Restoring and Conserving Fish and Wildlife Habitats Under Climate Change

A Case Study at Century Bog, Massachusetts

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Executive Summary

- The State of Massachusetts Department of Fish and Game has recently acquired from A.D. Makepeace the 250 acre Century Bog site in the southeastern coastal plain, fully protecting Red Brook from its source to the sea.
- Although a working cranberry bog, this site provides important fish and wildlife habitat, notably a coastal plain pond, a coldwater stream that supports rare species, and extensive upland pitch pine and scrub oak forest.
- Species at Century Bog that are considered priority for conservation by the Commonwealth include anadromous brook trout, river herring (alewife and blueback herring), and coastal plain pond plants and invertebrates.
- Previous investments and work in the Red Brook watershed by Trout Unlimited, The Trustees of Reservations and the Commonwealth agencies have been crucial in ensuring the continued existence of these important resources
- The Department of Fish and Game and its Divisions (Division of Fisheries and Wildlife, Division of Ecological Restoration, and Division of Marine Fisheries), The Trustees of Reservations, Trout Unlimited, Manomet Center for Conservation Sciences, and A.D. Makepeace are collaborating to plan and implement the restoration of Century Bog to functioning fish and wildlife habitat.
- Some of the important habitats at Century Bog, the cold water fish habitat and the coastal plain pond, are likely to be highly sensitive to climate change.
- The restoration at Century bog needs to be "climate-smart", i.e., performed in such a way as to safeguard the resiliencies and adaptive capacities of the climate change-sensitive habitats.
- The steering committee for the Century Bog restoration has developed a restoration vision that takes into account these future vulnerabilities.
- The restoration steering committee has selected restoration options and developed a plan for restoring the site that will help protect the climate change-vulnerable resources and provide a diverse and productive array of wildlife habitats at the site.
- This site is now becoming a "flagship" site for other sites across North America that are faced with climate change dilemmas.
- The restoration planning at Century Bog has resulted in a number of important lessons that will apply to the restoration and management of conserved sites under a changing climate across the U.S.

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Chapter 1. Introduction

Located in the towns of Wareham and Plymouth, southeastern Massachusetts (Figures 1-1 and 1-2), the 250 acres of Century Bog currently comprise a working cranberry bog bordered by upland pitch pine and scrub oak forest, lakes and ponds, and residential areas (Figures 1-3 through 1-5), through which flows Red Brook from its source in White Island Pond to its confluence with the sea at Buttermilk Bay (Figures 1-1 and 1-2).

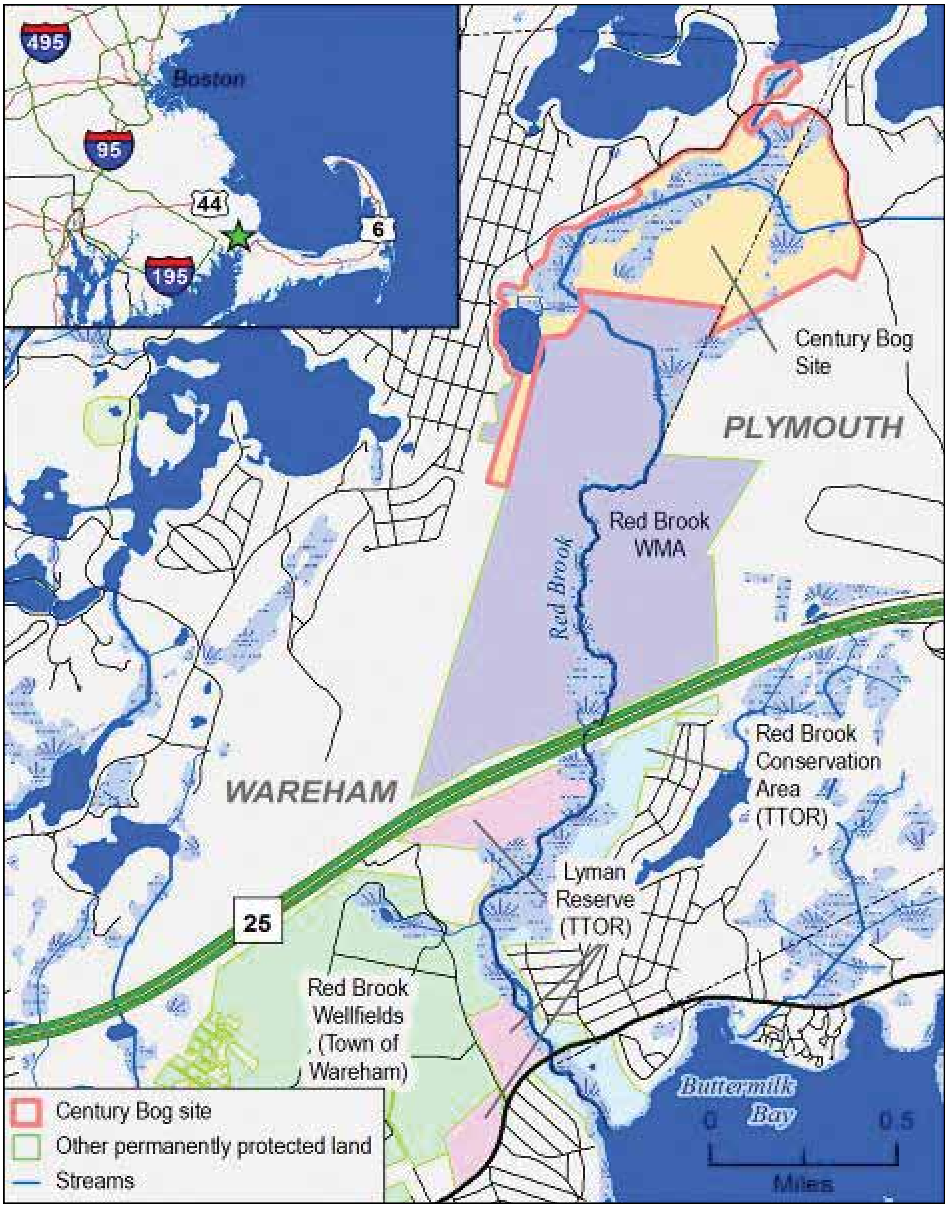

Figure 1-1. Century Bog showing its geographical locality, abutting townships, and neighboring conserved lands.

Figure 1-2. Aerial photographs (Spring 2009)

Aerial photographs (Spring 2009) of area around the Century Bog site in Wareham and Plymouth, Massachusetts, including White Island Pond and Bartlett Pond. Aerial photographs from USGS distributed by MassGIS; wetland and watercourse data from MassGIS DEP Wetlands (1:12,000).

Figure 1-3. Upper reaches of Red Brook channel
Upper reaches of Red Brook channel flowing through cranberry bogs (looking northeast). Upland pitch pine and scrub oak woodland in background.

Figure 1-4. Coastal plain pond (Bartlett Pond) in southern Century Bog site.

Figure 1-5. Lower reaches of Red Brook
Lower reaches of Red Brook where stream flows along southern perimeter of site and up which brook trout and herring gain access to the site.

Previously owned by the world's largest cranberry growers, the A.D. Makepeace Company (ADM), Century Bog was transferred to the State of Massachusetts Department of Fish and Game (DFG) in January 2010. This transaction was the latest result in a long and productive conservation collaboration between DFG and ADM. The state's acquisition of this site is an important capstone in its long-term strategy for land conservation in southeast Massachusetts. Together with the adjacent Red Brook Wildlife Management Area (WMA), owned and managed by the DFG, and the Theodore Lyman Reserve, owned and managed by The Trustees of Reservations (TTOR), the total protected area now comprises almost 900 acres of the Red Brook watershed. The site, and neighboring state-protected lands (including the 26-square mile Myles Standish State Forest and the Burrage Pond Wildlife Management Area to the north), also now comprise an extensive and important archipelago of protected lands across southeastern Massachusetts – an area within which important habitats have been lost as a result of residential and commercial development.

Figure 1-6. Anadromous brook trout
Anadromous brook trout, a cold water fish species that migrates from the sea to spawn and rear on Century Bog.

Figure 1-7. Blueback herring
Blueback herring an anadromous fish species that migrates from the sea to spawn in White Island Pond.

The protection of much of an entire watershed is an important contribution to the conservation of the unique ecological resources and ecosystem services in the region. Century Bog also supports a number of species and habitats that are rare or unusual or listed as being of special concern to the state. The three main habitat types that the acquisition of the Century Bog helps protect are the pitch-pine scrub oak forest of the upland parts of the site, cold water fish habitat of Red Brook, and a coastal plain pond – Bartlett's Pond, each of which supports unusual plant and animal communities (Figures 1-6 and 1-7).

Now that the DFG owns Century Bog, its main aim is to protect and restore its important ecological attributes and services. The planned restoration, which will be carried out by the state's Divisions of Fish and Wildlife (DFW) and Ecological Restoration (DER), will focus mainly on protecting and enhancing the current cold water fish habitat in Red Brook, returning much of the existing cranberry bog to natural habitat (primarily riparian or swamp woodland), protecting the coastal plain pond habitat, and ensuring the health of the existing pitch-pine and scrub oak forest. The new management and restoration regime at the site will also ensure that the public can continue to enjoy the recreational opportunities provided by the current and planned habitats. Working with the state agencies to ensure a successful restoration at the Century Bog, are a number of other partner agencies[1]. A.D. Makepeace will continue to support the restoration project by providing assistance in the actual restoration activities.

Many of the important ecological resources that are currently on the site and those that will be the focus of the restoration are likely to be vulnerable to current and future climate change, including the coastal plain pond and the cold water fish habitat. A climate change vulnerability assessment carried out by the DFW in collaboration with Manomet Center for Conservation Sciences shows that these habitat types may be particularly vulnerable to the changing climate (DFW/Manomet, 2010). Therefore, the planned restoration needs to be carried out in ways that will help ensure the survival of these habitat types under a changing climate. The Commonwealth of Massachusetts has been very active in the past in developing ideas about climate change vulnerabilities and has, to a great extent, led the rest of the U.S. Northeast Region in planning for climate change adaptation. In this project, the state will take the next important step forward by planning and implementing "climate-smart" on-the-ground site management.

[1] These include The Trustees of Reservations, Trout Unlimited, Manomet Center for Conservation Sciences, and The National Wildlife Federation.

The main purpose of this report is to describe, at a conceptual level[2], how the restoration partners intend to restore the Century Bog site in order to increase its resilience and resistance to the changing climate[3].

In Chapter 2 we describe the site, its ecology and conservation importance, and its land-use history. We also identify the key ecological attributes and services that are provided by the site and that are restoration targets. In Chapter 3 and Attachment 1we describe how the climate of southeastern Massachusetts is currently changing and the changes that are projected for the remainder of this century, focusing on those that could have the greatest impacts on the ecology of the restored site. In Chapter 4 we identify and discuss the likely vulnerabilities of Century Bog's ecological attributes to the changing climate. In Chapter 5 we identify specific restoration actions that we intend to implement at the site and how these will protect the key ecosystem attributes from climate change and other stressors. We also describe the stakeholder process that we adopted to encourage public input to the project and how this input was accommodated into the restoration strategy. Lastly, in Chapter 6 we describe the wider implications of the Century Bog restoration, particularly for other state, federal, non-governmental, and private agencies with responsibility for managing sensitive ecological resources under a changing climate.

2 This is not intended to be a detailed and quantitative adaptation work plan but, instead, its purpose is to describe the challenges posed by climate change to the conservation and restoration of this site and, at a conceptual level - how restoration activities will ameliorate potential impacts.

3 The funding for developing and writing this report was provided by the Wildlife Conservation Society, The Kresge Family Foundation, and the Open Space Institute. Crucial material support was also provided by all of the restoration partners.

Chapter 2. Site History And Description

Site History

Table 2-1 presents a condensed chronological history of human occupation, land-use, and ownership of the Century Bog from pre-colonial times until the present[4].

Table 2-1 History of human occupation, land-use and ownership of Century Bog and its watershed.

DATE	LAND-USE/OWNERSHIP
1200-European colonization	Native Americans using area for fish and shellfish harvesting and other subsistence activities
Colonization until early 19th century	Colonial farmers and harvesters of fish used and modified habitats (e.g., construction of channel to connect Red Brook and White Island Pond
1666	Purchase of Century Bog/Red Brook area by Plymouth Selectmen from Wampanoag Tribe
1666- 1800s	Use of Century Bog area by colonists for wood, fish, and iron ore extraction.
Prior to 1856	Cranberry cultivation began in watershed
1860s	Post-Civil War acquisition of portions of watershed began by Lyman Family
1870	First purchase of land by Theodore Lyman
1870's	Much of Red Book and bordering lands now owned by Lymans
1870-2000	Managed by Lymans for hunting and fishing
2001	Lymans donated 638 acres of watershed to Massachusetts Land Conservation Trust (MLCT). 428 acres than conveyed to DFW (Red Brook Wildlife Management Area)
2003	MLCT conveyed 210 acres to The Trustees of Reservations (Theodore Lyman Reserve)
2005	Theodore Lyman Reserve Management Plan released by TTOR
2005 and on	Efforts by TU and TTOR to restore the lower portions of Red Brook as functioning fish habitat
2010	A.D. Makepeace transferred 245 acres of Century Bog to DFW

The history and human use of the Century Bog and its environs dates back to before colonial times (TTOR, 2005). Archaeological evidence discovered close to the site indicates that Native Americans were using it seasonally to harvest fish, shellfish and other wildlife as early as 1200 AD. Up until and after the first contact with European colonists the Wampanoag Tribe continued to move through, camp on, and use the site, harvesting the seasonally abundant fish (presumably alewives, herring and trout). Use of the Century Bog and its environs by the colonial settlers probably began soon after the colonization but the first real evidence of this use dates to 1666 when the Selectmen of the Town of Plymouth bought 8,000 acres of the watershed from the Wampanoag Tribe (TTOR, 2005). Between then and the mid-1800s, there is evidence that the land around Century Bog and Red Brook was used by colonists for three main activities: harvesting timber; harvesting the seasonably abundant alewives, trout and herring; and the extraction of iron ore for the production of nails and other metal goods. In the 1860s, the first efforts to cultivate cranberries on a large scale began to be made in the vicinity of Red Brook and Century Bog.

After the purchase of the watershed land by the Town of Plymouth, it was sold off beginning in the 1670s and 1680s to private owners. Beginning in the 1860s, at the end of the Civil War, many of these holdings began to be acquired by Theodore Lyman, a wealthy Bostonian who valued the land for the natural landscape and for the hunting and the fishing opportunities that it provided. By the 1870s, much of the watershed was owned by the Lyman family. The Lymans owned and managed much of the Red Brook and Century Bog watershed until 2001 when they transferred almost 640 acres to the Massachusetts Land Trust Coalition (MLTC), who then conveyed 428 of these acres to the Massachusetts Division of Fisheries and Wildlife. This land became the Red Brook Wildlife Management Area. Two years later the MLTC conveyed 210 acres of the land that they had received from the Lyman Family to The Trustees of Reservations as the Theodore Lyman Reserve. Beginning at this time, TU and TTOR collaborated in important fish habitat restoration work in the lower part of Red Brook, preparing the way for the restoration activities that are currently being planned and implemented. In 2010 A.D.

4 A more detailed chronology is presented in Attachment 2 to this report.

Makepeace sold 245 acres of their working cranberry bog (Century Bog) and surrounding pine and scrub oak forest to the DFW. This brought the total holdings by conservation organizations within the watershed to 885 acres (Figure 2-1). The DFW and the TTOR continue to manage these three sites for nature conservation to the present.

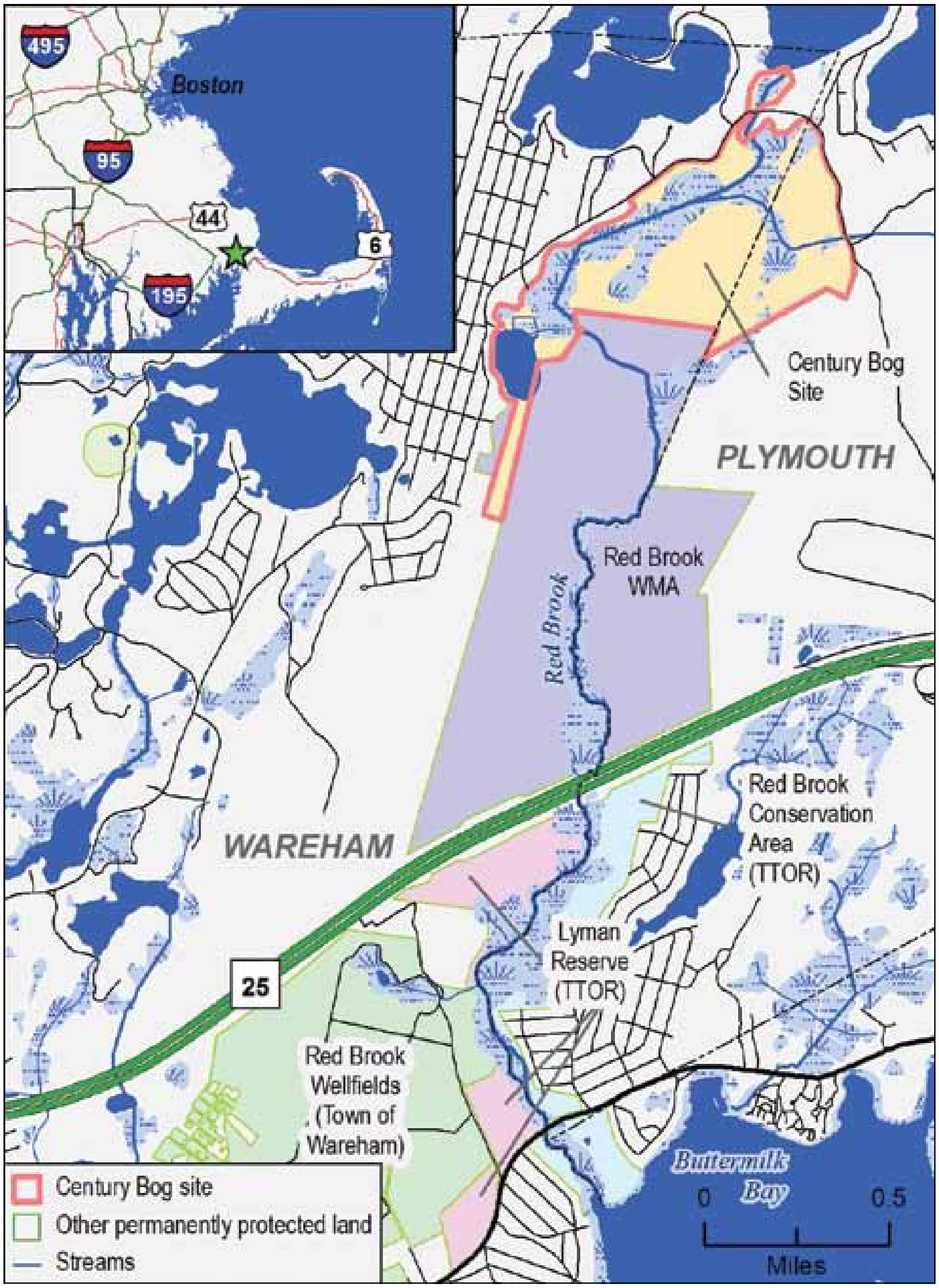

Figure 2-1. Century Bog and neighboring conserved lands.
Other lands permanently protected downstream of the Century Bog site in Wareham and Plymouth, Massachusetts. Wetland and watercourse data obtained from the NHD and MassGIS DEP Wetlands (1:12,000); roads and permanently protected lands from MassGIS.

Geography, Climate, Ecology, and Management of Century Bog

At about 30 feet above sea level, Century Bog is located in the towns of Wareham and Plymouth, and currently comprises a working cranberry bog bordered by upland pitch pine and scrub oak forest and through which flows Red Brook, from its source in the 289 acre White Island Pond to its confluence with the sea at Buttermilk Bay (Figure 2-1). The topography of the site is generally flat on the working areas of the cranberry bog but gently rolling on the surrounding pitch pine and scrub oak-clad hillsides. Soils are derived from glacial outwash formations or tills and are generally well-drained, sandy or gravelly, except where they are dominated by organic mucks under the working cranberry bog (TTOR, 2005).

Red Brook rises in White Island Pond above the cranberry bog and flows for 4.5 miles to the sea. Throughout its length it is approximately about 15-20 feet wide with slow to moderate flow. Water from White Island Pond is diverted through a series of drainage channels into the cranberry bog where it is used to irrigate and facilitate the harvest of the berries. Red Brook is tidally influenced for a distance of about 2,000 feet upstream of its confluence with Buttermilk Bay, but this does not reach as far upstream as Century Bog. Water in the Red Brook and Bartlett's Pond is classified by the state as Class B, that is, they are habitat for fish and other aquatic life and are suitable for contact recreation (swimming, boating, etc.).

At the southern end of the Century Bog site there is an 11.2 acre Coastal Plain Pond – Bartlett's Pond. In the past and prior to conversion to growing cranberries, this was a kettle pond that may have been part of a larger wetland that reclamation has whittled down to the pond itself.

The climate at Century Bog is typical of southeastern Massachusetts with warm summers and cool, wet winters. Air temperatures average 72ºF in July, and 28ºF in January, and annual precipitation is about 48 inches/yr (TTOR, 2005). Precipitation is evenly distributed throughout the year, although June and July tend to get somewhat less rainfall than the rest of the year. Most precipitation falls as rain although snow is common in the winter (however, due to the proximity to the ocean and its moderating effects on air temperature, snow does not lie on the ground for as long as in more inland areas). Major storms impact the area on average about once every 1-2 years, either during the hurricane season (late summer and fall) or during the late fall and winter "noreasters".

The four main ecological habitats on and adjacent to Century Bog are agricultural (the cranberry bog), the cold water aquatic habitat of Red Brook, bordering uplands forested with pitch-pine and scrub oak, and the coastal Plain Pond (Bartlett's Pond).

Pitch-pine scrub oak forests are limited in New England mainly to the southeastern part of Massachusetts (Figure 2-2). They are currently threatened there by a variety of factors, including loss and fragmentation for residential and commercial development and fire suppression - the maintenance of this habitat depends on regular burning (Swain and Kearsley, 2007). This vegetation community is particularly important in Massachusetts because it supports invertebrates, particularly lepidoptera, which are dependent on it for their existence in the state. It is identified as a Priority Natural Community by the Massachusetts Natural Heritage and Endangered Species Program, with a vulnerability rank of S2. This ranking is applied to habitats that have typically fewer than 6-20 occurrences in the Commonwealth and/or are vulnerable to extirpation (http://www.mass.gov/dfwele/dfw/nhesp/natural_communities/pdf/ncpriorityranks.pdf).

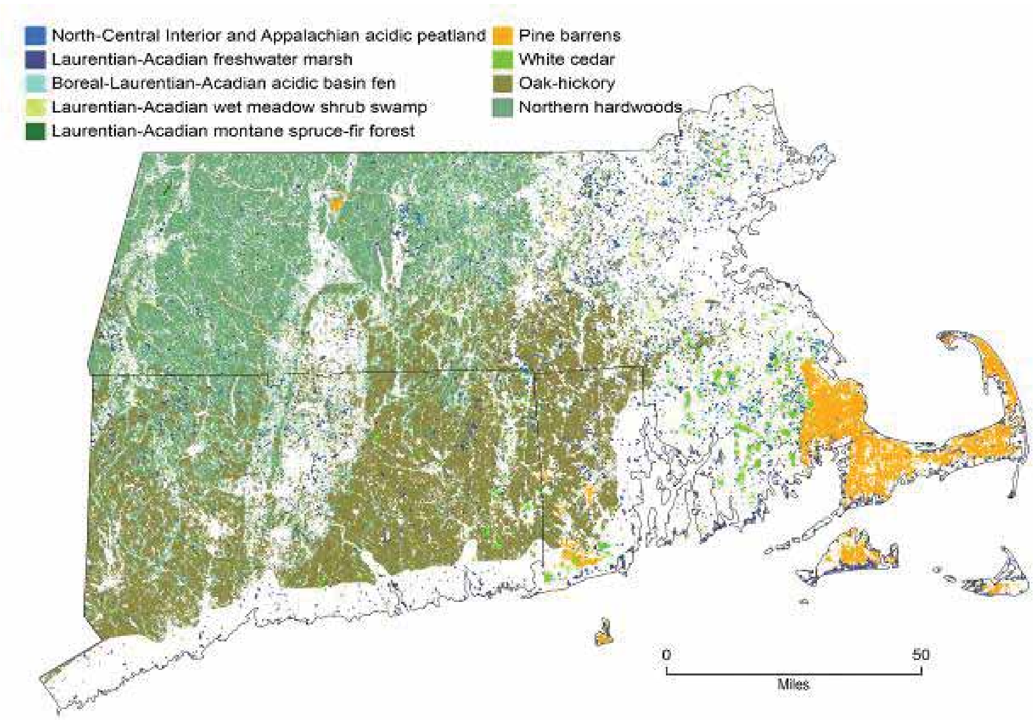

Figure 2-2. Distribution of major fish and wildlife habitat types in southern New England (from Manomet in prep).
Data from TNC/NEAFWA habitat map and database. Pitch pine and scrub oak forest is designated in this map as "Pine Barrens"

Coastal plain pond is also a threatened and rare habitat in Massachusetts (Figure 2-3) with an S2 vulnerability ranking. It is confined to southeastern Massachusetts and Cape Cod. Coastal plain pondshore plant and animal communities develop around ponds that have no inlets or outlets but are fed by underground aquifers. With permeable sand and gravel substrates, the water levels in coastal plain ponds rise and fall seasonally, leaving varying amounts of pondshore exposed for colonization by vegetation. The fall in water levels during the summer growing season is the dominant factor in providing habitat for the unique pondshore graminoid and herbaceous plant communities that characterize this habitat type (Swain and Kearsley, 2007). The periodic inundations during high groundwater periods helps prevent colonization by shrubs and upland plants. Many of the plants that are characteristic of this community type are rare or restricted in Massachusetts and confined to coastal plain ponds. The shores of the ponds may show a marked zonation in vegetation caused by the periodic fluctuations in water level.

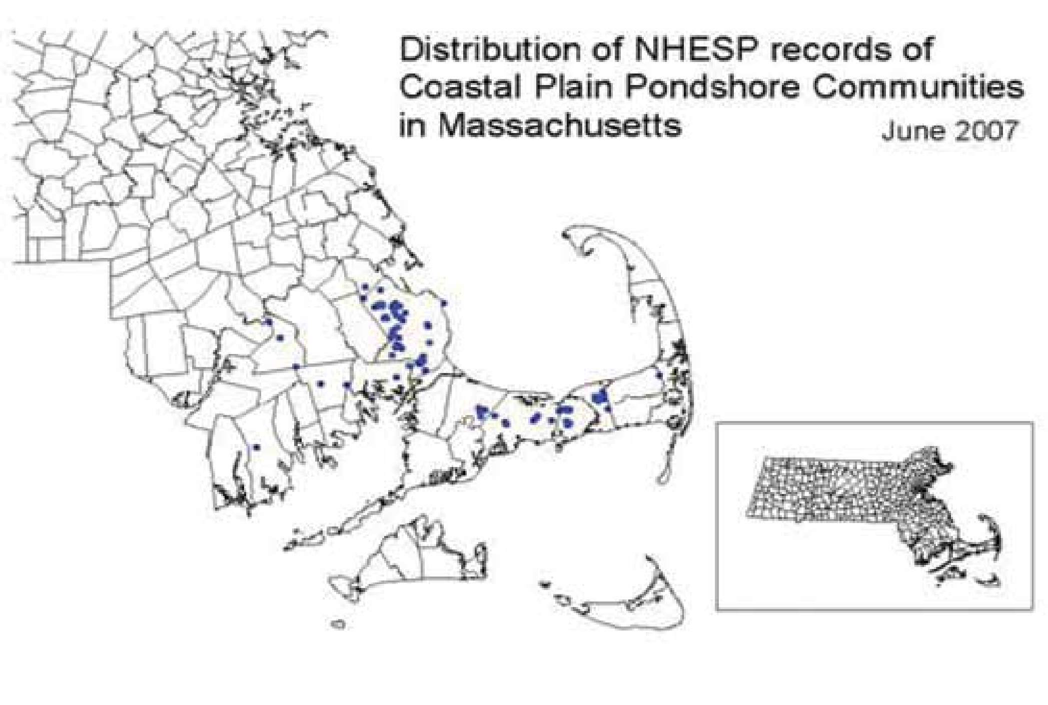

Figure 2-3. Distribution of coastal plain pondshore vegetation communities in Massachusetts (Swain and Kearsley, 2007)

Coldwater riverine or stream habitat in Massachusetts supports coldwater invertebrates such as the larvae of stoneflies and caddis flies, and coldwater-adapted fish, including sculpins and brook trout. It is mainly limited to the higher elevations and western part of the state on the Worcester Plateau and in the Berkshires; however, a few rare examples also occur on the southeastern coastal plain in streams that are fed by coldwater aquifers (C. Slater, Massachusetts DFW, pers comm.). At Century Bog, the Red Brook headwaters are fed by a coldwater aquifer and the resulting cool water temperatures provide spawning and rearing habitat for a fish community that was previously more widespread in New England, but is now rare in its occurrence (due to anthropogenic stressors such as dams, riparian vegetation destruction, the positioning of impermeable surfaces adjacent to streams and rivers, pollution, etc.). The Red Brook headwaters at Century bog provide habitat for three important fish species: anadromous brook trout (which spawn and breed in the headwaters but migrate to the sea for much of their growth), river herring (which are marine for much of their existence but spawn in Red Brook); and anadromous alewives, which also use Red Brook to reach their spawning areas. Anadromous (or "salter") brook trout populations are now rare in Massachusetts and Red Brook is an important site for them.

History of Conservation in the Red Brook Headwaters

Conservation of the sensitive ecological resources began at Century Bog immediately after the Civil War ended in the late 1860s when the Lyman family began acquiring land in the watershed. These acquisitions were made primarily for the angling and hunting potential that the watershed provided and are a good example of the beneficial impacts that exploitive activities can have on habitat and species conservation. By the 1870s, most of the watershed had been acquired and preserved by the Lymans, who actively managed it for hunting and fishing. With the transfer of substantial portions of the watershed to the MLCT and the TTOR beginning in 2001, the area entered a new, more active phase of habitat conservation. The management plan for the Theodore Lyman Reserve (TTOR, 2005) and a Memorandum of Agreement between TTOR, DFW, and Trout Unlimited signed in 2001 specifically note that future management and restoration at both the Theodore Lyman Reserve and the Red Brook Wildlife Management Area would focus on habitat management and restoration for the “ecological viability of the diverse natural resources and conservation values of the reserve”.

These ambitions began to be realized beginning in 2006 when four dams that were installed in the 19th century and that impeded normal sediment transport and adversely impacted trout spawning habitat were removed by a coalition of Trout Unlimited, DFW, DER, TTOR, and the A.D. Makepeace Company (Winders, 2009). The addition of the Century Bog site to the protected areas in the watershed now provides an even more important opportunity to manage and restore fish and wildlife habitat within the watershed.

Chapter 3. Climate Change In Southeastern Massachusetts And Century Bog

Introduction

As previously discussed (Chapter 2), the aim of the restoration of Century Bog is to convert what is now a working cranberry bog into stream, riparian, and upland fish and wildlife habitat, a process that may take up to 7-8 years to complete. At least two of the habitat types that will be the focus of this restoration are believed to be highly vulnerable to climate change – cold water fish habitat and coastal plain ponds (Manomet and DFW, 2010; Chapter 4 of this report). It is important to ensure that the restoration goals for the site and the restoration methods that will be used reflect these vulnerabilities and that the resulting "climate-smart" site will be more resilient to the current and future impacts of a changing climate.

If we are to restore the site so that the habitats have the greatest likelihood of surviving future climate change, it is important that we are clear about what, exactly, we mean by climate change in the southeastern part of the Commonwealth. What temperature and precipitation changes can we expect? How will drought frequencies change? What about changes in soil moisture, plant growing seasons, and snow cover? What about low flow periods in streams and the durations of low flow events? The answers to these and other questions must inform the restoration strategy if the restored site is to be resilient to the changing climate. In this chapter and in Attachment 1 of this report we use new analyses and existing data to describe in some detail how we expect the climate in southeastern Massachusetts to alter over the remainder of this century. The results are intended to help screen and craft restoration methods that are proposed for the site.

We first addressed the question – how has the climate in Massachusetts already changed over the last few decades? Second, we used existing data from the Northeastern Climate Impacts Assessment (NECIA, 2006) to project how biologically-relevant attributes of the climate in southeastern Massachusetts may change over the remainder of this century. This process generated a large number of graphs and figures. For the sake of readability these are not inserted in this chapter. They are presented in Attachment 1, but are referred to in the text of this chapter.

Recent Changes in the Massachusetts Climate

To explore and describe recent changes in the climate of Massachusetts, we employed The Nature Conservancy's Climate Wizard, a web interface to support "free and open sharing of climate information and knowledge" (http://www.climatewizard.org/). Our source for historical climate data was the Oregon State PRISM Group (Daly et al., 1999). PRISM (Parameter-elevation Regressions on Independent Slopes Model) is a statistical-geographical interpolation method to generate gridded estimates of temperature and precipitation (Daly et al., 2008). The method, regression-based and expert-guided, integrates point data (National Weather Service cooperative network, Natural Resources Conservation Service SNOTEL network, and local networks), digital elevation models, and additional datasets to produce GIS-compatible estimates; in addition to location and elevation, the method accounts for coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effectiveness of the terrain (Daly et al., 2008). The PRISM process is flexible, open-ended, and subject to extensive peer review (Daly and Johnson 1999; Daly et al., 2008).

The Cooperative Weather Station Network is the main foundation for PRISM data. Few weather stations were active in Massachusetts pre-1948; however, by 1960, most stations were operating. For this reason, we analyzed climate data (temperature: mean, maximum, and minimum, and total precipitation) for the most recent fifty years (1957-2006). This time period is important for two additional reasons: 1) it serves as a reference time period for the Intergovernmental Panel on Climate Change (IPCC); and 2) it includes the recent period of notable warming (IPCC, 2007).

The linear temperature trend in the State of Massachusetts during the last century was +0.011°C per year (Attachment 1, Figure 3-1). The rate of increase was not constant but accelerated during the post 1960s period, when the 50-year linear trend in annual mean surface temperature in Massachusetts was +0.018°C per year (Attachment 1, Figures 3-1 and 3-3). The total increase was 0.9°C (~1.6°F). These values match published estimates for the northeastern U.S. (Hayhoe et al., 2008: 1900-1999, +0.008 °C per year and 1970-1999, +0.025°C per year).

Average annual precipitation in Massachusetts is 1,185 mm (47 inches), but short-term high rainfall events and periods of drought are not uncommon. The 50-year linear trend indicates an increase in total annual precipitation, +3.92mm per year (Attachment 1, Figure 3-2). Hayhoe et al. (2008) document a pattern of increasing precipitation in the northeastern U.S. for the twentieth century (+1.0 mm per year), but a non-significant, decreasing pattern for the period 1970-2000 (-0.08 mm per year). Due to high inter-annual variability in precipitation, seasonal patterns are more difficult to discern.

Because many organisms and systems are more sensitive to extreme events, rather than means), minimum and maximum temperatures are of particular interest to biologists and resource managers. From the 1960s until the present the increases in annual mean maximum and minimum temperatures were 0.8°C (~1.4°F) and 1.1°C per year (~2.0°F), respectively (Attachment 1, Figure 3-3). Temperature increases varied by season, being greatest in winter. This seasonal pattern is likely attributable to decreasing snow cover and the resultant increase in the retention of solar energy.

The data reported in Figures 3-1 through 3-3 of Attachment 1 show that the climate in Massachusetts has been consistently changing over the last century, with increases both in temperature and precipitation. Furthermore, the data show that the rate of temperature change has accelerated over the last five decades. The types of observed changes are generally consistent with the changes projected to occur under climate change by current climate models.

Projected Twenty-First Century Climate Change

DATA SOURCES AND ANALYSES

In 2006, the NECIA published climate projections for the northeastern states (NECIA, 2006; Hayhoe et al., 2008). The study incorporated two IPCC emission scenarios, A1FI (fossil fuel intensive) and B1 (low emission scenario) as input for three atmosphere-ocean general circulation models (AOGCMs): NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1; the United Kingdom Meteorological Office's Hadley Centre Climate Model, version 3 (HadCM3); and the National Center for Atmospheric Research's Parallel Climate Model (PCM; NECIA, 2006). These models were selected because they are widely accepted as bracketing the range of most plausible emissions scenarios and model sensitivities. The authors documented the ability of the selected models to reproduce observed climate patterns in the Northeast; the models generally underestimated observed patterns and "regional processes may be acting to enhance warming trends in the Northeast relative to the global average in a way not captured by global-scale models" (Hayhoe et al., 2006). To improve the resolution of the general circulation models, and, hence, increase their relevance for the region, the authors employed statistical downscaling to generate monthly and daily temperature and precipitation projections on a 1/8° grid. The historical reference period for the analysis was 1971-2000. The results are available to the public (Hayhoe et al., 2008; http://northeastclimatedata.org). This data set is the source of the following results (Attachment 1, Figures 3-4 through 3-16) for the state of Massachusetts (as defined by Hayhoe et al., 2008: this includes portions of Vermont, New Hampshire, Rhode Island, Connecticut, and New York). The results shown in Figures 3-4 – 3-16 of Attachment 1 are based on the means of the projections from the three AOGCMs. The analyses carried out by NECIA do not extend over the Century Bog site, stopping a little to the west. However, they do come close enough and cover enough of the geographical area within which the bog exists (the southern coastal plain) to allow us to project future changes for the bog itself.

While it is not possible to use these results shown in Figures 3-4 through 3-16 of Attachment 1 to determine exactly how the climate will change at the scale of a single small site, such as Century Bog, it is possible to characterize likely climate changes over the region in which the site lies, the southeastern Massachusetts coastal plain. This is how the data are treated in these analyses.

The following conclusions can be drawn for the southeastern coastal plain from the NECIA results:

- By 2070-2099, annual average temperature will increase by 2-5°C depending on the emissions scenario (Attachment 1, Figure 3-4)
- By 2070-2099, the annual average precipitation will increase by 100-200mm (7-15%) depending on the emissions scenario (Attachment 1, Figure 3-5)
- By 2070-2099, the number of extreme heat days per year (>90°F) will increase from the current 10 to 20-40 days depending on the emissions scenario (Attachment 1, Figure 3-6)
- By 2070-2099, the average annual maximum temperature will increase by 3-4°C, depending on the emissions scenario (Attachment 1, Figure 3-7)
- By 2070-2099, the length of the plant growing season (days between last and first killing frosts) will extend by 30-50 days depending on the emissions scenario (Attachment 1, Figure 3-8)
- By 2070-2099, the plant hardiness zone in southeastern Massachusetts will change from the current 6b to 7a or 7b depending on the emissions scenario (Attachment 1, Figure 3-9)
- There is likely to be no significant change in snow depth in southeastern Massachusetts by 2070-2099 (Attachment 1, Figure 3-10)
- By 2070-2099, soil moisture content (percent saturation) will decrease during the spring and summer, but by <2% (Attachment 1, Figure 3-11)
- By 2070-2099, evapotranspiration rates in southeastern Massachusetts will increase in the spring and summer by 1-2% depending on the emissions scenario (Attachment 1, Figure 3-12)
- By 2070-2099, under the A1FI emissions scenario, the frequency of short-term droughts (1-3 moths in duration) will increase from the current 13 per 30 yr period to about 22 per 30 yr period. The frequencies of medium term droughts (3-6 months duration) will increase from the current 0.6 per 30 yr period to 2.2 per 30 yr period. Long-term droughts (>6 months duration) will increase from 0.3 per 30 yr period to about 0.4. Much smaller changes are projected under the B1 scenario (Attachment 1, Figure 3-13).
- By 2070-2099, under both emissions scenarios, runoff rates in southeastern Massachusetts are projected to increase from the current 1.14 mm/day to about 0.2 mm/day (Attachment 1, Figure 3-14). Nevertheless, peak flow periods in streams will advance by about 2 weeks and the summer low flow period will extend by about 25 days (Attachment 1, Figure 3-15).

Sea level rise

Sea levels in much of the Northern Hemisphere have been slowly rising for at least the last century. The observed rate at any point on the coast is a function of the current rate of sea level rise (SLR) and crustal processes, particularly coastal subsidence or elevation. The future rate of SLR is expected to accelerate due mainly to the steric expansion of the sea water (under increasing air temperatures) and to an acceleration (already being observed) in the melt rates of ice caps and glaciers. Our best estimate of the future degree of SLR due to the changing climate is that global sea levels will rise by the end of this century by between 1 and 2 meters (Pfeffer et al., 2008; Rahmstorf, 2007). One can estimate the likely extent of SLR at any point by adding these future estimates to the current observed rate of SLR.

Figures 3-16 through 3-18 of Attachment 1 show that SLR over the last 4-8 decades in coastal Massachusetts has been approximately 2.6 to 2.9 mm/yr (from http://tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ma). This translates over the next 89 years (by 2100) into a total rise of 231 to 258 mm, with a midpoint of 242mm. Assuming a global SLR due to climate change of 1 or 2 meters, this result becomes 1.24 to 2.24 meters, respectively, by 2100. While we do not know exactly how much sea level will rise at the coast adjacent to Red Brook/Century Bog (since we do not have tide gauge data) 1 – 2 m is a reasonable estimated range.

The effects that such degrees of SLR may have on the Red Brook/Century Bog site need to be evaluated. While it is highly unlikely that the site itself will be affected (since the elevation of Century Bog is about 30 feet above sea level), the lower stretches of the brook may be, as the brackish, tidally-influenced zone moves upriver.

Future Climate Change Summary

The results presented in Attachment 1 to this report indicate that the climate of southeastern Massachusetts is likely to change in a number of important ways over the remainder of this century. Many of these changes could have important impacts on the ecological resources that will be the foci of the site restoration. In particular, air temperatures are likely to increase by several degrees, increasing water temperatures and evapotranspiration rates. Associated with this will be a higher frequency, duration, and intensity of drought events and other extreme climatic events (floods, for example). Also, growing seasons and frost-free periods will become longer. All of these projected changes could adversely impact the abilities of valued ecological resources at the site, including the cold water fish community and the coastal plain pond, to persist in the future.

Chapter 4. Vulnerabilities Of Ecological Resources To Climate Change

To be effective and sustainable, any restoration/management activities that are implemented at Century Bog need to include measures to safeguard the site's ecological resources from the adverse impacts of climate change. Thus, management and restoration activities need to be "climate-smart". To be able to plan and implement such activities, it is necessary to first identify which of the valued resources are likely to be vulnerable to the changing climate and how they might be impacted. Fortunately, over the last 3-4 years, there has been much research carried out on the vulnerabilities to climate change of New England ecosystems, plants, and animals. Detailed vulnerability analyses have been carried out in Massachusetts (Manomet and DFG, 2010), Maine (Jacobson et al., 2009), and Connecticut (NRWG, 2009), and are being conducted in Vermont and New Hampshire. Using the results of these studies we can develop a vulnerability assessment of the valued resources at Century Bog to the changing climate. In this chapter we first identify the valued resources and services at Century Bog, then, based on the climate changes projected in Chapter 3 and the vulnerability assessments named above, their likely vulnerabilities to the changing climate. This information forms a template that is used to develop, refine, and plan adaptation and restoration activities at the site. These activities are described in Chapter 5 of this report.

Ecological Resources and Services at Century Bog

Century Bog supports fish and wildlife resources, the conservation of which is an important goal of the state's current conservation strategy. These are:

- Ecological habitats, including:
  - Pitch-pine and scrub oak habitat
  - Habitat for a cold or cool water fish community
  - Coastal plain pond habitat
- Species that are identified as being of Greatest Conservation Need.

The site was a key state acquisition target partly because it supports these resources.

In a larger context, the Century Bog site also provides to the southeastern region of Massachusetts a number of valuable ecosystem goods and services. Ecosystem services are those services that nature provides, free of charge, to human societies—e.g., clean water, food production, a stable climate, fiber, and biodiversity (Daly, 1997; MA, 2005). The ecosystem goods and services provided by Century Bog are listed in Table 4-1.

Table 4-1. Ecosystem services provided by Century Bog.

ECOSYSTEM SERVICE	EXPLANATION
Water purification	Groundwater discharge, recharge and purification are important services provided by wetlands, such as Century Bog
Flood regulation	By slowing runoff during heavy rain events, the wetlands of Century Bog mitigate potentially dangerous floods
Biodiversity maintenance	Providing habitat for a variety of rare and common plant and animal species (such as anadromous brook trout, herring, etc.), Century Bog makes an important contribution to the overall biodiversity of the southeastern region and to the entire state
Aesthetic/recreational activities	Century Bog provides a venue for local residents to indulge in such valued recreational activities as fishing, hunting, nature viewing, walking, etc.

Vulnerabilities of Ecological Resources and Ecosystem Services to Climate Change

In general, the climate change ecological vulnerability assessments that have been carried out in New England (e.g., Manomet and DFG, 2010; Jacobson et al., 2009) have shown that the most vulnerable species and services are likely to be those that are:

- Dependent on habitats restricted to cool or cold climatic conditions
- Sensitive to extreme weather events
- Drought intolerant
- Vulnerable to exotic/invasive species
- Vulnerable to pests
- Vulnerable to rising sea levels
- Vulnerable to maladaptive human responses to the changing climate

When the Century Bog ecological resources and ecosystem services are compared against these characteristics, it becomes obvious that all of them are or may be vulnerable to the anticipated changes in climate (Chapter 3, Attachment 1, and Table 4-2).

Table 4-2. Vulnerabilities of conservation goals and ecosystem services at Century Bog to future climate change.

CONSERVATION GOALS/ ECOSYSTEM SERVICES	VULNERABLE TO CLIMATE CHANGE?	RATIONALE
Pitch-pine scrub oak habitat	Probably not	The distribution and ecology of this habitat indicate that it likely is resilient to climate change
Cold water fish habitat	Yes	Changes in ambient temperatures and drought regimes could eliminate or degrade this habitat
Coastal plain pond habitat	Yes	Changes in ambient temperatures, precipitation patterns, drought regimes, and groundwater dynamics could adversely impact this habitat
Listed species	Yes	Loss of cold water and coastal plain pond habitats could adversely impact species
Water purification	Perhaps	Disruption of wetland function by changes in drought regimes and precipitation patterns could adversely impact capability of site to continue this service
Flood regulation	Perhaps	More severe, frequent, and prolonged precipitation events and storms could overwhelm ability of site to mitigate flood events
Biodiversity maintenance	Yes	Loss of climate-dependent habitats could entail loss of sensitive species and their contribution to biodiversity
Aesthetic/recreational activities	Perhaps	Loss of cold water-dependent quarry species such as brook trout could reduce recreational angling value of site

Thus, almost all of the resources and services for which Century Bog is valued, and for which it was acquired as a state-owned site, are likely to be vulnerable to anticipated climatic changes over the remainder of this century. It follows from this that climate change could adversely impact the ability of the state to effectively maintain these resources and services. Consequently, future management and restoration strategies must take climate change into account.

MANOMET Center for Conservation Sciences

Chapter 5. Century Bog Restoration Planning And Implementation

Participation of Restoration Partners

A number of different agencies and partners have been actively involved and have made crucial contributions to the planning of restoration activities at Century Bog. The participation of these agencies has arisen from the current and previous ownership of the site, the ownership of neighboring and abutting conservation sites, the responsibility for restoration planning and implementation in the State of Massachusetts, previous histories of site management and restoration in the vicinity of Century Bog, and expertise in climate change and its likely impacts on ecological resources.

Specifically, the agencies involved are:

Massachusetts Department of Fish and Game, Division of Fisheries and Wildlife, Southeast Wildlife District. Following the purchase of the Century Bog from the previous owners, A.D. Makepeace, the Massachusetts Division of Fisheries and Wildlife are now the site owners. Staff in the Southeast Wildlife District, particularly Jason Zimmer, District Supervisor, and Steve Hurley, Southeast District Fisheries Manager, have the responsibility of implementing and overseeing the restoration of the site.

Massachusetts Department of Fish and Game, Division of Ecological Restoration. The Division of Ecological Restoration's role at Century Bog is tasked with working with the Southeast Wildlife Division in identifying, selecting, and implementing restoration activities at the site. The lead in this has been taken by Nick Wildman.

The Trustees of Reservations (TTOR). TTOR have long played a leading role in the conservation of fish and wildlife and their habitats in the vicinity of Century Bog. They own and manage the abutting 210 acre Theodore Lyman Reserve through which runs the lower reach of Red Brook. Thus, the restoration of century Bog has important implications for the TTOR holding, and vice versa. Russell Hopping, Ecology Program Director at TTOR has taken a lead role in the planning of restoration activities at Century Bog.

Trout Unlimited (TU). Over the last decade, TU has been very active in ensuring the health of anadromous brook trout populations in southeast Massachusetts. On Red Brook they have taken the lead in dam removal and habitat improvement to ensure that the brook trout have access to high quality spawning and rearing habitat. TU, particularly Warren Winders of the Southeast Chapter of TU, plays an important role in the identification of restoration options at Century Bog.

Manomet Center for Conservation Sciences (MCCS). With expertise in both wildlife ecology and in the potential effects of current and future climate change on plant and animal populations and communities, Dr. Hector Galbraith of MCCS has advised the other parties involved in the future restoration and management of the Century Bog site about the likely vulnerabilities and sensitivities of ecological resources to the changing climate.

A.D. Makepeace (ADM). The previous owners of the Century Bog, ADM, particularly George Rogers – Senior Vice President, now play an important role in helping the other site partners to identify and evaluate restoration options that will result in the conservation of important ecological resources. Furthermore, under the terms of the sale agreement, ADM will be providing important practical assistance in the restoration of the bog, including landscaping and engineering help.

Restoration Vision, Planning and Identification of Options

RESTORATION VISION AND GOALS

Shortly after the transfer of the property to the State of Massachusetts all of the restoration partners came together to form an ad hoc steering committee that would be responsible for identifying restoration opportunities and constraints, developing a restoration "vision" for the site, evaluating and selecting specific restoration options, outsourcing early work at the site, raising funding for the planning and implementation of restoration, and, eventually, overseeing the restoration. Another focus of the steering committee has been outreach to local communities and the larger universe of restoration, conservation, and climate impacts agencies and actors.

The deliberations of the steering committee involved, over the last 18 months, numerous teleconferences, several face-to-face meetings and several on-site visits to discuss restoration ideas and goals. Without this important involvement of all of the above actors, it is highly unlikely that the restoration planning could have moved forward as quickly and as successfully as it has.

The acquisition of the Century Bog by the Commonwealth of Massachusetts was determined by the current ecological resources at the site, and their state and regional importance. Perhaps the most outstanding single ecological attribute at the site is the existence of the anadromous fish run, particularly the "salter" brook trout and blue-back herring. The future conservation of these specific resources was one of the main factors in the decision to acquire the site. More broadly, the acquisition of the site filled a gap in completing an archipelago of protected areas in southeast Massachusetts. In addition, there are few areas in the region where watersheds can be conserved for fish, wildlife, and their habitats, as much of the Red Brook watershed now is.

The overall vision, goals, and trajectory of the restoration are also informed by these resources, complicated by the changing climate. The future vision for the site as developed by the steering committee comprises:

> *ensuring a complex of linked habitats, including a healthy and flourishing cold water fish community where anadromous species like the brook trout and river herring continue to find spawning and rearing habitat, adjacent to and associated with native wetlands, a coastal plain pond community, and upland pitch pine scrub oak habitat together with the full complement of the species supported by these habitats.*

THE COMPLICATION OF CLIMATE CHANGE

As already discussed in Chapter 4 of this report, current and future climate change could jeopardize the continued existence of some of the valued Century Bog habitats, particularly the cold water fish habitat and the coastal plain pond, and the goal of their future conservation. Thus, it is imperative that the restoration and management prescriptions for the site are climate-smart, that is that they increase the resiliencies and adaptive capacities of these habitats to the changing climate and thereby enhance their sustainability. In this way, the prospect of a warming and more uncertain climate complicates how we plan and implement site management and adds an extra factor to the restoration equation. As illustrated by Century Bog, climate change has altered the basic "rules" of habitat and site restoration; it is no longer sufficient to ignore the climatic background when planning site restoration, or to assume that it is stable, the changing climate must be explicitly factored into planning and implementation.

THE IDENTIFICATION AND SELECTION OF CLIMATE-SMART RESTORATION OPTIONS

There were three main considerations and/or information sources that informed the identification and selection of restoration options by the steering committee:

1. **The steering committee's vision for the site.** As described above and based on the important ecological attributes of the Century Bog site, the steering committee determined that: (a) all restoration activities should have as their main outcomes the continued conservation of the site's important ecological habitats:

the cold water fish habitat, the planned wetlands, the coastal plain pond, and the surrounding pitch pine and scrub oak habitat; (b) restoration activities must be climate-smart, that is they will increase the resiliencies and adaptive capacities of these habitats to the changing climate.

Pitch pine and scrub oak habitat is not thought to be particularly vulnerable to climate change (Manomet and DFG, 2010). Also, this habitat type already exists on the upland areas of the site and, experience shows on other abandoned cranberry bogs in Massachusetts, it is likely to colonize the bog surface if preventative measures are not employed (Nick Wildman, Massachusetts Division of Ecological Restoration, pers comm.). Thus, extension of pitch pine scrub oak habitat is not a major goal of the restoration.

The coastal plain pond is certainly a habitat type that is valued as a conservation resource in the Commonwealth. Furthermore, it may be vulnerable to the changing climate if it results in alterations in the level and fluctuations of the groundwater table (Manomet and DFG, 2010). However, the climate model projections for those climate change characteristics that could result in impacts to this habitat type, i.e. precipitation rates and temporal patterns, evapotranspiration rates, and the frequencies, severities and durations of droughts are all very uncertain. Thus, the steering committee believes that it would not be productive at this early stage to identify and implement potential adaptation options – too much uncertainty surrounds this issue. Rather, it is felt that it will be much more effective to monitor the water fluctuations and ecological condition of Bartlett's Pond and develop any measures that may be necessary once it is better known how the changing climate will actually affect the habitat type.

In summary, the steering committee believes that the restoration effort should be focused mainly on the two remaining habitat types – the cold water fish habitat and the associated wetlands.

2. Hydrological and Soils Information. At the request of and funded by the State of Massachusetts, Princeton Hydro LLC, a New Jersey-based consulting company, installed in April 2011 30 soil borings at the site. The purpose of this was to generate information about soils and the hydrology of the site that could be useful to the restoration. Princeton Hydro's full subsurface characterization report is provided as Attachment 3 to this document. The main conclusions of this sampling effort were that:

   » The dominant soil types at the site are poorly graded sand (97% of borings), sappric soils and mucks and/or peat (67% of borings). The sands are present largely because they were introduced during cranberry cultivation to provide a substrate for growth

   » Sand layer thickness ranged up to 3 feet

   » Depth to water table was generally within one foot of the bog surface and was strongly correlated with rainfall and surface water flow.

   In December 2011 Comprehensive Environmental Inc performed soil and sediment sampling and chemical analysis at the site. A total of 21 samples were collected from 15 separate sites at depths of from the surface to 3 feet. These were then analyzed for a suite of chemicals including metals, pesticides, VOCs, etc. The resulting data showed that the insecticide Dieldrin was present at seven of the sampling sites at concentrations that exceeded Freshwater Sediment Screening Criteria (i.e., at concentrations that could pose risks to human health). Since Dieldrin is a lipophilic and highly bioaccumulable contaminant it may also pose a risk to food chains and high trophic level organisms. These pesticide residues have, no doubt, been present in the soils and sediments for a period of decades since the use of Dieldrin in the United States was discontinued in the mid-1970s.

3. Century Bog Design Guidance Investigations. Based on their investigations at the Century Bog and funded by the State of Massachusetts, Princeton Hydro LLC submitted to the steering committee in January 2012 a report identifying restoration design features and guidance intended to guide the climate-smart restoration of the site and meet the ecological restoration goals already determined by the committee (protection of

cold water fish habitat, restoration of native wetlands). The full report is provided as Attachment 4 to this report and the resulting plans are shown as Figure 5-1. Princeton Hydro (2012) comprises a menu of restoration options focused on two alternatives – a basic and less ambitious option shown in Figure 5-1 as the uppermost map, and a more ambitious option shown as the lower map in Figure 5-1. The various design features of the so-called "Advanced Concept" were intended to be considered a-la-carte in that most of the treatments could be pursued or ignored, for whatever reason, without peril to the ultimate goals of the project.

The steering committee's main tasks were to: review these information sources, to combine the results with their own specialized familiarity with the site, its ecosystems and the associated organisms; to determine which combination of options best safeguard the important ecological resources of the site under a changing climate; and to develop a concept plan that identifies restoration actions to inform and guide the restoration implementation. The resulting proposed restoration actions are presented below.

» Relocation of Red Brook. Currently, the upper reach of Red Brook from its source at White Island Pond almost to the western perimeter of the Century Bog is channeled through the middle of the cranberry growing area (Figure 5-1, upper). This exposes the stream to solar radiation (since there is little or no shade) and promotes a slow flow that efficiently warms when exposed to the sun. The result is thermal habitat that is unfavorable for the temperature-sensitive brook trout. In the basic plan provided by Princeton Hydro the stream is left in situ (except where it is routed along the existing "herring ditch" along the southern edge of the bog) but is shaded from at least some of the solar radiation by the construction of flanking berms on which riparian shrubs and trees will be planted (Figure 5-1, upper). The Steering committee believes that this may not be adequate to ensure the existence of cold water fish habitat in Red Brook under a warming climate. They believe that the stream has to be relocated to the south as shown in Figure 5-1, lower.

  This relocation will have three major benefits: first, it will move Red Brook into an area that is already well-shaded by the upland trees and shrubs of the pitch pine forest. Second, it brings the stream into closer proximity with the main discharge areas of the cold water aquifer (at the interface of the forested uplands and the bog itself). Thus, the stream will not only be better shaded than it currently is but it will be better positioned to accept more cold water discharge. Last, it separates the stream from the projected wetland area. If Red Book is retained in its current position it would have to be isolated from the projected wetlands) where water will warm since the wetlands will be exposed to the sun. The only way to do this would be to build protective berms running along either bank of the stream, not a natural or aesthetically pleasing solution.

» Wetland creation in cranberry bog. With Red Brook relocated to the southern perimeter of the site, this leaves the entire area that is currently used for cranberry cultivation (approximately 60% of the site) available for conversion to wetlands (Figure 5-1, lower). Subsurface investigation has revealed that certain portions of the cranberry plantation are not underlain by historic wetland soils. These areas were likely excavated from upland soils to extend the bog cells outward. As such, those areas would not be made into wetlands. In practice it will be unlikely that this entire bog area can be restored to wetlands because the costs would be prohibitive (the removal of the entire sand layer under the bog and the large effort required to grade the entire surface down to the water table would be extremely costly). Instead, one approach that the committee is exploring woul;d be to confine wetland restoration to an area extending south from the approximate mid line of the current cranberry bog to the relocated Red Brook.

  This restoration necessitates the removal of much of the sand layer that currently underlies this section of bog. Depending on the concentrations of contaminants in this sand, the volume and relative costs, and other factors, the sand will be either transported off-site or reused for upland habitat restoration onsite. Removal of the sand layer will lower the surface of the area to be restored to close to the water table, facilitating its conversion to wetland. Where this is not the case and the surface is above water table, additional soil may be removed.

Following sand removal and grading, the exposed wetland surface would be vegetated with species typical of southeastern Massachusetts' wetlands. Based on similar but unexploited landforms in southeast Massachusetts, this riparian site was likely to be historically vegetated with Atlantic white cedar swamp and this is one wetland type that the restoration will aim for. Activation of the native, dormant, seed bank is also highly desirable. Experience at other restored cranberry bogs in the area e.g., the Eel River site) has shown that revegetation with Atlantic white cedar can be accomplished relatively easily.

» Separation of Red Brook from the restored wetlands. As already noted there is a risk that surface water that has been warmed in the planned wetland area could flow into the Red Brook and raise the water temperature to a level that could be harmful to the cold water fish. Therefore, it will be necessary to approach the channel design and adjacent grading such that there isn't a direct outflow to the stream. Currently, the section of Red Brook that flows along the southern perimeter of the site (Figure 5-1, upper), is separated from the cranberry bog by a high berm (Figure 5-2). It may be necessary to extend this or something like it, along the northern bank of the relocated section of Red Brook, if the entire stream is to be protected from warmed water from the wetland.

  This may be essential for sustaining the health of the cold water fish community in the short term, however, in many respects, ecological and aesthetic, it is not optimal. It would be more integrated if the stream and bog were hydrologically connected and not isolated. However, the protection of the cold water resource takes precedence at this site. In practice, it may be possible to achieve a compromise solution where the berm separating the wetland and the relocated stream need not be as high or as obtrusive as the current berm on the western end of the site. It may also be that some surface connection between the wetland and the stream may be tolerated (for example, it may be possible to lower the berm in places so that there is a connection but only under extreme high flow events). These possibilities are still to be explored and resolved.

» Extension of upland forested habitat. The area of the site that is currently under cranberry cultivation and that extends north from the bog mid line (Figure 5-1, upper) may not be restored to wetlands if the costs to do so would be prohibitive. Instead, portions of it may be used as areas where sands excavated from the area of the bog being converted to wetlands will be disposed of. This will have the result of further raising the land surface, making it even more suitable for colonization by upland habitat, specifically pitch pine and scrub oak forest. This is the "volunteer" process that can be commonly observed on other abandoned cranberry bogs in the area. Rather than dispose of these sands so that they form a regular straight edge with the wetlands they will be mounded and graded to form peninsulas that extend partly out into the area being restored for wetland, thereby forming a much more complex, interdigitating, and natural ecotone between the upland and wetland communities.

OVERVIEW OF FUTURE CENTURY BOG LANDSCAPE

If the restoration at Century Bog goes according to plan, a future observer viewing the site would see a diverse and complex mix of wetland, riparian, upland forested, riverine, and lacustrine habitats. If this observer were to move across the site in a transect from north to south (Figure 5-3), he/she would initially be passing down a gentle slope through an upland area dominated by pitch pine and scrub oak habitat. After about 100 yards of this habitat the ground would level out, become wetter, and would be dominated by wetland plants until, by a point halfway across the site on this transect, the observer would have left the upland forest and be in wetland forest dominated by Atlantic white cedar and other hydrophytic species (e.g., red maple). Interspersed among this tree dominated landscape would be pools of standing water or marshy and graminoid dominated habitat. After wading through these wetlands on the north-south transect, the observer would encounter a low berm vegetated with upland plant species, on the other side of which Red Brook, with its cold water habitat for fish, runs to the west and into TTOR's Lyman Reserve. Thus, the observer would be passing through a changing ecological landscape with a rich assemblage of wildlife species. Furthermore, while he/she would be observing essential landscape elements that are potentially vulnerable to the changing climate, they will be configured in such a way as to maximize their future survival prospects.

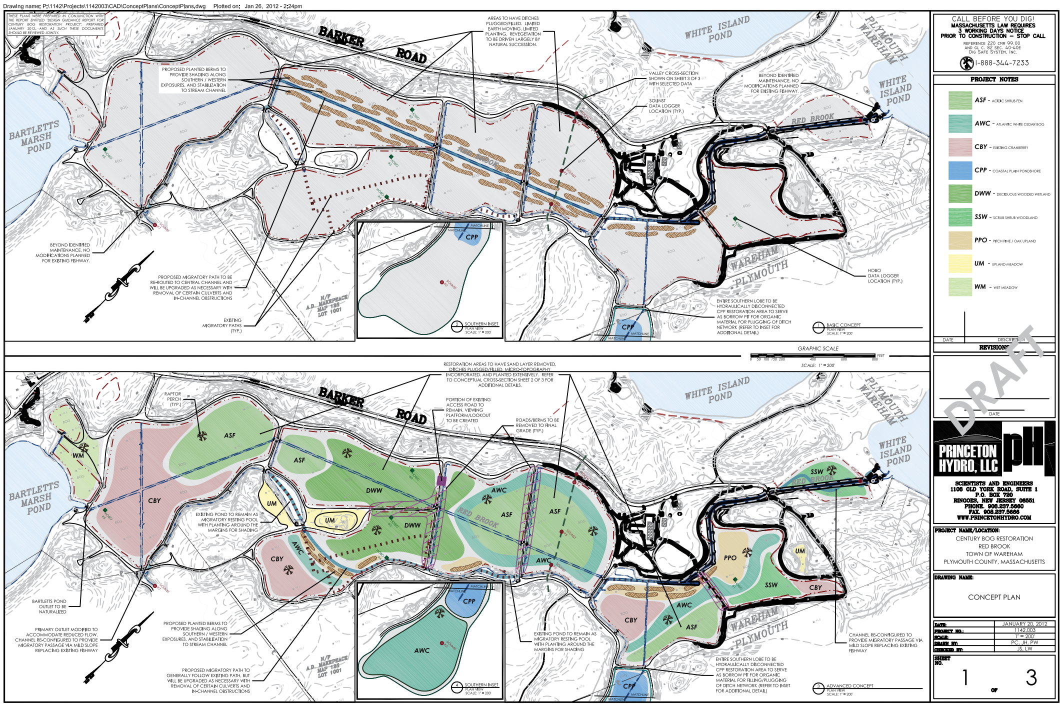

Figure 5-1. Princeton Hydro, 2012 Design Plan for Century Bog Restoration

Figure 5-2. Red Brook
Red Brook showing the dividing berm between the stream, and the cranberry bog (which was flooded when the photograph was taken) .

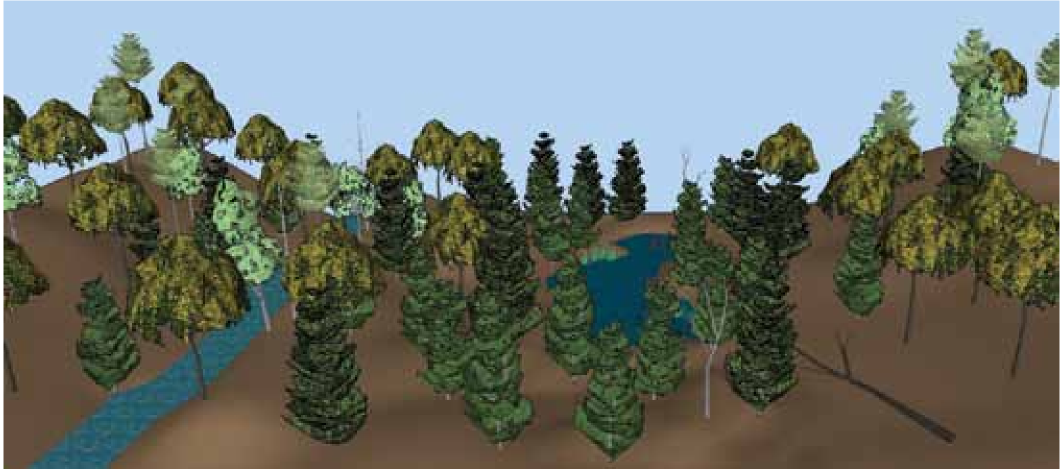

Figure 5-3. A cross sectional view through the restored Century Bog.
From north to south (right to left) the successive habitat types are pitch pine-scrub oak forest on uplands, Atlantic white cedar swamp with interspersed pools and marshy areas in valley bottom, pitch pine-scrub oak forest on the berm dividing the swamp from Red Brook, Red Brook, and uplands clothed again in pitch pine-scrub oak forest.

IMPLEMENTATION OF RESTORATION

The next stage in the adaptation process at Century Bog is for the steering committee to accumulate information on: (a) which firms are best qualified to carry out the development and refinement of restoration designs; (b) how they would go about translating the steering committee's vision for the site into on-the-ground action; and (c) how much it would cost. To these ends, the steering committee is currently reviewing bids from pre-qualified restoration design firms eager to lead the design development. The steering committee will then draw up a shortlist of organizations that are believed to be best qualified and continue to secure funding for the restoration.

It is anticipated that the restoration vision described in this report will cost in the neighborhood of $1-2 million to implement. It is unlikely that any one funder will provide all of this. Rather, we will be soliciting funding from a number of foundations and governmental sources. Also, under their sale agreement to the Commonwealth, ADM has offered to provide the resources (personnel, machines, and time) to carry out a least the initial earth-moving and engineering activities; this will have a major beneficial impact on lowering costs and providing attractive match for potential federal grant funds.

Given the large scale of the proposed restoration at Century Bog, we anticipate that the entire project may take in the region of 2-4 years to complete.

STAKEHOLDER OUTREACH

As well as developing a restoration vision and identifying and selecting climate-smart restoration activities at Century Bog, the steering committee recognized that it is necessary to keep local stakeholders apprised of the proposed activities – the site is an important recreational resource for local residents. Also, it was felt that state legislators, conservation leaders, and the media should also be informed about the site restoration. To this end, two outreach events were organized in 2011. The first of these was a meeting of local residents in summer 2011. About 30 local stakeholders attended this event which included an explanation of the restoration objectives and timeline. Staff from the DFG and Manomet answered questions from the attendees and attempted to resolve any uncertainties that they might have. More such meetings are planned as we move into the implementation phase of the project.

The second outreach event took place in fall 2011. This was held at ADM Headquarters in Wareham, close to the Century Bog. Approximately 40 participants from the State Legislature, the State Government, regional and national NGOs, and the media attended this event during which they heard presentations from ADM, Manomet, state lawmakers, the Secretary of Energy and Environmental Affairs Richard K. Sullivan, Jr., and the Commissioner of Fish& Game Mary Griffin about the importance of the site. The event was subsequently reported in several local newspapers and in interviews with steering committee members on local public radio stations.

Both of these events have served the purpose of publicizing the restoration among local communities. Steering committee members have also made public presentations about the wider significance of this ground-breaking restoration at several regional and national scientific and conservation conferences. The project is increasingly recognized as a “flagship” site for climate-smart restoration and a model for other sites.

A third outreach event is planned for summer 2012 when Massachusetts restoration and management professionals will be brought together at the site in a workshop intended to communicate the objectives of the restoration, the complication of climate change, and the approaches that will be used in the restoration. The intention of this is to educate the profession about the challenge of restoration under a changing climate.

Chapter 6. Lessons Learned And Being Learned

The importance of the work being carried out at Century Bog extends beyond the boundaries of the site, and even beyond the state boundaries. For a number of years biologists and climate scientists have been communicating through conferences, workshops, and publications about the need for climate-smart restoration and management activities at sites. Although we have theorized about such activities, we have yet to adequately test them in the field and to evaluate their effectiveness or the constraints and/or opportunities that may complicate their implementation. The larger importance of the Century Bog project (i.e., its importance at a national scale) is that it takes that next step. We are confident that the lessons that we are learning through the Century Bog restoration will be of relevance and salutary to site restorationists and managers who face similar climate change dilemmas elsewhere in the U.S. and North America.

Seven major lessons have emerged thus far from the project:

1. The Importance of Vulnerability Assessment. Without performing a formal vulnerability analysis it may be difficult to evaluate which resources at a site are at significant risk to climate change. The vulnerability analysis aids in the identification of sensitive and threatened resources (and, also, more robust ones). If performed well, the vulnerability analysis also provides information on <u>why</u> the resources are at risk and, thereby, helps identify adaptation options. Based on our experiences at Century Bog and at other sites in the Northeast, we believe that vulnerability analyses need to be carried out at all sites where future restoration or management actions are to be implemented.

2. Clarify Goals and Alternatives Early in the Planning Process. Conserving intrinsically sensitive plants and animals or systems under climate change will be challenging. As is discussed below, failure due to being overwhelmed by the changes is a possibility. Also, again discussed below, it can be an expensive process and obtaining the necessary funding may be difficult. Thus, it is important at the beginning of a project to think hard about the specific goals – exactly what are we attempting to do and why (what are the true values of the goals)? Also, given that complete success may not be possible (due to lack of funding or climate overwhelming our efforts), it may be important to select an array of "fall-back" goals based on cost-benefit and feasibility analyses. If it transpires during the restoration and afterward that the original goals may not be achieved, then there are already alternatives that may be more feasible and still attainable.

3. Managing or Preventing Climate Change Impacts. The goals at restoration and management sites under a changing climate are likely to be focused on either: (a) managing and facilitating changes that are brought about by the changing conditions; or (b) trying to prevent such change by maintaining the existence of sensitive resources. At Century Bog, we are pursuing both of these options in that we are attempting to restore, to the maximum extent practical, ecosystem processes that have been stressed or eliminated in the current condition. In this way we are facilitating change. However, we are also attempting to prevent some of the changes that we expect to occur in the future to conserve a vulnerable fish community. A clear understanding of which goals are to be pursued at a site is important for reasons of feasibility, long-term sustainability, and cost. In general, attaining the goal of managing change may be technically more feasible (since we are working with nature, rather than against it), less costly and resource-intensive, and more sustainable in the long-term than the goal of preventing change. It should also be realized that the costs of preventing change are likely to increase through time, as the climate continues to change.

   In the case of Century Bog the decision to try to conserve the cold water fish community is based on the regional conservation value of this resource and the putative ability to maintain cold water temperatures by moving and shading Red Brook. However, if through time, we realize that this strategy is failing or the costs become too high, we may be required to rethink what we are attempting to do. The important point is that there is a greater risk associated with attempting to prevent change in vulnerable resources than there is in facilitating "natural" change.

4. Expect Complications due to Non-climate Stressors. Subsequent to the formulation of the restoration option options by Princeton Hydro LLC it was determined by soil sampling that residues of Dieldrin, an organochlorine insecticide, exist in the soils of the cranberry bog. Furthermore, these residues occur at levels that may pose risks to humans and, potentially, food chains. If this is the case, the soils may need to be remediated either before or during the restoration. This could have important impacts on how the restoration is to be carried out, its timeline, and the trajectory of the restoration. This is a good example of how non-climate stressors at a site may affect our options for climate-smart restoration or management.

5. Be Flexible About Defining "Success". While we may do a good job in estimating and identifying vulnerabilities at restoration sites, and we are assiduous in selecting adaptation actions that we believe have the best chance of being effective, there is no guarantee that the actions undertaken in this project will successfully preserve the climate-sensitive resources. Specifically, at Century Bog there is no assurance that, despite our planning, our actions, and the allocation of resources, we will be successful in safeguarding the coldwater fish habitat or the coastal plain pondshore community. Perhaps the magnitude of climate change, or some unforeseen factor, will overwhelm our best intentions and actions and these habitats will lose the characteristics that define their current value to conservationists.

   This possibility poses important questions – how do we define success in the face of a changing climate? Does climate change alter the playing field enough that we have to consider being flexible about how we usually define success? More specifically for Century Bog, is the existence or eradication of the cold water fish habitat or the functioning coastal plain pond the <u>only</u> measures of success, or are there other "fall-back" or alternate success metrics? Focusing entirely on the preservation of a vulnerable (in some cases a highly vulnerable) ecosystem attribute and having no alternate acceptable outcomes ultimately may reduce the chances of our "success".

   At Century Bog we are aware of this problem and have planned the restoration so that even if we are not ultimately successful in retaining the valued but sensitive resource, we are likely, nevertheless, to safeguard other important (in a state and regional context) resources and ecosystem services. We will do this by taking science-based approaches to restore the vital ecological processes that provide for a healthy ecosystem that can support resources like a coldwater fishery. For example, we believe, based on the Massachusetts Vulnerability Assessment (Manomet, 2010), that Atlantic white cedar swamp may be relatively resilient to the changing climate; it already occurs in areas much further south than New England (as far south as Georgia) and this is good evidence that it might survive warming in Massachusetts. So even if our best-laid plans to preserve the cold water stream fail as a result of a rapidly changing climate, we are still likely to have high quality, functioning, fish and wildlife habitat on the site and a suite of important ecosystem services, certainly much better than the existing cranberry flats.

6. The Importance of Long-Term Monitoring. While the vulnerability assessment at Century Bog indicates which habitat types are likely to be affected most by the changing climate, and how they might be affected, it does not deal in certainties. Given the limitations of our current knowledge (particularly about the future specifics of climate change, or the adaptive capacities or sensitivities of species and systems) we cannot be certain about the fates of habitats and species. The vulnerability assessment, then, provides a best expert judgment, not a blueprint or map of future change. Nevertheless, it is important that we initiate adaptation measures that we believe to be climate-smart. Otherwise, if we wait until the change has occurred and is running its course, it may be too late, or too expensive, to conserve the affected resources.

Given this quandary, it is important that we collect real-time data on how the species, landscape features (like channel form) and ecological systems and processes are actually responding so that we are able to modify our adaptation plans and actions, if necessary. This requires long-term monitoring. Furthermore, the targets of monitoring need to be selected with great care in order to ensure that there is low ambiguity about what is actually causing change – the attribution of any observed effect. We need to be sure, for example, that the effect that we measure, and may want to respond to by changing our actions, is indeed caused by the changing climate. A monitoring program that focuses on species or processes that we believe to be sensitive to climate change, for which we have clear ideas about the likely direction and magnitude of response, that are readily measured, and that are likely to provide high signal-noise ratios are preferable.

Over the last few decades, monitoring of ecological systems has been given short shrift. Monitoring strategies are often written into proposals and research and management plans as an afterthought. The need to adapt effectively to climate change and with an efficient allocation of resources demands that we change this and invest more time, effort, and resources in identifying and implementing effective long-term monitoring as part of a comprehensive response to the changing climate. Without reliable monitoring data adaptive management of changing resources becomes highly problematic. We are fortunate at Century Bog in that the restoration partners are able, through their institutional goals and their previous actions at the site, to ensure that effective monitoring continues into the future.

7. Costs and Demands of Climate-smart Restoration/Management may be High. Previous work in Massachusetts and elsewhere indicates that in some circumstances and for some resources the elements that would figure in a climate-smart restoration might simply be an amplification of restoration/management measures that are routinely taken (Manomet, 2010). For example, stand age structure, control and eradication of invasive species and pests, or the control of grazing animals in forests are currently practiced by fish and wildlife agencies to increase the health of the stand. These are also the measures that might be employed (albeit, perhaps, with greater intensity) to increase the adaptive capacity and resilience of the stand under climate change. In such cases, climate-smart restoration/management might simply be an extension of current practice at relatively low additional costs.

   This, however, is not always the case. At Century Bog, a restoration strategy that did not address climate-vulnerable species might simply focus on replacing the cranberry bogs with a mix of functioning wetland, where the water table is close to the surface, and drier habitats elsewhere. The cold water fish habitat and the coastal plain pond would be allowed to be affected, potentially adversely, by the changing climate. The restoration plan would not involve stream relocation. This would be a comparatively inexpensive exercise, probably costing less than one million dollars. However, implementing the plan shown in the lower map in Figure 5-1, where climate change-sensitive resources are protected is a much more demanding exercise, costing perhaps 2-3 times that figure. It is likely that restoration goals that focus on preventing change, rather than facilitating it (see above) will incur greater costs.

   Conservation resources are not unlimited and a cost-effective allocation of resources is now and will continue to be an essential of conservation planning and management. In all cases, the benefits of restoring/managing for climate change-sensitive species need to be weighed against the costs and the trade-offs recognized.

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Attachment 1

Projections of Current and Future Climate Change in Southeastern Massachusetts

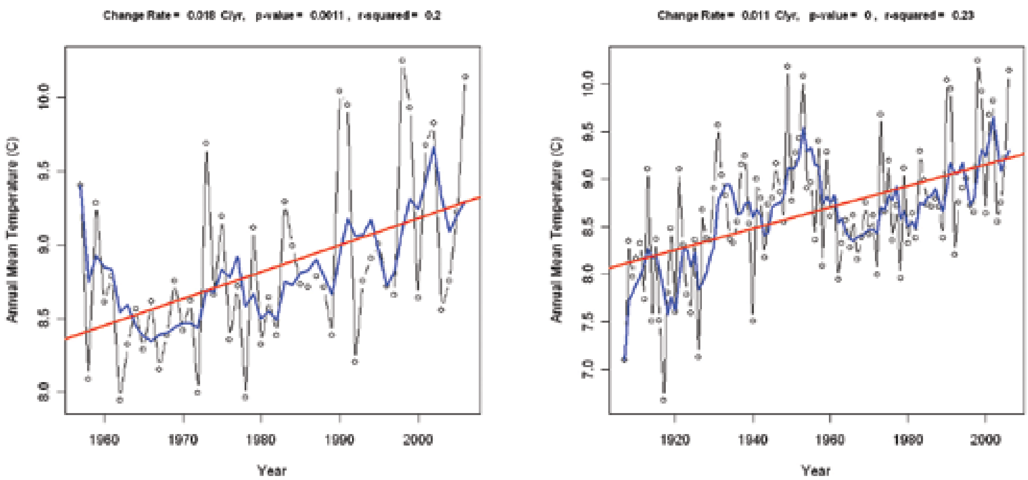

Figure 3-1. Annual mean temperature in Massachusetts for two historical periods: 1907-2006 (left) and 1957-2006 (right). The blue line represents the 5-year moving average and the red line is the least squares regression. The slope of the regression line is reported as the change rate. Data source: PRISM Group, Oregon State University, http://www.prismclimate.org, created December 2008; The Nature Conservancy Climate Wizard.

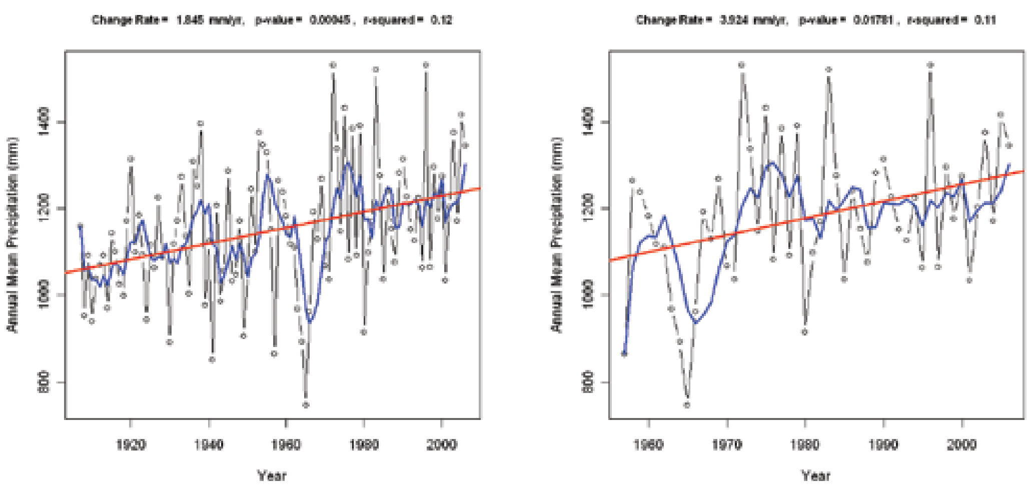

Figure 3-2. Annual precipitation in Massachusetts for two historical periods: 1907-2006 (left) and 1957-2006 (right). The blue line represents five-year moving average and the red line least squares regression. The slope of the regression line is reported as the change rate. Data source: PRISM Group, Oregon State University, http://www.prismclimate.org, created December, 2008; The Nature Conservancy Climate Wizard.

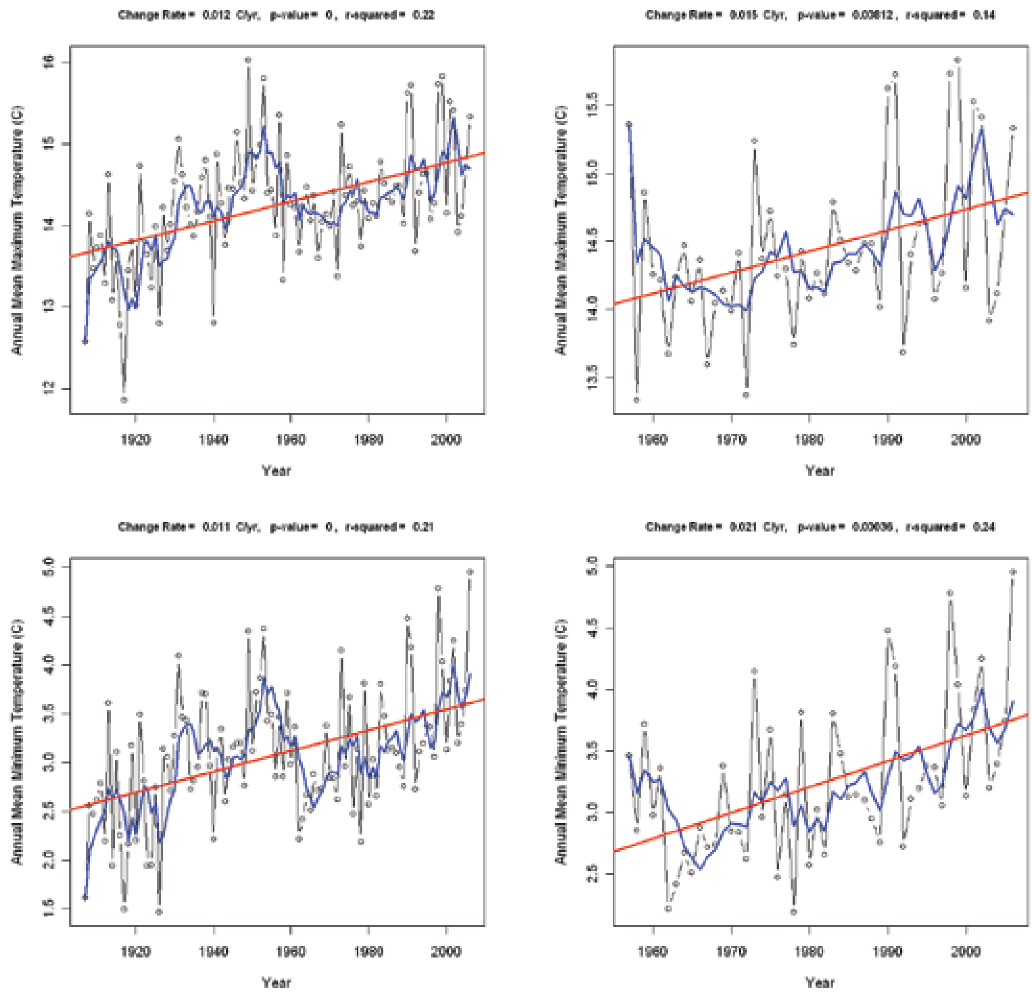

Figure 3-3. Annual maximum temperature (top) and annual minimum temperature (bottom) in Massachusetts for two historical periods: 1907-2006 (left) and 1957-2006 (right).

The blue line represents five-year moving average and the red line is the least squares regression. The slope of the regression line is reported as the change rate. Data source: PRISM Group, Oregon State University, http://www.prismclimate.org, created December, 200; The Nature Conservancy Climate Wizard.

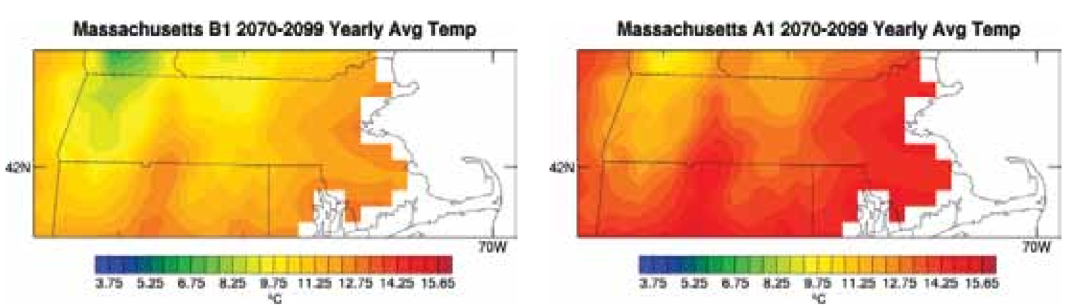

Figure 3-4. Current (left) and projected changes in Massachusetts yearly average temperature under the B1 and A1 emissions scenarios.

From NECIA (2006)

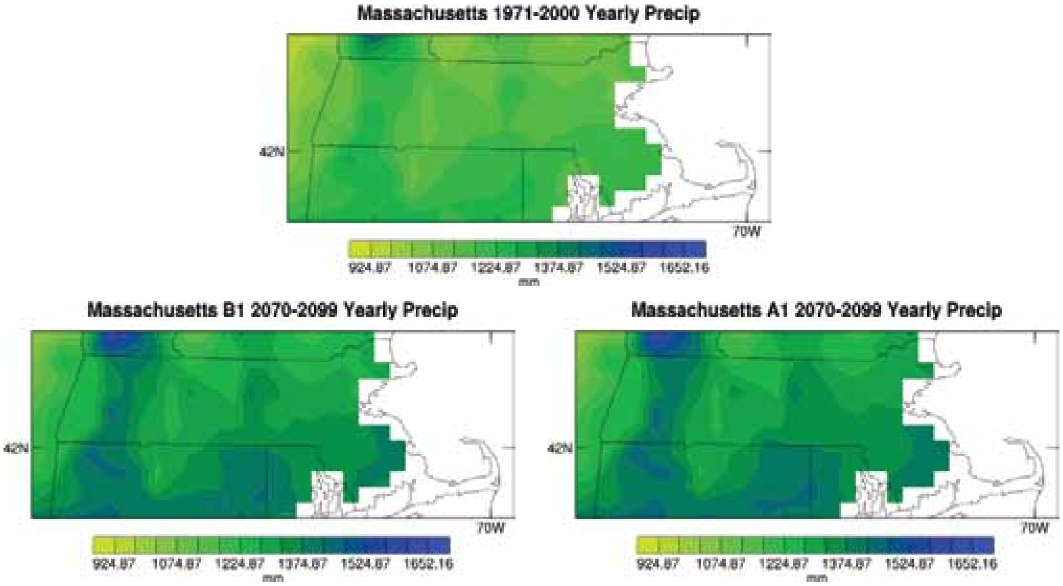

Figure 3-5. Current (top) and projected change in Massachusetts yearly average precipitation under the B1 and A1 emissions scenarios.
From NECIA (2006)

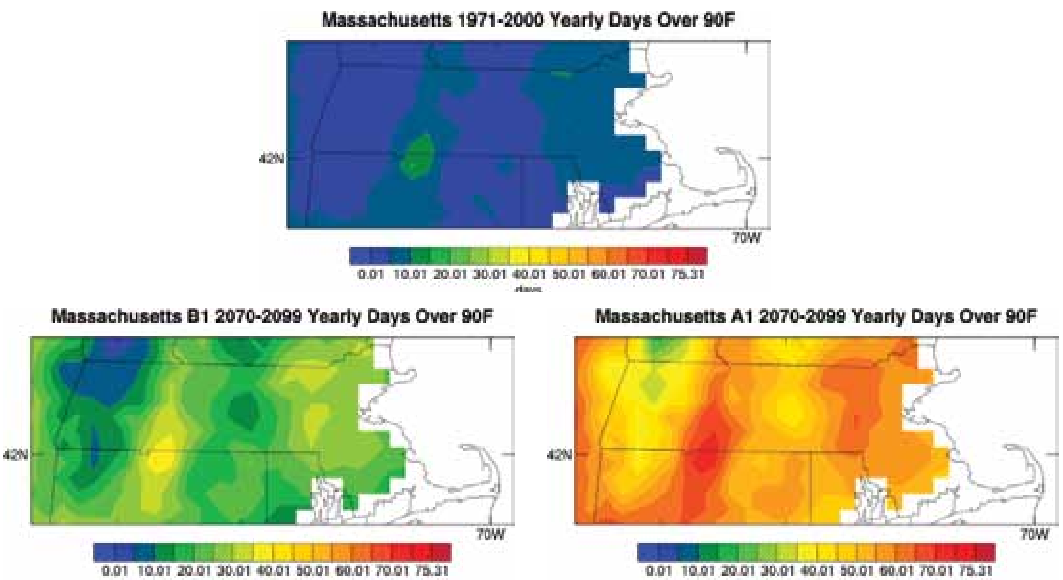

Figure 3-6. Current (top) and projected change in Massachusetts number of days >90°F per annum under the B1 and A1 emissions scenarios.
From NECIA (2006)

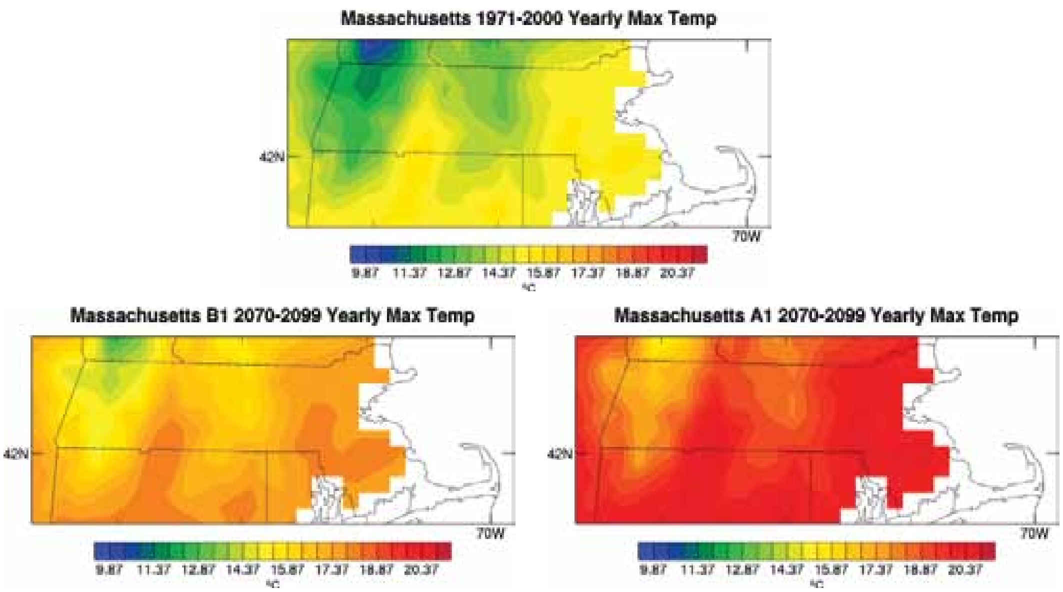

Figure 3-7. Current and projected change in yearly maximum temperatures in Massachusetts under the B1 and A1 emissions scenarios.
From NECIA (2006)

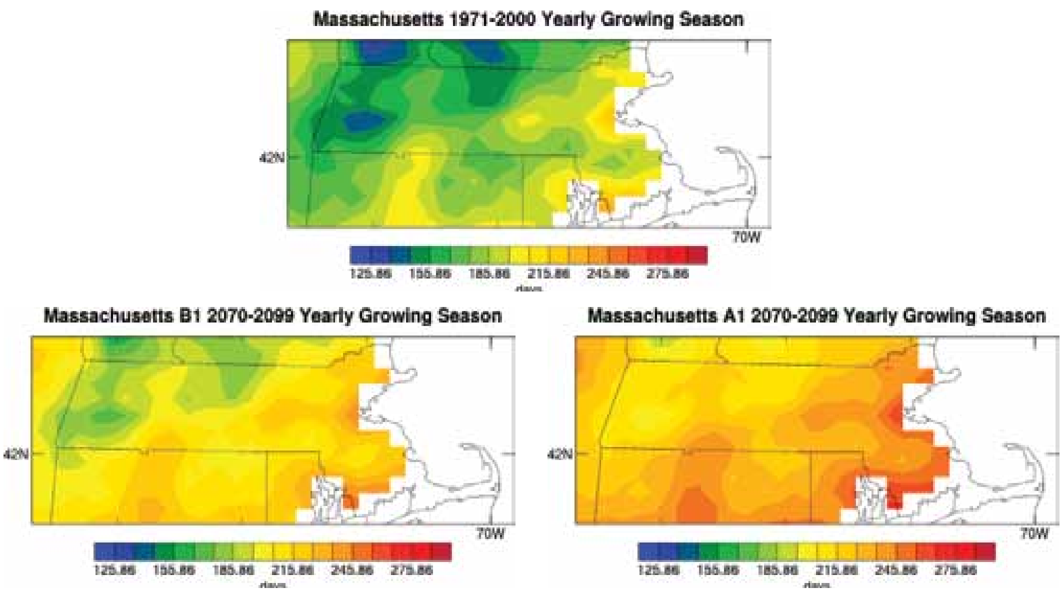

Figure 3-8. Current and projected changes in length of growing season under the B1 and A1 emissions scenarios.
From NECIA (2006)

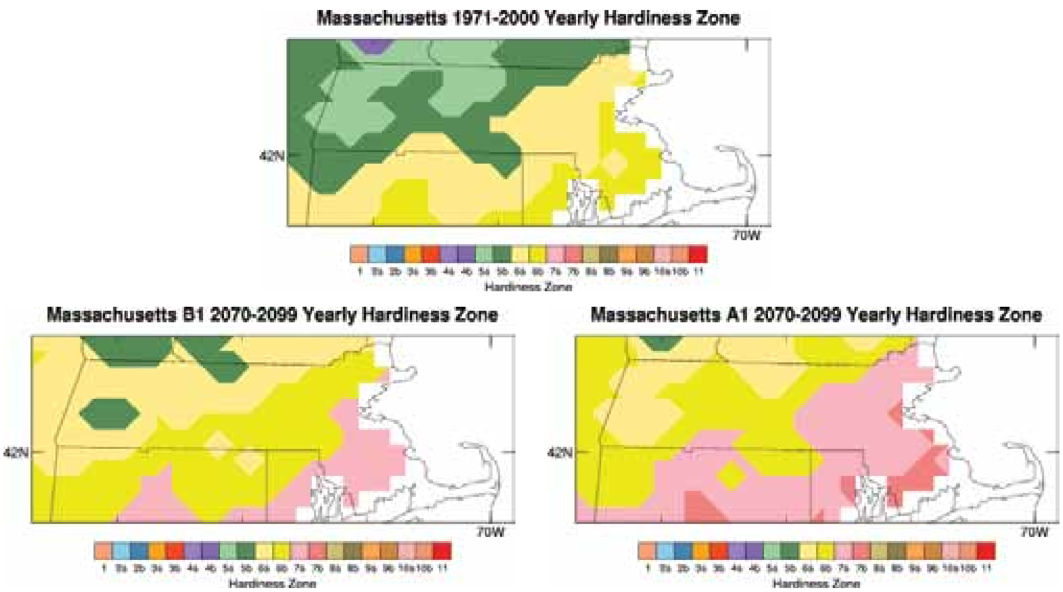

Figure 3-9. Current and projected changes in plant hardiness zones under the B1 and A1 emissions.
From NECIA (2006)

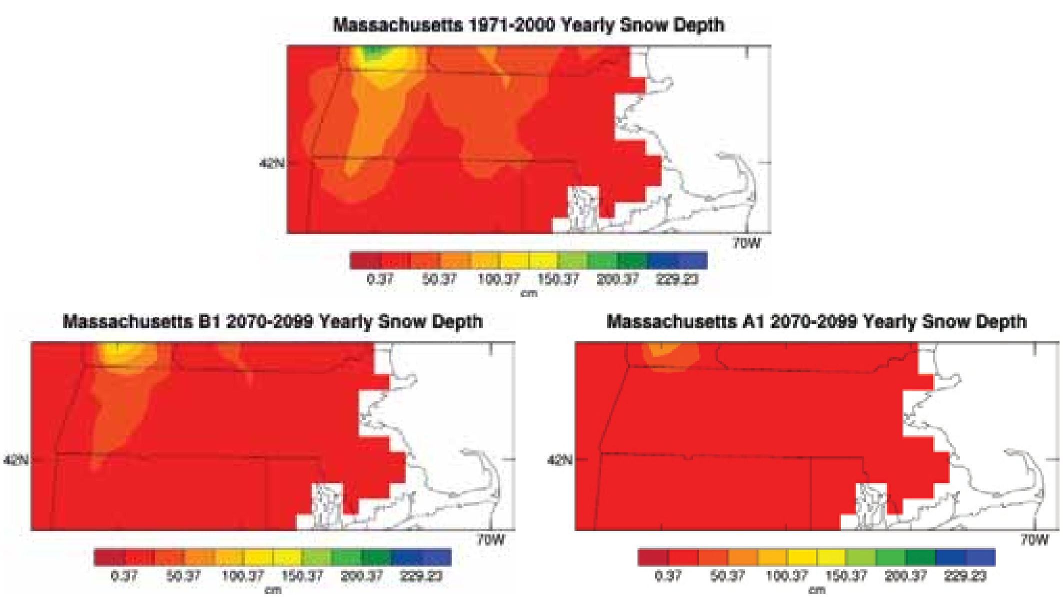

Figure 3-10. Current and projected changes in annual mean snow depth under the B1 and A1 emissions scenarios.
From NECIA (2006)

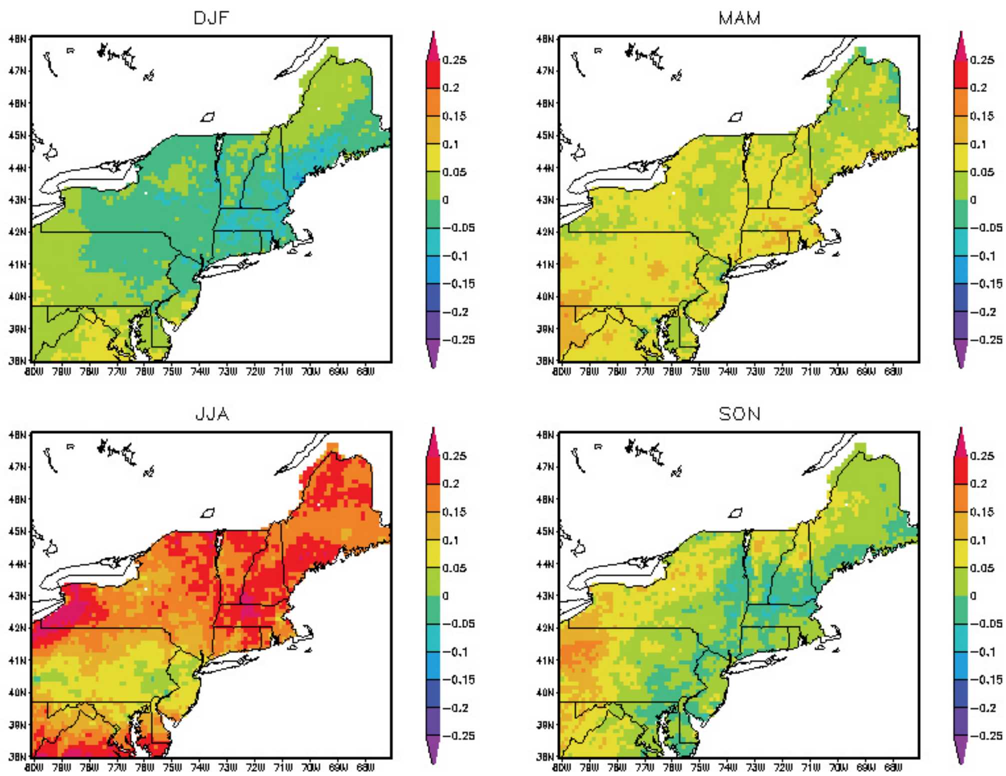

Figure 3-11. Projected changes (2070-2099) in soil moisture content (% saturation).
From NECIA (2006)

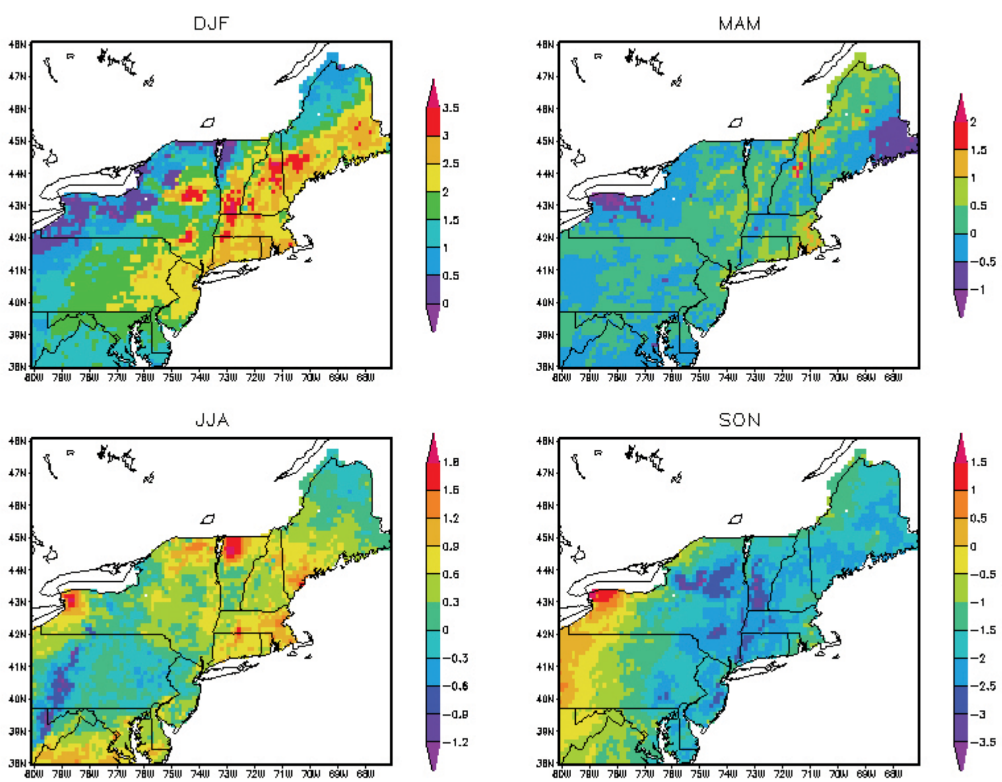

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Figure 3-12. Projected percent seasonal changes in evapotranspiration. 2030-2060 relative to 1970-1999. B1 emissions scenario.
From NECIA (2006)

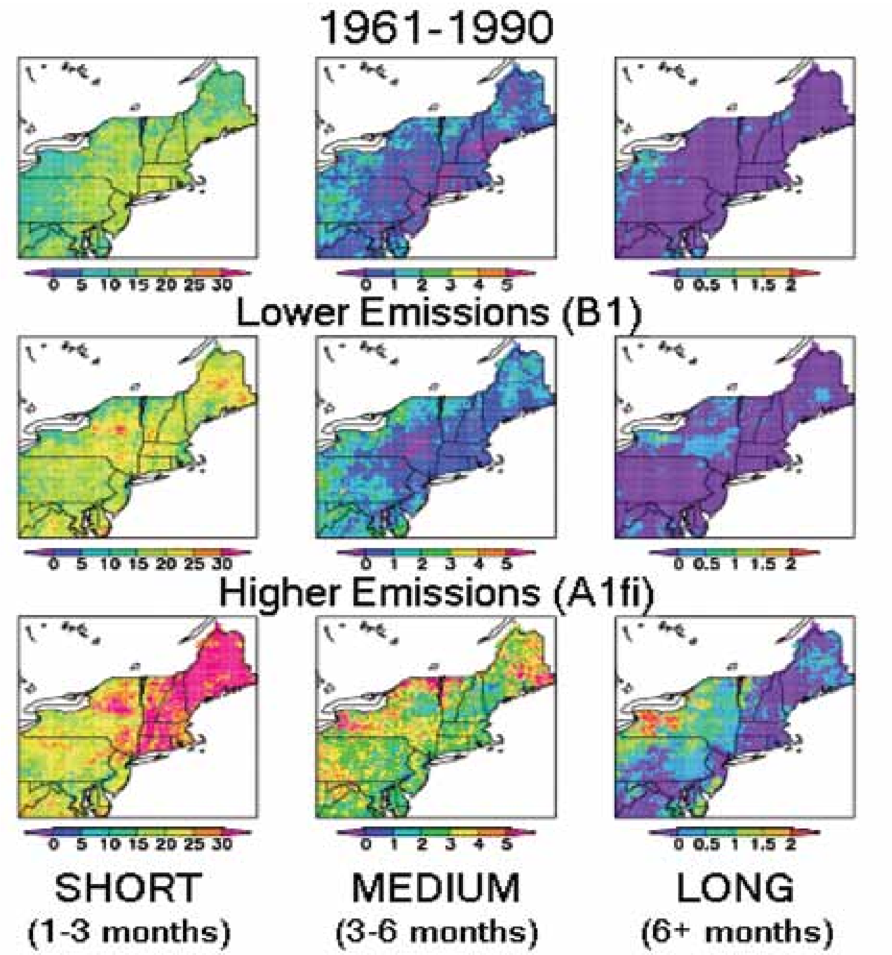


Figure 3-13. Frequencies of Short-, Medium-, and long-term droughts during 1961-1990 and projected for the 30 year period 2070-2099. Values are the average of the HadCM3 and PCM models.
From NECIA (2006)

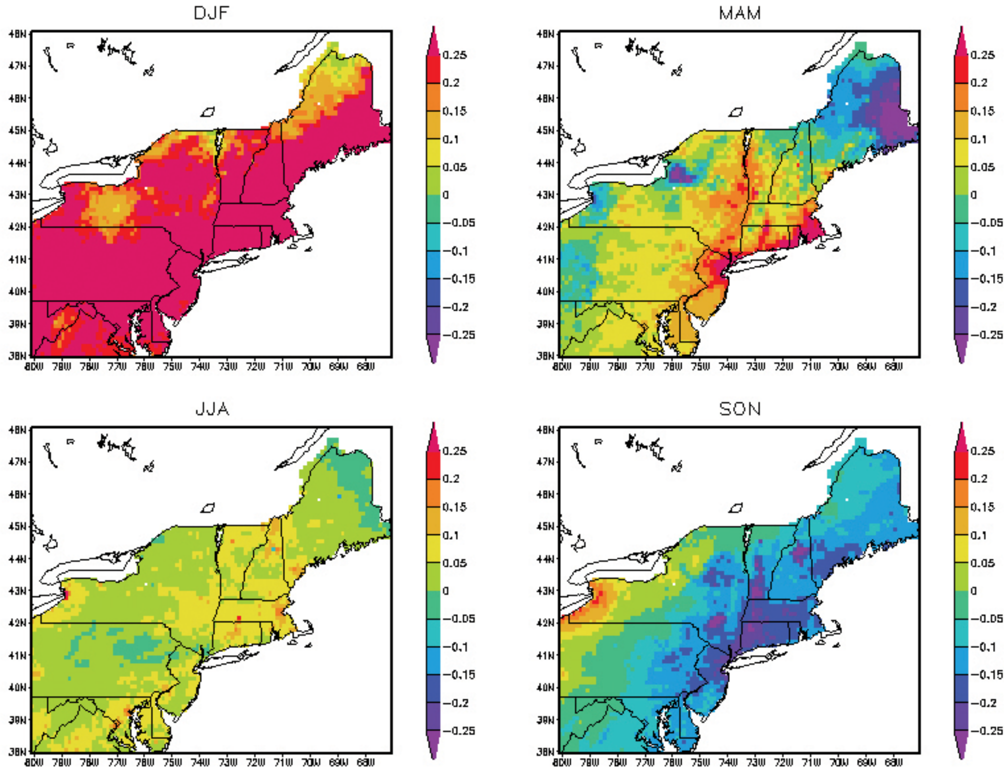


Figure 3-14. Projected average seasonal change in runoff (mm/day), 2030-2060 relative to 1970-1999. A1Fi emissions scenario.
From NECIA (2006)

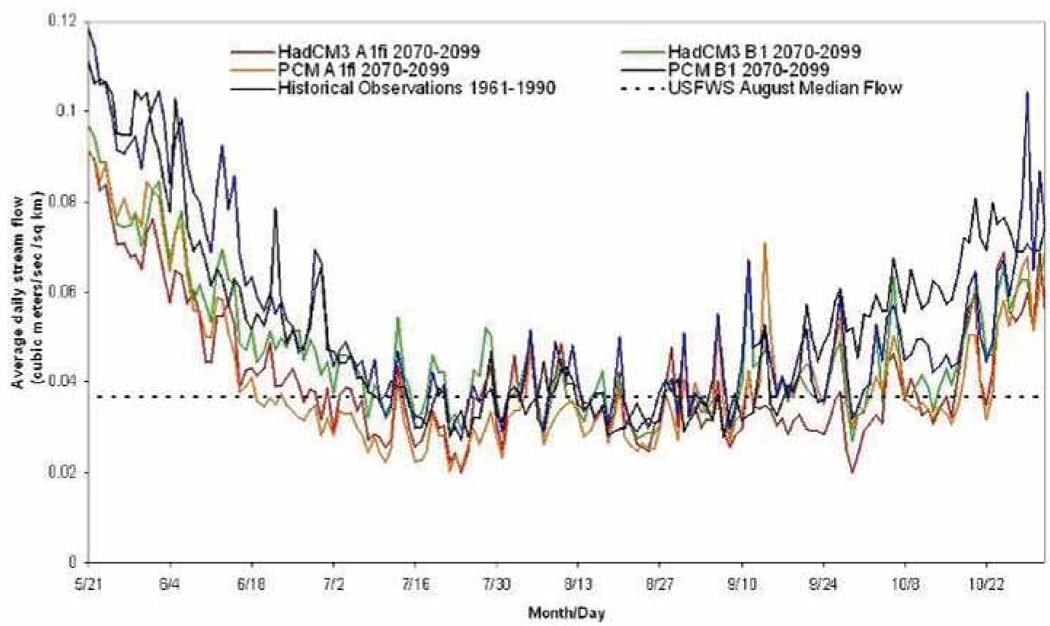


Figure 3-15. Increase in Duration of Summer Low Flow Periods.
From NECIA (2006)

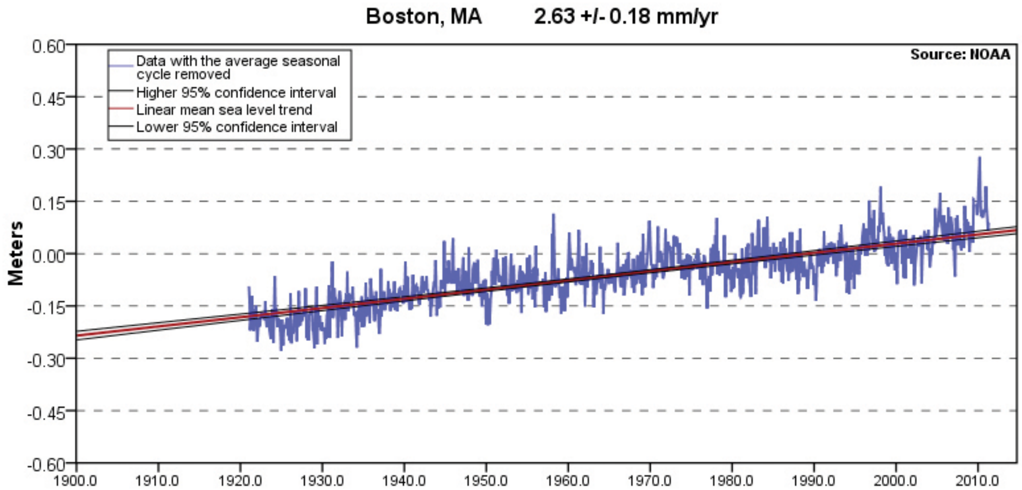


Figure 3-16. Current and historic rate of SLR at Boston Harbor (tide gauge data).

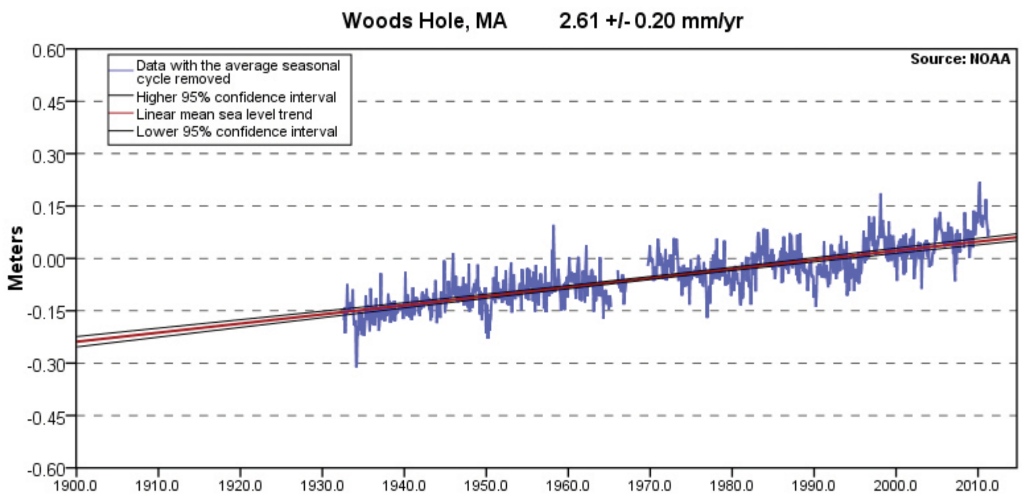


Figure 3-17. Current and historic rate of SLR at Woods Hole (tide gauge data).

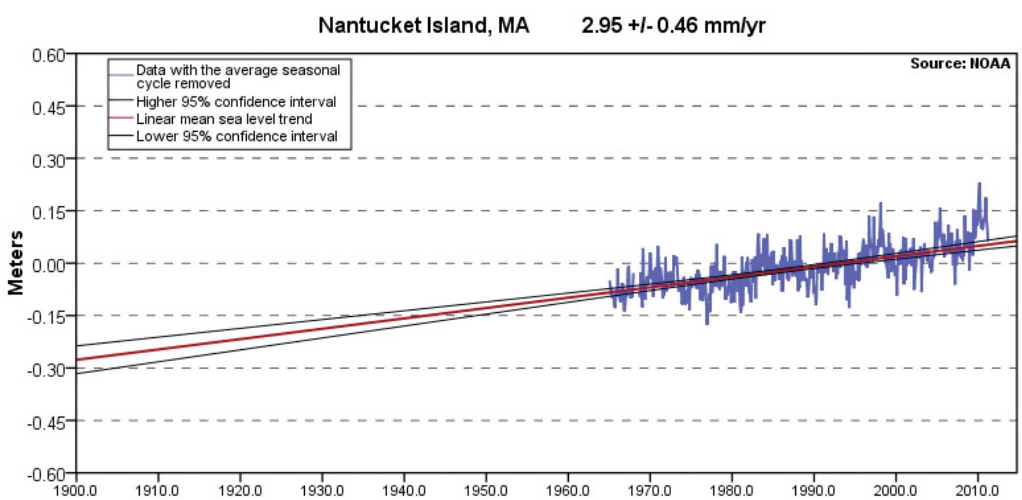
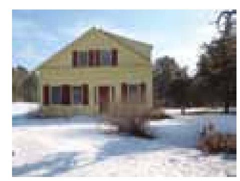


Figure 3-18. Current and historic rate of SLR on Nantucket Island (tide gauge data).

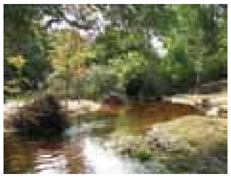
Attachment 2

Red Brook/Century Bog Timeline*

Red Brook is a coldwater stream flowing from White Island Pond to Buttermilk Bay, it forms the boundary between the towns of Wareham and Plymouth for much of its length. Century Bog is a large cranberry bog complex in the brook's headwaters that was purchased in 2010 by the Commonwealth of Massachusetts from the A. D. Makepeace Company.

About 12,000 BC	Eyestone (Red Brook landmark north of Route 25) deposited as a glacial erratic	
About 10, 000 BC	Red Brook forms as a spring sapping stream in the Wareham-Carver pitted outwash plain as the glaciers retreat	
About 5,000 BC	Brook trout (Salvelinus fontinalis) colonize Red Brook from glacial refugia in the vicinity of present day Georges Bank.	
About 2,000 BC	Sea levels rise, flooding Buttermilk Bay at the mouth of Red Brook	
Pre-1700s	Native Americans establish summer camps along lower reaches of Red Brook and create shell middens	
1666	Red Brook (ye gravelly stream) established as a boundary line	
circa 1800	Dutchman's Ditch connector to White Island Pond dug through swamp to create a herring run	
1850s	Crowell Brothers of Sandwich establish a cranberry bog near Bartletts Marsh Pond	
1867	Theodore Lyman III,MassachusettsFish Commissioner, visits Samuel Tisdale, Agawam River industrialist and fishes for sea run (salter) brook trout in Red Brook	
1870	Theodore Lyman acquires the Red Brook House and land along Red Brook	
1870-2001	The Lyman Family protects Red Brook and acquires additional land	
1900	Lebaron Barker expands Crowell Brothers Bog and renames it Century Bog in honor of the new	
TWENTIETH CENTURY		
1949	A.D. Makepeace Co. acquires Century Bog	

* Prepared by Steven Hurley, Massachusetts Division of Fisheries and Wildlife

1988	The Lyman Family approaches Trout Unlimited to pass their private stewardship of the Red Brook Property to conservation	
1999-2000	Trout Unlimited President Charles Gauvin negotiates final agreements for land transfer and memorandum of understanding between TU, The Trustees of Reservations and MassWildlife	
2001	Lyman family donates 638 acres of Red Brook property to Massachusetts Land Conservation Trust. MLCT conveys 428 acres to Massachusetts Division of Fish and Wildlife (Red Brook Wildlife Management Area)	
2003	MLCTconveysremaining210acrestoTheTrustees of Reservations (Theodore Lyman Reserve)	
2001-2005	TheodoreLymanReserveManagementPlan produced by TTOR – Red Brook Management Partnership formed between TTOR, TU and MDFW. Plan focuses on brook restoration, primarily through the removal of small dams (old cranberry bog flumes).	
2006	Dam removal in Lyman Reserve begins.	
2009	Dam removal completed. A total of four dams and one constriction removed restoring more than four miles of the brook as free flowing.	
2010	A.D. Makepeace Co. sells 245 acres of Century Bog and its surroundings to Massachusetts Division of Fish and Wildlife; five year lease of cranberry bogs signed. This land is added to the Red Brook Wildlife Management Area and is open to public recreational use for fishing (Catch and Release only), hunting, and other passive recreational uses including hiking, birdwatching, etc.	
2010	Red Brook/Century Bog restoration committee formed	
May 2011	Manomet submitted report on current and future climate change to Restoration Committee	
June 2011	Princeton Hydro submitted reports on Subsurface Characterization and Design Criteria to MDFW	
July 2011	Red Brook/Century Bog restoration stakeholder process begun with meeting of White Island Pond committee	
FUTURE ACTIVITIES		
2011-2012	Restoration alternatives developed, design plans drafted	
2012-2014	Permitting of new wetlands and channel modifications	
October 2014	Final cranberry harvest By A.D. Makepeace Co.	
November 2014	Wetland and Channel recreation begins, new channel established, new wetlands created, adaptive management to protect coldwater resources and new habitats begins	

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