Pinus strobus*) (LLCT, 2004). However, through our visit in 2016, most of the red maples were dead, while the scattering of topless trunks remained as the tallest structures in the field. Other tree saplings were hard to discover among the dense cat-tail (*Typha sp.*), wool-grass (*Scirpus cyperinus*), and other sedge species. Beavers arrived over 20 years ago, manipulated the water level, and cut down trees. The gradual transformation from one type of wetland to another is solely caused by beavers.

The northeast side of the property contains a red maple swamp and a non-agricultural grassland adjacent to it. It is also noticeable that the non-agricultural grassland is also an important habitat for many grassland species including bobolinks (*Dolichonyx oryzivorus*) and
Eastern bluebirds (*Sialia sialis*). It is also common to observe pollinators in this area. The west side of the property is bounded by Route 126 and the railroad.

**Figure 2. Natural Communities and Current Land Use around Baker Bridge Fields.** Created by: Li Z. (2016, November). This map identifies types of natural community and land use around Baker Bridge Fields and Walden Field.

**Codman East**

The second area is around Codman East, whose west boundary borders the MBTA railroad track (Figure 3). Codman East consists of upland, wetland habitat, and seasonally mowed hayfield. The north part is hilly and dry with mixed oak forest. The vegetation is composed of red oak (*Quercus rubra*), white pine (*Pinus strobus*), hemlock (*Tsuga canadensis*), and low bush blueberry (*Vaccinium vaccillans*) covering the ground (LLCT, 2003). Half of the
south parcel is Farm Meadow, an annually mowed hayfield. The field is surrounded by a belt of shade-tolerant tree species and other herbaceous species that is approximately 30 feet wide. Most of the species are non-native: Norway maple (*Acer plantanoides*), tree-of-heaven (*Ailanthus altissima*), Japanese honeysuckle (*Lonicera japonica*), glossy buckthorn (*Rhamus frangula*), common buckthorn (*Rhamnus cathartica*), and Japanese knotweed (*Polygonum cuspidatum*). The railroad corridor marks the west boundary. A red maple swamp is found to the east of the hayfield. Besides red maple (*Acer rubrum*), the understory is formed exclusively by glossy buckthorn.

**Figure 3.** Natural Communities and Current Land Use around Codman East. Created by: Li Z. (2016, November). This map identifies types of natural community and land use around Codman East.
Codman North

The third area is at Codman North, which is bounded by the MBTA railroad and Beaver Dam Brook on the north side (Figure 4). The south boundary reaches as far as Codman Road. The north half of the property is marked by two types of wetlands: shrub swamp and red maple swamp. Standing by the brook looking to the south, one sees that the vegetation transitions from surrounding short sedges and ferns (*Osmunda regalis* and *Osmunda cinnamonea*) in shrub swamp to red maple (*Acer rubrum*), elm (*Ulmus sp.*), and dogwood (*Cornus sp.*) in the red maple swamp. The wetlands provide habitats for animal species include Eastern garter snake (*Thamnophis sirtalis*), wood frog (*Rana sylvatica*), and widow skimmer dragonfly (*Libellula luctuosa*) (LLCT, 2004). As the hill rises in the south, the landscape becomes an oak-maple forest, with a dense stand of hemlock (*Tsuga Canadensis*) (LLCT, 2004). However, these hemlocks are threatened by the Woolly Adelgid parasite.

The field by Codman Road is a pasture managed by Codman Community Farm, which is a historical non-profit community farm aiming to preserve Lincoln’s rural heritage. The field used to be managed as a hayfield, and it was converted to a pasture recently. A belt of glossy buckthorn and other mixed invasive shrubs encompasses the field. There are also roadside trees planted on the non-agricultural grassland by Codman Road.
increasingly hard to find in Lincoln, this habitat is of high ecological importance. Fox scat and

(Figure 4. Natural Communities and Current Land Use around Codman North. Created by: Li Z. (2016, April). This map identifies types of natural community and land use around Codman North.

*Codman South*

The last parcel is around Codman South (Figure 5). It is bounded by Codman Road on the Northeast and Route 126 on the Northwest. The parcel is separated into agricultural fields, a red maple swamp, and an upland oak-maple forest on the east. The farmlands that are leased to Codman Community Farm have recently been transferred from hayfields to pastures. The forest supports native tree species and rich understory and saplings. Shade-intolerant species such as Norway maple (*Acer platanoides*), tree-of-heaven (*Ailanthus altissima*), and glossy buckthorn (*Rhamnus frangula*) are present around the property’s edges. Since oak-maple forests are increasingly hard to find in Lincoln, this habitat is of high ecological importance. Fox scat and red-tailed hawk feather were previously witnessed in this area. Due to its proximity to Mt.
Misery, Codman North, and Baker Bridge’s fields, it serves as a wildlife corridor that connects these parcels (LLCT, 2004).

Figure 5. Natural Communities and Current Land Use around Codman South. Created by: Li Z. (2016, April). This map identifies types of natural community and land use around Codman South.

These fields are of great study interest for several reasons. First, all four pieces of land cover different kinds of agricultural lands, and they support a broad range of flora and fauna species. For instance, Lincoln’s residents have reported witnessing grassland birds interacting within Baker Bridge’s tilled area. Understanding to what extent tilled land, hayfield, and pasture contributes to fauna species’ breeding and foraging behaviors, and how different biotic and abiotic factors presented in the fields affect these species helps resolve the question of compatibility between agriculture and conservation. Additionally, the ecological effect of the recent alternation of agricultural practice in Codman South and Codman North requires more
investigation. Concentrating on these areas would also identify a more ecologically superior farming practice, if there is one.

Second, invasive plant species, including tree-of-heaven, Japanese honeysuckle, glossy buckthorn, Japanese knotweed, oriental bittersweet, and etc., are all present in these four fields to different extent. It is urgent to understand the ecological roles of these species so that appropriate guidance could be followed to manage them without jeopardizing other species of concern and their habitats.

Third, the overall area covers a significant portion of wetlands, containing shallow emergent marsh, deep emergent marsh, and red maple swamp. As a town with approximately 30% wetland areas, Lincoln’s emphasis on the ecological value of these habitats would be more efficiently achieved by learning more about these areas. These wetlands also create edges adjacent to different agricultural fields. Multiple research articles have identified the avoidance of edges by grassland birds (Bollinger & Gavin, 2004; Renfrew, Ribic, & Nack, 2005). Studying edges between wetlands and agricultural fields is useful for the protection of crucial species.

III.3. Types of Natural Communities/Land Use and Ecology

Grasslands

“Grassland” is a broad term that covers various open land types. In general, it refers to a community dominated by grasses, whether it is generated by human or by nature (Missouri Agricultural Education, 2002). Cultural grasslands refer to the ones created by humans. In Lincoln, cultural grasslands can be further divided into two categories, agricultural grasslands and non-agricultural grasslands. Agricultural grasslands in New England are always in the form of pasture or hayfield, in which grasses and legume are intentionally planted or managed to
provide feed for livestock. Non-agricultural grasslands provide other services including conserving soil and water and recreation (Missouri Agricultural Education, 2002). Other types include abandoned fields, airports, and cemeteries. While grasslands can occur in areas with various types of soil, the soil in the studied grasslands is well-drained sand and gravel.

Grasslands are maintained by disturbances including burning, grazing, mowing, etc., the absence of which would allow shrubs and saplings to grow. They would go through the process of succession from grasslands to upland meadows, to young forests and eventually mature forests (Oehler, Covell, Capel, & Long, 2006). Therefore, this kind of habitat is referred as early-successional habitat.

Vegetation in Cultural Grasslands

In general, grasses can be divided into two categories, warm-season and cool-season grasses. Warm-season grasses include switchgrass (*Panicum virgatum*), indiangrass (*Sorghastrum nutans*), big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), and broomsedge (*Andropogon virginicus*). Warm-season grasses are grouped into this category because they grow best in warm temperatures. The optimal time for them is during summer when the temperature reaches 77° to 104°F (Missouri Agricultural Education, 2002). They are less tolerant to cold temperature and do not turn green until early summer.

Because seventy percent of the biomass is produced after June 1st, mowing and grazing in fields filled with warm-season grasses commonly take place during July and August (USDA, 1984). Mowing during this period is after the peak of grassland birds’ nesting season (Giuliano & Daves, 2002), and therefore avoids disturbance and destruction to the community of grassland birds. Also, the benefits of warm-season grasses include high adaptability to soil, low-cost for
maintenance, tolerant to fire, dependable habitats for birds, and reliable forage production (Oehler et al., 2006). Most species grow in clumps so that there is bare ground for the species which require open ground area (Oehler et al., 2006).

In contrast to warm-season grasses, cool-season grasses grow actively as the minimum temperature reaches 40 to 42°F in the spring and again in the fall (Oehler et al., 2006). The optimal growth occurs while the temperature ranges from 59°F to 77°F (Missouri Agricultural Education, 2002). Cool-season grasses include smooth brome grass (Andropogon glomeratus), Timothy (Phleum pratense), Kentucky bluegrass (Poa pratensis), tall fescue (Festuca arundinacea), and orchardgrass (Dactylis glomerata). These grasses prefer cool soil and wind in spring and fall. Cool-season grasses typically produce 60-70% of their biomass before June 1st (USDA, 1984) Nowadays, they are typically mowed or grazed from April to late June and mowed again in late summer and fall in New England (Giuliano & Daves, 2002).

Because of their high productivity, cool-season grasses and their associated legumes (alfalfa and clover) have played a major role in the livestock industry since the colonial period (Dwight, 1969). However, the dominance of cool-season grasses generates issues to the ecosystem. Agriculturally, maintaining them requires the application of herbicides, fertilizers, and lime (Oehler et al., 2006). Ecologically, such dense grasses are more difficult for animals to travel through. The reduction of plant diversity harms pollinator species, mammals, birds, and other species that rely on such habitats (Oehler et al., 2006). Currently, replacing cool-season grasses with native warm-season grasses (e.g., little bluestem, Indian grass), is a suggested conservation practice proposed by many groups (“An Action Plan”, 2013).

Today, artificial grasslands are mostly dominated by little bluestem, Pennsylvania sedge, poverty grass, and some non-native species including clovers, Timothy, etc. Some other
herbaceous species also include goldenrods and milkweeds (“A Guide to Natural Communities”, 2004). Rare plants, such as butterfly weed and wild lupine are also present in Lincoln’s grasslands (Town of Lincoln, 2017).

**Wildlife in Grasslands**

A broad variety of wildlife relies on grassland for various habitat functions. The species include meadow vole, meadow jumping mouse, white-tailed deer, red fox, cottontail rabbit, turkey, several kinds of sparrows, meadowlark, bobwhite quail, bat, some butterflies, amphibians, and reptiles including green snake and box turtle (Oehler et al., 2006). Much emphasis has been placed on grassland birds, which use these lands for nesting, brood-rearing, and foraging (Oehler et al., 2006).

In summer, migratory songbirds including bobolinks and eastern meadowlarks are present in New England and build their nests in hayfields, meadows, and pastures (Oehler et al., 2006). They continue to raise their young and forage until fall. Agricultural grasslands are also sites where migrating larks, sparrows, and warblers forage during fall. Hawks and owls including American kestrels, northern harriers, short-eared owls, and long-eared owls seek small mammals in these fields (Oehler et al., 2006). Other birds such as grasshopper sparrows and upland sandpipers require large and contiguous grasslands which are not in the range of the current study area. Grasslands provide numerous food resources for them, including insects and other invertebrates, small mammals for raptors, food, seeds, cultivated crops, and native grass seeds (USDA, 1999).

**Non-forested Wetlands: Deep and Shallow Emergent Marsh/ Shrub Swamp**
Non-forested wetlands, used to be called as “meadows”, are saturated with water (Town of Lincoln, 2017). Located on wet substrates, they all have less than 25% canopy cover (“Shrub Swamp”, 2016). All of the wetland types in our study area are within the palustrine system. This means that they are freshwater wetlands which are not parts of river channels or lake basins. The dominant species are persistent and normally remain until the next growing season (USDI, 1979). Wetlands perform valuable functions in supplying water, controlling floods, recharging groundwater, controlling pollution, and providing wildlife habitat (Town of Lincoln, 2017). In the study areas, there are three types of non-forested wetlands: deep emergent marsh, shallow emergent marsh, and shrub swamp. The physical and biological characteristics of these three natural communities overlap and are sometimes similar, yet they usually are arbitrarily separated (“Shrub Swamp”, 2016). This study identifies them through their unique vegetation, water depth, and other physical characteristics.

**Deep Emergent Marsh**

Deep emergent marshes are “tall graminoid/emergent herbaceous wetlands occurring on saturated, mucky mineral soils that are seasonally inundated and permanently saturated” (“Deep Emergent Marsh”, 2016). They are normally along water bodies including rivers, streams, lakes, and artificial impoundments. The water depth is from half of a foot to 3 feet, which might vary from year to year (“Deep Emergent Marsh”, 2016). The substrates are typically a well-decomposed organic muck layer over mineral soil (“A Guide to the Natural Communities”, 2004).

The dominant plant species of this natural community are tall graminoids like broad-leaved cat-tail (*Typha latifolia*) and phragmites (*Phragmites australis*) that form dense stands

Herbaceous associates include arrow-leaf tearthumb (*Persicaria sagittata*), bulblet water-hemlock (*Cicuta bulbifera*), swamp-candles (*Lysimachia terrestris*), beggar-ticks (*Bidens spp.*), bedstraw (*Galium spp.*), common arrowhead (*Sagittaria latifolia var. latifolia*), slender-leaved goldenrod (*Euthamia caroliniana*) and marsh-fern (*Thelypteris palustris*) (“Deep Emergent Marsh”, 2016). The associated fauna present in deep emergent marshes are rail, bittern, grebe, and moorhen. Other birds such as marsh wren, Northeastern harrier, and a variety of ducks also nest in deep emergent marshes. Amphibians and reptiles also dwell in this kind of habitat: wood frog and spotted salamanders may use such areas for egg-laying if vernal pools are present (“Deep Emergent Marsh”, 2016).

**Shallow Emergent Marsh**

Similar to deep emergent marshes, shallow emergent marshes are saturated with standing water, and occur in broad and flat areas adjacent to water bodies (“Shallow Emergent Marsh”, 2016). They are also present in abandoned beaver flowages. The main differences between them and deep emergent marshes are water depth and height of vegetation. The average water depth is no higher than half of a foot, and dominant plants are normally shorter than ones in deep emergent marshes.

Even though cattails, phragmites, and wool-grass might be present in these areas, they never dominate (“A Guide to Natural Communities”, 2004). Short grasses, sedges, rushes, and
scattered forbs are the dominant species. Species such as tussock sedge (*Carex stricta*) and Canada bluejoint (*Calamagrostis canadensis var. canadensis*) form tussock. There are also bur-reeds (*Sparganium spp.*), sedges (*Carex spp.*), rice cut-grass (*Leersia oryzoides*). Open water also supports water-lilies (*Nymphaea odorata* and *Nuphar spp.*) pondweeds (*Potamogeton spp.*), and duckweed (*Lemna spp.*). Scattered alder (*Eupatorium spp.*) and Spiraea (*Spiraea spp.*) mixed with tussock sedge-dominated marshes are abundant in old beaver flowages (“A Guide to Natural Communities”, 2004).

Shallow emergent swamps support similar frogs and salamanders as deep emergent swamps. Frog species include leopard, pickerel, green and bull frogs (“Shallow Emergent Marsh”, 2016). In addition, these swamps are valuable habitats for muskrats.

**Shrub Swamp**

The third kind of non-forested wetlands is shrub swamps. They occur in the transition zone between emergent marshes and forested swamps (“A Guide to Natural Communities”, 2004). The water table is also at or above the surface for most of the year. Their soils are seasonally or temporarily flooded and saturated permanently. The major distinction between them and emergent marshes are that they contain more than 25% of shrub coverage (“Deep Emergent Marsh”, 2016). Saplings of red maple, gray birch, and white pine may be present in these areas, but tree canopy cover is no more than 25%. They are highly variable with an intermix of shrubs, graminoids, herbaceous and open waters.

The typical shrub species are speckled alder (*Alnus incana ssp. rugosa*), smooth alder (*A. serrulata*), meadowsweet (*Spiraea alba var. latifolia*), steeplebush (*S. tomentosa*), buttonbush (*Cephalanthus occidentalis*), maleberry (*Lyonia ligustrina*), swamp azalea (*Rhododendron*
viscosum), silky dogwood (Swida amomum), winterberry (Ilex verticillata), sweet gale (Myrica gale), willows including pussy willow (Salix discolor) and black willow (S. nigra), arrowwood (Viburnum dentatum), and poison sumac (Toxicodendron vernix) (“Shrub Swamp”, 2016). The dominant species in shrub swamps is highly variable. Herbaceous layers are typically sparse because dense shrubs occupy most of the area (“Shrub Swamp”, 2016).

Vernal pools and shrub thickets allow amphibian larvae to develop free of predation by fish. The diverse species of shrubs are critical habitats for migratory birds to nest. New England cottontails seek protection in shrubs when the water surface is frozen. Many species of moths also utilize the plant species in shrub swamps as caterpillar hosts (“Shrub Swamp”, 2016).

Forested Wetlands: Red Maple Swamp

Typically, the concept of “open lands” excludes lands with over 25% tree canopy. The term normally includes cultural grasslands and natural communities like non-forested wetlands. Under such interpretation, forested wetlands such as red maple swamps would not satisfy the conditions of being open lands. However, patches of red maple swamps scatter in different locations of the study area. Such natural communities appear in the northeast of Baker Bridge’s Fields, east of Farm Meadow, and south of Codman North. In southern New England and northern New Jersey, 60-80% of inland wetlands are red maple swamps (FWS, 1993). It is the most common type of forested wetland in Massachusetts (“Red Maple Swamp”, 2016). In addition, these patches of red maple swamps are adjacent to open lands, creating edges between red maple swamp and tilled lands (LLCT, 2004), red maple swamp and hayfield (Farm Meadow), and red maple swamp and shrub swamp (LLCT, 2004). It is worth studying how plants and wildlife would be affected by these edges. Even though grassland birds are known to avoid edges
of all types (Renfrew et al., 2005), the influence of edges on other open lands species is understudied in Lincoln. Understanding the wildlife’s interaction close to edges between red maple swamps and their adjacent communities requires the study of red maple swamps. Furthermore, buckthorns are widely dispersed in the shrub layer of red maple swamps. It is necessary to focus on the invasion of such species in red maple swamps to understand their encroachment in open lands. Thus, our current study attempts to connect open lands management with the biological and physical characteristics of forested wetlands.

Red maples swamp is subdivided into three types based on landscape position and flora. The first type is hillside seeps and upland drainage ways which lack surface water. As the name indicates, this type of red maple swamp typically appears on slopes or in shallow depressions fed by groundwater seepage and overland flow (FWS, 1993). Seasonally flooded basin swamps are another type found in un-drained basins where surface water is present seasonally. They have an extremely dense shrub layer compared to moderately dense understory in the first type (FWS, 1993). The last type is alluvial swamps which occur in low-gradient rivers (“Red Maple Swamp”, 2016). In Massachusetts, this type is a separate natural community named alluvial red maple swamp.

In red maple swamps, red maple is the dominant species of overstory tree (Cowardin et al., 1979). In southern New England, red maple commonly composes over 90% of the cover (Lowry, 1984). It is a species with broad adaptability in both upland and wetland (Fowells, 1965). Red maple can grow in a wide range of bedrock types with dry, moist, or wet soils (Ecology, P6), and it is also a flood-tolerant species (Hall and Smiths, 1955). It thrives best in well-drained sites, and low to intermediate elevations (Fowells, 1965).
Even though the amount of red maple is abundant, a wide variety of trees can occur in red maple swamp depending on the physiographic and climatic conditions (FWS, 1993). These species include yellow birch (*Betula alleghaniensis*), black gum (*Nyssa sylvatica*), white ash (*Fraxinus americana*), white pine (*Pinus strobus*), American elm (*Ulmus americana*), hemlock (*Tsuga canadensis*), pin oak (*Quercus palustris*), and swamp white oak (*Quercus bicolor*) (FWS, 1993).

Besides pin oak and swamp white oak, other oaks like white oak (*Quercus alba*), and northern red oak (*Q. rubra*) are more common in southern Massachusetts and northern New Jersey compared to northern New England (FWS, 1993).

The shrub layer of red maple swamps in the Northeast is dense and well developed, exceeding 50%, yet the coverage varies from 21% to 99% (FWS, 1993, p36; Lowry, 1984). Species common in eastern Massachusetts such as sweet pepper-bush (*Clethra alnifolia*), swamp azalea (*Rhododendron viscosum*), and greenbriers (mainly *Smilax rotundifolia*) can grow up to 2-4 meter when they mature (FWS, 1993). Other shrubs found in red maple swamps include highbush blueberry (*Vaccinium corymbosum*), common winterberry (*Ilex verticillata*), spicebush (*Lindera benzoin*), arrow-wood (*Viburnum dentatum var. lucidum*), speckled alder (*Alnus incana*), nannyberry (*Viburnum lentago*), and poison sumac (*Toxicodendron vernix*) (FWS, 1993; “Red Maple Swamp”, 2016).

The herbaceous layer is highly variable, given that the composition depends on many different variables. Light intensity, tree and shrub cover, and foliage density contribute to the abundance and variety of species occur in this layer (FWS, 1993). Typically, ferns and graminoids are commonly found in red maple swamp. Skunk cabbage (*Symplocarpus foetidus*) is one of the most common species found in this layer (FWS, 1993).
Wildlife in Red Maple Swamps

Given their diverse vegetation structure and water regimes, red maple swamps support many wide-ranging species of wildlife. There are two broad categories of species that rely on wetland habitats, wetland-dependent species and facultative species (FWS, 1993). The prior type can be further grouped into species that depend on wetlands for most of their habitat requirements, wetland species, and species that rely on wetlands for part of their life cycle, wetland dependent upland species. Wetland species such as wood ducks (*Anas sponsa*), American black ducks (*Anas rubrip*), northern waterthrushes (*Sciuurus nouehmcensis*), beavers, river otters (*Lutra canademis*), and minks (*MusteZu vison*) seek food, water, cover, and breeding sites exclusively in wetlands.

Other species like spring peepers (*Pseudacris crucifer*), American toads (*Anaxyrus americanus*), wood frogs (*Lithobates sylvaticus*), and spotted salamanders (*Ambystoma macuktum*) need water regimes in wetlands to develop throughout the early (egg and tadpole) part of their life. These are wetland-dependent upland species (FWS, 1993). For them, vegetation structures might be less important than water regimes (Mocoy, 1989 <Ecology, p95>)

Even though facultative species use functions that wetlands provide, wetland habitats are not required for their life cycle (FWS,1993). Examples of birds that are partially dependent on forested wetlands are gray catbird (*Dumetella carolinensis*), black-capped chickadee (*Parus atricapillus*), common yellowthroat (*Geothlypis trichas*), and several species of warblers. These birds commonly breed in upland forests too. American crow (*Corvus brachyrhynchos*), American robin (Turdus migratorius), blue jay (*Cyanocitta cristata*), great crested flycatcher (*Myiarchus crinitus*), raccoon (*Pmcyon lotor*), Virginia opossum (*Didelphis virginiana*), and
white-footed mouse (*Peromyscus leucopus*) are some additional species utilizing red maple swamps (FWS, 1993)

**Wetland Dynamics**

All of the above wetland types have varied and will vary their functions and values because of change in abiotic and biotic factors over time. The term “wetland dynamics” is used here to describe the change of wetland features at the ecosystem level. “Progressive change” and “retrogressive change” are two terms which discriminate the direction of wetland dynamics. Wetlands in southern New England have gone through both progressive and retrogressive changes. Progressive changes are represented by the increase of structural complexity of vegetation and decrease of wetness. The alteration from emergent swamps to forested wetlands is an example of progressive changes (FWS, 1993).

On the other hand, in retrogressive change, the structural complexity of dominant plants decreases, and the water level rises. The majority of retrogressive changes are caused by beavers and humans through manipulating water levels, and cutting vegetation (FWS, 1993). One of the typical examples of retrogressive changes caused by beaver activity is the deep emergent marsh adjacent to Baker’s Bridge Fields. Scattered dead red maples are an indication of this area’s previous natural community, red maple swamps. Through cutting trees and flooding over the last two decades, beavers had converted this area to open lands.

A number of researchers have studied the changes of wetland types in southern New England in a 20- to 33-year span ending in the 1970s (Larson et al., 1980; Golet and Parkhurst, 1981; and Organ, 1983). During this period, about 20% of the original wetland area changed classification (Golet and Parkhurst, 1981; and Organ, 1983). Among these studies, progressive
changes are the most common type of changes, comprising 70% of changed area in Rhode Island and Massachusetts during this time. Non-forested wetlands (shallow marsh, wet meadow, and shrub swamp) changed more frequently because they share similar water regimes (FWS, 1993). The decline of mowing and grazing which normally help maintain these habitats also explains such dynamics. In contrast, forested wetlands were more stable: about 95% of them remained unchanged. However, it is controversial to interpret such successional change as directional, leading to more predictable stable communities (Bazzaz, 1996). Perhaps these forested wetlands were undisturbed by humans or beavers during this period.

**Threats to Wetlands**

All wetlands encounter threats to their functions and values. Significant wetland loss occurred in this region during the mid-1950s to the mid-1970s, but the loss has decelerated since then (EEA, n.d.).

The first threat to these wetlands is development. Massachusetts has a high pressure in residential and commercial development. Clearing, grading, filling, and building-construction can directly lead to the loss of wetlands (MassWildlife, 2015). Besides, highway construction constitutes one of the most significant factors causing wetland loss in New England (FWS, 1993). It also isolates wetlands into fragmented pieces, decreasing their values as habitat. For instance, fragmentation affects animals’ foraging and dispersing behavior by increasing the rate of being preyed upon (MassWildlife, 2015). Development is often associated with other threatening factors including water level manipulation, alteration of surrounding uplands, water pollution, and tree cutting.
Another factor resulting in the loss or degradation of wetlands is agriculture. New England farmers have been modifying wetland habitats since the colonial period (Donahue, 2004). Water levels were managed by digging drainage ditches and construction of dams (Foster, 1999). Even though the modification of wetlands has decreased as the role of agriculture has waned in this area, other forms of modern farming practices can imperil features of wetlands. The physical and chemical features of wetlands may be altered due to agricultural dumping (MassWildlife, 2015). The application of fertilizers, pesticides, and herbicides may change soil and water chemistry via agricultural runoff. It can also harm species using wetland habitats, especially amphibians (MassWildlife, 2015).

Invasive plants also pose a threat to wetlands. Purple loosestrife (*Lythrum salicaria*) is an invasive species found in all four types of wetlands in Lincoln. Since it relies on similar water depth as cat-tail, its amount will gradually increase if unmanaged (Deep Emergent Marsh). Other invasive species such as Reed canary grass (*Phalaris arundinacea*) and Common Reed (*Phragmites australis*) are present in Lincoln’s deep emergent marshes. Reed canary grass alters the habitat by changing water depths, while Common Reed can outcompete other native species and dominate the area (“Deep Emergent Marsh”, 2016). In term of shrub swamps, invasive shrubs including common buckthorn (*Rhamnus alnifolia*) and glossy buckthorn (*Frangula alnus*) can form monocultural stands given their ability in competing for resources (“Shrub Swamps”, 2016).

Other direct threats that cause wetland loss include construction of impoundments, highway construction, and beaver activities. Other factors, even though they do not directly contribute to the loss of wetland coverage, affect the functions and values of wetlands negatively.
These threats include water level manipulation, alteration of surrounding uplands, water pollution, and tree cutting.

**Invasive Edges**

Besides natural communities that are identified by the Massachusetts Natural Heritage & Endangered Species Program, a few patches of our study area do not match the descriptions of any natural community. They are all dominated by invasive species, with some more homogeneous whereas others are heterogeneous, and a large portion of them occur along field edges.

Specifically, a belt of invasive plants surrounds all edges of Farm Meadow. Invasive edges are also present around Codman North, Codman South, and Baker Bridge. They are dominated by a variety of non-native plants including glossy buckthorn, oriental bittersweet, Japanese honeysuckle, autumn olive, and other non-native plants that exclude endemic plants. Because more than 80% of the species are invasive plants that are less than 6 meters tall, we represent it as “>80% Mixed Invasive Shrub.” Even though the natural community in the east of Farm Meadow is categorized as red maple swamp, the understory in this area is almost monocultural, dominated by glossy buckthorns that are less than 6 meters tall. A layer referred as “>70% Buckthorn Shrub” is used to represent this habitat. Another place with this type of habitat is the edges of Baker Bridge North.

**The Distribution of Invasive Species**

Invaders often outcompete native species because of their traits including robustness, resource efficiency, ability to form a monoculture, high adaptability, and high reproductive
output (Webster, Jenkins, & Jose, 2006). They often have a small juvenile period, short interval between large seed crops, and small seed mass (Rejmanek & Richardson, 1996). Short development period allows them to mature rapidly, and lighter seeds are beneficial for distribution. Some species also use a “sit and wait strategy” (Webster et al., 2007). A “seedling bank” is accumulated when the canopy is dense. When disturbance causes the canopy to open up, they reach maturity rapidly.

Several invasive species established in the study area were first introduced to the United States intentionally and for a variety of reasons. For instance, multiflora rose was planted during the 1930s to the 1960s to prevent erosion (Mehrhoff et al., 2003). Some other species such as oriental bittersweet and Japanese Knotweed were introduced for ornamental purposes in the 19th century (Hollingsworth & Bailey, 2000; Mcdonald, Motzkin, & Foster, 2008).

McDonald, Motzkin, and Foster (2008) argue that the modern distribution of invasive species is related to the agricultural legacy in the past. They conclude that previously plowed areas are more than twice as likely to contain invasive species as are continuous woodlots. The presence of invasive species in old fields and soil conditions are interrelated. On the one hand, soils in agricultural lands always contain characteristics favored by invasive species, including saturation of moisture, and low C:N ratio. On the other hand, the occurrence of invasive species can modify soil characteristics (Mcdonald, Motzkin, & Foster, 2008).

Positive Value

The invasion of non-indigenous plants substantially could alter the function and composition of New England ecosystems (Blossey, 1999). Even though invasive plants have
critical negative effects to the local ecosystem, they have become important habitat components for animals including endangered and threatened ones (Litvaitis et al., 2013).

One of the users of invasive edges might be the New England cottontail (*Sylvilagus transitionalis*), a native rabbit listed as species of greatest concern need in Massachusetts 2015 State Wildlife Action Plan (MassWild, 2015). New England cottontails are brown rabbits that closely resemble another widely distributed introduced species, the eastern cottontails (*Sylvilagus floridanus*). One of the differences in their appearance is that half of New England cottontails have white spots on their foreheads, a physical characteristic never observed in eastern cottontails. The former also have shorter ears and black spots between ears (Litvaitis et al., 2013). Another major difference is that Eastern cottontails are found in a great variety of habitats, grassy openings and places with dense cover. In contrast, New England cottontails specifically demand early successional forests (FWS, 2006). However, thickets with native plants have become rarer as abandoned farmland has continued to develop into forests. (U.S. Fish & Wildlife Service, New England Cottontail).

Although the exact population of New England cottontails in Lincoln has not been documented, they are one of the species that might benefit from the presence of these invasive edges. For instance, species such as Japanese barberry, oriental bittersweet, and honeysuckle form thickets that provide food and cover. It is possible that these shrubby areas along fields like Baker Bridge, Farm Meadow, Codman South and North are excellent sites for New England cottontails to hide.

Another positive feature of invasive plants is that as many herbivorous insects are dependent on multiflora rose as native silky dogwood (*Cornus amomum*) (Fickenscher, 2009). In addition, distinctive growth form of invasive plants might be a positive factor for birds to nest in
habitats dominated by invasive plants. Schlossberg and King (2007) found that shrubland birds have a preference for invasive substrates over native ones.
Chapter IV. Species of Concern in the Study Area

IV.1. Introduction

This chapter identifies open land species that are of special concern in this study. The inventory emphasizes the population trend of each species and its ecological role in Lincoln’s open lands. The list also tends to include species with important economic, cultural, and social value. Both the species that contain these values and species that negatively affect these values are included in the list. To generate this inventory requires an understanding of the species’ historical and current distribution and abundance in New England.

In term of species with low population in Lincoln, eleven state-listed rare, threatened, and endangered species have been reported: the blue-spotted salamander, the four-toed salamander, the purple tiger beetle, the sharp-shinned hawk, the upland sandpiper, the barn owl, the sedge wren, the golden-winged warbler, the grasshopper sparrow, the Henslow’s sparrow, and the mocha emerald. Even though endangered, threatened, and rare species listed by the state deserve special concern, I consider additional species that are not listed in the Massachusetts State Wildlife Action Plan. More attention is given to species that are relatively more abundant, and whose population and distribution can be more significantly modified through management practices. Some of the state listed species such as barn owls have not been observed in Lincoln for over 60 years (Lincoln Open Space and Recreation Plan), so these species would be too rare to be included in the inventory. In addition, these rarer species would gain indirect benefits, such as improvement of habitats, if management practices are conducted to conserve other species.

Most of the species in this inventory have been reported in west Lincoln’s open lands by trusted local naturalists and other observers. Although a few species have not been sighted
recently in Lincoln, the study area has sufficient conditions to support them. It is possible that they are currently present and have the potential to be observed in the future.

**IV.2. Grassland Species**

The populations of native grassland species have gone through a tremendous fluctuation along with the change of grasslands since the European settlement. By the 1800s, these species gained benefits from the extensive loss of forest and expansion of hayfields and pastures (USDA, 1999). The amount of grasslands in the forms of hayfields, pastures, and croplands was greatest by the time of the mid-nineteenth century in Massachusetts (Vickery & Dunwiddie, 1997, p1), reaching 75% of the total area. Benefiting from the expansion of agricultural practices, many grassland bird species expanded their ranges and populations (Askins, 1993). Grassland specialists such as bobolinks, eastern meadowlarks build ground nests, and raise young and forage during the summer (Oehler, Covell, Capel, & Long, 2006). Other birds favored by grassland expansion in New England included migrating larks, and some species of sparrows, warblers, hawks, and owls (Oehler, Covell, Capel, & Long, 2006). However, the growth of these populations has reversed since the mid-nineteenth century. The dramatic decline in the population of many grassland and shrubland species emphasizes nature’s dynamics and the influence of human activities.

The primary reason for the decrease of these species was the loss of habitat (Askins, 1993, Vickery et al. 1994). The extent of grasslands has declined remarkably over the past 150 years (Whitney, 1994). Two main factors that led to the decline of open lands in agricultural regions are the abandonment of farmlands and the regrowth of forests. Without periodic grazing, haying, fire, and other forms of disturbance, grasslands gradually disappeared (Askins, 1999). As the
land went through the process of succession and transformed into forests, the available habitats for grassland species became fewer, smaller, and more fragmented. As a result, open land species frequently outnumber woodland species on the state-listed endangered and threatened species (Askins, 1993).

IV.3. Grassland Birds

Massachusetts supports a rich diversity of birds. More than 460 species have been recorded in Massachusetts, and 200 of them breed in the Commonwealth (Anderson et al., 2010). A large number of migratory shorebirds, ducks, raptors, and songbirds rest in Massachusetts for replenishment. One of the most valued groups is grassland birds.

Relying on grasslands for nesting, grassland birds were once common in New England prior to the late nineteenth century (Askins, 1993). The upland sandpiper (*Bartramia longicauda*), the bobolink (*Dolichonyx oryzivorus*), the eastern meadowlark (*Sturnella magna*), and the grasshopper sparrow (*Ammodramus savannarum*) were more abundant 150 years ago, but they are now listed as species of special concern. Their numbers have declined dramatically since the 1960s (Askins, 1999). For instance, during a 28-year-period starting from 1966, the population of the Henslow’s sparrow had an annual decline rate of 9%. The grasshopper sparrow’s annual rate of decline reached 6% (Askins, 1999). There is little doubt that the reduction of grassland bird’s abundance is correlated with the decline of grassland habitats and the change in agricultural practices. The loss of wetlands, the invasion of non-native plants species, and the abandonment of farmlands could result in the extirpation of many grassland birds in New England (USDA, 1999)
The Size of Grassland Bird Habitats

Generally, the variety and the density of grassland birds increase as the size of a field increases (Robbins et al. 1989). There are likely several reasons for this. First, large patches indicate large sample size, which might include more species than small patches (Connor & McCoy, 1979). It is worth noticing that the increase in diversity resulting from the increase in sample size should not be misinterpreted to account for some birds’ special requirement for large habitat.

Second, some bird species require a minimum number of breeding sites, because they need habitats large enough that contain limited essential resources (Ribic et al., 2009). Certain grassland bird species require grassland habitats that are large and contiguous. Among the five species listed as Species of Special Concern in the 2015 Massachusetts State Wildlife Action Plan (SWAP), the upland sandpiper needs the greatest amount of field size, more than 100 acres. The eastern meadowlark and the grasshopper sparrow require a minimum area of 60 acres. Fifteen acres is the threshold to sustain vesper sparrows. Even though Mass Audubon’s report (“Best Management Practices for Nesting Grassland Birds”, n.d.) suggests that the bobolink needs more than 10 acres of a habitat, Bollinger and Gavin (1992) claim that the bobolink abandons hayfields once they shrink to less than 25 acres. Therefore, large fields can support both species demanding large habitats and species commonly found in small habitats.

Third, large grasslands are more heterogeneous in structure compared to smaller ones, and diverse physical conditions are more likely to be found in large fields (Ribic et al., 2009). Having more variety of habitats available in a single patch, a grassland parcel attracts different species that prefer different kinds of vegetation and physical conditions. For instance, the horned lark (*Eremophila alpestris*) and the vesper sparrow (*Pooecetes gramineus*) are fond of spare
vegetation with plenty of bare ground, whereas the grasshopper sparrow has a preference for denser vegetation (Akins et al. 2007). The upland sandpiper (*Bartramia longicauda*) likes heterogeneous sites even though it tolerates a wide range of grasslands (Vickery et al. 1994). The presence of high structural variability and vegetation diversity is a key to conservation (Renfrew, Ribic, & Nack, 2005).

Fourth, small fields, with proportionately more edges, are considered by grassland birds as less desirable habitats. Large patches contain more interior habitat compared to small patches (Temple & Carry, 1988). There is a positive relationship between nest density and distance from edges for all edge types (Renfrew, Ribic, & Nack, 2005). One explanation for edge-avoidance is that the microclimate near edges might not be as suitable for grassland birds as the one at the center so that they avoid nesting close to edges (Bollinger & Gavin, 2004).

In addition, reproductive success is lower near edges, a situation explained by increased nest-predation (Temple & Carry, 1988; Ribic et al., 2009). On the one hand, Chalfoun et al. (2002) conclude that avian predators are more abundant along forest-pasture edges, yet they emphasize that the population of predators fluctuates according to different types of edge. On the other hand, Renfrew, Ribic, and Nack (2005) argue that placing nests away from edges does not necessarily reduce nest predation. Some predators, such as raccoons, move through fields of a wide range of sizes (Renfrew & Ribic, 2003).

Other reasons accounting for low preference of edges are reduced food density, increased competition with edge-associated species, and a high rate of brood parasitism by cowbirds (Brittingham & Temple, 1983; Renfrew, Ribic, & Nack, 2005).

*Grass Types*
Besides the loss of grassland habitats, the intensification of agricultural practices also contributes to the decline in the population of grassland birds. One example of intensified agriculture is replacing native warm-season grass to exotic cool-season grass in hayfields and pastures. Giuliano and Daves (2002) compared avian abundance and richness between warm-season fields and cool-season fields. They conclude that warm season fields support greater abundance and more variety of grassland birds. Seven species -- vesper sparrows, American tree sparrows, mallards, and Empidonax flycatchers -- were found exclusively in warm-season fields in their study area, Washington county, Pennsylvania. In Massachusetts, grasshopper sparrows are present almost only in warm season grasslands (“An Action Plan”, 2013). Cody (1985) suggests that grassland birds use the height and density of vegetation as indicators when choosing habitats. They are dependent on herbaceous cover to forage and nest (USDA, 1999). The preference for fields dominated by warm-season grasses is due to greater cover availability and lower disturbance rate in warm-season fields as the breeding period progresses (Giuliano & Daves, 2002).

The age of the field matters too because age is an indicator of grass types. Bollinger (1995) claims that as the age of a field increases, vertical and horizontal patchiness, plant richness, and plant diversity increase even though the field is dominated by exotic species. In that study, as the originally planted legume died out, the fields became sparse, patchy, and heterogeneous. The seven birds he studied also exhibited variation in abundance with respect to the age of fields. For instance, upland sandpipers, eastern meadowlark, grasshopper sparrows, and Henslow’s sparrows were more frequently found in old fields, whereas savanna sparrows were evenly found in all fields (Bollinger, 1995).
The Effects of Haying

Haying has become more intensified over the last 40 years. Not only did the schedule of the first mowing become earlier, but the frequency of mowing also increased (Bollinger et al., 1990). The first mowing date shifted from about July 1st to late May or early June (Perlut et al. 2008). In addition, some hayfields are mowed nowadays more than once during summer so that farmers can maximize yields. The vegetation is reduced to 7-10 cm tall during the first mow, and allowed to regrow afterward (Barnes and Sheaffer, 1985).

Most birds are in a vulnerable stage during early- to mid-June, because they are either in late incubation or have nestlings. For instance, bobolinks migrate to New England in May or early June and take about 25 days to finish the nesting cycle (Perlut et al. 2006). During this time, they build nests, lay eggs, incubate, and forage until the young birds are mature enough to fly. Mowing at this time is detrimental to breeding because modern mowing machines crush the nests on the ground and destroy the eggs and the nestlings (Perlut et al. 2006). Modern mowing practice also changes the structure and the density of vegetation frequently (Frawley, 1991). Frawley (1991) emphasizes the negative influence of vegetation change due to mowing. The density of species such as dickcissels, red-winged blackbirds, and grasshopper sparrows decreases significantly after mowing, whereas grassland birds have high degree of fidelity over their site of breeding, choosing the same sites during their 5-8 years of lifespan (Mass Audubon, n.d.).

Perlut et al. (2008) identified four types of hayfields that varied by mowing time, all located in the Champlain Valley located in Vermont and New York according to their mowing time. Among them, early-hayed fields were mowed twice, the first time between 27 May and 11 June, and the second time during early- to mid-July. The survival rate and annual productivity of
bobolinks and savanna sparrows were lowest in early-hayed fields (Perlut et al. 2008). Once the nests and nestlings were destroyed by the first mow, only a short window was left for grassland birds to re-nest (Perlut et al. 2008). Some species such as savanna sparrows returned to the fields to re-nest after mowing. Even though Bollinger et al. (1994) observed some bobolinks re-nested in unmowed part of the fields after mowing, Perlut et al. did not find any bobolink re-nested in two weeks after early-haying (Perlut et al. 2006). Neither did red-winged blackbirds re-nest after the fields were mowed (Bollinger, 1995). Since the first mowing destroyed all of the nests and nestlings, the number of bobolink fledglings was close to zero in early-hayed fields (Perlut et al. 2006).

In contrast, middle-hayed fields, mowed between June 21st to July 10th, and late-hayed fields, mowed after August 1st, proved to be much better breeding habitats for grassland birds, allowing a higher rate of reproductive success (Perlut et al. 2006).

Livestock Grazing

Pastures play an important role in farming and provide habitats for grassland birds. Livestock grazing produces constant disturbance to the land and prevents succession from happening. Additionally, light grazing pressure may diversify grassland structure and create distinct microhabitats to satisfy the needs of different grassland birds (Murphy, 2003) However, grazing can also put bird nests within pastures in a vulnerable situation. Low intensity grazing serves as maintenance of pastures, but heavy grazing often results in nest failure (“An Action Plan”, 2013). Cow harm birds like bobolinks and savannah sparrows when they trample or even eat the nests of the birds (Perlut et al., 2006)
Rotational grazing can be a method to minimize harms to grassland birds in pastures. Perlut et al. (2008) studied rotationally-grazed fields in the Champlain Valley. Cows were constrained in one paddock at a time with a density of 1-1.5 cows per acre. When the grass in one paddock was grazed to about 10 cm height, the cows were moved to the next paddock. Perlut et al. found that female bobolinks benefited from rotational grazing because it created a mosaic structure allowing them to re-nest when their first nest was lost. Nevertheless, nesting success of savannah sparrows and bobolinks in rotationally grazed pastures was only moderate. Grassland birds have higher nesting success in rotationally grazed pastures than early-hayed fields, yet the rate is not higher than that observed in middle- and late-hayed fields (Perlut et al., 2006).

It is worth noticing that the term “pasture” is ambiguous. There are many grazing methods based on multiple variables including “the size of the herd, available habitat for grazing, available time for management, and type of forage provided” (Perlut et al., 2008). It is too simplistic to conclude that pastures are better or as suitable habitats for grassland birds than hayfields.

Historically Abundant Species

Among the grassland birds that are listed as endangered, threatened, or rare by the state, species that have been previously observed in Lincoln include grasshopper sparrows (Ammodramus savannarum), upland sandpipers (Bartramia longicauda), barn owls (Tyto alba), Henslow’s sparrows (Ammodramus henslowii) and sedge wrens (Cistothorus platensis) (Town of Lincoln, 2017). None of these species have been observed in many years, and are very unlikely to occur in the study area nowadays.
First, the last documented witness of barn owls was in 1953 (Town of Lincoln, 2017). Although it is possible that barn owls might have occurred within this 60-year period, they are unlikely to use the studied habitats. Second, upland sandpipers, currently listed as an endangered species in Massachusetts, was the first species to decline as open lands reverted to forests (Foster, Motzkin, Bernardos, & Cardoza, 2002). They require a minimal grassland of 100 acres (Mass Audubon, 2017), yet the largest field in the study area, Codman South, is half that size (LLCT, 2004). Grasshopper sparrows require a threshold of 60 acres (Mass Audubon, 2017), which is not satisfied by any grassland or other open land in the study area. Even though some have argued that Henslow’s sparrows have been found in grasslands as small as 40 acres, which is satisfied by Codman South, Codman North, part of Baker Bridge’ Fields, and part of Codman East, the median size of their habitats are 70-130 acres (Kobal, Payne, & Ludwig, 1999; LLCT, 2004). Although they have been seen in Farm Meadow (LLCT, 2004), the last recorded witness in 1994 also indicates that Henslow’s sparrows tend to choose habitats larger than the study area. As an endangered species, sedge wrens are very rare in Lincoln, and last seen 20 years ago (Town of Lincoln, 2017). However, because they do not have a habitat size requirement as large as the other species considered it, they may be among the first to return if conditions in Lincoln’s open lands are improved.

IV.4. The Bobolink (*Dolichonyx oryzivorus*)

*Traits and Habitat*

The male bobolink has a black underpart and white back, with a straw-colored patch on its head (“Bobolink”, 2015). As summer ends, the male molts and turns into buff and brown as the female bobolink. The male has a bubbling song, which gives the species its name (Audubon,
In summer, most of the diet of bobolinks is insects and seeds, but bobolinks rely heavily on grains while they migrate to the south in winter (Audubon, n.d.).

Bobolinks build ground nests of dried grass and have a nesting cycle that lasts for 23-25 days (Perlut et al. 2006). Each female bobolink lays 4-7 eggs per brood. Incubation is conducted exclusively by female bobolinks, ranging from 11 to 13 days. Young are not able to leave nests until 8 to 14 days after hatching (Audubon, n.d.).

Bobolinks prefer to nest in old fields with sparser, patchier, grass-dominated vegetation rather than in young fields dominated by dense and homogeneous legumes (Perlut et al., 2006). Bobolinks rarely nest close to forest edges but they do not avoid agricultural edges (Bollinger & Gavin, 2004). The survival rate of bobolink nest within 25 meters of forest edges is low, and they re-nest farther away from forest edges once nesting fails (Bollinger & Gavin, 2004). In Lincoln, residents have reported witnessing bobolinks in all four of the fields in the study area.

In term of migration, bobolinks arrive in New England before summer and start to breed in late May to mid-July, with time only enough to raise one brood. (Perlut et al. 2006). They migrate southward during autumn and reach as far as Argentina. Each year they make a round-trip for about 12,000 miles (Renfrew et al., 2015)

The Decline of Bobolinks

Bobolinks were once common in the Northeastern United States, but the population of bobolinks has been through a dramatic change during the past hundreds of years. They are now listed as a Species of Concern in the Massachusetts 2015 State Wildlife Action Plan. The population of bobolinks reached its peak in the late 1800s and early 1900s, and it has declined substantially since 1900s (Leck, 1984; Foster et al., 2002).
One of the factors causing the decline is the widespread slaughter while they migrate to the southern states and South America (Renfrew & Saavedra, 2007). They are called “ricebirds” because they form enormous flocks in winter and feed on rice crops (BBA2). In Bolivia, a major wintering ground for the species, rice farmers tend to view them as pests and apply poisons to kill them (Renfrew & Saavedra, 2007). They also have been “shot in southern United States, trapped and sold as pets in Argentina, and collected as food in Jamaica” (Renfrew et al., 2015).

Another threat is mowing. Early and repetitive mowing by machinery is detrimental to bobolinks. Removal of cover also makes the adults to more susceptible to predators (Bollinger, Bollinger & Gavin, 1990). As discussed previously, in some fields the mowing schedule nowadays starts two weeks earlier than 50 years ago (Warner & Etter, 1989). Compared to young fields dominated by legumes, old fields chosen by bobolinks can be harvested at later dates, reducing mowing mortality (Bollinger, Bollinger & Gavin, 1990).

In a study conducted in the Champlain Valley located in New York and Vermont, the rate of reproductive success in middle-hayed and late-hayed fields was higher than early-hayed fields (Perlut et al. 2006). In middle-hayed fields, there was enough time for some birds to fledge before late June and mid-July so that they can escape the machinery. Mowing after August 1st gave females which had early nesting failure due to weather events and predation a longer window to re-nest (Perlut et al. 2006).

IV.5. The American Kestrel (*Falco sparverius*)

*Traits and Habitat*

The American kestrel is colorful compared to other raptors. Its back and tail are in rusted-brown color with spotted black patterns. The male has blue-gray wings while the female’s wings
are reddish brown (“American Kestrel”, 2015). The kestrel feeds on a variety of small animals including grasshoppers, lizards, mice, snakes, and small birds.

American Kestrels can be found throughout much of North America. They prefer open lands with little vegetation and spare trees. They are distributed in grasslands, deserts, suburbs, and farmlands. American Kestrels nest in cavities, such as woodpecker holes, tree hollows, and human constructed structures, but they cannot excavate the holes by themselves (“American Kestrel”, 2015). They also use nest boxes, some of which are constructed by Lincoln residents and are located on the north of Baker Bridge Fields. Preferable nesting sites are by suitable hunting grounds and have unobstructed entrances. Kestrels also rely on cavities in dead trees, which can be found in the deep emergent marsh east of Baker Bridge fields. The dead red maples in the wetland might serve as valuable nesting spots for them.

The Decline of American Kestrels

The population of kestrels undoubtedly expanded during the 18th and 19th century along with the advancement of the agrarian nation (Smallwood & Bird, 2002). Most of the areas surveyed by Mass Audubon’s Atlas have witnessed a decrease in the population of American kestrels from the 1970s to current days (BBA2). The USGS’s Northern American Bird Survey has recorded a significant decline of American kestrels in Massachusetts and approximately a 50% decline in population throughout the country (Sauer et al., 2015).

Analogous to the destiny of other grassland birds in the Northeast, the decline of the population of American kestrels correlated with the shrinkage of agricultural fields. Other factors include the loss of nesting cavities and prey sources. Traditional tree lines, hedge rows, and shrubs have all declined with the decline of local agriculture. These habitats traditionally
provided either nesting cavities or good hunting areas for American kestrels (Smallwood & Bird, 2002).

IV.6. The Eastern Bluebird (*Sialia sialis*)

*Traits and Habitat*

An example of grassland birds that has seen a resurgence of its population in our area is the eastern bluebird. The recovery of eastern bluebirds emphasizes the tremendous role of conservation actions for saving a species whose status was once threatened.

The adult male bluebird has a blue head and blue back, red-brown breast, and white belly. The female has a gray-brown head and orange-brown breast (“Eastern Bluebird”, 2015).

Bluebirds prefer open lands with scattered trees but can also be found in some disturbed human-modified habitats (Gowaty & Plissner, 2015). They have similar nesting requirements as American kestrels, seeking cavities such as woodpecker holes, natural hollows in trees, or birdhouses (Audubon, n.d.).

*The Resurgence of Eastern Bluebirds*

Similar to other birds dwelling in open lands, eastern bluebirds became more abundant when more grasslands and edges were available starting in the early 1800s (Gowaty & Plissner, 2015). Since the 1870s, house sparrows (*Passer domesticus*), an introduced species, have expanded from urban areas and competed against bluebirds for nesting cavities (BBA2). Another introduced species, the European Starling (*Sturnus vulgaris*), later entered the competition. Due to these non-natives, the status of the eastern bluebird was further threatened. From 1967 to 1990, the population experienced a steady decline (Sauer et al., 2015).
Even though direct harm of pesticides to bluebirds has not been proven, exposure to DDT and other pesticides does disrupt the bluebird endocrine system (Gowaty & Plissner, 2015). Bluebirds’ prey, mainly insects and other ground arthropods, contained DDT in their body before the ban of DDT. The accumulation of DDT chronically elevated the level of a stress hormone, corticosterone, and led to the decline and death of neuronal cells (Gowaty & Plissner, 2015). Bluebirds exposed to pesticides also tend to have a high rate of thyroid disease, which is negatively correlated with their survival rate and breeding success (Gowaty & Plissner, 2015). Furthermore, polychlorinated biphenyl's (PCBs) also disrupted the hormone system of eastern bluebirds (DeWitt et al. 2006).

Since the 1960s and 1970s, nesting-box campaigns have led to a growth in the availability of better designed nesting boxes that prevent occupation by European starlings. Locating boxes away from buildings and grain sources also reduces competition with house sparrows (Gowaty & Plissner, 2015). The adverse effects of DDT and PCBs have gradually faded away since the ban of these compounds, although there remain some vestigies in the environment. As a result of these improvements, the population of eastern bluebirds in Massachusetts started to bounce back since the 1990s (Sauer et al., 2015).

IV.7. The Eastern Spadefoot Toad (Scaphiopus holbrookii)

Amphibians

Because amphibians have three or four life stages (egg, larva, juvenile, and adult), they interact with many different species over their lifecycle. In Massachusetts, amphibians are most common in the seasonal freshwater ponds known as vernal pools. Amphibians are important as prey for fish, snakes, raccoons, and herons (NHESP, 2010). Of the 21 amphibians in
Massachusetts, seven are considered Species of Conservation Concern in the 2015 SWAP, and the Massachusetts Endangered Species Act includes four of them as threatened species.

**Traits and Habitat**

One of the seven amphibians listed as threatened in Massachusetts is the eastern spadefoot toad (*Scaphiopus holbrookii*). Even though there has never been any documented population of eastern spadefoot toads in the study area, the conditions required for their survival can be found in southwest Lincoln. These are big-headed toads with elliptical pupils, ranging from 4.4-5.7 cm in body length (Mass Fisheries and Wildlife, Eastern Spadefoot). The toad has a sickle-shaped spade on each hind foot and two yellow lines running from its eyes and continuing to its dorsum (Penn Species Action Plan, Eastern Spadefoot).

Spadefoot toads occur in sandy, gravelly, and dry soils in wooded and open areas (Mass Fisheries and Wildlife, Eastern Spadefoot). They are also found in floodplains of stream and rivers as well as depressions in agricultural fields (Hulse et al. 2001). Some of these depressions can become temporary or permanent pools after rains (Penn Species Action Plan, Eastern Spadefoot). The eastern spadefoot toad spends most of its life underground, up to 200 days in a year. It burrows as deep as 2.5 to 5 cm below the surface. Eastern spadefoot toads prefer substrates that are mechanically accessible for burrowing and that contain adequate moisture (Ruibal et al., 1969; Creusere and Whitford, 1976). Codman South would be a suitable habitat for them in southwest Lincoln, given the existence of a vernal pool adjacent to the west pasture.

Eastern spadefoot toads are explosive breeders. As opportunists, they do not breed in a specific season. Reproduction occurs during and after heavy rains that create vernal pools and accumulation of water in farmlands (Hulse et al., 2001). The metamorphosis from tadpole to
adults is so rapid that they can complete development in just 25 days. Sexual maturity is reached at the end of 15 months for males and 19 months for females (Mass Fisheries and Wildlife, Eastern Spadefoot).

The Population of Eastern Spadefoot Toads

Thirty-two populations of eastern spadefoot toads have been documented in the state of Massachusetts since 1982 (Mass Fisheries and Wildlife, Eastern Spadefoot). Among the threats that they face is habitat loss and habitat degradation due to urbanization. Jansen, Summers, & Delis (2001) claim that eastern spadefoot toads cannot burrow in grass sod, which is commonly associated with developed areas. Even though they can burrow in gravel, it takes them 7.6 times longer than burrowing in sand. The replacement and fragmentation of sandy habitats make them susceptible to dehydration while searching for sites to burrow. The fragmentation of available sites further isolates the population (Jasen, Summers, & Delis, 2001). In addition, because the species breeds in vernal pools, wetland protections do not necessarily create more available habitats for them. The requirement of upland for foraging and burrowing areas add another layer of constraint to protect the toad (Penn Species Action Plan, Eastern Spadefoot).

IV.8. Pollinators

Biology and Habitat

Animal pollinators contain bees, butterflies, moths, wasps, flies, beetles, ants, bats, and hummingbirds (NRCS, 2013). Ecosystem health and agriculture wealth are dependent on them to deliver pollination services. Besides fruits, vegetables, and seed crops, they also pollinate forages and hay crops like alfalfa and clover, which critically determine the function of hayfields and
pastures (Committee on the Status of Pollinators in North America, 2007). There are two basic needs required by pollinators: a diversity of flowering plants and nesting sites (NRCS).

Solitary bees are non-social bees with no division in labor. Most nest in well-drained soil with bare or partial vegetation, while some of them construct domed nests. Other bees, like the highly social bumble bees, nest in cavities (NRCS). Many ground-nesting bees and wasps have a preference for nesting along sunny roadsides where soils are warm and compacted (Cane & Tepedino, 2001). Others nests in wooden fences, barns, and stone walls that provide substrates above ground (Westrich, 1989).

Butterflies and moths feed as caterpillars on a wide variety of host trees and other plants while loose soil, bushes, tall grass, trees, piles of leaves are used as pupation sites of various species and for shelter by adults. Hummingbirds require trees, shrubs, and vines (NRCS) for nesting and feeding. In sum, grasslands, habitat edges, along with adjacent upland forests in the study area collectively provide necessary nesting conditions for a wide variety of pollinators.

**Threats to Pollinators**

Pollinators are so diverse and so varied in their habitat requirements, it is difficult to generalize about them, but it is fair to say that most are harmed by urbanization. The replacement of native vegetation by roadways, manicured lawns, crop fields, and other simplified land use types reduce available food and nesting sites. It causes the direct loss of habitats as well as the isolation of land. An issue associated with fragmentation is the island effect (Tepedino, 1979). Pollinator fauna and flowering plants are constrained in parcels surrounded by unsuitable areas. Depending on the size and available flora species, some pollinators, typically specialists, are more vulnerable than others. Specialists also have the danger of extirpation once a particular host
plant species disappears. Furthermore, they are more susceptible to the fluctuation of potential resources (Tepedino, 1979).

The common insecticides are often as toxic to beneficial species as to pests (Johansen & Mayer, 1990). For instance, in one study a population of bumble bees collapsed and took three to four years to return to the pre-spray level (Tepedino, 1979). Due to bees’ relatively low fecundity, they are less likely than other species to develop resistance to insecticides (Tepedino, 1979). Particularly, neonicotinoids, a group of popular insecticides that have been commercially introduced worldwide since the 1990s, can be present at low concentrations throughout most plant tissues yet still kill pests effectively (Lundin et al., 2015). Though the role of these compounds in pollinator declines generally remains controversial, they are highly toxic to pollinators such as honey bees (Iwasa et al., 2004). Neonicotinoids can be transmitted to pollen and nectar and remain in soil for a long time, causing acute death in bees (Lundin et al., 2015).

Another factor that causes the change of population status is parasites. For example, nonnative protozoan parasites, such as Nosemabombi and Crithidia bombi are part of the reason for the decline in native bumble bees. Leaf Cutter Bees (Megachile rotundata) are also victims from the harm of a disease, chalkbrood, caused by fungal pathagon (Committee on the Status of Pollinators in North America, 2007).

As pollinator faunas encounter threats from various aspects, some non-agricultural plant species are more vulnerable to extinction. There is a positive correlation between pollinator diversity and floral diversity (Heithaus, 1974). The plant-pollinator interaction determines that declining pollinator population leads to greater difficulty for reproduction of wild plants (Committee on the Status of Pollinators in North America, 2007).
IV.9. The American Black Duck (*Anas rubripes*)

*Biology and Habitat*


American black ducks are more commonly found breeding in forested wetlands and aquatic habitats, but they also utilize assorted wet meadows and deep marshes. During winter, they dwell in coastal salt marshes and bay areas in Massachusetts (“American Black Duck”, n.d.). Codman North and the forested wetland adjacent to Baker Bridge’s Fields are suitable breeding sites for American Black Ducks.

*Threats to American Black Ducks*

American black ducks used to be common throughout Massachusetts, showing a greater concentration in the east of Massachusetts by Boston Basin, Bristol Lowlands and Cape Cod in the 1970s (BBA2). However, American black ducks are rarely found breeding inland now. They also vanished from about 30% of the study area at Boston Basin. The habitats in Massachusetts became inhospitable for the species since the 1940s. The increase of mallard population and the loss of habitats create challenges to the species. As a primary source of ducks for hunters, American black ducks’ population was further exploited by the hunting community until a restriction on harvesting in 1983 (Longcore, McAuley, Hepp & Rhymer, 2000). The number of kills by hunters were strikingly high before the restriction. For instance, the 5-year mean of
annual sports harvest from 1967 to 1971 was 819,000 ± 39,000 SD (Longcore, McAuley, Hepp & Rhymer, 2000). American black ducks also suffered from contaminations of DDT, lead, and plastics. These chemicals resulted to shallow eggshells, sickness, and death (Longcore, McAuley, Hepp & Rhymer, 2000).

In addition, habitat loss and degradation further put the species in threat. Human development and urban sprawl encroach wetlands used by them. Half of the shallow water marshes in Massachusetts was gone from 1951 to 1971 (BBA2). Acidic depositions that were negatively affecting invertebrate food supplies might be another threat encountered by American black ducks (Mass Fisheries and Wildlife). However, it is possible that some other foods might gain benefits from acidification since their prey (some fish) decline (Bendell & McNicol, 1995).

VI.10. The Northern Leopard Frog (*Lithobates pipins*)

*Biology and Habitat*

Northern leopard frogs (*Lithobates pipins*) are spotted frogs with smooth skin in bright green, brown, or yellow-green. The size is between 5-9cm, and females are typically larger ("Northern Leopard Frog", n.d.).

As a species dwells in the northern part of the country, The Northern leopard frogs occur in at least eight counties in Massachusetts including Middlesex (Mass Fisheries and Wildlife, Northern Leopard Frog). Northern leopard frogs require aquatic habitats for breeding, permanent pools or side channels along streams or rivers. Accumulation of water in wetlands are also suitable for them to breed. Emerging tadpoles are dependent on vegetation like sedges and rushes ("Northern Leopard Frog", n.d.). Emergent marshes and shrub swamps also contain vegetation that they need. During late spring to early fall, they are found in upland fields, grasslands, and
wet meadows (Mass Fisheries and Wildlife, Northern Leopard Frog). They have also been observed in Lincoln previously (Town of Lincoln, 2017). The diverse natural communities in the study area meet the distinct survival needs of northern leopard frogs.

 Threats to Northern Leopard Frogs

The range and distribution of Northern Leopard Frogs have been contracted in Massachusetts (Mass Fisheries and Wildlife, Northern Leopard Frog). As other species relying on wetlands, Northern leopard frogs also suffer from habitat loss and habitat degradation mostly due to residential and commercial development. Fragmentation of habitats and high road density further draw the population down. Besides these factors, Northern leopard frogs are also threatened by several pathogens that affect other amphibians elsewhere, since they are not resistant to exotic pathogens introduced from other locations (Mass Fisheries and Wildlife, Northern Leopard Frog).

IV.11. The Spotted Turtle (*Clemmys guttata*)

Growing up to 12 cm long, spotted turtles (*Clemmys guttata*) have smooth and dark shells with yellow dots. They use diverse aquatic and wetland habitats in different seasons. The habitats include vernal pools, shallow slow-moving streams and rivers, marshes, wet meadows, shrub swamps, and forested wetlands (Milam & Melvin, 2001). Nesting and estivation in summer also rely on upland buffers nearby wetlands and pool (Milam & Melvin, 2001).

In summer, female turtles search for nesting habitats with open canopies and bare ground. Establishing nest sites in modified areas such as agricultural fields and residential lawns are vulnerable to disturbance from human activities and pets (New Hampshire Wildlife Action Plan
Appendix A Reptile). Mortality from vehicles is another factor besides habitat loss and degradation that is threatening the species. The high density of roads and railways segregates parcels into fragmented pieces and increases the chance for spotted turtles to go across them (Milam & Melvin, 2001). Because of their late age of maturity and low fecundity, having a slight decrease of the population would raise the possibility of extirpation (New Hampshire Wildlife Action Plan Appendix A Reptile).

IV.12. The Eastern Ribbon snake (*Thamnophis sauritus*)

The eastern ribbon snakes (*Thamnophis sauritus*) is an eastern dweller with a slender body ranging from 41 to 71 cm long (“Eastern Ribbon Snake”, n.d.). Three yellow stripes stand out on its dark reddish-brown body (“Snakes of Massachusetts”, 2014). It is hard to differentiate this species from another common snake in Massachusetts, the garter snake (*Thamnophis sirtalis*) (Mass Fisheries and Wildlife).

Eastern Ribbon Snakes are diurnal, and semi-aquatic snakes that are mostly found along water bodies (Bell, Herman, & Wassersug, 2007). They also thrive in marshes, wet meadows, and shrub swamps (Mass Fisheries and Wildlife). Over 90% of their diets are amphibians (Wisconsin Department of Natural Resources, 2017).

This species is included in Species of Concern by Massachusetts Fisheries and Wildlife, although the exact distribution and abundance in the state are not yet clear. The decline in wetlands not only directly limits habitat availability but also reduces the amount of their prey. Besides the common themes applying to wetland species, human and beaver activities that cause hydrological alteration negatively influence eastern ribbon snakes because of their close bond to water (Wisconsin Department of Natural Resources, 2017). Contaminations from roads and
surface materials can disrupt breeding behaviors by altering pheromone trailing (Shine et al. 2004).

### IV.13. Beavers (*Castor Canadensis*)

Beavers (*Castor Canadensis*) are the largest rodents in North America and are associated with open wetlands and forested wetlands. Even though they were once extirpated in the 1700-1800s in Massachusetts due to hunting, they are now nearly fully restored (MassWildlife, 2015). Without major predators and trapping, the density of beavers may exceed pre-extirpation density (Foster, 2001, p150).

Beavers are environmental engineers that dramatically influence ecosystem structure and dynamics. Regarding open lands and forested wetlands, their activities can create and maintain wetlands, modify nutrient decompositions, influence community composition and diversity through altering habitats, etc. (Naiman, Melillo, & Hobbie, 1986). Forested wetlands can have dramatic alteration if beavers appear. By knocking down trees, building dams, and altering waterflows, beavers generate water impoundments. Understory vegetation is inundated while overstory trees are killed. Beavers eradicate previous forested wetlands, while non-forested wetlands are created. In the initial three years after damming, some trees are alive. During the next four to ten years, emergent vegetation appears and many standing dead trees remain in the field (Collen & Gibson, 2001). The emergent marsh in the east of Baker Bridge’s Fields is an example of such early successional habitats. It used to be forested swamps until beavers arrived about a decade ago, but it is an early succession habitat now.

As beavers abandon dams after the depletion of food sources such as deciduous and hardwood barks and twigs, the impoundments drain and go through a succession (MA SWAP
Wet meadows continue to develop into shrubby wetlands, which further transfer to forested wetlands (MA SWAP 2015 CH4). If beavers return to the same areas, another cycle occurs.

As ecosystem engineers, they modify plant diversity by creating wetland habitats supporting plants that live nowhere else (Wright & Jones, 2002). Nonetheless, it is hard to predict whether a beaver-modified area would have increased or decreased plant species richness. The original forested lands might contain a high species diversity, yet the replacement of successional habitats might not achieve its previous species richness. Since the process of transformation of each piece of land ranges from a year to centuries, beavers also create shifting mosaic of environmental conditions (Naiman, Johnston, & Kelly, 1998).

While the influences of fire and agriculture on the New England landscape are nowadays incomparable to the historical level, beavers are one of the remaining factors that maintain open land habitats utilized by a variety of avian species and other wildlife (DeGraaf & Yamasaki, 2003). Some historical open land birds such as grasshopper sparrows and Henslow’s sparrows might reoccur if more beaver-modified open lands are available. Most of the species of our concern, including American black ducks, northern leopard frogs, spotted turtles, etc., can gain benefits from beaver activities.

However, there are also some potential issues caused by beavers. Overpopulation of beavers is associated with consumption of excessive resources and the decrease in species richness. Beavers returning to previously flooded areas would eradicate late-successional species. Reducing rare species and facilitating species invasion are also negative effects caused by ecosystem engineering (Bartel, Haddad, & Wright, 2010). Farmlands close to beaver ponds might be inundated.
IV.14. Winter Moth (*Operophtera brumata*)/Gypsy Moth (*Lymantria dispar*)

Winter moths (*Operophtera brumata*) and gypsy moths (*Lymantria dispar*) are two species of invasive moths that have detrimental effects on tree species in New England. Although they do not cause direct harms to open land habitats, the negative influences of trees and shrubs jeopardize the value and function of forested wetlands and edges used by the concerned species. As species endemic to Asia and Europe, gypsy moths were originally introduced to the Boston area in 1868 or 1869 (USFS, 2003), and Winter Moths, also from Europe and part of Asia, arrived North America decades later (Elkinton et al., 2015).

In spring, winter moths feed on a wide range of trees including oaks, maples, birches, and other species (Wint, 1983). They also cause damage in orchards, killing plants such as cranberry, blueberry, and apple (Elkinton et al., 2015). Their larvae bore into buds of host trees and affect the trees before leaf expansion. Feeding on leaves also causes defoliation, which has a lasting damage on trees (Elkinton et al., 2015). Particularly, the growth of red oak (*Quercus rubra*) decreases when defoliation occurs (Simmons et al., 2014), and the annual growth rate can reduce as much as 47% (“Winter Moth”, n.d.). The succession of defoliation even has the potential to kill an entire tree.

Gypsy moths also lead to defoliation, whereas they tend to occur in uniform stands of tree species, especially oak. However, moderate defoliation caused by them might not be as disastrous as broadly conceived. It is even possible that the existence of gypsy moths in forests somewhat promotes diversity in the ecosystem (“Gypsy Moth”, 2016). First, moderate thinning of monocultural tree stand caused by them contributes to a more diverse forest stand and provides more opportunities for understory growth. Also, the larvae serve as food for birds and
other wildlife. Their droppings also fertilize the soil (Mass Audubon, Gypsy Moth). However, the benefits gained from gypsy moths may due to the consequence of adaptation of the ecosystem. More research is needed to evaluate the level of abundance to provide positive effects.

IV.15. Invasive Plant Species

One of the most unfortunate changes in Lincoln is the rapid spread of invasive plants. Invasive plants constitute more than 80% of the species in some regions in some of the study area (e.g. edges of Farm Meadow, Codman South, and Baker Bridge). On the one hand, invasive species can lead to major adverse effects on local fauna and flora species. Invasive plants can become the dominant species of an area (Mitich 2000), reduce the available food resources (Tallamy & Shropshire 2009), and transform the structure of habitats (Schmidt and Whelan 1999). On the other hand, some studies (Sherley & Hayes 1993) have proven that invasive species have become an essential composition of local habitat, and provide resources for other native, even endangered species. Thus, the abundance and trend of spreading of invasive species can determine types of management, whether removing the species completely or regulating the environmental conditions (Moles, Gruber, & Bonser, 2008).

Multiple invasive species are commonly seen in Lincoln open lands. Originated in Europe, glossy buckthorn (*Rhamnus cathartica*) forms dense thickets in the understory, competing with native plants for resources and inhibiting tree regeneration (Taft and Solecki 1990). As a perennial and deciduous woody vine (Silveri et al. 2001), oriental bittersweet (*Celastrus orbiculata*) was planted in coastal towns for ornamental purpose a century and a half ago (APWG 2005) and has been spread in Massachusetts since 1950. It is more abundant on former logging-road site, where has south aspect and east aspect, and positively correlates with
soil pH and amounts of exposed mineral soil. Another plant that affects soil conditions is garlic mustard (*Alliaria petiolata*). It changes soil microbiology and pH (Town of Lincoln, 2017). Originated in Asia, autumn olive (*Elaeagnus umbelata*) was planted for ornamental purpose and has spread in the Midwest and the east coast (Ebinger and Lehnen 1981). Other invasive plants in the area are Japanese knotweed, black wwallow-wort, burning bush, bush honeysuckle, Japanese barberry, multiflora rose, Norway Maple, wall lettuce, yellow iris, and purple loosestrife (Town of Lincoln, 2017).
Chapter V. Existing Management

V.1. Introduction

This chapter covers current management regimens focusing on the conservation of open lands. Some management programs are designed to conserve a group of species, such as grassland birds; others intend to preserve the ecological value of certain habitats. This section starts with programs maintained by the federal government as well as national non-profit organizations and shifts to programs in the state of Massachusetts. I emphasize local management of open land, and special attention is paid to the study areas in southwest Lincoln to understand the philosophy and goals of management practices at those sites.

This section introduces some management measures used by The Nature Conservancy, Mass Audubon, and other groups. By constructing a framework of existing management programs, I aim to gain insights for creating a specific management program for the study area.

Some challenges impede the process of open land management in Lincoln. One of my goals in this section is to answer the question: “What are some social, economic, and environmental conflicts in Lincoln that have hampered the development of successful land management strategies?”

V.2. Management at the National Level

U.S. Fish and Wildlife Service

At the federal level, the U.S. Fish and Wildlife Service (FWS) is an agency dedicated to “conserve, protect and enhance fish, wildlife and plants and their habitats for the continuing benefit of the American people” (FEW, n.d.).
One way the FWS conserves wildlife is by establishing National Wildlife Refuges (NWRs). One of the preserves nearby the study area is the Great Meadow National Wildlife Refuge, located along the boundary of Concord and other towns. It is mostly comprised of fresh water and wetlands. With special emphasis on migratory birds, the refuge provides habitats for over 220 species of plants and animals. The old fields in the refuge are mowed annually. Even though FWS finalized a fire management plan in 2003, fire is still not a tool used to manage the Great Meadow (FWS, 2005).

The Endangered Species Act is administered by FWS to identify rare species and recover populations. Not only does FWS protect rare species’ habitats, in some cases FWS have reintroduced species to their original occupied habitat. The FWS also regulates a variety of national programs that benefit wildlife species and their habitats. One example is the Migratory Bird Program, which utilizes legislative actions such as enforcing the Migratory Bird Treaty Act and other actions including identifying birds of concern (U.S. Fish and Wildlife Service, 2016). Most species of concern in this study including bobolinks, American kestrels, and American black ducks are protected by the legal regulations of this program.

Natural Resources Conservation Service

Regarding agriculture and the preservation of open land habitats, Natural Resources Conservation Service (NRCS) is an agency of the United States Department of Agriculture (USDA) that provide farmers and rangers support to balance the needs of agriculture and conservation.

There are several programs administrated by NRCS that provide funding and technical supports to landowners who desire to provide benefits to wildlife. By signing contracts to
establish land-specific plans for the improvement of soil, water, plant, animal, air quality, and other natural resources on agricultural lands, the Environmental Quality Incentives Program (EQIP) provides funding and expertly supports to land owners. The Conservation Stewardship Program (CSP) provides annual payment for landowners who maintain and improve existing conservation activities and who undertake additional conservation activities that concern resources and habitat on agricultural lands. Another program that helps prevent the abandonment of farmlands and preserving wetlands is the Agricultural Conservation Easement Program (ACEP). Through purchasing agricultural land easement and wetland reserve easements, NRCS allows these areas to continue to serve as habitats for open land species.

Before 2014, the Wildlife Habitat Incentive Program (WHIP) provided a funding for landowners who delay cutting to improve and support habitats for grassland birds and other species. Landowners may receive over 75% cost-share from NRPS. Nonetheless, the Agricultural Act in 2014 repealed this program.

NRCS also issued a grassland bird conservation guideline in 2010 called “Managing Considerations for Grassland birds in Northeast Hayfields and Pasturelands. This guideline proposes creating late-cut refuges, delaying the second cut, optimizing field shape, and using rotational grazing (USDA, 2010). The guideline also suggests increasing rotational rate and extending the period of undisturbed time to more than 60 days (USDA, 2010).

Most of the time, profit is one of the major considerations of farmers in Lincoln. These programs are potential opportunities that can provide economic incentives to help Lincoln’s farmers adopting sustainable farming methods. Besides the financial compensation, these programs promote conversation between experts and local farmers and design specific
management program for each farm. The education ensures conservation with agriculture to be more comprehensive and scientific.

**USDA Forest Service**

Another federal agency of USDA, the Forest Service, also emphasizes the conservation of open space. Even though their definition of “open space” includes working and natural forests, they also focus on grasslands, farms, wetlands, and other natural lands that provide ecological services. The Forest Service applies four strategies to conserve open space. First, they identify and protect priority open space through partnerships with agencies and organizations in federal, regional, and local scale (U.S. Forest Service, n.d.). The protection of open space is conducted through land acquisition and conservation easements with both Federal and non-Federal funds. Second, they generate economic incentives for landowners to conserve open space through promoting Federal policies and supporting market-based approaches (Forest Service, 2007). The third strategy is sharing expertise and tools to communities. The last strategy is to help planning community growth and reducing ecological impacts and wildfire risks (Forest Service, 2007). These comprehensive actions conducted by the Forest Service protect the ecological values of open space, minimize the impact of development, and foster biodiversity in open space.

In terms of wetland protection, the Clean Water Act is the primary vehicle applied by the Federal Government to regulate activities that occur in wetlands (Votteler & Muir, 2002). Enforced by U.S. Army Corps of Engineers (Corps) and the U.S. Environmental Protection Agency (EPA), the Clean Water Act plan to control the discharge of dredged or fill materials into wetlands and other water (Votteler & Muir, 2002). Other Federal agencies that are
responsible for regulating wetlands include U.S. Fish and Wildlife Service, NRCS, and National Oceanic and Atmospheric Administration (NOAA).

The Nature Conservancy

The Nature Conservancy (TNC) is a non-profit organization that strives to conserve lands and water both domestically and internationally. TNC collaborate partners to research and protect designated reserves. In term of TNC’s work in Massachusetts, it contains strategies of “securing fresh water, restoring our oceans, conserving critical lands, <advocating> environmental policies, and stewarding our future” (TNC, n.d.).

Where appropriate, TNC staff have been using fire to manage their conservation lands. Prescribed burning is particularly applied at prairie reserves in the Midwest. TNC also uses fire in some of its reserves in New England. For instance, TNC cut and burned shrubs and Pitch pines on the Katama grassland on Martha’s Vineyard, MA (Foster & Motzkin, 2003). At a site nearby the Katama grassland, TNC works with Massachusetts Division of Ecological Restoration to burn oak forests. In addition, TNC-Massachusetts also work on prescribed fire program that concentrates on open lands and scrub vegetation (TNC, n.d.).

V.3. Management Practices by the State of Massachusetts

The Executive Office of Energy and Environmental Affairs

The Executive Office of Energy and Environmental Affairs (EEA) are collective agencies and offices that have the mission of planning for a clean energy future. Conservation restriction (CR) Acquisition is one of EEA’s approaches to limit development on lands. By having a legal agreement with EEA, landowners preserve the ownership of the lands when the type and amount
of future development are constrained (EEA, n.d.). On the agriculture side, EEA also has a special kind of CR, Agricultural Preservation Restriction Acquisition (APR). APR ensures the parcel to remain its agricultural purpose by limiting non-agricultural and non-open space use.

Besides APR, agricultural practitioners can apply for a few other loans and grants from the state that aim for conservation. One of them is Agricultural Environmental Enhancement Program (AEEP), which funds practices that mitigate adverse impacts to the environment. These sources of funding motivate farmers and owners of farmlands to be conscious of the impacts of their practices. Such environmental consciousness would benefit wildlife species and plants that utilize these fields.

*The Massachusetts Division of Fish and Wildlife (MassWildlife)*

As one of the agencies under EEA, the Department of Fish and Game is responsible for preserving wildlife species, plants, natural communities, and the habitats supporting them. One of the divisions that is responsible for conservation of wildlife resources is the Division of Fish and Wildlife (MassWildlife).

Articulated in the Constitution and General Law of Massachusetts, MassWildlife’s responsibilities are the protection, restoration, and management of Massachusetts’s flora and fauna. Their stewardship covers endangered, threatened, and special concern species, and other species (“About MassWildlife”, n.d.). The 2015 State Wildlife Action Plan (SWAP) was enacted by MassWildlife with a goal to “keep common species common and to conserve the breadth of biodiversity of the Commonwealth” (MassWildlife, 2015). It addresses 570 Species of Greatest Conservation Need (SGCN), identifies 24 types of habitats, and proposes conservation actions to ensure the state’s biodiversity. What SWAP categorizes as Endangered, Threatened, and Special
Concern species are “globally rare species, species which are listed as being of regional concern as determined by the Northeastern Association of Fish and Wildlife Agencies, species of high regional responsibility that occur in Massachusetts, and other species that are of conservation concern within the Commonwealth” (MassWildlife, 2015). Some examples of the SWAP conservation actions related to open lands are mowing abandoned agricultural lands to prevent succession and selectively applying herbicides to control invasive plants (MassWildlife, 2015).

The Natural Heritage and Endangered Species Program (NHESP)

One of the programs within MassWildlife, the Natural Heritage and Endangered Species Program (NHESP), is responsible for “the inventory, research, and protection of rare plant and animal species and maintenance of computerized and manual records of rare species locality information” (NHESP, n.d.). It enforces two acts in Massachusetts General Law that protect rare species and their habitats in Massachusetts. Enacted in December 1990 as Chapter 131A, the Massachusetts Endangered Species Act (MESA) establishes the procedures to list and protect rare species. MESA lists 169 species of vertebrate and invertebrate animals and 258 species of plants as either Endangered, Threatened, or of Special Concern in Massachusetts based on their risk of extirpation (“MESA Overview”, n.d.)

NHESP use BioMap2 as a tool to protect these species and their habitats. BioMap2 identifies critical areas sustaining rare species and containing high ecological values in Massachusetts and provides insights for conserving biodiversity. Biomap2 emphasizes the need to develop “target protection priorities proactively”. It also underscores that reactive management can result in inefficient use of conservation budget (NHESP, 2010).
As far as mowing, NHESP has proposed a mowing advisory guideline for protecting rare turtle habitats including grasslands, shrublands, pastures, and hayfields. On the one hand, mowing can provide spare vegetation and bare ground which are required by turtles, especially wood turtles and box turtles. On the other hand, mowing machinery kills more turtles than roads (NHESP, 2009). The guideline suggests avoiding mowing during May 15\textsuperscript{th} to September 15\textsuperscript{th}, a peak time when turtles use the fields. Although this suggestion might not be applicable for fields used for hay production, other alternatives can reduce turtle mortality due to mowing: elevating the deck of mowing machines to mowing deck to at least 18 cm high; using a slow mowing speed, reducing mowing frequency. Another way is to start mowing from the center and mow in a circular pattern to the edges. This mowing directionality leaves time for turtles to react. Leaving the edges unmowed until September 15\textsuperscript{th} provides sanctuaries for turtles (NHESP, 2009).

Even though this guideline does not target spotted turtles specifically, they will benefit from the management. Wood turtles are not in the inventory of species in the study, but they also present in Lincoln’s open lands. These suggestions can be used in the study area to conserve turtles and other species.

In conclusion, the Department of Fish and Game construct the framework for conservation based on the rarity of species and ecological significance. The Department of Fish and Game provides local land managers the guidance to efficiently distribute resources to rare species and crucial habitats. Different sources of conservation funding yield economic incentive to prevent agricultural practices that imperil the land and adjacent area providing ecological services. Besides state agencies, there are additional groups that also engage in the conservation of open lands.
OTHER LOCAL ORGANIZATIONS MANAGING OPEN LANDS

Mass Audubon

Founded in 1896, the Massachusetts Audubon Society (Mass Audubon) is a leading nonprofit organization that actively engage in “<protecting> the nature of Massachusetts for people and for wildlife” (Mass Audubon, 2017). Mass Audubon manage over 35,000 acres of open fields, forests, beaches and other areas that serve as wildlife habitat. Through the acquisition of lands, Mass Audubon establish wildlife sanctuaries, creates inventory, monitors the land, and implement management actions. One of Mass Audubon’s sanctuaries is Drumlin Farm Wildlife Sanctuary which is in south Lincoln. As a working farm, Drumlin Farm serves as a model of balancing the needs of agriculture and conservation. Not only does the Wildlife Care Center habituate native wildlife that cannot survive in the wild, but the farm itself is a valuable 232-acre-habitat for a variety of birds including bobolinks and eastern meadowlarks. Along with volunteers, they also establish cavity nest boxes that host eastern bluebirds, black-capped chickadees, and tree swallows (Mass Audubon, 2017).

Aside from establishing sanctuaries, Mass Audubon conduct research with partners to investigate the status of a variety of open land species. The Massachusetts Herpetological Atlas, a 7-year project conducted during 1992 to 1997, is the collective effort of Mass Audubon and University of Massachusetts Amherst to document the distribution of amphibians and reptiles in the state. Another research on breeding birds is the Breeding Bird Atlas 2 (BBA2), conducted from 2007 to 2011. It documents the transformation of population trends and compares the result to previous data collected in the 70s. One of the results of BBA2 is that the American black duck and the American kestrel, two of species of concern of this study, are the top two species suffering the greatest decrease in distribution over the last three decades. Eastern meadowlark,
another species used to appear in Lincoln, is the third among the list of birds with the greatest
decrease in range (Mass Audubon, 2011).

In addition to BBA2, Mass Audubon also designates Important Bird Areas (IBA), sites
that constitute important bird habitats, and provides information to land managers on habitat
management and land acquisition (Mass Audubon, 2017).

Specific to grassland birds, Mass Audubon has adopted the Bobolink Project to promote
conservation of Bobolinks and other grassland birds on private farms (“The Bobolink Project”,
2017). Protecting grassland birds from the harm of hayfield mowing, the project assists the
farmers financially while they agree to postpone their mowing schedule. Since late-hayed fields
serve as high-value habitats that diminish nesting failure due to mowing (Perlut et al., 2008), this
project has important implications for land managers who wish to increase nesting success of
migratory grassland birds in hayfields.

Incorporating with MassWildlife, the Trustees of Reservations, and TNC, Mass Audubon
issued an action plan to conserve state-listed obligate grassland birds in Massachusetts in 2013.
The plan underscores the importance of monitoring grasshopper sparrow and upland sandpiper
breeding population. It is also critical to understand nesting success to indicate habitat quality
(“An Action Plan”, 2013). The plan also proposes planting warm-season grasses (little bluestem,
indiangrass, etc.) to replace cool-season grasses. Because warm-season grasses mature earlier
than cool-season grasses (USDA, 1984), the replacement can delay mowing time and avoid peak
grassland bird breeding period. However, the mature time of grasses is not the only determinant
of early mowing. As discussed in Chapter II, mowing by farmers is always driven by the
incentive of maximizing the economic benefit. When farmers own the hayfields, they are
unlikely to plant grasses which are inferior in productivity and nutrient. Furthermore, mowing schedule has to compromise with the farmers’ availability.

In the “Best Management Practices for Nesting Grassland Birds” released in 2017, Mass Audubon provides suggestions for managing non-commercial grasslands. They suggest avoiding mowing from May 15 through August 15. If land managers are not able to avoid mowing during this time. Mowing every two to three weeks from late May through mid-July can intentionally make the fields unattractive to breeding birds, reducing mortality due to the process of haying (Mass Audubon, 2017). Spring mowing should be avoided too because the loss of cover in the fields does not attract grassland birds (Mass Audubon, 2017). Mass Audubon recommend leaving the cut hay in fields for at least three years so that it can provide cover and protection. The report also encourages enlarging fields by clearing edges and maintaining contiguous shape.

V.4. Management at the Local Level

The town of Lincoln

In a local scale, many of Lincoln’s residents recognize the core natural resource, agricultural, recreational, and aesthetic values of the town. The Conservation Department works closely with Conservation Commission to protect Lincoln’s “natural resources, agriculture and habitat fields and trails” (“Conservation Department”, n.d.). Their mission is to generate open land plans, steward the lands, protect wetland and water resources, and educate the public.

The following list demonstrates types of Lincoln’s protected open space:

- Town-owned conservation land designated under MA Article 97 for conservation;
- Land Trust-owned conservation land;
• Conservation restrictions held by the Town;
• Conservation restrictions held by private organizations;
• Agricultural preservation restrictions;
• National Parks;
• States Park;
• Trail easements.

(Town of Lincoln, 2017)

The town does not emphasize the protection of any particular species nor has a specific management plan that targets specific species, but the Conservation Department protects a wide range of species by ensuring the integrity of the town’s diverse natural habitats. The main strategy employed is land acquisition. Since the first piece of conservation land was acquired in 1957, the town has been able to increase the total area of permanent protected land to 38% of the total area (Town of Lincoln, 2017). Currently, 3,091 acres are under the protection of conservation deeds or conservation restrictions.

Deeded conservation lands are owned by the town, land trust, or other conservation organizations. The Conservation Department manages about 1500 acres out of 2391 acres of publicly-owned deeded conservation lands, 200 acres of which are leased for agricultural purposes. Every parcel in my study is a piece of conservation land owned by the town.

The town, Mass Audubon, LLCT, and Massachusetts Commissioners of Agriculture all have established Conservation Restrictions (CR) and Agricultural Preservation Restrictions (APR) at various times with private land owners in Lincoln. By yielding the right to develop and/or maintaining agricultural practices, private landowners can obtain a reduction on their
property taxes. Currently, there are approximately 1,209 acres of privately-owned lands under some kind of CR or APR.

Besides deeds and restrictions, the Conservation Department collaborates with the non-profit organization the Lincoln Land Conservation Trust (LLCT) to hold a stewardship program. Monitoring is conducted to provide baseline inventory and to ensure that a series of deeds and restrictions are not violated.

Of the total 547 acres of open lands for agricultural use, 71% is on permanently protected lands, while 158 acres are unprotected. In addition to Agricultural Commission which aims to preserve Lincoln’s agricultural heritage, the Agricultural Subcommittee of the Conservation Commission is in charge of licensing agricultural operations on conservation lands and ensuring the practices are ecologically responsible.

About 47% of the wetlands is protected by conservation deeds or conservation restrictions (Town of Lincoln, 2017). In addition to the State Wetlands Protection Act, Lincoln has a local Wetland Protection Bylaw to cover a wider range of protection (“Lincoln Wetland Protection Bylaw”, 2007). For instance, the Conservation Commission requires homeowners who want to operate work in Buffer Zone Resource Area (within 100 feet of Wetland Resource Area or 200 feet in the case of rivers or perennial stream) to agree on the absence of development in the remaining intact buffer zone.

Lincoln uses a few methodologies to assess the diversity and abundance of its natural species wealth. One of them was surveying animals and plants during State’s Biodiversity Day from 2000 to 2002. Once a year over those three years, citizens were challenged to record as many species as possible over the course of a single day. Participants found and learned about the species in conservation lands, backyards, and other open space. Other methodologies include
Christmas bird counts, breeding bird counts, and wildlife tracking surveys. Additionally, local residents have recorded birds and insects occurring in the town. However, most of the data collected from these programs have not been analyzed. It is difficult to gain any insight from these raw data. A comprehensive and systematic inventory of species occurring in grasslands, farmlands, and wetlands has not yet been completed.

In terms of invasive species, the Conservation Department recognizes the wide distribution of invasive plants along field edges and within wetlands. Yet the town admits that “it is impossible to eradicate them, even on just town-owned conservation land” (Town of Lincoln, 2017). Plants such as honeysuckle, common buckthorn, Japanese knotweeds, etc. are mowed when they have the potential to encroach upon agricultural fields. The town also takes the initiative to eliminate certain species such as garlic mustards, which are detrimental to native plants such as lady slippers (Town of Lincoln, 2017). Current efforts include educating residents and recruiting volunteers for eradication.

V.5. Other Local Stakeholders

The Sudbury Valley Trustees

About 6 miles away from the study area, the Sudbury Valley Trustees (STV) use fire to restore pitch-pine/scrub oak barrens at STV’s Memorial Forest in Sudbury, MA. In 2013, STV thinned 50% of selected trees in a 15-acre area in a pitch-pine/scrub oak forest and prepared for a future burning in several years. Firebreaks, roads, trails, and wetlands will prevent the spread of fire. The optimal time for burning interval that STV propose is 7-15 years. The plan, if conducted successfully, will benefit species including prairie warblers, eastern towhees, brown
thrashers, American woodcocks, and eastern whip-poor-wills. Another area as large as 35 acres was thinned to compare the effects with the burned field’s (SVT, n.d.)

SVT staff also remove invasive plants in Memorial Forest with the help of contractors and volunteers. Volunteers focus mainly on removing glossy buckthorn manually. The management of invasive species prevents them from taking over the burned area.

Even though SVT do not burn open lands, burning a field as small as 15 acres in an area nearby the study area provides valuable insights. Similar methods of creating an interval of 7-15 years, constructing firebreaks and removing invasive plants could be adopted when using fire to manage some of Lincoln’s open areas. The consequences of fire on Memorial Forest can improve understanding of the potential effects of fire management in some areas in southwest Lincoln.

The Walden Woods Project

The Walden Woods Project is a nonprofit organization which aims to “preserve the land, literature and legacy of Henry David Thoreau to foster an ethic of environmental stewardship and social responsibility” (“Mission and History”, n.d.). It achieves its mission through approaches that include conservation, education, research, and advocacy. Since 1990, the institution has protected 180 acres of lands in Walden Woods with other partners. The Walden Woods Project and these partners including the Massachusetts Department of Conservation and Recreation, Towns of Lincoln and Concord, the Lincoln Land Conservation Trust and Concord Land Conservation Trust, have turned approximately 80% of Walden Woods into conservation lands (“Mission and History”, n.d.).
One parcel of the lands that the Walden Wood Project owns is the Thoreau Institute. Locating at the end of Baker Farm Road, the Thoreau Institute Property is a 22-acre headquarter and conservation site adjacent to one of my study areas. Given its proximity to the study area and its goal to preserve the land, the Walden Wood Project positively contributes to the conservation of our species of concern, even though it does not directly express this aim. The protection of valuable land around Walden Pond as well as the educational efforts concerning the importance of environmental stewardship has surely helped conserve local plant and animal species.

Local Residents

The total population in Lincoln has been stable around 5200 people for the past decade. Many Lincoln’s residents engage in conservation management practices and are dedicated to preserve local aesthetics. They value the town’s emphasis on conservation and enjoy the benefits from conservation lands, while it is crucial to include them to the maintenance of sustainable open lands.

One example of citizen engagement is their involvement in the conservation planning process. The 2017 Open Space and Recreation plan incorporated the input of many residents. During the forums and online survey, people raised the demand of increasing recreational lands, such as athletic fields. Nevertheless, athletic fields, due to constant disturbance, illumination, and noise pollution, can disrupt animals using the fields.

Lincoln’s residents also provide other forms of support to the Conservation Department. For instance, they regularly volunteer in removing garlic mustards and other invasive plants. Some residents also take effort in investigating the status of local wildlife such as birds. For example, Nancy Soulette, a local bird enthusiast, has conducted numerous surveys of local bird
species and has created an inventory of birds mostly around the Baker Bridge Fields. Gwyn Loud, who works for the local newspaper, collects and reports local observations of wildlife. The residents’ consciousness on conserving agricultural features, wetlands, and other open lands and their actions are valuable resources in addition to the town’s effort.

However, it remains important to educate the residents about the practices of achieving conservation goals. Some residents engage in activities that jeopardize the environment. The Conservation Department has discovered incidents of disposing of construction materials in wetlands. Unregulated cutting of trees in conservation lands also occurs now and then. Education about local plants and wildlife can better connect the residents to nature and advance their consciousness in preserving the open lands in Lincoln.

Local Farmers

The farmers who are currently working in the study area are from Pete and Jene’s Backyard Birds and Farmyard/ Codman Community Farm and The Food Project. Working on Lincoln’s conservation lands, they have to ensure the farming practices follow the Conservation Department’s regulations and meet the requirement of sustainability. However, their choice of farming practices and environmental consciousness are critical for many animal and plant species using these agricultural fields.

For instance, the town does not regulate the time of mowing in farmland except for one location -- the 10-acre bobolink sanctuary at Farm Meadow. On other land, the farmers can decide the mowing schedule on their own. If they are willing to postpone mowing, grassland birds would benefit during the breeding season. For pastures, farmer decisions on the variety and abundance of grass species, and the severity of livestock grazing on the fields can have a
significant influence on the features of the grasslands used by a variety of species. As mentioned earlier, the extent of grazing correlates with the rate of bird mortality caused by trampling (Perlut et al., 2006). The clearing of shrubby edges by farmers can also determine the size of open lands that grassland species can use.

Besides agricultural practices, farmers have the potential to provide assistance to researchers studying the ecology of open lands. While conducting a baseline inventory of open land species, farmers can provide local knowledge on these species, given their intimacy with the fields. In addition, the process of data collection might include their participation. Researchers can recruit farmers to record grassland birds while farmers are working in the fields.

V.6. Management of Each Parcel

Baker Bridge Fields

Both pieces of farmlands at Baker Bridge and the adjacent wetland surrounding a brook are owned by the town. Starting from 1994, the Food Project has leased agricultural land from Lincoln Conservation Commission and expanded the field’s size. In 2002, additional 10 acres of land was added to the twenty-one acres of the field at Baker Bridge Fields. The Food Project is a nonprofit organization that obtains support from the community as well as distributes and donates sustainable food to the surrounding community. Most of the crops grown on Baker Bridge Farm are maintained with sustainable methods, without the application of chemical fertilizers and pesticides (The Food Project, n.d.). The crops grown on the farm vary from year to year, while legumes are usually grown during winter.
The southeast side of the farm lies a belt of grassland which is not used for agricultural production. It is adjacent to a belt of invasive buckthorns and other species. Farmers from the Food Project mow the grassland constantly, yet the schedule of mowing is not set.

The Conservation Commission has established some wooden cavity nesting boxes in the grassland locating in the north of Baker Bridge Road. Many bird species such as eastern bluebirds are using these boxes. In addition, neighborhoods have mixed opinions on cutting a cluster of shrubs with more than 80% of invasive species. The cluster is located by the north grassland and in front of a residential unit. Residents have reported witnessing many birds use these shrubs as habitat. However, the closest neighborhood prefers to have them cut. The town varies the management on these shrubs from year to year.

In term of the woodlands and wetlands in Baker Bridge, the Conservation Commission conducts annual monitoring and regulates dumping from residents.

Since there are exotic and invasive plant species growing across the railroad, removal of these plants is regularly conducted to ensure that they do not intrude the railroad.

**Codman North**

Three parcels of land at Codman North as large as 83.67 acres are owned by the town and set as conservation lands (LLCT). Identified as shrub swamps and red maple swamps, the wetland is protected by the Conservation Commission with annual monitoring. Since it serves as a wildlife corridor connecting Baker Bridge and Mt. Misery, maintaining the integrity of the field is a critical mission for the Conservation Commission.

A locally significant area in the woodland is the area behind the Codman House. A stand of mature hemlocks grows there, but they are affected by the Woolly Adelgid parasite. The town
has taken efforts to save the stand from the harm of pathogen by injecting chemical treatment from the roots. However, the cost of applying this method is substantial.

The farmlands are managed by Codman Community Farm. The use of the land has transformed since 2016 from a hayfield to a pasture. In 2016, Pete and Jene’s Backyard Birds and Farmyard, a local farm started in 2003, began to raise small flocks of chickens, sheep, and pigs on the pastures.

Even though no hazardous materials are present on the property, a potential threat is from the gas station on the north. The wetland is susceptible from potential seepage of toxic or harmful materials from the gas station (LLCT, 2004). Given the recent transformation of the use of the farmlands, the effect of grazing on other plants and animals sharing the field is unknown.

**Codman South**

Composed of two agricultural fields, Codman South is owned by the town and managed by the town. Analogous to Codman North, it serves as an important ecological corridor connecting Adams Woods to Mt. Misery. Most of the management efforts are focused on preserving agriculture, protecting the woodland, and maintaining paths and trails.

Adjacent to the pastures in Codman North property, the agricultural fields in Codman South are also managed by Codman Community Farm. They were also recently altered from hayfields to pastures with free-ranging farm animals. To prevent further encroachment of invasive shrubs, the Conservation Department mowed the east edge of the field in fall 2016 while the other edges remain with invasive plant species.
Since the town does not harvest forest resources in woodlands, the woodland in Codman South is set aside to preserve its integrity and biodiversity. Trail maintenance is regularly conducted to ensure the access of residents.

Codman East

The town owns Farm Meadow, its adjacent wetlands, and woodlands as large as 71.51 acres while Lincoln Land Conservation Trust owns the wetlands and woodlands with the size of 43.78 acres in the north. Farm Meadow is currently leased to Codman Community Farm.

Farm Meadow is a hayfield that provides critical habitat for numerous grassland birds. It is the only parcel that is listed as Priority Habitat for rare species by NEHSP in the study area. Mowing is conducted by Codman Community Farm during late May to mid-June by farmers from Codman Community Farm. The land manager from the town’s conservation department is in charge of “controlling woody and exotic plant invasions; keeping brush down along historic stone walls; mowing around trees and field stones; field edge clearing; and keeping field footpaths open” (Mowing Plan, 2016). Given Bobolinks’ use of Farm Meadow as a breeding habitat during summer, the Conservation Commission sets 10 acres of the field as a Bobolink sanctuary, which should not be hayed until July 20\textsuperscript{th}. Part of the invasive shrubs on the northwest side and northeast side were cleared during January 2017.

The woodland parcel in Codman East owned by LLCT is required to be used only for walking, horseback riding, and the study and enjoyment of nature and other applications compatible with the preservation of the land (LLCT, 2004).

V.7. Challenges to Open Land Managements in Lincoln
Development

One of the most remarkable challenges is the conflict between development and conservation. Suburban sprawl continues as a major trend affecting Lincoln and even as demand on enjoying conservation land continues to rise, more large-sized houses are constructed through extensive forest clearing. Not only does this behavior result in the fragmentation of forested habitats, it also affects the surrounding ecosystems through the increase of human influence. Construction close to wetlands imperils the ecological integrity. The issue of noise pollution also poses a challenge to wildlife. The interface of human and animals becomes problematic when users of conservation lands exceed the carrying capacity of conservation (Town of Lincoln, 2017). Along with rural development, there is a rising demand for recreation lands. Given the town’s low population, Lincoln’s recreation activities cluster at Lincoln Public School. There are three athletic fields on the school campus, and one by the town office. However, multiple groups have expressed the necessity to construct more athletic fields, and the possibility of transforming conservation lands to recreational use. Currently, none of the fields in the study area are proposed as sites for recreational fields. Only can species of concern and their habitats be effectively protected if the challenges of development are well understood and resolved. Communication between land managers, developers, and residents is a critical element for effective land management.

Invasive Species

The presence of invasive plant species within or next to agricultural fields in town might be troublesome because they will encroach farmlands and disperse into forested areas. The encroachment in agricultural fields would lessen the total area of arable lands.
Previous management has tried to cut back edges of invasive species once they encroach the fields, whereas these species grow back rapidly and require removal every year. The encroachment into the forests and wetlands is more difficult to control than open sites.

It is controversial whether invasive plants worth devoting efforts to manage against because they may be beneficial to some other rare species (see Chapter III and IV).

On the contrary, some invasive fauna species in Lincoln undoubtedly require management actions to limit their expansion. These species include winter moths, gypsy moths, and European starlings.

**Mowing**

As indicated several times in this paper, modern mowing can cause significant harm to grassland birds breeding in hayfields (Perlut et al. 2006). The application of tractors, early mowing, and high frequency of mowing all result in reduced breeding success (Perlut et al. 2006; Perlut et al. 2008).

Since changing the use of the farmlands in Codman North and Codman South, the remaining fields needed to be mowed are Farm Meadow and the non-agricultural grassland in Baker Bridge. Because the Conservation Department does not have a regulation on mowing schedule besides the Bobolink Sanctuary at Farm Meadow, farmers can decide their own schedule of mowing.

Farmers mow the fields when grassland birds are in a vulnerable state. One of the reasons given for early mowing is that farmers need to fit other farming activities into their schedule. The more direct reason is related to the profits gained from early hay. As mentioned in Chapter II,
early hay serves as better forage compared to late hay. The quality of forage determines the amount of milk production, which links to the incomes of the farmers.
Chapter VI. New Management Measures

VI.1. Introduction

This chapter proposes management regimes to conserve open lands in southwest Lincoln. Based on conservation efforts at the federal, state, and local levels, this section aims to fill in some gaps in current management regimes. It is important to realize that this implication of management should accommodate uncertainties and imprecision. Since inventories of fauna and flora species are still incomplete in Lincoln, and the effects of proposed management activities require further investigation, adaptive management is required, allowing land stewards to modify practices while feedbacks are obtained.

Six measures are proposed to include in the management regimes. These measures are

1. Re-examining the objectives of land conservation and management;
2. Convene partners to create a more complete inventory of species and establish monitoring programs;
3. Monitor and modify current agricultural practices to ensure the compatibility of agriculture and conservation;
4. Research and experiment with the effects of prescribed fire on managing grasslands;
5. Continue to protect wetlands and identify critical wildlife habitat within wetlands;
6. Educate local farmers and residents to raise awareness of environmental issues and increase engagement in conservation activities.

VI.2. Re-examining the Objectives of Land Conservation and Management
The open lands in Lincoln are the products of human culture. As a piece of cultural landscape lies within a rural setting, it provides valuable aspects that are worth conserving. There are at least three reasons for maintaining cultural landscapes: (1) cultural landscapes including agricultural fields and wetlands are historically important and aesthetically pleasing; they can provide attraction of tourism and economic benefits or enjoyment for residents and visitors (Norderhaug et al., 2000); (2) the habitats modified by humans can become substitution for natural habitats which used to support many species yet degraded or transformed (Vickery, 1994); (3) maintaining biodiversity of each landscape is critical even if it is based on cultural landscapes (Lawton, 1997). While concerning the management of Lincoln’s open lands, the first action is identifying objectives of the management plan and choosing the emphasis of conservation. The goal of current management practices is to conserve species of concern and maintain the sustainability of Lincoln’s open lands. The actions that achieve this goal will also protect the historical, cultural, and aesthetic value of the landscape. Aiming the protection of concerned species as well as the removal of undesired species results in a biodiverse community.

VI.3. Convene Partners to Create an Inventory of Species and Establish Monitoring Programs

Uncertainties exist regarding the distribution and population of a few species of concern in Lincoln open lands. The effects of human disturbance on these species are not fully studied. On the one hand, several species of concern such as American black ducks, spotted turtles, eastern spadefoot toads, northern leopard frogs, and eastern ribbon snakes have not been observed in the study area, even though they have the potential to reside in Lincoln open lands. Since these species dwell in wetlands where residents would not commonly access, it is
reasonable to have few witnesses of these species. The uncertainty of these species is also due to the fact that a system to record species in Lincoln’s wetlands is absent.

On the other hand, most of the listed species, including bobolinks, American kestrels, eastern bluebirds, beavers, and other invasive species have been witnessed in the study area. Birds are more commonly studied in Lincoln partly due to their accessibility. However, the data cannot provide implication unless they are organized and analyzed. There are still a few puzzles regarding the interaction between agricultural practices and animal species living on farmlands. For instance, the acceptable grazing intensity balancing breeding success remains unclear. The Conservation Department also needs more data to evaluate the result of delayed cutting in the Bobolink Sanctuary at Farm Meadow. Furthermore, the ecological benefits and negative influences of invasive edges are understudied.

Therefore, it is crucial to obtain scientific-based information of open land species for understanding the effects of current human activities and for establishing management plans (Motzkin & Foster, 2002). The documentations of long-term dynamics of major species are highly informative in selecting conservation objectives and analyzing existing practices. While the fluctuation of these species’ population is compared with human activities within their range, more insights would be obtained regarding the correlation between these activities and concerned species.

Among the species of concern, beavers deserve considerable attention. As ecological engineers, their abundance and distribution are closely tied to the type of natural communities. It is worth comparing the abundance of beavers both between different parcels and knowing the trend of population among a parcel. This information helps for understanding their influences on the landscape.
Some existing programs of evaluation can be used as guiding information for establishing a model, even if these programs are conducted at a broader level. For instance, Mass Audubon’s Breeding Bird Atlas 2 can provide useful information in the potential methodology of recording data of birds.

Multiple groups can cooperate to construct a scientific-based framework to collect long-term data on major species and complete data analysis. The Conservation Department would be responsible for convening wildlife researchers from universities and other organizations. For example, researchers from Harvard Forests such as Jason Aylward are potential advisors for generating an inventory of plants in the study area. Bryan Windmiller, a conservation biologist from a non-profit organization based in Concord, Grassroots Wildlife Conservation, is willing to provide expertise in reptiles and amphibians. Ornithologists from Mass Audubon, such as Jon Atwood and Wayne Peterson, can provide guidance on constructing breeding bird survey in Lincoln. In addition, local residents who are concerned about open land species can provide local knowledge of these species and where they usually appear.

Once the research protocols are established, data collection can be conducted regularly and periodically with the assistance of a variety of groups, including volunteers, high school students, or students from local universities such as Brandeis University. More significantly, because most of the grassland birds breed in agricultural fields, local farmers have the potential to be essential participants in data collection. They tend to encounter these species more often than other people so that their participation would be highly valuable.

However, it is important to realize that conservation resources are limited in searching a particular rare species. The record of species should be based on a habitat-by-habitat style
investigation. The aim is to provide an inventory of species specific to each parcel of habitat and to continue long-term, scientific-based survey on population and distribution.

VI.4. Monitor and Modify Current Agricultural Practices to Ensure the Compatibility of Agriculture and Conservation

Historical agricultural practices are valuable insight for current management. Nevertheless, to respect an area’s historical status and transformation is not identical to restore the field to its historical stage. The management of the land should be considered within the contemporary context. Even though historical farmlands in southwest Lincoln cover more area, it is impractical to restore as many farmlands as before given the limited agrarian population, restrained resources, and current rural development.

In New England, the application of traditional (agricultural) management regimes might be most effective for the restoration and conservation of grassland communities (Motzkin & Foster, 2002). Mowing, grazing, tilling and burning have been applied to keep the lands open and prevent forest regeneration. This research recommends maintaining the agricultural characteristics of the study area. As the town’s 2017 Open Space and Recreation Plan articulates, the Conservation Department will continue to lease the open lands to farmers and non-profit organizations which farm in a sustainable manner, while LLCT would assist the conservation ranger to monitor the sustainability of practices in these fields.

Expanding the size of current farmlands would provide more open lands to attract more wildlife. Several methods can be used to enlarge the fields. First of all, hedgerows and trees between fields should be removed to avoid fragmentation and attract more birds. (Mass Audubon, 2017). Second, mowing encroaching shrubby or woody edges allows all of the agricultural fields
to increase in size. However, the effects of eradicating edges are disputable, usually composed
with shrubs, can become sanctuaries for species such as New England cottontails and diversify
vegetation types. Thus, we propose removing shrubs dominated by invasive plants only when
they encroach agricultural fields.

As far as mowing the non-agricultural grassland at Baker Bridge, we recommend haying
them every 2-3 years to benefit grassland birds and other species (Bollinger, 1990). The town
should convene with the Food Project to negotiate a plan for mowing the field less frequently.
Spring mowing should be avoided. This study recommends mowing the field no earlier than
mid-July. In addition, mowing should have a relative high mowing height (7-14 inches) because

In term of Farm Meadow, the economic incentive for farmers is the most difficult issue to
resolve. Given early-hayed fields are detrimental for several grassland birds (Perlut et al., 2006;
Perlut et al., 2008), early mowing should be avoided if possible (Bollinger, 1990). The
Conservation Department should discuss the possibility of delayed haying with Codman
Community Farm. Ideally, turning the field to middle-hayed field, which is hayed between June
21\textsuperscript{st} and July 10\textsuperscript{th}, would significantly reduce the failure of breeding by grassland birds (Perlut, et
al., 2008). Their financial loss might be compensated by applying for NRCS’s programs (EQIP
and CSP mentioned in Chapter V) which fund farmers who benefit wildlife and who improve
conservation activity. Two of the EEA’s programs, APR and AEEP, can also provide funding to
compensate farmers. Landowners may receive a 75 percent cost-share from the NRCS for
implementing a delayed cutting practice on their property to enhance habitat for grassland birds
and other wildlife. If farmers are willing to mow after August 15\textsuperscript{th}, they would be qualified to
apply for the compensation from The Bobolink Project.
If the farmers are unable to delay haying, increasing the area of the Bobolink Sanctuary can provide a larger area without disturbance until July 20th. In addition, this study proposes refining mowing style to reduce the harm to grassland species. If farmers start by mowing the field from the center in a circular motion and continue to mow to the side, and if they mow in a low speed, grassland species such as turtles will have time to escape to edges. This study also recommends leaving the edges unmowed until September 15th so that they can provide sanctuaries for turtles, and possibly some grassland birds (NHESP, 2009).

Even though planting native warm-season grasses, such as switchgrass and big bluestem, is an alternative management practice to provide more suitable and preferable habitats for wildlife (Belding et al., 2000), this study does not encourage planting warm-season grasses to replace current cool-season grasses. Because of the disadvantages of warm-season grasses mentioned in Chapter III (low tolerance to trampling and grazing and low nutrient), this measure might significantly conflict with the farmers’ interests.

Cows could be detrimental to grassland birds either by eating or trampling nests (Perlut et al., 2006). If possible, apply rotational grazing and allow non-grazing intervals as long as possible since extending intervals between grazing would increase nesting success (Understander et al., 2000). One possible solution is dividing the pastures at Codman North and Codman South into smaller patches. Constraining cattle in one patch and moving them frequently would reduce mortality of grassland species due to trampling. In addition, the current plan suggests leaving 4 inches of grasses ungrazed. Leaving more than 4 inches of growth not only protect birds from predators, but plants also recover at a faster rate (Understander et al., 2000). Moving cattle to alternate rather than adjacent paddock is more desirable (Understander et al., 2000).
investigations are required to evaluate the effect of grazing on grassland birds and other open
land species.

Avoiding disturbance from humans and cattle would mitigate the stress of grassland birds. All of the trails in the study area do not transverse non-agricultural grasslands or agricultural lands, but they lie along the fields. Although it is not practical to eliminate the use of these trails from runners, hikers, dog walkers, or other people, preventing trail users and dogs from entering the fields between May 15th and August 15th would protect the breeding process of most grassland birds (Mass Audubon, Best Management Practices). Establishing fencings and signs along critical grassland bird sanctuaries during breeding season could also protect them from residents and dogs.

VI.5. Research and Experiment the Effects of Prescribed fire on Managing Grasslands

Fire has been one of the natural disturbances changing the landscapes of New England before humans arrived the lands (Foster & Motzkun, 1998). Even though evidence is in dearth, native fire may have helped to maintain grasslands and shrublands in New England. It was also a tool used by Native Americans to maintain forest resources, facilitate hunting, and help for farming. Later farmers in New England continued to adopt this method to prevent trees from growing and fertilize arable lands (Foster, 2001). Decades of fire exclusion caused the decline of many species and degradation of ecosystems.

In southern tallgrass prairie, rotational disturbance patches are created by patch-burning technique to manage for grassland birds (Coppedge et al. 2008). Such method reduces the abundance of brood parasitism, increases overall biodiversity, and provides habitats for species like Henslow’s sparrows (Coppedge et al. 2008). However, each rotational patch managed by
fire in southern tallgrass prairie is larger than 900 acres. It is dubious whether rotational-patch-burning would be applicable in fields that are less than 100 acres.

Rudnicky, Patterson III, and Cook (1997) compared the physical characteristics and status of grassland birds after burning in April, burning in August, and mowing in late August in Floyd Bennett Field, a recreational grassland in Brooklyn, New York. Compared to burning, mowing led to the loss of features desired by grassland birds, such as bare ground and preferable plant species (Whitmore, 1979). Mowing can also lead to the invasion of nonwoody exotics plants and low shrubs (Rudnicky, Patterson III, & Cook, 1997). On the contrary, burning increased bare soil cover significantly as well as litter cover (Rudnicky, Patterson III, & Cook, 1997). The time of burning also has an effect of the field’s features. Summer burns change vegetation compositions more drastically than spring burns because burning in summer open space for new species to enter the field (Rudnicky, Patterson III, & Cook, 1997).

In a three-year-study in Nantucket Island, MA, Zuckerberg and Vickery (2006) found that prescribed burning and mowing produce the similar effects in maintaining grasslands. The responses of grassland generalists to management types vary among bird species. Savanna sparrows show no preference on mowed, burnt, or unmanaged fields, whereas song sparrows prefer unmanaged grasslands (Zuckerberg & Vickery, 2006). Coppedge et al. (2008) concluded that pastures with discrete portions burned each year have most diverse bird species compared to regular annual burning of the whole field.

Dunwiddie and Caljouw (1990) call attention to simply labelling the amount of plant species as “increases” or “decreases” after prescribed fire. Some species might vary significantly in height or cover but not frequency. Flowering, seed production, susceptibility to browsing are also factors to be concerned in postburn grasslands (Dunwiddie & Caljouw, 1990). The variation
of timing, intensity, and frequency of prescribed burning could result in different ecological responses.

All these historical implications and research results suggest that prescribed burning could become a practical management method applied to open lands in Lincoln. It can be used as a complementary tool other than mowing to maintain early successional fields and create diverse environmental features.

However, it is unclear that the effects of prescribed burning on areas less than 100 acres. In addition, the application of fire may shoulder its social burden. When fire occurs in rural areas like Lincoln, residents might oppose such practice. The town can convene with institutions and governmental agencies, including The Nature Conservancy, Sudbury Valley Trustees, and the state’s Division of Ecological Restoration, all of which have used prescribed fire for management. While previous studies might not cover the results of burning in rural open lands, this study suggests experimenting prescribed fire at Farm Meadow and adapting the practice at the same time. The size of the experimental area is remained to be determined by the town and other experts.

VI.6. Continue to Protect Wetlands and Identify Critical Wildlife Habitat within Wetlands

The town of Lincoln has endeavored to maintain healthy wetland habitats and protect the quality of water among them. Current Wetland and Buffer Zone restrictions imposed by the Conservation Commission limits the threat from nearby development.

In addition to current efforts, the town should investigate important species among wetlands. It is necessary to investigate whether species like eastern spadefoot toads, northern leopard frogs, and eastern ribbonsnakes exist in the study area. If some of these rare species use
the open lands in Lincoln, identifying critical parcels in which these species are observed would help to protect these species and prevent extirpation. Investigators should pay special concern on vernal pools due to their importance in the life cycle of concerned reptiles and amphibians. Furthermore, recording the transformation of wetland types annually and mapping the change of vegetation, especially the ones due to beavers, would help compare the population of wildlife species with the impacts of various disturbances.

We also suggest creating an inventory of invasive plant species in wetlands as well as locations where they are most dominant. Although the town has not identified any approach to limit the spread of invasive plants in wetlands efficiently, identifying where they frequently occur facilitates the understanding of their trend of spreading.

Previous research projects were always conducted by interns in the Conservation Department or local residents. Having researchers from Tufts University, University of Massachusetts or institutions like Mass Audubon to guide the research would allow the investigation to be more systematic.

VI.7. Educate Local Farmers and Residents to Raise Awareness of Environmental Issues and Increase Engagement in Conservation Activities

The Conservation Department and other local conservation organizations should take the initiative in educating farmers and residents about the status of open lands in New England and important species among them. First, residents and farmers may begin to realize behaviors jeopardizing open lands if they become conscious of the local ecosystem and the important species among them. Furthermore, many conservation programs cannot be completed without the support of residents. Previous programs of removing garlic mustards and surveying
biodiversity could not be as successful as they were without local volunteers. Once the local populations are aware of the environmental challenges, more of them will be willing to participate in conservation programs.

Multiple approaches can connect Lincoln residents to local open lands. First of all, this study suggests the Conservation Department recruiting local volunteers to participate in research programs that survey local species and their habitats. Reviving Biodiversity Days, a program engaging observers to record as many fauna and flora species as possible, would give the participants a chance to learn about the species in the field. While collecting baseline inventory of open land species, the town can recruit local volunteers and students from local high schools. Second, this management suggests that the town advertises the needs of building wooden cavity boxes following protocols. Engaging in the construction of wooden cavity boxes for birds of concern, residents can learn about the characteristics and needs of these birds as well as ways to protect them. Third, campaigns should be held by the town or other institutions to advocate the harm of pesticides applied in residents’ yards and promote alternative gardening methods. Residents can also learn from the campaigns to identify invasive species in their backyards and other open lands.

To educate farmers might even be more crucial in the propensity of open land species. Besides current farmers who are leasing conservation lands, the town seeks to expand farming by supporting new farmers who wish to farm in Lincoln (Lincoln Open Space and Recreation Plan, 2017). The town should take the responsibility to explain the impacts of farming choices on local ecosystems. Guiding them to seek technical supports from the NRCS’s programs and assisting them to generate plans will even create beneficial effects upon species of concern and surrounding wetlands. Moreover, another way is advocating farmers to apply for funding which
supports environmentally friendly agriculture so that they have the economic drive to farm sustainably. The town can inform current farmers the application deadlines for programs such as the NRCS’s programs and the Bobolink Project.

VI.8 Conclusion

The measures proposed above are in response to six aspects of open land management: goal identification, investigation, conservation with agriculture, fire management, wetland protection, and education. These measures have considerable flexibility due to the uncertainty and the dynamics nature of the study area. The experimental feature of these management regimes reflects the adaptive characteristic of open lands.
Chapter VII. Conclusion

VII.1. The Philosophy of Open Land Conservation

The study of history reveals that the New England landscape is a constantly changing landscape. Change is an inherent feature so that future changes are inevitable (Foster & Motzkin, 1988). The rise and wane of open lands were due to centuries-long evolution of the US economy, especially as change affected agriculture. The increase of open land species in the mid-nineteenth century was the consequence of artificial creation.

It is controversial whether conservation resources should be spent on preserving open land species which were not significant members of the New England region prior the expansion of the agrarian nation. The divergence of opinions on open land conservation stems from the perception of “nature.” A radical view contracts human with nature. People advocating this view think that “what is nature is that which occurs through the workings of that massive whole independently of human will or action” (Vogel, 1998). Even though humans emerge from nature, in practice people adopt “instrumental” rationality with an attempt to achieve control over nature (Vogel, 1998). Adopting this philosophy, some people argue that the landscape in New England should be returned to the pre-European or even pre-human conditions because humans should not indulge in the fantasy of overriding natural rules. The landscapes created by humans, including open lands, should not be maintained, while nature will continue as an organic whole without these modified landscapes.

Other people might argue that the biodiversity in New England may not necessarily decline over the past 150 years. The overemphasis on agriculture was once criticized by environmentalists because it deprived the habitats of forest dwelling species. The current
decrease of open land species has been accompanied by the reestablishment and proliferation of forest species including deer, turkeys, beavers, bears, coyotes, pileated woodpeckers, and fishers (Foster, 2001). In this perspective, we should welcome the reintroduction and the thriving of these species. Scarifying some degree of forests for the revival of open lands may put these species into a dangerous situation again.

However, instead of polarizing nature and human, we should recognize that many natural communities and landscapes are “actually novel, highly humanized, and recently developed” (Foster & Motzkin, 1988). There are no static baseline ecological conditions throughout history (Foster & Motzkin, 2003). Humanity has incessantly left imprints in nature, and it is impossible to identify which piece of landscape is not “contaminated by humans.” Even if large blocks of the landscape could be returned to pre-European conditions, it would be inevitable that humans would continue to influence the land indirectly. Furthermore, the conservation of open lands is not the attempt to override natural orders. On the contrary, it is an effort to maintain what has evolved from this organic entity.

Conserving open lands and open land species have various meanings. From a biocentric point of view, the fauna and flora the range expansions of these Western species, humans should take the responsibility to maintain their status. Preventing the decline of open lands and protecting these species from harm will safeguard their intrinsic values.

From an anthropocentric view, open lands and open land species provide incalculable ecological services. An obvious example is pollinators, which contribute to the reproduction of about 35% of the world’s food crops (NRCS, n.d.). Conserving open lands and open land species is protecting the interests which we gain from them.
Furthermore, the conservation of open lands does not contradict with the conservation of forests. As proposed in Chapter VI, instead of clearing forests, the protection of open land species can be achieved by adopting grassland-species-friendly farming and sustainable open land management.

Aldo Leopold once concluded: “A thing is right, when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise” (Leopold, 1966, p240). I believe that conserving open lands is right not only in the sense of our moral obligation to maintain the intrinsic values of Lincoln’s fauna and flora species but also in the sense of maximizing the goods of all human beings.

Once the goal of conserving open lands and open land species is established, the following question is to what extent should open land species and their habitats be expanded. Should we not protect them only until they reach the point of endangered, threatened, rare, or other standards established by the state or federal agencies?

I would argue that the answer is definitely “No.” Reactive conservation, protecting open lands when a crisis emerges, is inefficient. Developing conservation goals and taking actions proactively improves the efficiency of conservation and helps avoid irreversible crises (BioMap 2). However, if a species has the trend of declining yet it has not reached the level of rarity, it is difficult to determine when we should start to take action targeting this species specifically. When and how should species-specific management be imposed? Perhaps the answer will become less controversial as the understanding of the open land ecosystem becomes more comprehensive.

VII.2. Limitations of this Study and Future Direction
There are several constraints of the current study. First of all, the inventory of critical species is created with uncertainty. Whether do certain species (eastern spadefoot toads, American black ducks, eastern ribbon snakes, and spotted turtles) currently exist in the study area is in doubt. It is also possible that some historically observed species (eastern meadowlarks, grasshopper sparrows, etc.) or other new species are active in the study area, but they are excluded from the list. The presumption of the existence and extirpation of these species is mostly based on the estimations of local ornithologists, ecologists, and conservation practitioners. The exclusion of certain species might miss the opportunities of maintaining desired habitats specifically for them. This limitation is due to the absence of a comprehensive record of open land species, especially within wetlands. The second measure in Chapter VI emphasizes the need for conducting a systematic inventory of open land species in Lincoln.

Second, the management of edges dominated by invasive plants is based on the uncertainty of the ecological role of these edges. The reaction to these invasive plants is hindered by two conflicting objectives of preventing encroachment and leaving habitats for New England cottontails and other animals. Therefore, this study adopts a conservative approach: mowing only when these plants encroach the fields. However, future study should attempt to understand the ecological role of these invasive shrubby edges and verify management practices according to the research results.

Third, little attention is paid to consider residents’ and farmers’ opinions and suggestions on open lands and open land management. This study does not interview residents or farmers who are connective to the land. There may be a gap between the goal of farmers and the goal of land managers. If the local population has a distorted perception of open land conservation,
management practices cannot proceed successfully. Future investigation of local residents and farmers’ attitude on open lands and open land conservation should be performed.

Last but not least, the current study does not consider the most updated proposal in managing Farm Meadow. Managers from Codman Community Farm are currently consulting with the Conservation Department to turn Farm Meadow into a pasture (April 2017). The consensus is that Farm Meadow will be divided into multiple patches in a certain size, where cattle is constrained to graze in each patch for about two weeks and turn to a new one. There will be about eight adult beef cows and six young.

Furthermore, five acres of land at the center will become a bobolink preserve. The town will establish fencing encircling the preserve so that grazing in spring is prevented. Turkeys will be moved into the sanctuary on or after July 20th, whereas they will rotationally graze on three subdivided patches in the sanctuary.

The Lincoln Conservation Department believes that the new setup will achieve the balance of conservation and agriculture. First, rotational grazing will allow some portion of the field to remain undisturbed. Second, this grazing style also results in a variety of growth stages of grass and different ground features. As mentioned in Chapter IV, multiple grassland species (horned larks and vesper sparrow) prefer bare ground and patchy vegetation (Akins et al. 2007). Third, the fencing will exclude dogs and humans from disturbing grassland birds in the sanctuary. Fourth, the introduction of turkeys will fertilize the sanctuary.

The management of Farm Meadow proposed by the current study is based on the fact that Farm Meadow is used as a hayfield. However, future study should investigate the effects of the new management at Farm Meadow. Specifically, the abundance and breeding success of grassland birds inside and outside the sanctuary should be compared. The effects of grazing
turkeys in grassland species habitats are understudied. Cows can trample and eat the nests of bobolinks while the density of cows is 1-1.5 cow/acre (Perlut et al. 2006). Since each paddock will have a higher ratio, the breeding success in each paddock might be low. Future study can research on this topic and testify this assumption.

VII.3. Conclusion

The dynamics of open lands is one of the most extraordinary aspects of the evolving landscape in New England. We have the opportunity to protect, modify, or expand open lands while balancing the demands of open lands species and various needs of humans. Exclusively relying on science does not help land managers make conservation decisions efficiently, especially decisions of managing a type of land created and maintained by human. Open land management should not exclude the demands and interests of human. The ramification of historical human activities and current human demands are too great to be ignored by land managers and ecologists.
Acknowledgement

I would first like to thank my advisor, Prof. Brian Donahue, for his academic support and encouragement. Without him, I would not be able to complete this research. I appreciate the help from Angela Kearney, Thomas Gumbart, Jane Layton, and David McKinnon from Lincoln Conservation. I learn a lot of detailed knowledge through the conservations with Angela and Tom and through the field trips with Jane. I would also like to thank Jay Aylward for his vegetation data and other support. I am grateful for the assistances from Nancy Soulette, Wayne Petersen, Jon Atwood, Bryan Windmiller, Michele Grenzda, and Prof. Dan Perlman. In addition, I would like to thank Prof. Colleen Hitchcock and Prof. Eric Olson for being part of the committee. I also want to express my gratitude to my family and friends who have always believed in me. Last but not least, I would like to thank Brandeis University and the Environmental Studies program for creating all of my wonderful experiences during my undergraduate study.
Works Cited


Johnson, E. S. (1996). *Discovering the ancient past at Kampoosa Bog, Stockbridge, Massachusetts. Amherst, Mass. Amherst, MA.*


Massachusetts Natural Heritage and Endangered Species Program (NHESP). (n.d.). Eastern Ribbon Snake.


Missouri Agricultural Education. (2002). Introduction to grassland management. Missouri Agricultural Education.


Wisconsin Department of Natural Resources. (2017). Eastern Ribbonsnake (Thamnophis sauritus) Species Guidance.