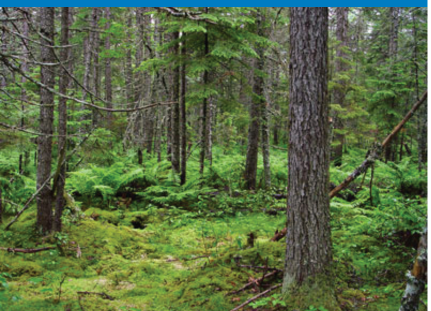

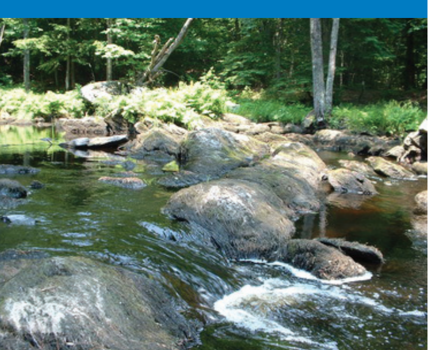

CLIMATE CHANGE AND MASSACHUSETTS FISH AND WILDLIFE:

Volume 3
HABITAT MANAGEMENT

Manomet Center for Conservation Sciences
&
Massachusetts Division of Fisheries and Wildlife
An Agency of the Massachusetts Department of Fish and Game

April 2010

A Report to the Commonwealth of Massachusetts

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Commonwealth of Massachusetts

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1. INTRODUCTION

Beginning in 2008, and funded by The Wildlife Conservation Society, the Manomet Center for Conservation Sciences (Manomet) and the Massachusetts Division of Fisheries and Wildlife (DFW) within the Department of Fish and Game (DFG) began a cooperative effort to determine: (1) how vulnerable Massachusetts fish and wildlife habitats and Species in Greatest Need of Conservation are likely to be to climate change; and (2) how conservation and management practices could be adapted or created to respond to a rapidly changing climate.

Previous reports from this work describe how the climate is likely to change in Massachusetts over the current century, and the likely vulnerabilities of fish and wildlife and their habitats to a changing climate (Manomet and DFW, 2010a; and Manomet and DFW, 2010b, respectively). This report provides at least partial answers to the second question: how valued ecological resources might be effectively managed as climatic conditions continue to change.

2. BACKGROUND

Land Conservation in Massachusetts and Climate Change

Two of the central planks of land conservation in the Commonwealth of Massachusetts are the acquisition and the management of fish and wildlife habitats. This process began early in the history of the state, with the purchase of the 48 acres of the Boston Common in 1634 and the ban on private development on it in 1822. Now, thanks to the actions and persistence of state and federal agencies, non-profit organizations, and land trusts, approximately one million acres (17% of the surface area of the state) are conserved for natural resources (NHESP, 2001 and 2003). Furthermore, the process of land acquisition and management continues to this day (Figure 1).

Many of the conserved sites in the state were acquired because of their biodiversity or the sensitive species that they support, and they are actively managed to ensure the survival of these conservation values. The result of this historical process of land preservation and management is that the Commonwealth, although highly developed and the third most densely populated state in the Union, continues to support a high diversity of plant and animal populations and natural communities (NHESP, 2001 and 2003).

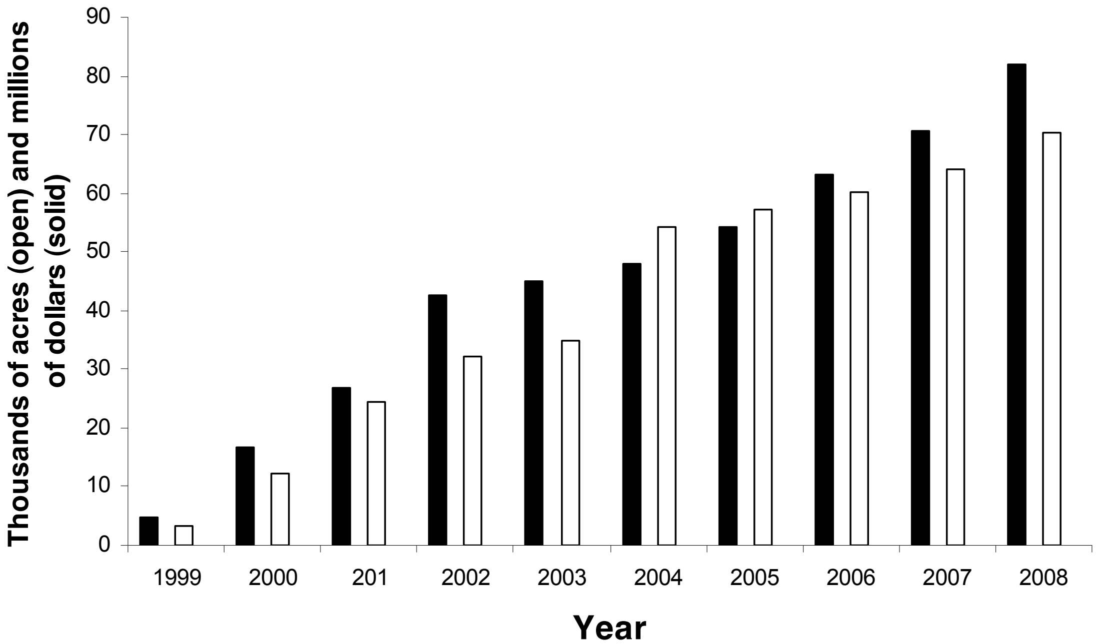


Figure 1. Cumulative thousands of acres of habitat acquired and millions of dollars spent by the Commonwealth of Massachusetts, through the DFG and in cooperation with the DFW, to protect and manage wildlife habitat (1999-2008).

The management of these important resources in the past has largely assumed a stable climatic background. In fact, many of our most successful conservation tools and approaches are based on this assumption. Fixed-area protection, for example, is one of the main cornerstones of ecological resource conservation: We assume that if we protect an area of land and manage the valued resources that it contains, it will retain its conservation value in perpetuity.

However, climate change[1] is expected to alter temperature, precipitation, the frequencies and intensities of extreme events (storms and drought), and sea level, to the point where conditions may exceed the climatic envelopes to which organisms are adapted. Northeastern plants and animals have already begun to respond to climate change (Manomet and DFW, 2010a and b), and will likely continue to respond by shifting their ranges or changing their phenologies to track their climatic optima – under climate change, change, rather than stasis, will become the norm.

Under such dynamic circumstances, how well will our traditional habitat management tools function? Climate change has the potential to fundamentally alter how conservation management is carried out – it may no longer be sufficient to acquire sites and manage them as if against a static background. We need to re-evaluate our current approaches and tools and consider new options that anticipate continually changing climatic conditions, and we need to adapt our management practices to absorb the impacts of climate change. If we fail to be flexible and adaptive in our responses to climate change it is likely that important ecological resources will be lost unnecessarily.

[1] For a description of the climatic changes that are already occurring and may occur in the State of Massachusetts over the next century, see the first report in this series: Climate Change and Massachusetts Fish and Wildlife: Introduction and Background (Manomet and DFW, 2010a).

Adaptation to Climate Change – What Is It?

Our two main opportunities to minimize the effects of climate change on the planet's biosphere are through mitigation and adaptation. Mitigation includes the societal changes that will be necessary to reduce greenhouse gas emission rates and keep their atmospheric concentrations below harmful levels. Adaptation, in the context of safeguarding human and natural resources in a changing climate, may be defined as "human actions that are…intended to minimize the adverse effects of climate change on human infrastructure and sensitive aspects of the natural environment" (The Heinz Center, 2007). When applied to land management and conservation, this translates into managing habitats, species, and sites to minimize, where feasible, the adverse direct or indirect impacts of climate change on valued resources. Thus, the management of ecological resources is an essential component of adaptation.

No matter how successful our mitigation efforts are, it will still be vital to adopt adaptation planning and implementation as major components of our future conservation strategies and tactics. This is due to two reasons: (1) We are already seeing clear climate change signals in ecological systems (Parmesan and Galbraith, 2004; Root *et al*., 2003; Parmesan and Yohe, 2003) and we need to understand how to manage these changes. (2) Even if we were to drastically reduce greenhouse gas emission rates overnight, the planet would continue to experience warming for at least the next two or three decades due to the gases emitted over the past 20 years.[2] Even if all greenhouse gas emissions were stopped, global temperatures would rise by almost 2°F above that which we have already experienced (Wigley, 2005). Thus, adaptation is not something that we should consider if mitigation fails – it is an equally important and urgent imperative.

Goals

Previous work carried out under this project has established that several Massachusetts fish and wildlife habitats that are the focus of the Commonwealth's State Wildlife Action Plan (SWAP; DFW, 2005) are likely to be threatened and adversely impacted by climate change (Manomet and DFW, 2010b). This raises the question: How do we most effectively manage vulnerable habitats so that they retain their ecological values despite the changing climate? The main objective of this report is to identify and describe some answers to these questions.

In Section 3 we present an overview of the adaptation literature, describing the general consensus about adaptation that has emerged in the scientific and management community over the last 3 or 4 years. In Section 4, we describe the methods that we used to arrive at identifying potentially effective adaptive management options for Massachusetts fish and wildlife habitats. Lastly, in Section 5, we describe potential management options for four major habitat types: forests; wetlands; lakes, rivers, and streams; and intertidal habitats.

3. ADAPTATION LITERATURE OVERVIEW

A number of recent publications have explored potential adaptation options under climate change (e.g., DEFRA, 2008; The Heinz Center, 2007 and 2008; WWF, 2003; Defenders of Wildlife, 2008; NCSE, 2009). The conclusions reached in each of these reports are broadly similar, consistently identifying a suite of adaptation goals that fall into three main categories:

1. **Promoting Resilience.** The ability of a system or species to resist adverse impacts from climate change will depend largely on its intrinsic resilience – that is, its ability to resist and recover from stress. The resilience of many species and systems has already been compromised by anthropogenic stressors and are now in a weakened state. While there are no guarantees that increasing the

[2] Due to the inertia of the climate system, additions to atmospheric concentrations of greenhouse gasses in the atmosphere are not immediately expressed in warming, but may take 20-30 years to exert their effects.

resilience of these resources will safeguard them under climate change, it is certain that the current lack of resilience in many systems and species will render them vulnerable. Four main solutions to promoting resilience have been proposed:

- *Mitigating the Effects of Non-climate Stressors*. Non-climate stressors including habitat destruction and fragmentation, contaminants, invasive species and pest outbreaks are all major factors that are currently degrading habitats and ecosystems and reducing their resilience. If we can reduce the impacts of these current stressors on vulnerable resources it may be possible to increase their resiliencies and moderate the future effects of climate change.
- *Conserving Existing Biodiversity, Ecological Functions, and High Quality Habitats*. Ecosystems and habitats that have structural and functional complexity and their full complement of species are likely to be more resilient to climate change. By preserving such habitats and not allowing them to be diminished or degraded by other stressors, the overall resilience of fish and wildlife habitats to climate change will be strengthened.
- *Restoring Degraded Habitats*. Many habitats have been so degraded by anthropogenic stressors that they lack ecological function and their full complement of species. The resilience of such habitats is low, but could be raised if attempts were made to restore their former ecological function and composition.
- *Managing Habitats for Ecological Function*. The core of resilience to stressors is a full complement of ecological functions (e.g., nutrient cycling, hydrology, etc.). If these functions can be maintained or improved through active management, the resilience of habitats will be supported.

2. Implementing Landscape-level Planning. One of the main impacts of climate change will be to increase the likelihood and magnitude of shifts in the distributions of species, habitats, and ecosystems. A landscape-level planning focus will be necessary to accommodate this. Specifically, it will be important to:

- Identify and preserve movement corridors;
- Improve habitat connectivity to facilitate movement of displaced organisms;
- Improve buffering to safeguard core, high-quality habitats;
- Conserve large blocks of habitat.

3. Promoting Effective On-the-ground Management of Sites and Habitats. The first adaptation goal identified above (promoting resilience) needs to be translated into effective on-the-ground management actions that will strengthen the abilities of sites, habitats, and species to resist stress under a changing climate. <u>Specifically, site managers and biologists need to focus on two primary objectives – managing resilience and managing change</u>.

4. OBJECTIVES AND METHODS

The primary objective of this component of the DFW climate change project was to work with state, federal, and NGO biologists and managers to identify approaches to managing sites and habitats under climate change. This addresses response category Number 3 of Section 3 above, “Promoting Effective On-the-ground Management of Sites and Habitats.” We focused on developing site-level solutions and actions, rather than thinking at the landscape level, which is being addressed by other investigators (e.g., the Massachusetts Chapter of The Nature Conservancy, the University of Massachusetts at Amherst). Also, an additional report from this project will focus at the landscape level by addressing future DFW land acquisition strategies under climate change.

What we needed to develop were practical *and* effective adaptive strategies for managing resilience and change, and it became obvious that a collaboration between Manomet scientists and state and federal habitat and site managers – combining scientific expertise with practical management experience – would be essential to the success of the project. Further, the demarcation between scientists and managers is fortunately not clear-cut, since many of the site managers involved are also trained and prominent scientists, and contributed a great deal to the scientific discussion, in addition to their management expertise and experience. Practical management input has been conspicuously absent from the adaptation dialogue, which has been dominated by scientists with limited or no knowledge about practical site or habitat management challenges. It was clear that practical and effective solutions could be developed only by a collaborative and cross-disciplinary approach combining these two fields of knowledge and expertise.

The scientists/managers who participated in this process are identified in Table 1, together with their affiliations and the main habitat types for which they contributed expertise.

Table 1. Participants in the process of developing site and habitat adaptation management approaches for this project.

Participant	Affiliation	Expertise/Habitat Type
Hector Galbraith	Manomet	Ecology and climate science
John Scanlon	DFW	Forest ecology and management
Tom O'Shea	DFW	Forest ecology and management
John O'Leary	DFW	Fisheries biology
Tim Simmons	DFW	Habitat management
Caleb Slater	DFW	Fisheries biology
Sonja Christensen	DFW	Ungulate biology
Pat Swain	DFW	Wetland ecology
Jan Smith	Massachusetts Bays Program	Intertidal habitats
Graham Taylor	Parker River NWR Refuge Manager	Intertidal habitats

Galbraith of Manomet and O'Leary of DFW met with each of the participants either in the field or at their offices, where the first step was for Galbraith to briefly present the current state of our knowledge about projected climate change in the Northeast (based on Hayhoe *et al*., 2007 and 2008) and our knowledge about the likely vulnerabilities and trajectories of habitat types in Massachusetts (Manomet and DFW 2010b). The participants then summed up current ecological values and management practices for each of their habitats. Galbraith and O'Leary then facilitated a discussion to identify the main future threats to habitats (including climate-change and non-climate factors), their likely impacts and importance, and what management actions could be taken to mitigate these impacts. The results of these discussions comprise Section 5 of this report.

5. RESULTS

In this section we present the outcomes of our discussions with site scientists/managers about adaptation options that may be effective in reducing the impacts of climate change on important ecological resources. We focus these results through the lenses of the two primary management goals outlined above – managing resilience and managing change.

It is important to note that we do not attempt to formulate a "menu" of adaptation actions that can be applied to specific sites or habitats. This is not a site or habitat adaptation plan, though the development of such plans is much needed. Rather, we begin the process of working toward such adaptation plans by identifying and describing categories of management actions that may aid habitat management under climate change.

We present the results separately for each of the four main habitat types investigated: forests, wetlands, freshwater aquatic habitats, and coastal intertidal wetlands. First, however, we identify the main non-climate stressors that currently pose conservation challenges to important Massachusetts fish and wildlife habitats.

Non-climate Stressors

During the vulnerability assessment process in an earlier stage of this project (Manomet and DFW, 2010b) we gathered information on the major current stressors affecting habitats that are vulnerable to a changing climate (Table 2). The mitigation of these non-climate stressors offers opportunities to increase their intrinsic resilience and resistance to future climate change impacts. For example, controlling habitat loss and fragmentation to conserve wildlife travel corridors that connect larger reservoirs of habitats could be an adaptive response that reduces the future impacts of climate change on forested habitats.

Table 2. Non-climate stressors currently affecting vulnerable habitats (from Manomet and DFW, 2010b).

Habitat	Non-climate Stressors
Spruce-fir Forest	• Invasive Species and Pest Outbreaks • Fragmentation • Periodic Fire
Boreal Swamp	• Pest Outbreaks • Periodic Fire
Northern Hardwood Forest	• Pest Outbreaks • Invasive Species • Fragmentation • White-tailed Deer Browsing • Periodic Fire
Riparian Forest	• Water Management/Withdrawals • Non-point Contaminants • Dams
Small Coldwater Lakes and Ponds	• Adverse Management Practices • Non-point Contaminants • Dams and Culverts
Large Coldwater Lakes	• Adverse Management Practices
Coldwater Rivers	• Water Withdrawals • Elimination of Shade Vegetation • Impervious Surfaces
River Mainstems	• Water Management/Withdrawals • Non-point Contaminants • Introduced Exotic Species
Kettle Ponds	• Aquifer Depletion • Adverse Management Practices
Intertidal Wetlands	• Habitat Loss and Fragmentation

Forested Habitats

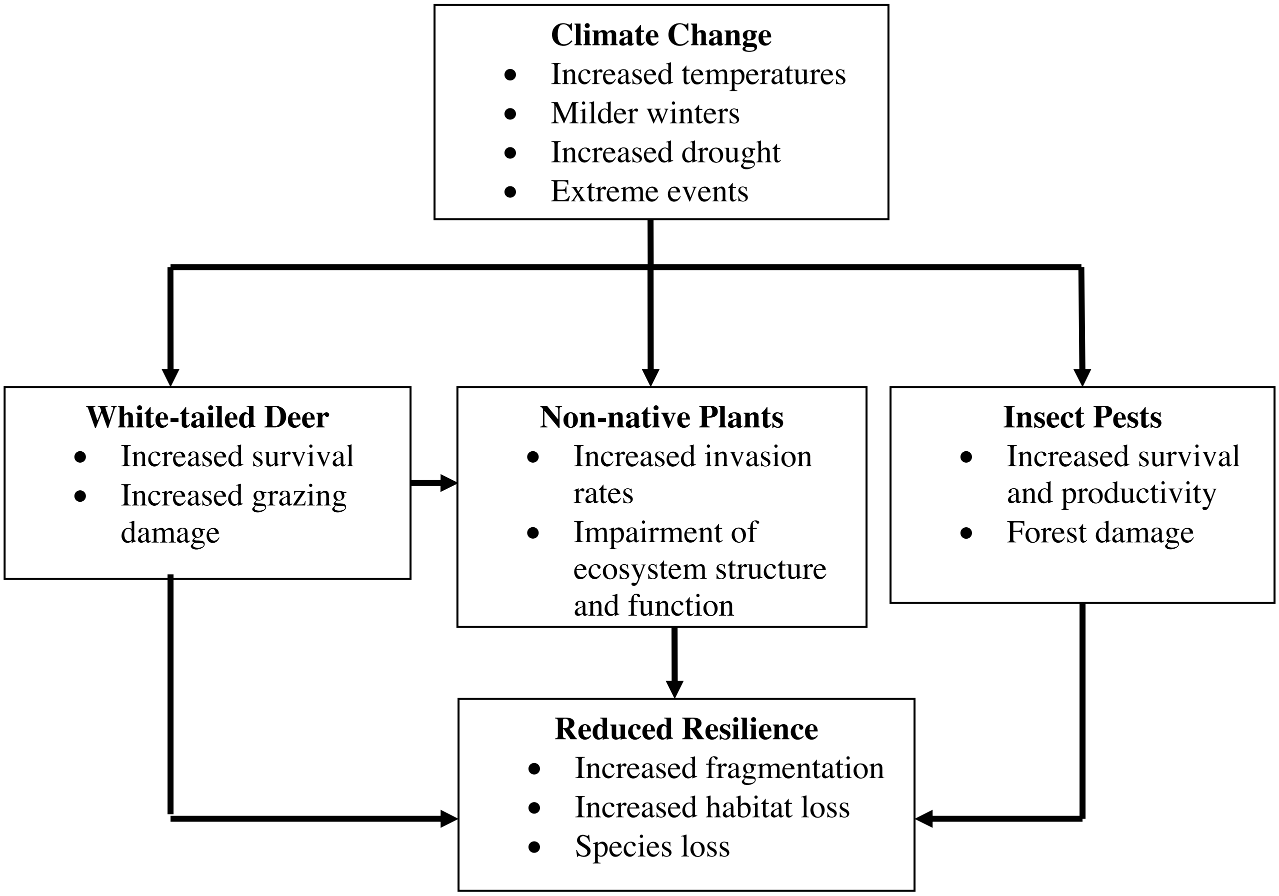
Managing Resilience

Maintaining and enhancing ecological resilience has long been a focus of DFW's habitat management strategies in forested habitats. Historically, three main factors, over-browsing by White-tailed Deer, non-native plant infestations, and damaging outbreaks of invertebrate pests, have been the most important stressors reducing forest resilience, and have been the main targets of the state's management (Figure 2). Some of the management approaches that are currently used by the state to manage these factors are also likely to be important tools under climate change. These include adjusting the age structure of forest patches, managing deer densities, and intervening to eliminate invasive species and pests.

Forest age structure. Massachusetts DFW currently manages resilience across a maturing forest landscape by identifying structurally diverse and species-rich areas of mature forest for retention and regenerating more homogeneous areas of second-growth trees to young forest habitat through publicly-bid timber sales. This has the effect of establishing a mosaic of forest age classes and conditions on the landscape and could well be an important adaptation response to climate change. Diversifying the age structure and species composition of the forested landscape in advance of climate change could increase resilience of forested ecosystems and overall resistance to the impacts of a changing climate.

Control of White-tailed Deer Densities. High levels of browsing by White-tailed Deer have adversely affected the structure, composition, and functioning of Massachusetts forested ecosystems, particularly through the elimination of preferred food species such as Red Oak, and thereby reduced their diversity and resilience. Also, overgrazing by deer has opened the way for increased rates of infestation by non-native plants.

Figure 2. Interactions of climate change and existing stressors in reducing forest habitat resilience.



The White-tailed Deer is a valued native wildlife species in the state. Massachusetts is divided into 15 Wildlife Management Zones (WMZs), each of which is assigned an ideal deer density goal set by DFW (Figure 3 and Table 3). These goals were scientifically established to meet three main objectives: to maintain healthy deer populations at levels that keep them in balance with their environment (i.e., do not allow them to exceed biological carrying capacity); to maintain levels which allow sustainable deer harvest and deer viewing opportunities for hunters and wildlife watchers; and to minimize impacts on public health, public safety, and property damage (i.e., do not allow them to exceed cultural carrying capacity).

Figure 3. Wildlife Management Zones in Massachusetts.

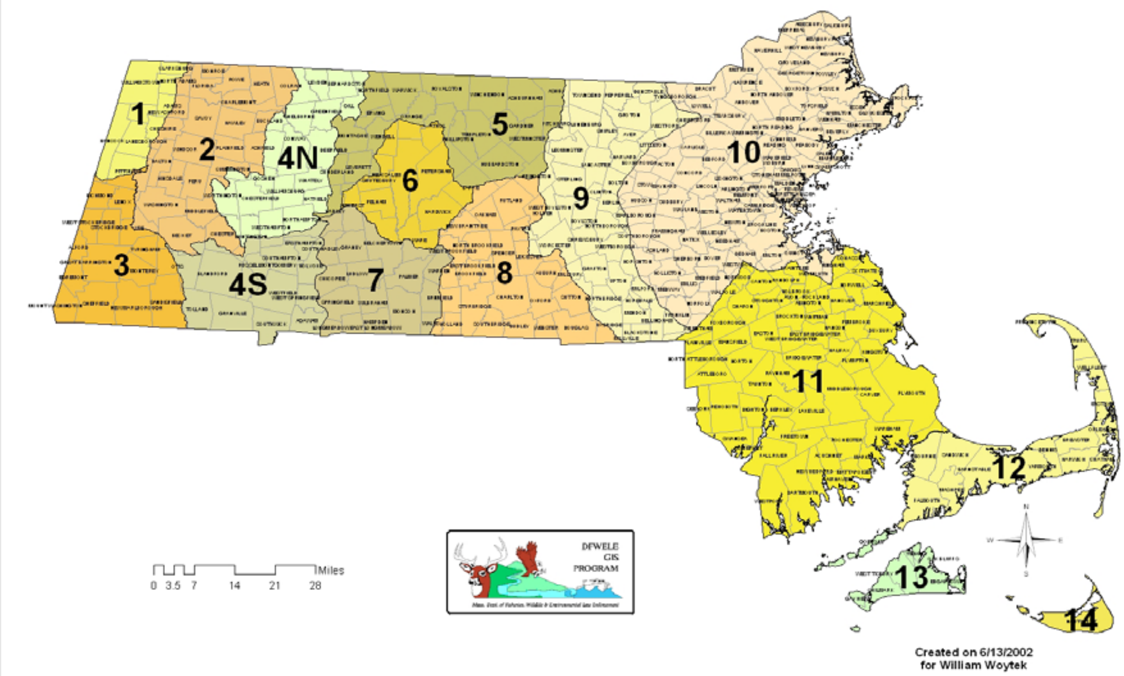
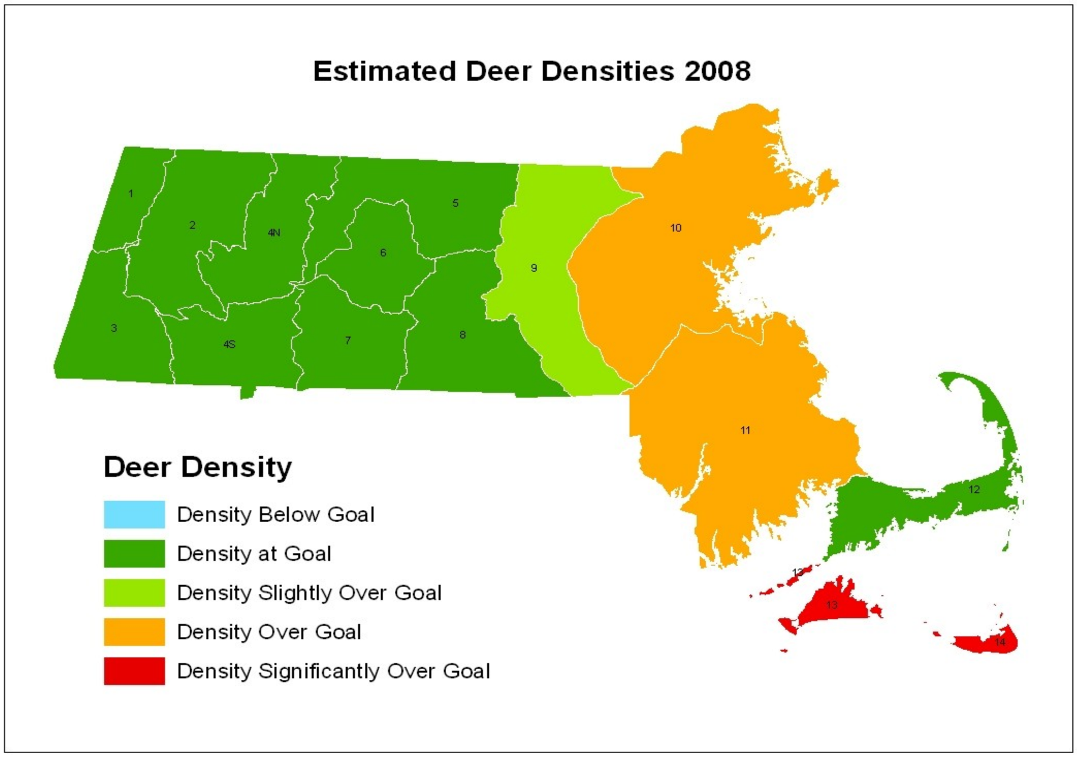


Table 3. DFW deer density goals, by Wildlife Management Zone.

Current Deer Density Goals	
Wildlife Management Zones	Deer per Square Mile of Forest
Zones 1-6	12-15
Zones 7-9	10-12
Zones 10-14	6-8

Regulated hunting is an effective method of deer population management and allows managers to increase, reduce, or maintain deer populations relative to the density goals. Unfortunately, reduced land access and the changing demographics of the hunting community hamper the ability to reduce deer populations where needed in some regions of the state. Although most regions in Massachusetts have successfully maintained their deer density goal (Figure 4), climatic stressors will likely compound the effects of on-going non-climatic stressors, making it increasingly difficult to manage deer populations.

Figure 4. Estimated deer densities in Massachusetts.



Under climate change, lengthened growing seasons, increased availability of browse, and milder winter weather will likely occur. These changes will likely increase deer reproductive and survival rates. Nevertheless, keeping numbers of White-tailed Deer at or below deer density goals will be a critical tool in maintaining the diversity and resilience of forested habitats in Massachusetts under a changing climate. It is possible that future deer density goals in the Wildlife Management Zones may have to be adjusted to reflect these changing realities. If the hunting community continues to diminish, other more aggressive measures, such as organized culling, may have to be taken to maintain target densities.

Pests and invasive species: Keeping densities of deer below critical levels will also help the invasive species problem (Figure 2). Non-native plants, such as Japanese Barberry, Japanese Knotweed, and Common Buckthorn, have already reduced the ecological value and resilience of many state-protected lands. Non-native insect pests are increasingly inflicting high levels of damage, notable examples being the Hemlock Wooly Adelgid infestations that have now spread throughout the state, and the recent outbreak of Asian Longhorned Beetle that led to the removal of 6,500 maple trees over approximately 64 square miles in the Worcester area. However, even if deer numbers are reduced, it is likely that the invasive plant problem, and that posed by pests, will become more serious under climate change. If so, it will be increasingly necessary to (1) detect and track infestations and outbreaks in their early stages, and (2) take aggressive actions to eliminate these problems before they escape control. This requires that we establish effective and more intensive monitoring and response strategies. This is dealt with in greater detail below.

Managing Change

As already reported in this project (Manomet and DFW, 2010b), some forested habitats in the Commonwealth are likely to be highly vulnerable to climate change, including high-elevation spruce-fir forests, forested boreal swamp, and higher-elevation northern hardwoods. Their extents in the state may be drastically reduced or eliminated altogether, even under relatively modest greenhouse gas emissions rates. What are the appropriate management actions for such habitats? Should we acknowledge that they are likely to be lost or much reduced in extent and not allocate management resources? Or should we try to manage them so that their existence in the state is maintained for as long as is possible, and then redirect our management goals to guiding change so that the risk of having these habitats replaced by unwanted communities (e.g., invasives-dominated) is minimized? The fact is that these habitats are rare in the Commonwealth and they support plants and animals that are also rare. The habitats themselves and their associated species are also charismatic and popular with the public. Given this, it may not be possible to simply assign them to a "lost cause"; we may need to expend management resources on them.

How do we manage habitats or species that are at high risk? The first acknowledgement that needs to be factored into our thinking is that any preservation action is likely to be unsuccessful in the long term: Change will occur eventually. Our challenge is to (1) define that change point where expending further resources to maintain a *status quo* is futile, and (2) guide the change to a new equilibrium so that ecological value is not entirely lost. Thus, the paradigm for management of these habitats becomes a two-stage process: preservation, giving way to managed change. This differs from our current paradigm, which is one-stage, i.e., it seeks to preserve the *status quo*.

The second of these actions requires the tools that we have already developed: tracking invasives and pests and eliminating them where feasible and, in some cases, the transplanting of preferred species. The first illustrates a general point that is common to all habitat adaptation under climate change: Effective, focused monitoring as a tool for adaptive management will be increasingly vital under climate change. Not only must we instigate well-thought-out and effective monitoring schemes, but we must also identify future thresholds that can be identified from our monitoring data and that will trigger new adaptive management goals. In the case of spruce-fir forest, the threshold for changing management goals may be the loss of some key floristic characteristic, or the loss of associated animal species such as Blackpoll Warblers, Yellow-bellied Flycatchers, or Snowshoe Hares. Once this threshold is reached, the management strategy will focus on a goal other than preservation – it will switch into the guided-change mode.

Freshwater Wetlands

Under climate change, the main threats to freshwater wetlands in Massachusetts are likely to be the same ones that currently affect wetland quality and function: impaired hydrology and habitat loss, and ecological injuries caused by non-native pest species (e.g., Water-chestnut, Purple Loosestrife, water-milfoil spp.). However, climate change is likely to exacerbate these stressors by:

- Further disrupting the hydrology of the wetlands, due to higher summer temperatures, increased evapotranspiration rates, and a higher incidence and severity of droughts. This could lead to greater drying out and habitat loss.
- Facilitating infestations of non-native pest species. The losses due to drying out under climate change could be exacerbated by more frequent and intense ecosystem degradations by these pest species.

Effective management under climate change will likely not require new tools and approaches, but will necessitate increased efforts to protect hydrology and control pests. There are already a number of tools that will be useful in this effort, though some may require a sharper focus to respond to the changing circumstances.

Regulations That Protect Wetlands and Their Hydrology

There are already regulations in place to protect wetlands and their plants and animals in Massachusetts, including the Massachusetts Wetland Protection and Endangered Species acts, and local wetland protection ordinances. Also, a number of state and federal regulations seek to regulate water use and quality (the Massachusetts Water Management Act and Interbasin Transfer Act, the federal Clean Water

Act, and the Massachusetts Water Quality Certification Regulations and Surface Water Quality Discharge Standards). Each of these has some influence on regulating the amount of water going into and being withdrawn from wetlands, and the quality of the inflow.

If wetlands in the Commonwealth are to be conserved under climate change, it will be necessary to more tightly focus existing regulations on the protection of wetland functions and values. Applications of the regulations that address water withdrawals and discharges must take into account that the very existence of many wetlands in the Commonwealth may be jeopardized by drying out and that more water needs to be allocated to wetland hydrology. Thus, allocations to wetlands must be protected and, if necessary, increased at the expense of other uses.

The regulations that currently protect wetland plants and animals have been highly successful in the past and will continue to be so in the future. However, the onset of climate change may require us to rethink how these regulations are applied. Active management will be a major tool under climate change when it may become necessary to go into existing wetlands and, for example, alter their hydrologies, or expand their boundaries. If such management is impeded by the way that some regulations are currently written or interpreted, they may have to be modified to reflect the changing circumstances.

Invasives Control

It is likely that the problems that are currently posed by invasive plant species to wetlands will be exacerbated by the higher levels of environmental stress introduced by climate change (droughts, extreme events, etc.). If we are to continue to protect valued wetlands, it will be vital to increase efforts aimed at detecting and eliminating or controlling outbreaks. This requires three things:

- *More active monitoring*. It will be essential that we detect pest outbreaks in their earlier stages, rather than later when they have secured a foothold. This can only be accomplished if active detection and monitoring schemes are implemented.
- *Aggressive elimination and control activities*. More resources will need to be allocated to interventions that will eliminate outbreaks in their early stages.
- *Education on and enforcement of best management practices*. Many pests are transported from site to site by humans. To reduce this hazard, it will be necessary to educate users of wetland resources (e.g., anglers, hunters, nature viewers) about the dangers posed and to provide them with guidance and facilities to reduce off-site transport.

Watershed Protection

Wetland functions and quality are affected by events that take place in areas actually abutting the wetland. However, they may also be affected by activities within the entire watershed. For example, land-use changes from agriculture or forestry to urban developments can have major impacts on more or less distant wetlands (through altered runoff or sediment loads). The nexus of expanding human populations, land-use change, and climate change requires that we adopt a watershed focus when considering how to protect wetlands. Specifically, we may not be able to protect wetlands if we do not protect the hydrologic, geomorphological, and ecological matrices within which they are situated. In this sense, land protection – whether or not the land is hydric – is wetland protection.

Another benefit of watershed planning is that, at this scale, it becomes easier to identify important buffer areas, i.e., habitats that may not necessarily be wetlands but that buffer them from anthropogenic stressors.

Targeted Protection, Restoration, and Management of Large, Functionally-healthy Wetland Complexes

Fragmentation and habitat loss are factors that have in the past reduced the resilience of Massachusetts wetlands. With the advent of climate change it is becoming increasingly important that we preserve and support the large wetland complexes that remain in the Commonwealth. Moreover, we should be seriously considering how existing wetland complexes could be increased in size through habitat restoration (e.g., on floodplains).

Lakes, Rivers, and Streams

The main threats posed by climate change to lakes, rivers, and streams in the Commonwealth stem from warming and a consequent loss of coldwater habitats that support specialist cold-adapted species such as salmonids. This could result in contractions in the volume of coldwater hypoliminia in larger lakes and reservoirs not fed by cold groundwaters, such as Quabbin and Wachusett, and loss of coldwater habitat in smaller headwater streams and rivers.

Coldwater Lake Habitats

Quabbin and Wachusett are reservoirs managed for human water supply. Their fates under climate change are only partly a function of temperature, and they may be equally or more vulnerable to changes in management regime (Manomet and DFW, 2010b). As the climate changes, human water needs may also change, necessitating potentially disruptive management practices. Both reservoirs are used by humans as recreational resources. As the climate warms, the aquatic ecosystems may be disrupted in ways that are viewed by humans as aesthetically undesirable (e.g., increased frequencies of algal blooms, more emergent vegetation). These could lead to management practices (e.g., drawdowns to eliminate algae or weeds) that could jeopardize the remaining coldwater habitat. However, absent these maladaptive practices, it is likely that the lake hypolimnia would persist, albeit reduced in volume (Manomet and DFW, 2010b). Consequently, the main adaptation management tactic to be applied in these habitats will be the prevention of maladaptive societal responses to climate change.

Coldwater Rivers and Streams

As temperatures rise in the Commonwealth, the main adaptive management approach that could result in coldwater habitat preservation will be maintaining existing habitat and mitigating the effects of other, non-climate stressors. These actions will include

- *Ecological manipulations*, such as maintaining or expanding riparian buffer zones that shade the steams and assist in keeping water temperatures low.
- *Engineering solutions*, such as the removal of barriers to fish passage to allow access to and spawning in upriver areas; the replacement of smaller-bore culverts with larger ones that facilitate passage; and the redesign of future retention ponds so that warmed water is not released into streams.
- *Regulatory solutions,* such as regulation forbidding the building of impervious surfaces (e.g., parking lots and other developments) close to coldwater streams and rivers, as this may result in warmed runoff entering the waterbody; reappraisal of regulations that allow inter-basin transfer of water out of coldwater streams; and rethinking and modifying stream allocation regulations and permits that do not incorporate climate change considerations.

Mainstem Rivers

The Connecticut and the Merrimack are predominantly warmwater systems in Massachusetts, and intrinsically less vulnerable to climatic warming. However, they could be sensitive to changes in the amount and seasonality of flow (as longer and more severe droughts become more frequent and the hydrograph is altered by winter precipitation shifting from snow to rain). The quantity and seasonality of flow in these mainstems is already managed in some places for wildlife and fish populations using the elaborate system of dams already in place. While dams have had adverse impacts on some fish populations in the past, they could provide a partial engineering solution to climate change in that releases of water may be timed to benefit migration, rearing, and spawning (Yates *et al*. 2008).

Intertidal Wetlands

The main climate-change-related threat to Massachusetts coastal wetlands, particularly intertidal habitats, is sea-level rise. Current projections for global sea-level rise over the next century range from about 0.5m up to 2.0m, depending on the assumptions made about ice melt at high latitudes (IPCC, 2007; Rahmstorf, 2007; Pfeffer *et al*., 2008).

As was discussed extensively in Attachment 19 to Manomet and DFW (2010b), the vulnerability of selected coastal intertidal habitats in Massachusetts to climate change has been evaluated in U.S. Fish and Wildlife Service sea–level-rise modeling studies at three coastal Massachusetts National Wildlife Refuges (NWR), Parker River, Monomoy, and Mashpee (Clough and Larsen, 2009). Regardless of the modeled differences among these sites, the results indicate that intertidal habitats in Massachusetts are highly sensitive to sea-level rise, even under relatively conservative estimates.

Adaptation Options

Likely adaptation options at Massachusetts' coastal wetlands can be divided into five categories:

Removing existing impediments to tide line migration. As sea levels continue to rise, the whole system of coastal wetlands and subtidal habitats will move inland. As it does, the composition and structure of these habitats will be maintained. However, this cannot occur in areas where either the topography does not permit it, or where human-built barriers, such as roads, seawalls, or settlements, prevent it. Where possible, such impediments can be relocated to facilitate the inland shift in habitats.

Acquiring and protecting future wetland sites. Current wetlands protection regulations in Massachusetts are effective at conserving *existing* wetlands. However, sea-level rise may cause these habitats to shift into areas that are not currently hydrophitic and therefore not protected by these regulations. If the current pace of coastal development continues, these "future wetlands" may be developed before they can act as refugia. It is important that we begin to use LIDAR and other data to identify these wetland "destinations," protect them from development, and set in place corridors that will facilitate habitat migration.

Establishing better relationships between engineering and ecological solutions to sea-level rise. Hurricane Katrina dramatically illustrated the adverse consequences of removing natural ecological wetland buffers to coastal storms and relying entirely on engineered solutions. Even after this catastrophic event, coastline planners continue to view the preservation of coastlines through an engineering lens. We urgently need to be shifting the focus from purely engineering-based and infrastructure-focused solutions toward a union of engineering and ecological panning that will make coastal ecosystems major components of our coastal protection solutions.

Developing more ecologically sound planning and conservation regulations. For most coastline areas in the U.S., local planning regulations are generally not "climate-smart." In the worst cases they subsidize settlement and development close to the high-tide line, and at best they do not sufficiently deter this. We need to take a much closer look at how we regulate coastline development so as to avoid the construction of yet more impediments to inland migration of habitats. Also, some of our current wetland protection regulations do not permit modification of existing intertidal habitats. These strictures could impede our ability to adapt to rising sea levels and protect existing habitats. These regulations should be reviewed in the light of the sea-level-rise challenge.

Replenishing sediments. Sea-level rise destroys habitats because the rate of rise exceeds the rate at which wetland soils are replenished by sediments. It may be possible at some sites to mitigate this and preserve the wetlands by replenishing sediments. However, it would be a massive task to preserve all of Massachusetts' wetlands by this procedure and it is likely to be feasible only at a small number of sites. Further, this procedure is not sustainable over the long term.

Instituting integrated/community planning. Coastal habitats in Massachusetts and elsewhere are often areas where there are a multiplicity of adjacent – sometimes competing – interests and stakeholders. At the mouth of the Parker River, for example, the landscape comprises a mosaic of state-, federally-, and privately-owned lands. Municipalities and agriculture abut the protected lands and a variety of recreational activities (e.g., bathing, beach activities, sailing, nature viewing) attract large numbers of participants from throughout Massachusetts and further afield, who make important contributions to the local economy. Thus, any measures contemplated by the state- or federally-owned reserves to meet the challenge of climate change could affect at least some other members of this varied constituency. Also, sea-level rise may threaten privately-owned or municipal lands as much as it does the state and federal reserves. If effective adaptation measures are to be carried out to protect these wetland habitats, it will be important that any planning extend beyond the state and federal agencies and involve the other stakeholders. What is needed in such a situation is integrated or community planning that represents and integrates all interests.

6. SUMMARY

The management of Massachusetts' fish and wildlife habitats under climate change will likely have two main objectives, depending on the sensitivity of the habitats and degree of climate alteration:

- Preserving the current ecological values of habitats that are less vulnerable to climate change or in vulnerable habitats in their early stages of change; and
- Guiding change in the most climate-sensitive and vulnerable habitats.

The two managerial strategies that can be used to achieve these objectives are managing resilience and managing change. Following are suggested approaches to implementing these strategies, for each of the four main habitat types:

Forested Habitats

- Promote resilience by aggressively managing current stressors: grazers and browsers, invasive species, pests.
- Promote resilience by managing the age structures of forest stands to favor an increased representation of young vigorous trees.
- Manage change by selective cutting, introductions of preferred species, and the control of non-climate stressors.

Freshwater Wetlands

- Develop and strengthen regulations that protect wetlands and their hydrologies. Regulations are already in place to protect wetlands and their plants and animals in Massachusetts. Under climate change, it will be necessary to more tightly focus existing regulations that protect wetland functions and values, particularly those that govern water withdrawals and discharges.
- Introduce necessary flexibility in regulations. Active management will be a major tool under climate change when it may become necessary to go into existing wetlands and, for example,

alter their hydrologies, or expand their boundaries. If such management is impeded by the way that some regulations are currently written or interpreted they could be modified to reflect the changing circumstances.

- Control non-climate stressors. The threats currently posed by invasive plant species to wetlands will be exacerbated under climate change. If we are to continue to protect valued wetlands, it will be vital to increase efforts aimed at detecting and eliminating or controlling outbreaks. This will require more active monitoring and detection, aggressive elimination, and the education of the public about and the enforcement of best management practices
- Protect watersheds. We can best preserve wetlands by protecting the hydrologic, geomorphological, and ecological matrices within which they are situated. This requires the management and conservation of watersheds.
- Protect, restore, and manage large, functionally-healthy wetland complexes. We must aim to preserve and support the large wetland complexes that remain in the Commonwealth. We should also aim to increase the size of existing wetland complexes through habitat restoration (e.g., on floodplains).

Lakes, Rivers, and Streams

- Implement ecological manipulations, such as maintaining or expanding riparian buffer zones that shade the steams and assist in keeping water temperatures low.
- Engineer solutions, such as the removal of barriers to fish passage to allow access to and spawning in upriver areas, the replacement of smaller-bore culverts with ones that facilitate passage, and the redesign of future retention ponds so that warmed water is not released into streams.
- Develop and apply regulatory solutions that focus on ecological outcomes, such as regulation forbidding the building of impervious surfaces (e.g., parking lots and other developments) close to coldwater streams and rivers as this may result in warmed runoff entering the waterbody; reappraisal of regulations that allow inter-basin transfer of water out of coldwater streams; and rethinking and modifying stream allocation regulations and permits that do not incorporate climate change considerations.
- Avoid maladaptive responses, such as aggressive drawdown in large lakes with hypolimnia.

Intertidal Wetlands

- Remove existing impediments to tide line migration. As sea levels continue to rise, the whole system of coastal wetlands and subtidal habitats will move inland. This cannot occur in areas where either the topography or human-built barriers prevent it. Where feasible, such barriers should be removed and/or relocated to facilitate the inland shift in habitats.
- Acquire and protect future wetland sites. Sea-level rise will cause coastal wetlands to migrate inland into areas that may not currently be hydrophitic. It is important that we identify and protect these future wetlands from development, and set in place corridors that will facilitate habitat migration.
- Establish better relationships between engineering and ecological solutions to sea-level rise. It is important that we shift our focus toward a union of engineering and ecological planning that will result in coastal ecosystems becoming a major part of our coastal protection solutions.
- Develop more ecologically-sound planning and conservation regulations. For many coastline areas in the U.S., local planning regulations are generally not "climate-smart." It is important that we change how we regulate coastline development so as to avoid the construction of yet more impediments to inland migration of habitats.

- Replenish Sediments. It may be possible at some coastal sites to preserve wetlands by replenishing sediments. However, this is likely to be feasible at only a small number of sites, and it is not sustainable over the long term.
- Institute integrated/community planning. Coastal habitats in Massachusetts and elsewhere are often areas where there are a multiplicity of adjacent, sometimes competing, interests and stakeholders. At such sites it is important that planning efforts include all stakeholders in an integrated or community planning process.

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