Chapter 6

Ecosystems

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Introduction

Valuable ecosystem services provided by New York's landscapes include harvested products (food, timber, biomass, maple syrup), clean water and flood control, soil conservation and carbon sequestration, biodiversity support and genetic resources, recreation, and preservation of wild places and heritage sites. Ecosystems recharge groundwater supplies and reduce soil erosion by creating catchments that enhance rainwater infiltration into soils as opposed to allowing rapid runoff of storm water into streams. The healthy vegetation of landscapes helps to stabilize and conserve soils, and also sequesters carbon above ground in the standing biomass of trees and perennial plants and below ground in the form of roots and soil organic matter. The diverse flora and fauna supported by New York landscapes play a role in maintaining Earth's biological heritage, and the complex interactions among species benefit society in many ways, such as natural control of insect pests and disease. Genetic diversity will be essential for the natural adaptation of our ecosystems to environmental stresses such as high temperatures and drought that will be exacerbated by climate change. In addition, genetic diversity has potential economic value for new pharmaceuticals, or for organisms or compounds with biotechnology applications.

Figure 6.1 depicts a conceptual framework for how these services are related to ecosystem function, species composition, and habitat integrity. As this framework indicates, the impacts of climate change cannot be viewed in isolation, as other stressors are also affecting ecosystems and will affect vulnerability to climate change. While society and policy-makers are likely to focus on ecosystem services, adaptation interventions by natural resource managers often will be implemented at the level of species, communities, and habitats. As climate changes and the habitable zones of wild species continue to shift northward and/or upward in elevation throughout the century, natural resource managers will face new challenges in maintaining ecosystem services and difficult decisions regarding change in species composition.

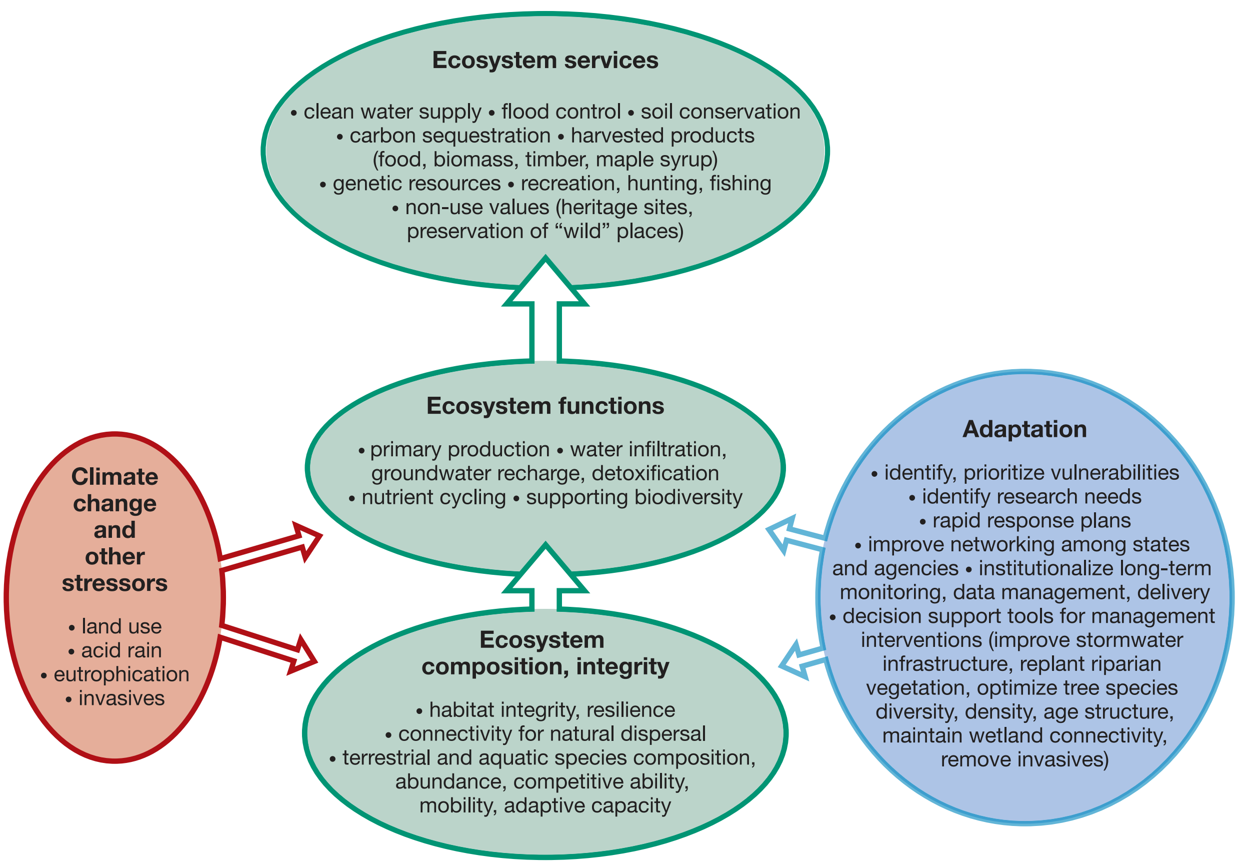


Figure 6.1 Ecosystem services in relation to climate change and adaptation

6.1 Sector Description

New York State covers an area of 54,556 square miles comprised of 47,214 square miles of land and 7,342 square miles of inland waters, including extensive lake and river systems throughout the state as well as substantial portions of Lake Erie and Lake Ontario. Variation in topography and proximity to bodies of water cause large climatic variations and distinct ecological zones (**Figure 6.2**) that support the complex web of biological diversity and provide important ecosystem services.

Ecosystems, as defined in this ClimAID report, encompass the plants, fish, wildlife, and resources of all natural and managed landscapes (e.g., forests, grasslands, aquatic systems) in New York State except those land areas designated as agricultural, coastal, or urban. This sector includes timber and maple syrup industries and tourism and recreation businesses conducted within natural and managed ecosystems. It also encompasses interior wetlands, waterways, and lakes as well as their associated freshwater fisheries and recreational fishing. Water resources per se are covered in Chapter 4, "Water Resources." Marine fisheries are covered in Chapter 5, "Coastal Zones," as are coastal wetlands and marine shoreline ecosystems.

6.1.1 Terrestrial Ecosystems (forests, shrublands, and grasslands)

Sixty-one percent of New York's land area (18.5 million acres) is covered by forest canopy. This reflects considerable forest regrowth since the late 1800s when forest cover was at a low point (about 25 percent of

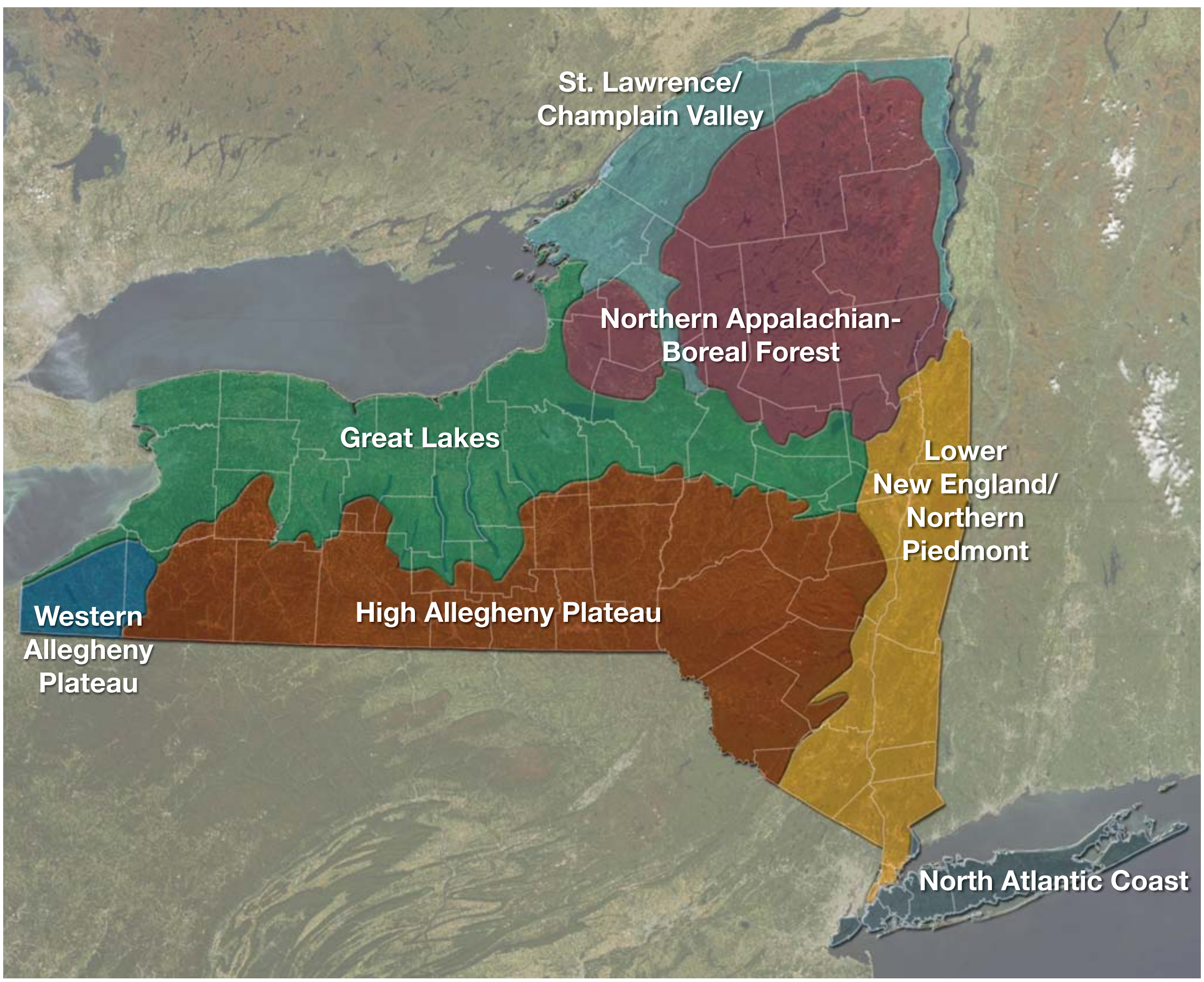
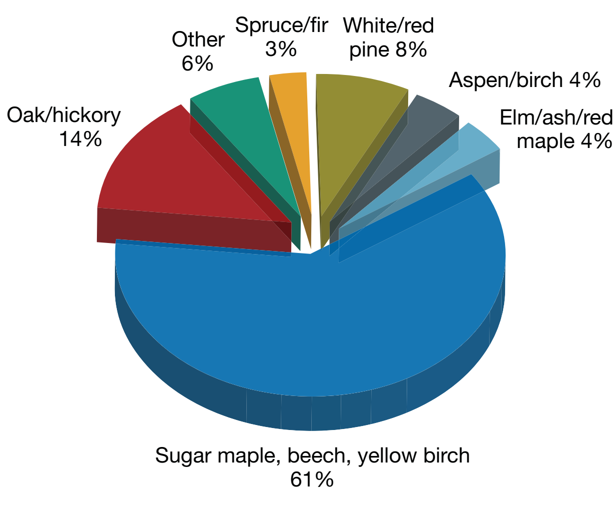


Figure 6.2 New York State Department of Environmental Conservation ecoregions

total land area) due to agricultural expansion during European settlement. Those tree species categorized as northern hardwoods by the U.S. Forest Service form the most common type of forest in New York, occupying 7.4 million acres or 40 percent of total forested area, but many other tree species are important (**Figure 6.3**). The state also is home to many shrub and woodland acres, representing various stages of forest succession on abandoned farmland and recently harvested forestlands.

Among the tree species inhabiting these forests, some have particularly important functional roles. Spruce and fir trees are key components of the unique and cherished high-elevation forests of the Adirondacks, although they occupy just 1 percent of the state's forested land. White pine and hemlock are important evergreen species found throughout the state. Hemlock trees often provide shade to stream banks (which is important for coldwater fish species) and are essential habitat to many species. While hemlock stands have largely recovered from heavy logging during the previous centuries (when they were used in the tanning industry), more recently they are under threat by infestations in some areas by the hemlock wooly adelgid insect pest (Paradis et al., 2008; and see Case Study A: Hemlock).



Note: Oak/hickory forest is defined as containing a mixture of red oak, black oak, scarlet oak, white oak, chestnut oak, pignut hickory, bitternut hickory, shagbark hickory, flowering dogwood, blueberry, mountain laurel, and hawthorn. The other categories are defined as containing high proportions of the two or three species named in the type title. The "Other" category includes oak/pine, exotic softwood, loblolly/shortleaf, pinyon/juniper, and oak/gum/cypress trees. Source: Data for figure were taken from the USDA Forest Inventory and Analysis 2005 webpage http://fia.fs.fed.us

Figure 6.3 New York State forest types

New York's terrestrial ecosystems also include meadows, grasslands, and wetlands. The wetlands in particular are home to many vulnerable species. The mountainous high elevations of the Adirondack State Park and the Catskills are the only regions of the state with a cool climate suitable for alpine boreal communities and alpine bogs, containing many specialist species that are limited to habitats within 5°F of current temperatures (Jenkins, 2010). The Adirondacks are home to unique alpine tundra communities with additional specialist species found nowhere else within New York State.

6.1.2 Aquatic Ecosystems

New York's rich assemblage of water resources provides a wide array of habitat types and supports a high diversity of plant and animal species. There are 70,000 miles of streams and rivers and 4,000 lakes and ponds spread over New York's 17 major watersheds (DEC website, www.dec.ny.gov/61.html) and seven ecoregions (**Figure 6.2**). There are more than 2.4 million acres of wetlands widely distributed throughout the state, with 1.2 million acres legally protected and administered by the Department of Environmental Conservation and 0.8 million administered by the Adirondack Park Agency.

Wetlands are distinguished from stream and lake habitats by the presence of emergent vegetation (e.g., cattails, sedges, shrubs, and trees). Wetlands are most extensively developed in the more level topography of the western Lake Plains and in the Adirondacks, which together account for 74 percent of all New York's wetlands. Seventy-five percent of New York's wetlands have a forested cover, but this figure does not reflect the full diversity of the different wetland types, which have distinctive flora and fauna (Edinger et al., 2002) and differing levels of vulnerability to climate change. Wetlands are distinguished by the degree to which they are fed directly by precipitation, runoff, and/or groundwater seeps and by their hydroperiod, the length of time each year that the soils are submerged. Wetlands with short or intermediate hydroperiods, such as forest vernal pools (shallow seasonal pools in woodland depressions where wood frogs and some salamanders breed) and intermittent headwater streams, lack fish and are extremely important for the reproductive success of some amphibians. Small, isolated wetlands are home to a disproportionate number of rare and endangered species.

6.1.3 Fish and Wildlife

New York's diverse ecosystems are habitat for abundant wildlife, including 165 freshwater fish species, 32 amphibians, 39 reptiles, 450 birds, 70 species of mammals, and a variety of insects and other invertebrates. The Comprehensive Wildlife Conservation Strategy is a collaborative effort led by New York State Department of Environmental Conservation's Division of Fish, Wildlife, and Marine Resources. The Comprehensive Wildlife Conservation Strategy lists 537 "Species of Greatest Conservation Need," which includes federally endangered or threatened vertebrate and invertebrate species occurring in New York State, as well as state-listed species of special concern (**Table 6.1**) (for species added by Department of Environmental Conservation staff based on status, distribution, and vulnerability, visit www.dec.ny.gov/animals/9406.html).

In all, 70 mammal species inhabit the state (NYSDEC, 2007). Two mammals—the New England cottontail (*Sylvilagus transitionalis*) and the small-footed bat (*Myotis leibii*)—are state species of concern. In addition, the Indiana bat (*Myotis sodalis*) is federally endangered.

The breeding bird atlas (McGowan and Corwin, 2008) lists 251 species that breed in the state and 125 additional species that spend the winter or visit occasionally. Several forest and grassland bird species are area-sensitive and depend upon large, unfragmented areas of habitat to breed and successfully raise young (Herkert, 1994). Important migratory and stopover habitats occur for waterfowl, raptors, and songbirds. The Shawangunk Ridge is a well-known raptor migration route. Waterfowl and other birds migrate along the shores of Lakes Ontario and Erie. Similarly, the Montezuma National Wildlife Refuge is significant regionally as a major staging, feeding, and resting area for an estimated 1 million migratory birds.

Information on amphibians and reptiles is found in the New York State "Herp Atlas" (Gibbs et al., 2007). Diverse habitats support 32 amphibian and 33 native reptile species (excluding sea turtles). The amphibians include 18 salamander species and 14 frogs and toads

Table 6.1 Endangered (E), threatened (T) and special concern (SC) fish and wildlife species in New York State (continued on next page)

Common Name	Scientific Name	Federal Status	State Status	Primary Habitat
Amphibians				
Hellbender	*Cryptobranchus alleganiensis*		SC	Streams and rivers
Marbled salamander	*Ambystoma opacum*		SC	Forest habitat, seasonal pools
Jefferson salamander	*Ambystoma jeffersonianum*		SC	Forest habitat, seasonal pools
Blue-spotted salamander	*Ambystoma laterale*		SC	Forest habitat, seasonal pools
Eastern tiger salamander	*Ambystoma tigrinum*		E	Pine barrens, seasonal or permanent pools
Long-tailed salamander	*Eurycea longicauda*		SC	Forest, shale banks, streams, springs
Eastern spadefoot toad	*Scaphiopus holbrookii*		SC	Sandy soils, seasonal pools
Northern cricket frog	*Acris crepitans*		E	Shallow ponds, slow-moving water
Southern leopard frog	*Lithobates sphenocephala*		SC	Freshwater ponds
Reptiles				
Eastern mud turtle	*Kinosternon subrubrum*		E	Fresh or brackish water with vegetation
Spotted turtle	*Clemmys guttata*		SC	Bogs, swamps, marshy meadow
Bog turtle	*Clemmys muhlenbergii*	T	E	Open, wet meadow, shallow water
Wood turtle	*Clemmys insculpta*		SC	Forest, riparian areas
Eastern box turtle	*Terrapene carolina*		SC	Fields and forest
Blandings turtle	*Emydoidea blandingii*		T	Shrub swamps, open field
Eastern spiny softshell	*Apalone spinifera*		SC	Rivers, lakes
Northern fence lizard	*Sceloporus undulatus*		T	Rocky areas surrounded by forest
Queen snake	*Regina septemvittata*		E	Streams with rocky bottoms
Eastern hog-nosed snake	*Heterodon platirhinos*		SC	Barrens, woodlands
Eastern worm snake	*Carphophis amoenus*		SC	Barrens, woodlands
Eastern massasauga	*Sistrurus catenatus*		E	Bog, swamps, barrens
Timber rattlesnake	*Crotalus horridus*		T	Deciduous forest, rocky ledges

Common Name	Scientific Name	Federal Status	State Status	Primary Habitat
Mammals				
New England cottontail	*Sylvilagus transitionalis*		SC	Shrubland, early successional forest
Small-footed bat	*Myotis leibii*		SC	Caves, rock crevices, forest
Indiana bat	*Myotis sodalis*	E		Caves, forest
Alleghany woodrat*	*Neotoma magister*		E	Rocky outcrops, oak forest
Birds				
Spruce grouse	*Falcipennis canadensis*		E	High elevation spruce/fir forest
Common loon	*Gavia immer*		SC	Lakes
Pie-billed grebe	*Podilymbus podiceps*		T	Ponds, marshes, estuarine wetlands
Manx shearwater	*Puffinus puffinus*	T		Pelagic, small islands
American bittern	*Botaurus lentiginosus*		SC	Marsh
Least bittern	*Ixobrychus exilis*		T	Marsh
Osprey	*Pandion haliaetus*		SC	Lakes, rivers, marshes
Bald eagle	*Haliaeetus leucocephalus*	T	T	Lakes, rivers
Northern harrier	*Circus cyaneus*		T	Grasslands
Sharp-shinned hawk	*Accipiter striatus*		SC	Forest
Cooper's hawk	*Accipiter cooperii*		SC	Forest
Northern goshawk	*Accipiter gentilis*		SC	Extensive mature forest
Red-shouldered hawk	*Buteo lineatus*		SC	Forest near water
Golden eagle	*Aquila chrysaetos*		E	Grassland
Peregrine falcon	*Falco peregrinus*		E	Cliffs, buildings
Black rail	*Laterallus jamaicensis*		E	Coastal marshes
King rail	*Railus elegans*		T	Coastal and freshwater marshes
Piping plover	*Charadrius melodus*	E	E	Beaches
Upland sandpiper	*Bartramia longicauda*		T	Grasslands
Roseate tern	*Sterna dougallii*	E	E	Beaches, salt marsh islands
Common tern	*Sterna hirundo*		T	Beaches, grassy uplands
Least tern	*Sterna antillarum*		T	Beaches, river sandbars
Black tern	*Chlidonias niger*		E	Wetlands, lakes, river edges
Black skimmer	*Rynchops niger*		SC	Coastal
Short-eared owl	*Asio flammeus*		E	Grasslands
Common nighthawk	*Chordeiles minor*		SC	Rooftops, open habitats
Whip-poor-will	*Caprimulgus vociferus*		SC	Open forest
Red-headed woodpecker	*Melanerpes erythrocephalus*		SC	Open forest, forest edge, beaver meadows with dead standing trees
Loggerhead shrike	*Lanius ludovicianus*		E	Hedgerows, hayfields, pasture
Horned lark	*Eremophila alpestris*		SC	Grassland
Sedge wren	*Cistothorus platensis*		T	Damp meadows and marshes
Bicknell's thrush	*Catharus bicknelli*		SC	High elevation spruce/fir forest
Golden-winged warbler	*Vermivora chrysoptera*		SC	Early successional forest
Cerulean warbler	*Dendroica cerulea*		SC	Large deciduous forests, tall trees
Yellow-breasted chat	*Icteria virens*		SC	Shrubland
Vesper sparrow	*Pooecetes gramineus*		SC	Grasslands
Grasshopper sparrow	*Ammodramus savannarum*		SC	Grasslands
Henslow's sparrow	*Ammodramus henslowii*		T	Grasslands
Seaside sparrow	*Ammodramus maritimus*		SC	Marsh

*The Allegheny woodrat, classified as Endangered, has not been found in New York State since the mid-1980s and is already considered to be extirpated at this point. http://www.dec.ny.gov/animals/6975.html
Source: www.dec.ny.gov/animals/7494.html

(NYSDEC, 2007). Six salamanders and three of the frogs and toads are endangered or of special concern (**Table 6.1**). The reptiles include four lizards, 17 snakes, 11 species of freshwater or land turtles, and one turtle that inhabits saltwater or brackish water. Seven of the 12 turtles, one of the 4 lizards, and five of the 17 snakes are endangered, threatened, or of special concern at the state and/or federal levels. Amphibians and reptiles exhibit the greatest species richness values (number of species per given area) in the Hudson River Valley, which is globally significant for its high diversity of turtles (www.dnr.cornell.edu/ gap/land/land.html).

New York is currently home to approximately 165 freshwater fish species, dominated by north temperate species living in watersheds draining to the Great Lakes and the St. Lawrence River. The coldwater fish range throughout lakes and rivers in the northern United States and Canada. New York also has many freshwater fish species representative of southern fauna found in watersheds that extend southward to the Gulf of Mexico and Middle Atlantic.

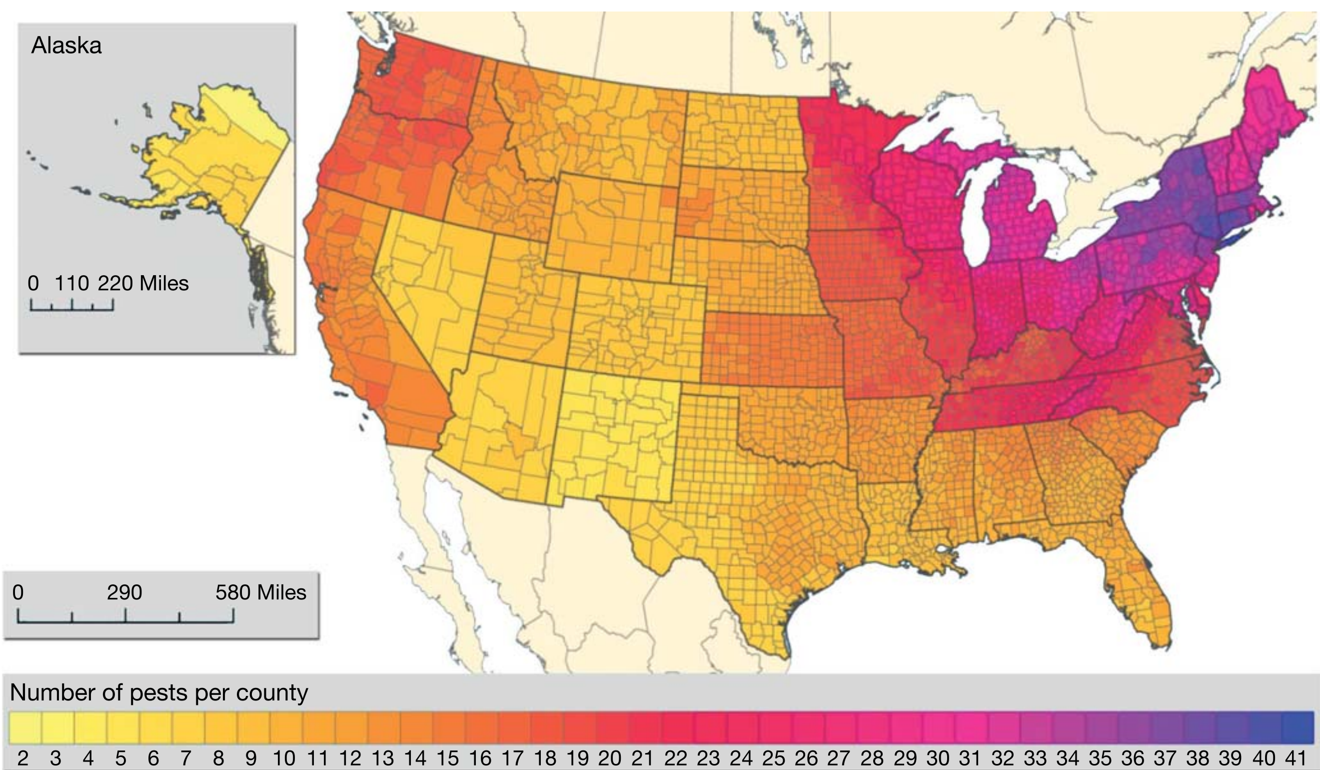
6.1.4 Non-climate Stressors

Several factors currently negatively impact natural ecosystems in New York State with various levels of severity. Some of these may be exacerbated by climate change, or may reduce the adaptive capacity of ecosystems or certain species to respond to climate change.

Invasive Species

As a major port of entry, New York State, with its vast natural and agricultural resources, is particularly vulnerable to damage from many invasive species (**Table 6.2**, **Figure 6.4**). Increases in global commerce and human travel have led to increasing rates of species invasion (Mack et al., 2000; Liebhold et al., 2006) that show no sign of slowing down in the years to come (Levine and D'Antonio, 2003; Liebhold et al., 2006; McCullough et al., 2006; Tatem, 2009) and pose serious threats to the integrity of the state's lands and waters. Most recently, the devastating emerald ash borer (*Agrilus planipennis* Fairmaire), an invasive forest pest from Asia, was detected in Cattaraugus County in western New York in June 2009 (NYSDEC, 2009), and the invasive aphid-like insect pest, hemlock wooly adelgid (*Adelges tsugae*), has been observed in some hemlock stands of the state.

Invasive species have altered and continue to alter the ecological structure and function of New York's ecosystems. Invasive understory shrubs and plants, like Amur honeysuckle (*Lonicera maackii* (Rupr.) Herder) and pale swallow-wort (*Vincetoxicum rossicum* (Kleopow) Barbar.), commonly crowd out or smother native vegetation, impeding forest regeneration (Gorchov and Trisel, 2003) and reducing understory plant diversity (DiTommaso et al., 2005). Invasive pests and pathogens, including gypsy moth (*Lymantria dispar*) and beech bark disease, can intensely impact the productivity, nutrient cycling, and food-web structure of the forests (Lovett et al., 2006).



Source: Alien Forest Pest Explorer, USDA Forest Service

Figure 6.4 Number of invasive forest pest and pathogen species established per county throughout the United States

Table 6.2 Invasive species of management concern across New York ecosystems and the predicted direct impacts of climate change on those species based on current scientific information

Species	Habit	Origin (date introduced or detected)	Habitat	Impact	Management Options	Possible Direct Impacts of Climate Change on Species
Plants						
Common reed *Phragmites australis* (Haplotype M)	Perennial clonal grass	Europe (late 1800s)	Freshwater & brackish tidal wetlands	↓ native biodiversity & habitat; alters nutrient cycling & hydrology	M, C, B*	↑ CO_2 may stimulate growth (Farnsworth & Meyerson 2003; Meyerson et al., 2009); sea level rise may aid restoration of *Phragmites*-invaded coastal wetlands (Hellmann et al., 2008)
Eurasian watermilfoil *Myriophyllum spicatum* L.	Submerged aquatic perennial herb	Europe (~1900)	Freshwater ponds, lakes, & pools	Displaces native vegetation; negative impacts on macroinvertebrate & fish communities; impedes recreation	M, C, B	Higher water temperatures may ↑ growing season & require control actions to be implemented earlier & longer (Rahel & Olden, 2008)
Giant hogweed *Heracleum mantegazzianum* Sommier & Levier	Biennial or perennial herb	Caucasus Mtns, between Black & Caspian Seas (1917)	Wet areas (e.g., stream & river banks, along RRs & roads)	Displaces native vegetation; toxic sap causes severe photodermatitis and burns	M, C	Requires low winter temperatures for seeds to germinate in the spring (Pyŝek et al., 1998)
Japanese knotweed *Polygonum cuspidatum* Siebold & Zucc.	Perennial herbaceous shrub	Japan (late 1800s)	Riparian areas, ditches & disturbed areas	Spreads rapidly, forming dense thickets that crowd and shade out native vegetation; adversely affects species diversity and wildlife habitat	M, C, B*	Milder winters may result in increased seedling survival (Forman and Kesseli, 2003)
Mile-a-minute *Persicaria perfoliata* (L.) H. Gross	Annual herbaceous vine	India, East Asia, Japan to Philippines (1930s)	Open & disturbed areas	Crowds out native species	M, C, B, G	No information available
Swallow-wort Black: *Cynanchum louiseae* Pale: *Cynanchum rossicum*	Perennial herbaceous vine	Europe (mid-1800s)	Upland areas, including old fields & woodland ground layers	Crowds out native vegetation & adversely affects native wildlife, including grassland birds and monarch butterflies	M, C, B*	No information available
Water chestnut *Trapa natans* L.	Annual aquatic herb	Western Europe, Africa to Asia (late 1870s)	Ponds, shallow lakes & river margins	Displaces native vegetation; impedes recreation; reduces dissolved oxygen	M, C, B*	No information available
Invertebrates						
Asian long-horned beetle *Anoplophora glabripennis*	Generalist wood-boring beetle	China & Korea (1996)	Urban & natural forests	Attacks and kills hardwood trees including: maples (*Acer* spp.), horsechestnut (*Aesculus hippocastanum*), willows (*Salix* spp.), American elm (*Ulmus americana*) birches (*Betula* spp.) and poplars (*Populus* spp.)	Tree removal, C (limited), B*	No information available
Emerald ash borer *Agrilus planipennis* Fairmaire	Specialist metallic wood-boring beetle	Eastern Russia & Asia, including Japan & Taiwan (2002)	Urban & natural forests	Attacks and kills all North American ash (*Fraxinus* spp.) trees	Tree removal, C (limited), B*	No information available
Hemlock woolly adelgid *Adelges tsugae*	Aphid-like insect	Southern Japan (1951, eastern United States)	Deep-shade riparian forests	Attacks and kills eastern hemlock trees (*Tsuga canadensis*)	C, B	↑ temperatures may release hemlock woolly adelgid from overwintering constraints and promote range expansion (Paradis et al., 2008)
Zebra mussel *Dreissena polymorpha* Pallas; Quagga mussel *Dreissena rostriformis bugensis*	Bi-valve mollusks	Black, Caspian & Aral Seas; Ural drainage in Eurasia (1988)	Zebra: hard substrates along lakeshores & river bottoms; Quagga: deeper waters & softer substrates	Excess removal of plankton & detritus from water column, resulting in changes to food web, lake productivity & water clarity; displacement of native mussel communities; colonization & obstruction of water pipelines and canals; ship hull fouling	M, C, B*	Increased water temperatures may ↑ growing season & require control actions to be implemented earlier & longer (Rahel & Olden, 2008)

Below ground, invasive earthworms from Europe and Asia alter soil structure and nutrient retention, with cascading impacts on the soil food web and native plant communities that can be detrimental (Bohlen et al., 2004). Invasive plants, such as purple loosestrife (*Lythrum salicaria*) and common reed (*Phragmites australis*), have

Species	Habit	Origin (date introduced or detected)	Habitat	Impact	Management Options	Possible Direct Impacts of Climate Change on Species
Vertebrates						
Feral swine *Sus scrofa*	Mammals	Eurasia (1500s)	Rural & natural areas	Damage to croplands & sensitive natural areas including riverbanks & springs; degrades wildlife habitat; competition with & predation of native species; can transmit diseases to domestic swine, including pseudorabies & swine brucellosis	Trapping & shooting	No information available
Northern snakehead fish *Channa argus*	Air-breathing freshwater fish	China, Russia & Korea (2002)	Shallow ponds, swamps & slow streams	Voracious predator; competes with native species for food & habitat	C	No information available
Pathogens						
Beech bark disease	A complex syndrome involving attack by beech scale (*Cryptococcus fagisuga* Lind.) followed by invasion of *Nectria* fungi	Europe (1890)	Deciduous forests	Decline and death of American beech, *Fagus grandifolia* (Ehrh.)	Tree removal, C (at local scales)	Fungal cankering may be worse after mild winters, favoring survival & spread of the scale insect and infection (Harvell et al., 2002)
Viral hemorrhagic septicemia	Aquatic rhabdovirus	Eastern & Western Pacific coasts; Atlantic Coast of North America	Freshwater & saltwater	Infects at least 50 freshwater & saltwater fish species, including commercially & recreationally important brook trout, Chinook salmon, lake trout, rainbow trout, walleye, smallmouth bass, northern pike, yellow perch & muskellunge	None but regulations to prevent spread (e.g., prohibiting transport of live fish, restricting use of baitfish	VHS virus is less active in warmer water (higher than 59°F) (Meyers & Winton, 1995)

Note: While this is not an exhaustive list, it provides a selection of species of concern that are the focus of management efforts statewide. Abbreviations for management options are: M, mechanical; C, chemical; B, biological control; B*, biological control in development; G, grazers. See http://nyis.info for additional information.

replaced diverse wetland plant communities with monocultures, leading to cascading consequences on wetland food webs and biogeochemical cycles. Over the last century, invasive aquatic plants like Eurasian water milfoil (*Myriophyllum spicatum* L.) and water chestnut (*Trapa natans* L.) have spread extensively throughout New York's lake and river systems (Boylen et al., 2006), displacing native vegetation (Boylen et al., 1999), negatively impacting fish and invertebrate communities (Keast, 1984), and impeding recreational activities like swimming, boating, and fishing (U.S. Congress, 1993). The filter-feeding zebra and quagga mussel species (*Dreissena polymorpha* and *Dreissena rostriformis bugensis*), introduced to the Great Lakes from the Pontic-Caspian region via ballast water, have transformed the food webs in Lakes Erie and Ontario from largely pelagic systems (where fish and other organisms thrive throughout the water column) to benthic systems (where fish and other organisms are all concentrated near the lake bottom).

The economic impacts of invasive species are equally as profound as the ecological impacts, with a cost to the United States by one estimate of $120 billion per year in damage and control expenditures (Pimentel et al., 2005). The economic impact of a single species, the emerald ash borer (*Agrilus planipennis* Fairmaire), which is now established in 13 states including New York, is projected to amount to $10.7 billion from urban tree mortality alone over the next 10 years (Kovacs et al., 2009). Specifically in New York State, invasive species pose serious economic threats to agriculture, forestry, maple sugar production, and recreation.

Increasing Deer Populations

High deer populations in many areas of New York State cause concern for resource managers, farmers, and homeowners. In addition to damage caused to residential landscape plants and agricultural crops, selective feeding of white-tailed deer alters plant community structure and can negatively affect the health and diversity of forests and other natural areas. Through their direct effects on plants, deer have cascading effects on many other wildlife species.

Many of the preferred forage species of deer, such as sugar maple and oaks, are valued for timber or as food-producing trees for wildlife. Deer also feed on wildflowers like trillium and lady slipper, but they tend to avoid ferns, invasive species like garlic mustard and barberry, and native tree species such as American beech and striped maple. Selective feeding of deer has led to dominance of ferns and grasses (Horsley and Marquis, 1983), along with invasive species and monocultures of beech in some New York forests (Stromayer and Warren, 1997). Over-browsing by deer leads to loss of forest understory vegetation that is an important habitat and food source for many songbirds and other forest wildlife.

Land Use Change, Land Ownership, and Habitat Fragmentation

Management of New York's "natural" ecosystems ranges from minimal to intensive depending on land use and ownership. While public lands are important habitats for abundant birds, wildlife, and fish, private land owners and nonprofit organizations control the vast majority of non-agricultural land. For example, 90.2 percent of the 15.8 million acres available for timber production is privately owned (NEFA, 2007). Less than 10 percent of terrestrial vertebrates in New York State are on public lands. This has important implications for developing adaptive management strategies for coping with climate change or other environmental changes. In addition, land in New York supporting natural plant and animal communities is becoming increasingly urbanized and suburbanized, altering its ability to support these communities and the water and other resources supplied by these lands to neighboring habitats.

Urbanization and other forms of human land-use change threaten some habitats and lead to fragmentation—the breaking up of large, connected terrestrial or aquatic habitats. Habitat fragmentation constrains plant and animal dispersal patterns across habitats, alters plant and wildlife community composition, and increases vulnerability to pathogens, insect pests, and invasive species. It can also reduce nesting habitat for forest interior birds and area-sensitive grassland bird species, and increase rates of predation and parasitism on nesting songbirds.

Acid Rain, Nitrogen Deposition, and Ozone

Acid rain is produced when nitrogen and sulfur compounds, emitted primarily from power plants and automobiles, react with water in the atmosphere and are deposited as acidic precipitation and dry deposition. The Adirondacks, Catskills, Hudson Highlands, Rensselaer Plateau, and parts of Long Island are particularly sensitive to acid deposition because they lack the capacity in the soil to neutralize the acid (Adams et al., 2000). Acidic compounds damage leaf tissue, leach vital nutrients from the soil (Rustad et al., 1996; Fernandez et al., 2003), and mobilize toxic aluminum that damages roots and impairs decomposition in forests (USEPA, 2010). Acid rain also negatively affects some fish and other aquatic species and can increase the sensitivity of both aquatic and terrestrial species to other stresses, such as high temperatures. Extended periods of nitrogen deposition can lead to saturation and consequent leaching of nitrogen from soils with negative effects on water quality (Stoddard, 1994). While environmental regulations have reduced emissions of contributing air pollutants in recent years and enabled substantial recovery of many forest and aquatic systems (NYSERDA, 2009), acid rain remains an important stressor in some parts of the state.

Excess quantities of nitrogen deposition also can disrupt ecosystems by fertilizing the growth of a few plant species to the detriment of others (Howarth et al., 2006; Aber et al., 2003). The most common examples of this are stream and lake eutrophication, where algal and other populations grow rapidly to the detriment of many others. Ozone is also a product of high nitrogen emissions reacting in the atmosphere. High levels of ozone impede the growth of key plant species, disrupting the normal competitive relationships among species (Krupa, 2001).

6.1.5 Economic Value and Ecosystem Services

Linking ecosystem goods and services to ecosystem structure and function and identifying the best approach for placing a value on those goods and services is a major challenge of this century. **Figure 6.1** describes a conceptual framework for placing ecosystem services, values, and functions into context with adaptation to climate change and multiple stressors.

Valuation Challenges

The economic value of some ecosystems goods and services is relatively straightforward, such as recreational value and value of commodities including timber and maple syrup (see more details, below). However, many services fall under the category of ecological functions, which have indirect value, such as carbon sequestration, water storage and water quality maintenance, flood control, soil erosion prevention, nutrient cycling and storage, species habitat and biodiversity, and dispersal/migration corridors for birds and other wildlife. These functions clearly have value, but quantifying them is much more complex. Even more difficult to quantify are the existence or non-use values associated with concepts such as preservation of cultural heritage, resources for future generations, charismatic species, and wild places.

The National Research Council recently commissioned a review of ecosystem value by experts in the field (NRC, 2005). It lays out the challenges of valuation in the context of uncertainty. It also describes various approaches such as nonmarket valuation, revealed- and stated-preference methods, and the use of production functions. The review also discusses how the results of valuation analysis can be linked to policy. More recently, new modeling tools are being developed that use ecological production functions and valuation methods to examine the impact of projected changes in land use and land cover on ecosystem services, conservation, and the market value of commodities produced by the landscape (Daily et al., 2009; Nelson et al., 2009). A recent study conducted in New Jersey used several approaches and concluded ecosystem services within the state had a value of $11.6–19.4 billion per year (Costanza et al., 2006).

Recreation and Tourism

Hunting, fishing, and wildlife viewing have a significant impact on the economies of New York State. More than 4.6 million state residents and nonresidents fish, hunt, or watch wildlife in the state (USFWS, 2006), spending $3.5 billion annually on items such as equipment, trip-related expenditures, licenses, contributions, land ownership, and leasing and other items. The 2007 New York State Freshwater Angler Survey (www.dec.ny.gov/outdoor/56020.html) indicated that there were more than 7 million visitor-days fishing for warmwater game fish (predominantly smallmouth and largemouth bass, walleye, and yellow perch) and nearly 6 million days spent in pursuit of coldwater game fish (predominantly brook, brown, and rainbow trout). About 20 percent of the freshwater angling effort was directed toward Great Lakes fisheries, with the remainder directed toward inland fisheries.

Winter recreation is another major component of the economic value of the state's natural ecosystems. New York has more ski areas than any other state in the nation. Lake Placid in the Adirondacks is known internationally as a former winter Olympics site. Combined, the state's ski areas host an average of 4 million visitors each year, contributing $1 billion to the state's economy and employing 10,000 people (Scott et al., 2008). New York is also part of a six-state network of snowmobile trails that totals 40,500 miles and contributes $3 billion each year to the Northeast regional economy.

The local economies of the Adirondacks, Catskills, Finger Lakes, coastal, and other recreation areas are dominated by tourism and recreation. The Northeast State Foresters Association, using U.S. Forest Service statistics for 2005, found that forest-based recreation and tourism provided employment for ~57,000 people and generated a payroll of $300 million in the region (NEFA, 2007).

Timber and Forest-based Manufacturing

In 2005, the estimated value of timber harvested in the state exceeded $300 million (NEFA, 2007). The manufactured conversion of these raw timber components into wood products such as commercial-grade lumber, paper, and finished wood products adds considerably to the value of this industry to the state. The total forest-based manufacturing value of shipments in 2005 was $6.9 billion (NEFA, 2007). Each 1,000 acres of forestland in New York supports three forest-based manufacturing, forestry, and logging jobs. This industry is particularly important to the regional economies of areas like the Adirondacks, where wood- and paper-product companies employ about 10,000 local residents (Jenkins, 2010).

Maple Syrup Industry

Sugar and red maple are New York's most abundant forest tree species and, historically, the state's climate has been conducive to profitable maple syrup production. It is estimated that less than 1 percent of New York's maple trees are currently used for maple syrup production (compared to about 2 percent in Vermont) (personal communication, Michael Farrell, Director, Uihlein Forest). In 2007, New York produced 224,000 gallons of syrup (making New York second in the United States, after Vermont) at a value of $7.5 million (New York State Agriculture Statistics Service, www.nass.usda.gov/ny).

6.2 Climate Hazards

Several climate change factors that are particularly relevant to New York's ecosystems are highlighted and briefly introduced below. These factors are discussed in more detail in section 6.3 and in the case study analyses. See Chapter 1, "Climate Risks," for further information about climate change factors.

6.2.1 Temperature

Increased temperatures will have numerous effects on both plants and animals. Some effects are very direct, like the physiological tolerances of different organisms to specific temperature ranges. Some are indirect, such as increased water requirements at higher temperatures or changes in habitats due to less snow and ice cover.

Warmer Summer Temperatures and Longer Growing Seasons

Warmer summer temperatures and longer growing seasons will affect plant and animal species non-uniformly, and thus will affect species composition and interactions. Primary productivity of some ecosystems could potentially increase if other environmental factors do not limit plant growth. Changes in ecosystem processes are expected, such as the timing and magnitude of the depletion of soil water and nutrients by vegetation. Some insect pests and insect disease vectors will benefit in multiple ways, such as more generations per season and increased over-winter survival, and weaker resistance of stressed host plants (Rodenhouse et al., 2009).

In aquatic systems, warmer waters and a longer summer season could increase vegetative productivity, but also increase the risk of algal blooms and other forms of eutrophication, leading to low dissolved oxygen (Poff et al., 2002) and negative effects on fish and other aquatic species. Many aquatic organisms mature more quickly but reach smaller adult sizes at higher temperatures. Rising temperatures are likely to be particularly harmful to coldwater fish, including brook and lake trout, while favoring warmwater species, such as large-mouth bass.

Increased Frequency of Summer Heat Stress

Increased frequency of summer heat stress will negatively affect many plant and animal species, constraining their habitable range and influencing species interactions. Temperature increases will drive many changes in species composition and ecosystem structure, most notably leading to eventual complete loss or severe degradation of high-elevation spruce and fir, and alpine bog and tundra habitats.

Warmer Winters

Warmer winters will have substantial effects on species composition, as the reproductive success and habitable ranges of many plant, animal, and insect species currently south of New York are now constrained by winter temperatures. Warmer winters will also increase the winter survival and spring populations of some insect, weed, and disease pests that today only marginally overwinter in the New York region. If climate change leads to more variable winter temperatures, perennial plants may be negatively affected. Variable winter temperatures may make them more vulnerable to mid-winter freeze damage (due to de-hardening) or spring frost (due to premature leaf out and bud break). Variable winters could also have negative effects on hibernating animal species, including some threatened and endangered species.

6.2.2 Precipitation

Changes in precipitation can include changes in total annual precipitation, its seasonal distribution, how much of it comes as rain versus snow, and the intensity of individual storms.

Reduced Snow Cover

Reduced snow cover will have numerous cascading effects on species and habitats. Winter survival of many small mammals (e.g., voles) that depend on snow for insulation and protective habitat will be at risk. This could protect some trees and other vegetation from winter damage by these mammals, but it will have negative implications for predators that depend on them as a winter food source (e.g., fox). In contrast, reduced snow cover will favor herbivores such as deer by exposing more winter vegetation for browsing, to the detriment of those plant species preferred by the herbivores. Less snow-cover insulation in winter will affect soil temperatures, with complex effects on soil microbial activity, nutrient retention (Rich, 2008; Groffman et al., 2001), and winter survival of some insects, weed seeds, and pathogens (see section 6.3.4 on pests).

Changes in Rainfall, Evapotranspiration, and Hydrology

Changes in rainfall, evapotranspiration, and hydrology are described in detail in Chapter 1 ("Climate Risks") and Chapter 4 ("Water Resources") and in Case Study C: Drought in Chapter 7 ("Agriculture"). Increased frequency of high rainfall events and associated short-term flooding is currently an issue and is projected to continue. This leads to increased runoff from agricultural and urban landscapes into waterways, which can lead to pollution or eutrophication effects, erosion and damage to riparian zones, flood damage to plants, and disturbance to aquatic ecosystems. Summer water deficits are projected to become more common by mid- to late-century, and the impacts on ecosystems could include reduced primary productivity (vegetation growth), and reduced food and water availability for terrestrial animals. Summer water deficits could lead to a reduction of total wetland area, reduced hydroperiods of shallow wetlands, conversion of some headwater streams from constant to seasonal flow, reduced summer flow rates in larger rivers and streams, and a drop in the level of many lakes. Late winter and spring will continue to be the seasonal period of peak groundwater recharge and stream flow rates, but the total snowpack accumulation will be lower, so stream and river flows directly associated with spring thaw are likely to decrease. If spring rainfall increases, however, this could compensate for low snowpack. Thus, it is uncertain whether spring flood events will be more or less common than they are today.

6.2.3 Other Climate Factors

The lack of robust projections for some climate factors makes assessment of some vulnerabilities and planning adaptive management for them difficult. (See Chapter 1, "Climate Risks," for further discussion.) Factors of particular concern are discussed here.

Climate Variability and Frequency of Extreme Events

Most climate scenarios assume no change in climate variability per se, but there is not a high degree of certainty that this will be the case. Changes in winter temperature variability could have profound effects on hibernating animals and on the risk of cold damage to plants. The frequency of crossing environmental thresholds (e.g., freezing temperatures) and storms and extreme events can cause a cascade of effects leading to disruption of entire communities and ecosystem function (Fagre et al., 2009), particularly if they occur in clusters. We currently are not able to determine whether such events are part of a long-term climate change trend, and climate models cannot yet project these trends reliably.

Changes in Cloud Cover

Current climate models cannot reliably project changes in cloud cover, yet such changes can have profound effects on the surface radiation balance (the net balance of solar radiation and exchanges of thermal radiation between the Earth's surface and the sky), which influences vegetation water use and total photosynthetic production.

Higher Atmospheric Carbon Dioxide Levels

Higher atmospheric carbon dioxide levels can potentially increase growth of many plants, particularly those with the C_3 photosynthetic pathway growing under optimum conditions. The magnitude of the carbon dioxide effect varies widely among species and, even without climate change, could alter species composition in some ecosystems by favoring some species over others. Many fast-growing species, including many invasive plants and aggressive weed species, tend to show greater growth stimulation than slow-growing species and can gain a competitive advantage at high carbon dioxide concentrations (Ziska, 2003). An analysis by Mohan et al. (2007) suggested that in the understory of temperate forest ecosystems some late successional, shade-tolerant species benefit more than shade-intolerant species. In general, when plant growth is constrained by nutrients, high or low temperature stress, or environmental factors, the absolute magnitude of the carbon dioxide benefit is reduced or not apparent (Wolfe, 1995).

6.3 Vulnerabilities and Opportunities

The initial impacts of climate change on species are already apparent, with documented accounts of changes in phenology (i.e., seasonal timing of events like bud-break or flowering) and species range shifts across the Northern Hemisphere (Backlund et al., 2008; Parmesan and Yohe, 2003; Parmesan, 2007). Within the northeastern United States, researchers have documented earlier bloom dates of woody perennials (Wolfe et al., 2005; Primack et al., 2004), earlier spring arrival of migratory birds (Butler, 2003), and other biological and ecological responses discussed in more detail below. Species and ecosystems are responding directly to climate drivers and indirectly to secondary effects, such as changes in timing and abundance of food supply, changes in habitat, and increased pest, disease, and invasive species pressure. Ultimately, biodiversity, net primary productivity, vegetation water use, and biogeochemical cycles could be affected by climate change. To date, however, there is not unequivocal evidence of climate change impacts on ecosystem services such as carbon sequestration or water storage and quality in New York State. The certainty in projecting climate change impacts diminishes as projections are scaled up from individual species and ecosystem structure to ecosystem function and services.

6.3.1 Criteria for Determining Vulnerability of Species, Communities, and Ecosystems

Criteria for determining vulnerability of species, communities, and ecosystems to climate change have been discussed by a number of studies (e.g., Bernardo et al., 2007; Foden et al., 2008; Pörtner and Farrell, 2008; Kellerman et al., 2009). The vulnerability criteria encompassed in the ClimAID analysis include:

- location currently near the southern border of habitable range;
- low tolerance for environmental change or stress;
- specialized habitat requirements;
- specialized food requirements;
- specialized interactions with other species that will be disrupted by climate change;
- poor competitor with species infringing on range;
- susceptibility to new pests or disease infringing on range;
- poor dispersal ability;
- limited genetic diversity; and
- low population levels or current status as an endangered species or species of concern.

Species and Communities Identified as Highly Vulnerable

Species and communities identified as highly vulnerable to climate change projected for New York, as defined by the metrics above, include:

- boreal and spruce- and fir-dominated forests;
- high-elevation alpine tundra communities of the Adirondacks;
- brook trout, Atlantic salmon, and other coldwater fish;
- snow-dependent species such as the snowshoe hare;
- moose;
- some bird species, such as Bicknell's thrush, Baltimore oriole, and rose-breasted grosbeak; and
- amphibians and other wetland species.

Species Likely to Benefit

Species likely to benefit include habitat and food generalists that are currently constrained by cold temperatures, as well as some invasive species. Examples include:

- white-tailed deer;
- warmwater fish species such as bass;
- some bird species such as northern cardinal, robin, and song sparrow;
- invasive insect pests such as the hemlock wooly adelgid; and
- invasive plant species such as kudzu.

See below for a more detailed discussion of each of these.

6.3.2 Forest, Grassland, and Alpine Communities

The distribution of most vegetation types is strongly influenced by the interactions of climatic variation with elevation, latitude, lake effects, topography, etc. Climate change is therefore expected to cause substantial changes in habitable range and plant community structure throughout the state.

Northern Hardwood Forests

Climate change is not expected to cause a net loss of forested land in New York, but slow change in forest composition over this century is expected as the state's forests disassemble and reassemble into new forest types that have combinations of species different than those today (Rock and Spencer, 2001; Iverson and Prasad, 2002; Iverson et al., 2008; Mohan et al., 2009). The extent to which each species can persist or shift its range into more suitable locations will depend on a combination of factors, including competition from other species, rates and distance of seed dispersal, habitat fragmentation affecting seed supply and dispersal, suitability of soils, soil microbial populations (beneficial or pathogenic), tolerance to stress caused by drought or warmer temperatures, and changes in disturbance frequency and duration. Survival and migration (dispersal) may also be restricted or increased by invasive plants and pests, air pollution, overgrazing by deer, forest fire suppression, and urban sprawl or other land-use change.

Some climate change factors have the potential to increase tree growth. A recent analysis of hardwood forests in Maryland found that growth rates have increased in the past 20 years (McMahon et al., 2010). Rising atmospheric carbon dioxide levels can increase photosynthesis and/or permit more efficient water use during photosynthesis. Whether or not this translates into increased growth depends on availability of soil nutrients, other stressors affecting plant growth, and a plant's genetic capacity to increase growth with increased supply of sugars produced by photosynthesis (Wolfe, 1995; Mohan et al., 2009). A recent study determined that atmospheric nitrogen deposition has important effects on the ability of northern forest tree species to use carbon dioxide (Thomas et al., 2010). Species differ in their responses to carbon dioxide and nitrogen, with the type of mycorrhizal association (symbiosis between roots and certain species of fungi) seeming to affect the response. Studies such as these illustrate the complexity of potential responses to climate change. A recent modeling study for northeastern forests suggested an increase in forest productivity in regions dominated by deciduous hardwoods through the first half of the century, assuming a substantial beneficial effect of the increased atmospheric carbon dioxide and longer growing seasons projected under a lower-emissions climate change scenario (Ollinger et al., 2008). The same was not true for regions dominated by spruce-fir forests, because projected temperature increases significantly constrained their growth and response to increased carbon dioxide.

One study of the likely abundance of tree species across the Northeast indicated that oak forests will have the climatic opportunity to dominate many areas of New York presently occupied by maple and other valuable hardwood species, including black cherry, yellow birch, paper birch, quaking aspen, bigtooth aspen, American beech, and white ash (Iverson et al., 2008). The study's models, which are based on species environmental preferences and a range of future climate scenarios (**Table 6.3**), assumes that as the climate envelope in which species currently exist moves northward, so will the species.

Interactions between species will affect the northward advance of some species as climate changes. For example, while the climate may become more suitable for oak, at the seedling stage they are a favored food for deer, whose populations are also likely to increase with a warming climate. Elevated deer browsing pressure has already been observed to be retarding oak seedling establishment in some areas of New York (Todd Forrest, New York Botanical Garden, personal communication).

For many species the pace of climate change could exceed the pace at which they can disperse and shift to new locations to stay within their optimum climate zone. The pace of climate change projected over the next 100 years (e.g., a 6- to 13°F temperature increase) is an order of magnitude or more faster than the pace of change during recent ice age transitions that occurred over 10,000 to 30,000 years. To remain in the same climate zone throughout the projected change for this century, trees would have to shift their ranges by more than 9,800 to 16,400 feet per year (Petit et al., 2008)—a pace much faster than those documented in the paleobiological record (up to 1,650 feet per year) in response to the relatively slow changes in climate that occurred over the past 10,000 years (Clark et al., 2003). Such complexities could lead to a transition period in this century marked by degraded forests and increased opportunities for invasive species and non-timber species to become established.

Climate change may alter the coordination of timing between tree reproductive events, such as flowering and pollen production, and the availability of pollinators (Mohan, 2009). Further, if extreme storms were to increase in frequency this would have large effects on the activity of pollinators and seed dispersers. These effects are even more likely in the northern part of species' ranges where migratory/dispersal pathways will be most needed (Mehlman, 1997). Reductions in snowpack could also have a marked effect on overwintering pollinators and seed dispersers (Inouye and McGurie, 1991).

A longer growing season and warmer temperatures are likely to increase water use by vegetation and lead to mid- to late-season soil water deficits by mid- to late-century (Hayhoe et al., 2007; also see Case Study C: Drought in Chapter 7, "Agriculture"). In addition, changes in tree species composition of New York's forests will alter biogeochemical cycling through their effects on forest productivity, water and nutrient use, and other factors (Campbell et al., 2009). Direct climate effects and indirect tree species effects on soil biological processes such as decomposition, mineralization, and nitrification (conversion of soil ammonia to nitrite and then to nitrate) are likely to lead to increases in nitrate leaching out of the forests into streams and rivers. Changes in the services that forested ecosystems provide, such as their ability to regulate water resources and retain nitrogen in the soil, could be profound impacts of climate change, although the level of certainty about the timing and magnitude of such effects remains low.

Spruce-fir, Boreal, and Alpine Plant Communities

Among the most vulnerable of New York's ecosystems are the cool-climate boreal communities and red spruce/balsam fir forests of the Adirondacks (Jenkins, 2010) and the Catskills. A recent study projected that balsam fir will lose from 40 to 70 percent of its suitable habitat across New York by the end of this century; red spruce is projected to lose 55 to 64 percent of its suitable habitat (**Table 6.3**; Iverson et al., 2008). Another study indicated that 67 percent of the current Adirondack boreal species are not likely to survive more than a 5°F rise in temperature, based on environments where they are found today (Jenkins, 2010). It also found that of the 246 common Adirondack forest species, only 34 percent are found at temperatures more than 10°F warmer than those in the Adirondacks today (Jenkins, 2010).

The cold-adapted, high-elevation trees and other perennials in New York will be particularly vulnerable to month-to-month variations in winter temperatures, which can cause mid-winter de-hardening or late-winter premature leaf-out, an effect that can increase their susceptibility to cold damage. Winter temperature fluctuations in the eastern United States in 2007 led to increased freeze damage in many woody perennials (Gu et al., 2008). Although this has not yet become a widespread problem and there is not a high degree of certainty that climate change will increase winter temperature variability, freeze damage may occur more frequently if such temperature fluctuations do increase with climate change. Acid rain exposure can also reduce cold hardiness of red spruce trees (Schaberg and DeHayes, 2000).

Black spruce/tamarack swamps, high-elevation open river shores, and peatlands common in the Adirondacks are rare in more southern locations. Ice meadows are a high-northern habitat that are rare in the Adirondacks and are unknown elsewhere at latitudes similar to that of New York. All of these habitats support animal populations that are highly dependent on specific

Species Most Likely to Decrease	Percent (%)
Quaking aspen	-92.3
Black ash	-80.5
Balsam fir	-68.9
American beech	-68.9
Yellow birch	-66.3
Black cherry	-63.4
Sugar maple	-62.9
Red spruce	-61.6
White ash	-57.9
Eastern white pine	-53.2
Species Most Likely to Increase	**Percent (%)**
Eastern red cedar	930.0
Flowering dogwood	759.7
Black walnut	466.2
Black oak	405.6
Sassafras	380.2
Yellow poplar	328.2
White oak	240.9
Chestnut oak	134.5
Post oak	134.5
American elm	59.3

Note: Percentages are based on changes in each species' area-weighted importance value for a high carbon dioxide emission scenario. Area weighted importance values are an index that includes both geographic area and the relative abundance of a species in different areas.
Source: Iverson and Prasad 2002

Table 6.3 Important tree species in New York predicted to show the most dramatic decreases or increases in habitable area with climate change by the end of the century environments and are not likely to be capable of supporting themselves if these climate-maintained habitats disappear.

Vegetation changes are expected to be large in the alpine tundra found at high elevations in the Adirondacks (Walker et al., 2001; Arctic Climate Impact Assessment, 2004). Alpine plants will become rare, and tundra will likely eventually disappear in New York as timberline moves to higher elevations and the mountaintops are taken over by boreal trees. A field experiment of Arctic plant communities, which increased plant-level air temperatures by 1.8–5.4°F, found that within two growing seasons there were significant changes in the plant communities, including increased height and cover of deciduous shrubs and grasses, decreased cover of mosses and lichens, and decreased species diversity (Grime et al., 2008). This suggests that observed increases in shrub cover in many alpine tundra regions in recent years may be attributed to warming.

Grasslands

Soil fertility may play an important role in determining the vulnerability of grasslands to climate change. One study found that plant composition in low-fertility grasslands in England did not change over a 13-year period in which experimental manipulations increased temperature and reduced rainfall (Grime et al., 2008). Long-lived, slow-growing grasses, sedges, and small forbs maintained their dominance, with only minor shifts in the abundance of other species. Only minor species losses occurred in response to drought and winter heating. In montane meadows elevated temperatures have been observed to cause a decrease in forb cover and an increase in woody shrub cover (Harte and Shaw, 1995). The response of more fertile grasslands could be quite different, because they tend to be dominated by more rapidly growing species that are more sensitive to temperature changes. Currently, low temperatures often prevent the few fastest growers from taking over these grasslands. This limitation will be removed by increasing temperatures. Fast-growing invasive species may also find more opportunities to successfully invade fertile grassland communities as temperatures increase, at the expense of native species. The number of invasive species becoming established in open forest-grassland ecosystems has been shown to be directly correlated with the decrease in the number of frost-free days in a year (Walther, 2000).

6.3.3 Aquatic Ecosystems and Wetlands

Diverse aquatic systems extend throughout New York State, providing extensive wildlife habitat as well as critical services for human populations. (See also Chapter 4, "Water Resources," and Chapter 5, "Coastal Zones".)

Rivers and Streams

River and stream systems are abundant in New York and have predominantly perennial flow regimes. With climate change, a larger fraction of small streams could become seasonally dry. Flow regimes are likely to show greater seasonal and temporal variation with a similar likelihood of high, spring-flood conditions and considerably lower low-flow conditions during summer dry spells. Intense mid-summer storms may also contribute to sudden, intermittent flooding, especially near urban areas or natural areas of thin rocky soils where water infiltration rates are low. Large aquifers are primarily recharged during the winter and early spring, and thus their annual recharge is less in jeopardy than shallower and higher-elevation perched groundwater, which will be more sensitive to the length of dry summer conditions.

High variation in flow regime is often associated with reduced diversity of fish and other aquatic species due to intense scouring of the river bottom during high-flow periods, damaging eggs and reproductive activity. It also can lead to low-flow water-quality issues, including high water temperature, low dissolved oxygen, high concentrations of pollutants, and more eutrophic conditions (which reduces dissolved oxygen content, negatively affecting many species). Siltation and scouring during more frequent flood conditions may affect invertebrate populations that are primary foods for fish, birds, and amphibians.

Because New York's river systems are divided into many separate watersheds, few of which have great north-south extent, and many of which are further fragmented by the presence of some 6,000 dams, there are limited options for aquatic species in the state to adapt to rising temperatures via dispersal and range shifts. Sections of low water quality can also severely limit movement of aquatic species up and down stream. Species that are already restricted to headwater regions because these areas tend to be the coolest are most immediately at risk.

Lakes and Ponds

New York has a tremendous diversity of water bodies—both large and small, shallow and deep. In some regions of the state, lake levels may show increased seasonal variation. A recent study of the Lake Champlain watershed (Stager and Thill, 2010) found that peak, springtime levels in Lake Champlain had risen by a foot in the last 30 years due to increases in rainfall. Further increases in peak lake level are projected with increases in rainfall projected for this century, but this may be moderated somewhat by warmer winter temperatures, less snow pack, and lower water volume in spring thaw events. Many lakes will show major alterations in their patterns of temperature stratification (sharp temperature boundaries with depth) and seasonal turnover under climate change, features that are essential determinants of lake ecology. Turnover events (periods of great water exchange between surface and deeper volumes of the lake during freeze and thaw periods) bring nutrients up to surface waters, stimulating primary production (e.g., plankton) and affecting the depth of suitable habitat for fish. Fundamental changes in stratification and turnover dynamics may occur due to failure to form surface ice in winter. Warmer waters may further reduce oxygen availability in deeper levels, especially in more eutrophic lakes. While refuge locations of suitable habitat for coldwater fish are likely to continue to be present year-round in the state's deepest lakes, the total number of lakes sustaining suitable habitat for viable populations year-round will be reduced (see Case Study D: Brook Trout, this chapter).

Wetlands

Increased summer evapotranspiration and increasing water deficits projected for mid- to late-century (See Case Study C: Drought, "Agriculture," Chapter 7) are likely to reduce the total extent of wetlands in the state and shorten the hydroperiod of many remaining wetlands. A recent study concluded that seasonal wetlands in the Northeast will be most vulnerable, drying faster and remaining dry longer with warming (Brooks, 2009). Those ephemeral wetlands that are not fed by permanent springs are important amphibian breeding habitat and currently rely on melting snow to fill pools and initiate the breeding season at the end of winter. Reduced snowpack may make this pattern less reliable, but late winter and early spring is also predicted to be a season of increased precipitation with a likelihood of high runoff and river flooding. Ephemeral ponds may still fill, and earlier spring temperatures could allow earlier biological activity, possibly compensating for earlier summer dry-down. It is difficult to predict how reliably these altered dynamics and seasonal cues will affect amphibians and other wetland species (see Section 6.3.4 for more discussion).

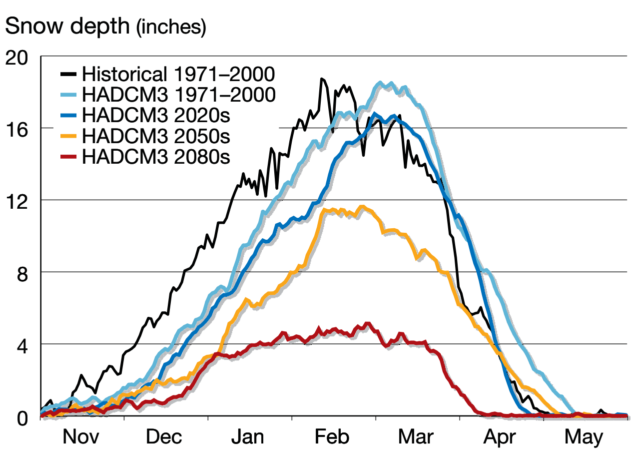
Wetlands supported by reliable groundwater sources will be more buffered from summer droughts than rain-fed wetlands (Poff et al., 2002). Seeps associated with reliable groundwater springs are also buffered from extreme summer temperature fluctuations. Groundwater seeps associated with lower elevation, thick till deposits, or other reservoirs capable of storing large volumes of water may be expected to continue to enjoy full winter-spring recharge and provide such stability. Aquifers perched on relatively shallow impermeable layers or thin till deposits, such as those found in higher-elevation basins in the Adirondacks, are less certain to have the storage volume to cope with longer, hotter summer conditions. They may be more affected by lack of summer recharge, becoming less reliable water sources. In such areas, rain-fed depressions could benefit from high intensity rainfall and associated runoff, even in summer, and may fare better. These dynamics require case-by-case studies to make firm predictions, and are very sensitive to rainfall patterns, which are currently predicted with less certainty than temperature changes.

6.3.4 Fish and Wildlife

In recent decades, climate change has affected the distribution, abundance, and behavior of wildlife species in the Northeast (Rodenhouse, 2009) and throughout the northern hemisphere (Parmesan and Yohe, 2003). Winter-resident species in the Northeast that remain active during winter, as well as species that hibernate, may be particularly vulnerable as winters have been warming more and have been more variable than annual average temperatures (Rodenhouse et al., 2009). Future range shifts will depend on factors such as the inherent capacity of species to migrate and on the availability of dispersal corridors, suitable new habitats, and food resources. Land-use change and habitat fragmentation can present significant barriers to species range shifts and may limit the potential for some species to move northward, particularly those with low dispersal abilities. As a result, the effects of climate change on wildlife may be profound, affecting common species, rare species, and species that provide important ecological services such as pollination and insect control (Inkley et al., 2004).

Mammals

Changes in temperature, water and food availability, and habitat structure will tend to favor habitat and food generalists such as the white-tailed deer (*Odocoileus virginianus*). Generalists are species that forage and browse on numerous kinds of plants, or use a wide range of habitats. It will be important to monitor the response to climate change of species with potential widespread impact on ecosystem structure, such as deer and beaver. Currently, climate plays a role in limiting deer population growth in some regions (e.g., the Adirondacks) where prolonged winter snow cover reduces availability of winter vegetation as a food source. As annual snow cover diminishes during this century (**Figure 6.5**), areas where deer populations currently are kept in check by climate may experience increasing deer populations and less protection for winter vegetation from deer feeding damage. Oaks,



Note: Based on the United Kingdom Meteorological Office Hadley Centre Climate Model version 3 (HadCM3; Pope et al. 2000) using the A2 high emissions scenario. Regional downscaling and calculation of snowpack dynamics was done at Cornell University (Tryhorn and DeGaetano, unpublished). Each line represents an average over a 30-year period. The climate model correctly estimates the amount of maximum snow-cover and the shape of the distribution for the baseline period (observations are shown in black and the model is shown in teal); however, the model distribution is shifted slightly to later in the season. Future projections of snowpack at Wanakena for the 2020s (blue), 2050s (orange) and 2080s (red) are also shown. These projections are broadly consistent with those of other climate models used in ClimAID.

Figure 6.5 Seasonal snow depth at Wanakena (Adirondacks), showing projected changes in snow depth

which otherwise are likely to be favored by warming trends (Iverson et al., 2008), are currently difficult to establish in high-deer areas because their seedlings are a food favored by deer.

In contrast to deer, mammals on the southern edge of their range under the current New York climate or with specialized habitat requirements may not fare well with projected warming. Moose will be particularly vulnerable to climate change, because they are currently at the southern edge of their range in New York and will be adversely affected by the direct effects of warming, as they are cold-adapted and intolerant of summer heat. During hot summer periods, moose reduce food consumption and lose significant body weight. When winter temperatures rise above 23°F their energy requirements increase, demanding increased food consumption to maintain body temperatures (Renecker and Hudson, 1986).

Predicted declines in the extent and duration of snow cover could negatively affect specialized animals like the snowshoe hare and small mammals that can better survive and remain active in winter under insulating snowpack (e.g., voles). Their predators (e.g., mink, weasels, fisher, and bobcat), which rely on subnivean (living in or just under the snowpack) animals for winter food, also may be affected negatively by declines in snow cover. As the extent of snow cover decreases over time, changing host-parasite relationships are likely. For example, moose are well adapted to snow cover, while deer avoid areas with heavy snow cover. As the extent of snow cover declines, moose and deer winter ranges will overlap more than they do today. Deer carry a brain parasite (*Parelaphostrongylus tenuis*) that is harmless to deer, but lethal to moose (Murray et al., 2006). As deer and moose habitats begin to overlap more, this parasite may cause increased mortality in the state's moose populations.

Changes in temperature, soil moisture, and stream flow will alter the quantity and quality of food available to many mammals, primarily by their impact on plant species composition and plant productivity. Warmer, dryer summers may make it difficult for some mammals to put on enough fat reserves to make it through winter hibernation (Rodenhouse et al., 2009). Cumulative precipitation during the period of bat activity (April–October) is strongly associated with annual survival because of its impact on insect abundance (Frick et al., 2010). High precipitation is associated with increased abundance of insects, including culicids (mosquitos), dipterans (flies), and lepidopterans. In addition, while elevated levels of carbon dioxide may increase productivity of some plants (section 6.3.1), they also can reduce the nutritional (protein) quality and digestibility of many plants that herbivores feed on.

Birds

Twenty-seven of 34 Northeast bird species for which range shifts have been documented in recent decades show a northward shift in range (Rodenhouse et al., 2009). These shifts include an assortment of permanent residents, short-distance migrants, and neotropical migrants (e.g., birds from South and Central America, Caribbean islands, and southern Florida). Between 1980 and 2005, the range of many New York bird species extended northward, with the ranges of more northerly species, like the Carolina wren (*Thryothorus ludovicianus*), contracting at the southern edge of their distribution as well (McGowan and Corwin, 2008). These northward shifts occurred across habitats and regardless of food preference. In black-throated blue warbler (*Dendroica caerulescens*) populations, habitat degradation due to climate change has altered nestling survival and growth by altering vegetation structure and the abundance of food and nest predators. For gray jays (*Perisoreus Canadensis*) nesting in high-elevation spruce/fir forests, increased fall temperatures result in the loss of perishable food hoarded for winter. This leads to poor health condition of adults, later breeding, and lowered reproductive success (Waite and Strickland, 2006).

At the Mohonk Preserve, long-term data collection has shown that migratory birds such as the fox sparrow (*Passerella iliaca*), eastern phoebe (*Sayornis phoebe*), eastern towhee (*Pipilo erythrophthalmus*), and whip-poor-will (*Caprimulgus vociferous*) now arrive more than a week earlier than they did in the 1920s (http://www.mohonkpreserve.org). Some birds not found in the Shawangunks in the 1930s have moved north, such as the brown-headed cowbird (*Molothrus ater*), northern cardinal (*Cardinalis cardinalis*), turkey vulture (*Cathartes aura*), black vulture (*Coragyps atratus*), and red-bellied woodpecker (*Melanerpes carolinus*). Others that once migrated are now becoming year-round residents or migrate inconsistently, such as the robin (*Turdus migratorius*), song sparrow (*Melospiza melodia*), chipping sparrow (*Spizella passerine*), white-throated sparrow (*Zonotrichia albicollis*), and northern flicker (*Colaptes auratus*).

In the future, habitat generalists—species able to withstand a wide range of habitat conditions—are likely to flourish at the expense of habitat specialists. Birds like the Bicknell's thrush (*Catharus bicknelli*), which breed only in high-elevation spruce/fir forests, have little opportunity to shift to new locations and are expected to decline in abundance. Notable declines are expected for some of New York's popular northern resident species, such as the black-capped chickadee (*Poecile atricapillus*) and ruffed grouse (*Bonasa umbellus*). Short-distance migrants, such as the Baltimore oriole (*Icterus galbula*), and colorful neotropical migrants, such as the Blackburnian warbler (*Dendroica fusca*) and rose-breasted grosbeak (*Pheucticus ludovicianus*), are also expected to have notable declines (Rodenhouse et al., 2008).

A number of wetland bird species, such as the American bittern (*Botaurus lentiginosus*), common loon (*Gavia immer*), and sora (*Porzana Carolina*), are projected to decline as a result of climate-driven changes, including degradation of inland wetlands (due to summer drought and winter or spring flooding) and loss or degradation of coastal wetlands (due to rising sea levels).

There is evidence that a number of phenological changes have already occurred in bird populations. For example, some populations of American black duck (*Anas rubripes*) have shifted their historical migration patterns farther north and east (Brook et al., 2009). Tree swallows (*Tachycineta bicolor*) are laying eggs nine days earlier than they did in the 1950s in response to increasing spring temperatures (Dunn and Winkler, 1999).

Amphibians

While not all species of amphibians are aquatic and their tolerances vary, all amphibians depend at least on the availability of humid refuges. The projected increased frequency of summer drought and shorter periods that wetlands and seasonal pools hold water (Section 6.3.2) will negatively affect amphibians dependent on these habitats for part or all of their lifecycle. If breeding pools dry earlier, this will increase competition for resources, decrease the size of young when they leave the pool, hamper dispersal from the pool, and strand young that have not yet metamorphosed (Rodenhouse et al., 2009). Decreasing soil moisture may also limit surface activity of terrestrial and stream salamanders, reduce feeding opportunities, and increase competition for refugia.

On the other hand, increased winter and early spring temperatures may lead to increased foraging opportunity for salamanders and other amphibians early in the year, provided that their prey respond similarly and are available earlier. Also, earlier springs associated with climate change could lead to earlier breeding and larger amphibians with competitive advantages. In Ithaca, an analysis of historical records documented that four frog species are initiating spring mating calls an average of 10 to 13 days earlier now than they did in the early 1900s (Gibbs and Breisch, 2001). Earlier breeding will not compensate for possible negative effects associated with drier conditions and loss of aquatic habitat, but it further complicates attempts to project the magnitude of climate change effects on growth and reproductive success of amphibians (Rodenhouse et al., 2009).

Reptiles

The physiology of reptiles is temperature sensitive and could be influenced profoundly by climate change. For example, painted turtles (*Chrysemys picta*) grow larger during warmer years and reach sexual maturity more quickly (Frazer et al., 1993). Therefore, increasing temperatures may result in a higher rate of reproduction. However, for some species (like the painted turtle), the sex ratio of hatchlings is determined by the average July temperature in the nest. A change of as little as 3–4°F could skew the sex ratio in favor of female hatchlings (Janzen, 1994), with very few or possibly no males being produced. In addition, a decrease in the amount of snow cover (which serves as insulation) could lower overwinter survival of turtle hatchlings (Breitenback et al., 1984).

Many species of turtle in the state are already of special concern. Their limited dispersal abilities, combined with relatively small, isolated populations of animals, make them more prone to local extirpations than larger, more widespread populations of animals. Landscape changes that alter or fragment habitats will limit the potential for these animals to move across the landscape in response to environmental stresses such as climate change.

Fisheries

Temperature plays a primary role in governing most life processes in fish (Brett, 1971). The potential for climate change impacts on freshwater fisheries in New York has generally focused on coldwater fish species, which require year-round access to water temperatures below 68°F. The most prominent New York coldwater fisheries target both native (e.g., brook trout, lake trout, Atlantic salmon) and non-native (e.g., brown trout, rainbow trout, and Chinook salmon) trout and salmon. Fish populations in rivers and shallow lakes will experience relatively significant reductions in coldwater refuges with continued warming and, thus, will be particularly vulnerable to climate change. Coldwater fish in many New York streams and shallow lakes currently require coldwater refuges provided by shaded stream banks, upwelling groundwater, and lakes with sufficient depth to stratify (maintain a stable zone of cold water) during summer. Any reduced availability of these refuges during warm summer conditions will reduce the future distribution and abundance of coldwater fish in New York (see Case Study D: Brook Trout, this chapter). Although New York coldwater fish communities in cooler, high-elevation regions of the Adirondacks and Catskills have already suffered population declines due to acid rain, these well-documented impacts—and subsequent 30-year efforts to reduce those losses of coldwater fish—provide a useful foundation to address the negative impacts of climate change on freshwater fisheries

In contrast to the climate warming effects on rivers and shallow lakes, sufficient bottom coldwater regions are likely to be maintained in deep, large lakes (such as the Great Lakes, Finger Lakes, Lake Champlain, and the larger Adirondack lakes) and be able to support breeding populations of coldwater species even after decades of projected warming climate trends. However, other aspects of these large lake habitats will be affected by other stressors, such as eutrophication and changes in water chemistry.

Two native coldwater fish species appear to be particularly susceptible to climate-risk factors: brook trout and round whitefish. Brook trout (*Salvelinus fontinalis*) are popular for recreational fishing and have been designated as New York's state fish. Brook trout have disappeared from many New York waters in response to non-native fish introductions, acid rain, habitat destruction, and hydrological disruption. The thermal preferences and effects of temperature on brook trout and closely related species are well known (Baldwin, 1956; Hokanson et al., 1973; Reis and Perry, 1995; Schofield et al., 1993; Selong et al., 2001). Brook trout populations are particularly vulnerable because this species requires cool water temperatures and relies on upwelling groundwater for reproduction and thermal refuge during hot summers (Curry and Noakes, 1995; Borwick et al., 2006). Brook trout populations have already been greatly reduced in their native range, and changes in thermal regimes are one of the greatest threats to their continued persistence (Hudy et al., 2005). Several studies have provided information regarding the potential impact of temperature increases on stream (Meisner, 1990a; Meisner, 1990b; Wehrly et al., 2007) and lake populations of brook trout (Robinson, 2008). Water temperature changes associated with a warming climate and human modifications to watersheds have been shown to reduce brook trout growth (Reis and Perry, 1995; King et al., 1999), available thermal habitat (Meisner, 1990a), and range (Meisner, 1990b).

Round whitefish (*Prosopium cylindraceum*) is another key coldwater species that could suffer from projected climate changes, though the single largest reason for the disappearance of New York round whitefish populations to date is the presence of non-native species, such as smallmouth bass and yellow perch. If changing climate conditions favor bass and perch by providing more abundant warmwater habitat, round whitefish would be affected indirectly, even without the loss of suitable coldwater refuges.

New York's threatened and endangered species include both southern species that were never widely distributed in the state (e.g., bluebreast darter and mud sunfish) and northern species (e.g., round whitefish and deepwater sculpin) that have been disturbed by habitat changes and introductions of non-native species. The coldwater threatened and endangered species are likely to be susceptible to projected warming trends in climate conditions. In contrast, a few southern species that were historically rare in New York, but remain abundant in suitable southern habitats (e.g., longear sunfish), could increase in distribution in New York if warmer conditions prevail.

6.3.5 Pests, Pathogens, and Invasive Species of Concern

It is likely that New York wildlife and land managers will experience new challenges with insect and disease management as longer growing seasons increase the number of insect generations per year, warmer winters lead to larger spring populations of marginally over-wintering species, and earlier springs lead to earlier arrival of migratory insects. New invasive species (discussed below) will also be an issue as habitat ranges of some pests shift northward. Numerous studies throughout the northern hemisphere have already documented changes in spring arrival and/or geographic range of many insect and animal species due to climate change (Parmesan and Yohe, 2004). Also, those plants and wildlife negatively affected by changes in climate will become more vulnerable to insect pests and disease, which could increase both individual mortality and in some cases promote widespread outbreaks. This is of particular concern with regard to forest stands made up of potentially long-lived individuals, because climate changes are likely to be much faster than adaptive changes in species composition through natural dispersal, competition, and gradual replacement (Dukes et al., 2009).

Climate factors such as warmer temperatures, increased frequency of heavy rainfall events, and wet soils in spring will tend to favor some leaf and root pathogens (Coakley et al., 1999). However, increases in short- to medium-term drought during some summer seasons would tend to decrease the duration of leaf wetness and wet soils and reduce some forms of pathogen attack on leaves and roots, respectively.

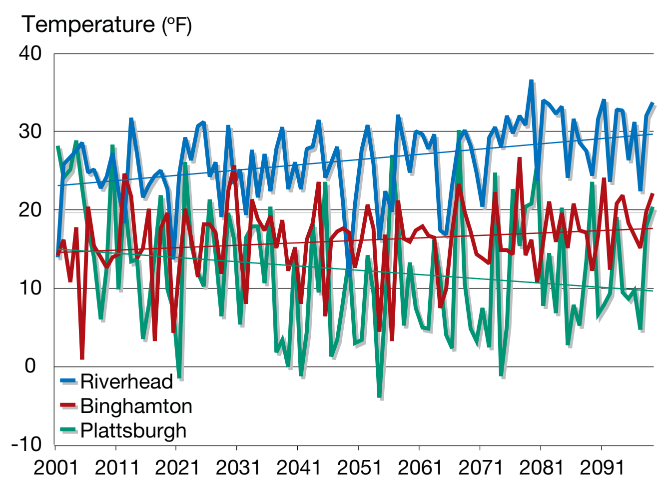
While there is not a high level of certainty regarding projections of humidity and precipitation events, it is possible to make some generalizations for New York: 1) higher winter temperatures are likely to result in larger populations of pathogens surviving the winter that can initially infect plants, 2) increased temperatures are likely to result in the northward expansion of the range of some diseases because of earlier appearance and more generations of pathogens per season, and 3) more frequent and more intense rainfall events will tend to favor some types of pathogens over others and also cause wash-off from leaves of fungicide or other pesticides.

Climate change may have serious implications for diseases affecting wildlife and people. Vector species, such as mosquitoes, ticks, midges, and other biting insects, respond dramatically to small changes in climate, which in turn alters the occurrence of diseases they carry. For example, Lyme disease, erlichiosis, and other tick-borne diseases are spreading as temperatures increase, allowing ticks to move northward and increase in abundance. Epizootic hemorrhagic disease, a viral disease affecting white-tailed deer, spread to New York State in 2007. Epizootic hemorrhagic disease is transmitted by the bites of infected midges, commonly referred to as gnats. During periods of drought, animals congregate around limited water sources where midges occur in greatest numbers, allowing for the rapid spread of the virus (Sleeman et al., 2009). Outbreaks end with the onset of the first hard frost in fall. The combination of drought and delayed first frost allows for the spread of this disease.

Snow Cover Effects on Overwintering

Minimum winter air temperature has often been used to assess the potential overwinter survival of insect pests, weed seeds, and disease pathogens. However, this does not account for possible climate change effects on snow cover, which has an insulating effect on soil temperatures. **Figure 6.6** shows simulations predicting the annual minimum soil temperature at ground level underneath snow for three locations in New York. Currently, these locations vary in the number of their average annual snow cover days (DeGaetano et al., 2001). At Riverhead, the southernmost and least snowy location, temperatures at the soil surface show a projected increase that is similar to that of the air temperature. At the snowier Binghamton location, the increase in soil surface temperature is muted relative to the air temperature, with air temperature increasing more quickly than soil temperature (0.04°F per year for the soil surface versus 0.07°F per year increase in air temperature). The difference in the soil-temperature relationship between Riverhead and Binghamton is presumably a result of the greater impact of the reduction in winter snow cover at the snowier Binghamton relative to less-snowy Riverhead. At Plattsburgh, the northernmost (and snowiest) location, air temperature increases are similar to the other locations, but the ground surface temperature decreases through time at a rate of -0.05°F per year. Thus, winter soil temperatures at Plattsburgh are projected to actually become colder than they are today because the air temperature warming trend is not enough to compensate for the loss of snow cover depth and duration and, thus, the insulating effect of snow cover.

The results of **Figure 6.6** illustrate the complexities of projecting climate change impacts on survival of insects and pathogens overwintering in the soil. For regions of New York that currently have low snow cover, using projections of winter air temperature to project winter survival of insects and pathogens in soil may be reliable. In these locations, overwintering insect populations may increase. However, for historic high-snow regions in which snow cover is projected to decline during the coming decades, winter soil temperatures could remain the same or actually become colder than they are today despite a trend for warming winter air temperatures because of the loss of the snow-cover insulation effect. In locations where soil temperatures decrease, overwintering insect populations may decrease.



Note: These sites differ in current winter snow cover, which affects the response of future soil temperatures to rising air temperatures. Riverhead is the southernmost and least snowy location; Plattsburgh is the northernmost and snowiest location; Binghamton is between the two, both in terms of its location and amount of snow. As snow depth decreases in Plattsburgh, ground-level temperatures are projected to decrease as air temperature increases, because the ground will lose some of the warming effect of the insulating snow cover. National Center for Atmospheric Research, USA (PCM) model simulations for the A1F1 emission scenario. These projections are broadly consistent with those of other climate models used in ClimAID.

Figure 6.6 Minimum annual temperature (°F) at ground level under ambient snow cover for grids near Riverhead (blue), Binghamton (red), and Plattsburgh (green)

Invasive Species

Invasive species are defined as those species that are not currently native to New York's ecosystems and cause harm to the economy, environment, or human health (U.S. Executive Order 13112, 1999; Laws of New York, 2008, Chapter 26). For the analyses reported here, we are primarily concerned with "transformer" invasive species (sensu Richardson et al., 2000)—those species not native to North America that have the capacity to profoundly change the structure and function of ecosystems, as the chestnut blight did in the early 1900s (Gravatt, 1949; Anagnostakis, 1987) and as the emerald ash borer threatens to do now. Furthermore, we suggest that spending significant management effort on native species migrating within the continent in response to climate change may not be a good use of limited resources. Climate change is already resulting, and will continue to result, in the northward range expansion of some native southern species, and efforts to halt the movement of these species would be counterproductive. Strategically directing attention and prevention/ management actions toward those species known to be aggressively invasive elsewhere, and that will increase ecosystem vulnerability to climate change (Crooks, 2002), would be more sensible.

There is some recent evidence regarding the impacts of climate change on invasive species. Predictions that the hemlock wooly adelgid (*Adelges tsugae*), an invasive insect whose range is largely constrained by overwintering temperatures, would spread more rapidly throughout the Northeast with a warming climate (Paradis et al., 2008) have already come to pass in New York's Finger Lakes Region (USDA Forest Service, 2008). Recent work examining the flowering time of native and non-native species over 150 years in Concord, Massachusetts, indicates that non-native plants—particularly invasive species—have adapted better to long-term temperature increases than native plants. Over the last 100 years, invasive plants, on average, are flowering 11 days earlier than native plants. This may confer greater advantage to the invasive species (Willis et al., 2010).

Native communities stressed by climate change and other elements of global change (e.g., land-use change, habitat fragmentation, and nitrogen deposition) may become even more vulnerable to species invasions (Dukes and Mooney, 1999; Shea and Chesson, 2002). Further, invasive species may stand poised to exploit the changing climate via new transport pathways, overcoming previous environmental constraints, expanding ranges, and increasing competitive abilities. Although the specific outcomes of invasive species/climate-change interactions may be difficult to predict, it is certain that the combinations of species composing New York's ecosystems will look and interact differently than they do presently (Williams and Jackson, 2007).

By changing patterns of tourism and commerce, climate change may alter mechanisms of transport and introduction of invasive species (Hellmann et al., 2008). For example, expected air traffic increases and climatic convergence between China and parts of northern Europe and North America may result in increased invasion risk (Tatem, 2009). Loss of Arctic sea ice could open new shipping channels, shorten transport time, and connect new geographic regions via the Northwest Passage (Hellmann et al., 2008). Particularly relevant for New York State, climate change could allow for longer shipping seasons in the Great Lakes and, thus, more opportunities for detrimental species introductions, such as the monkey goby, an invasive fish species (Kolar and Lodge, 2002).

Before a new invasive species can become established and spread, it must first overcome a number of environmental and ecological constraints. Projected warmer winters and hotter summers facing the Northeast in the coming century ("Climate Risks," Chapter 1) will allow invasive species previously unable to persist to overcome temperature constraints. For example, kudzu (*Pueraria montana*), a prevalent invasive plant species in the southeastern United States, may expand its range northward (Wolfe et al., 2008). Additionally, increasing temperatures, precipitation, and humidity may benefit invasive forest pathogens (Dukes et al., 2009). Elevated carbon dioxide concentration, temperature, and precipitation may all contribute to increasing the competitive ability and dominance of some invasive plants over native species (Dukes and Mooney, 1999; Song et al., 2009). Furthermore, climate stress, the loss of species poorly adapted to future climate changes, and altered biotic interactions between species may open new niches and increase a native ecosystem's vulnerability to invasion. Increased incidence of extreme weather events, such as floods and drought, may also create additional windows of opportunity for the establishment and spread of invasive species, many of which are well-adapted to disturbed environments (Hobbs and Mooney, 2005).

The impacts of species currently invading New York's ecosystems will be exacerbated by climate change (Table 6.2). Some invaders, particularly herbivorous insects that have a physiology sensitive to temperature, may increase in abundance and impact within their range as a result of faster development times and longer growing seasons for plant hosts (Dukes et al., 2009). Climate change may also affect the phenology and efficacy of natural enemies to invasive species (e.g., parasites) and introduced biological control agents, with the potential to indirectly benefit invasive species (Burnett, 1949; Dukes et al., 2009). Increased water temperatures could result in earlier and longer growing seasons for aquatic invaders like Eurasian watermilfoil (*Myriophyllum spicatum*) and zebra mussels (*Dreissena polymorpha*), which in turn would require more frequent (and costly) implementation of control actions (Rahel and Olden, 2008). Additionally, there is some evidence to suggest that climate change may lead to increased per capita impact of invasive species. For example, one study observed that Japanese beetles (*Popillia japonica*) increased their feeding on soybean plants grown under elevated carbon dioxide concentrations, because plant leaves had increased sugar levels that served as a feeding stimulant (Hamilton et al., 2005). Undoubtedly, the impacts of invasive species under climate change will interact, perhaps synergistically, with other elements of global change in unpredictable ways. Thus, it is important to keep in mind that there remains very high uncertainty in the ability to predict what, how, and where new species will invade and existing invaders will spread.

6.3.6 Effects on Natural Resource Use and Human Communities

Climate change will also make products and activities based on natural resources, such as timber, maple syrup, and winter recreation, more vulnerable.

Timber Industry

Those managing forests for timber harvest will be faced with new challenges as climate change favors the competitive ability of some tree species over others and as range shifts occur in potential insect, disease, and invasive plant pests. Foraging and selective feeding by increasing deer populations will remain a problem and could become exacerbated by climate change. Some hardwoods currently grown in the region will not be suited to the new climate emerging this century (**Table 6.3**) (Iverson et al., 2008). However, there will be considerable variability among hardwoods. A modeling effort discussed previously (Section 6.3.1) suggests that longer growing seasons and increasing atmospheric carbon dioxide concentrations could increase productivity and growth rates of some hardwoods (Ollinger et al., 2008), while spruce and fir would not benefit because of their sensitivity to projected high temperatures.

Maple Syrup Industry

Although one study projected that the distribution of sugar maple will largely shift out of New York and into Canada during this century (Iverson et al., 2008), trees managed for sugar production are protected from competition, much as are agricultural crops, and are likely to remain part of the New York landscape. The majority of sugar maple in unmanaged forests could have a different future.

Maple sap flow requires days with alternating freezing and thawing. Currently the period with the greatest likelihood of such days is mid-March to early April, but this period is gradually shifting to occur earlier in the year. One study of sap production in four northeastern states, including New York, shows that as average winter temperature increases, sap production decreases (Rock and Spencer, 2001). Another study, which examined 40 years of weather records, found significant increases in potential sap-flow days for three Quebec stations and non-significant trends in the same direction for other Canadian stations, two sites in Vermont, and one site at Watertown, New York (Maclver et al., 2006). A study that compiled sap production records for the past 30 years in four northeastern states, including New York, found a trend for fewer sap-flow days, because the end of sap-flow has advanced by more days (come earlier in the year) than the onset of sap-flow (Perkins, personal communication). This study projects adverse impacts from climate warming on sap production should these trends continue. A study that drew on similar evidence concluded that climate warming is already contributing to a northward shift in maple sugar production (Frumhoff et al., 2007). A more recent analysis considering all these factors suggests that impacts of climate change on sap production in New York will vary greatly by region (Skinner et al., 2010), but that the industry should remain strong in many parts of New

York State through the end of this century and beyond. For a more detailed analysis, see Case Study C: Maple Syrup Industry, this chapter.

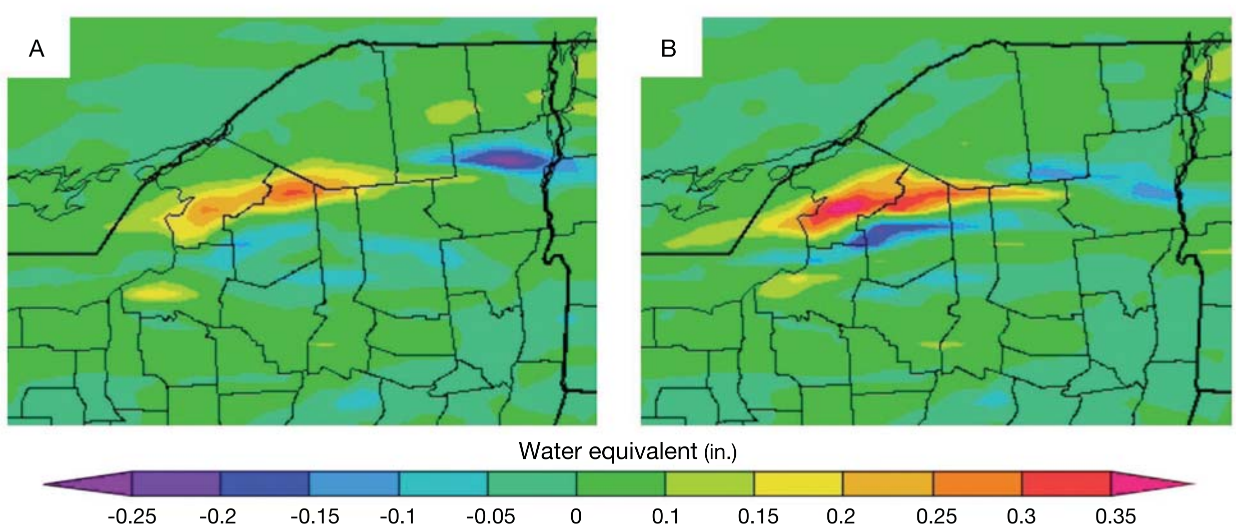
Winter Recreation and Lake-Effect Snows

The ski industry in New York will be vulnerable to climate change and the reductions in snow cover projected for the region. Increasing the use of artificial snowmaking is an adaptation that already is being used by the industry. However, a recent analysis concluded that the number of ski resorts that could continue to maintain a reasonable profit margin using this strategy will diminish to only those located at the highest elevations by end of century as snowfalls and snow cover duration continue to decline (Scott et al., 2008). Snowmaking may provide a sufficient number of years of buffer for some resorts to diversify and survive, such as by developing alternative winter activities and expanding summer recreation offerings. Even with adaptation, certain communities and individual operations that rely on ski tourism are likely to suffer. Those communities with economies linked with snowmobiling recreation will be particularly vulnerable because of their inability to compensate by making snow.

Although reductions in snow cover have already been occurring and are expected to continue for much of the state, the analysis is more complex for those regions subject to lake-effect snows. In the near term, warming lake temperatures and decreased ice cover will increase air humidity above the lakes, with the potential to cause increases in lake-effect snow during cold events that trigger snowfall, and this is consistent with observed increases in lake-effect snow in the recent years (Burnett et al., 2003). **Figure 6.7** presents a new analysis that illustrates how increasing lake temperatures above those recorded during a recent historical Lake Ontario snow event (November 9, 2008) would increase water-equivalent precipitation from the event by as much as 0.35 inches. The modeling study projected that this phenomenon of increased lake-effect snow with climate change would continue in the short term; by the end of this century, however, lake-effect snows are expected to decline by 50 to 90 percent, becoming lake-effect rain events as winter air temperatures become too warm to trigger snow (Kunkel et al., 2002).

6.4 Adaptation Strategies

New York ecosystems have adapted to climate change in the past, but the pace of change projected for this century is faster by several orders of magnitude than that of the most recent ice age transition and other historical events in the paleobiological record. There is a lack of reliable information and consensus regarding the future resilience and capacity of ecosystems to maintain



Note: Areas of increased and decreased lake effect snow are color coded showing inches of water equivalent. A) Weather conditions of wind and temperature gradients identical to an historic event recorded Nov. 9, 2008, but with lake and air temperatures uniformly increased by 1.8°F. B) The same conditions as A, but lake temperatures (not air) increased an additional 1.8°F (3.6°F total). Areas of red color show increases in lake-effect snow. These increase with further warming of water temperatures (B). (Weather Research and Forecasting model)

Figure 6.7 Simulations of the effects of climate change on lake-effect snow, in inches of water equivalent[1] function through the replacement of lost species with new species that serve similar functions or by redundancy of function among species currently present.

The capacity of resource managers to facilitate ecosystem adaptation to rapid climate change is uncertain. A concern is that, to date, prior to the confounding effects of climate change, we have had only limited success with management interventions attempting to control species declines or invasions or undesirable damage by individual species. Many potential management interventions for coping with climate change exist, but most of these have not been tested on a wide scale and some are controversial even among experts in the field. The adaptation strategies proposed below are generally supported in the science literature and among the experts consulted for this study, but some may be considered too expensive or not cost-effective by policy-makers, unless better and more persuasive methods for documenting the value of ecosystems can be developed.

A few fundamentals for building the adaptive capacity of communities and ecosystems have emerged in this analysis:

- Maintain healthy communities and ecosystems more tolerant or better able to adapt to climate change by minimizing other biotic (e.g., insect infestations) and abiotic (e.g., acid rain, nitrogen deposition, drought) stressors.
- Manage primarily for ecosystem function and biodiversity rather than attempting to maintain indefinitely the current mix and relative abundance of species present today.
- Facilitate natural adaptation to climate change by improving connectivity among habitats to allow species dispersal, migration, and range shifts.

Below, we first describe adaptation options for specific habitats (Sections 6.4.1 to 6.4.4), followed by adaptations that would be implemented at the institutional or agency level (Section 6.4.5).

6.4.1 Forest, Grassland, and Alpine Communities

A recent review suggests that, in the context of climate change in the Northeast, it will be preferable to focus on future desired ecosystem function rather than aiming for specific species mixes (Evans and Perschel, 2009). Management strategies might, therefore, emphasize maintaining a diverse suite of species with some redundancy in function to hedge against loss of individual species. Diversity in species and tree age distribution will also help buffer against losses due to biotic or abiotic disturbance. Thinning and planting of trees can be designed to reduce the dominance and dependence of ecosystem function on tree species that are most vulnerable. However, the majority of older, intact forests should be maintained and allowed to evolve in their own way because of their ability to resist invasive species. Goals might include retaining selected legacy trees with heritage value, or habitats that can provide a seed source or refuge for plant and animal communities that are underrepresented in the landscape and are under stress due to climate change.

A key to adaptation is maintaining healthy tree stands, and from this standpoint many “best management practices” already suggested will be beneficial. This includes emphasis on low-impact harvest techniques, such as minimizing soil compaction (e.g., harvest when soils are relatively dry or frozen), and directional felling and careful removal of harvested trees. Biological or chemical control may be warranted in some cases for rapid-response containment of pests, disease, or invasive species, particularly for protection of unique habitats or species with irreplaceable function. Intervention solutions in alpine systems, however, will likely be problematic because of the multitude of sensitive and unique species.

6.4.2 Aquatic Ecosystems and Wetlands

Adaptation options exist for aquatic ecosystems and wetlands and include restoring and expanding riparian buffer zones, improving habitat connectivity, restoring legal protection, limiting water withdrawls, limiting invasives, and minimizing eutrophication.

Restoration and Expansion of Riparian Buffer Zones

Riparian (streamside) zones provide natural corridors for dispersal and migration of terrestrial and aquatic species and thus are vital to species shifting range in response to climate change. Other co-benefits of riparian zones include providing a unique and valuable terrestrial habitat, moderating flood and erosion damage, contributing to the energy and food web of adjacent aquatic communities, and shading streams and pools and thus providing cool-water refuges for coldwater fish in summer. The goals should be both to protect currently intact riparian zones and to restore those that have been degraded wherever practical. Options to accomplish this could include support of local governments with model ordinances, education and outreach, and support of voluntary conservation easement efforts. The New York State Open Space Conservation plan recommends a 100–300 foot (or more) zone around all streams that is free from physical development or high-impact activities, such as forestry, farming, or animal husbandry (www.dec.ny.gov/lands/47990.html).

Improve Habitat Connectivity by Removing Dams, Replacing Culverts

Dams and culverts (pipe-like constructions passing under roads) fragment habitats and limit dispersal potential for both animals and plants, which may make it difficult for them to shift their ranges in response to climate change. Programs at the federal and State level to develop inventories of abandoned and derelict obstructing dams that are barriers to fish and wildlife could be further developed. It would be beneficial to remove dams that are no longer necessary. Most culverts were not designed with consideration of their effects on aquatic and terrestrial species. Many are too long, some do not carry water year-round, and some are set at an elevation the wildlife and fish cannot access (L. Zicari, U.S. Fish and Wildlife Service, personal communication). For high-priority regions or species affected by climate change, redesign and replacement of these culverts to minimize barriers to aquatic and terrestrial species will be an important approach to building ecosystem adaptation capacity.

Restore Legal Protection to Isolated Wetlands

The New York State Department of Environmental Conservation protects wetlands larger than 12.4 acres, but this does not cover many small isolated wetlands, particularly fens and vernal pools that support a disproportionate amount of biological diversity relative to their total acreage (Comer et al., 2006). As a result of their scattered distribution across the landscape, these smaller wetlands also provide connectivity for the dispersal of many wetland species. These isolated wetlands need protection, as called for in the New York State Open Space Conservation Plan of 2009.

Limit Water Withdrawals that Affect Wetlands

Many wetland systems may be negatively affected by increased agricultural water use as summer soil water deficits intensify with climate change (see "Agriculture," Chapter 7, Case Study C: Drought). Land-use change and groundwater depletion by rural populations may also adversely affect many wetlands. A current high priority is to develop an inventory of wetlands and their landscape position in relation to hydrology and current and projected land and water use.

Limit Transport of Aquatic Invasive Species

Given that climate change is likely to increase the number of invasive species that will be able to survive and spread throughout New York's waters, limiting the transport of invasive species via infested boats and angling gear and from bait and aquarium releases will be increasingly important. A number of boat launch steward programs are currently in place in the Adirondacks (Adirondack Park Invasive Plant Program, personal communication); similar programs should be considered statewide. Regulatory approaches, such as enforceable aquatic invasive species transport laws, may be warranted.

Minimize Eutrophication

The impact of climate change on pollutant and nutrient loads to New York waterways is uncertain (see "Water Resources," Chapter 4). While increase in pollutant-laden runoff is possible in winter and early spring, algal growth response will be constrained by low temperatures during this time of the year. Of more concern might be diminished low-flows in late summer that lower dilution potential, increase summer water temperatures, and reduce dissolved oxygen. The State Pollutant Discharge Elimination System permitting processes and guidelines for combined sewer overflow releases may need to be revised in recognition of lower dilution potential in summer and fall. Excluding cattle from riparian zones can sometimes be more effective than more costly manure-management options (Easton et al., 2008).

6.4.3 Fish and Wildlife

Adaptation options for fish and wildlife include management of core habitat and connecting corridors, hunting seasons and bag limits, wildlife disease surveillance, conservation priorities, and coldwater refuges.

Core Habitat and Connecting Corridors

Range shifts of wildlife will depend, in large part, on the availability of dispersal or migration corridors (e.g., connected habitats, riparian zones), suitable habitats, and the concurrent movement of forage and prey. Minimizing landscape changes that result in habitat fragmentation and barriers to species range shifts will be key to helping New York State's wildlife adapt to climate change. A strategy for facilitating wildlife adaptations to climate change includes closely coordinated landscape- and regional-level approaches, complemented by on-the-ground management and conservation efforts carried out on a variety of scales. Conserving or creating newly connected, contiguous habitats from north to south, and ensuring connection of east-west gradients as well, can assist movement of habitats and wildlife by providing northward migration corridors (Inkley et al., 2004). Corridors could focus on connecting key diversity hotspots for specific taxa between regions (e.g., Pennsylvania and New York, New York and Canada), as identified from sources such as Gap Analysis Program data and USDA Forest Service Highlands Project data. Examples of local and regional projects that could serve as templates include the Wildlife Habitat Connectivity in the Hudson River Valley (a joint project of the New York Natural Heritage Program and the Hudson River Estuary Biodiversity Program) and the Finger Lakes Land Trust's Emerald Necklace Project, a proposed greenbelt that could link 50,000 acres of protected open space in and around Ithaca.

Hunting Seasons and Bag Limits

A changing climate is likely to affect the state's popular game species. Resulting changes could include earlier breeding seasons, earlier migration, and/or altered migration pathways and changes in habitat suitability and productivity. If the timing and/or pattern of seasonal movements or breeding changes, maintaining hunting seasons during their historical time period could mean that harvest levels are either over- or underachieved. Adaptations to such changes include increased flexibility in setting hunting seasons and bag limits, combined with a monitoring program designed to detect relevant population changes and inform decision-making.

Climate change may increase the impact of game species on the landscape. Increasing deer populations and damage from deer are likely to be exacerbated by reduced snow cover exposing more winter vegetation for browsing (Section 6.3.3). Promoting increased harvest of this species is one adaptive approach to better control. Conversely, stressed populations of other species, such as waterfowl and ruffed grouse, may need temporary protection from harvest until populations recover. Hunting seasons may change to correspond with changing migration dates.

Wildlife Disease Surveillance and Monitoring

With warmer fall temperatures and later fall frosts, diseases vectored by biting insects and ticks will likely be of greater importance. For example, epizootic hemorrhagic disease is spread between white-tailed deer by biting midges. The disease may have locally severe impacts on deer herds. Other diseases that affect species in southern states may spread northward with warmer and milder winters. Enhanced surveillance can help identify and reduce impacts of disease hotspots. A monitoring network at the state and regional levels can provide an early warning system in years with potentially severe outbreaks.

Prioritizing Conservation Efforts

While a focus on preserving ecosystem function may be the most cost-effective adaptation strategy in many cases, some individual species may deserve special attention, such as "responsibility species"—species that have their core populations in New York or species for which a significant proportion of the world's breeding population is found in New York. This might include common species such as the scarlet tanager or rare species such as the Chittenango ovate amber snail, a species whose entire global population can be found within the state. New York also supports species on the northern edge of their current distribution, including animals such as the long-tailed salamander and the bog turtle. Currently, New York is in the early planning stages for identifying and managing species of responsibility. Such priorities may be reflected in the future in the State's list of Species of Greatest Conservation Need.

Fisheries

An overall adaptation strategy for sustaining the survival, growth, and abundance of coldwater fisheries is to maintain the provision of coldwater refuges during seasonal periods in which warm water temperatures prevail throughout lakes and flowing water ecosystems. Maintaining well-vegetated, canopied riparian zones and lake shorelines is one approach to meeting this objective. Maintaining flow of relatively cold groundwater inputs to waterways and lakes is another strategy. This would require landscape management practices that minimize disturbance to surface vegetation, soils, and hydrological flow paths. A more complex and expensive approach would be to artificially increase cold groundwater flow by piping cold water from higher elevation water sources to lower elevation lakes or stream shorelines where coldwater fish populations require augmented cold thermal refuges in order to survive. For example, Cornell University fisheries biologists have developed such water sources to enhance groundwater upwelling required for brook trout reproduction; brook trout have been observed during warm summer periods at these locations of cool groundwater inputs.

An additional general adaptation strategy for sustaining the survival, growth, and abundance of coldwater fisheries is to manage specific competing fish populations at lower densities so that available food resources can sustain the target population size. For example, Cornell University fisheries biologists have observed that a smaller population of self-sustaining brook trout exhibited greater growth, survival, and reproduction than a larger population in the same thermally stressed Adirondack lake during a series of recent warm summers. The larger brook trout population was the result of stocking fish in a lake which already had a substantial self-sustaining population of brook trout. Greater population abundance reduced the relative amount of available forage for each fish in the population, leading to reduced growth during stressful warm summer conditions. Reduced growth can also result in reproductive failure during the subsequent spawning season.

6.4.4 Invasive Species

Changing conditions associated with climate change are likely to allow some invasive species to overcome environmental and ecological constraints that previously prevented their establishment in New York's ecosystems. For transformer species (i.e., those invasive species that may fundamentally change the structure and function of ecosystems), in particular, increased vigilance will be necessary for successful early detection and rapid management response. Current invasive species monitoring (from the large-scale USDA-sponsored Cooperative Agricultural Pest Survey to small community-based programs) and mapping efforts (e.g., iMapInvasives; see Case Study B: Creative Approaches to Monitoring and Adaptive Management) must consider the consequences of climate change on species invasion (see **Table 6.2**) and may need to adapt monitoring protocols and mapping tools accordingly. Further, these programs should be coordinated and integrated with other state and regional biological monitoring programs to provide natural resource managers and policy-makers with necessary high-quality, comprehensive information for decision-making. The eight Partnerships for Regional Invasive Species Management (PRISMs) may provide a useful infrastructure for implementing climate-related monitoring, education, outreach, and citizen science programs (see Case Study B: Creative Approaches to Monitoring and Adaptive Management).

Climate change will necessitate an adaptive-management approach, where management actions are paired with data collection and subsequent evaluation and learning, particularly with respect to the management of invasive species. Current control practices used to contain invasive species populations may lose effectiveness under the future climate change scenario. For example, the efficacy of some herbicides used to treat terrestrial invasive plants may decline if plants experience increased herbicide tolerance with increasing atmospheric carbon dioxide concentrations (Ziska et al., 1999). Particularly in aquatic ecosystems, increased temperatures may necessitate more costly and aggressive control tactics for invasive species. Manually removing locally distributed invasive aquatic plants that were previously limited by ice cover may no longer be sufficient to control populations if climate change enables these plants to survive the winters (Hellmann et al., 2008). Furthermore, the effectiveness of biological control agents may decline with climate change, particularly if there is a mismatch in climate tolerances between the control agent and the target invader (Hellmann et al., 2008). This scenario could be played out in the Finger Lakes region, where researchers are in the process of establishing a population of *Laricobius nigrinus* beetles, derived from a cold-tolerant population in Idaho, to control the recently detected hemlock woolly adelgid (*Adelges tsugae*). Increasing temperatures may alter the phenology and interaction of these species, potentially resulting in reduced adelgid control.

Prevention of species introductions, in some cases by regulation, is the most cost-effective invasive species management tool (Wittenberg and Cock, 2001). To date, prevention efforts have consisted largely of the following: monitoring the pathways on which invasive species are introduced (particularly those related to transportation, e.g., container and ballast water inspections); species risk assessments prior to importation of goods and merchandise (Gordon et al., 2008); and regulatory actions (e.g., quarantines and New York State's firewood movement regulation, which restricts transporting firewood from areas with known infestations of pests like the emerald ash borer or Asian long-horned beetle). With climate change and accompanying altered mechanisms of transport and species introduction, prevention efforts (particularly risk assessments and regulatory species lists) must be expanded to include a growing pool of potential invasive species.

6.4.5 Larger-scale Adaptations

In addition to strategies that can be implemented at an organization or agency level, some adaptation strategies should be considered at a state or region-wide scale. These larger-scale adaptation options are discussed here.

Institutionalize a Comprehensive and Long-term Monitoring and Data Dissemination Program

This will involve monitoring from the scale of individual species (e.g., movement of invasives) to monitoring indicators of ecosystem function vulnerable to climate change. Data management and dissemination would be centralized, perhaps within a government agency or other institution, but to be effective the design and implementation would require collaboration among multiple agencies, scientists, resource managers, and individual stakeholders and citizen scientists. Components and activities of this program could include:

- gathering and organizing baseline data, including collecting existing datasets, identifying information gaps, gathering economic and other data for valuation of ecosystem services, and securing funding to fill gaps;
- identifying and prioritizing indicators to monitor specific goals;
- improving and coordinating monitoring efforts, including training for citizen scientists;
- creating a task force of scientists to synthesize data and to produce reports and maps on a regular basis;
- centralizing data management, data quality control, and user-friendly data dissemination; and
- actively engaging with resource managers and policy-makers to continually refine the research agenda and improve access to meaningful data for decision-makers.

Develop Prioritization Criteria

These would be used to identify those species, populations, habitats, and ecosystems requiring concerted monitoring, adaptive management, or protection. Criteria might be based on the following:

- vulnerability assessment results
- high level of certainty of climate change impacts and/or near-term impacts
- economic valuation
- maintenance of biodiversity
- provision of ecosystem services (e.g., water supply and quality)
- habitat importance as a dispersal corridor
- habitat importance for one or more endangered or species of concern

Develop Adaptive Management Plans and Improve Adaptive Capacity of Land Managers

This would rely on the input from the monitoring and prioritization activities described above in the two prior recommendations. Specific components could include:

- incorporating up-to-date climate change information into all government planning activities

(as opposed to using out-dated historical climate data);
- developing rapid response plans for emerging challenges (e.g., for control of new invasive species);
- improving data sharing and other networking with other states and agencies;
- improving adaptive capacity of land managers through development of new decision tools and training and education; and
- developing policies to facilitate interventions by resource managers.

Develop Better Regulation and Incentive Programs

These should be created as needed for specific purposes, such as incentive programs to encourage private landowners to maintain key habitats and new regulations to control the transport of invasive species into New York ecosystems.

Expand Educational Outreach and Citizen Science Programs

Educational outreach to private landowners should be a high priority to raise their awareness of the issues and their critical role in minimizing negative impacts of climate change on New York biodiversity, habitat integrity, and maintenance of important ecosystem services. All sectors of society will benefit from sound information on climate change, its potential impacts on natural areas, its implications for ecosystem services affecting human communities, and what they can do to participate in adaptation and mitigation.

6.5 Equity and Environmental Justice Considerations

Climate change will modify the character and quantity of ecosystem services, creating both direct and indirect vulnerabilities and new distributions of winners and losers. The most immediate impacts will be felt by those who draw directly on ecosystem services for well-being, subsistence, and income. Some communities are deeply dependent on one particular type of resource, such as fisheries, and will be uniquely challenged by its increased scarcity or its degraded quality. In other cases, a change in ecosystem services will be felt as an indirect property loss. For example, one study used hedonic modeling (an economics method that estimates value by breaking an item into its constituent parts) to demonstrate the significant impact that forest disturbances can have on residential property values (Huggett et al., 2008).

Changes in the character and quantity of ecosystem services will expose differences in the ability of people and communities to anticipate these changes and to adapt. Those land owners and local managers with the resources to invest in the upkeep of amenity and ecosystem services on local private and public property will be able to take advantage of these changes and maintain the value of their resources to the extent possible. In some cases, climate change will change the basis by which entire landscapes are valued, which could put pressure on alternative development strategies or create emergent contexts for new ones, each with differential outcomes and inherent equity issues. Within urban areas, equity issues also emerge with respect to creation and preservation of open space and access to environmental amenities such as water bodies. Some examples from a few industries—forestry, winter recreation, and maple syrup production—illustrate these issues.

6.5.1 Forests, Parkland, and Urban Ecosystems

Whether forests are valued as an inherent aesthetic whole or as a select portfolio of constitutive economic services (e.g., timber products) has bearing on how ecosystem change can and will be managed and which users will be affected. Changes in forest ecosystems may devalue the existing natural resources and amenities, potentially driving regional deforestation and commercial development. Changes may also exacerbate existing fragilities. Around the Adirondacks, for example, managing a patchwork of public and private land amid a transition from natural resource extraction to tourist economies is already a challenge for park managers, land managers, and local communities (Hubacek, 2002). As climate change affects the physical composition of the forests and the regional tourist industry, it may increase tensions over the rights to development. It may also cause increasing burdens on those private property owners who are forced to internalize the regional economic impacts of climate change because of regulatory constraints on their development options. Currently, perceived inequities in conservation interventions and regulations are latent concerns (Michaels et al., 1999).

Within urban settings, ecosystems services associated with forests, parklands, and wetlands play a vital role but are frequently contested (Gandy, 2002). For example, a frequent source of dispute in New York City and in other cities is the inequitable distribution of urban forests and lack of access to open space for health and well-being. Several communities in New York City have been strong advocates of preserving and restoring wetlands for the various ecosystem services they provide. For example, on the North Shore of Staten Island, community leaders have fought to conserve Arlington Marsh from a variety of threats and development pressures. Research suggests some of the best-maintained urban forests tend to be in the more wealthy areas (Heynen et al., 2006). Under climate change scenarios, park vegetation will potentially require more water, fertilizer, and pesticides. The increased costs of maintenance could exacerbate differences in quality of park vegetation and urban forests between wealthy and non-wealthy areas. Which urban parks and forests should be maintained in light of the impacts of climate change, and who is serviced by the park system, are questions that will become ever more important under the fiscal constraints of a budget impacted by climate change.

6.5.2 Winter Recreation, Resource Dependency, and Equity

In a review of the ski industry's vulnerability, one study notes that the ski operations that are smaller and less well capitalized or more southerly and at lower altitude may have more difficulty keeping up with increasing demands on artificial snowmaking capacity (Scott et al., 2008). Also, when faced with warm spells, larger establishments are more likely to be able to absorb losses without going under and afford measures for spreading risk, such as taking advantage of new markets for weather derivatives (i.e., financial instruments that can be used to reduce risk associated with adverse weather conditions). A further consolidation of the industry, a current trend likely to intensify under multiple pressures from climate change, then could create barriers to entry for smaller businesses.

Any consolidation of the industry would have cascading localized and regional effects on employment and related tourist businesses. The survival of certain communities will depend on anticipating the double exposure of warmer temperature and economic vulnerability. The timing of adaptation strategies, therefore, becomes critical, as does early planning to diversify local economies through new ventures or retraining.

6.5.3 Maple Syrup Industry: Vulnerability and Inequity

The maple syrup industry may be affected in a variety of ways (for additional information, see Case Study C. Maple Syrup Industry: Adaptation to Climate Change Impacts). Climate change effects on sap flow may vary in different parts of New York State, requiring some regions to increasingly rely on more expensive technology. The industry also provides a good example of the difficulty in anticipating nonlinear economic feedbacks and how these will combine with climate change to create differences in vulnerability across regions and states. In recent years, Canada has begun aggressively marketing maple syrup and introducing technological improvements that have reduced the competitiveness of maple production in the northeastern United States (New England Regional Assessment Group, 2001).

In 2009, a cold winter followed by a warm spring caused a decrease in Canadian maple production. This led to a rise in maple syrup prices. In the short term, this produced a good year for the New York maple industry, with expanded production by established producers and the development of new producers. At the same time, restaurants and retailers have passed on the price increases to customers by charging more for pure maple syrup, in some cases switching to corn syrup products (Schwaner-Albright, 2009).

As climate warming proceeds, New York maple syrup producers will need to consider how the industry should be structured to deal with increased seasonal variability in sap production, to increased variability in supply between regions, and to price and supply competition with alternative sugar sources.

6.6 Conclusions

This ClimAID analysis of ecosystems focuses on those aspects of climate change already occurring in New York or anticipated to occur within this century and that have known biological and ecological effects. **Table 6.4** summarizes selected climate factors, as linked to vulnerabilities/opportunities and adaptation strategies. A qualitative level of certainty is assigned to all three of these components (see Chapter 1, “Climate Risks”). The relative timing of when specific climate change factors and their associated impacts are projected to become pronounced is also indicated in the table, as these features will be critical in setting priorities for adaptation. **Table 6.4** illustrates an approach and a possible tool for setting priorities and for climate action planning, but is not meant to be comprehensive. It can and should be modified as new information and expertise become available.

Below, key findings regarding vulnerabilities and opportunities, adaptation options, and knowledge gaps are highlighted and discussed in more detail.

6.6.1 Main Findings on Vulnerabilities and Opportunities

The ClimAID study found that certain ecosystems are already undergoing changes or are vulnerable to the projected changes in climate while others may be less negatively affected or even benefit from climate change.

Vulnerable Ecosystems

Some species-level responses are already being observed in New York. Current species responses that are consistent with climate change include:

- northward expansion of the range of some birds, insects, and other species, including invasive species such as the hemlock wooly adelgid;
- increased winter survival and feeding of deer populations;
- earlier spring arrival of some migrating bird and insect species;
- earlier spring breeding of some animals and insects; and
- earlier spring bloom of some woody perennials.

The particular characteristics of species that make them vulnerable to climate change include:

- habitat or food specialization;
- location at the southern fringe of their habitable range;
- narrow environmental tolerances;
- poor dispersal ability;
- low population levels or current endangerment;
- lack of competitive advantage with species infringing on their range; and/or
- high dependence on snow cover for survival.

The major ecosystems vulnerabilities for New York include the following:

- Within the next several decades there are likely to be widespread shifts in species composition of forests and other natural landscapes. By mid- to late-century the Catskill and Adirondack mountain ranges of New York will no longer have a climate suitable for spruce/fir forests, alpine tundra, or boreal plant communities.
- Climate change will favor the expansion of some invasive species into New York, such as the notoriously aggressive weed kudzu, and the aphid-like insect pest hemlock wooly adelgid, which has already devastated hemlock stands to the south.
- Warming water temperatures will negatively affect brook trout and other native coldwater fish species, except in water bodies that are deep enough, have sufficient shade, or cold groundwater inputs to maintain coldwater refuges in summer.
- Lakes, streams, inland wetlands, and associated aquatic species will be highly vulnerable to changes in the timing, supply, and intensity of rainfall and snowmelt, groundwater recharge, and duration of ice cover. An increase in summer water deficits is likely by mid- to late-century, but for many of the climate change factors relevant to aquatic habitats we cannot project with a high degree of certainty the future magnitude or timing of change.

Species Likely to be Less Negatively Affected by Climate Change, or Even to Benefit

These species include those that are habitat and food “generalists,” those whose habitable range is currently constrained in New York due to current winter temperatures, and some invasives. Specific examples include the following:

Climate Factor	Climate Certainty	Associated Vulnerabilities/ Opportunities	Certainty*	Timing	Adaptation Strategies	Adaptation Capacity
Increasing carbon dioxide	High	Potential increase in plant growth, with large differences between species affecting plant community structure, potential for invasive species	Response dependent on other environmental constraints to growth that are difficult to predict	Now	Increase timber production by identifying and selecting carbon dioxide-responsive tree species; regionally coordinated monitoring and rapid response eradication of invasive species	Low to Moderate
Warmer summers; longer growing seasons	High	*Plants:* Potential increase in plant growth, with large differences between species affecting plant community structure, potential for invasive species; will increase plant water use and soil water deficits	Moderate to High, but water availability or other factors may constrain response	Early to mid-century	Increase timber production by identifying and selecting responsive tree species; regionally coordinated monitoring and rapid response control or containment of invasive species; prepare regionally for effects on hydrology	Low to Moderate
		Insects: More generations per season; shifts in species range	Moderate to High	Early to mid-century	Regionally coordinated monitoring and rapid response control or containment of insect pests and invasive species	Low to Moderate
		Coldwater fish species: Negative effects on populations of brook trout and other native species	Moderate to High	Early to mid-century	Maintain coldwater refuges through shading and by maintaining groundwater flows	Low
		Summer recreation: Increased opportunities	Moderate to High	Early to mid-century	Investment in and policies to facilitate summer recreation business	Moderate to High
Increased frequency of summer heat stress	High	High-elevation species: Eventual loss of spruce/fir forests, boreal communities; negative effects on other cold-adapted plant and animal species	Moderate to High	Mid to late century	Few options except facilitate species dispersal by maintaining corridors (e.g., riparian zones)	Low
Warmer winters	High	Northward shift in range of many plant, animal, insect species, including undesirable pests, diseases and vectors of disease, invasive species	High	Now	Facilitate dispersal, with monitoring and containment of undesirable species; wildlife disease surveillance	Low
		Increased winter survival of deer populations, increasing deer damage	High	Now	Modify hunting seasons and bag limits	Low to Moderate
		Increased survival of marginally overwintering insect pests	High	Now	Monitor and rapid response control or containments	Low to Moderate
		Negative effects on maple syrup production	Moderate	Early to mid-century	Earlier tapping; new tapping equipment; bring more trees into production	High
Reduced snow cover	High	Negative effects on winter recreation	High	Now	Increased snowmaking; diversification toward warm-season recreation business	Moderate to High
		Negative effects on survival of snow-dependent animals and insects	Moderate to High	Now	Few options	Low
		Increased vegetation damage from winter deer feeding	Moderate to High	Now	Few options except reducing deer populations through hunting season and bag limits	Low
Increased flooding	Moderate to High	Erosion and damage to stream banks; flood damage to plants; disturbance to aquatic ecosystems	Moderate to High	Now	Expansion of riparian zones and wetland protection; infrastructure (culvert, dam, etc.) planning to minimize damage	Low to Moderate
Increased summer drought	Moderate	Loss of some native plant species in severe years; Increased vulnerability to invasive species; negative effects on wetlands, streams, lakes, and aquatic species	Moderate to High	Mid to late century	Infrastructure planning to maintain water supplies to high priority regions; facilitate species dispersal and establishment of more drought-tolerant species.	Low
Changes in frequency of extreme events	Low	Sudden and severe devastation to entire communities and ecosystem services	Moderate to High	Unknown	New climate science research to determine current trends and predict extreme events	Low to Moderate
Increased climate variability	Low	Increased freeze damage of woody plants due to loss of winter hardiness or premature leaf-out and frost damage; disruption of winter hibernation negatively affecting winter survival	Moderate	Unknown	New climate science research to determine current trends and predict climate variability	Low to Moderate
Changes in cloud cover and radiation	Low	Important factor affecting plant growth and plant water use, primary production as food supply to animals	High	Unknown	New climate science research to determine current trends and better model these factors	Low to Moderate

* Climate certainty in this table is qualitatively consistent with more quantitative assessments in Chapter 1, "Climate Risks," and formulated from expert opinion from chapter authors and stakeholder groups.

Table 6.4 Summary table for climate factors, vulnerabilities/opportunities, and adaptation strategies for ecosystems in New York State

- Productivity of some tree species (e.g., oak, hickory, pine) adapted to warmer temperatures could benefit from longer growing seasons and increasing atmospheric carbon dioxide concentrations, provided that other environmental factors such as drought, nutrient deficiency, pests, or invasive plant infestations, do not limit their growth
- White-tailed deer could benefit from warmer winters and less snow cover, which will expose more winter vegetation as a food source
- Warm-water fish species such as bass
- Plant and animal species currently inhabiting regions south of New York, which will benefit from the state's warming temperatures and/or may be relatively tolerant to periodic droughts
- Some bird species, such as northern cardinal, Canadian goose, robin, and song sparrow
- Invasives with northward expanding range due to climate change, such as the insect pest hemlock wooly adelgid and the aggressive weed kudzu

With the exception of a few highly vulnerable communities (such as high-elevation plant communities and some coastal zones vulnerable to flooding), projecting future climate impacts on biodiversity and on ecosystem function and services is relatively uncertain compared to future impacts on specific species within ecosystems. While historical evidence such as the most recent ice age transition suggests ecosystems have responded to climate change in the past with some maintenance of function, the pace of change projected for this century is faster by several orders of magnitude than that of the ice age transition, which occurred over many thousands of years. Current habitat fragmentation due to human land use will make species dispersal more difficult. The human spread of invasive species also will complicate ecosystem-level adjustments to climate change in some areas. There is a lack of reliable information regarding the future resilience and capacity of ecosystems to maintain function through replacement of lost species by new species with similar function, or through redundancy of function among the species currently present.

The general lack of certainty regarding the broader effects of climate change on ecosystem function is not meant to suggest these impacts can be ignored. Impairment or loss of ecosystem services in the future could have profound effects on human health and on local and regional economies. Identifying reliable indicators of such impacts should be a high priority for future climate change research and assessment (see also Knowledge Gaps, section 6.6.3, below).

6.6.2 Adaptation Options

The context for adaptation will be one of uncertainty, not only about the climate but also about the degree to which observed species and ecosystem changes are due to climate versus other factors, such as land-use change and human transport of invasive species. Also, management interventions can be expensive, and there is limited experience and only a few historical examples of success in controlling species declines or invasions. Based on current knowledge, some adaptation strategies for specific land and aquatic vulnerabilities are as follows (see also **Table 6.4)**:

- Maintain healthy ecosystems more tolerant or better able to adapt to climate change by minimizing other stressors (e.g., invasive pests, acid rain).
- Manage primarily for important ecosystem services and biodiversity rather than attempting to maintain indefinitely the exact mix of species present today.
- Facilitate natural adaptation to climate change by minimizing habitat fragmentation and protecting stream (riparian) zones and other avenues for dispersal and migration of species adjusting to changes in the climate. Policies to encourage the development or maintenance of migration or dispersal corridors should be a high priority. Protection and expansion of riparian zones will serve this need and have many other positive co-benefits, such as flood and erosion control. Policies will need to address human land-use patterns and the challenge that more than 90 percent of New York forests are privately owned.
- Institutionalize a comprehensive and coordinated monitoring effort at multiple scales to track species range shifts and indicators of habitat and ecosystem responses to climate change. Identifying and prioritizing what to monitor and, in some cases, developing new indicators, will be required. Land managers, policy-makers, and other potential users should play a central role in developing plans for research, data synthesis and format, and mechanisms for data dissemination.
- Develop or modify processes and criteria for prioritization of management interventions in the context of a changing climate. Decisions at small

spatial scales can often be made by land managers, but those with ecosystem and large geographic range implications will involve policy decisions and require inputs from advisory groups such as the New York State Climate Action Council.
- A well-planned, comprehensive educational outreach program is needed. A high-priority sector to target for such a program would be private landowners and land managers, but all sectors of society will benefit from sound information on climate change science, potential impacts on natural areas, and implications for ecosystem services affecting human communities.
- Industries and supporting agencies should be poised to take advantage of any benefits from climate change in New York State. Examples include the possible increase in productivity of some northern hardwood forests and an extended summer outdoor recreation season.

6.6.3 Knowledge Gaps

The capacity of resource managers to facilitate ecosystem adaptation to rapid climate change is uncertain. A concern is that, to date, prior to the confounding effects of climate change, there has been only limited success with management interventions attempting to control species declines or invasions, or undesirable damage by individual species. Many potential management interventions for coping with climate change exist, but most of these have not been tested on a wide scale, and some are controversial even among experts in the field. Following are some examples of research needs to improve climate change ecosystem impact assessments and build adaptation capacity:

- Develop reliable indicators of climate change impacts on biodiversity and ecosystem functions, and cost-effective strategies for monitoring these impacts.
- Design management interventions to reduce vulnerability of high-priority species and communities, and determine the minimum area needed to maintain boreal and other threatened ecosystems.
- Evaluate techniques for rapid and reliable assessment of vertebrate abundance at the landscape scale.
- Improve the techniques used to identify and target invasive species likely to benefit from climate change.
- Create citizen science programs that can provide accurate and reliable data on change in species distributions and movements.
- Focus climate science research on the potential for changes in variability and on the frequency and probability of clustering of extreme events, which can have widespread impacts on ecosystems.
- Develop better spatial resolution of climate projections for land managers, encompassing even microclimate effects.

Case Study A. Hemlock: Cascading Effects of Climate Change on Wildlife and Habitat

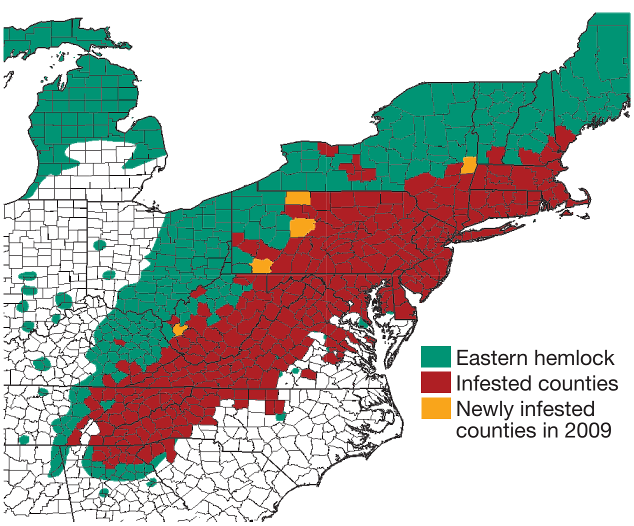
Characteristically shaded and cool, hemlock forests are highly valued for their aesthetic qualities as well as the unique wildlife habitat they provide. The eastern hemlock (*Tsuga canadensis*) is the single most prevalent conifer species in New York State. It adds structural diversity to the state's forest habitats, provides winter thermal cover for a variety of wildlife, shades and maintains lower water temperatures in streams, and serves as an important food source for many animals.

According to the U.S. Forest Service Climate Change Atlas, habitat suitability for the eastern hemlock is expected to decline in New York as a result of climate change, primarily in response to warmer projected average July temperatures as well as other factors (United States Forest Service, 2011). The extent of these changes depends largely on emission levels over the next century, with less dramatic changes under a low-emission scenario.

The effects of climate change on hemlock forests is further complicated by the spread of the hemlock woolly adelgid (*Adelges tsugae*). A small, aphid-like invasive insect from Japan, the hemlock woolly adelgid first arrived in Virginia in the 1950s and in New York State in 1985. The adelgid is now well established and recently spread to the central part of the state (**Figure 6.8**), in part due to warmer winter temperatures that are allowing the insect to survive. Hemlock mortality is already occurring in the southeastern parts of the state. However, it is uncertain how quickly mortality will occur in more northern and western parts of New York State. While trees in the southern part of the hemlock's range die within a few years following infestation, trees in the north may live for 10 years or more. Though scientists are working on ways to combat this pest, currently there is no way to prevent its spread or its effects. Extensive loss of hemlock forests will have cascading, far-reaching effects on a variety of wildlife species within New York State.

One group of wildlife with a high probability of being affected is New York's stream salamanders. Hemlocks often grow in riparian zones adjacent to our headwater streams. Widespread mortality of hemlock in these areas will lead to erosion and sedimentation, decreased shading, warmer water temperatures, and lower dissolved oxygen levels. These changes are likely to lead to the loss of quality stream and streamside habitat for species such as the spring salamander (*Gyrinophilus porphyriticus*), which completes its entire lifecycle in highly oxygenated, coldwater streams, as well as the two-lined (*Eurycea bislineata*) and northern dusky (*Desmognathus fuscus*) salamanders, which find refuge under the forest cover adjacent to streams.

The eastern hemlock also has unique structural characteristics that provide important habitat for many birds. Ninety-six bird species are associated with hemlock forest types in the northeastern United States (Yamasaki et al., 2000). Although none of these birds is limited only to hemlock forest, a number of species are strongly associated with this forest type. The black-throated green warbler (*Dendroica virens*), Acadian flycatcher (*Empidonax virescens*), blackburnian warbler (*Dendroica fusca*), hermit thrush (*Catharus guttatus*), and solitary vireo (*Vireo solitarius*) are strongly associated with intact hemlock stands during the breeding season (Tingley et al., 2002; Yamasaki et al., 2000). During the winter, others benefit from hemlock forests as well as the presence of individual trees or clumps of trees contained within other forest types. Ruffed grouse (*Bonasa umbellus*) and wild turkey (*Meleagris gallopavo*) often roost in hemlocks under the protection of the thermal cover they provide. The great horned owl (*Bubo virginianus*), barred owl (*Strix varia*), and goshawk (*Accipiter gentilis*) use hemlock branches as hunting perches. Eastern hemlock trees provide an important winter seed source for pine siskin (*Carduelis pinus*), goldfinch (*Carduelis tristis*), evening grosbeak (*Coccothraustes vespertinus*), and others.



Note: The native range of eastern hemlock is shown in all colors but white. The color scheme distinguishes counties where hemlocks currently are uninfested by the hemlock wooly adelgid (green) from those with severe and prolonged infestation (red). Newly infested counties (orange) are mostly along the northern boundaries of the infested zone, and warming temperatures may be playing a role in the further expansion of the insect range.
Source: U.S. Forest Service, Northeastern Area State and Private Forestry, Forest Health Protection Program.

Figure 6.8 Counties with existing and new infestations of hemlock woolly adelgid as of 2009[2]

Some mammals, such as the red squirrel (*Tamiasciurus hudsonicus*), also benefit from the food provided by hemlock seeds. Other small- to mid-sized mammals that prefer hemlock include the snowshoe hare (*Lepus americanus*), deer mouse (*Peromyscus maniculatus*), southern red-backed vole (*Clethrionomys gapperi*), and porcupine (*Erethizon dorsatum*). Hemlock trees with internal cavities are an important source of summer roosts for forest bats such as the hoary bat (*Lasiurus cinereus*). Four carnivore species—red fox (*Vulpes vulpes*), black bear (*Ursus americanus*), marten (*Martes Americana*), and bobcat (*Lynx rufus*)—also have some seasonal preference for hemlock forest (Yamasaki et al., 2000).

Loss of hemlock cover may significantly affect the future occurrence and distribution of wildlife across the state. In the near term, the most vulnerable areas of the state are those where hemlock is abundant and where increased average January temperatures are expected to allow for more rapid rates of adelgid infestation (Paradis et al., 2008). Replacement of hemlock forests will be complicated by other wildlife-related issues. For instance, in New Jersey and Pennsylvania forests where high levels of hemlock mortality overlapped with high deer densities, invasive species were more likely to take hold (Eschtruth and Battles, 2009). Adapting to forest changes resulting from hemlock woolly adelgid will require attention to direct effects as well as other interacting factors.

iMap Invasives is an online, GIS-based, invasive species mapping tool (http://imapinvasives.org). This website now provides real-time information on the locations of numerous invasive species in New York State and allows individuals to report new locations of invasive pests. Private landowners, volunteers, and State and federal agencies all can play a role in monitoring for the hemlock woolly adelgid.

Adaptations for dealing with hemlock woolly adelgid include monitoring the spread of hemlock woolly adelgid and its impacts on forests and dependent wildlife species, education on control options as they emerge, and managing to reduce other stressors currently affecting hemlock forests, including overabundant deer populations and invasive plant species, both of which threaten forest regrowth following hemlock mortality.

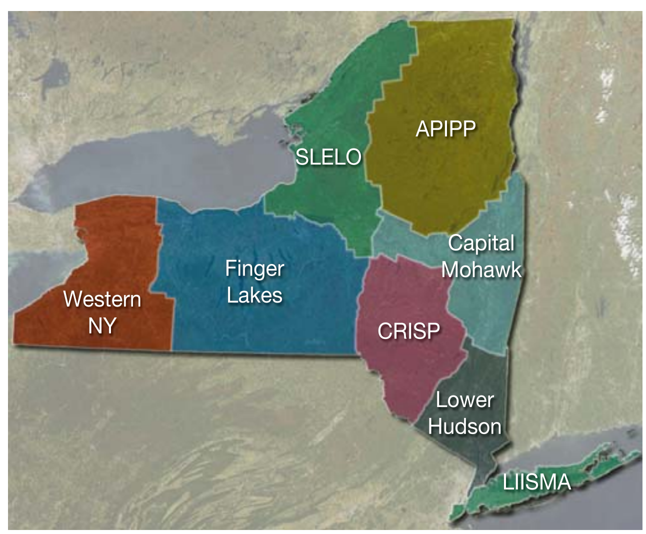
Case Study B. Creative Approaches to Monitoring and Adaptive Management: New York's Invasive Species Program as a Model

The comprehensive adaptive management approach New York State has employed toward invasive species may serve as a useful model for adaptation to a wider range of emerging climate change challenges. The State's invasive species program provides a framework for coordination among local, State, and regional efforts; a broad educational outreach program; and research, information management, and regulatory policy recommendations.

In 2003, Governor George Pataki signed legislation convening the Invasive Species Task Force (ISTF, Laws of New York, 2003; Chapter 324). The Task Force was composed of representatives from diverse stakeholder groups, including key State agencies, environmental advocacy and non-profit organizations, academia, and trade and industry groups. In November 2005, the Invasive Species Task Force released a final report that outlined the invasive species problem, identified existing efforts and, most significantly, provided 12 strategic recommendations for action (ISTF, 2005). These recommendations have been codified into New York State law (Laws of New York, 2008; Chapter 26) and have significant funding from the state's Environmental Protection Fund.

To coordinate all invasive species efforts at the State level, a permanent leadership structure, which was modeled after the federal approach to invasive species, was established. It consists of an agency executive-level council and an advisory committee of non-government stakeholders. The council, advisory committee, and day-to-day statewide coordination are supported by the Office of Invasive Species Coordination at the Department of Environmental Conservation.

Building on existing grassroots partnerships that formed to address local invasive species concerns, the Invasive Species Task Force recommended the formation of eight Partnerships for Regional Invasive Species Management (PRISMs) (**Figure 6.9**). These partnerships coordinate local invasive species management functions, including engaging partners, recruiting and training citizen volunteers, delivering education and outreach, establishing early-detection monitoring networks, and implementing direct eradication and control efforts—all within the context of the local landscape. The Adirondack PRISM, also known as the Adirondack Park Invasive Plant Program, has served as a successful model for the other PRISMs, delivering educational programs and coordinating volunteer monitoring programs for terrestrial and aquatic invasive species since 1998 (http://www.adkinvasives.com). Due to the State fiscal crisis, most PRISMs have not yet received intended State funds, but do benefit from voluntary



Note: Abbreviations are as follows: APIPP—Adirondack Park Invasive Plant Program; CRISP—Catskills Regional Invasive Species Partnership; LIISMA—Long Island Invasive Species Management Area; SLELO—St. Lawrence – Eastern Lake Ontario. Source: Brad Stratton, The Nature Conservancy.

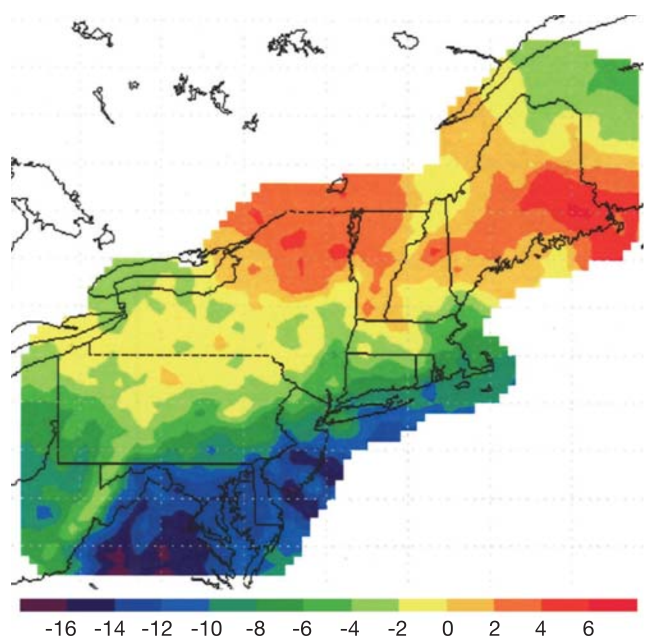
Figure 6.9 The eight Partnerships for Regional Invasive Species Management (PRISMs)[3] coordination and the in-kind support of partners. A strong communication network has also developed within and among PRISM partners to share educational resources, promote outreach events, and rapidly disseminate information about new invasions.

Other key Invasive Species Task Force recommendations now implemented as part of the State invasive species program include the following:

- The New York Invasive Species Research Institute, located at Cornell University. This group serves the scientific research community, natural resource and land managers, and State offices and State-sponsored organizations by promoting information-sharing and developing recommendations and implementation protocols for research, funding, and management of invasive species (http://nyisri.org).
- Use of iMapInvasives, an online, GIS-based, all-taxa invasive species mapping tool, coordinated by the New York Natural Heritage Program. The tool aggregates species records and locations from new observations and previously existing databases to provide a real-time, fully functional tool to serve the needs of volunteers and professionals working to manage invasive species (http://imapinvasives.org).
- The New York Invasive Species Information Clearinghouse, which is coordinated by the New York Sea Grant and Cornell Cooperative Extension. The Clearinghouse website is a comprehensive, online information portal (http://nyis.info) that provides stakeholders with links to scientific research, State and federal invasive species management programs and policy information, outreach education, and grassroots invasive species action in and around New York.

Case Study C. Maple Syrup Industry: Adaptation to Climate Change Impacts

Production of maple sugar products is based on sap flow from maple trees caused by positive internal sap pressures. These pressures are mostly from a physical process caused by freezing and thawing of a tree's woody tissues (Tyree, 1983). One analysis used historical data and climate models for individual states to project maple distribution and sugar production (Rock and Spencer, 2001). The study predicted an end to both the presence of sugar maple and to the maple industry in the northeastern United States by the end of this century. Another analysis, which used historical data from four northeastern states, concluded that, over the past 30 years, trees are being tapped for sap increasingly earlier and that sap flow is also ending earlier (Perkins, personal communication). The sap flow season is becoming shorter; the movement of the end of the season to earlier in the year is outpacing its earlier onset. A more recent study coupled a simple model for sap flow with downscaled global climate model results to project the number of sap flow days during the spring period and annually for about 10,000 locations across the northeastern United States (Skinner et al., 2010). This fine-scale analysis revealed that different parts of New York are likely to experience different impacts of climate warming on sugar production (**Figure 6.10**). Areas in New York at lower elevations and in southern counties have fewer days with freezing temperatures. In these areas, climate warming will force a continuing decrease in freezing temperatures with a resulting loss of sap production. In contrast, cooler parts of the state, at higher elevations and in northern New York, currently have fewer thawing days. The model predicts that, with warming, the number of days with sap flow will initially increase in these areas through the end of this century,



Note: The average change shown here is based on climate projections from the HadCM3 climate model (one of the 16 used in ClimAID), using the B1 emissions scenario. Northern areas in New York show an increase in sap flow days and southern areas a small decrease. Source: Based on data from Skinner et al., 2010

Figure 6.10 Average change in the total number of days (see color-coded scale at bottom) of modeled sap flow per season comparing the 1969–1999 historical climate data with projections for 2069–2099 period followed by a decrease of days with sap flow with further warming after the end of this century. This analysis also shows that the sap flow season is moving earlier in the year such that by the end of the century tapping will begin in January rather than March. Eventually, it will merge with temperature conditions in November and December that are favorable for sap production.

Contrary to the prediction that the maple industry in New York will disappear by the end of the century (Rock and Spencer, 2001), this ClimAID analysis suggests that with adaptation to climate change the industry can remain viable for at least the next 100 years. There are several approaches to adaptation:

1) *Maintain attention on tree health through good forest management.* Competition from other tree species and pest impacts can be substantially reduced by existing management options. Research projects are under way to examine the optimal tree spacing for maximal growth and sugar production. Effective methods to control competing woody vegetation are also being studied.
2) *Begin tapping trees earlier in the year.* It is both essential and possible to move the sap production period to earlier in the season as the climate warms. Maple producers already pay considerable attention to weather forecasts to determine when to begin tapping. One analysis mentioned above (Skinner et al., 2010) predicts that the loss of production could amount to 14 days, if tapping begins at traditional times; normal seasons are 24 to 30 days long. If tapping begins earlier, there could be no net loss in number of sap flow days in warmer areas and there could be a net gain of sap flow days in cooler areas.
3) *Increase the sap yield from trees.* Recent research regarding why tap holes "dry up" has led to the introduction of a new type of spout. The main cause for loss of production from a tap hole relates to microorganisms plugging the xylem elements, which are the water-conducting elements of the tree. This is accelerated by increases in temperature and, thus, could be affected by a warming climate. The new spout has a check valve that prevents backflow of sap from the tubing into the tree, thus reducing the rate of microbial plugging. Initial results show a substantial production increase that could offset declining production from climate warming.
4) *Bring more maple trees into production.* One study, which uses U.S. Forest Service Forest Inventory Analysis data, estimates that in New York there are about 138 million sugar and 151 million red maples that are the correct size for tapping (Farrell, 2009). About 0.5 percent of these are currently used in sugar production. Vermont taps about 2 percent of its potential trees; Quebec taps about 30 percent of its trees. Thus, the potential to compensate for loss of production by bringing more trees into production and better utilizing red maples is enormous. Increasing the number of trees tapped seems to be occurring in response to economic incentives, as the price of syrup has increased dramatically in recent years.
5) *Increase use of red and silver maples for sugar production.* Whereas producers are currently tapping roughly 80 percent of the sugar maples on their own property, they are only using 20 percent of the available red maples (Farrell and Stedman, 2009). One of the main objections to using red and silver maples has been the lower sugar concentrations in the sap. However, with increased use of reverse osmosis to remove 80 to 90 percent of the water before boiling, this concern is not as great as it once was. Red maple (*Acer rubrum*) has a broader environmental tolerance than does sugar maple and is becoming the dominant tree species throughout the Northeast. It will be affected less by climate warming and tends to grow faster than sugar maple on a variety of sites. Thus, even if sugar maple disappears from New York's forests, syrup production could continue with better use of red maples.

Case Study D. Brook Trout: Reduction in Habitat Due to Warming Summers

The historical abundance of brook trout, New York's state fish, is likely to be severely reduced by climate warming, since it is currently located near the southern extent of its habitable range.

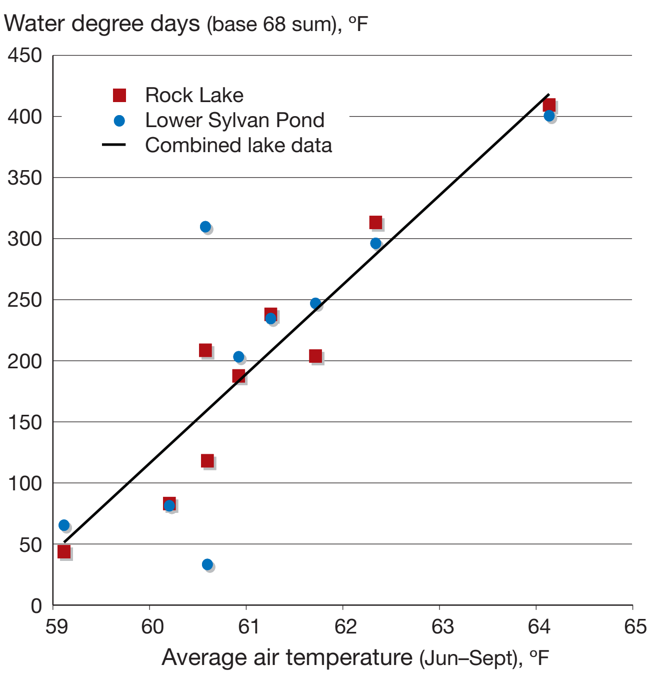
To examine the effects of regional warming on brook trout populations, three classes of water bodies in the Adirondack region were considered by ClimAID: 1) unstratified lakes, which have extensive water mixing during the summer and minimal temperature gradients with depth, 2) stratified lakes, which have deep zones that remain cold and unmixed with surface waters throughout mid-summer, and 3) streams and rivers.

Details of the analysis, including economic and social equity issues are provided below.

Unstratified Lakes

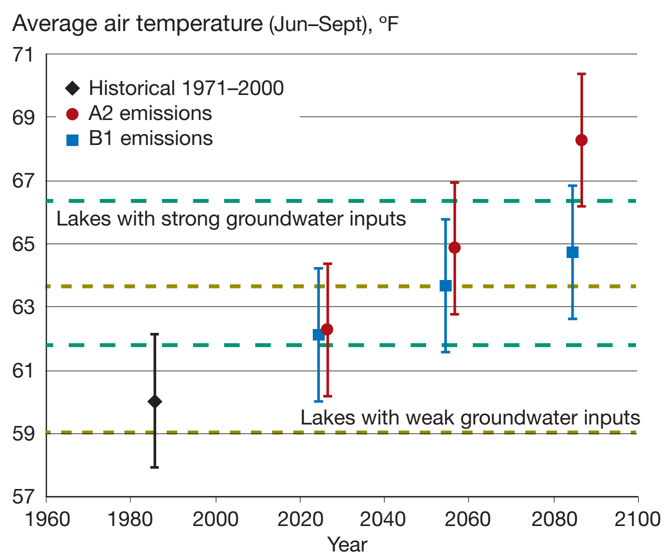
Primary findings are that brook trout in unstratified lakes, which represent about 41 percent of brook trout lakes in the Adirondacks (Scofield et al., 1993), will be most vulnerable to continued warming associated with climate change because of the lack of cold water refugia. Brook trout in streams and rivers will also be vulnerable, but may be less vulnerable than those in unstratified lakes. Least vulnerable will be those brook trout in stratified lakes where large, deep coldwater refugia are maintained (e.g., Great Lakes, Finger Lakes). However, the deep coldwater refugia in large stratified lakes can become oxygen depleted, and this stress may be exacerbated in many lakes by the lengthening summer season as a result of global warming.

A brook trout seasonal heat-stress index (Robinson et al., 2008 and 2010) was developed based on Rock Lake, an unstratified lake in the Adirondacks. The index uses a water degree-day metric that sums daily average lake-bottom temperatures above 68°F (e.g., a daily water temperature of 67°F would contribute 0 to the total, 68.5°F would contribute 0.5, and 71°F would contribute 3 degree-days). Annual reproductive success correlates with cumulative water degree-days over the summer ($r^2 = 0.85$). Reproductive success drops to zero at a water degree-day value of 365, i.e., years in which the average temperature at the lake bottom is much higher than 68°F for prolonged periods. Full mortality of the oldest age classes of brook trout was also observed in years with this heat index level. **Figure 6.11** illustrates that, for this class of unstratified lakes, the average air temperature observed from June 1 to September 30 accurately predicts lake temperature water degree-days. This is important because it indicates that climate model projections of air temperature can be reliably



Note: Water degree days are a measure of predicted temperature stress on brook trout that takes into account both the amount of warming on single days and the total amount of time spent at the high temperatures (see text for more details). The y-axis is calculated from daily water temperature data throughout the summer using temperatures at maximum lake depths—6 meters (about 20 feet) for Rock Lake and 4 meters (about 13 feet) for Lower Sylvan Pond. Air temperature data are taken from the nearby Indian Lake weather station and daily values have been averaged into seasonal values on the x-axis. The regression line shown is fit to all data from both lakes and shows that the seasonal stress index can be accurately predicted from the average summer temperature of the air. Brook trout are predicted to be free of high temperature stress (degree days = 0) when average summer air temperature is below 58.4°F, and increases by 73 degree days for every one degree rise in the average summer temperature.

Figure 6.11 Cumulative water degree days related to seasonal air temperature for two Adirondack lakes: Rock Lake and Lower Sylvan Pond



Note: Temperature projections for the lower-emissions B1 scenario and the higher-emissions A2 scenario by year, for the Adirondacks region. Projections are based on the B1 and A2 greenhouse gas emissions scenarios as indicated in the legend and utilizing five global climate models (GFDL, GISS, MIROC, CCSM and UKMO), a subset considered broadly representative of the full suite of 16 GCMs used by ClimAID. The green and brown horizontal lines represent the upper and lower boundary of the air temperature range where injury to brook trout will occur for unstratified lakes with strong groundwater inputs (green) and weak groundwater inputs (brown). Air temperatures exceeding the upper boundary of either range would lead to complete mortality for that lake class.

Figure 6.12 Climate projections for air temperatures under two emissions scenarios and potential damage to brook trout populations used as indicators of trends in water temperature for unstratified lakes in the region.

Figure 6.12 illustrates the summer air temperature changes predicted for the Adirondack region for two different greenhouse gas emission scenarios and the effect this is likely to have on brook trout reproduction and survival. The lower threshold is the temperature where negative effects on brook trout reproduction would first be detected and the upper threshold is the temperature at which there would be complete elimination of reproduction and lethal effects on adult fish. The lower and upper thresholds for two unstratified lakes with differing levels of cold groundwater inputs are compared (groundwater inputs will have an overall cooling effect). The magnitude of groundwater inputs is controlled by soil depth in the surrounding basins, as determined by the thickness of till from past glaciations (Newton and Driscoll, 1990). Rock Lake is an example of an unstratified lake formed in thin glacial till, which results in weak groundwater inputs. Such lakes represent 56 percent of all unstratified Adirondack brook trout lakes. The vulnerability of these lakes to climate change is indicated by brown threshold lines in **Figure 6.12**. Thermal regimes in most years during the historical record from 1971 to 2000 were warm enough to adversely affect reproduction, but even the hottest years would not have caused full adult mortality. In contrast, by the 2020s, the hottest years will produce full mortality. While one single such year in isolation will not extirpate brook trout from a lake (because first-year fish can find thermal refuges in small shoreline groundwater seeps), two or three such years in succession would effectively eliminate all age cohorts. After the 2050s, even the average year will result in lethal temperatures, and brook trout will most likely not be viable in these lakes.

Temperatures monitored in lakes formed in thick glacial till and having high groundwater inputs (e.g., Panther Lake) indicated that cold groundwater was able to reduce average lake temperatures by 3.0°F relative to lakes in areas with thin till. This class represents only 20 percent of all unstratified lakes. The vulnerability of resident brook trout in lakes with high groundwater inputs to climate change is indicated by the green threshold lines in **Figure 6.12**. Under a high emissions scenario, none of these lakes would retain viable brook trout habitat, but under a low emissions scenario lethal temperatures occur in only the most extreme years, which would allow some brook trout populations to persist.

Stratified Lakes

Deep lakes and lakes with more color from algae and dissolved organic compounds develop a thermocline, which separates warm surface water from cold deeper water (i.e., become stratified). Weakly and strongly stratified lakes represent 59 percent of Adirondack brook trout lakes. Stressful warm temperatures are unlikely to occur below the thermocline in these lakes. However, these lakes are prone to oxygen depletion in deep waters that lack contact with the lake surface (Schofield et al., 1993). Oxygen levels often drop throughout the summer, and this stress may be exacerbated in many lakes by the lengthening summer season under global warming. Such dynamics require further study to determine how many lakes may develop serious oxygen deficiencies in the zones favorable to coldwater fish.

Rivers and Streams

Finally, rivers and streams make up a large fraction of the Adirondack waters fished for trout, though many of these bodies are stocked with hatchery-reared brown trout. One study, which examined brook trout that were released into a fifth-order river with radio transmitters and temperature sensors, showed that brook trout maintained body temperatures that averaged 4°F cooler than the temperature of the bulk river water; this difference increased to more than 7°F during periods when bulk river water was more than 68°F (Baird and Krueger, 2003). The brook trout were able to maintain lower body temperatures than that of the bulk river water by using cool refuges where tributary streams fed the larger river or pool bottoms were fed by groundwater seeps. Studies such as this emphasize the ability of brook trout to use thermal refugia when available. These studies also indicate, however, that bulk river temperatures are similar to the unstratified lakes discussed above and already are crossing thermal stress boundaries in mid-summer, with possible effects on brook trout reproduction success and adult mortality. Another study showed a similar pattern by which stocked brown trout also used thermal refuges during mid-summer in the Hudson River upstream from North Creek (Boisvert, 2008). Both surface-flow waters (e.g., where tributary streams feed the larger river) and groundwater seeps will increase in temperature with regional warming, and many rivers are likely to become too hot for brook or brown trout. More thermal monitoring is needed to define the prognosis for Adirondack rivers through the coming century.

Groundwater seeps are crucial to the thermal properties of the thick-till lakes discussed above and for the presence of thermal refugia in rivers and streams. Leaving aside the direct effects of climate change on air temperatures, groundwater supply is likely to become less reliable in the Adirondacks as global warming progresses. While the Adirondacks is likely to remain the wettest region of the state, it may nonetheless experience greater and more frequent levels of soil drying in the coming century. As a result, it may have a decrease in the abundant groundwater resource that supports thermal refugia.

Adaptation Options

Possible adaptations to ameliorate rising temperature effects on brook trout include maintaining or increasing vegetation that provides shade along stream, river, and lake shorelines, and minimizing disturbances that would impede water flows and groundwater inputs. More elaborate interventions for high-priority regions could include piping cold water from springs or lakes located at higher elevations to shoreline locations of thermally stressed lakes, and manipulations that might darken the "color" of the water in order to darken the propensity to form stable thermal stratification. Adding lime to some Adirondack lakes has already been practiced to partially compensate for pollutant acidity and promote primary production; primary production and a healthy level of natural algae also tends to darken water color and, thus, also shades the depths and promotes thermal stratification. This practice has not been approved in the context of thermal modification and could only be implemented if justified by further evaluation and after lake policy review.

Economics, Equity, and Environmental Justice Issues

Trout fishing is prominent in most of the state's major fishing areas, and trout is the second most popular group of species for recreational fishing in the state after black bass (Connelly and Brown, 2009a). To highlight the economic and equity issues associated with possible reduction of brook trout with climate change, a geographic region in the Adirondacks where brook trout are a key species for recreational fishing is analyzed (**Figure 6.13**). As described in Chapter 3 ("Equity and Economics"), the economy of the Adirondacks region depends heavily upon natural resource-related activities and tourism. Among the counties in the case study region, Herkimer, Lewis, and St. Lawrence are especially dependent on natural resources and agriculture as a share of total county employment (see Chapter 3, **Figure 3.4**). It also is important to note that all counties in the Adirondacks region have relatively high poverty rates and lower median income levels than the state overall (see Chapter 3, **Figures 3.1** and **3.2**), suggesting that these regions may face significant challenges adapting to all types of climate-change-related stresses.

Concerning fishing-related economic activities, **Figure 6.14** illustrates total fishing-related expenditures across all counties in New York in 2007 for all fish species. The map reveals that nearly all counties in the state benefit from fishing-related revenue, but counties in the case study region generally tend to have higher fishing-related expenditures than other counties. As illustrated in **Figure 6.15**, which estimates expenditures related specifically to trout fishing (based on estimates of percentage of angler days devoted to trout), trout represent an important component of fishing-related expenditures in the case study region. While the data used to construct **Figure 6.15** combine brook, brown,

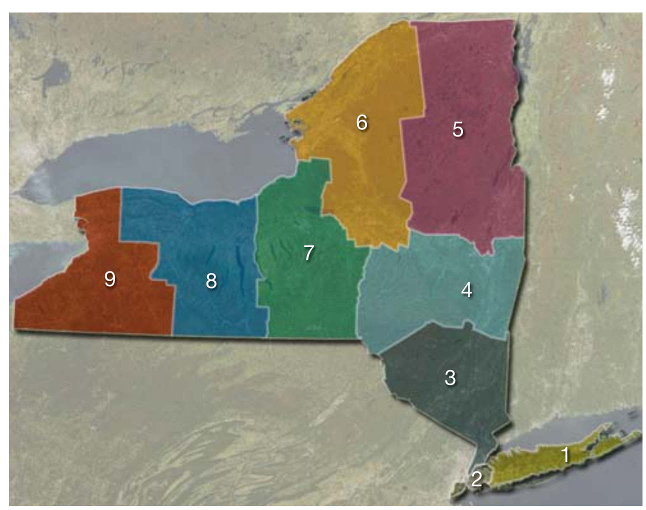


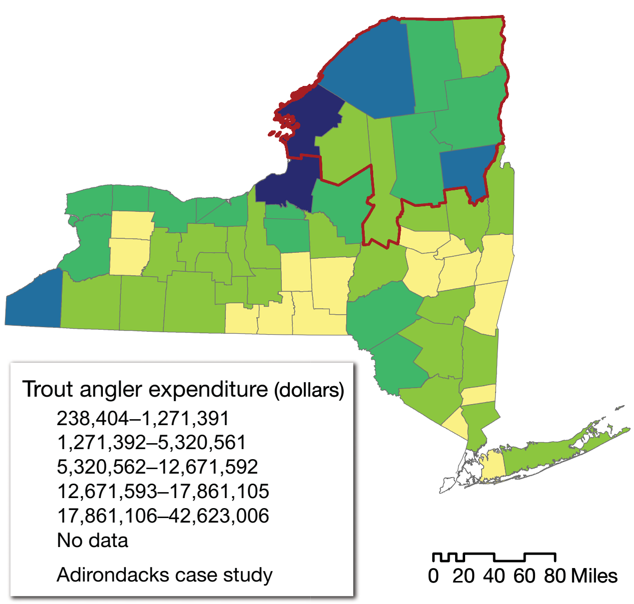
Figure 6.13 New York State Department of Environmental Conservation fishery management regions used for regional classification; the Adirondacks are located within regions 5 and 6

and rainbow trout, brook trout represent the most popular species of trout for anglers within the Adirondacks region. Moreover, anglers who are fishing specifically for brook trout are often willing to travel significant distances to lakes where this species is plentiful. Although other species are likely to replace brook trout under warmer temperatures, such species (e.g., bass) may not have the same type of appeal for out-of-town anglers—and particularly out-of-state anglers—who are willing to travel to the region for brook trout, but who would be able to fish for warm water species, such as bass, in areas closer to home.

Total expenditures in New York by anglers fishing in the Adirondacks case study region was estimated at $112 million in 2007 (**Table 6.5**) (personal communication, Nancy Connelly, based on 2007 New York Statewide Angler Survey). To determine how much of this was associated with the trout lakes identified above as being most vulnerable to loss of brook trout, this analysis assumes the following: 1) the fraction of the total expenditure related to trout fishing is proportional to the days spent fishing for trout (32.2 percent), and 2) trout fishing is equally divided in the Adirondacks between rivers and lakes. Together, there was an estimated $17.8 million in economic activity in 2007 associated with fishing for trout in Adirondack lakes. Forty percent of these lakes have been identified above as unstratified lakes, which are likely to lose their brook trout populations by the 2050s. The loss of brook trout in these lakes is associated with a total economic activity loss of $7.2 million annually, of which $4.8 million is spent at or near the fishing locations. Brook trout in summer-stratified lakes and in the river and stream systems are also threatened by rising temperatures as previously discussed, but specific predictions for these trout are not yet available.

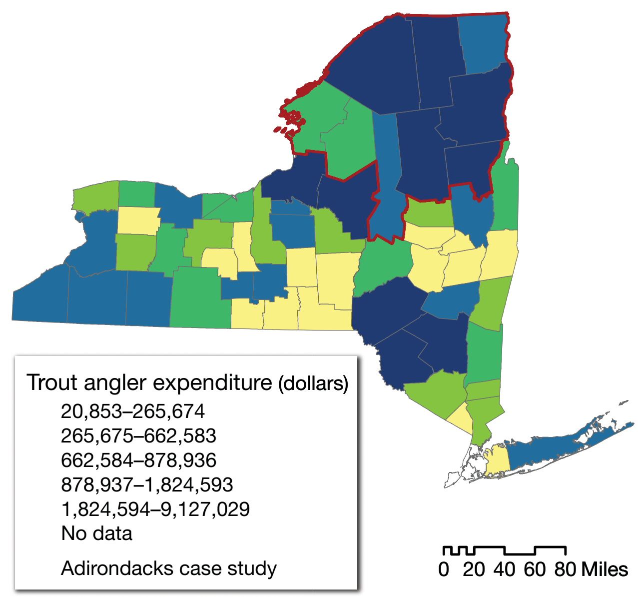
The counties within the case study region may be especially vulnerable to loss of tourism revenue, as each has a significant presence of anglers from other regions in the state as well as from other states. Nearly half of the total angler days spent in the region are accounted for by anglers who live outside the region (**Table 6.5**). In terms of fishing-related expenditures within the region, which were estimated at approximately $74.5 million in 2007, local expenditures by anglers from other regions in the state and out-of-state regions represented more than 85 percent of this total (**Table 6.5**). The loss of revenue that is associated with anglers from other regions and states would represent a significant economic blow to the area's tourism-related industries, such as hotels, gas stations, and restaurants.

While loss of brook trout would hurt the region's fishing economy overall, such losses may have a



Source: Connelly and Brown (2009b) Statewide Angler Survey, NYSDEC

Figure 6.14 Total angler expenditure by county



Note: Total fishing expenditures in the survey were translated into an estimate of expenditures for trout fishing by assuming that the percent of days spent fishing for different kinds of fish was equal to the percent of expenditure attributable to each kind of fish. Source: Connelly and Brown (2009b), Statewide Angler Survey, NYSDEC (authors' calculations)

Figure 6.15 Angler expenditure by county for trout fishing

Residence Areas of Anglers	Angler days		At-location Expenditures		En-route Expenditures	
	Number	Confidence limit ±	1,000s of $	Confidence limit ±	1,000s of $	Confidence limit ±
Total	2,912,938	200,203	$74,564	$6,613	$45,464	$4,761
Live in selected Adirondack region	1,241,905	150,836	$10,602	$2,601	$6,761	$1,431
Regions 5, 6—outside selected region	380,184	58,798	$6,878	$1,743	$5,030	$1,129
Regions 1, 2	59,995	9,826	$4,199	$1,551	$1,325	$292
Regions 3, 4	421,745	60,643	$14,698	$3,231	$9,762	$2,602
Regions 7, 8, 9	509,327	80,505	$17,763	$2,930	$11,902	$2,511
Out-of-state	299,794	36,001	$19,455	$3,134	$9,012	$2,256

Note: The selected Adirondack region was defined as the Department of Environmental Conservation regions 5 and 6, not including Washington, Saratoga, Fulton, and Oneida counties and not including fishing effort originating in the region on Lake Ontario, Lake Champlain, and the St. Lawrence River.

Table 6.5 Estimated number of angler days with at-location and en-route expenditures for fishing in the selected Adirondack region in 2007

disproportionate effect on small, fishing-dependent communities. Those areas that are dominated by unstratified lakes (which are likely to lose all of their trout) may also be particularly hard hit. Within fishing communities of the region, smaller tourism operators (e.g., fishing guides) may be most affected. They are likely to have limited ability to withstand any reduction in angler visits and may have limited capital to shift to other types of recreational businesses. Small, independently owned restaurants and hotels may be similarly vulnerable to reductions in angler expenditures by those living outside the region.

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Appendix A. Stakeholder Interactions

The Ecosystems team gathered information and enlisted participation from key stakeholders in this sector through existing relationships and collaboration with the New York State Department of Environmental Conservation; other State and federal governmental organizations (e.g., U.S. Geological Survey, U.S. Fish and Wildlife Service); Cornell Cooperative Extension (natural resources specialists); non-governmental organizations (e.g., The Nature Conservancy, National Wildlife Federation, Audubon NY, Wildlife Conservation Society, Adirondack Mountain Club); business associations (e.g., New York Forest Landowners Association, Empire State Forest Products Association, Olympic Regional Development Authority); land, fish, and wildlife managers; and maple growers.

Meetings and Events

On December 8, 2008, a meeting was held with over 50 stakeholders, including representatives of State and federal government organizations, leaders of non-government organizations, leaders of recreational-user organizations, representatives from affected industries, and academics. After a series of presentations, there was a two-hour breakout session with small groups. Each group provided its input regarding high-priority vulnerabilities and potential opportunities; feasible adaptation strategies; and needs for additional information, decision tools, and/or resources to help stakeholders cope with climate change and protect the state's natural resources. These data were summarized and sorted into groups of statements with thematic similarity, and contributed to the development of the chapter.

On August 6, 2009, the Ecosystems and Water Resources sectors and representatives of the ClimAID team at Columbia University met with stakeholders at the New York State Department of Environmental Conservation headquarters in Albany for an all-day workshop. This meeting was used to update stakeholders on ClimAID activities and progress and, especially, to collect input on needs and current relevant activities and planning by Department of Environmental Conservation and related stakeholder groups.

On November 6, 2009, an expert panel was assembled to meet with the Ecosystems sector team in Albany to review initial findings and provide suggestions regarding the project. The meeting included introductory presentations, followed by discussions focused on climate factors and key vulnerabilities, adaptation strategies, prioritization, and broad issues and recommendations. The 25 people in attendance included scientists from non-governmental organizations, State and government agencies, and research institutes within the state.

Web-based Survey Tool and Analyses

The results from early-phase stakeholder input were used to create a Web-based survey that cast a wider net among stakeholders and gathered expert opinion regarding the current state of knowledge regarding climate change; evidence of climate change impacts; high-priority vulnerabilities; high-priority climate change factors; importance and feasibility of various adaptation strategies; current efforts to adapt to climate change; research, monitoring, and communication gaps; and needed decision tools (Chatrchyan et al., 2010).

The survey was reviewed by several experts and stakeholders before dissemination in November 2009. The survey was sent to research scientists; land and water resource managers, educators, and others from State and federal government agencies; elected officials; private industry and landowners; non-government organizations; and universities and other research institutes. One section of the survey allowed participants to choose among several areas of specialization: water resources; forests, grassland, wetland, and riparian zones; fish and wildlife; and invasive species.

After survey responses were collected, the analysis characterized how issues were conceptualized by stakeholders and identified issues of priority/importance, using an approach similar to that described by Cabrera et al. (2008). Results were integrated into this report.

Appendix B. Relevant Ongoing Adaptation-planning Efforts

This section discusses ongoing adaptation-planning efforts related to climate change and ecosystems in New York State.

New York State Department of Environmental Conservation 2009 "Climate Change Steering Committee Adaptation Strategy Outline"

In 2009, the New York State Department of Environmental Conservation Division of Fish, Wildlife, and Marine Resources identified a climate change steering committee to initiate the development of an adaptation strategy. The outline of their report, still in progress in 2011, includes sections on the following:

- current trends (observed impacts, other stressors, downscaled climate models)
- vulnerability analysis (exposure, sensitivity analysis, adaptive capacity, levels (e.g., high, medium, low))
- risk assessment
- uncertainties
- forecasted impacts by sector
- prioritized vulnerabilities, habitats, ecosystem processes
- adaptation strategies (planning, acquisition, restoration and management, regulation, incentives, research, monitoring, education outreach)
- data gaps and research needs
- monitoring for adaptive management

New York State Department of Environmental Conservation 2009 Open Space "Climate Change Adaptation Plan"

This report has recommendations specific to riparian buffers and wetlands (11 recommendations), forests (15), climate-smart communities (17), and eight other recommended initiatives.

(http://www.dec.ny.gov/lands/47990.html)

U.S. Forest Service "Global Change Research Strategy 2009–2019"

This document by Birdsey et al. (2009) identifies research priorities to:

- enhance ecosystem sustainability (adaptation);
- increase carbon sequestration (mitigation); and
- provide decision support for policymakers and land managers.

A fourth objective of this Forest Service plan is to develop a shared infrastructure for researchers (e.g., strengthen remote sensing, simulation modeling, data management, and delivery capacity) and promote collaboration for research and education outreach to effectively reach natural resource planners and management.

[1] Areas of increased and decreased lake effect snow are color coded showing inches of water equivalent. A) Weather conditions of wind and temperature gradients identical to an historic event recorded Nov. 9, 2008, but with lake and air temperatures uniformly increased by 1.8°F. B) The same conditions as A, but lake temperatures (not air) increased an additional 1.8°F (3.6°F total). Areas of red color show increases in lake-effect snow. These increase with further warming of water temperatures (B).

[2] The native range of eastern hemlock is shown in all colors but white. The color scheme distinguishes counties where hemlocks currently are uninfested by the hemlock wooly adelgid (green) from those with severe and prolonged infestation (brown). Newly infested counties (yellow) are mostly along the northern boundaries of the infested zone, and warming temperatures may be playing a role in the further expansion of the insect range. Source: U.S. Forest Service, Northeastern Area State and Private Forestry, Forest Health Protection Program.

[3] Abbreviations are as follows: APIPP—Adirondack Park Invasive Plant Program; CRISP—Catskills Regional Invasive Species Partnership; LIISMA—Long Island Invasive Species Management Area; SLELO—St. Lawrence – Eastern Lake Ontario. Source: Brad Stratton, The Nature Conservancy.