CHAPTER 3
Threats

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Introduction

Setting the stage for recovery and protection of Pennsylvania's Species of Greatest Conservation Need (SGCN) and their habitats is founded, in part, in identifying causes of imperilment. As described in this chapter, threats to SGCN and their habitats in the northeast region and Pennsylvania are diverse and dynamic, often requiring significant time to rigorously and methodically research pathways and impacts. Yet, changes can happen quickly, such as with introduction of an invasive species or disease, thus complicating well-designed assessments. In addition to the temporal perspective, across the landscape an overarching threat such as climate change, can broadly affect fish and wildlife further confounding our understanding of specific threats to species. For example, fish and wildlife may be affected directly (positively or negatively) by elevated temperatures or altered precipitation patterns induced by climate change. Yet, these altered thermal or precipitation regimes also may contribute to changes in habitat composition. Thus, multiple factors may be simultaneously influencing a species survival: direct effects such as temperature or precipitation, and indirect effects of altered habitats, can obscure identification of imperilments and development of compensatory conservation actions.

The distribution of Pennsylvania's SGCN often extends throughout the northeast region and beyond, so we need to be concerned about threats outside of the state. Identifying and understanding current threats, and proactively recognizing new threats, both in Pennsylvania and regionally over the next 10 years, will be vital to the health of Pennsylvania's SGCN. In this section, we first provide an overview of threats in the northeast region and then generally describe threats to Pennsylvania's habitats and their SGCN. Species-specific threats are described in Chapter 1, Species.

Classification of Threats

Detecting, identifying and understanding threats to Pennsylvania Species of Greatest Conservation Need (SGCN) and their habitats, locally and regionally, provides the foundation for successful conservation and recovery. A common language for direct threats is necessary to catalyze these investigations and develop appropriate conservation actions. The Conservation Measures Partnership (CMP) recognized this need at the global scale, and thus developed a standard classification of threats (this chapter) and conservation actions (Chapter 4) (Salafsky et al. 2008). The International Union for Conservation of Nature (IUCN) adopted these classifications and their use is a "best practice" in State Wildlife Action Plans (AFWA 2012). Salafsky et al. (2008) also serves as the basis for the Northeast Lexicon (Crisfield 2013) to enable a region-wide synthesis of 2015 State Wildlife Action Plans.

We used 2 classification levels for the species threats assessments (Table 3.1; Master et al. 2012). Broader "Level 1" direct-threat classifications were always referenced, whereas more specific "Level 2" classifications were used when possible. For consistency, we present the northeast regional and state threats discussion within this classification framework.

Table 3.1. International Union for Conservation of Nature (IUCN) (Salafsky et al. 2008) threat classifications used in the 2015 Pennsylvania Wildlife Action Plan threats assessment and adopted by the northeast region (Crisfield 2013).

IUCN Code	Level 1 Description	IUCN Code	Level 2 Description
1	Residential and Commercial Development	1.1	Housing and Urban Areas
		1.2	Commercial and Industrial Areas
		1.3	Tourism and Recreational Areas
2	Agriculture and Aquaculture	2.1	Annual and Perennial Non-timber Crops
		2.2	Wood and Pulp Plantations
		2.3	Livestock Farming and Ranching
		2.4	Marine and Freshwater Aquaculture
3	Energy Production and Mining	3.1	Oil and Gas Drilling
		3.2	Mining and Quarrying
		3.3	Renewable
4	Transportation and Service Corridors	4.1	Roads and Railroads
		4.2	Utility and Service Lines
		4.3	Shipping Lanes
		4.4	Flight Paths
5	Biological Resource Use	5.1	Hunting and Collecting Terrestrial Animals
		5.2	Gathering Terrestrial Plants
		5.3	Logging and Wood Harvesting
		5.4	Fishing and Harvesting of Aquatic Resources
6	Human Intrusions and Disturbance	6.1	Recreational Activities
		6.2	War, Civil Unrest and Military Exercises
		6.3	Work and Other Activities
7	Natural Systems Modifications	7.1	Fire and Fire Suppression
		7.2	Dams and Water Management/Use
		7.3	Other Ecosystem Modifications
8	Invasive and Other Problematic Species, Genes and Diseases	8.1	Invasive Non-native/Alien Species/Diseases
		8.2	Problematic Native Species/Diseases
		8.3	Introduced Genetic Material
		8.4	Problematic Species/Diseases of Unknown Origin
		8.5	Viral/Prion-induced Diseases
		8.6	Diseases of Unknown Cause
9	Pollution	9.1	Domestic and Urban Waste Water
		9.2	Industrial and Military Effluents
		9.3	Agricultural and Forestry Effluents
		9.4	Garbage and Solid Waste
		9.5	Airborne Pollutants
		9.6	Excess Energy
10	Geological Events	10.1	Volcanoes
		10.2	Earthquakes/Tsunamis
		10.3	Avalanches/Landslides
11	Climate Change and Severe Weather	11.1	Habitat Shifting or Alteration
		11.2	Droughts
		11.3	Temperature Extremes
		11.4	Storms and Flooding

SNAPSHOT

Threats to Fish, Wildlife and Habitats in the Northeast
Adapted from Terwilliger Consulting & NEFWDTC (2013)

- ✓ ***Permanent roads are the primary fragmenting features in the Northeast.***
- ✓ ***Changes in water quantity and quality pose significant threats to aquatic systems.***
- ✓ ***The northeast region has the highest density of dams and road crossings in the country, with an average of 7 dams and 106 road-stream crossings per 100 miles (161 kilometers) of river.***

Northeast Region-Threats to Fish, Wildlife, and Habitats

Adapted from Terwilliger Consulting & NEFWDTC (2013).

Background

The northeast region (Maine to West Virginia) (Fig. 3.1) is host to several landscape-scale initiatives supported by the Northeast Association of Fish and Wildlife Agencies (NEAFWA), the Northeast Fish and Wildlife Diversity Technical Committee (NEFWDTC) and the Landscape Conservation Cooperatives (LCCs). Within the LCC network, the northeast region is served by the North Atlantic LCC (NALCC), Appalachian LCC (APPLCC) and Upper Midwest Great Lakes LCC (UMGLLCC). Several analytical approaches have been used by this group to identify and interpret threat impacts to fish, wildlife and habitat across the northeast region. For example, after states completed their 2005 State Wildlife Action Plans, in which numerous threats to fish, wildlife and habitats were identified, the Association of Fish and Wildlife Agencies compiled information from these plans noting 37 common, recurring threats to SGCN or their habitats in the northeast region (Table 3.2) (AFWA Unpublished 2011). The most frequently mentioned threats included invasive species (noted by 100% of northeast states) and industrial effluents; commercial and industrial areas; housing and urban development; and agricultural and forestry effluents (all of which were mentioned by at least 83% of northeast states). Other important challenges identified by 50% or more of the northeast states included: dams and water management; habitat shifting and alteration; recreational activities; roads and railroads; storms and flooding; temperature extremes; logging and wood harvesting; problematic native species; harvest or collection of animals; lack of information or data gaps; and droughts. Recent work in the northeast states has emphasized the importance of additional, emerging threats such as climate change, exurban developments, new invasive species, and diseases.

Fig. 3.1. Map of the northeastern United States region encompassed by this Plan.

Table 3.2. Threats identified by northeastern states (Maine to Virginia) in the 2005 State Wildlife Action Plans (in descending order of occurrences), coding is based on the International Union for Conservation of Nature (IUCN) threats classification (when available). Adapted from (AFWA Unpublished 2011; Terwilliger Consulting & NEFWDTC 2013).

IUCN LEVEL 1		IUCN LEVEL 2	
Code	**Description**	**Code**	**Description**
8	Invasive & Other Problematic Species & Genes	8.1	Invasive Non-Native/Alien Species
9	Pollution	9.1 9.2 9.3	Household Sewage & Urban Waste Water Industrial & Military Effluents Agricultural & Forestry Effluents
1	Residential & Commercial Development	1.1 1.2	Housing & Urban Areas Commercial & Industrial Areas
6	Human Intrusions & Disturbance	6.1	Recreational Activities
7	Natural System Modifications	7.2	Dams & Water Management/Use
11	Climate Change & Severe Weather	11.1 11.4 11.3	Habitat Shifting & Alteration Storms & Flooding Temperature Extremes
	Barriers/Needs		Lack of biological information/Data gaps
11	Climate Change & Severe Weather	11.2	Droughts
4	Transportation & Service Corridors	4.1	Roads & Railroads
5	Biological Resource Use	5.1 5.3	Harvesting/Collecting Terrestrial Animals Logging & Wood Harvesting
7	Natural System Modifications	7.3	Other Ecosystem Modifications
8	Invasive & Other Problematic Species & Genes	8.2	Problematic Native Species
5	Biological Resource Use	5.4	Harvesting Aquatic Resources
9	Pollution	9.5	Airborne Pollutants
	Barriers/Needs		Natural Resource Barriers: Low-population levels, insufficient habitat requirements, etc.
9	Pollution	9.4	Garbage & Solid Waste
2	Agriculture & Aquaculture	2.2	Wood & Pulp Plantations
9	Pollution	9.6	Excess Energy

	Barriers/Needs		Lack of capacity/funding for conservation actions Lack of education/outreach with public and other stakeholders
7	Natural System Modifications	7.1	Fire & Fire Suppression
2	Agriculture & Aquaculture	2.1	Non-Timber Crops
1	Residential & Commercial Development	1.3	Tourism & Recreation Areas
	Barriers/Needs		Lack of monitoring capacity/infrastructure Lack of capacity/infrastructure for data management Administrative/political barriers
4	Transportation & Service Corridors	4.3	Shipping Lanes
5	Biological Resource Use	5.2	Gathering terrestrial plants
3	Energy Production & Mining	3.2	Renewable Energy Mining & Quarrying
	Other: Non-IUCN Threat		Non-IUCN Threat

Recognizing the need for more structured assessments, Anderson & Olivero Sheldon (2011), Anderson et al. (2013a; 2013b), and Terwilliger Consulting & NEFWDTC (2013) compiled, analyzed or summarized threats to fish and wildlife across the region. These assessments highlighted multiple threats in every major habitat (Table 3.3), each with consequences for SGCN in the Northeast and Pennsylvania. The resulting reports serve as the foundation for the regional threats overview in this section.

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Table 3.3. Threats to key habitats in the northeast region. Adapted from Terwilliger Consulting & NEFWDTC (2013).

IUCN Code (Level 1)	Habitat Type-> Threat/Stressor Description	Forests	Wetlands	Lakes and Ponds	Rivers and Streams	Coastal Zones	Uncommon [Unique] Habitats
1	Development	●	●	●	●	●	●
	Fragmentation	●	●	●	●	●	●
	Impervious Surfaces			●	●	●	
2	Agriculture		●				
3	Energy Development[1]	●	●	●	●	●	●
4	Roads	●	●	●	●	●	●
7	Dams			●	●		
	Water Flow				●		
8	Invasive Species	●	●	●	●	●	●
9	Pollution	●	●	●	●	●	
11	Soil Erosion		●	●	●	●	

[1]Off-shore, hydraulic fracturing, wind, biomass

Habitat Loss and Degradation

(IUCN Level 1: Codes 1, 4, 9)

Since its colonization approximately 400 years ago, the Northeast continues to be the most densely populated region in the United States (Moore et al. 1997), and this population is projected to increase by nearly 6 million (10%) between 2000 and 2030. Not surprisingly given this dense human population, “housing and urban development” was identified as a top threat to every state’s key wildlife habitats and SGCN in the 2005 State Wildlife Action Plans (Table 3.2). Commercial and industrial development inevitably accompanies urban sprawl, compounding this threat. More recent commercial developments in the Appalachian region include expansion of wind turbine (Energy) and communication towers on ridgetops, as well as the rise in “big-box developments” (e.g., superstores and regional distribution facilities). Even in northern New England, one of the most heavily forested regions in the country, most forest habitat is fragmented by networks of scattered development and roads. Transportation infrastructure, including roads, railways, and tunnels, contribute to fragmented habitat and interrupt wildlife travel corridors. Fragmentation subdivides contiguous natural land into smaller patches, resulting in each patch having more edge habitat and less interior habitat. Because edge habitat contrasts strongly with interior habitat, the surrounding edge habitat tends to isolate the interior region and contribute to its degradation. Thus, fragmentation can lead to an overall deterioration of ecological quality and a shift in associated species from “interior specialists” to “edge generalists.” Habitat fragmentation can also limit dispersal which may contribute to reduced genetic variability as well as increases in: exposure to human activity, rates of parasitism, predation and disease, and exposure to introduced species (Ewers and Didham 2006).

The northeast region is inhabited by 71 million people and is paved with 732,000 miles (117,804 kilometers) of permanent roads, but people and roads are not distributed randomly across the region (Anderson & Olivero Sheldon 2011). Permanent roads are the primary fragmenting feature providing access into intact, interior regions, and decreasing the amount of sheltered secluded habitat preferred by many species. Moreover, heavily used paved roads create noisy disturbances that many species avoid, and the roads themselves may be barriers to movement of small mammals, reptiles, and amphibians. These roads have caused shifts in the type and abundance of wildlife, including a decrease in forest-interior species, a spike in the abundance of open habitat species, and an increase in forest generalists and game species (Forman et al. 2003; Anderson et al. 2013a).

The effects of development can span multiple habitat types such as creating fragmenting features for aquatic and adjacent shorelines habitats. Coastal developments typically involve beach stabilization that interferes with natural stabilizing mechanisms, such as beach grass establishment. Stabilized cliffs deprive downstream beaches of a sediment supply while jetties and groins interrupt shoreline drift of sediments. On the Atlantic Coast, trails, roads, and walkways exacerbate erosion by creating channels through the dunes where winds and waves can overwash interdunal areas with salt water.

In a region with several geographically small states and high human-population densities, the combination of large metropolitan areas and industries results in significant human-generated waste, including household sewage, solid waste, and industrial effluents (Terwilliger Consulting & NEFWDTC 2013). Pollutants from these sources impair key riparian, aquatic, and terrestrial habitats throughout the region. Changes in water quality and quantity now pose serious threats to all northeastern aquatic systems including rivers, streams, inland and coastal wetlands, lakes, and ponds. Buildings and infrastructure in the Northeast reflect its older character, often containing out-of-date septic and wastewater systems. Household sewage, garbage, solid waste, storm water run-off, and other types of urban waste generated by the many northeastern cities and towns leach residual contaminants into groundwater and riparian areas. Garbage and solid waste are of major concern, and throughout the region many landfills are closing and seeking ways to convert trash into energy. Impairments to aquatic and terrestrial habitats by residential development are exacerbated by industrial developments that are generally located near populated areas with essential water and transportation networks. These developments further contribute to stormwater runoff and ever-increasing impervious surfaces, posing a major threat to small streams and the aquatic communities they support. Roadway runoff, acid mine drainage, siltation and associated sedimentation, and even acid deposition and mercury originating in the industrial Midwest, can degrade soil chemistry (Terwilliger Consulting & NEFWDTC 2013).

As a non-point source of pollution, soil erosion, runoff and siltation are also substantial threats to water quality and associated aquatic life (Waters 1995; Palone & Todd 1997). Across the United States, siltation has been noted as the most prevalent pollutant contributing to stream impairment (Waters 1995). Discussed later in this chapter, a contributing factor to erosion and runoff is impervious surfaces that allow water to flow more rapidly into receiving waterways thus increasing flooding and bank erosion (Anderson 2013a). Consequently, stream channels can become wider and less stable further intensifying stream bank erosion. Poor land use practices that reduce protective terrestrial vegetative cover can further increase erosion and runoff. Degraded terrestrial habitats resulting from, and contributing to, accelerated erosion and soil loss would presumably have reduced capacity to support terrestrial wildlife.

High-density anthropogenic development of natural habitats can alter local hydrology, increase stress to habitats from recreational activities, contribute to introduced invasive species with vehicles as a vector, and bring significant disturbance to the area. Urbanization and forest fragmentation are inextricably linked to the effects of climate change, and the dispersal and movement of forest plants and animals are disrupted by urban development and roads (McDonnell & Pickett 1990; Anderson et al. 2013a).

As the population in the region continues to grow, loss and degradation of habitat will continue to impact wildlife, especially when conversion exceeds land conservation. In the Northeast, 16% of the region is secured against conversion while 28% of the land has converted to development or agriculture (Anderson & Olivero Sheldon 2011). Conversion to development or agriculture outweighs total conservation by a factor of 2-to-1. Moreover, only 5% of the land is conserved primarily for nature, and 11% is conserved for multiple uses. Essentially, for every 1 acre (0.405 hectare) conserved for nature, 5 acres (2.02 hectares) have been converted to development. In spite of great successes, the pattern of protection reveals widespread and fundamental biases in the network of protected areas, with significant implications for biodiversity (Anderson & Olivero Sheldon 2011).

Threats to Terrestrial Habitats

Adapted from Anderson et al. (2013a)

In their comprehensive regional assessment, Anderson et al. (2013a) used newly released region-wide spatial datasets to illustrate threats to, and condition of, habitats. The following sections are adapted from their findings.

Predicted Land Use Changes from Development

Understanding future land-use changes can inform conservation strategy development of resource managers. In their assessment, Anderson et al. (2013a) found the types of habitats affected reflect the general pattern of future development in the region, which is expected to be concentrated in the coastal plain, valley bottoms, and low elevations. Detailed summary of current and predicted acreage losses by habitat type are provided in Anderson et al. (2013a).

In the Northeast, from 2010 to 2060, the average estimated conversion of natural habitats to development is predicted to be nearly 5% (Tayyebi et al. 2013), with wetlands more affected (10% loss) than uplands (5% loss) (Anderson et al. 2013a). Among all upland habitats assessed, the 5 most threatened types were identified in the coastal plain (Table 3.4). Hardwood Forest is one of the dominant matrix-forming forest types with an extensive estimated actual acreage loss of 296,000 acres

(119,787 hectares). Central Atlantic Coastal Plain Maritime Forest and the small-patch Serpentine Woodlands also are among the 5 most threatened habitats. Conversely, during this same 50-year period (2010 to 2060), most montane forest habitats and small-patch outcrop, summit, cliff and flatrock habitats are estimated to have little loss to development (Anderson et al. 2013a).

Notable losses in wetlands are predicted in tidal habitats, flatwoods, floodplains and swamps (Table 3.4). The tidal wetland on the south shore of the James River (North Atlantic Coastal Plain Brackish/Fresh and Oligohaline) is predicted to lose almost one-fifth (17.4% loss) of its current extent. Among other habitats assessed by Anderson et al. (2013a), the greatest absolute loss of 109,524 acres (44,328 hectares) is estimated for the North-Central Appalachian Acidic Swamp (8% loss). Peatlands are expected to be mostly free from development pressure with 4 types of Northern Peatland (i.e., Boreal-Laurentian Bog, Laurentian-Acadian Alkaline Fen, Acadian Maritime Bog, Boreal-Laurentian-Acadian Acidic Basin Fen) (0.2% – 0.4% loss) and 1 type of Coastal Plain Peatland (i.e., Atlantic Coastal Plain Peatland Pocosin and Canebrake) (0.01% loss) expected to have the least development.

Table 3.4. Predicted percent habitat loss in the northeast region, 2010-2060 (Tayyebi et al. 2013). A complete list of habitats and predicted percent loss can be found in Anderson et al. (2013a).

Upland (Macrogroup: *Habitat*)	**Predicted % Loss**
Coastal Grassland and Shrubland: *North Atlantic Coastal Plain Heathland and Grassland*	23.1
Central Oak-Pine: *Maritime Forest (North Atlantic)*	22.1
Southern Oak-Pine: *Maritime Forest (Central Atlantic)*	19.7
Glade, Barren and Savanna: *Small-patch Serpentine Woodlands (Central Atlantic)*	17.0
Central Oak Pine: *Hardwood Forest (North Atlantic)*	14.6
Wetland	
Tidal Marsh: *North Atlantic Coastal Plain Brackish/Fresh & Oligohaline Tidal Marsh*	17.4
Central Hardwood Swamp: *North-Central Interior Wet Flatwoods*	14.6
Central Hardwood Swamp: *Central Interior Highlands and Appalachian Sinkhole and Depression Pond*	13.9
Southern Bottomland Forest: *Southern Piedmont Lake Floodplain Forest*	12.3
Large River Floodplain: *North Atlantic Coastal Plain Large River Floodplain*	10.9
River and Stream	
Tidal Large River: *Tidal Large River*	60.3
Tidal Small and Medium River: *Tidal Small and Medium River*	55.6
Tidal Headwaters and Creeks: *Tidal Headwaters and Creeks*	49.9
Headwaters and Creeks: *Moderate Gradient, Cool, Headwaters and Creeks*	48.8
Headwaters and Creeks: *Low Gradient, Warm, Headwaters and Creeks*	45.7

Habitat Fragmentation

The scope of habitat fragmentation within the Northeast can be assessed in a geographic information system (GIS) using a Landscape Condition Index (LCI) (also Landscape Context Index) (Anderson et al. 2013a). The LCI represents the relative amount of development, agriculture, quarries, roads, or other fragmenting features directly surrounding each (98.4 foot, 30 meter) cell (pixel) of land (Anderson et al. 2013a), thus providing an estimate of isolation and current encroachments on each cell. Values for the LCI range from 0 to 400 with a LCI score <20 indicating an area surrounded primarily by natural cover (i.e., more intact system). Progressively higher LCI scores indicate increasing encroachment by roads, development, and agriculture (Fig. 3.2).

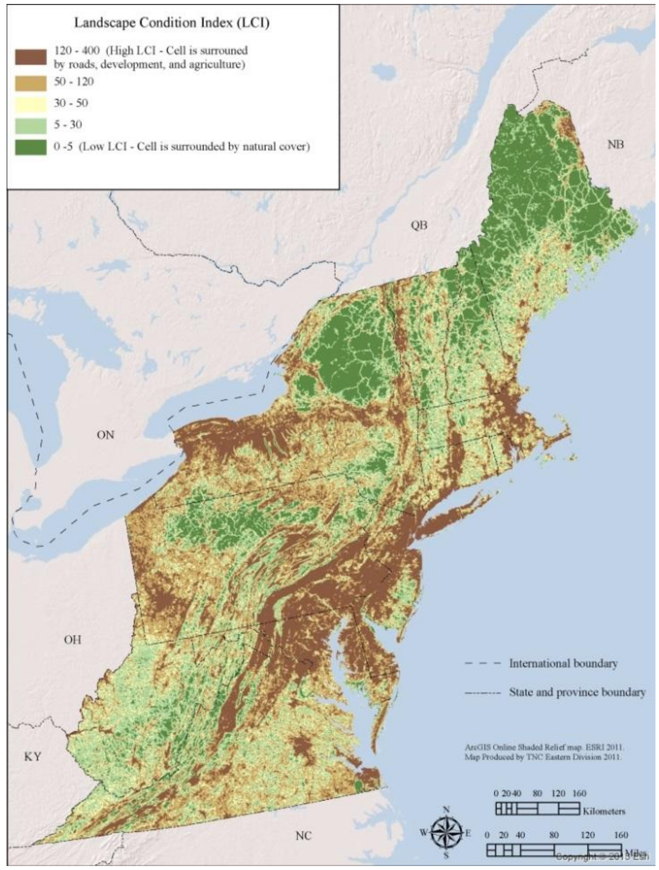

Fig. 3.2. Distribution of fragmented habitats as determined using the Landscape Condition Index (LCI), in the northeastern United States. (Source: Anderson et al. 2013a).

The mean LCI score for natural habitats in the northeast region ranged from 1.1 (best) to 140 (worst), with an average of 41. The average score for all lands in the region increased to 68 when developed and agricultural lands are included. Upland habitats (LCI=40) had a lower average score than the wetland habitats (LCI=55). High-elevation forests and patch systems were least fragmented, with LCI scores <10 for alpine, outcrops and summits, and northern spruce fir habitats. The Glade, Barren, and Savanna macrogroup (i.e., a level of habitat category) were highly fragmented with an average LCI of 62. The Piedmont Hardpan Forest (LCI = 111) and Eastern Serpentine Woodland (LCI = 103) were the only terrestrial habitats with LCI scores exceeding 100.

Peatlands were found to have the most surrounding natural cover among wetlands, with Atlantic Coastal Plain Peatland Pocosin and Canebrake (LCI=1), Boreal-Laurentian Bog (LCI=4), Boreal-Laurentian-Acadian Acidic Basin Fen (LCI=7), and Northern Appalachian-Acadian Conifer-Hardwood Acidic Swamp (LCI=12) all with scores below 15. The habitats with the poorest scores included 2 limestone-related habitats: North-Central Interior and Appalachian Rich Swamp (LCI=92) and Central Interior Highlands and Appalachian Sinkhole and Depression Pond (LCI=140), yet limestone geology has been found to support a rich diversity of flora and fauna (Anderson and Ferree 2010). Also scoring poorly were the North Atlantic Coastal Plain Basin Swamp and Wet Hardwood Forest (LCI=92) and North-Central Interior Wet Flatwoods (LCI=122).

Threats to Forests

(IUCN Level 1: Codes 1, 4)

Habitat Loss

Historically, the northeast region was 91% forested, but nearly one-third of this habitat, about 39 million acres (15.7 million hectares), is now developed. Despite this development, the region has a long history of public and private conservation (Anderson & Olivero Sheldon 2011) and it is important to consider lands conserved for nature. Anderson & Olivero Sheldon (2011) found that 20 million acres (8.9 million hectares) of forest have been secured against conversion, including 6.5 million acres (2.6 million hectares) of forest secured primarily for nature conservation and 13.9 million acres (5.6 million hectares) secured for multiple uses, such as forest management. When lands secured primarily for nature are considered across the region, lands lost to development exceed forested lands secured for nature at a ratio of 6-to-1 and the secured lands are not evenly distributed across forest types. For example, Upland Boreal Forests are 30% secured with 12% secured for nature, whereas Northern Hardwood Forests are 23% secured with 8% primarily for nature and, Oak-Pine Forests with only 17% secured and 5% primarily for nature.

Fragmentation, stand age and size

On average, 43% of forests are in blocks of less than 5,000 acres (2,023 hectares) and are completely encircled by major roads, resulting in an almost 60% loss of local connectivity between habitats. Conservation has been an effective strategy for preventing fragmentation, with a high proportion of conserved land within most of the remaining large contiguous forest blocks. Yet, within these larger blocks, understanding forest condition can inform management decisions. At the regional scale, forests average only 60-years old and are overwhelmingly composed of small trees 2-to-6 inches (5.08-to-15.24 centimeters) in diameter (Anderson & Olivero Sheldon 2011; USDA-FS 2009). Approximately two-thirds (68%) of these forest stands averaged between 50 and 90 years old. Of almost 7,000 forest samples collected in this region by the U.S. Forest Service's Forest Inventory and Analysis Program, Upland Boreal Forests were the most heavily harvested (Anderson & Olivero Sheldon 2011; USDA-FS 2009). No forest stands were dominated by old trees or had the majority of their canopy composed of trees over 20 inches (50.8 centimeters) in diameter. Compared to regional forest assessments, the majority of Pennsylvania's forests are 95 to 125 years old, originating from widespread clearing during the final decades of the 19th century to fuel the industrial revolution (PADCNR 2010b).

Threats to Rivers and Streams

IUCN Level 1: Codes 1, 4, 7)

Water quality in rivers and streams reflects what is happening on the land, thus the ecological integrity of aquatic habitats is influenced greatly by surrounding terrestrial habitats. Within these aquatic systems, instream structures can prevent species dispersal, alter flow, and reduce connectivity. Anderson et al. (2013a) assessed aquatic habitat condition using 6 metrics: impervious surfaces, riparian land cover, road-stream crossings, dam type and density, flow alteration from dam storage, and network size. We provide a brief overview of the study below.

Impervious Surfaces

Impervious surfaces (e.g., roads, parking lots, roofs) prevent percolation of precipitation into soils, and instead accelerate runoff into waterways, which can increase peak flows, pollution and water temperatures, and channel erosion, (Anderson et al. 2013a). Biological impacts also may be reflected in increasing levels of imperviousness such with reduced maximum species richness and Index of Biotic Integrity (IBI) scores (Wang et al. 2001). To assess the extent of impervious surfaces in the region, Anderson et al. (2013a) summarized the amount of impervious cover for the total upstream watershed of each stream reach. For this assessment, Anderson et al. (2013a) used the 2006 National Landcover Impervious Surface Dataset (Fry et al. 2011). After data compilation, each stream and river reach in the region was grouped into 1 of 4 impact categories guided by the thresholds highlighted in King & Baker (2010).

<u>Watershed Percent Imperviousness Impact Categories</u>

- Class 1: Undisturbed: 0 < 0.5%
- Class 2: Low impacts: 0.5-2%
- Class 3: Moderate Impacts: <u>></u> 2-10 %
- Class 4: High Impacts: <u>></u> 10%

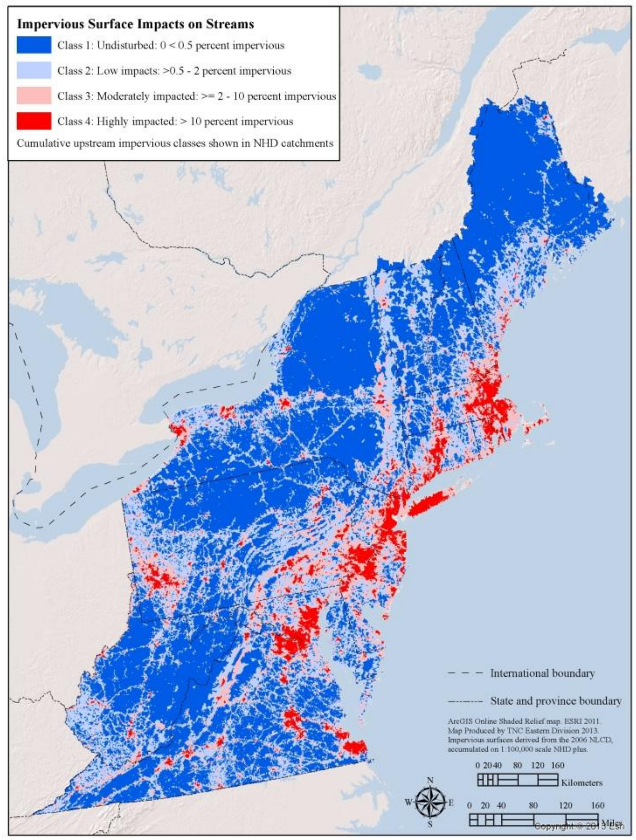

Fig. 3.3. Regional distribution of impervious surfaces. (Source: Anderson et al. 2013a).

For all northeast stream and river types, this analysis found 53% were undisturbed by impervious surface impacts (0 < 0.5% impervious) and 30% were in the Low-Impact Class (0.5%-2% impervious). Yet, 12% were in the Moderately Impacted Class (<u>></u> 2% - 10% impervious), and 5% were in the Highly Impacted class (<u>></u> 10% impervious), particularly along the Atlantic coast (Fig. 3.3) (Anderson et al. 2013a). Relatively low levels of impervious surface can have ecological implications for stream systems.

Riparian Land Cover

Riparian zones are the transition between aquatic and terrestrial habitats and thus are ecologically diverse, supporting rare and common species and natural communities (Anderson et al. 2013a). As a transitional area, riparian zones provide many important functions such as nutrient exchange, modifying hydrology, bank stabilization, and in forested riparian buffers, thermal control by trees (Palone & Todd 1997). To assess the extent and condition of riparian land cover in the Northeast, Anderson et al.

(2013a) considered the riparian zone within 328 feet (100 meters) on either side of mapped streams and rivers. Across the northeast region, 73% of the riparian land is in a natural condition, with the majority (56%) in forested cover. Of the converted riparian land, 16% is in agricultural use, 10% in low-intensity development and, 2% in high-intensity development. Currently, in the Northeast, conversion of this natural habitat exceeds conservation 2-to-1, with 27% of riparian areas converted to development or agriculture and 14% secured for biodiversity or multiple uses (Anderson & Olivero Sheldon 2011).

The condition of riparian habitat in the Northeast was also summarized in a Riparian Landcover Index (Anderson et al. 2013a). This index is based on the percent of development and agriculture in the riparian zone. Index scores range from "0" (completely natural) to "100" (fully developed). Major stream habitat types with the highest index scores (i.e., more disturbed) included warm large rivers, moderate-gradient cool headwaters and creeks, and tidal large rivers. Low-intensity development and agriculture were among the more common types of disturbances. By comparison, low-gradient cold headwaters and creeks, low-gradient cold small rivers, and cold medium rivers were found with higher levels of intact riparian areas (Anderson et al. 2013a).

Road Stream Crossings

Improperly designed road-stream crossings can fragment stream networks by restricting or preventing aquatic organism passage, and also disrupt ecosystem processes such as hydrology, sediment transport, and large woody debris transport (Jackson 2003; Anderson et al. 2013a). In the northeast region, the density (average number of road crossings for every 100 miles (161 kilometers) of stream) varied among habitat types with an average of 114 road crossings/100 miles of headwaters and creeks (Anderson et al. 2013a). The least impacted habitats were low-gradient, cold headwaters and creeks (30) (number indicates number of road crossings/100 miles of stream), tidal headwaters and creeks (86), and moderate gradient, cold, headwaters and creeks (92). The most highly impacted stream types were moderate-gradient, cool headwaters (167) and high-gradient, warm headwaters (159) (Anderson et al. 2013a).

Dam Type and Density

The ecological effects of dams on aquatic systems are well-known and include: altered flow regime, sediment transport and loss of movement by aquatic biota (Natural System Modification, Dams). Isolation and reduced access to habitat due to dams has been linked to the precipitous decline of many North American fish and mussels over the last 50 years (Busch et al. 1998; Pringle et al. 2000; Fausch et al. 2002). The northeast region has an average of 7 dams per 100 miles (161 kilometers) of stream (Anderson & Olivero Sheldon 2011). Several northeast states have programs to remove unwanted dams and restore habitat connectivity and, through the Regional Conservation Needs (RCN) Grants Program, The Nature Conservancy (TNC) prepared the first regional assessment of aquatic habitat connectivity (Martin and Apse 2011; Terwilliger Consulting & NEFWDTC 2013).

Anderson et al. (2013a) characterized the type and distribution of dams across the northeast region. The analysis included 13,824 dams on streams with drainage areas > 1 mile^2 (259 hectares). Dams on smaller streams were not considered. Similar to uses of dams in Pennsylvania, regionally the most common uses of dams included impounding waters for recreation, water supply, hydroelectric, and flood control (Fig. 3.4). Hydroelectric dams had their highest density on medium and large rivers, whereas recreational dam density was highest on headwaters and creeks. Small and medium rivers had the highest dam density along with tidal headwaters and creeks. Tidal headwaters and creeks had very high dam densities because dams were built at nearly every head of tide throughout New England and much of the Mid-Atlantic region. The coastal northern states such as Massachusetts, Connecticut, Rhode Island, and New Jersey also had higher densities of dams than other states, which likely reflect the patterns of population density in the early dam-building era of the late 1880s–early 1900s when dams supplied power to many local farms and grist mills. New England and New York also have higher densities of hydroelectric dams, which likely reflect steeper topography and potential for hydropower generation (Anderson et al. 2013a).

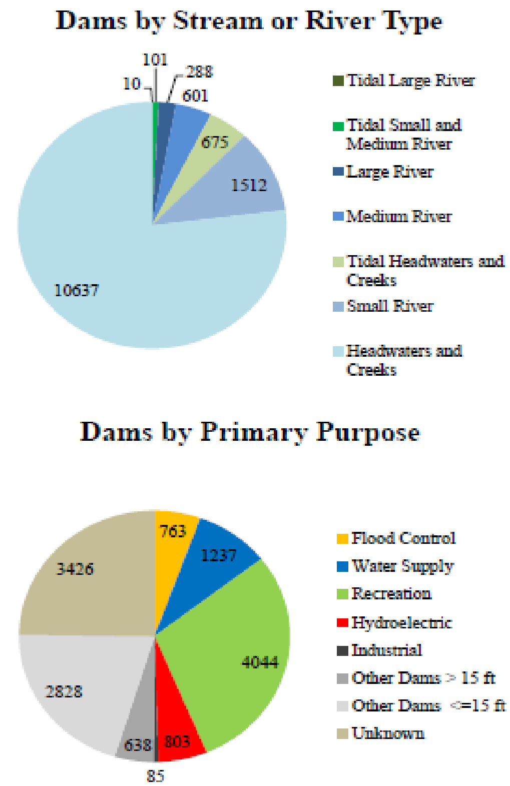

Fig. 3.4. Density of dams by primary purpose and river size-class. (Source: Anderson et al. 2013a).

Alterations to Flow

Hydrology is a driving factor of stream ecosystems and results from 807 U.S. Geological Survey gages in the northeast region showed that 66% of the sites had either altered minimum flows, altered maximum flows, or both; 34% were unaltered (Anderson and Olivero Sheldon 2011). Fish community impairment was most prominently found at sites with: 1) diminished maximum flows; 2) diminished minimum flows; or 3) inflated minimum flows, but unaltered maximum flows (Carlisle et al. 2010; Anderson & Olivero Sheldon 2011). Currently, an estimated 61% of the region's streams have flow regimes sufficiently altered to suggest likely effects on fish communities (Carlisle et al. 2010; Anderson & Olivero Sheldon 2011). One-third of all headwater streams have diminished minimum flows and are therefore subject to desiccation, resulting in habitat loss. Seventy-percent of the large rivers have reduced maximum flows (smaller floods) which can reduce flood-pulse movement of nutrient-rich waters to floodplains.

Storage by Dams: Flow alteration is among the most serious threats to freshwater ecosystems (Anderson et al. 2013a). Natural, seasonal patterns of rising and falling water levels shape aquatic and riparian habitats provide cues for migration and spawning, distribute seeds and foster their growth, and enable rivers, lakes, wetlands, and estuaries to function properly (Poff et al. 1997; Bunn & Arthington 2002; Anderson et al. 2013a). Maximum volume of water capable of being stored behind all dams upstream of a given reach was derived from the U.S. Army Corps of Engineers (USACOE) National Inventory of Dams (USACOE 2010) and compared to the mean annual flow from the National Hydrography Database Plus (NHDPlus) Version 1 dataset from the U.S. Geological Survey (USGS) (USGS 2006) (Anderson et al. 2013a). Dam data for the northeastern United States were compiled from multiple state and federal sources by TNC and edited for use in the Northeast Aquatic Connectivity project (Martin & Apse 2011).

Categories of maximum "Potential Risk of Flow Alteration from Upstream Dam Water Storage" follow Zimmerman (2006) and are based on upstream storage volume of dams as a percent of mean annual flow volume:

- Class 1: < 2% Very low risk
- Class 2: >= 2 < 10% Low risk
- Class 3: >= 10 < 30% Moderate risk
- Class 4: >= 30 < 50% High risk
- Class 5: >= 50% Severe risk

From this analysis, the proportion of miles in the moderate-to-severe risk category increased as the size of the freshwater system increased. Collectively, rivers also were much more impacted than headwaters-creeks by upstream dam storage. For example, 94% of all headwater and creek miles were in the very low-risk category, while only 51% of river miles were at very low risk. This reflects the increasing occurrence of large-storage dams as rivers grow in size and the increasing effect of the accumulated upstream water storage behind all upstream dams from the many streams and rivers that flow into a given medium or large river. Considering only the severe risk category, the largest proportion of miles in this category occurs in medium-sized rivers followed by large tidal rivers, tidal medium and small rivers, and small freshwater rivers. Charts in the Northeast Habitat Guides (Anderson et al. 2013b) present the risk of flow alteration from dam water storage information for each river type.

Water Use (Withdrawals): Water withdrawals in streams can seriously affect water quality and available habitats for aquatic life and 2 RCN projects focused on this hydrological feature. Defining environmental flows seeks to preserve or restore enough variability in these hydrologic measures to protect the ecologic functions essential to diverse aquatic communities (Taylor et al. 2013). For tributaries of Lake Erie, Lake Ontario, and the Upper St. Lawrence River, the Ecological Limits of Hydrologic Alteration (ELOHA) framework was used to develop a spatially explicit process for evaluating the ecological impacts of new water withdrawals (Poff et al. 2010; Taylor et al. 2013). From this work, information is now available to develop and implement instream-flow standards for managing the Great Lakes surface waters and groundwaters of New York and Pennsylvania under the terms of the Great Lakes Compact 2005 (Great Lakes-St. Lawrence River Basin Water Resources Council (Compact Council 2005). Additional multi-state benefits include: testing transferability of the holistic ELOHA-based technique being developed in the Susquehanna Basin to the Great Lakes Basin; guidance on implementation of the Great Lakes Compact in at least 2 states, with useful information for other states and provinces in the Great Lakes Basin that are part of, or work closely with the Northeast Association of Fish and Wildlife Agencies (NEAFWA, e.g., Vermont, Ontario, Quebec, Ohio); assessment and documentation of the transferability of the project methods and models, to enable other NEAFWA states to determine the utility and applicability of the approach to their states or watersheds (Taylor et al. 2013; Terwilliger Consulting & NEFWDTC 2013).

Network Size

Anderson et al. (2013a) defined a connected flowing aquatic network based on the set of stream and river segments bounded by fragmenting features (dams) and/or the topmost extent of headwater streams. As a factor associated with density of dams, connectivity within a river and stream network is essential to healthy freshwater ecosystems (Anderson et al. 2013a) and:

- Allows movement throughout the network to find the best feeding and spawning conditions.
- Enables individuals to colonize, recolonize, and migrate to locations where conditions are more suitable for survival during times of stress.
- Facilitates maintenance of metapopulations and accompanying genetic diversity.
- Enables water flow, sediment and large woody debris transport, and nutrient regimes to function naturally.

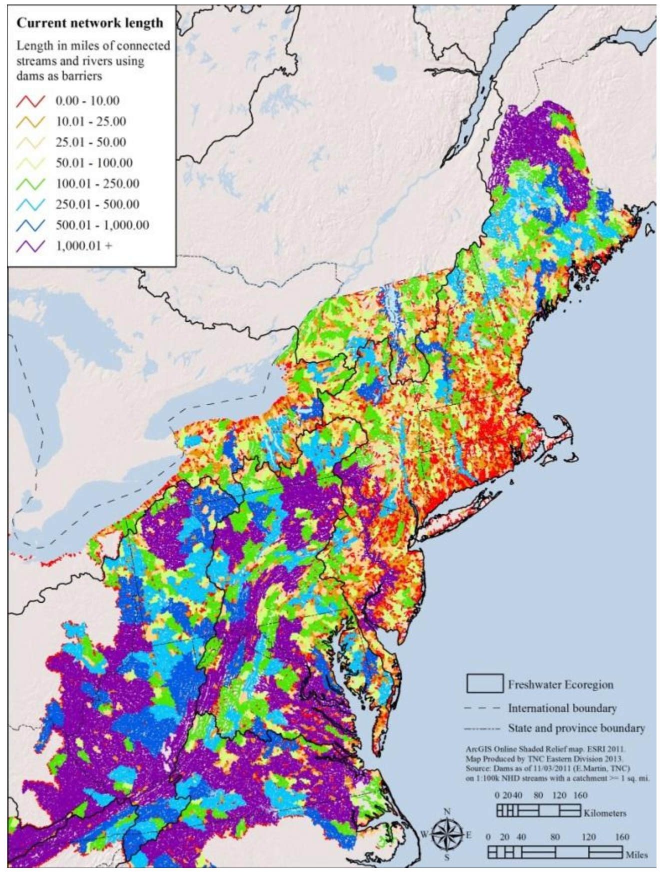

Fig. 3.5. Average network length in the northeastern United States. (Source: Anderson et al. 2013a).

For this feature, Anderson et al. (2013a) calculated total linear length of all segments bounded by dams or the upper most extent of headwater streams, and with drainage areas > 1 square mile (2.59 square kilometers). They found longer networks in the Mid-Atlantic region and shorter networks throughout much of New England, New York, and New Jersey (Fig. 3.5). Similarly, the Mid-Atlantic has a larger mean network size and higher proportion of its networks in the larger size-classes (Anderson et al. 2013a).

In an earlier assessment, Anderson & Olivero Sheldon (2011) noted that historically, 41% of the region's streams were linked in interconnected networks, each over 5,000 miles (8,046 kilometers) long. Today, none of those large networks (i.e., over 5,000 miles; 8,046 kilometers) remain, and even those over 1,000 miles (1,609 kilometers) long have been reduced by half (Fig. 3.6). By comparison, there has been a corresponding increase in short networks (i.e., < 25 miles; 40 kilometers), which now account for 23%

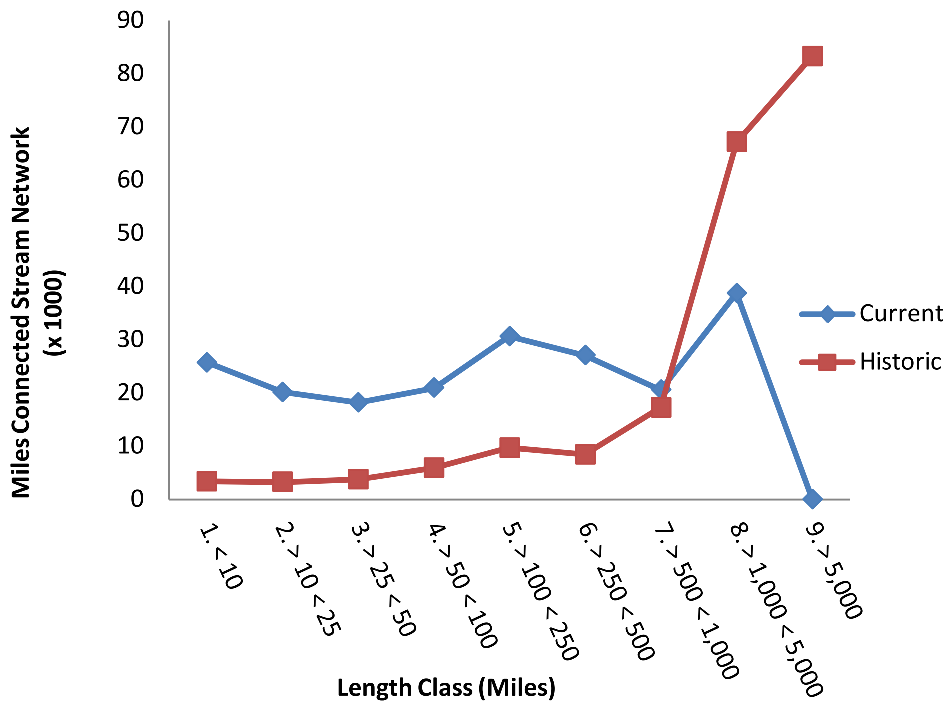

Fig. 3.6. Miles of currently and historically connected stream network by length class (Anderson & Olivero Sheldon 2011).

of all stream miles – up from 3% historically. This highly fragmented aquatic connectivity reflects the density of barriers, such as dams (Natural System Modifications).

Beyond the threats to aquatic habitats noted above, we further highlight threats to major habitat types in the following segments.

Threats to Wetlands

(IUCN Level 1: Codes 1, 2, 4)

Habitat Conversion: Among the most diverse wildlife habitats, wetlands, including swamps, peatlands, and marshes, once covered 7% of the region Anderson & Olivero Sheldon (2011). At least 2.8 million acres (1.1 hectares) and up to 5.6 million acres (2.3 million hectares) of wetlands, cumulatively, approximately one-quarter of the original extent has been converted to development and drained for agriculture. Riverine wetlands, such as floodplain forests, have lost 27% of their historic extent and are only 6% conserved for nature, the greatest discrepancy of any wetland type (Anderson & Olivero Sheldon 2011).

The area immediately surrounding a wetland, its buffer zone, has a strong influence on the quality and diversity of the wetland species richness of birds, amphibians, reptiles, and plants within an individual wetland is negatively correlated with the density of paved roads surrounding a wetland (Forman 2003), with the sensitive impact distances varying from 1,640 feet (500 meters) to 6,561 feet (2,000 meters) depending on the taxa (Findlay & Houlahan 1997). In the Northeast, 66% of these habitats have development or agriculture in 328-foot (100-meter) buffer zones (Fig. 3.7). To assess condition of wetlands across the region, Anderson and Olivero Sheldon (2011) developed an index of disturbance based on development and agriculture in the buffer zone. They developed categories of impact based on the correlation of the impact scores to observed measurements of shoreline human disturbance for sites sampled by the U.S. Environmental Protection Agency (USEPA) National Lake Assessment (USEPA 2009, $R^2 = 0.56$, $p < 0.0001$). They then matched the 3 disturbance categories used in the lake assessment by calculating the mean impact score for the set of known sites in each disturbance category, using the point halfway (log scale) between the means as the criteria:

- Low disturbance 0 < 3.7
- Moderate disturbance >= 3.7 < 15.0
- Severe disturbance >=15.0

Across all wetlands, the results indicated a nearly equal distribution of total acres in each of the 3 impact categories (Table 3.5). By type, tidal wetlands were the most disturbed, with only 15% of them in the undisturbed class. Basin wetlands were the least disturbed with 43% undisturbed, and alluvial wetlands were intermediate with 31% undisturbed. Conservation efforts have secured 25% of the remaining acres including one-third of the largest tidal marshes. The majority of individual wetlands have expanded slightly over the past 20 years, but 67% have paved roads in close proximity and in high densities, and have likely experienced loss of species.

Table 3.5. Percent of wetland acreage in each impact class across wetland type and sub-regions. (Source: Anderson & Olivero Sheldon 2011).

Region	Type	Low Disturbance (%)	Moderate Disturbance (%)	Severe Disturbance (%)
Mid-Atlantic	Alluvial	15	55	30
	Basin	26	37	37
	Tidal	14	49	37
	Total	**18**	**46**	**36**
New England & New York	Alluvial	37	23	40
	Basin	47	24	29
	Tidal	18	24	58
	Total	**43**	**24**	**33**
Region	Alluvial	31	31	38
	Basin	43	26	31
	Tidal	15	44	41
Region Total-All Wetlands		**36**	**30**	**34**

Threats to Lakes and Ponds

(IUCN Level 1: Codes 1, 2, 4, 7)

Habitat Loss to Development: Of the region's nearly 34,000 water bodies, only 13% are fully secured against conversion to development. Very large lakes (over 10,000 acres; 4,046 hectares) are the least conserved of these habitats (4%). As a measure of ecological integrity, using National Lake Assessment (NLA) data from the USEPA (USEPA 2009), biological data collected in 142 lakes (Observed) in the northeast region were compared to reference lakes (Expected). Over 50% of small-to-large water bodies have lost over 20% of their expected plankton and diatom taxa, and a third of the water bodies have lost over 40% of the diversity of these organisms (USEPA 2009; Anderson & Olivero Sheldon 2011). Additionally, Anderson & Olivero Sheldon (2011) noted general correlation ($p > 0.05$) between taxa loss and shoreline conversion, as well as impervious surface in the watersheds of small lakes (10 to < 100 acres; 4 to < 40 hectares).

Shoreline Conversion: Forty percent of the northeast region's water bodies have severe disturbance impacts in their shoreline buffer zones, reflecting high levels of development, agriculture, and roads in these ecologically sensitive habitats. Although these habitats are disturbed, shoreline zones also have a high level of securement and in most lake types the amount of securement exceeds the amount of conversion.

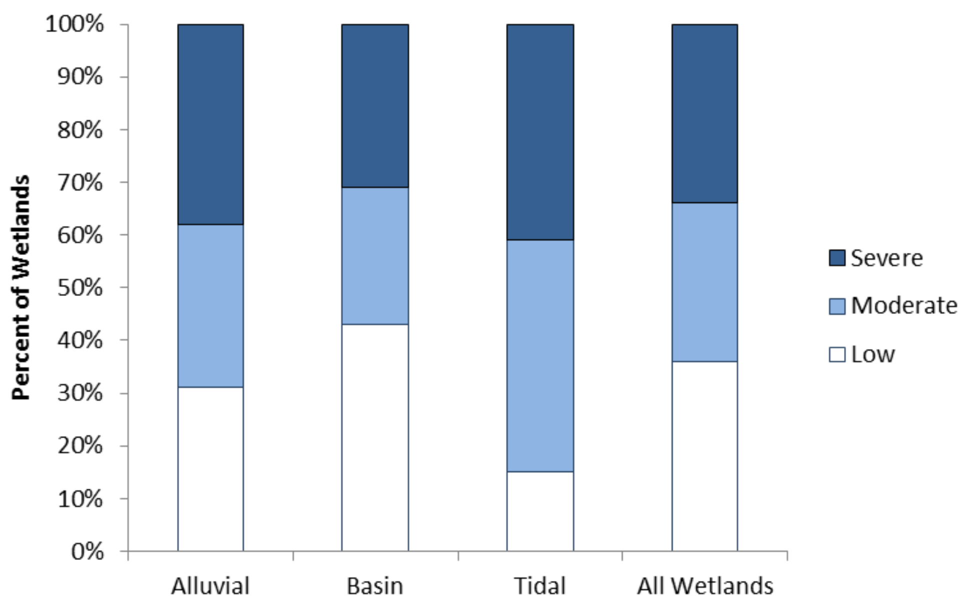

Fig. 3.7. Intensity of disturbance in 161 foot (100 meter) wetland buffer zone. Percent of wetlands in each disturbance class, based upon 435,000 individual wetlands. Only includes wetlands > 2 acres (0.8 hectares). (Source: Anderson and Olivero Sheldon 2011).

Roads, Impervious Surfaces, and Dams: Lakes and ponds in this region are highly accessible; only 7% are located over 1 mile (1.6 kilometers) from a road and 69% less than 0.1 miles (0.16 kilometers) from a road. Vehicles can serve as a vector for transporting invasive species. Therefore, this proximity to roads suggests that most lakes and ponds are likely to have non-native species. Dams are associated with 70% of very large lakes, 52% of large lakes, and 35% of medium-size lakes, and are likely to have altered thermal regimes and water levels.

Threats to Distinctive (Unique) Habitats

(IUCH Level 1: Codes 1, 4, 7)

Habitat Loss: In the Northeast, 11 distinctive, or "unique", habitats support over 2,700 restricted, rare species (Table 3.6). Three geologic habitats (i.e., coarse-grained sands, limestone bedrock, and fine-grained silts) have very high densities of rare species. Unfortunately, these habitats also are the most developed lands, the most fragmented, and in 2 cases, least protected. Conservation (i.e., securement for nature) was equal-to or greater-than conversion on granite settings, on summits and cliffs, and at high elevations. By comparison, habitat conversion to developed conditions was found to exceed conservation for nature on:

- calcareous settings (51:1) because these conditions are prized by farmers for their rich soils
- shale settings (29:1)
- dry flat settings (23:1)
- moderately calcareous settings (19:1)
- low elevation settings (18:1)

These habitats need concerted conservation attention if the full range of biodiversity in the region is to be maintained.

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Table 3.6. Habitat type, geophysical setting and number of rare species with over 50% of their locations reported in each setting, based upon 4 or more occurrences (Anderson & Olivero Sheldon 2011).

Habitat Type	Geophysical Setting	Number of Rare Species
Limestone valleys, wetlands and glades	Calcareous	106
Soft sedimentary valleys and hills	Moderately calcareous	120
Acidic sedimentary pavements and ridges	Acidic sedimentary	656
Shale barrens and slopes	Shale	71
Granitic mountains and wetlands	Granite and Mafic	99
Serpentine outcrops	Ultramafic	19
Coarse sand barrens and dunes	Coarse-grained sediment	395
Silt floodplains and clayplain forests	Fine-grained sediment	88
Alpine meadows and krumholz	High elevation	55
Steep cliff communities	Cliff landforms	55
Wetlands (e.g., bogs, swamp, marsh, fen floodplain)	Wet Flats	479

Fragmentation and Connectivity: Fragmentation and loss of connectivity is pervasive at lower elevations across all geology classes of the northeast region. Even the least-fragmented setting in the region, granite, retains only 43% of its local connectivity. The highest level of fragmentation, with over 80% loss of local connectivity, was found in calcareous settings composed of coarse-grained sands, fine-grained silts, and low elevations under 800 feet (244 meters).

Energy Production

(IUCN Level 1: Code 3)

Regionally, energy extraction is an increasingly substantial threat to SGCN and key habitats, particularly as additional areas of the Northeast are explored for new energy opportunities. These developments can result in large-scale habitat loss or degradation. Hydraulic fracturing, off-shore drilling and wind energy are current forms of extraction that are increasing and, more information on their potential impacts is warranted. For Pennsylvania, this threat is described in Energy.

Offshore Energy Development

Additional regional threats include disturbances to marine birds from offshore energy development activities. To more fully understand the implications of this development, a risk assessment of marine birds in the Northwest Atlantic Ocean is in-progress, under the auspices of the North Atlantic Landscape Conservation Cooperative (NALCC) and partners (NALCC Project 2011-07). This project will develop maps depicting the distribution, abundance and relative risk to marine birds from offshore activities (e.g., offshore drilling and wind energy development) in the northwestern Atlantic Ocean (Terwilliger Consulting & NEFWDTC 2013). The goal is to develop and demonstrate techniques to document and predict areas of frequent use and aggregations of birds and the relative risk to marine birds within these areas. This NALCC project is supporting several components of mapping and technique development by leveraging large, ongoing projects funded by the Bureau of Ocean Energy Management (BOEM), U.S. Department of Energy (USDOE), USGS, and National Oceanic and Atmospheric Administration (NOAA) and involving research groups at the Biodiversity Research Institute, North Carolina State University, City University of New York-Staten Island, the USGS-Patuxent Wildlife Research Center, and the NOAA National Centers for Coastal Ocean Science-Biogeography Branch.

Biomass

With increasing demand for energy, biomass energy systems are a potential source in the northeast region and can include use of: native warm-season grasses, grass monocultures, dedicated deciduous and coniferous woody species, native forest regeneration, and timber stand improvement practices. To understand likely impacts on regional SGCN and habitats, Klopfer (2011) in Regional Conservation Needs (RCN Project 2007-07), made the following observations for major taxonomic groups:

Birds: The most favorable biomass options for birds would be to avoid the removal of existing mature forest and use thinning to acquire biomass material. This would result in a net positive for bird SGCN while minimizing heavy habitat losses of complete stand removal. Where biomass applications are focused on lands presently in agriculture, it would be advisable to replace current agricultural practices with either warm-season grass plantings or dedicated woody plantations for maximum SGCN benefit, as appropriate to the state in which the planting occurs.

Mammals: The maximum benefit to mammal SGCN would be achieved by replacing agricultural crops with either native warm-season grass or early successional woody vegetation systems. Complete removal of mature forests will have the most detrimental impacts, especially if those areas were converted to some sort of system such as dedicated silvicultural practices that use fast-maturing trees in closely spaced rows as opposed to allowing natural stand regeneration (Klopfer 2011).

Amphibians & Reptiles: Amphibians and Reptiles are particularly at risk from conversion of mature forests (particularly deciduous forests) to any type of biomass energy system. The most significant potential benefits are achieved when existing agricultural lands are converted to a dedicated woody crop or allowed to regenerate naturally.

Overall, northeast SGCN will be further impacted if biomass energy activities are focused on forestlands cleared for non-woody biomass system. Benefits could be realized with mature stand thinning and the subsequent increase in understory vegetation, while the most obvious benefits would come from the conversion of intensively managed agriculture to an early successional biomass system.

Invasive and Other Problematic Species, Genes and Diseases

Invasive Species

(IUCN Level 2: Code 8.1)

Non-native invasive species pose a significant threat to SGCN throughout the Northeast. Impacts may be direct (i.e., affecting health or productivity of individual animals), indirect (i.e., affecting habitat or ecosystem processes) or both (Klopfer 2012). Across the region, Klopfer (2012) assessed 238 invasive species within 12 broad taxonomic categories for their potential to adversely affect SGCN. The majority (58%) of these species occurred in seven or more states, with 71 (30%) invasive species common to all northeastern states. By comparison 44 (18%) were reported in only one state suggesting that, despite a general distribution, some invasive species remain localized. Across the region, invasive species predominantly inhabited “forest edge” (115, or 48% of species), followed by 94 species (39%) in pasture and 86 species (36%) in grassland habitats (Table 3.7). The percentage of invasive species was disproportionately higher than SGCN in these same habitats. Plants comprised the majority (68%) of the invasive species. Although extensive, Klopfer (2012) noted the incompleteness of this list and a detailed species-specific evaluation would be required for a more thorough perspective of pervasiveness, severity, and cumulative effects on SGCN.

Table 3.7. Species of Greatest Conservation Need and invasive species by habitat class (Klopfer 2012).

	All SGCN		All Invasive Species	
General Habitat Class	**Number**	**Percent**	**Number**	**Percent**
Freshwater				
Lake	124	19	76	32
River	258	39	59	25
Wetland	206	31	62	26
Marine				
Intertidal	27	4	6	3
Marsh	73	11	17	7
Beach	42	6	12	5
Forest				
Deciduous	43	6	23	10
Coniferous (Hemlock)	7	1	10	4
Coniferous other	41	6	8	4
Mixed	50	7	15	6
Young Forest	14	2	37	16
Other				
Shrubland	56	8	58	24
Grassland	66	10	86	36
Border/Edge	29	4	115	48
Woodland	96	14	77	32
Pasture	46	7	94	39
Agriculture	43	6	61	26
Rock/Cliff	20	3	5	2

The NEFWDTC identified additional threats not specifically captured in the RCN Grant Program projects, but are nevertheless considered notable threats to northeast fish and wildlife and their habitats (Terwilliger Consulting & NEFWDTC 2013). The following threats merit further regional attention:

Wildlife Disease

(IUCN Level 1: Code 8)

Wildlife diseases are impacting a broad range of wildlife, including amphibians, bats, birds, and ungulates. Found in Pennsylvania and described in Diseases, two emerging diseases, fungal dermatitis and white-nose syndrome (WNS) have received regional attention. Since 2009, timber rattlesnakes from separate populations in eastern, central and western Massachusetts have been found with fungal dermatitis, which has been documented as a cause of morbidity and mortality in both captive and free-ranging Viperidae snakes (Jessup & Seely 1981; McAllister et al. 1993; Cheatwood et al. 2003; Terwilliger Consulting & NEFWDTC 2013). Through the RCN Grant Program (RCN Project 2012-03), Perrotti et al. (2012) are actively trying to understand the spread of this disease and factors contributing to its virulence in rattlesnake populations.

Two RCN Grant Program-funded projects also have investigated WNS (*Pseudogymnoascus destructans, Pd*), a fungus that is estimated to have killed more than 5.7 million hibernating bats in the northeast states (discussed more fully for Pennsylvania in Diseases). Reeder et al. (2012) (RCN Project 2007-09) demonstrated that bats affected by WNS arouse from hibernation significantly more often than healthy bats. The severity of cutaneous fungal infection correlates with the number of arousal episodes from torpor during hibernation. Reeder (RCN Project 2010-01) is currently developing methodologies under laboratory conditions to combat WNS in bats by testing potential treatments for efficacy against cultured *Pd*. This study was designed to evaluate the safety of treatments in healthy bats and potential efficacy against *Pd* in hibernating bats.

Insufficient Resources for Conservation

An indirect threat, the lack of resources to support conservation of fish and wildlife species and their habitats, could undermine the good work of state fish and wildlife agencies. Resources dedicated to improving species life history, distribution, abundance, and on-the-ground conservation can proactively preempt listing of species as threatened or endangered species and implement conservation actions to recover species already listed. Great strides have been made through the RCN Grants Program and the LCCs to address regional data deficiencies. Yet, given dynamic environmental conditions (e.g., land use, climate change), support for additional research, surveys and monitoring are insufficient to adequately address the informational and resource management needs and of the northeast regional landscape and its diverse wildlife.

Insufficient conservation of habitats required by Regional Species of Greatest Conservation Need (RSGCN) is a significant threat to these species. For regional species listed as “High Responsibility,” 25% of their known locations are currently on conserved lands, including 9% on land secured primarily for nature. Surprisingly, high-responsibility species are conserved less (25%) than low-responsibility species (32%). For widespread or high-concern species, 32% of their known locations are on conserved land, including 16% on land conserved primarily for nature. Species of concern are declining in many geographic regions. Thus, conservation in the northeast region is only one part of a larger approach to protect these species. Among all species of concern, mammals had the highest percentage of land conserved for their needs (46%), followed by amphibians (40%), birds (36%), and reptiles (26%). Fish had the lowest inventory and habitat protection (14%) (Terwilliger Consulting & NEFWDTC 2013).

Northeast Region – Climate Change Impacts

(IUCN Level 2: Code 11.2. 11.3, 11.4)

This Regional Climate Change section is based on Staudinger et al. (2015a), as distinguished by chapters and associated authors, and has been adapted for the 2015 Pennsylvania Wildlife Action Plan.

Adapted from Bryan, A., A. Karmalkar, E. Coffel, L. Ning, R. Horton, E. Demaria, F. Fan, R. S. Bradley, R. Palmer. 2015a. Chapter 1: Climate Change in the Northeast and Midwest United States. In Staudinger et al. (2015a).

SNAPSHOT

Regional Climate Change
Adapted from Bryan et al. 2015a

Climate Change Feature	Trend
Temperature	✓ **Warming is occurring in all states and seasons.** ✓ **Heat waves are becoming more frequent, more intense, and lasting longer.**
Precipitation	✓ **Annual precipitation is increasing, particularly in winter, though with less certainty in future projections than with temperature.** ✓ **Heavy rainfall events are intensifying, particularly in the Northeast.**
Surface Hydrology	✓ **Streamflow is intensifying, but varies by season and sub-region, and is not proportional to increases in extreme rainfall.** ✓ **Stream temperatures are rising.**
Extreme Events	✓ **Severe thunderstorms may become more severe; tornadoes may decrease in annual number, but increase in daily number.** ✓ **Floods are becoming more intense.** ✓ **Droughts are becoming more frequent.** ✓ **Winters are becoming less severe.**

Introduction

As a broad ecological threat, climate change is anticipated to affect a wide array of SGCN and habitats in the northeast region, although uncertainty remains in the scope and severity, or even the direction of the impacts (i.e., positive, negative).

Increasing data availability and enhanced climate models can assist natural resource managers with developing adaptation strategies and conservation actions to protect and recover SGCN. However, compiling and analyzing these data, as well as technical requirements for interpretation, pose significant challenges for resource managers already tasked with directly managing trust-species imperiled by other threats. Therefore, state fish and wildlife agencies can benefit greatly from advanced climate change research by working with climate scientists who can synthesize data and summarize potential impacts to wildlife.

Recognizing this need, in 2010, the U.S. Department of the Interior (USDOI) (USDOI 2010) Secretarial Order No. 3289 established Climate Science Centers (CSC). In the northeast region, the Northeast Climate Science Center (NECSC) in Amherst, MA is a major resource for acquiring and analyzing regional climate-based data. As an example of their analytical support, NECSC scientists compiled and summarized data for use by states in their 2015 State Wildlife Action Plans (Staudinger et al. 2015a).

Temperature

Over the last century, mean temperature in the Midwest and Northeast has increased by approximately 1.4°F (0.8°C) and 1.6°F (0.9°C), respectively (Hayhoe et al. 2007, 2008; Kunkel 2013). In the Northeast, annual temperature has increased 0.16°F (0.09°C) per decade during the period 1895-2011 and this warming has been more pronounced during winter (0.24°F/decade, 0.13°C/decade), but statistically significant increasing trends are observed in all seasons. Studies suggest that the rate of climatic warming has been faster at higher elevations, though availability of long-term meteorological data sets at high elevations is limited (Diaz et al. 2014; Bryan et al. 2015a; Pepin et al. 2015).

Future projections consistently show continued warming over the next century across the region (Hayhoe et al. 2007, 2008; Rawlins et al. 2012; Kunkel et al. 2013; Ning et al. 2015). All models agree that the climate is warming, but vary in magnitude toward the end of the century, depending on the emissions scenario. The Northeast and Midwest are projected to see average temperature increases that exceed the global average, with potential warming of 4 to 5°F (2.2°C to 2.8°C) annually by 2050-2070 under a high-emissions scenario (Kunkel 2013; Coffel & Horton 2015). The simulated annual changes increase with latitude and inland due to the regulating effects of the Atlantic Ocean and Great Lakes on air temperatures over the surrounding landscapes (Hayhoe et al. 2008; Notaro et al. 2013).

Seasonal changes show more spatial variability (Kunkel 2013), with winter and spring showing higher increases in the north compared to southern Midwest (Fig. 3.8). The greatest warming is projected to occur in northwestern Minnesota and upper New England in winter (6°F, 3.3°C) and in the northeastern states in spring (4-4.5°F) (2.2-2.5°C). Summer and fall show a reversed spatial pattern, with the greatest

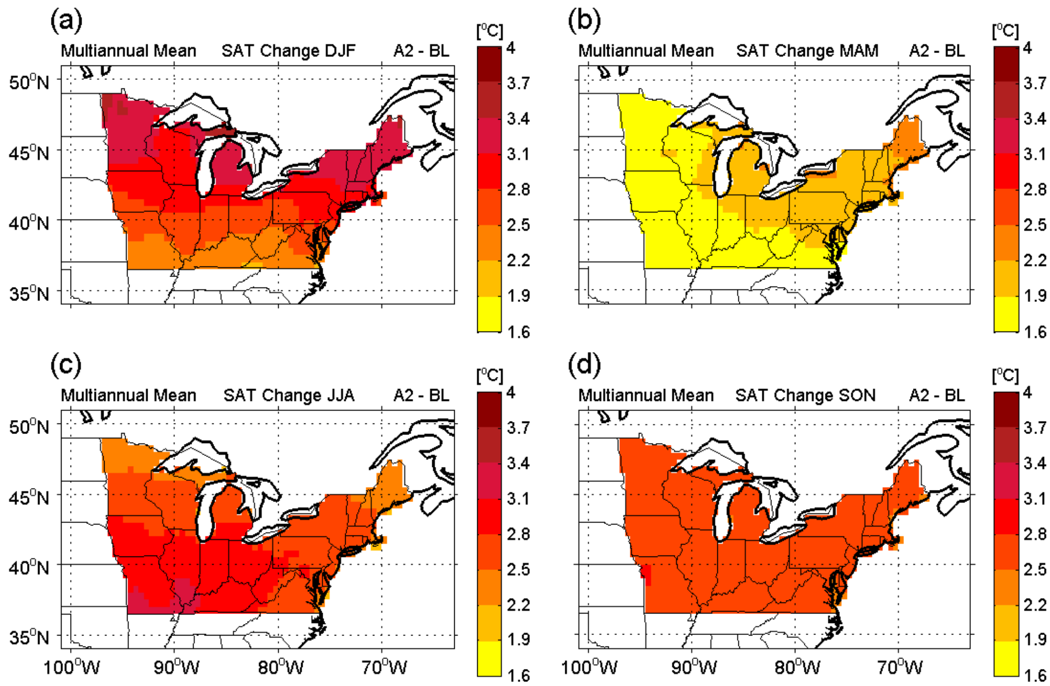

Fig. 3.8. Projected warming across the NE CSC region by season: (a) winter (December, January, February), (b) spring (March, April, May), (c) summer (June, July, August), and (d) autumn (September, October, November). Values represent the differences between the 1979 – 2004 and 2041 – 2070 average temperatures for each season. Multi-model means from the North American Regional Climate Change Assessment Program (NARCCAP), based on a high emissions scenario, are used (Data and maps for Northeast published by Rawlins et al. (2012); maps extended by F. Fan, written communication). (Source: Bryan et al. (2015a)). *Used with permission by the DOI Northeast Climate Science Center.*

simulated increases to be in the southwestern part of the region and a north-south gradient ranging from 4.0 to 6.0°F (2.2 to 3.3°C).

Anthropogenic warming has led to more extreme heat events (Fischer & Knutti 2015). However, a distinct "warming hole" over the past half-century has been observed across the eastern United States, where the number of warm days have been stagnant or slightly decreasing (Alexander et al. 2006; Perkins et al. 2012; Donat et al. 2013). Additionally, linear trends over the past half-century indicate more cool days, albeit slight. Daytime extremes show cooler trends, whereas nights have been getting warmer, with fewer cold nights and more warm nights. Long warm spells early in the spring season are particularly threatening to vegetation as such spells can trigger premature leaf-out and flowering (Cannell & Smith 1986; Inouye 2008), leaving plants vulnerable to frost damage later in the season. Frost damage can affect overall productivity of a plant for the entire growing season (Gu et al. 2008; Hufkens et al. 2012). Trends over the past century indicate the last spring freeze is occurring earlier, at a faster rate than leaf-out, suggesting that damaging late-season spring freezes are becoming less likely (Peterson & Abatzoglou 2014).

Heat wave intensity, frequency, and duration are expected to increase across the United States in the 21st century, with the greatest increases projected in the southwest portion of the northeast and midwest region (Meehl & Tebaldi 2004). Fewer cold days and nights, and more warm days and nights, are expected over the next century (Sillman et al. 2013a, 2013b; Ning et al. 2015). Southern states in the region are projected to experience more additional warm days (days with maximum temperatures exceeding 90th percentile) than northern states, although the Great Lakes region is likely to see the greatest reductions in cold days (days with maximum temperatures below the 10th percentile; Ning et al. 2015). The greatest increases in nighttime minimum temperatures are expected for inland areas and areas at higher latitudes due to reduced snow cover associated with warmer winters (Sillman et al. 2013a, 2013b; Thibeault & Seth 2014). From the Great Lakes northward, the minimum temperature on the coldest night of the year is expected to increase by 19.8°F (11°C) by the end of the century, more than triple the expected increase for areas south of the Great Lakes (Sillman et al. 2013a; 2013b). Projected increases in the daily maximum temperatures are generally greatest inland (Sillman et al. 2013a; 2013b), with the exception of major urban centers along the coast due to heat island effects (Thibeault & Seth 2014). Higher elevations also are likely to see larger increases in the summer daily maximum temperatures, though past observations suggest greater increases in daily minimum temperatures (Diaz and Bradley 1997; Pepin and Lundquist 2008; Diaz et al. 2014; Thibeault & Seth 2014; Pepin et al. 2015). An increase in the inter-annual variability (in addition to the frequency) of extremes heat events also is anticipated under future climate (Ning et al. 2015).

Precipitation

Annual total precipitation has increased over the past century on a global scale (Zhang et al. 2007). In the Midwest and Northeast, the last 2 decades (1991-2012) were wetter than the first 60 years by about 10-15% (Walsh et al. 2014). Based on data from a dense network of station observations from the National Climatic Data Center (NCDC), annual precipitation amounts across the NECSC region have increased at a rate of over 1 inch (2.54 centimeters)/decade since 1895, with the greatest increases of nearly 2.5 inches (6.3 centimeters)/decade in Maine (NCDC 2015).

Over the next century, overall annual precipitation amounts are expected to increase over the NECSC region (Schoof 2015), largely due to greater intensity in precipitation events (Thibeault & Seth 2014). Further, precipitation events are expected to become less frequent (i.e., more consecutive dry days, or extreme dry spells), but last longer (i.e., more persistent) (Schoof 2015; Guilbert et al. 2015). Heavy rainfall events occurring at a reduced frequency raises the risk for both flooding and drought (Horton et al. 2014).

Projections consistently predict wetter winters (Hayhoe et al. 2007; Rawlins et al. 2012; Kunkel 2013; Alder & Hostetler 2013; Schoof 2015), though with more rain than snow. Drier summers are projected, particularly for the southern Midwest, with some areas seeing little change or some increasing. Rainfall events in the summer are anticipated to become more intense and shorter with longer dry periods between events, hence little change in the seasonal total. More frequent severe thunderstorm activity

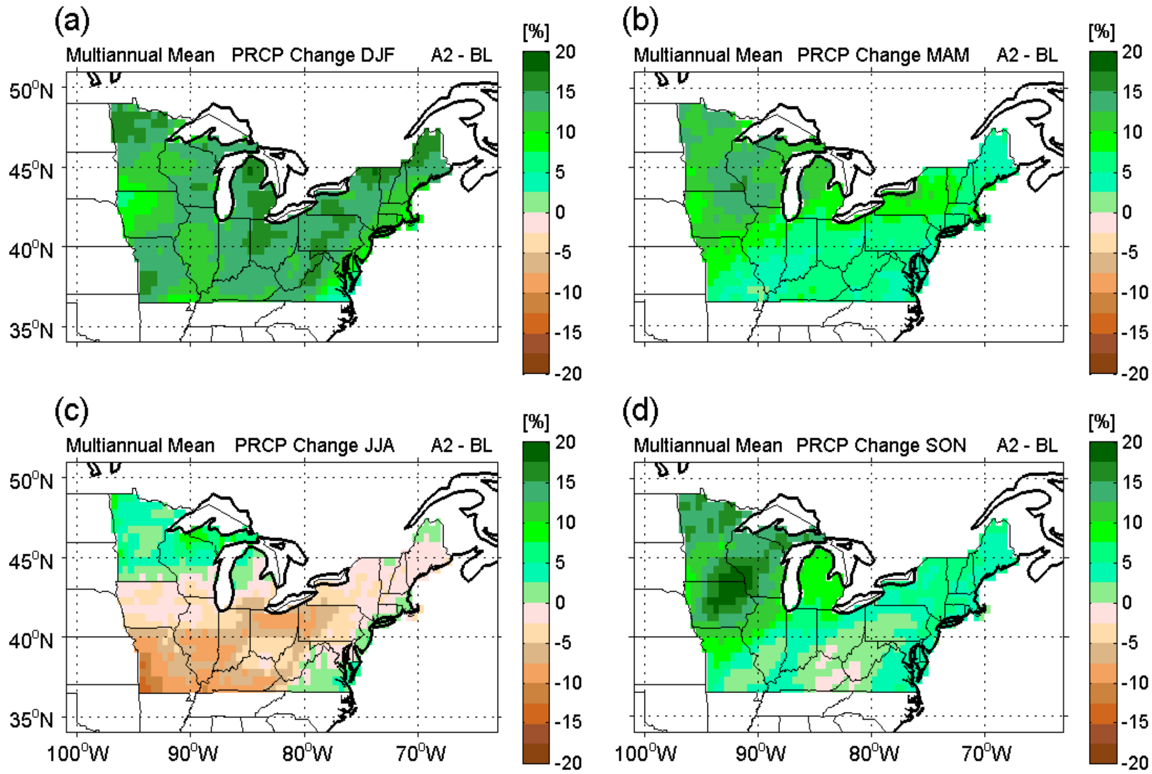

Fig. 3.9. Projected precipitation changes across the NECSC region by season: (a) winter (December, January, and February), (b) spring (March, April, and May), (c) summer (June, July, and August), and (d) autumn (September, October, and November). Percent change is calculated as (future – baseline) / (baseline) × 100% between the 1979 – 2004 and 2041 – 2070 average precipitation for each season. Multi-model means from the North American Regional Climate Change Assessment Program (NARCCAP), based on a high emissions scenario, are used (Data and map for Northeast published by Rawlins et al. (2012); maps extended by F. Fan, written communication). Source: Bryan et al. (2015a). *Used with permission by the DOI Northeast Climate Science Center*.

may mean more frequent hail events in summer (Gensini & Mote 2015). In the Northeast, precipitation may become more persistent in summer and more intense in winter (Guilbert et al. 2015). For spring and fall, model projections agree on small positive changes in the Northeast, which are significant over much of the region in spring and within the level of natural variability in the fall (Rawlins et al. 2012).

Changes in seasonal precipitation amounts vary regionally (Fig. 3.9); wetter conditions are projected for the Northeast and Midwest in winter, spring and fall, with significant drying projected for the southern Midwest in summer. However, some projections over the next century show significant summertime drying in the upper Great Plains (Swain & Hayhoe 2015). In spring and fall, the largest increases are in the northern Midwest. Winter increases do not show a distinct regional gradient. There is however, a lack of confidence in the regional distribution of precipitation, as discussed below (Collins et al. 2013).

Projected changes in precipitation patterns are less robust than for temperature (Hawkins & Sutton 2011; Collins et al. 2013; Knutti & Sedláček 2013), particularly with respect to annual and seasonal totals. Not all models agree on the sign of the change for certain sub-regional averages. Part of the discrepancy can be attributed to challenges simulating cloud formation and convection due to the complex nature of these processes and difficulties representing them in the model. Additionally, not all models adequately capture large-scale climatic drivers of precipitation in the region, such as the Great Plains low-level jet or lake-effect precipitation.

Consequently, models vary widely in the placement of precipitation maxima and minima, and planners should use caution when interpreting spatial distributions of precipitation in future projections. At present, model projections are insufficiently reliable to identify which part of a state or region may experience the most or least precipitation in the future.

The Northeast and Midwest have seen pronounced increases in the frequency and intensity of extreme precipitation events in the past several decades (Groisman et al. 2005, 2013; Kunkel 2013; Schoof 2015; Guilbert et al. 2015), a trend that appears robustly simulated by the latest suite of general circulation models (GCMs) (Scoccimarro et al. 2013; Toreti et al. 2013; Kendon et al. 2014; Wuebbles et al. 2014). Anthropogenic climate change is almost certainly a contributor of heavier precipitation events (Min 2011; Fischer & Knutti 2015). The northeast United States has seen the largest increases in events compared to the rest of the country (a 74% increase in the heaviest 1% of all events since 1958; Groisman et al. 2013), with increases as high as 240% observed in the Connecticut River Basin over the past 60 years (Parr & Wang 2014). Therefore, changes in the magnitude and frequency of extreme precipitation events are of great importance (Bryan et al. 2015a).

Increased intensity of precipitation is projected for all seasons (Toreti et al. 2013), at a rate faster than the increase in annual mean precipitation (Kharin et al. 2013). The greatest increase in number of heavy precipitation events is projected for northern latitudes, higher elevations, and coastal areas (Thibeault & Seth 2014). The Northeast, particularly along the Atlantic coast and in the Appalachians, should see the largest increase in number, intensity, and inter-annual (i.e., between years) variability of extreme precipitation (Ning et al. 2015). Total wet-day precipitation amounts and the number of days with precipitation greater than 0.39 inches (10 mm) are projected to increase in the northeast United States, with models agreeing on the sign of the change (Sillman et al. 2013a, 2013b).

Climatic warming is expected to reduce snowpack depth across the Northeast and Midwest and lead to earlier snow melt (Mahanama et al. 2012). Climate projections for the 21st century indicate decreases in snow depth and the number of days with snow cover, as have already been observed (Hayhoe et al. 2007). Snow cover retreat is projected to occur earlier, shifting from spring to winter (Pierce & Cayan 2013; Maloney et al. 2014). Observed reductions in snow cover extent over the 2008-2012 period exceeded the decrease predicted by global climate model projections (Derksen & Brown 2012).

Some studies have observed changes in snow quality and characteristics of the snow pack, namely harder, crustier snow conditions (Klein et al. 2005; Chen et al. 2013). As the climate warms, temperatures are likely to cross above the freezing line more often during the winter. This will lead to more rain and freezing rain events, which alter the quality of the existing snowpack when the rain freezes upon the snow, resulting in an ice-like texture.

Surface Hydrology

Climate change will have significant impacts on river and stream flows throughout the region served by the NECSC. The most direct sources of these changes are projected shifts in temperature, rainfall, and evapotranspiration. These changes are unlikely to be uniform across the region and will be altered by the specific characteristics of individual basins. Basin characteristics that will have particular impacts include the basin's vegetation, degree of urbanization, underlying geology, longitude, latitude, elevation, the contribution of groundwater, and basin slope (Bryan et al. 2015a).

Annual flows have increased during the last part of the 20th century in the Northeast (Collins 2009; Hodgkins et al. 2005; McCabe & Wolock 2011). However, despite recent intensification of precipitation events, observed maximum annual flows have not yet increased (Douglas et al. 2000; Lins & Slack 1999; Villarini & Smith 2010; Villarini et al. 2011).

Step changes in the mean and variance of observed mean and minimum annual streamflows around the year 1970 have been documented for the continental United States by McCabe & Wolock (2002). Similarly, step changes in maximum annual values were identified around the same time in 23 (out of 28) basins in New England and attributed to the natural variability of the North Atlantic Oscillation (Collins 2009). By comparison, step changes in the mean and variance of flood peaks were observed in 27% and 40% of the stations in the eastern and midwestern states, respectively, and linked to changes in land use-land cover practices in the region and not to external climatic conditions (Villarini & Smith 2010; Villarini et al. 2011).

Projected warmer summers along with reduced precipitation may impact soil moisture conditions in the region if evapotranspiration increases. Additionally, diminished groundwater reserves, linked to declining snow pack, will impact base flows in streams (Hayhoe et al. 2008).

Earlier winter-spring peak flows in the range of 6-8 days also have been observed in the Northeast and Midwest and thought to be linked to increased snowmelt and rain-on-snow episodes (Hodgkins & Dudley 2006). This trend is projected to continue during the 21st century (Campbell et al. 2011). A shift toward higher winter flows and lower spring flows has been documented for 2 northeastern watersheds (Connecticut River Basin, and a small forest site in New Hampshire) using climate-driven streamflow simulations (Marshall & Randhir 2008; Campbell et al. 2011). Changes in the timing and the magnitude of spring snowmelt in eastern United States are crucial to maintain ecosystem functions since some aquatic species rely on the time and volume of streamflows for vital life cycle transitions (Hayhoe et al. 2007; Comte et al. 2013). Larger peak flows can contribute to increases in river scour magnitude and frequency and affect egg burial depths of some salmon species (Goode et al. 2013). Additionally, larger flow velocities in river channels can impede the natural displacement of some small fish (Nislow & Armstrong 2012).

Warming has been observed in many streams across the continent (Webb 1996; Bartholow 2005), and also is seen in future projections (Mohseni et al. 1999). Warming stream temperatures seem to be more a function of warmer nights than warmer days or daily averages (Diabat et al. 2013).

Extreme Events

Examining observed and projected trends in severe weather have been difficult due to a limited observational record and inconsistent metrics to describe weather events (e.g., structural damage, storm reports) (Walsh et al. 2014). Studies reporting reliable estimates in observed trends in severe thunderstorm activity could not be located. One study reported increases in damage costs from storms over recent decades; however, this trend was not statistically significant and may owe more to population and wealth increases than severe activity (Kunkel 2013). The number of tornadoes per year has not changed since 1970; however, one study found that the number of days with tornadoes is decreasing while the number of tornadoes per day is increasing (Brooks et al. 2014). Climatic warming may increase the frequency of severe storms (Del Genio et al. 2007) and future projections indicate an increase in occurrence of hazardous events, such as tornadoes, damaging wind, and hail (Gensini & Mote 2015), with greatest increases estimated for the Great Plains in March, and southern Illinois and Indiana in April. Little change in severe activity is projected for the Northeast; however, trends show an increase in Atlantic hurricanes making landfall in the northern coastal states (Atlantic Coast Section).

Associated with increases in annual precipitation, trends of increasing floods have been observed in the Northeast and the Midwest (Peterson et al. 2013; Wuebbles et al. 2014). Within the United States, the NECSC region is most susceptible to increases in flood events (Wuebbles et al. 2014). It is expected that overall annual precipitation totals will increase over the northeast region throughout the century, but precipitation events will become less frequent. As a consequence, the events that do occur are projected to be more intense, raising the risk for both flooding and drought (Horton et al. 2014).

The average number of consecutive dry days over the region is projected to increase by 1-5 additional days (Sillman et al. 2013a, 2013b; Ning et al. 2015), suggesting a potential increase in drought frequency. However, simultaneous increases in annual precipitation (Schoof 2015), particularly extreme rain events, may help minimize the severity of droughts. Thus, statistically significant increases in the frequency of short-term (1-3 month) droughts are projected with minimal threat of increased long-term droughts (Hayhoe et al. 2007).

More frequent droughts are expected in the future for all states in the Northeast and Midwest. Maine, New Hampshire, Vermont, western Massachusetts, Connecticut, Rhode Island, and the Adirondacks may see the greatest increases in short-term (lasting 1-3 months) droughts (one every year, up from one every 2-3 years), while more long-term (lasting 6+ months) droughts are expected predominantly in western New York. However, it is important to note that projections are not very reliable at capturing regional distributions in precipitation, and that long-term trends in drought events have yet to be observed (Hayhoe et al. 2007; Karl et al. 2012).

Rather, droughts may be occurring less frequently than in the past in the Northeast (Peterson et al. 2013) due to amplifications in precipitation, particularly in extreme events. Nonetheless, warming and less frequent precipitation favor an increase in drought intensity.

As another measure, the Winter Severity Index (WSI) combines the influence of intensity and duration of severe cold and snow cover (Notaro et al. 2014). This indicator is a useful metric for tracking wildlife populations (e.g., deer expansion or waterfowl migration). For instance, Schummer et al. (2010) found that southward migration of ducks generally begins when WSI exceeds 7.2. Notaro et al. (2014) estimate a 20-40% decrease in the probability of a 7.2 or greater WSI in December across the Northeast and Midwest, suggesting that waterfowl migration may occur later in the winter. Changing WSI patterns are largely attributed to a 40- 50% decrease in snowfall. Severe winters, with heavy snow and extreme cold, also negatively impact deer (Verme 1968), and thus deer populations and some other wildlife populations are likely to expand northward as decreases in WSI allow regions to become more suitable for deer.

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Northeast Sub-Regional Climate Change Impacts

SNAPSHOT

Sub-Regional Climate Change Impacts
Adapted from Bryan et al. 2015a

Sub-region	Trend
Atlantic Coast	✓ ***Sea level is rising at an accelerating rate*** ✓ ***Coastal storms, such as tropical cyclones, hurricanes, and Nor'easters, may be intensifying.*** ✓ ***Oceans are warming*** ✓ ***The ocean is becoming more acidic.***
Great Lakes	✓ ***The lakes are warming.*** ✓ ***Lake ice is decreasing in areal extent.*** ✓ ***Lake evaporation rates are increasing.*** ✓ ***Wind fetch over the lakes are expected to increase.*** ✓ ***Lake-effect snow events are likely to become more severe, last longer and shift to rain, but occur less often.***
Appalachians	✓ ***Warming may be occurring at a faster rate at higher elevations.*** ✓ ***The Appalachians may see greater intensification of extreme precipitation.***

Atlantic Coast

Although Pennsylvania does not have marine habitats, species and non-marine habitats may be affected by biological, physico-chemical changes and meteorological influences from the Atlantic Ocean. Changing ocean levels could influence the saline status (i.e., salt wedge) of the lower Delaware River and thus estuarine habitats in southeastern Pennsylvania (Ross et al. 2013). Pennsylvania also is host to anadromous (i.e., use both marine and freshwater habitats) fish species including American eel (*Anguilla rostrata*), American shad (*Alosa sapidissima*), shortnose sturgeon (*Acipenser brevirostrum*) and Atlantic sturgeon (*Acipenser oxyrhynchus*). Further, changing weather patterns, including intensity of hurricanes and Nor'easters, have the potential to influence Pennsylvania habitats with flooding and

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associated erosion, as well damage to terrestrial habitats (e.g., forests). Thus, it is within this context that we include this overview of climate-change impacts on the Atlantic coast.

The coastal region of the northeast region has high, and increasing, vulnerability to coastal flooding (Horton et al. 2014). This vulnerability is based on low-slope coastal areas, especially in southern parts of the region, with the potential for faster regional sea-level rise than the global average (Yin et al. 2009). Whereas global sea levels have risen by about 8 inches (20.3 centimeters) since 1900, much of the Northeast has experienced approximately a 1 foot (30.5 centimeters) increase, whereas the Mid-Atlantic states have seen an increase of approximately 1.5 feet (45.7 centimeters) (Horton et al. 2014). Sea-level rise threatens coastal environments through more frequent coastal erosion, flooding, and salt-water intrusion (Kane et al. 2015), as well as more severe flooding during storms (Horton et al. 2014). Storms are likely to become more destructive in the future as sea-level rise contributes to higher storm surges (Anthes et al. 2006).

Sea-level rise is uniquely threatening to the U.S. Atlantic coast, both due to the more rapid than average rate of increase expected in the area, as well as particular vulnerability of developed coastal areas, including New York City. Sea-level rise is much less responsive to emissions reductions than temperature (Solomon et al. 2009); therefore, even under an aggressive climate change mitigation policy, seas will continue to rise for the remainder of the 21st century and beyond. Due to the near certainty of continued sea-level rise, coastal adaptation is essential to prevent increasing damage from flooding events (Bryan et al. 2015a).

Sea-level rise is projected to accelerate in the future. By mid-century, much of the region could see between 8 inches (20.3 centimeters) and 2.5 feet (76.2 centimeters) of sea level rise relative to 2000-2004 levels; by the end of the century, between 1.5 feet (45.7 centimeters) and 6 feet (182.9 centimeters) of sea-level rise is possible (Collins et al. 2013; Horton et al. 2015). Worst-case projections would require rapid acceleration of land-based ice melt in Greenland and West Antarctica, yet such rapid melting cannot be disregarded (Joughin et al. 2014). Faster-than-expected slowdown in the Atlantic meridional overturning circulation also contributes to high-end projections in sea-level rise (Rahmstorf et al. 2015). Even at the mid-range of the projections for late in the century – ~2.5 feet (76.2 centimeters) – coastal flood frequency would increase dramatically, even if storms remain unchanged. In the New York City region, for example, the current 1-in-100-year-flood-level could become a 1-in-20-year-event under such a sea level scenario (Horton et al. 2015). Bryan et al. (2015a) note high uncertainties in projections of future sea-level rise, particularly in the high emissions scenario.

Changes in the frequency and intensity of tropical cyclones (warm-season coastal storms) or Nor'easters (cool/cold-season coastal storms) would modify these coastal flood risks. The balance of evidence suggests that the strongest tropical cyclones may become more intense due to climate change and especially warming of the upper oceans (Knutson et al. 2010; Christensen et al. 2013), as has already been observed over the past 40-45 years (Emanuel 2005; Webster et al. 2005). Additionally, tropical cyclones may track further north toward the poles over the course of the 21st century (Yin 2005). However, confidence in how tropical cyclones may change is relatively low due to high natural variability, a short observed record, and uncertainty in how other climate variables important for tropical cyclones may change (e.g., wind shear, vertical temperature gradients in the atmosphere, and warming in the tropical Atlantic ocean relative to the tropical oceans as a whole). Hurricane intensity also is projected to increase (Emanuel et al. 2008; Ting 2015). It also is unclear how Nor'easters may change (Horton et al. 2015), although some research suggests growing risk for northern-most parts of the U.S. Atlantic coast and decreasing risk for southern parts (Colle et al. 2010).

It is unclear exactly how storms may change in the future, although we know our coasts are highly vulnerable today. Sea-level rise, even at the low end of the projections, is very likely to dramatically increase flood risk. It should be noted that sea-level rise impacts can penetrate far inland in tidal estuaries. Saltwater intrusion into coastal ecosystems and aquifers will be of increasing concern. Furthermore, in low-lying areas, rainfall flooding may become worse, due not only to heavier rain events, but because high sea levels will reduce drainage to the ocean (Horton et al. 2014). This may worsen pollution, especially in (former) industrial sites.

Warming of ocean waters has been observed in recent decades, with many of the record temperatures occurring within the last 10 years (Mann & Emanuel 2006; Holland & Webster 2007; Domingues et al. 2008; Rhein et al. 2013). This suggests a direct link with anthropogenic climate change. Changes in coastal water ecology have been observed along the northern Atlantic coast (Oviatt 2004; Nixon et al. 2009).

With more carbon in the atmosphere from human activity (Sabine et al. 2004), and thus greater absorption of carbon by the Earth's oceans (Feely et al. 2004; Canadell et al. 2007; Cooley & Doney 2009), the oceans and coastal waters are becoming more acidic (Walsh et al. 2014). The pH level of the oceans and coastal waters will continue to drop as atmospheric carbon continues to rise (Rhein et al. 2013). Ocean acidity has not changed in the last 300 million years with the exception of a few rare events (Caldeira & Wickett 2003), highlighting the impact of recent anthropogenic climate change. More importantly, these changes in ocean acidity are irreversible and thus will have prolonged impacts on marine and aquatic ecosystems.

Great Lakes

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Like other parts of the NECSC region, warmer conditions and more extreme events are expected for the Great Lakes Basin (Bartolai et al. 2015). However, there are changes that specifically impact the states adjacent to the lakes. Warming has already been observed (McCormick & Fahnenstiel 1999, Jones et al. 2006; Austin & Colman 2007; Dobiesz & Lester 2009), and is expected to continue (Trumpickas et al. 2009; Music et al. 2015). Observations indicate warming by 1-3°C (1.8-5.4°F) over the past 40 years (Dobiesz & Lester 2009). Lake Erie is warming, but at a slower rate than the other lakes (Dobiesz &

Lester 2009), while lake temperatures are warming faster than surrounding air due to a reduction in ice cover (Austin & Colman 2007). Given the influence of the lakes on regional climate, particularly their role in moderating air temperatures (Notaro et al. 2013), warming of the Great Lakes is very likely to lead to warmer air over the surrounding landscape compared to areas far away from the lakes. Since ice cover reduces the ability of the lakes to regulate temperatures, reductions in ice cover due to warmer lake temperatures may lead to faster warming of air temperatures immediately surrounding the lakes than other parts of the adjacent states (Bryan et al. 2015a).

Long-term decreases in extent of ice cover have already been observed (Assel 2005; Austin & Colman 2007; Bartolai et al. 2015) and are likely to continue to decline dramatically (Notaro et al. 2015) as a result of long-term climatic warming. Ice cover extent varies interannually, associated with phases of large-scale climatic phenomena such the El Niño/La Niña cycle (Bai et al. 2015). Specifically, low ice cover tends to occur under strong positive phases of the North Atlantic Oscillation (NAO) and La Niña phase of the El Niño Southern Oscillation pattern. It is uncertain how climate change will impact these oceanic oscillations, let alone their influence on Great Lakes ice cover.

Lake ice acts as a barrier that inhibits evaporation from the lakes. As ice-cover extent decreases and waters warm, enhanced lake evaporation is expected. Increases in lake evaporation rates have already been observed over the past 50 years on account of warmer waters and decreasing ice coverage (Gronewold et al. 2013). Future projections anticipate continued increases in evaporation from the lakes as ice cover extent continues to decrease (Notaro et al. 2015). Due to the large size of the lakes, coupled with the capacity of water to store heat, lake temperatures, and thus evaporation rates, have an offset seasonal cycle relative to land surface temperatures and evapotranspiration (Bryan et al. 2015b). Specifically, most lake evaporation tends to occur in the winter when waters heated from the previous summer are much warmer than the overlying air. Accordingly, warmer lakes under a changing climate may lead to proportionally greater evaporation enhancements in the winter season.

In winter, lake-effect snow is driven by intense evaporation from the lakes when lake waters are significantly warmer (i.e., 23.4°F; 13°C or more typically) than the overlying air (Wright et al. 2013). As lake waters warm, this temperature gradient between the lake and air may become stronger, leading to shifts in lake-effect snow. Ice cover inhibits lake-effect snow (Vavrus et al. 2013; Wright et al. 2013), so decreases in ice-cover extent also may contribute to more lake-effect snow events. Given projected increases in future global temperature, areas downwind of the Great Lakes may experience increased lake-effect snowfall for the foreseeable future.

Lake-effect snow has increased in the 20th century (Andresen et al. 2012) and model projections indicate continued increases in the future (Notaro et al. 2015). Lake-effect events especially are expected to become more intense and longer lasting, but less frequent than present events. As the climate warms, however, lake-effect snow is likely to transition to lake-effect rain, which is predicted for 4 of the 5 lakes (Notaro et al. 2015); Lake Superior is expected to be cold enough over the next century given its high latitude to support lake-effect snow. However, as warming continues into the far future, we may expect lake-effect rain as far north as the Lake Superior region (Bryan et. al 2015a).

Appalachians

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Though observational networks on mountain tops are limited, there is evidence on several mountain peaks worldwide that temperatures are increasing at a faster rate on mountaintops than at the base of mountains (Diaz & Bradley 1997; Pepin & Lundquist 2008; Rangwala & Miller 2012; Diaz et al. 2014; Pepin et al. 2015). Based on model simulations, under future warming, the magnitudes of temperature increases over the mountain region also are larger than the low-elevation regions (Bradley et al. 2004; Bradley et al. 2006; Diaz et al. 2014). The potential physical mechanisms that contribute to this elevation-dependent warming include: a) snow albedo and surface-based feedbacks; b) water vapor changes and latent heat release; c) surface water vapor and radiative flux changes; d) surface heat loss and temperature change; and e) aerosols (Pepin et al. 2015).

Consistent with these model results, future projections indicate a more rapid increase in summer daily highs (Thibeault & Seth 2014) and lengthening of the growing season (Ning et al. 2015; Fig. 3.10) in the Appalachians than the surrounding landscape. A further consequence may be an accelerating decrease in snow pack and upslope regression of the snowline (Cohen et al. 2012). Regardless of the variability in rate with elevation, warming will likely lead to decreased depths and earlier melting of snow in mountain regions (Barnett et al. 2005) as have already been observed since the start of the century (Dedieu et al. 2014). Wildlife or habitats that depend on specific timing and magnitude of snow melt and thicknesses of winter snow cover will be most vulnerable to these changes. For example, some species rely on snow cover for camouflage, and as snow packs melt away earlier, there may be a mismatch in timing with changes in seasonal coat (e.g., snowshoe hare; Mills et al. 2013a). Additionally, up progression of the temperate-boreal transition zone may accelerate with future warming.

The precipitation environment along mountain slopes is distinct from flat terrain due to the influence of orographic lift on the windward side and subsidence on the leeward side (Roe 2005). Overall precipitation amounts and frequency of extreme events on mountain slopes are likely to increase and shift from snow to rain under warming climate suggests heavier runoff and flooding (Shi & Durran 2015). Projections suggest the Appalachians, in addition to the U.S. Atlantic coast, may see greater increases in the number, intensity, and inter-annual variability of extreme precipitation (Ning et al. 2015). The windward side of mountains is particularly sensitive to climatic warming due to the influence of orographic lift in producing high amounts of precipitation in that region (Shi & Durran 2014). Warming may increase both the intensity and duration of orographic precipitation due to elevation-varying changes in the moist adiabatic lapse rate, winds along the slope, and orographic lift. Changes in the progression of mid-latitude storms may also impact precipitation on the slopes of the Appalachians.

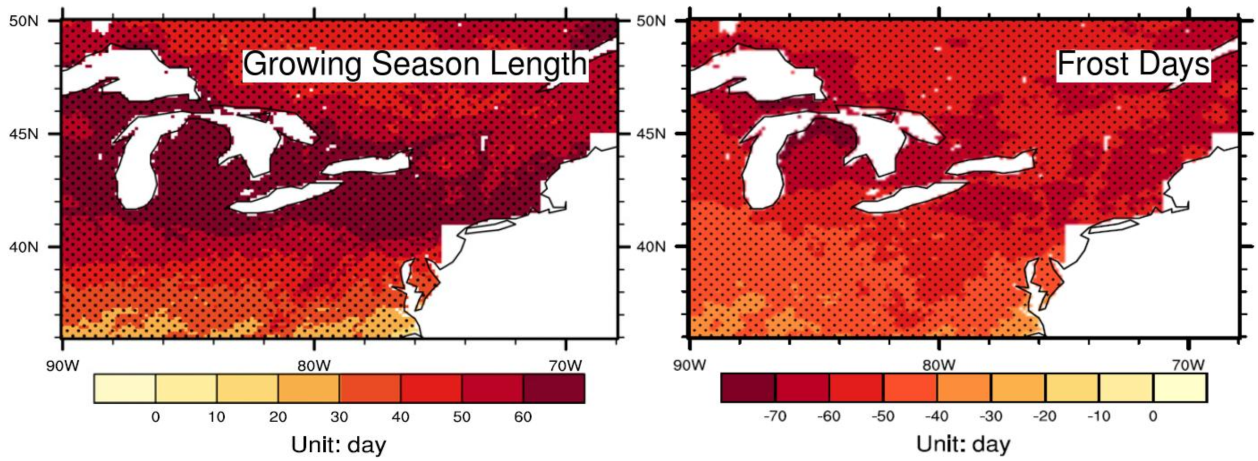

Fig. 3.10. Change in the number of days in the growing season (left) and number of frost days (right) by the end of century (2050-2099) relative to the 1950-1999 average, following a "business-as-usual" greenhouse gas emissions scenario (Used with permission from Ning et al. 2015) Source: Bryan et al. (2015a). *Used with permission by the DOI Northeast Climate Science Center*.

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Northeast Regional Species and Habitats Climate Change Vulnerability

This section is adapted from Staudinger, M., L. Hilberg, M. Janowiak, and C. Swanston. (2015b). Chapter 2: Northeast and Midwest Regional Species and Habitats at Greatest Risk and Most Vulnerable to Climate Impacts. In Staudinger et al. (2015a).

SNAPSHOT

Regional Species and Habitats Climate Change
Adapted from Staudinger et al. 2015b

NatureServe© Climate Change Vulnerability Index (CCVI) was most commonly used to assess fish and wildlife species.

- ✓ ***Extreme-to-High Vulnerability: Freshwater mussels, amphibians, and fish.***
- ✓ ***Moderate-to-Low vulnerability rankings: Majority of birds and mammals.***

Climate Change Response Framework (CCRF) was the most commonly used methodology to assess habitats.

- ✓ ***High Vulnerability: Spruce-Fir, Lowland Conifer, Appalachian Northern Hardwood Forests, Bogs and Fens.***
- ✓ ***Low Vulnerability: Jack Pine-Red Pine Barrens, Woodlands and Northern Oak-Pine-Hardwood, and Central Hardwoods Oak-Pine Forests.***

Other (non-CCRF) habitat-focused assessments were used.

- ✓ ***High Vulnerability: Tundra, freshwater aquatic and coastal habitats.***

Birds were the most frequently assessed taxonomic group across the region.

- ✓ ***Vulnerability of migratory birds and other species may be underestimated when the full life-cycle or connections among breeding, wintering, and migratory habitats are not taken into account***.

Introduction

This chapter is a synthesis of methods, locations (i.e., states) where vulnerability assessments were conducted, lists of individual species and habitats; including their respective vulnerability rankings, and compares how vulnerability rankings were determined among studies.

To characterize climate change effects on species and habitats, the International Panel on Climate Change (IPCC) (IPCC 2007a, 2014b) has defined important factors for characterizing assessments. These include:

- ***Vulnerability of a species or habitat to climate*** as the susceptibility (of a species, system or resource) to be negatively affected by climate change and other stressors. Under this definition, vulnerability is composed of three separate, but related components: exposure, sensitivity and adaptive capacity.

- ***Exposure*** is the character, magnitude and rate of change a species experiences, and includes both direct and indirect impacts of climate change. Exposure may take the form of changes in temperature, precipitation, and extreme events, but also could include habitat shifts due to changing vegetation or ocean acidification.
- ***Sensitivity*** to climate change indicates degree to which a species or habitat is dependent upon environmental and ecological conditions. Sensitivity factors could include temperature requirements or dependence on a specific hydrological regime.
- ***Adaptive capacity*** is the ability of a species to cope and persist under changing conditions through local or regional acclimation, dispersal or migration, adaptation, and/or evolution (Dawson et al. 2011; Glick et al. 2011). A species' potential for behavioral changes, dispersal ability, and genetic variation are examples of factors relating to adaptive capacity.

Traits and Characteristics Effecting Species' Vulnerability to Climate Change

A recent study conducted by Pacifici et al. (2015) reviewed 97 studies published during the last decade reporting on risk and vulnerability of global species to climate change. They concluded that species traits, rather than taxonomy and distribution, were most important in determining climate change vulnerability.

Biological traits and characteristics that make species relatively vulnerable to climate change (Both et al. 2009; Glick et al. 2011; Bellard et al. 2012; Lurgi et al. 2012; Staudinger et al. 2013; Pacifici et al. 2015) include:

i. Specialized habitat and/or microhabitat requirements
ii. Specialized dietary requirements
iii. Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle
iv. Populations living near the edge of their physiological tolerance or geographical range
v. Dependence on habitats expected to undergo major changes due to climate
vi. Dependence on specific environmental triggers or cues likely to be disrupted by climate change
vii. Dependence on interspecific interactions which are likely to be disrupted by climate change
viii. Poor ability to disperse to or colonize a new range
ix. Low genetic diversity; isolated populations
x. Restricted distributions
xi. Rarity
xii. Low phenotypic plasticity
xiii. Long life-spans or generation times, low fecundity or reproductive potential or output

Biological traits or characteristics that may create opportunities or benefit species under future climate change include:

i. Habitat or dietary generalists
ii. High phenotypic plasticity
iii. Disturbance-adapted species
iv. Large thermal tolerances

v. High dispersal capabilities
vi. Short life-spans or generation times, high fecundity and reproductive potential or output

Assessing Climate Change Vulnerability

There is no standard method or framework to assess vulnerability to climate change. A variety of approaches are reported in the literature, and implemented by different institutions and organizations globally. Generally, the approach selected to evaluate vulnerability should be based on the goals of the practitioners, confidence in existing data and information, and the resources available.

Climate Change Vulnerability Assessments (CCVA) are emerging tools in the fields of climate science, conservation, management, and adaptation. By assessing climate change vulnerability and considering risk in the context of other environmental stressors (e.g., exploitation, pollution, land use change, disease), natural resource managers can identify which species and systems are relatively more vulnerable or resilient to climate change, ascertain why they are vulnerable or resilient, and use this information to prioritize management decisions (Glick et al. 2011). Federal and state agencies, as well as conservation organizations, have begun conducting vulnerability assessments on a variety of management and conservation targets.

Differences exist in interpretation of climate change vulnerability in the literature as well as across different sectors (e.g., policy, scientific, natural resources) and institutions. Vulnerability of a species, system, or resource to climate change has been considered a starting point for conservation efforts and a characteristic brought about by other stressors (e.g., environmental, anthropogenic) that is exacerbated by climate change (O'Brien et al. 2004). Vulnerability also may be viewed as the consequence or result of the net impacts of climate change minus actions to reduce the effect of climate change (i.e., adaptation) (O'Brien et al. 2004). These different interpretations have important implications for how research, management decisions, and actions related to a resource are made.

Approaches and methodologies for evaluating vulnerability also may differ in consideration of exposure, sensitivity, and adaptive capacity (methodologies more thoroughly evaluated in Staudinger et al. (2015b). For example, some assessments evaluate adaptive capacity; some have combined it as part of sensitivity, and some have ignored it completely and just assessed exposure and/or sensitivity (Joyce et al. 2011; Beever et al. 2015; Thompson et al. 2015). The ability to understand and predict a species' or a system's responses to climate change is limited when adaptive capacity is not explicitly considered. Therefore, an integral activity of assessing vulnerability should be to evaluate the uncertainties related to each of the 3 components and other relevant factors including those that were or were not able to be assessed. This will highlight the places where additional research or monitoring is needed to inform future decisions and actions. Where limited information is available on adaptive capacity, a vulnerability assessment might suggest research or monitoring to fill in that knowledge gap.

For species to be successful, adaptive capacity and resiliency to predicted rapid changes in global temperatures will require biogeographic connectivity (i.e., corridors) allowing species to reach suitable habitats and adequate time for adaptive changes (Williams et al. 2008).

Analysis by Staudinger et al. (2015b) included results of 21 completed or anticipated Climate Change Vulnerability Assessments (CCVAs) conducted across the northeast and midwest United States (summarized in Appendix 3.1, Exhibit 1; for details see Appendix 2.1 in Staudinger et al. 2015b). CCVAs were examined for 2 conservation targets: 1) fish and wildlife species, primarily those of Greatest Conservation Need (SGCN); and 2) habitats. Fish and wildlife species were grouped into major taxonomic groups including; amphibians, birds, fish (freshwater and marine), freshwater mussels, insects, marine invertebrates, other invertebrates, mammals, and reptiles. Regional habitats were grouped into 7 categories including; forests, terrestrial wetlands, freshwater aquatic systems, coastal systems, terrestrial cliffs and rocky outcrops, heathland and grasslands, and tundra (Appendix 2.7 in Staudinger et al. (2015b) for a detailed review of these studies).

Two vulnerability indices were applied across multiple studies and provide consistent metrics for comparison. The NatureServe© Climate Change Vulnerability Index (CCVI) (Young et al. 2011) was used in 6 studies focused on assessing fish and wildlife species, whereas the Climate Change Response Framework (CCRF), employed by the Northern Institute of Applied Climate Science (NIACS) and partners, was used in 5 studies targeting forests and other habitats. The objective of the CCRF vulnerability assessment is to determine vulnerability to climate change among forest community types within an ecological province (i.e., broad geographic areas that share climate, glacial history, and vegetation types). The assessment uses a range of downscaled climate projections incorporated into dynamic and species distribution modeling to determine the future habitat suitability of tree species.

The results of other vulnerability studies (referred to as "non-CCVI" when discussing fish and wildlife targets, and "non-CCRF" when discussing habitat targets) also are summarized; however, because methodologies were not consistent among non-CCVI and non-CCRF studies, comparisons among study results should be considered with the caveat that vulnerability ranking categories may not be equivalent. Consult the original reports for more detailed accounts of the climate change vulnerability ranking for a species or habitat (Staudinger et al. 2015b).

Across the region, the NatureServe© CCVI was the most commonly used CCVA framework to assess fish and wildlife species' vulnerability to climate change. The CCVI was used in 6 studies, targeting West Virginia (Byers and Norris 2011), Pennsylvania (Furedi et al. 2011; Cullen et al. 2013), Michigan (Hoving et al. 2013), New York (Schlesinger et al. 2011) and the North Atlantic Landscape Conservation Cooperative Region (Sneddon and Hammerson 2014). Within these 6 studies, 842 species were assigned vulnerability rankings (Fig. 3.11; Table 3.8; Staudinger et al. 2015b). From studies using the NatureServe© CCVI framework, freshwater mussels, amphibians, and fish (primarily freshwater species) were the taxonomic groups most often ranked as extremely or highly vulnerable to climate change. Conversely, mammals and birds had the highest frequency of relatively low vulnerability rankings across studies (Staudinger et al. 2015b). However, the vulnerability of birds, especially migratory species, may be underestimated as no assessments accounted for the full life cycle of migratory birds or the connections between breeding, wintering, and migratory habitat (Small-Lorenz et al. 2013). Species-specific vulnerability rankings across all CCVI studies can be found in Staudinger et al. (2015b; Appendix 2.4). Refer to the original study for climate factors that influenced vulnerability outcomes and the confidence in those rankings.

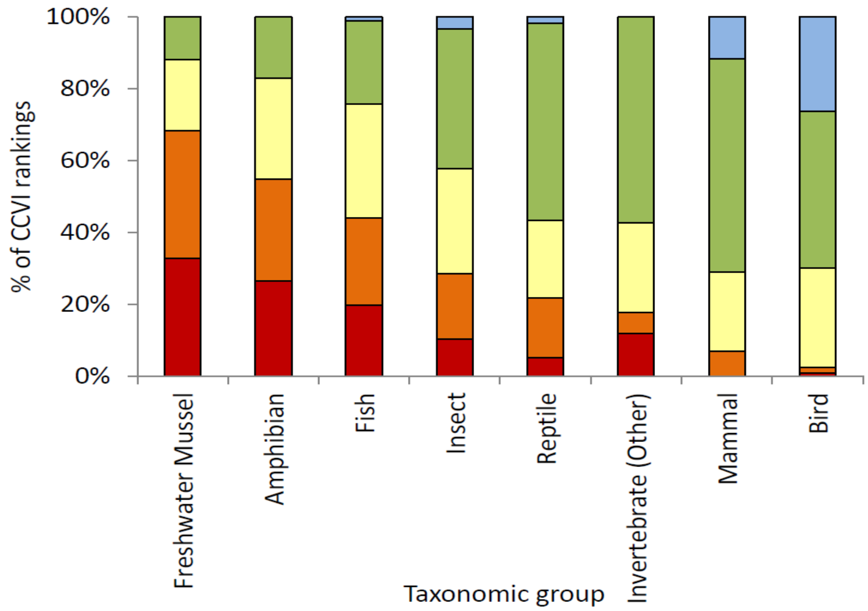

Fig. 3.11. Percent of counts of vulnerability rankings using the NatureServe© CCVI method delineated by taxonomic group. Bars show the distribution of vulnerability ranking scores of extremely vulnerable (red), highly vulnerable (orange), moderately vulnerable (yellow), presumed stable (green) and increase likely (blue). Results show combined rankings across 6 studies, targeting WV, PA, MI, NY and the North Atlantic LCC region (Byers & Norris 2011; Furedi et al. 2011; Schlesinger et al. 2011; Cullen et al. 2013; Hoving et al. 2013; Sneddon & Hammerson 2014). Source: Staudinger et al. (2015b). *Used with permission by the DOI Northeast Climate Science Center*.

Four additional studies did not use the CCVI method, but rather vulnerability rankings were compared across a combined approach of qualitative and quantitative methods that largely drew upon expert opinion to assess the vulnerability of each species (Adaptation Subcommittee to the Governor's Steering Committee on Climate Change 2010; Galbraith et al. 2014; Tetratech 2013; Whitman et al. 2013).

Within these 4 studies, there were 329 rankings of vulnerability across major taxonomic groups (Fig. 3.12). All marine fish (N = 4) and invertebrates (N = 1) were ranked as highly vulnerable (Note that at the time this synthesis was completed the results of a multi-species vulnerability assessment of 79 marine fishes and invertebrates were not yet available but are anticipated in 2015 (J. Hare, written communication). Birds and mammals were the only taxonomic groups with species that were assigned rankings in the extremely vulnerable category, but the majority of birds and mammals were ranked as having moderately or low vulnerability. Species and region-specific vulnerability rankings, as well as the original source for information on which climate factors influenced vulnerability outcomes and confidence in those rankings are found in Appendix 2.5 in Staudinger et al. (2015b).

Table 3.8. Counts of vulnerability rankings across 6 studies using the NatureServe© CCVI method - by study, taxonomic group. Adapted from Staudinger et al. (2015b). Individual species information in Appendix 2.4 of Staudinger et al. 2015b. Source studies: Byers & Norris 2011; Furedi et al. 2011; Schlesinger et al. 2011; Cullen et al. 2013; Hoving et al. 2013; Sneddon & Hammerson 2014.

Taxonomic Group	Extremely Vulnerable	Highly Vulnerable	Moderately Vulnerable	Presumed Stable	Increase Likely	Total
Amphibian	14	15	15	9	0	53
Bird	2	4	65	104	62	237
Fish	18	22	29	20	1	90
Fish (Marine)				1		1
Freshwater Mussel	25	27	15	9	0	76
Insect	18	32	51	68	6	175
Invertebrate	8	4	14	39	0	65
Invertebrate (Marine)			3			3
Mammal	0	6	19	51	10	86
Reptile	3	10	13	33	1	60

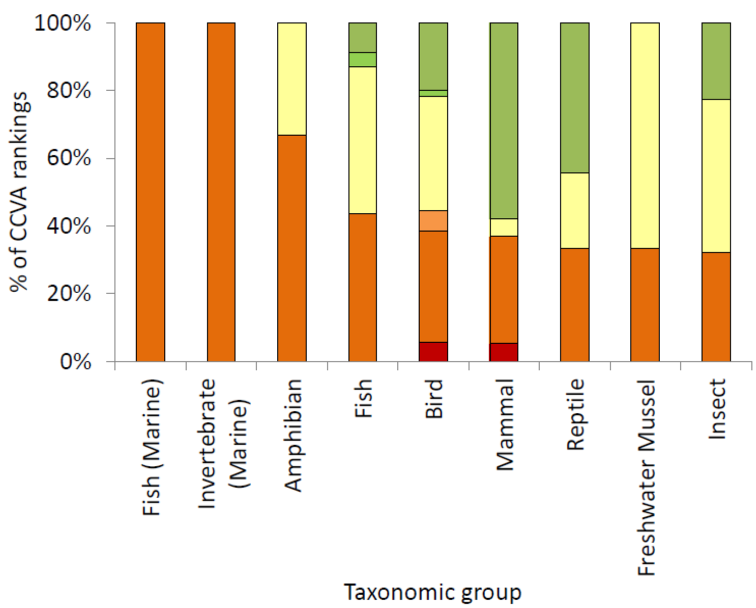

Fig. 3.12. Percentage of counts of vulnerability rankings by taxonomic group for studies using methods other than the NatureServe© CCVI. Bars show vulnerability ranking scores of extremely vulnerable (red), highly vulnerable and high concern (orange), moderately vulnerable (yellow), low concern and presumed stable (green). No rankings were scored within studies indicating species would increase or expand their abundance. Results show combined rankings across 4 studies targeting CT, VT, ME, and North Atlantic coastal and seabirds (Adaptation Subcommittee to the Governor's Steering Committee on Climate Change, 2010; Galbraith et al. 2014; Tetratech 2013; Whitman et al. 2013). Source: Staudinger et al. (2015b). *Used with permission by the DOI Northeast Climate Science Center*.

Forest and Habitat Assessments

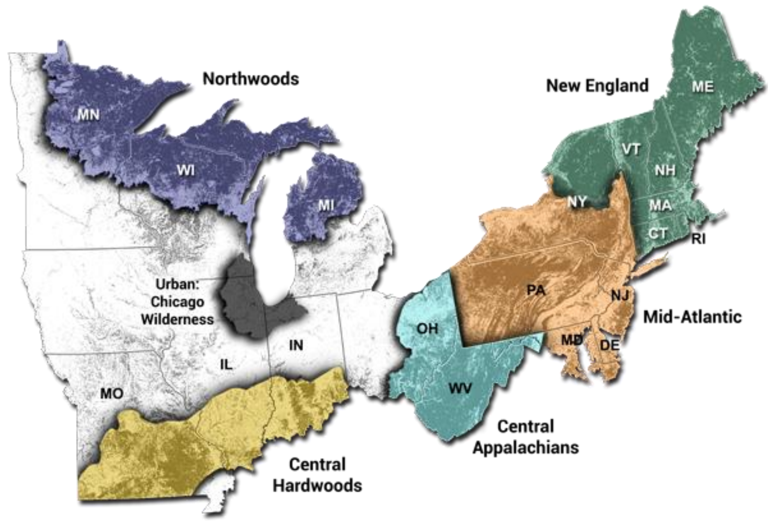

Fig. 3.13. Areas assessed and anticipated (in 2016) for climate change vulnerability through the Climate Change Response Framework. Source: Staudinger et al. (2015b) and Northern Institute of Applied Climate Science. *Used with permission by the DOI Northeast Climate Science Center*.

Eleven studies evaluated climate change vulnerability of terrestrial, aquatic, and coastal habitats across the northeast and midwest regions. A total of 224 unique assessment records were compiled for habitats across the region (Appendix 2.7 in Staudinger et al. 2015b). Similar to fish and wildlife CCVAs, all habitat vulnerability studies assessed more than 1 target habitat. The number of targets within studies ranged from 8 to 43. Seven statewide assessments (CT, MA, VT, NH, ME, MI, MN) and 4 regional-scale assessments (NEAFWA, Central Appalachians, Central Hardwoods, and Northwoods) were conducted across studies (Appendix 2.7 in Staudinger et al. 2015b). Forest habitats were the most frequently assessed habitats (N = 102), followed by freshwater wetlands (N = 40) and freshwater aquatic systems (N = 40), while tundra (N = 4) and heathlands and grasslands (N = 6) were the least frequently assessed.

Among all studies, 29 out of the 82 habitats (35%) were evaluated multiple times in the Northeast and Midwest.

The Climate Change Response Framework (CCRF) used the same process to conduct 5 regional assessments (Fig. 3.13) that included the vulnerability of forest and other habitats in the Central Appalachians (WV and Appalachian portions of OH and MD), Central Hardwoods (southern MO, IL, IN), and Northwoods (northern MN, WI, MI) regions (Brandt et al. 2014; Handler et al. 2014a, 2014b; Janowiak et al. 2014a; Butler et al. 2015). Assessments are currently in progress for the Mid-Atlantic, New England and northern New York, and Chicago areas (expected 2016). In addition to the CCRF Vulnerability Assessment, the U.S. Forest Service (NIACS) and TNC are conducting a Forest Adaptation Planning and Practices workshop (early 2016). Working with partners, this workshop will further investigate habitat vulnerability, management and mitigation options at the site level, ideally with results broadly applicable.

CCRF assessments primarily targeted forest habitats (N = 41); however, in a few cases, heathland and grasslands (N = 2) and terrestrial wetlands (N = 1) also were assessed (Appendix 2.8 in Staudinger et al.

2015b). Staudinger et al. (2015b) (Appendix 2.9) also provided a matrix of habitat type by area/study as a quick guide to consistently ranked habitats across all areas assessed by the CCRF to-date.

The CCRF scored Appalachian Northern Hardwood, Low-Elevation Spruce-Fir, and Lowland Conifer Forests as highly vulnerable to climate change (Fig. 3.14). Freshwater wetlands, particularly Bogs and Fens also scored as highly vulnerable to climate change. Jack Pine-Red Pine Barrens, Woodlands and Northern Oak-Pine-Hardwood, and Central Hardwoods Oak-Pine Forests were scored with relatively low vulnerability as were Glades (Heathland and Grasslands). Refer to Staudinger et al. (2015b; Appendix 2.8) for habitat- and region-specific vulnerability rankings as well as the original source for information on which climate factors influenced vulnerability outcomes and confidence in those rankings. An

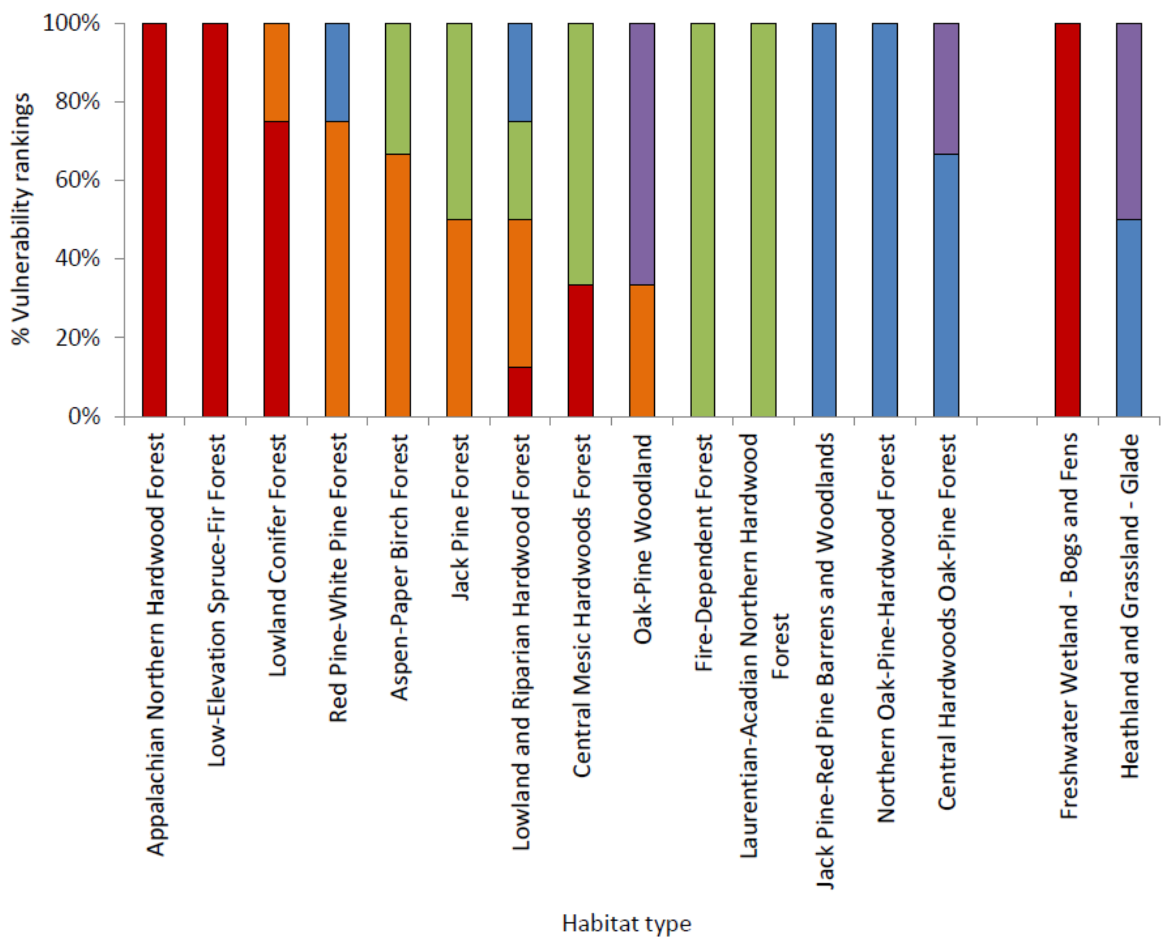

Fig. 3.14. Percent of vulnerability rankings using the CCRF framework delineated by habitat. Bars show the distribution of vulnerability ranking scores of High (red), Moderate-High (orange), Moderate (green) and Low-Moderate (blue), and Low (purple) vulnerability. Results show combined rankings across 5 studies, targeting Central Appalachians, Central Hardwoods, and Northwoods regions (Brandt et al. 2014; Handler et al. 2014a, 2014b; Janowiak et al. 2014a; Butler et al. 2015). Source: Staudinger et al. (2015b). *Used with permission by the DOI Northeast Climate Science Center*.

additional 6 studies assessed the vulnerability of terrestrial, aquatic and coastal habitats from across the region (Adaptation Subcommittee to the Governor's Steering Committee on Climate Change 2010; Manomet and MADFW 2010; Manomet and NWF 2013; NH Fish & Game Department 2013; Tetratech 2013; Whitman et al. 2013). All of these assessments were qualitative, with rankings developed from expert opinion gathered through online surveys and workshop panel discussions. Studies encompassed Connecticut (Adaptation Subcommittee to the Governor's Steering Committee on Climate Change 2010), Maine (Whitman et al. 2013), Massachusetts (Manomet and MADFW 2010), New Hampshire (NH Fish & Game Department 2013), Vermont (Tetratech 2013), and four latitudinal zones within the New England Association of Fish & Wildlife Agencies (NEAFWA) region. Subdivisions were: Zone I (Maine, northern NH, VT, and part of NY), Zone II (Majority of NY, southern NH and VT, MA, CT, and RI), Zone III (PA and MD), and Zone IV (VA and WV) (Manomet and NWF 2013). Amassed vulnerability rankings across all habitats are organized by: a) study and region; and b) vulnerability score. Total counts for each vulnerability ranking (extremely high-to-low vulnerability) are reported in Appendix 2.10; Staudinger et al. (2015b).

Forest and freshwater aquatic habitats were the only groups assigned the extremely vulnerable classification across non-CCRF assessments. Generally, non-CCRF assessments ranked tundra, freshwater aquatic and coastal habitats as highly vulnerable. Heathlands and grasslands, and cliffs and rocky outcrops were assigned relatively low vulnerability scores in about half of the studies in which they were assessed (Fig. 3.15). Refer to Appendix 2.10 in Staudinger et al. (2015) for habitat and study/region-specific vulnerability rankings as well as the original information source on which climate factors influenced vulnerability outcomes and confidence in those rankings.

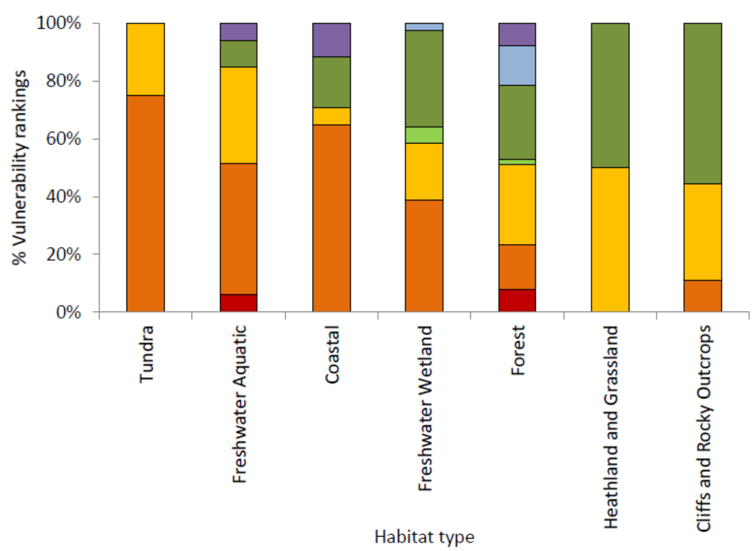

Fig. 3.15. Percentage of counts of vulnerability rankings in *non*-Climate Change Response Framework (non-CCRF) studies by habitat type. Vulnerability ranking scores of extremely vulnerable (red), highly vulnerable and high concern (orange), moderately vulnerable (yellow), low concern and presumed stable (green), minimal increase (blue), and least vulnerable or large increase projected (purple). Results show combined rankings across 5 studies targeting CT, MA, VT, ME, NEAFWA region (Source Studies: Adaptation Subcommittee to the Governor's Steering Committee on Climate Change 2010; Manomet and MA DFW 2010; Manomet and NWF 2013; Tetratech 2013; Whitman et al. 2013). Source: Staudinger et al. (2015b). *Used with permission by the DOI Northeast Climate Science Center*.

Northeast Regional Species of Greatest Conservation Need (RSGCN)-Climate Change Impacts

Adapted from Morelli, T. L., W. DeLuca, C. Ellison, S. Jane, S. Matthews. 2015. Chapter 3: Biological Responses to Climate Impacts with a Focus on Northeast and Midwest Regional Species of Greatest Conservation Need (RSGCN) In Staudinger et al. (2015a).

SNAPSHOT

Climate Change Impacts On Regional Species of Greatest Conservation Need
Adapted from Morelli et al. (2015)

- ✓ ***Climate change will have cascading effects on ecological systems.***
- ✓ ***These changes are expected in the form of shifts in timing, distribution, abundance, and species interactions.***
- ✓ ***Some wildlife groups in the Northeast and the Midwest, including montane birds, salamanders, cold-adapted fish, and freshwater mussels, could be particularly affected by changing temperatures, precipitation, sea and lake level, and ocean processes.***
- ✓ ***Interspecific interactions and land use change could exacerbate the impacts of climate change.***
- ✓ ***A focus on habitat connectivity, water quality, and invasive species is among the many options to increase resilience for wildlife populations in the face of climate change.***

Introduction

The northeast and midwest United States are experiencing, and will continue to experience, an altered climate as a consequence of human-induced global climatic warming (Morelli et al. 2015). Warming is occurring in all seasons, particularly in the winter and at higher latitudes and elevations. Winters are getting wetter, with snow shifting to rain, resulting in lower snowpack in all areas except downwind coasts along the Great Lakes, where warming lake water is enhancing lake-effect precipitation. In summer, rainfall events are becoming more intense but occurring less often, resulting in little net change in annual precipitation totals in the Northeast and upper Midwest. Along the Atlantic coast, the sea level is rising at an accelerating rate, and tropical storms and storm surges may be intensifying. These changes are expected subsequently to influence lake levels, hydrological flows, storm frequency, distributional shifts in vegetation, and, ultimately, ecosystem structure and function (Morelli et al. 2015).

Climate change may have cascading effects on ecological systems. Some species' distributions already are shifting northward, upslope, upstream, and to deeper depths (Staudinger et al. 2013; Melillo et al. 2014) and interdependent species will shift in response, adapt in place, or be unable to cope with the changes. Species distributional shifts will likely not be synchronized, as species respond to different cues and at different rates. For some species, shifts could be hindered by lack of connectivity as well as life history traits or lack of diversity that prevent movement or adaptation. Changes in species abundance and distribution are more likely to occur at the edge of a species range than in its center (Trumbo et al. 2011; Morelli et al. 2012). Increased disturbance related to climate change could increase invasive species and pests, which could, in turn, lead to more ecological disturbance. These changes will likely result in community turnover, with novel species assemblages, including complex interactions between species and new predators (Herstoff & Urban 2014).

Biological responses to climate change already can be seen across taxa in the Northeast and Midwest. Some species, such as most small mammals in the Northeast and Midwest, have broad distributions across the region and thus may be able to adapt to shifting temperatures and precipitation. Some montane birds, on the other hand, rely on habitats that are at the southern edge of their distribution in the northern United States; for example, the Bicknell's thrush (*Catharus bicknelli*) is predicted to severely contract its range northward and upslope in the spruce-fir ecosystems it relies on for breeding (Rodenhouse et al. 2008). High temperatures will likely negatively affect insects and amphibians due to desiccation stress. Yet, high temperatures coupled with high humidity could cause thermal stress to moose (*Alces alces*) at the southern edge of their range (Murray et al. 2006). Low snowpack will affect the thermoregulation of hibernating mammals and other species (Morelli et al. 2012).

Life-history traits are a key determinant of how species will respond to climate change. Turtles, with their temperature-dependent sex determination, may have particularly strong population responses to warming. Some small mammals and grassland birds are expected to be affected more by changes in precipitation than temperature. Low mobility species, like freshwater mussels, are highly threatened by both warming and drying waters and habitat conversion and pollution (Furedi 2013). By comparison, some large mammals and fish species may be able to track their climate niche, as long as habitat connectivity is available.

Phenological shifts are already seen in species. For example, anadromous species like the American Shad appear to be changing the timing of reproduction (Kerr et al. 2009). However, detecting the full consequences of these changes is complicated by delayed responses, compounding effects of other stressors such as land use and harvest, and by interactions with competitors, predators, invasive species, disease, pests, and prey.

Mammals

Small Mammals

Small mammals play an important role in their respective ecosystems as seed and fungal spore dispersers and prey for birds and other mammals. They also have the potential to play an important role in climate adaptation, particularly in more arid ecosystems, where they can mediate vegetation change (Curtin et al. 2000). These roles may be affected by the shifting patterns of precipitation and temperature across the United States.

Many small mammals in the Northeast and Midwest have broad temperature tolerances. Thus, climate change will likely be mediated through indirect effects on their life history and distribution. For example, the American red squirrel (*Tamiasciurus hudsonicus*), an important predator on eggs and nestlings in the spruce-fir ecosystem of northern New England and the upper Midwest, appears to be expanding its range upslope (T.L. Morelli, unpublished data), possibly in response to reduced snowpack or more food availability. However, there are examples of geographically-limited species that could be highly vulnerable to warming temperatures, such as the Allegheny woodrat *(Neotoma magister*) (Manjerovic et al. 2009).

Precipitation patterns, which can drive small mammal abundance and distribution, are changing across the Midwest and Northeast. Some small mammal species such as the smoky shrew (*Sorex fumeus*) move more when it rains (Brannon 2002), especially in dry environments. The star-nosed mole (*Condylura cristata*) is dependent on rain events for dispersing, and thus may be adversely affected in areas where rainfall events are projected to become less common (McCay et al. 1999). Extreme events also can have a detrimental effect on small mammal populations, and thus overall diversity, favoring particular species (Pauli et al. 2006).

Not all effects of climate change will be negative. The New England cottontail (*Sylvilagus transitionalis*) may benefit from decreased snow cover and forest disturbance in the Northeast. But indirect effects through changing relationships with other species, such as predators and competitors, are difficult to predict. For example, if climate change affects eastern cottontails positively, there may be increased competition for New England cottontails (Fuller & Tur 2012).

Northern flying squirrels (*Glaucomys sabrinus*) are an example of a species threatened by the indirect effects of climate. Their northern forest habitat is shifting northward (Iverson et al. 2008b). Moreover, climate change may decrease the fungi and lichen that are important food sources for the northern flying squirrel. Most notably, habitat and temperature changes are already allowing southern flying squirrels (*Glaucomys volans*) to expand northward, with a subsequent decline of northern flying squirrels associated with disease transmission and competition (Smith 2012). Furthermore, climate-induced hybridization was detected between southern and northern flying squirrels in the Great Lakes region and Pennsylvania, as a result of increased sympatry after a series of warm winters (Garroway et al. 2010). A parasite of these 2 species, apparently influenced by temperature, appears to have less deleterious effects on *G. volans* in the southern and central portion of its range and thus may impart an advantage over *G. sabrinus* in sympatric areas (Weigl 2007).

Climate change is expected to shift the ranges of boreal species, such as the snowshoe hare (*Lepus americanus*), northward; fragmentation and loss of southern populations are anticipated (Cheng et al. 2014). Further, snowshoe hare exhibit seasonal changes in pelage color that help them to evade detection by predators. The timing of molting shows limited response to snow conditions within a given location and appears to be fixed by photoperiod; thus as the number of snow-free days increases, snowshoe hares will likely experience longer mismatches between coat color and ground cover, leading to increased vulnerability to predators (Zimova et al. 2014). Hares do not appear to recognize this mismatch as they show no behavioral changes when coat color is mismatched to ground cover (Zimova et al. 2014).

Bats

Climate change-induced habitat loss may lead to losses of wildlife, including bats. For example, hoary bats (*Lasiurus cinereus*) in the northeastern United States have been known to roost exclusively in eastern hemlock (*Tsuga canadensis*) (Veilleux et al. 2009). The eastern hemlock, however, is expected to be severely reduced by the hemlock wooly adelgid (HWA) (*Adelges tsugae*), a tree pest that seems to be increasing due to climate change (Paradis et al. 2008).

Increasing climate variability may affect some bat species, with both increases and decreases in precipitation having negative impacts. For example, big brown bats (*Eptesicus fuscus*), have shown higher mortality in response to extreme droughts that may increase in the future, especially for some areas of the Midwest (O'Shea et al. 2011). Lower weight-gain for juvenile and adult female big brown bats was associated with years with lower rainfall and higher temperatures in spring and summer (Drumm et al. 1994). Decreased summer precipitation may even lead to higher mortality for little brown bat (*Myotis lucifugus*) (Frick et al. 2010).

Yet, increases in precipitation at the right time may be beneficial for insectivorous bat species (Moosman et al. 2012). Moreover, climate change may increase riparian habitat in some areas of the Northeast and Midwest in coming decades, which has been shown to be important for bat foraging (e.g., hoary bats and big brown bats; Menzel et al. 2005). In Indiana, even heavy rains in spring may have a positive effect on reproduction in big brown bat, which already seem resilient to natural fluctuations in climate (Auteri et al. 2012).

Climate change also could have additional positive effects. The eastern red bat *(Lasiurus borealis)* may be expanding its range in response to climate change, in this case, into Canada (Willis & Brigham 2003). Bats are not as active in very cold climates and thus may begin to become more active in the future. However, cold-adapted species at the southern edge of their range, such as the eastern red bat, might pull out of the Northeast and Midwest (Arndt et al. 2012). Increased temperatures have also been shown to negatively affect the northern long-eared bat (*Myotis septentrionalis)* (Johnson et al. 2011).

Disease is an important consideration when discussing bats in the Northeast and Midwest. The connection between white-nose syndrome and climate change is still unclear, but warming climates could ultimately reduce vulnerability of little brown bat and other bats to this fungal pathogen (Ehlman et al. 2013).

Carnivores

Carnivores in the Northeast and Midwest could see a mix of effects from climate change, especially if the region is at the southern edge of their distribution. Snowpack, competition, and prey availability may be the key drivers of these effects. For example, Canada lynx (*Lynx canadensis*) has been shown to be negatively affected by increased rain and decreased snow, as is projected for much of the Northeast and Midwest (Stenseth et al. 2004; Yan et al. 2013). Moreover, bobcat (*Lynx rufus*) will likely outcompete Canada lynx in this new habitat (Peers et al. 2013) and bobcat range expansion could result in increased interspecific hybridization.

Climate change is interacting with human activities such as forest harvesting and trapping to cause declines in mammal populations. For example, Canada lynx and American marten (*Martes americana*) are negatively affected in some United State forests (Carroll 2007). Models show that American Marten populations in the western United States could be isolated due to climate change (Wasserman et al. 2012), although it is unclear how this research applies to species in the eastern United States (Koen et al. 2014).

Generalist species like the coyote (*Canis latrans*) are more likely to persist during periods of rapid environmental change than specialist species (Malcolm et al. 2002; Koblmüller et al. 2012). Martínez-Meyer et al. (2004) found that climatic variables were poor predictors of coyote distributions through past periods of climate change, and suggested that distributions were determined by factors not directly related to climate. Effects of climate change on abundance are unclear, although coyote abundance is typically tied to the abundance of prey species (Todd and Keith 1983; Knowlton & Gese 1995; O'Donoghue et al. 1997). An observed trend toward greater coyote abundances at lower latitudes has been interpreted by some as resulting from greater food availability in southern regions during the critical winter months (Windberg 1995). If this interpretation is correct, milder winters may result in higher abundances in the Midwest and Northeast. However, like with many other carnivores in the region, potential climate-related impacts on coyote abundance will likely depend upon climate-related impacts to prey species abundance.

Other Mammals

American beaver (*Castor canadensis*) is a habitat specialist, requiring streams with gentle gradients and at least intermittent flow, and lakes or ponds with standing water (Howard & Larson 1985; Baker & Hill 2003). Climate change scenarios for the Northeast and Midwest generally predict that increased temperatures will lengthen the growing season and increase the frequency of short-term drought and decreased soil moisture, resulting in some reduction of suitable habitat for beavers. If so, decreases in beaver populations could exacerbate climate effects as the presence of beavers has been associated with increased groundwater recharge, higher summer stream flows, and refugia for cold-adapted species such as moose and some amphibians (Gurnell 1998; Popescu & Gibbs 2009; Westbrook et al. 2006).

Birds

Additional information on species-specific habitat shifts due to climate change can be found in Appendix 3.2, Exhibit 1, modified from the Climate Change Bird Atlas (Matthews et al. 2007, 2011; http://www.fs.fed.us/nrs/atlas) in Morelli et al. (2015).

Grassland birds

Changing precipitation regimes could have large effects on grassland bird populations. For example, spring densities of Baird's sparrow (*Ammodramus bairdii*) were negatively correlated with the previous winter's snowfall whereas grasshopper sparrow (*Ammodramus savannarum*) densities were positively correlated with May precipitation (Ahlering et al. 2009). Climate appears to drive the abundance of some grassland bird species, especially the grasshopper sparrow, and also the bobolink (*Dolichonyx oryzivorus*), Henslow's sparrow (*A. henslowii*), sedge wren (*Cistothorus platensis*), and upland sandpiper (*Bartramia longicauda*) (Thogmartin et al. 2006).

In North Dakota, grassland birds during drought showed a decline in species richness and abundance, with detrimental (although primarily short-term) effects on nearly all species studied: Baird's sparrow (*Ammodramus bairdii),* grasshopper sparrow, upland sandpiper, sharp-tailed grouse (*Tympanuchus phasianellus*), mourning dove (*Zenaida macroura*), eastern kingbird (*Tyrannus tyrannus*), Sprague's pipit (*Anthus spragueii*), clay-colored sparrow (Spizella pallida), field sparrow (S. pusilla), vesper sparrow (*Pooecetes gramineus*), lark sparrow (*Chondestes grammacus*), Brewer's blackbird (*Euphagus cyanocephalus*), and brown-headed cowbird (*Molothrus ater*) (George et al. 1992). On the other hand, forest clearing may cause grasshopper sparrows to increase across the eastern United States (Naujokaitis-Lewis et al. 2013). Similarly, northern bobwhite (*Colinus virginianus*) will likely increase in the Midwest and parts of the Northeast as pine woodland and savanna replace some hardwood forests (Matthews et al. 2007; Rodenhouse et al. 2008).

Forest birds

Perhaps best studied are effects of climate change on forest-dwelling passerine birds with changing temperature and precipitation regimes to be observed in various responses. For species with seasonal migrations, phenological mismatches with food and habitat availability are one of the biggest concerns, especially when birds are arriving earlier to their breeding grounds across the northern United States (Butler 2003; Marra et al. 2008; Wilson 2013). American woodcock (*Scolopax minor*) distribution has expanded in recent decades, possibly in response to climate change (Thogmartin et al. 2007), and this short-distance disperser has begun arriving to its breeding grounds earlier in the spring in the Northeast (Butler 2003). Wood thrush (*Hylocichla mustelina*) and Louisiana waterthrush (*Parkesia motacilla*) also have advanced their arrival times in the Northeast over the last century (Butler 2003). The scarlet tanager (*Piranga olivacea*) has been shown to be vulnerable to shifting seasons and spring mistiming (Zumeta & Holmes 1978). Black-throated blue warblers (*Setophaga caerulescens*) studied in New Hampshire initiated breeding earlier in warmer springs, with early breeders more likely to have a second brood, leading to higher reproductive rates (Townsend et al. 2013). Climate variability could exacerbate problems with timing. For instance, late spring storms and extreme weather events have been shown to kill migrating birds (Zumeta and Holmes 1978; Dionne et al. 2008).

By comparison, as found in Rhode Island, at end of the breeding season some birds are departing later in the autumn including; the black-and-white warbler (*Mniotilta varia*), blackpoll warbler (*Setophaga striata*), red-eyed vireo (*Vireo olivaceus*), eastern towhee (*Pipilo erythrophthalmus*), hermit thrush (*Catharus guttatus*), song sparrow (*Melospiza melodia*), and yellow-rumped warbler (*Setophaga* *coronata*), gray catbird (*Dumetella carolinensis*), veery (*Catharus fuscescens*), white-throated sparrow (*Zonotrichia albicollis*), and the ruby-crowned kinglet (*Regulus calendula*) (Smith and Paton 2011).

Birds may be affected by climate change through shifts in habitat. The Canada warbler (*Cardellina canadensis*), for example, is projected to shift its distribution northward concurrent as boreal and northern hardwood forest that it inhabits shifts northward, with the most severe model scenarios showing complete extirpation from the northeastern United States (Rodenhouse et al. 2008; Appendix 3.2., Exhibit 1). Likewise, the Bicknell's thrush (*Catharus bicknelli*) is expected to diminish its United States range by more than half as temperatures increase and its habitat subsequently shifts northward. Similar negative trends are expected for other birds that inhabit the montane spruce-fir forest of the Midwest and Northeast at the southern edge of their range, including; ruby-crowned kinglet, blackpoll warbler, spruce grouse (*Alcipennis canadensis*), three-toed woodpecker (*Picoides tridactylus*), black-backed woodpecker (*P. arcticus*), yellow-bellied flycatcher (*Empidonax flaviventris*), gray jay (*Perisoreus canadensis*), boreal chickadee (*Poecile hudsonica*), and white-winged crossbill (*Loxia leucoptera*) (Rodenhouse et al. 2008). The blue-headed vireo (*Vireo solitarius*) is predicted to decline 6 to 8% across its range within the next 50 years due to shifts in its conifer habitat (Rodenhouse et al. 2009).

Additionally, the Designing Sustainable Landscapes Project at the University of Massachusetts Amherst and Northeast Climate Science Center has developed models to predict future landscape capability for a suite of species (DeLuca and McGarigal 2014). The Landscape Capability Index (LC) represents the capability of the landscape to provide suitable and accessible conditions for a species to survive and/or reproduce. The LC is the product of three separate modeling efforts for each species: habitat capability

Table 3.9. Relative change in Landscape Capability between 2010 and 2080 for 14 representative species. DeLuca & McGarigal (2014) *in* Morelli et al. (2015).

Species	Percent Change in Landscape Capability by 2080
American woodcock	-9%
Blackburnian warbler	-71%
Blackpoll warbler	-66%
Eastern meadowlark	+17%
Louisiana waterthrush	+14%
Marsh wren	+40%
Moose	-3%
Northern waterthrush	-70%
Prairie warbler	-18%
Ruffed grouse	-54%
Saltmarsh sparrow	-59%
Wood duck	+37%
Wood thrush	-1%
Wood turtle	-2%

(HC), climate suitability (CS), and prevalence. For example, LC for the blackpoll warbler is predicted to decrease by 66% and the LC for the blackburnian warbler (*Setophaga fusca*) is predicted to decrease by 71% of their 2010 northeastern range by 2080 (DeLuca & McGarigal 2014; Table 3.9; Fig. 3.16).

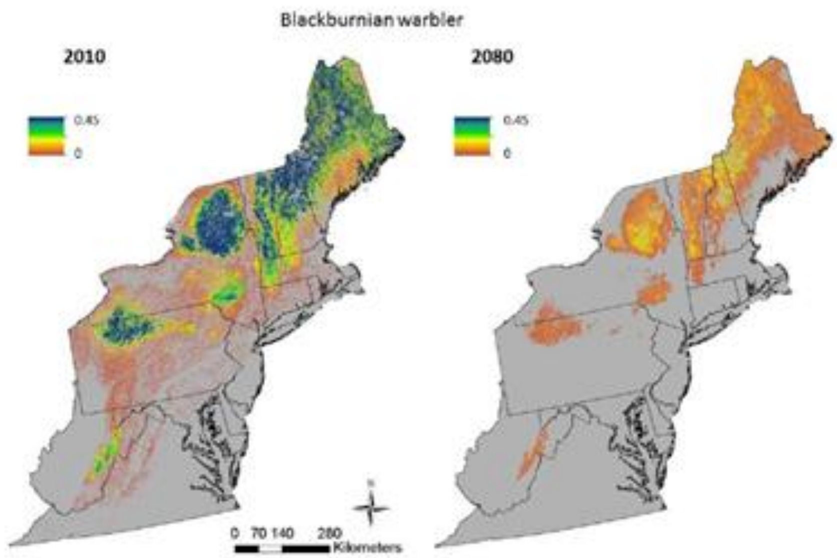

Fig. 3.16. Predicted change in Landscape Capability (LC) from 2010 to 2080 for the Blackburnian Warbler. A 71% decrease in LC is predicted. (Source: DeLuca & McGarigal (2014) *in* Morelli et al. (2015). *Used with permission by the DOI Northeast Climate Science Center*.

DeLuca and McGarigal (2014) first calculated Landscape Capability (LC) for each species in 2010. LC is an index that represents the capability of the landscape to provide suitable and accessible conditions for a species to survive and/or reproduce. LC is the product of three separate modeling efforts for each species: habitat capability (HC), climate suitability (CS), and prevalence. DeLuca and McGarigal (2014) derived LC-climate in the year 2080 for each species by multiplying 2010 HC by 2080 CS, thus keeping the effect of habitat constant and focusing the potential change in LC solely on the changing climate. This metric can be interpreted as: 1) For species with % change in LC in 2080 is near 0%, suitable climate conditions are predicted to prevail in the Northeast; 2) For species with substantial positive % change values, the amount of area in the Northeast that has suitable climate conditions is predicted to increase; and, 3) For species with substantial negative % change values, the amount of area in the Northeast that has suitable climate conditions is predicted to decrease. For further details on the General Circulation Models (GCMs) and emissions scenarios used, see http://jamba.provost.ads.umass.edu/web/lcc/DSL_documentation_climate.pdf.

By comparison, species like the black-throated green warbler (*Setophaga virens*), may remain stable due to more flexible habitat use and large populations (Cullen et al. 2013). This is despite potential negative impacts from habitat change driven by increasing temperatures, pests like hemlock woolly adelgid (HWA), as well as mismatched phenology (Cullen et al. 2013). Some species may see positive impacts of climate change (e.g., Louisiana waterthrush, eastern meadowlark (*Sturnella magna*) and marsh wren (*Cistothorus palustris*) (Table 3.9); the eastern wood-pewee has been arriving earlier in the spring and is expected to increase in abundance across its range in response to precipitation and other climate changes (Rodenhouse et al. 2008). Similarly, the hooded warbler may increase in abundance in the Northeast and Midwest, its northern range edge. Likewise, species that depend on early successional habitat may see increases due to climate change-induced increases in disturbance (Cullen et al. 2013).

Populations of ruffed grouse (*Bonasa umbellus*) have been declining in much of the eastern United States as early successional habitats have given way to mid-aged and mature forest (Blomberg et al. 2009). The distribution of ruffed grouse is closely associated with the distribution of quaking aspen (Kubisiak 1985), and population densities are typically high in this forest type (Dessecker et al. 2007). Declines in quaking aspen due to climate change, reduced logging, and forest succession could lead to declines in grouse populations compared to recent centuries (Iverson et al. 2008b; Worrall et al. 2013). Moreover, snow cover can be important for overwinter survival in grouse, as they will burrow into deep, soft snow during cold winter periods (Whitaker & Stauffer 2003). Warming temperatures likely will change snow quantity and characteristics (e.g., crusting conditions), making snow roosting more difficult. Models predict that, over the long term, climate change will greatly reduce the proportion of the Northeast that is capable of supporting ruffed grouse (Matthews et al. 2007; DeLuca & McGarigal 2014; Appendix 3.2, Exhibit 1; Table 3.9). Studies of grouse also highlight a cascading effect of climate change: plants may become more heavily defended and less nutritious with warming temperatures, posing an increasing threat to the birds that consume them (Buskirk 2012).

Complex interspecific interactions also must be considered. For example, black-billed cuckoos (*Coccyzus erythropthalmus*) feed primarily on gypsy moth caterpillars that are expected to increase with climate change (Cullen et al. 2013). Interspecific nest parasitism with the yellow-billed cuckoo (*Coccyzus americanus*) also may be affected, but the outcome for the black-billed cuckoo is uncertain. Likewise, competitive interactions could exacerbate or even drive species shifts. If climate change causes carolina chickadee (*Poecile carolinensis*) to expand northward, the black-capped chickadee (*Poecile atricapillus*) may see a significant range reduction due to competitive exclusion (Wilson 2012). Cox et al. (2012) highlighted the complex effects of climate change, finding an interaction effect of temperature and forest cover on the productivity of the acadian flycatcher (*Empidonax virescens*) and indigo bunting (*Passerina cyanea*). Higher temperatures were correlated with lower productivity due to increased nest predation by snakes, but only in areas with higher forest cover, which otherwise had higher productivity. Greater forest cover resulted in greater productivity because of reduced brood parasitism and increased nest survival, whereas greater temperatures reduced productivity in highly forested landscapes, because of increased nest predation but had no effect in less-forested landscapes. Climate change also can reduce access to prey through phenological mismatch. Aerial insectivores like flycatchers may see food shortages due to climate change (Nebel et al. 2010).

Land-use change is an important consideration for expected future fish and wildlife populations. For example, dramatic geographic shifts upslope and northward are projected for the hooded warbler (*Setophaga citrina*) (Sohl 2014), a species that seems to already be shifting its breeding distribution north in response to climate change (Melles et al. 2011). Land-use change modeling resulted in diverse local-scale changes in habitat suitability; for example, development around the Great Lakes is a limiting factor for range expansion for the hooded warbler (Naujokaitis-Lewis et al. 2013).

Coastal Birds

Many bird species, such as wading birds, are dependent on the coastal habitats that may be reduced as the sea level rises to meet nearshore human development (National Wildlife Federation-NWF and Manomet Center for Conservation Sciences (NWF & Manomet 2014). In addition to direct habitat loss from sea-level rise, changes in precipitation and increased temperatures could lead to salt accumulation in soils and less productive habitat, ultimately resulting in reductions in suitable bird habitat (Woodrey et al. 2012). However, tidal flats are projected to increase, which may benefit some shorebirds and waterfowl.

Piping plover (*Charadrius melodus*) has been well-studied in the context of climate-change impacts on coastal environments and appears to have low adaptive capacity (Saunders & Cuthbert 2014). Projections indicate that the Atlantic piping plover population will lose critical nesting habitat due to the dual pressures of sea-level rise and urban development (Seavey et al. 2011; NWF & Manomet 2014). Sea-level rise and urban development together could result in the loss of habitat for the acadian flycatcher and other salt marsh wildlife as well (Thorne et al. 2012). These effects are exacerbated by the nutrient enrichment that often accompanies development, which can eventually cause community shifts (Woodrey et al. 2012). In response to increasing salinity, the marsh wren (*Cistothorus palustris*) and least bittern (*Ixobrychus exilis*) may become less common although the clapper rail (*Rallus longirostris*) and seaside sparrow (*Ammodramus maritimus*) could benefit (Rush et al. 2009).

Extreme events, specifically severe winter storms, could increase mortality for the great blue heron, little blue heron, snowy egret, tricolored heron, and green heron (DuBowy 1996). Drastic fluctuations in annual precipitation have been shown to influence the mechanism by which watershed development impacts coastal waterbirds (Studds et al. 2012). Additionally, increasing frequency and intensity of coastal storms and surges could negatively impact shorebirds, but also could create new habitat (Cohen et al. 2009). Migrating birds have been shown to be negatively impacted by extreme events, such as chimney swift populations during Hurricane Wilma (Dionne et al. 2008). More intense hurricanes, expected due to climate change, could disturb foraging and nesting habitat for shore- and marsh-birds, which can have both negative and positive effects (Woodrey et al. 2012).

In addition to affecting habitat availability, climate change can shift the timing of prey availability through direct effects of climate change on prey species abundance and distribution. For example, a climate change-driven decrease in horseshoe crabs is causing a decrease in ruddy turnstones (*Arenaria interpres*), with interacting effects related to the avian influenza virus (Brown & Rohani 2012).

Wetland birds

Precipitation and percentage of wetland area, which are affected by climate change, are good predictors of abundance for many bird species, including the black tern (*Childonias niger*) and marsh wren (*Cistothorus palustris*) in the Prairie Pothole region of the Northern Great Plains (Forcey et al. 2014).The black tern, American bittern (*Botaurus lentiginosus*), American coot (*Fulica americana*), pied-billed grebe (*Podilymbus podiceps*), and sora (*Porzana carolina*), 5 waterbird species common to the region, were predicted to lose significant parts of their range; up to 100% for the sora and black tern (Steen & Powell 2012). The Prairie Pothole region of the Midwest and Great Plains has a high density of shallow wetlands that produces 50-80% of the continent's ducks (Sorenson et al. 1998). Climate models project increased drought conditions for this region, resulting in northward shifts in breeding distribution, with the potential for dramatic reductions in overall waterfowl populations (Sorenson et al. 1998). Additionally, loss of pothole wetlands through drying can concentrate predators, which would have a greater impact on birds nesting in the remaining potholes. Duck production varies greatly from year to year due to changes in the area of wetlands in this region linked to variable weather patterns (Klett et al. 1988).

Typical responses to drought conditions in waterfowl include decreased frequency of breeding and renesting, decreased clutch sizes, shortened breeding season, and other responses that depress production (Davies & Cooke 1983; Krapu et al. 1983; Cowardin et al. 1985; Sorenson et al. 1998). Dramatically reduced duck populations could reduce the number of birds migrating throughout the country. For example, although the blue-winged teal (*Anas discors*) breeds from coast-to-coast, its distributional center is in the Prairie Pothole Region of the Northern Great Plains. Changes in migration timing are likely, and have already been documented for blue-winged teal in Massachusetts and New York (Butler 2003).

Climate variability is expected to increase in the Northeast and Midwest, with more precipitation in fewer events (Bryan et al. 2015). Rainfall has been shown to have a negative effect on nest abundance in herons and egrets, particularly in wet or dry years, at least in San Francisco (Kelly & Condeso 2014). Since the 1960s, the rusty blackbird (Euphagus carolinus) has retracted its continental range northward by 88.8 miles (143 kilometers), by which presence is correlated with cyclical climate patterns, indicating climate change is having a strong negative effect on this once common species (McClure et al. 2012).

Raptors

Raptors are showing responses to climate change as well. Precipitation and percentage of wetland area are the best predictors of the abundance of the northern harrier (*Circus cyaneus*). A study of 6 raptor species; northern harrier, American kestrel (*Falco sparverius*), golden eagle (*Aquila chrysaetos*), prairie falcon (*Falco mexicanus*), red-tailed hawk (*Buteo jamaicensis*), and rough-legged hawk (*Buteo lagopus*) showed significant poleward shifts in their wintering distributions since 1975 (Paprocki et al. 2014). Raptors appear to be arriving earlier in the spring and leaving later in the autumn as well (Buskirk 2012).

Some raptors may be affected positively by climate change. A study in the western United States showed that kestrel migration distance decreased significantly over the last half century and that earlier nesting, and thus higher reproductive success, appeared to be driven by warmer winters (Heath et al. 2012). In addition, the northern goshawk (*Accipiter gentilis*) also has been shown to have high tolerance to windstorm damage (Penteriani et al. 2002).

Amphibians

Amphibians are often considered indicators of environmental health due to their sensitivity to their surroundings, as well as their use of both terrestrial and aquatic environments. They also have been in global decline; first recognized in the late 1980's (Adams et al. 2013). In South Carolina, the mole salamander (*Ambystoma talpoideum*), tiger salamander (*A. tigrinum*), ornate chorus frog (*Pseudacris ornate*), and southern leopard frog (*Rana sphenocephala*) declined during a 30-year drying period, raising concerns for certain areas of the Midwest, and for the rest of the region by end of the century. By comparison, the marbled salamander (*Ambystoma opacum*) increased in abundance during this time (Daszak et al. 2005).

Stream salamanders have been particularly well-studied in the Northeast, although focusing mostly on habitat fragmentation and issues other than climate change. In a South Carolina wetland, 2 autumn-breeding species, the dwarf salamander (*Eurycea quadridigitata*) and the marbled salamander arrived at the wetland significantly later in recent years whereas 2 winter-breeding species, the tiger salamander and the ornate chorus frog arrived significantly earlier in later years (Todd et al. 2010).

Direct effects of changes in precipitation have been studied in salamanders. Milanovich et al. (2006) found that precipitation influenced fecundity in a population of western slimy salamanders (*Plethodon albagula*). Spring salamander (*Gyrinophilus porphyriticus*) abundance at a site in New Hampshire was negatively correlated with annual precipitation; increasing precipitation appears to be causing a decline in adult recruitment, possibly through mortality of metamorphosing individuals during spring and fall floods that have increased in volume and frequency with the increasing precipitation (Lowe 2012). Likewise, the blackbelly salamander (*Desmognathus quadramaculatus*), Ocoee salamander (*D. ocoee*), and Blue ridge two-lined salamander (*Eurycea wilderae*) in the southern Appalachian Mountains showed reduced body condition, productivity, and abundance, which were correlated with increased drought (Hamed 2014). Drought is expected to increase in that area as well as some areas of the Northeast and Midwest with climate change (Bryan et al. 2015a).

Microhabitat and seasonal habitat use can indicate effects of climate change. For example, both the spotted salamander (*Eurycea lucifuga*) and western slimy salamander (*Plethodon albagula*) were more likely to be found in climate refugia such as caves with cooler temperatures in summer, higher relative humidity conditions in autumn and near-permanent streams (Briggler & Prather 2006).

Despite all of these changes, salamanders are expected to have some capacity to adapt to climate change. Price et al. (2012) found that, although drought negatively affected larvae, high survivorship of adult northern dusky salamanders (*Desmognathus fuscus*) likely buffers this effect. Moreover, movement around the landscape in response to drought conditions allows adult salamanders to be resilient to these climate change effects (Price et al. 2012) yet, generally for amphibians, habitat fragmentation may constrain movement and efforts to find suitable habitats (Cushman 2006). Furthermore, adaptive capacity to respond to variability in climate has been shown in salamanders; for example, the immune system of the hellbender (*Cryptobranchus alleganiensis*) seems to show compensatory effects at stressfully high temperatures (Terrell et al. 2013).

Reptiles

Freshwater Turtles

Freshwater turtles will be affected by climate change in a variety of ways; mostly through effects on water temperature and flow. For example, climate change and human development can act synergistically to decrease habitat for bog turtle (*Glyptemys muhlenbergii*) (Feaga 2010). Similarly, studies of the Blanding's turtle (*Emydoidea blandingii*) showed increasing temperatures correlated with decreases in habitat suitability, which can potentially be offset (or exacerbated) by human development (Millar & Blouin-Demers 2012). For wood turtles (*Glyptemys insculpta*) in Massachusetts, floods displaced over 40% of the subpopulation annually, elevated mortality rates, and decreased breeding success (Jones & Sievert 2009). Floods are expected to intensify and become more common; impervious surfaces and hardening of upstream riverbanks may be amplifying these effects (Jones & Sievert 2009). For map turtle (*Graptemys geographica*) hatchlings emerge later with increasing temperatures and rain events resulting in higher survival (Nagle et al. 2004).

Sex-ratio determination, which is driven by temperature, is an important consideration in turtles. Thus, there is concern that species will begin to be artificially skewed toward more females or more males, depending on the particular life history of the species and location of the population. Experimental manipulation has shown a lack of adaptive capacity to compensate for sex ratio bias due to warming nest temperatures, at least in some species (Refsnider et al. 2013). However, other studies have pointed out that atmospheric warming required to raise the nest temperature enough to affect the sex ratio is not expected until late in the century, at least for eastern box turtle (*Terrapene carolina carolina*; Savva et al. 2010).

Snakes

A few studies indicate that climate change effects could negatively affect snakes in the Northeast and Midwest. Extreme precipitation events might result in negative effects on snakes. For example, after a year with exceptionally high summer rainfall, a skin infection caused significant mortality in New Hampshire's timber rattlesnake (*Crotalus horridus*) population (Clark et al. 2011). Likewise, extreme fluctuations of the water table in their habitat, especially near hibernacula, caused demographic stress in populations of eastern massasauga (*Sistrurus catenatus catenatus*), trends that will likely be exacerbated in the future (Pomara et al. 2014). By comparison, higher temperatures can increase the activity patterns, and perhaps the survival rates of ectotherms such as snakes (Sperry et al. 2010; Cox et al. 2012).

Fish

For fish, more than any other taxonomic group, there is a better understanding of how ambient temperatures affect survival and reproduction and thus, in some ways, the effect of climate change is better understood for fish than for other species (Morelli et al. 2015).

Freshwater Fish

Warming water temperatures could influence activity levels, consumptive demands, growth rates, interspecific interactions, and the amount of suitable habitat available for freshwater fish. Adaptability to changing water temperature is expected to vary among species. One of the best studied species in the Northeast is the brook trout (*Salvelinus fontinalis*), a riverine fish adapted to cold temperatures (Shuter et al. 2012). There is concern that climate change will cause rivers to increase in temperature beyond the thermal tolerance of brook trout, yet some studies show that the effects are more complicated than simply elevated temperatures. For example, brook trout populations have different temperature tolerances and refugia, resulting from groundwater inputs and riparian cover, can buffer the effects of increasing temperatures (Argent & Kimmel 2013), potentially allowing for adaptive capacity in the species (Stitt et al. 2014). Moreover, the temperature sensitivity of brook trout, for example, is compounded by competition with introduced and native species. This competition for prey and thermal refugia has been attributed to constrained Brook Trout growth (Petty et al. 2014).

Shifting the timing of important life-history events (e.g., morphological development required for exogenous feeding) may disrupt temporal overlap between predators and prey (Winder and Schindler 2004). In recent years, larval yellow perch (*Perca flavescens*) in Oneida Lake, New York, attained a length of 18 millimeters earlier, correlated with above-average May water temperatures (Irwin et al. 2009). Beyond intrinsic physiological thermal limitations, habitat fragmentation and land conversion are negatively impacting some fish populations (Argent & Kimmel 2013; NWF & Manomet 2014).

An even more cold-adapted species, the burbot (*Lota lota*), has been shown to be adapted to low temperatures and low levels of oxygen and food in the winter (Shuter et al. 2012). Burbot hatchling and larval success decreases significantly with increasing temperatures (Lahnsteiner et al. 2012). For example, the burbot population in Lake Oneida, New York, has declined significantly over the last 50 years in conjunction with rising summer temperatures, apparently from reduced access to prey. This situation appears to be exacerbated by the lack of climate refugia at this site and is expected to continue, with possible extirpation of burbot from the lake (Jackson et al. 2008).

Climate change is expected to decrease the number of lakes suitable for cold-water adapted species (Herb et al. 2014). The cold-adapted lake trout (*Salvelinus namaycush*) may begin to disappear both from direct effects of climate change (e.g., increasing temperatures) and the indirect effects of competition from smallmouth bass (*Micropterus dolomieu)* moving northward in response to warming temperatures (Sharma et al. 2009). The lake whitefish (*Coregonus clupeaformis*) is another species adapted to cool temperatures and lower levels of oxygen (Shuter et al. 2012). Gorsky et al. (2012) showed that Lake Whitefish closely track temperature in their lake habitats in May, indicating that the species' distribution may be affected by climate change. Further, warming water temperatures advance hatching in Lake Whitefish, indicating that climate change might cause a timing mismatch between the larvae and prey availability, thus increasing mortality (Patrick et al. 2013). Moreover, Lake Whitefish condition and growth are affected by factors in addition to climate change, including invasive mussel presence (Rennie et al. 2009). By comparison, American brook lamprey (*Lethenteron appendix*) also may have some ability to adapt to warming temperatures; in a warm year in southeastern Minnesota

American brook lamprey spawned a month earlier than the historical norm (Cochran et al. 2012) although with unknown effects on the food web.

In Wisconsin, some smaller tributaries are projected by mid-century to warm above the critical thermal threshold for lake sturgeon (*Acipenser fulvescens*), and identification of climate-change refugia is a key recommendation for mitigating these effects (Lyons & Stewart 2014). By comparison, year-class strength was found to be positively correlated with mean June air temperature in Minnesota (Adams et al. 2006) and year-class strength in the St. Lawrence River was positively correlated with warm June conditions and fast flows (Nilo et al. 1997).

Climate change already is affecting the Great Lakes (Bryan et al. 2015a). Projections show that thermally suitable habitat will remain for most species, although in different locations than currently distributed. It is predicted that cold-adapted species will shift north and move deeper in the water column, with warmer-adapted species filling the niches they leave behind (Lynch et al. 2010). Invasive species could be an important exacerbating factor. For example, invasion by the parasitic sea lamprey (*Petromyzon marinus*) already has contributed to major declines in many Great Lakes fish populations and will likely lead to even higher rates of mortality as warmer waters lead to larger lamprey, higher feeding rates, and eventually higher mortality of host fishes (Swink 1993; Cline et al. 2014).

Changes in community structure also can be caused by extreme events, stemming from or exacerbated by climate change (van Vrancken & O'Connell 2010; Boucek & Rehage 2014). A population of slimy sculpin (*Cottus cognatus*), a cool-adapted species with low mobility, declined significantly as a result of a mid-winter ice break-up and the associated flood and ice scour disturbance (Edwards & Cunjak 2007).

Anadromous Fish

A future of warmer temperatures, higher salinity, lower dissolved oxygen, increasing ocean acidification, and changing water currents all are expected to strongly impact anadromous fish populations (Kerr et al. 2009). These factors are expected to impact negatively on food availability for eel larvae (Knights 2003). For example, glass eel declines in the Northern Hemisphere are hypothesized to be tied to a climate-driven decrease in ocean productivity and thus food availability during early life stages (Bonhommeau et al. 2008).

Changes in precipitation and stream flow are closely linked to the reproductive success of anadromous species like American shad (*Alosa sapidissima*). Atlantic coast studies have shown that water temperature and discharge affect year-class strength of American shad populations (Crecco & Savoy 1984). Temperature appears to cue the northward movement of American shad for spawning, as well as the migration of smolts; climate change already appears to be changing this timing (Kerr et al. 2009).

The effect of climate change on Atlantic salmon (*Salmo salar*), a species adapted to cool temperatures (Shuter et al. 2012) is of great interest. As with other anadromous fishes, river and ocean changes will be important (Piou & Prévost 2013). The federally listed Atlantic salmon has experienced large declines in the last two decades, down to low abundance and even extirpations in some areas of New England. The decline may be related to, and will undoubtedly be exacerbated by, the effect of increased predation pressure from mackerel and other species, reduced prey availability, and increased metabolism at warmer temperatures (Friedland et al. 2003; Mills et al. 2013b). The Atlantic salmon range is predicted to continue to contract poleward with increasing temperatures. Projections in Norway found that Atlantic salmon at southern sites could be affected negatively by increasing temperatures, with the opposite effect found in more northern latitudes (Hedger et al. 2013). This could result in some community turnover, with Atlantic salmon replacing the more cold-adapted Arctic char (*Salvelinus alpinus*; Shuter et al. 2012; Penney et al. 2014). However, Budy and Luecke (2014) found that Arctic char may benefit from climate change in some places because of the positive effects of more ice-free days. Likewise, some adaptive capacity to warming waters has been found in the cardiac plasticity of Atlantic salmon (Anttila et al. 2014).

Coastal (Marine) Fish

Increasing temperatures will likely act, in conjunction with low dissolved oxygen and prey availability, to decrease growth and reproduction in some coastal and marine fish species (Kerr et al. 2009). In the Northwest Atlantic Ocean, 24 out of 36 commercially exploited fish stocks showed significant range (latitudinal and depth) shifts between 1968 and 2007 in response to increased sea surface and bottom temperatures (Nye et al. 2009). For instance, the winter flounder (*Pseudopleuronectes americanus*) could be affected negatively by climate change. It has poor recruitment in warm years in New Jersey, potentially related to predator response to temperature (Able et al. 2014). Likewise, winter flounder growth and survival rates were lower in sites with low dissolved oxygen levels in New Jersey and Connecticut tidal marsh creeks (Phelan et al. 2000). Phenological changes and increased predation on winter flounder have been seen in Narragansett Bay over the last century, likely in response to increased temperatures, precipitation, and sea level, and the subsequent ecological changes (Kerr et al. 2009; Smith et al. 2010).

Changes in other Atlantic coast species have been recorded as well. The growth rate of tautog (*Tautoga onitis*) is higher at lower temperatures (Mercaldo-Allen et al. 2006). Moreover, as a reef-based fish strongly associated with structure, distributional shifts in prey species could negatively impact tautog, which is expected to lag behind (Kerr et al. 2009). Similarly, although the Atlantic herring (*Clupea harengus*) is expected to shift its distribution northward, predators like the Atlantic cod (*Gadus morhua*) may not be able to follow at the same pace (Kerr et al. 2009). Some species life histories are disrupted by climate variability; increases and decreases in average temperature during the spring have been shown to negatively affect the probability of capturing spiny dogfish (*Squalus acanthias*) along the Atlantic coast, although the species became more abundant in northern sites in warm years (Sagarese et al. 2014).

Whether climate change will shift the distribution or abundance of a species in a particular location often depends on whether it is at the southern or northern edge of its range limit, or whether it is in the center of its distribution. For example, a study in Maryland found that abundance of northern puffers (*Sphoeroides maculatus*) increased in association with high winter temperatures and low flows, whereas the opposite was true for the Atlantic silverside (*Menidia menidia*, Wingate & Secor 2008).

Invasive species will interact with the effects of climate change in complex ways. Zebra mussels (*Dreissena polymorpha*) seem to increase colonization in warmer water, thus further decreasing growth and abundance of striped bass, American shad, alewife (*Alosa pseudoharengus*), and blueback herring (*Alosa aestivalis*) (Kerr et al. 2009).

Disease may be increasingly important in marine ecosystems. Increasing temperatures, ocean acidification, and shifting precipitation regimes may be increasing susceptibility to outbreaks and the dynamics of pathogens. For example, mortality in the longhorn sculpin (*Myoxocephalus octodecemspinoszu*) from a protozoan gill parasite increases with increasing water temperatures (Brazik & Bullis 1995). Oysters, too, are seeing new disease outbreaks with warmer temperatures (Burge et al. 2014).

Invertebrates

Freshwater Mussels

Freshwater mussels (Unionidae) are among the most imperiled wildlife in the eastern United States (Ricciardi & Rasmussen 1999). Their habitat has been, and continues to be, under threat from habitat degradation and pollution (Strayer et al. 2004). Hydropower development also can have a large negative impact on mussels; many species are non-migratory with limited vertical movement and rely on flood events to make large distribution shifts (Furedi 2013). Dams could prevent migration to thermally appropriate habitat northward and upstream in the face of climate change. Moreover, the increased flooding events predicted by climate change will decrease water quality as well as displace individuals from suitable habitat. Increasing temperatures may have additional direct detrimental effects. Drought during summer could slow or eliminate critical flows (Santos et al. 2015). Additionally, mussels use fish as hosts for larval development and dispersal, often having a limited number of fish species they can parasitize. Fish hosts may themselves be negatively affected by environmental changes and will likely shift distributions at different rates than mussels. Finally, the increasing spread of zebra mussels and other invasive species will continue to negatively affect freshwater mussels (Furedi 2013; Archambault et al. 2014).

The dwarf wedgemussel (*Alasmidonta heterodon*) and triangle floater (*Alasmidonta undulate*) are considered extremely vulnerable to climate change. Their habitat is threatened by future hydropower development (Furedi 2013). Dwarf wedgemussel populations are highly localized in areas within a narrow band of precipitation. Thus, these populations could be disrupted by climate change and especially increased flooding in the Northeast. Dams located upstream of some triangle floater populations could prevent movement in response to climate change. More intense precipitation, predicted in the region, threatens both species (Furedi 2013). Increasing stream temperatures and droughts may increase mortality, reduce burrowing capacity, and inhibit juvenile dispersal in the eastern lampmussel (*Lampsilis radiata*) (Archambault et al. 2014). The fatmucket clam (*Lampsilis siliquoidea*), pink heelsplitter (*Potamilus alatus*), black sandshell (*Ligumia recta*), butterfly (*Ellipsaria lineolata*), white heelsplitter (*Lasmigona complanata*), washboard (*Megalonaias nervosa*), and eastern creekshell (*Villosa delumbis*) are expected to be negatively affected by increasing water temperatures (Pandolfo et al. 2010).

As a habitat specialist, the brook floater (*Alasmidonta varicosa*) also is considered extremely vulnerable to climate change. With low thermal tolerances as juveniles and adults (Pandolfo et al. 2010), and located mostly in upstream habitats, this species will have difficulty shifting in response to climate change. Moreover, increases in drought or decreases in flow will have a detrimental impact. There are similar concerns for the eastern pondmussel (*Ligumia nasuta*), as well as impacts from the zebra mussel due to the slow water habitats it uses (Furedi 2013).

The yellow lampmussel (*Lampsilis cariosa*) is considered highly vulnerable to climate change due to destruction and degradation of habitat and spreading zebra mussel populations. The pocketbook (*Lampsilis ovata*) also is considered highly vulnerable to climate change, with a narrow precipitation range and sensitivity common to freshwater mussel species (Furedi 2013). The widespread black sandshell (*Ligumia recta*) already is declining in certain areas and also is considered highly vulnerable to typical threats of freshwater mussels (Furedi 2013).

The green floater (*Lasmigona subviridis*) is considered extremely vulnerable and is currently in decline because it requires still, clear water in upstream habitats, which is being degraded through pollution and siltation and the introduction of non-native species. The thermally sensitive deertoe (*Truncilla truncata)* showed that a period of high-water temperatures, drought, and low discharge from reservoirs caused a turnover in the species assemblage, with an advantage to thermally tolerant species and important implications for water management (Galbraith et al. 2010).

The eastern pearlshell (*Margaritifera margaritifera*) is considered extremely vulnerable to climate change as it is found in cold, nutrient-poor, unpolluted streams and smaller rivers with moderate flow rates (Furedi 2013), although another study found that it might have some capacity to adapt to increasing temperatures and shifting flows (Hastie et al. 2003). The species also may be sensitive to sea-level rise. Cascading effects could result from shifts by its host species. The species already has been extirpated as a result of pollution from coal mining in certain areas of the Northeast, and is threatened by the presence dams (Furedi 2013; Santos et al. 2015). By comparison, the northern lance (*Elliptio fisheriana*) seems to have higher capacity to adapt to low dissolved oxygen levels than some other species (Chen et al. 2001).

Insects

Relatively few insect SGCN have been studied in the context of climate change. Northeastern species thought to have high vulnerability to climate change include; tiger spiketail (*Cordulegaster erronea*), pale barrens bluet (*Enallagma recurvatum*)*,* Roger's clubtail (*Gomphus rogersi*), Delaware River clubtail (*Gomphus septima delawarensis*)*,* and ringed boghaunter (*Williamsonia lintneri*) *(*White et al. 2014). The U.S. federally threatened northeastern beach tiger beetle (*Cicindela dorsalis dorsalis*) is predicted to be negatively affected by climate change via sea-level rise and increased storm events that will lead to coastal erosion (Fenster et al. 2006). Likewise, insects associated with prairie fens like the rare Mitchell's satyr butterfly (*Neonympha mitchellii mitchellii*) will be threatened by habitat loss due to drying headwater streams and reduced water quality (Landis et al. 2012).

Phenological mismatches may be particularly problematic for Lepidoptera in coming decades. Caterpillars must synchronize their timing with food availability, which is changing. Host plants may be shifting northward in response to changing temperatures, with caterpillars potentially responding to different cues. Moreover, leaf quality may be decreasing, with increasing rates of secondary metabolites, requiring longer feeding times. Larvae also could be affected directly through increasing temperatures and changing moisture availability. Habitat specialists are expected to be most vulnerable (Keating et al. 2013).

Pennsylvania-Threats to Habitats and Species of Greatest Conservation Need

In Pennsylvania, as throughout the northeast region, understanding threats to SGCN and their habitats is important for developing appropriate conservation strategies and actions. In this section, we describe these threats at the state-scale, with general descriptions of effects on species and habitats (Table 3.10). Specific analysis and discussion of threats to species are provided in Chapter 1, and threats to habitats in Chapter 2, Habitats, and in this chapter.

Land Use

As described for the northeast region, in Pennsylvania, conversion of native habitats to residential, industrial, transportation or other anthropogenic uses is a significant threat to SGCN. Beyond this direct loss of use by fish and wildlife, associated habitat stressors such as air, water and land pollution, habitat fragmentation, enhanced pathways for invasive species and diseases, and related factors can result from changing land use and contribute to further imperilment of SGCN.

Although conversion of native forests and other native habitats to residential development can be characterized as a threat, the interrelatedness between habitat description and land use is more appropriately discussed in Chapter 2.

The associations between SGCN and habitats have been thoroughly discussed (Chapter 2) so reasonably, threats to habitats also can affect distribution and abundance of fish and wildlife. Species-specific threats, which may include effects of land use change, are described in Chapter 1. Beyond impacts to habitats, additional threats such as illegal harvest or shift in species range from climate change also can directly imperil SGCN (Table 3.11).

Agriculture

(IUCN Level 1: Code 2)

Landscape-scale changes in native habitats, such as with agriculture practices, can have substantial current and long-term impacts on fish and wildlife. Bird populations, especially grassland and shrubland birds, have been linked to changes in agricultural practices and land use (Murphy & Moore 2003) and even in restored watersheds, long-term impacts of historical agricultural practices have been observed (Harding et al. 1998).

Table 3.10. Threats to key habitats in Pennsylvania, as discussed in this section, unless otherwise noted.

	Habitat	**Forests**	**Grassland**	**Wetlands & Seasonal Pools**	**Lakes and Ponds**	**Rivers and Streams**	**Coastal Zones**	**Distinctive [Unique] Habitats**
IUCN Code Level 1	**Threat Description**							
1, 4	Land Use (Development, Roads)				See Chapter 2			
2	Agriculture							
	Traditional Agriculture	●	●	●	●	●		
3	Energy Development							
	Hydraulic Fracturing	●		●	●	●		●
	Wind Energy (Ridgetops)	●				●		●
	Wind Energy (Offshore)						●	
	Biomass	●						●
	Hydropower					●		
5	Biological Resource Use							
	Forestry (Logging & Wood Harvesting	●		●	●	●		
7	Natural System Modifications							
	Dams			●		●		
	Culverts					●		
	Water Use			●	●	●		
	Fire Suppression	●	●	●				●
8	Invasive Species	●	●	●	●	●	●	●
9	Pollution							
	Air	●		●	●	●	●	●
	Water			●	●	●	●	
	Land[1]	●	●	●		●		
11	Climate Change	●		●	●	●	●	●

[1]Abandoned Mine Lands

Table 3.11. Additional direct threats to Species of Greatest Conservation Need (SGCN) not included in Table 3.10 and discussed later in this chapter.

IUCN Code Level 1	Threat Description	SGCN
5	Biological Resource Use	
	Illegal Harvest	●
11	Climate Change	
	Range Shifts	●
	Phenological Changes	●
---	Disturbances (e.g., noise)	●
---	Pesticides	●

Agriculture, based on the IUCN categories (Table 3.1), includes a broad range of harvest practices such as non-timber crops, wood and pulp plantations, livestock farming and ranching and aquaculture activities. Of these categories, traditional agriculture (i.e., row crops, livestock farming and ranching) is major activity in Pennsylvania contributing over $7.4 billion in market value to the Pennsylvania economy. The top three valued commodities are milk (from cows), poultry and eggs, and grain (U.S. Department of Agriculture-USDA 2015a). A total of 58,800 farms operate on 7,720,000 acres (3,124,173 hectares) (USDA 2015a) or approximately 23% of land in the Commonwealth (Chapter 2). Of this land, hay (2.8 million acres; 1.1 million hectares) and corn (1.44 million acres; 0.58 million hectares) are the primary uses (USDA 2015a).

Threats from agricultural practice can encompass many habitats. Impacts from draining wetlands, clearing forests, and damage to riparian zones by livestock can directly affect the distribution of species. Indirect impacts (i.e., stressors) may include excessive nutrients into streams from livestock and, soil erosion into streams, ponds and seasonal pools.

Energy Resources

(IUCN Level 1: Code 3)

Pennsylvania's history is replete with development of its natural resources for energy. This growth continues to present and includes: enhanced technologies for natural gas extraction from the Marcellus and Utica Shale geologic formations, as well as renewed interest in wind energy and biomass. These energy sources once again have placed Pennsylvania among the leaders in addressing the energy needs of the Commonwealth and United State (Johnson et al. 2010). Development of these resources contributes to economic and energy security, yet these activities also can degrade habitats for fish and wildlife, and directly impact species. Here we provide an overview of major energy resources and general effects on species and habitats.

Shale gas development

(IUCN Level 2: Code 3.1)
Nate Zalik, PGC

Over the past decade, economic forces and technological advances of horizontal drilling and hydraulic fracturing have combined to make natural gas production from shale (known as "unconventional" gas) a profitable business (Vidic et al. 2013). Approximately two-thirds of Pennsylvania lies atop the highly productive Marcellus shale formation, as well as the deeper and, to-date, less explored Utica shale formation (PADEP 2013c). Natural gas production from the Marcellus shale in Pennsylvania began in 2005, and since that time unconventional natural gas development in the state has increased rapidly. As of March 2015, over 9,000 unconventional wells have been drilled, concentrated largely in the northcentral, northeastern and southwestern parts of the state (Whitacre & Slyder 2015).

Shale gas development has brought economic benefits (Kelsey et al. 2012), yet it also poses risks to fish and wildlife habitat. For terrestrial species, loss and fragmentation of habitat, especially forests, is a considerable concern (Brittingham & Goodrich 2010; Drohan et al. 2012; Brittingham et al. 2014; Dunscomb et al. 2015). It has been estimated that 38 to 54% of well pads constructed in Pennsylvania prior to June 3, 2011 occurred in forest cover (Drohan et al. 2012). Further, 23% of pads were located in core forest (forest habitat over 328 feet (100 meters) from edge), with areas of intensive shale gas development overlapping with the large core forests of northern Pennsylvania (Brittingham and Goodrich 2010; Drohan et al. 2012). In a study conducted by The Nature Conservancy, Johnson et al. (2010) found that shale gas pads averaged 3.1 acres (1.25 hectares), and the associated infrastructure (roads, water impoundments, pipelines, compressor stations) occupied an additional 5.7 acres (2.31 hectares), for a total footprint of 8.8 acres (3.56 hectares). Additionally, for well pads constructed in interior forest, an average of 21.2 acres (8.58 hectares) of interior forest was indirectly affected through the creation of new forest edge (Johnson et al. 2010). A study conducted in northcentral Pennsylvania, supported by the State Wildlife Grants Program, found that species of forest interior birds were significantly less abundant near shale gas well pads than in interior forest (Barton 2013). With the potential for 7,000 to 16,000 well pads to be constructed in Pennsylvania by 2030 (Johnson et al. 2010), forest loss and fragmentation are substantial threats to Species of Greatest Conservation Need such as Northern Goshawk, Scarlet Tanager, and Black-throated Blue Warbler that require interior forest habitat and are sensitive to edge effects (Brittingham & Goodrich 2010; Johnson et al. 2010).

Pipelines needed to transport natural gas to market also are permanent fragmenting features. Rights-of-way for gathering pipelines range from 30 to 150 feet (9.1 to 45.7 meters) in width, while transport pipelines have rights-of way widths of up to 200 feet (61 meters) (Johnson et al. 2011). Johnson et al. (2011) described scenarios where 10,000 to 25,000 miles (16,093 to 40,234 kilometers) of new natural gas pipelines could be built in Pennsylvania by 2030. The impacts of pipelines on interior forest are predicted to be substantially greater than impacts from the well pads themselves, through direct habitat loss and creation of new forest edges (Johnson et al. 2011). This has been demonstrated in Bradford and Washington counties by examining changes in forest patch size and number due to gas development between 2004 and 2010 (Slonecker et al. 2012).

Shale gas development has the potential to impact the quantity and quality of surface waters important to aquatic species (Brittingham et al. 2014; Dunscomb et al. 2015). Each Marcellus shale gas well requires from 3 to 6 million gallons (11.3 to 22.6 million liters) of water to complete the hydraulic fracturing process (USDOE-NETL 2013). Water withdrawals of this magnitude can stress local streams and rivers, especially during times of low-flow or drought (Weltman-Fahs & Taylor 2013; Brittingham et al. 2014). The construction of well pads, roads, and pipelines, can cause increased stream sedimentation (Entrekin et al. 2011). Stream crossings of pipelines and roads also contribute to sedimentation, as well as fragment stream habitat for species such as eastern brook trout (*Salvelinus fontinalis*)(Weltman-Fahs & Taylor 2013). Produced or "flowback water" from wells is high in total dissolved solids, salts, metals, naturally occurring radioactive material, and chemicals used in the fracturing process. Accidental spills of these fluids could significantly affect water quality (Entrekin et al. 2011; Weltman-Fahs & Taylor 2013; Brittingham et al. 2014). To understand the potential impacts to native eastern brook trout, Johnson et al. (2010) intersected projected well pad installations with intact – or predicted intact – eastern brook trout watersheds as defined by the Eastern Brook Trout Joint Venture. From this assessment, 81.9% of native eastern brook trout watersheds were predicted to have Marcellus Shale gas development activities.

As shale gas development in Pennsylvania is expected to continue to grow, it will be important to monitor impacts to fish and wildlife at both local and landscape scales. Research is needed to develop best management practices (BMPs), refine existing BMPs, and to define areas on the landscape where development can occur with minimal impacts to wildlife. Additionally, some impacts of shale gas development on wildlife have received little attention and warrant future study. These include human disturbance and noise pollution, from both short-term sources associated with well pad and road construction and long-term sources such as compressor stations (Brittingham et al. 2014).

Wind Energy

(IUCN Level 2: Code 3.3)
Andrea Evans, PGC

In the intervening years since publication of the 2005 Wildlife Action Plan, Pennsylvania has become a leader on the east coast in land-based wind energy production, with 717 wind turbines generating over 1,300 megawatts of wind power at 27 wind projects (Pennsylvania Department of Environmental Protection-PADEP 2015a). This surge in renewable energy development resulted from the Pennsylvania Alternative Energy Portfolio Standards Act of 2004 that required 18% of electricity sold to retail customers originate from renewable energy sources within 15 years. Currently, only an estimated 4% of Pennsylvania energy production is from renewable energy sources (<2% from wind) (U.S. Department of Energy-USDOE 2012), yet wind energy in Pennsylvania could achieve 2 to 3 times the current megawatt generation (>3300 MW) if fully developed (National Renewable Energy Laboratory-NREL and AWS Truewind 2010). The ridge-and-valley topography of Pennsylvania provides prime real estate for wind turbines; however, ridgetops also serve as migration corridors, migratory stopover habitat, and breeding sites for several Species of Greatest Conservation Need (e.g., timber rattlesnake, Allegheny woodrat, golden eagle). Offshore wind energy in Lake Erie also has been considered, but development may be delayed for the foreseeable future (Public Radio International-PRI 2014).

Touted for generating clean energy, wind energy development is not without direct or indirect risks to wildlife, including mortality from turbine operation and habitat loss and degradation (Kuvlesky et al. 2007; Taucher et al. 2012; U.S. Fish and Wildlife Service-USFWS 2012). Injury or mortality to wildlife from wind turbine operation is well-documented (Arnett et al. 2008; Taucher et al. 2012; Loss et al. 2013; Dai et al. 2015). However, collision risk depends on a variety of factors such as wind project design, turbine specifications, weather conditions and topography, as well as the type and abundance of species at the site (Kuvlesky et al. 2007). Habitat loss and degradation occurs through clearing of contiguous, forested ridges for development of wind turbine pads, buildings, access roads and development of electrical transmission infrastructure (Kuvlesky et al. 2007; Johnson et al. 2010). Dunscomb et al. (2015) estimate that nearly 20% of interior forest habitat within the Appalachian Landscape Conservation Cooperative geography could be at high-risk from wind development by 2035. Johnson et al. (2010) projected that over 40,000 forest acres (16,187 hectares) in Pennsylvania could be directly or indirectly impacted by wind turbine development by 2030 under a high development scenario (Table 3.12).

Table 3.12. Projected wind turbine development scenarios for the period from 2010 to 2030 and potential acres of forested habitat directly and indirectly impacted by this activity. (Source: Johnson et al. 2010).

New Wind Turbine Development Scenario	Number of New Wind Turbines (projected)	Forest acres directly impacted (projected)	Forest acres indirectly impacted (projected)
Low	600	1,900	13,400
Medium	1,520	2,900	20,400
High	2,720	5,200	36,500

Habitat loss associated with the turbine footprint will be a function of the size and numbers of turbines constructed on the site. Wind turbine footprints range from 0.2 acres (0.08 hectares) to 0.5 acres (0.20 hectares) and compose 2-5% of the wind energy project site (Fox et al. 2006), which may affect local wildlife diversity. For example, research from the Buffalo Ridge Resource Area, Minnesota found fewer birds and generally fewer species near turbines than in control areas without turbines (Osborn et al. 2000). Additionally, roads can negatively affect biotic integrity, through range expansion of exotic plants and suppression of native species (Rentch et al. 2005); possibly resulting in loss of biodiversity at local and regional scales (Trombulak & Frissell 2000; Saunders et al. 2002; Dunscomb et al. 2014). This habitat loss and degradation, particularly within a forested landscape, may adversely affect terrestrial and aquatic communities (Dunscomb et al. 2014).

To further understand, avoid and minimize potential impacts to wildlife and its habitat, in 2007 the Pennsylvania Game Commission (PGC) proactively engaged the wind industry to determine solutions collaboratively. The resulting Wind Energy Voluntary Cooperative Agreement (WEVCA) requires pre-construction risk assessments, at least one year of standardized pre-construction surveys, and 2 years of standardized post-construction mortality monitoring at proposed or active wind energy facilities (PGC 2013). From 5 years of monitoring at Pennsylvania wind sites that followed established protocols, we have learned that passerines (songbirds) account for the largest proportion (73%) of bird fatalities, though bird mortality is low (4 birds/turbine/year) relative to bat mortality (25 bats/turbine/year) (Taucher et al. 2012). Of the bat fatalities, migratory tree bats, particularly adult males, are most affected, with Hoary Bats (*Lasiurus cinereus*) alone comprising 31% of all bat mortality between 2007 and 2011 (Taucher et al. 2012). As a result of the pre-construction review and post-construction studies, the PGC and WEVCA Cooperators developed best management practices for Pennsylvania wind energy facilities (PGC 2013), which have been applied at several sites to further reduce negative impacts on wildlife.

Pennsylvania has been a leader in proactive attention to potential effects of wind energy development over the last 8 years, yet work remains. Bat fatalities continue to be of high concern, particularly with the recent precipitous decline in cave bat species due to white-nose syndrome (*Pseudogymnoascus destructans).* Curtailment (i.e., slowing down of turbine blades at low wind speeds) has been shown to reduce bat mortality (Arnett et al. 2011); though experiments to better understand the effectiveness of curtailment at various sites still are needed (Taucher et al. 2012). Additionally, it is unknown how the cumulative conversion of habitat at wind sites may affect bird communities (Taucher et al. 2012). These and other questions will continue to be addressed over the next 10 years.

Biomass

(IUCN Level 2: Code 3.3)

With over 60% forest habitat and 25% row crop or pasture, opportunities are available in Pennsylvania to develop biomass fuel sources (Klopfer 2011, RCN Project 2007-07). Historically, in the late 19th and early 20th centuries, Pennsylvania's forests were extensively harvested as a fuel source and for construction materials (MacCleery 1992). In the intervening decades, many of these forests have matured and once again hold potential as a fuel source. As a renewable resource, envisioning biomass harvest as a "threat" is contingent upon how and where this activity would be conducted, as well as associated SGCN. Native species that prefer young forest conditions may benefit from this activity, however, overall, in Pennsylvania, biomass systems using wood from mature forests are considered to have an overall negative impact on SGCN (Klopfer 2011, RCN Project 2007-07).

Sources for biomass-generated energy also may originate from non-woody plant materials such as cultivated perennial grasses (McGuire and Rupp 2013). With this source, the effects on native biodiversity would be dependent upon several factors including: the types of plant materials (e.g., native vs. introduced), use of chemical amendments (e.g., herbicides, pesticides), and timing of management activities (i.e., harvesting). If implemented on active agricultural lands, SGCN preferring grasslands may benefit from biomass systems (Klopfer 2011, RCN Project 2007-07). In northeast Ohio and northwest Pennsylvania, an area for propagating non-woody biomass has been established and may encompass up to 5,344 acres (2,162 hectares) using a sterile cultivar of Giant Miscanthus, an introduced species (U.S.

Department of Agriculture-USDA 2011). Although localized impacts are possible, at the statewide scale, this activity is not expected to be a substantial threat or benefit to SGCN.

Hydropower

(IUCN Level 2: Code 3.3)

Hydroelectric facilities represent a small number of the overall major dams in Pennsylvania U.S. Army Corps of Engineers (USACOE)-National Inventory of Dams (NID) (USACOE 2015), yet these facilities and other dams on the Susquehanna River (Fig. 3.17; Fig. 3.18), Lehigh River, and Schuylkill River are of concern for migratory SGCN fishes such as American shad (*Alosa sapidissima*), blueback herring (*A. aestivalis*) and American eel (*Anguilla rostrata*). For American shad in Pennsylvania, dams and their respective fish passage structures often obstruct, impede and delay migrations. Impingement at power plants and turbine mortality also are concerns. Additional threats posed by these facilities include: alteration of freshwater flows and discharge patterns in spawning and nursery habitats, and placement of additional water intakes (Atlantic States Marine Fisheries Commission-ASMFC 1999; Hendricks & Tryninewski 2011).

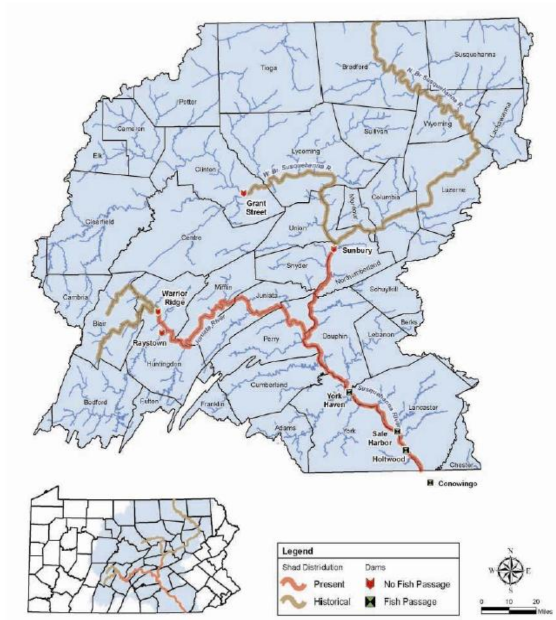

Fig. 3.17. American Shad distribution and dams in the Susquehanna River Basin of Pennsylvania (From Hendricks & Tryninewski 2011).

Biological Resource Use

(IUCN Level 1: Code 5)

Pennsylvania's forests have been the source of fuel, fiber and construction materials during much of the state's development. Forest products remain a major economic asset to Pennsylvania with annual economic contribution exceeding $5 billion (Pennsylvania State University-PSU 2004). Pennsylvania's 500,000 private landowners own 75% (12.5 million acres; 5.06 million hectares) of the state's forestland and supply 80% of its timber products (PSU 2004); there is a statewide total 16.7 million acres (6.76 million hectares) of forestland (McCaskill et al. 2013). Associated with activity, development of logging roads can contribute to direct loss of habitat. Loss of vegetative cover on erodible lands can be a source of silt draining into streams, wetlands and seasonal pools thus contributing to degraded habitats.

Illegal Harvest

Illegal harvest can be a direct threat to SGCN, especially species with delayed or limited reproductive capabilities; additional harvest can further degrade the SGCN population status. Illegal harvest of these species can harm recovery initiatives. Although use for consumption may be one purpose for illegal harvest of SGCN, frequently the intent is financial gain such as providing animals for the pet trade. In Pennsylvania, reptile species often are sought for pets, including the federally listed bog turtle (PFBC 2011a), timber rattlesnake (PFBC 2011b), and other turtle species (e.g., box turtle, wood turtle). The scope of illegal harvest was recently highlighted in an interstate and international turtle-smuggling operation (Baton Rouge, LA-The Advocate 2014).

Natural System Modifications

Fire Suppression

(IUCN Level 2: Code 7.1)

The transition of habitats through the natural process of succession would not initially be considered a threat. Yet the change from grassland to a shrubby young forest or from young forest to a mature forest can affect use of these habitats by SGCN. Depending on the availability (i.e., abundant or rare) of the initial habitat type and the adaptive capacity of the affected SGCN (i.e., species ability to move to other suitable habitats or use alternative habitats) this change could have severe consequences for population persistence. Historically, naturally occurring fire precluded development of trees in grasslands, but fire suppression has allowed habitat transition from grasslands/shrublands to forest. Similarly, habitat composition can be dictated by frequency and intensity of fire. For example, oak forests and barrens habitats benefit from fire by reducing competition from more aggressive, faster-growing trees. Yet, fire-suppression has negatively altered these habitats and associated wildlife composition.

Dams

(IUCN Level 2: Code 7.2)

Although hydroelectric facilities, a specific type of dam, were discussed in Hydropower, this section more broadly discusses threats posed by dams to the ecological integrity of streams.

The River Continuum Concept (Vannote et al. 1980) describes the physical and biological processes of river systems, from headwaters to large rivers, and is illustrated in the stream function pyramid (Harman et al. 2012). In streams, dams directly disrupt major functions including flow regimes, fluvial geomorphological processes, and ecological functions (Ward & Stanford 1995; Kondolf 1997; Bunn & Arthington 2002). Across the landscape in the United States, dams represent a significant source of aquatic habitat fragmentation with over 80,000 large dams documented (USACOE 2015; Heinz Center 2002), and when small structures are considered, estimates may exceed 2 million dams (Graf 1993; Heinz Center 2002). These numbers illustrate the fragmentary potential of these structures on aquatic systems.

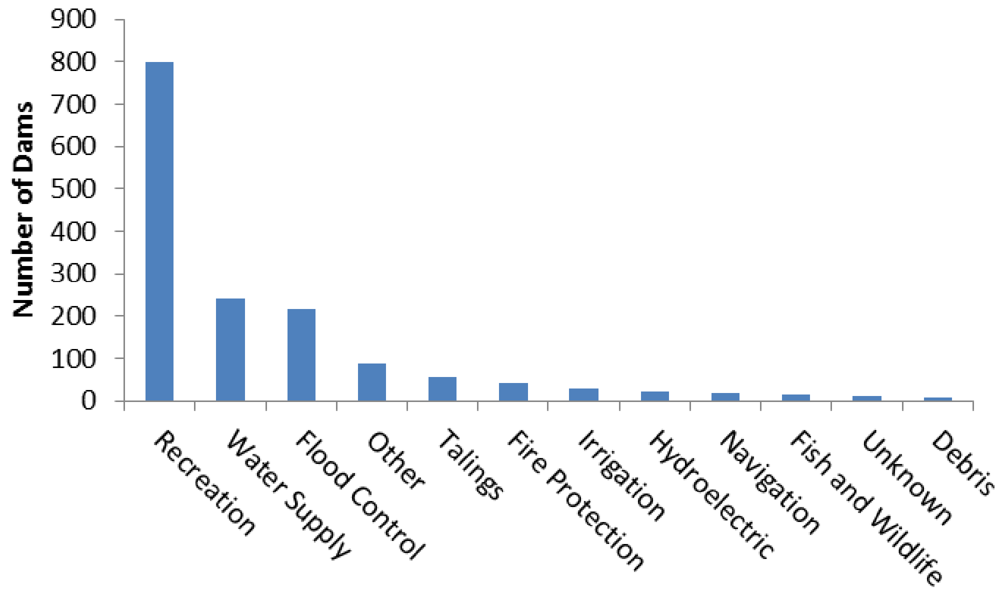

Fig. 3.18. Primary purpose of Pennsylvania dams identified in the U.S. Army Corps of Engineers, National Inventory of Dams (NID).

Historically, as human population increased in Pennsylvania and throughout the country, use of dams expanded beyond early mill operations and navigation. Eighty-one percent (1,226) of Pennsylvania's dams in the U.S. Army Corps of Engineers (USACOE) National Inventory of Dams (NID) are identified for recreational opportunities, water supply, and flood control (Pennsylvania Organization for Watersheds and Rivers-POWR 2001; USACOE 2015) (Fig. 3.18). In Pennsylvania, the USACOE-NID reports a total of 1,552 dams (USACOE 2015). This list of dams includes structures classified as large or posing a significant hazard, if they were to fail. The Pennsylvania Department of Environmental Protection Dam Inventory (PADEP 2015d) documents smaller dams than reported in the USACOE-NID and consequently, approximately 3,500 dams are recognized by the PADEP. Regulation of dams began long after many were built; therefore the Pennsylvania Dam Inventory likely underestimates the actual number of dams.

Physical Effects of Dams

The primary physical effect of dams on river systems is the disruption of the natural flow regime resulting in loss or reduction of connectivity between downstream and upstream habitats. Dams also disrupt the temporal flood-pulse cycle, influence stream temperature regimes and alter riverine habitat heterogeneity (Bunn and Arthington; Ward and Stanford 1995). The alteration of flows, including connection with floodplain habitats, has been considered the most serious threat to the ecology of river systems (Sparks, 1995; Bunn and Arthington 2002). A crucial function of stream flows is sediment transport, which, in turn, influences channel formation and eventually, habitat for macroinvertebrates and fishes (Kondolf 1997). Sediment accumulation above dams covers pre-dam habitats and this water is then capable of transporting more sediment; often from downstream streambank and streambeds. Thus, changes in stream flows influenced by dams can have systemic effects on riverine ecosystems (Kondolf 1997).

Biological Effects of Dams

As direct, physical impediments, movement of aquatic organisms from habitats downstream to upstream of dams can be diminished or completely interrupted. This loss of connectivity may preclude fish from reaching suitable spawning and nursery habitats thus limiting fish productivity and fish community diversity. For downstream macroinvertebrates and fishes, dams may impede transport of organic matter which can influence the composition of invertebrate communities (Bunn and Arthington 2002). Biological processes including cues for fish spawning and migration, changes in aquatic plant production, use by shorebirds and other crucial functions are often driven or influenced by the hydrologic regime (Sparks 1995; Bunn and Arthington 2002). Because dams alter the hydrologic regime, they can disrupt these ecological functions.

The effect of dams on complex biological functions also is exemplified in the life history of freshwater mussels, which depend on fish as hosts for immature mussels (i.e., glochidia). The migratory American Eel (*A. rostrata*) (a SGCN) is a glochidial host for the eastern elliptio mussel (*Elliptio complanata*) for which reduced upstream movement in the Susquehanna River has been attributed to main-stem dams (Walsh and Meyer 2011; PGC-PFBC 2005). In their study of hosts for this mussel, Lellis et al. (2013) found that success of glochidia transitioning to juvenile mussels was highest on American eel and that glochidial eastern elliptio mussel did not reach the juvenile (metamorphose) stage on any other fish or amphibian species tested. With American eel, the primary host for eastern elliptio mussels, limited upstream passage of eels on the Susquehanna River suggests the low numbers of the eastern elliptio mussel may, in part, be attributable to dams, especially when compared to the Delaware River where no main-stem dams are in Pennsylvania.

Also on the Susquehanna River, American shad were abundant until the early 1900s, and then declined precipitously due to dam construction (Gay 1892, Meehan 1895, Gerstell 1998; Hendricks and Tryninewski 2011). This species has been the focus of restoration efforts since the 1950s (Hendricks and St. Pierre 2002), as noted in Hydropower, yet Susquehanna River dams continue to limit American Shad populations in Pennsylvania. The loss of natural reproduction has been apparent since 1989, with domination by hatchery-reared American Shad in the Susquehanna River population at the Conowingo Dam (Susquehanna River Anadromous Fish Restoration Cooperative-SRAFRC 2010). From 1997 to present, volitional fish passage measures at each of the 4 lower Susquehanna River dams have provided American Shad the possibility of moving upstream during the spring spawning run. However, typically less than 2% of shad passing through the Conowingo Dam successfully ascend the river beyond the 4th hydroelectric facility, York Haven Dam (SRAFRC 2010; Hendricks and Tryninewski 2011). These Susquehanna River examples illustrate that not only fish movement can be directly impeded by dams, but as with the American eel, complex ecological relationships can be affected with implications for other taxonomic groups.

Culverts

(IUCN Level 2: Code 7.2)

In smaller stream systems, road-crossing culverts can function similarly to dams by reducing connectivity and movement by aquatic biota. This threat from culverts is recognized both regionally (North Atlantic

Landscape Conservation Cooperative Projects, NALCC Project 2013-02, NALCC Project 2014-06) and within Pennsylvania (e.g., Western Pennsylvania Conservancy- WPC 2015, Allegheny National Forest Project). There is increasing interest by state agencies and conservation organizations in Pennsylvania to address the threats posed by culverts.

Among the tasks of regional work is to: reconfigure an existing database to allow inclusion of data from multiple sources throughout the region; compile data from field assessments of road-stream crossings; develop recommended protocols for use across the North Atlantic Region; and develop hydraulic response models. With climate change models predicting increasing extreme precipitation events, the proper size and design of road-stream crossings is expected to be crucial for not only aquatic system connectivity, but also to minimize damage or loss of utilities and transportation infrastructure.

Water Use

Beyond water quality and flow regime, water availability can be of concern for aquatic biota. In Pennsylvania, there are substantial demands on both surface water and groundwater sources. Thermoelectric generation and public water supplies are the primary uses of surface water whereas public water supplies, self-supplied domestic use dominate groundwater consumption (Table 3.13) (Maupin et al. 2014). Other notable groundwater uses include self-supplied industrial uses, mining, aquaculture and livestock. These 2010 data may not fully represent development of the Marcellus Shale formation and use for hydraulic fracturing, which has expanded in subsequent years.

According to the Susquehanna River Basin Commission (SRBC 2012), a typical hydraulic-fracturing operation for a horizontal gas well in a tight shale formation uses 3 to 5 million gallons of water over a 2- to 5-day period. In 2011, in the Susquehanna River Basin, total industry consumptive use averaged approximately 10 million gallons (37.8 million liters) per day. Improved water-use efficiencies may help reduce this demand. SRBC (2015) notes that as more wells are drilled, the natural gas industry continues to focus on water management and conservation practices to limit increases in demand for water. Many companies reuse of flowback and production fluids reduce the quantity of freshwater necessary for hydraulic fracturing; other companies use treated wastewater effluent and mine drainage water to offset the need for water withdrawals. It is highly unlikely that the total peak day withdrawal at all approved locations will ever be used by the natural gas industry because of the geographically distributed operations and redundant sources.

At this rate of use, SRBC believes the largely water-rich Susquehanna basin can accommodate the natural gas industry’s water needs, along with the demands from other uses, especially during times when waterways are at normal to very high levels. When water quantities are stressed, such as during droughts, many protective conditions will ensure the withdrawals cease until water supplies naturally recover. SRBC has estimated that water use for the entire gas industry developing tight shale formations in the Susquehanna basin at full build-out to be approximately 30 million gallons per day. Substantial natural gas development occurs outside of the Susquehanna River Basin and the rate of water use will be contingent upon drilling of new wells and maintenance of existing wells, in addition to improved efficiencies in water use.

Table 3.13. For Pennsylvania, total water withdrawals by water-use category, 2010, in million gallons per day. (Source: Maupin et al. 2014).

	Surface Water	Groundwater
Public Supply	1,200	226
Self-Supplied domestic	0	201
Irrigation	19.8	7.39
Livestock	6.75	45.6
Aquaculture	59.7	47.9
Self-supplied Industrial	792	73.8
Mining	10.5	51.4
Thermoelectric	5,390	4.49
Total	7,480	657

Invasive and Other Problematic Species, Genes and Diseases

(IUCN Level 1: Code 8)

Invasive Species

(IUCN Level 1: Code 8)

Invasive species pose an ever-increasing threat to the Commonwealth's native fauna. Like many newly colonizing species, under favorable conditions, invasive species can be aggressive and out-compete native species for food and habitat.

The complexity and scope of problems associated with invasive species are beyond the capacity of any single agency or organization and, in Pennsylvania, organization and guidance is provided through the Governor's Invasive Species Council (also Pennsylvania Invasive Species Council-PISC). This collaborative body supports implementation of the Pennsylvania Invasive Species Management Plan; "a framework to guide efforts to minimize the harmful ecological, economic and human health impacts of nonnative invasive species through the prevention and management of their introduction, expansion and dispersal into, within and from Pennsylvania" (PISC 2009). Success of the Pennsylvania Invasive Species Management Plan, especially for the goals of *Prevention*, *Early Detection,* and *Rapid Response,* is crucial to the 2015 Pennsylvania Wildlife Action Plan (Table 3.14). A citizenry well-informed about invasive species is consistent with the relevant outreach strategies in the 2015 Pennsylvania Wildlife Action Plan.

If the recent rate of change in composition of invasive species continues over the next 10 years, the current composition of invasive species would soon be expected to be out-of-date. Success of management and eradication programs, as well as occurrences of new invasive species, are factors contributing to this dynamic list. Therefore, rather than providing a current list of invasive species in

Pennsylvania, we refer readers to resources dedicated to invasive species for ongoing information and guidance on the current status of invasive species and relevant conservation actions (Table 3.15).

Table 3.14. Goals of the Pennsylvania Invasive Species Management Plan. (Source: PISC 2009)

Preliminary Risk Assessments	Utilize preliminary risk assessments to prioritize nonnative invasive species management and expedite response at the first indication of a new or likely introduction.
Prevention	Identify, evaluate, and address pathways used by nonnative invasive species to minimize their introduction and spread into and throughout the Commonwealth.
Early Detection and Rapid Response	Detect new introductions of nonnative invasive species quickly and control or contain target species before they can become permanently established in the Commonwealth or move into areas in which they previously did not exist.
Control	Prioritize nonnative invasive species on which to focus control and anti-dispersal efforts, and, when feasible, control established nonnative invasive species that have significant impacts in Pennsylvania.
Restoration	Integrate restoration efforts whenever feasible into control and management activities as well as other activities which may disturb ecosystems and facilitate colonization by nonnative invasive species.
Survey and Monitoring	Expand survey and monitoring efforts of nonnative invasive species in Pennsylvania.
Data Management	Develop a statewide nonnative invasive species database clearinghouse or information sharing system linking data from various state, federal, and non-governmental entities.
Research	Support research efforts on nonnative invasive species issues and impacts in Pennsylvania and work with partners to facilitate the dissemination of data and information generated from these efforts.
Key Personnel	Identify key personnel needed to coordinate nonnative invasive species issues among local, state, and federal agencies and organizations.
Education and Outreach	Educate the general public and key target audiences about nonnative invasive species issues so that they do not facilitate the introduction and spread of these organisms through their activities.
Communication and Coordination	Facilitate communication and coordination across jurisdictional boundaries to ensure that state policy effectively promotes the prevention, early detection, and control of nonnative invasive species in Pennsylvania.
Funding	Work with the Governor's office, legislature, partners, industry, and federal entities to identify permanent funding sources for nonnative invasive species programs in the commonwealth.

Invasive species impacts are found across a broad range of habitat types and in all major taxa including: animal (e.g., vertebrate and invertebrate), plant (e.g., macro and microscopic) and microbial (e.g., bacterial, viral, fungal, prion) (PISC 2009). Invasive species can have ecological consequences for sensitive Pennsylvania species (Table 3.16) such as recent observations of round goby (*Neogobius melanostomus*) (PFBC 2014a) in Lake LeBoeuf in northwest Pennsylvania. The outlet for Lake LeBoeuf drains into the French Creek Watershed, one of the most biologically diverse aquatic communities in the northeastern United States (Smith et al. 2009) and presence of round goby is expected to negatively impact numerous state threatened and endangered species. Other invasive species. such as the emerald ash borer (*Agrilus planipennis* Fairmaire) (PADCNR 2015a), Asian longhorned beetle (*Anoplophora glabripennis*) (PADCNR 2015b), and feral swine, (Suidae) (Lovallo 2014) are destructive of native habitats, thus degrading conditions for native fauna. Prevention, early detection, rapid response, and outreach are important actions to address invasive species and concurrently benefit SGCN. With limited effectiveness of invasive species eradication methods, emphasizing invasive species prevention requires focus on potential sources well before a threat colonizes the Commonwealth or major ecosystems.

Table 3.15. Resources dedicated to invasive species outreach, prevention and management in Pennsylvania.

Resource
Governors Invasive Species Council of Pennsylvania (PISC)
Pennsylvania Invasive Species Management Plan
Pennsylvania Department of Conservation and Natural Resources (PADCNR)
Pennsylvania Department of Agriculture, Emerald Ash Borer Survey Program
Pennsylvania Fish and Boat Commission (PFBC)
Invasive Species of the Great Lakes Region
U.S. Department of Agriculture (USDA)
Pennsylvania Sea Grant-Invasive Species Resources
Pennsylvania Field Guide to Aquatic Invasive Species
Common Invasive Plants in Riparian Areas - Pennsylvania Field Guide. Alliance for the Chesapeake Bay
iMapInvasives (on-line geospatial database and mapping service)
Pest Tracker

Table 3.16. Select list of invasive species that may be potential direct, or indirect, threat to Pennsylvania Species of Greatest Conservation Need (SGCN).

Invasive Species	**Primary Habitats Impacted**	**SGCN potentially affected by invasive species.**	**Sources**
"Didymo" (*Didymosphenia geminata*)	Small & Medium Rivers	Dwarf wedgemussel *(Alasmidonta heterodon);* Aquatic insects-mayflies, Caddisflies, Stoneflies.	Spaulding and Elwell 2007; 2015 Species Assessments
Bighead carp (*Hypophtalmichtys nobilis)* Black carp (*Mylopharyngodon piceus)* Silver carp (*Hypophtalmichtys molitrix)*	Large Rivers	Paddlefish *(Polyodon spathula)*	PFBC 2015a
Rusty crayfish *(Orconectes rusticus)*	Small, Medium & Large Rivers	Spinycheek crayfish *(Orconectes limosus);* Freshwater mussels; Aquatic Insects	PFBC 2015b
Red-eared slider *(Trachemys scripta elegans)*	Small & Medium Rivers; Lakes; Freshwater Wetlands	Red-bellied turtle	Somma et al. 2015.
Round goby *(Neogobius melanostomus*)	Lakes; Small, Medium Rivers	Eastern sand darter *(Ammocrypta pellucida)*	Pennsylvania Sea Grant-PSG 2013 2015 Species Assessments
Emerald ash borer *(Agrilus planipennis* Fairmaire)	Forest, Urban	Moths: *Papaipema furcata; Manduca jasminearum; Olceclostera angelica; Podosesia syringae; Copivaleria grotei; Plagodis kuetzingi; Sphinx chersis; Palpita magniferalis*	2015 Species Assessments
Gypsy moth *(Lymantria dispar)*	Forests	Northern flying squirrel (*Glaucomys sabrinus*)	PADCNR 2015c
Flathead catfish *(Pylodictis olivaris)* in the Delaware River	Large Rivers	White catfish *(Ameirus catus)*	2015 Species Assessments

Diseases

(IUCN Level 2: Code 8.1)

Wildlife diseases, especially in recent years, have contributed to significant declines in several species across major taxonomic groups. Although diseases may be considered invasive species, given their impacts on several SGCN in Pennsylvania and the northeast region, we specifically discuss diseases in this section. For birds and mammals, the list of wildlife diseases is extensive (PGC 2015), and a comprehensive summary is beyond the scope of this plan. Therefore, we provide an overview of current or emerging diseases that currently, or are anticipated to, have population-level effects on SGCN (Table 3.17) during the 10-year implementation of this plan. Species-specific impacts and associated conservation actions can be found in (Chapter 1, Appendix 1.4).

Table 3.17. Current or emerging diseases that affect, or have potential to affect, Species of Greatest Conservation Need (SGCN) populations.

Disease	SGCN potentially affected
White-nose syndrome (*Pseudogymnoascus destructans*)(*Pd*)	Hibernating bats (*Myotis spp.*)
Chytrid fungus (*Batrachochytrium dendrobatidis*) (*Bd*)	Amphibians: Frogs (*Lithobates spp.*), eastern hellbenders (*Cryptobranchus sp.*); other amphibians
Ranavirus	Amphibians (*Bufo* spp., *Rana* spp., *Pseudacris* spp., *Ambystoma* spp., *Notophthlamus* spp).
Fungal dermatitis	Timber rattlesnake (*Crotalus horridus*)

White-nose Syndrome

Nathan J. Zalik, PGC

White-nose syndrome (WNS) is an emergent infectious disease affecting hibernating bats. Caused by the fungus *Pseudogymnoascus [=Geomyces] destructans* (*Pd*; Gargas et al. 2009; Lorch et al. 2011; Minnis & Lindner 2013), biologists estimate that the disease has been responsible for the deaths of over 6 million hibernating bats across eastern North America. WNS was first observed in caves near Albany, New York in the winter of 2006-2007 and has since spread to 25 states and 5 Canadian provinces (Blehert et al. 2009; USFWS 2015b). Confirmation of the disease in Pennsylvania occurred during the winter of 2008-2009 (Turner & Butchkoski 2009). Strong evidence now suggests that the fungus was introduced to North America from Europe via human activity (Warnecke et al. 2012; Leopardi et al. 2015). All significant bat hibernacula across Pennsylvania are now considered to be infected (Turner et al. 2014).

WNS derives its name from the symptomatic white fungal growth commonly found on infected bats' muzzles, but such growth also is found in other areas of exposed skin, such as wing membranes and ears. The fungus invades and erodes the skin and underlying connective tissue (Meteyer et al. 2009). Bats infected with the disease have been shown to suffer from dehydration and electrolyte depletion (Cryan et al. 2013), and other physiological maladies (Warnecke et al. 2013) and arouse from torpor more frequently (Reeder et al. 2012). Ultimately, the fat reserves of bats are greatly depleted, leading to mortality (Reeder et al. 2012; Warnecke et al. 2012).

WNS has affected all 6 species of cave-hibernating bats that reside within Pennsylvania (Turner et al. 2011). Using survey data from 34 Pennsylvania hibernacula, Turner et al. (2011) demonstrated an overall decline of 98.8% for all cave bat species combined since the introduction of WNS, with declines of 96-99% seen in little brown bats, northern long-eared bats, and tri-colored bats, and lesser declines in Indiana bats (76%), eastern small-footed bats (37%), and big brown bats (33%).

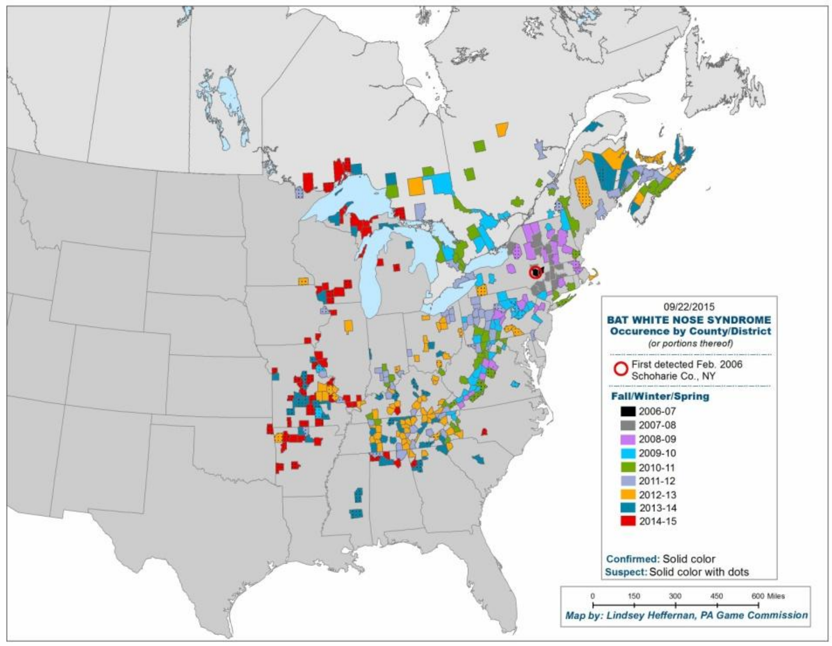

Fig. 3.19. North American distribution of white-nose syndrome in bats from the fungus (*Pseudogymnoascus destructans)*, 22 September 2015 (Pennsylvania Game Commission, Harrisburg, unpublished data).

From the early stages of this epizootic, Pennsylvania has been at the forefront of WNS monitoring and research. In 2009, Pennsylvania was the lead state for a multi-state coordination, investigation, and response project funded through the competitive State Wildlife Grants Program. This project enabled states to increase monitoring efforts, establish systems to gather information and respond to inquiries from the public, and support collaboration and research among WNS investigators. WNS also has been the focus of 2 Regional Conservation Needs projects led by scientists at Bucknell University that demonstrated increased arousal patterns in WNS-infected bats (Reeder et al. 2012, RCN Project 2007-09; Terwilliger Consulting & NEFWDTC 2013) and investigated potential WNS treatments (Reeder 2013, RCN Project 2010-01; Terwilliger Consulting & NEFWDTC 2013).

Pennsylvania Game Commission biologists are actively involved in many aspects of the WNS response. PGC continues to gather reports of WNS and distribute maps that track the spread of the disease to agencies and researchers across the country (Fig. 3.19). Turner et al. (2014) developed the first non-lethal field assessment technique for assessing WNS using ultraviolet light. Extensive monitoring efforts are conducted throughout the year, including at hibernacula, summer roosts, summer acoustic surveys, spring emergence, and fall swarms. As the initial mass mortality phase of the disease has largely passed in Pennsylvania, the focus over the next 10 years will be on studying characteristics of surviving bats, protection of remaining colonies, and continued research into effective WNS preventative measures and treatments.

Chytrid fungus, Fungal Dermatitis and Ranavirus

A broad range of pathogens (e.g., fungal, bacterial, viral) have been attributed to declines in amphibian populations (www.amphibiaweb.org). Among the more devastating diseases is the Chytrid fungus *(Batrachochytrium dendrobatidis-Bd*). Demonstrating its global distribution, Olson et al. (2013) found *Bd* in 52 of 82 countries that reported sampling for the fungus, with detections in 516 of 1,240 (42%) of amphibian species. In Pennsylvania, *Bd* has been detected on both non-SGCN (Groner & Reylea 2010) and SGCN species (Bales et al. 2015). The eastern hellbender (*Cryptobranchus alleganiensis alleganiensis*), a Pennsylvania SGCN, was the target of sampling in New York, Pennsylvania, Ohio and West Virginia to assess the presence of a *(Batrachochytrium salamandrivorans)* (*Bs*), a new species of this genus that has been reported in European salamanders (Bales et al. 2015). Specifically, in Pennsylvania, 61 animals were tested for both *Bd* and *Bs* and, although *Bs* was not found, *Bd* was confirmed on 20% of these animals. The effects of this pathogen on survival are not well understood and recognized as a research need by Bales et al. (2015). In their study, no significant differences were found in body condition between *Bd*-positive and *Bd*-negative animals, although compared to other *Bd*-susceptible species, low levels of the fungus were found.

Another infectious disease afflicting amphibians in the northeast is the Ranavirus (Family Iridoviridae) (Smith et al. 2012, RCN Project 2012-01). Little is known about the timing, extent, and frequency of outbreaks, yet it is known to affect 6 amphibian species (i.e., toads-*Bufo*, tree frogs-*Hyla*, leopard frogs-*Rana*, chorus frogs-*Pseudacris*, mole salamanders-*Ambystoma,* and newts-*Notophthlamus*). Mortality from this virus is considered high and has been noted as perhaps the greatest pathogenic threat to the biodiversity of amphibians in North America (Smith et al. 2012, RCN Project 2012-01). At submission of this plan, this project was not complete.

A fungal dermatitis, known to affect timber rattlesnakes (*Crotalus horridus*), is an emerging regional disease (McBride et al. 2015). A RCN Grants Program project (Perrotti et al. 2012, RCN Project 2012-02) is evaluating the extent and impacts on timber rattlesnake populations in New England. The effects of fungal dermatitis on timber rattlesnakes in Pennsylvania are not currently known.

Pollution

(IUCN Level 1: Code 9)

Acidic Precipitation

In Pennsylvania, and throughout northeastern United States, acidic precipitation (i.e., acid rain) has been detrimental to both terrestrial (Pabian & Brittingham 2007) and aquatic systems (Schindler 1988), especially streams and watersheds with limited buffering capacity. Acidic precipitation occurs when sulfur dioxide and nitrogen oxide emissions are transformed in the atmosphere and return to earth in rain, fog, or snow (USEPA 2008). The scope of this threat is expressed in Title 42 United States Code Chapter 85 Subchapter IV-A §7651 (U.S. Congress) in which the U.S. Congress noted, in part, the following findings: the presence of acidic compounds and their precursors in the atmosphere and, in deposition from the atmosphere, represents a threat to natural resources, ecosystems, materials, visibility, and public health; the principal sources of the acidic compounds and their precursors in the atmosphere are emissions of sulfur and nitrogen oxides from the combustion of fossil fuels; the problem of acid deposition is of national and international significance; current and future generations of Americans will be adversely affected by delaying measures to remedy the problem; reduction of total atmospheric loading of sulfur dioxide and nitrogen oxides will enhance protection of the public health and welfare and the environment.

In over 40 years of implementing the Clean Air Act of 1970 (USEPA 2013), great strides have been made to improve environmental conditions for humans, fish and wildlife caused by pollution. These achievements are clearly evident, for example, in temporally distinct data of an acidic precipitation constituent, wet sulfate (SO_4^{2-}) (USEPA 2008). Average regional decreases in wet deposition of sulfate between the periods 1989-1991 (Fig. 3.20) and 2004-2006 (Fig. 3.21) were approximately 35% in the

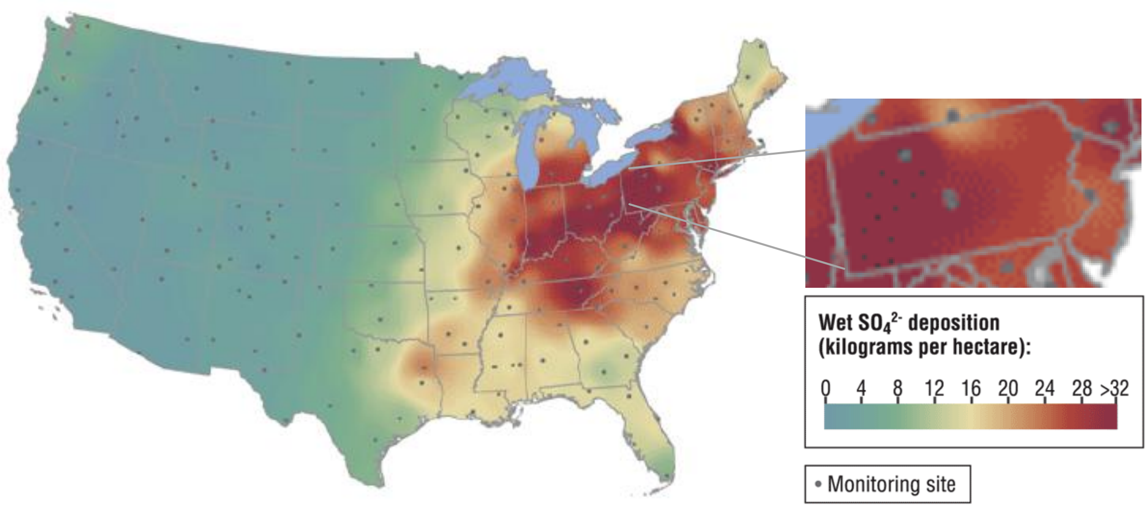

Fig. 3.20. Average wet sulfate (SO_4^{2-}) deposition in the contiguous United States, 1989-1991 (Pennsylvania enlarged). (Source: NADP 2007; USEPA 2008)

Northeast, 33% in the Midwest, 28% in the Mid-Atlantic, and 20% in the Southeast (USEPA 2009). In these same periods, decreasing trends have also been reported for another acidic precipitation component, wet nitrate (NO_3^-). In Pennsylvania, acidic precipitation has been attributed to depressed populations of native eastern brook trout (*Salvelinus fontinalis*) (Eastern Brook Trout Joint Venture-EBTJV 2006; 2008) and also has influenced resource management practices. For example, since 1969, the Pennsylvania Fish and Boat Commission has removed 21 streams (87.4 miles, 141 kilometers) and a 4.2-acre (1.7 hectare) lake from the trout stocking program due to adverse chemical impacts associated with acid precipitation (PFBC 2014b). In the 2014 Pennsylvania Integrated Water Quality Monitoring and Assessment Report, the PADEP reported 505 stream miles impaired by atmospheric deposition (PADEP 2014a). So, despite clear progress, ongoing efforts to reduce to acidic precipitation will be necessary to remove this threat to Pennsylvania's SGCN and their habitats.

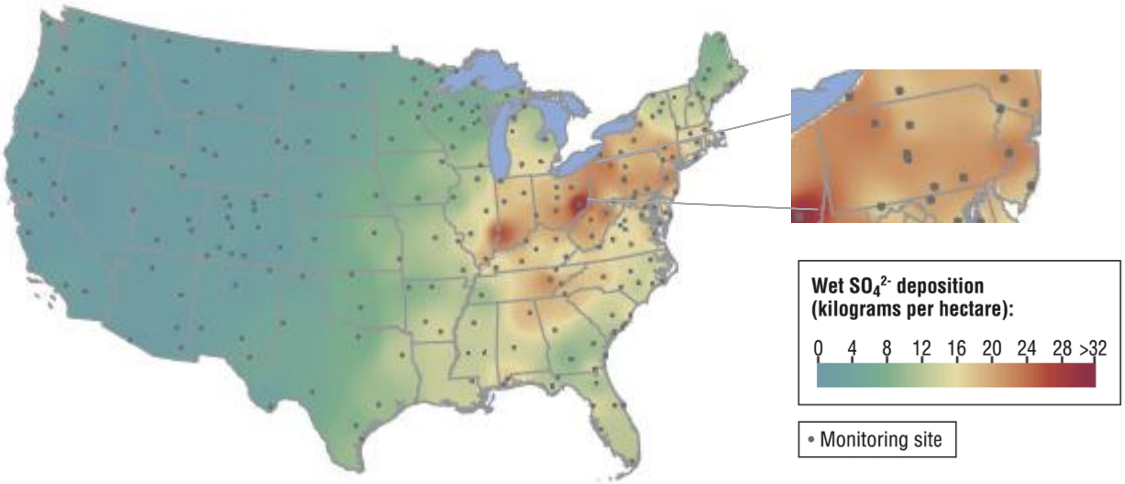

Fig. 3.21. Average wet sulfate (SO_4^{2-}) deposition in the contiguous United States, 2004-2006 (Pennsylvania enlarged). (Source: USEPA 2008; NADP 2007).

Water Pollution

As noted above, air pollution can contribute to water pollution through atmospheric borne chemicals, yet this is only one of many constituents contributing to diminished water quality and associated habitats in streams. The PADEP protects 4 stream water uses: aquatic life, fish consumption, potable water supply, and recreation. If a stream segment is not attaining any one of its 4 uses, it is considered impaired (PADEP 2015b) and the PADEP is responsible for reporting on the Clean Water Act Section 305(b) and Section 303(d) listings. As with the Clean Air Act of 1970, the Clean Water Act of 1972 (USEPA 2015) has provided impetus for notable progress in remediating degraded water quality and implementing protective measures. Nevertheless, over 15,000 miles of Pennsylvania streams remain impaired for aquatic life use (PADEP 2015b). To facilitate analysis we categorized impairments, and based upon these categories, over 70% of impairments are attributable to factors associated with runoff from urban storm sewers, roads and small residential areas, various agricultural activities and abandoned mine drainage (Fig. 3.22; Fig. 3.23). Water quality impairments clearly remain a systemic problem for Pennsylvania's rivers and streams and associated aquatic life.

Abandoned Mine Lands

At a regional scale, coal and mineral mines have been found to stress stream fish assemblages even when mines are at low densities across the landscape (Daniel et al. 2014). In Pennsylvania, a coal-producing state, abandoned mine lands have been a legacy source of pollution for decades and

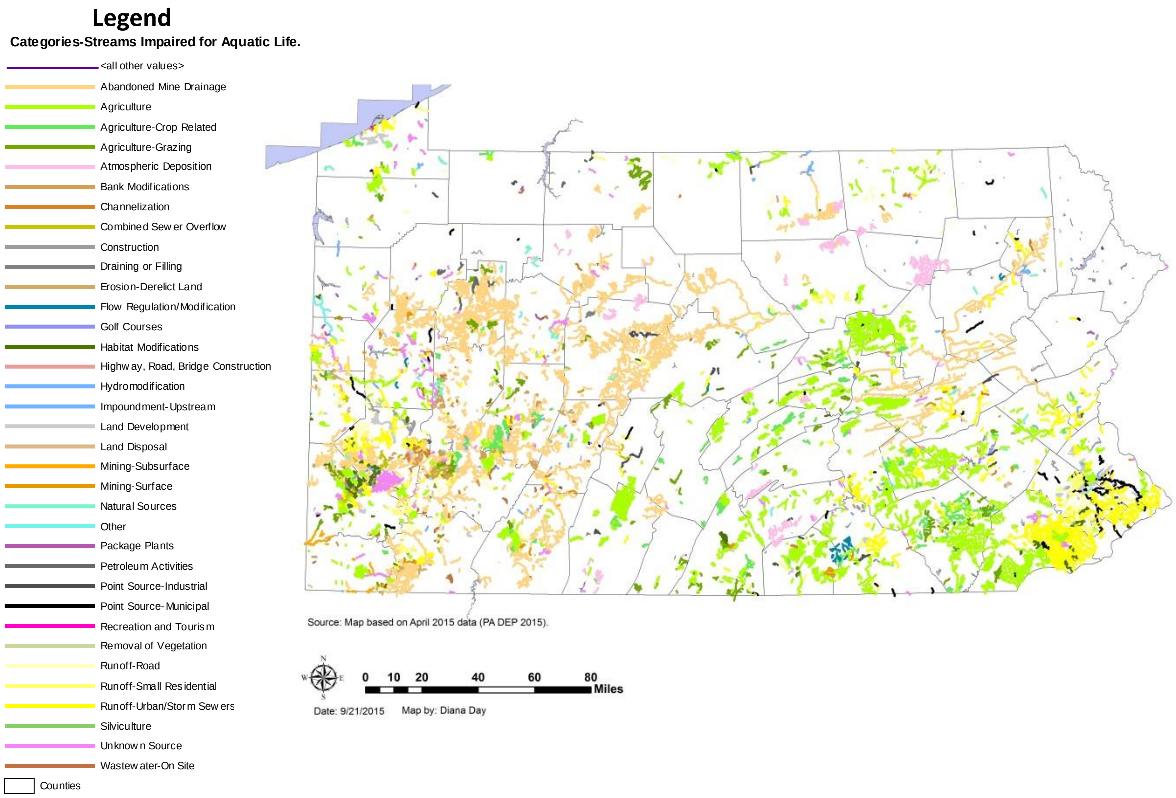

Fig. 3.22. Assessed streams with impaired aquatic life based on major categories developed for this assessment. (Data source: PADEP 2015b.)

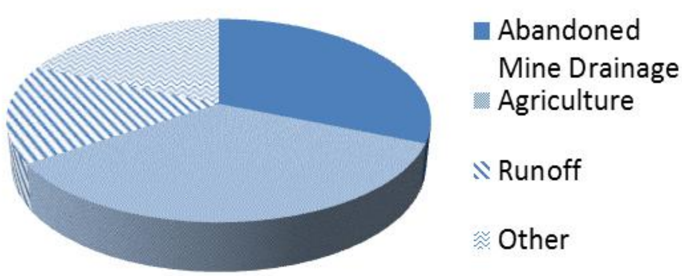

Fig. 3.23. Major categories of impairment to aquatic life in assessed streams. “Other” consisted of 28 categories. (Data source: PADEP 2015b.)

continues to impair waterways (Fig. 3.22; Fig 3.23). Pennsylvania's Abandoned Mine Lands (AMLs) (Fig. 3.24) still account for approximately one-third of the AML problems in the United States (PADEP 2015c, 2013b). Yet, through the Surface Mining Control and Reclamation Act (SMCRA) of 1977 measurable progress has been made to recover these altered habitats and provide associated environmental benefits. Cumulatively, under SMCRA Title IV, the Pennsylvania Abandoned Mine Land (AML) program administered by the Pennsylvania Department of Environmental Protection, 55,491 acres (22,456 hectares) have been reclaimed with construction costs of $581.6 million (PADEP 2013a). Additional AML remediation accomplishments have been made with support from organizations and coalitions such as Trout Unlimited, West Branch Susquehanna River Watershed Coalition (WBSRWC), Eastern Pennsylvania Coalition for Abandoned Mine Reclamation (EPCAMR), Foundation for Pennsylvania Watersheds, and Western Pennsylvania Coalition for Abandoned Mine Reclamation (WPCAMR). These organizations and other concerned citizens have implemented on-the-ground recovery and fostered vital community support for recovery initiatives.

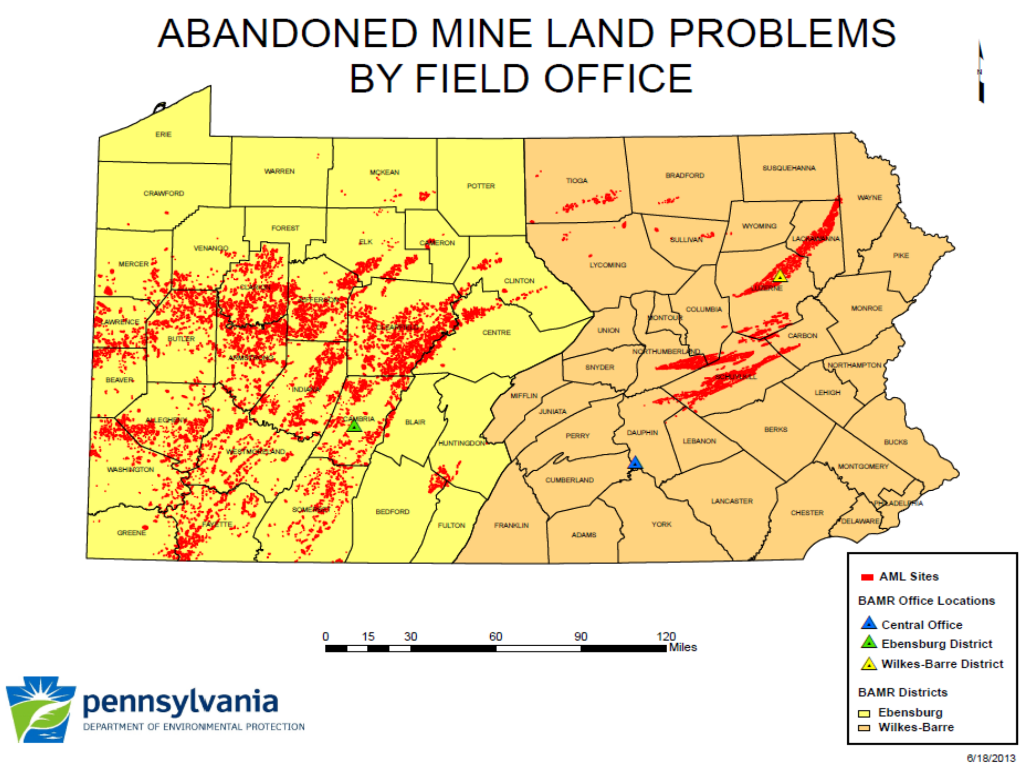

Fig. 3.24. Abandoned Mine Lands (AML) identified by the Pennsylvania Department of Environmental Protection (PADEP). (Source: PADEP 2013b.)

Other Threats

Disturbances

Off-road activities (e.g., motorbikes, all-terrain vehicles (ATVs), horseback riding), when not conducted on designated trails, can impact habitats and disturb wildlife. These are popular recreational activities in Pennsylvania and can be conducted responsibly, with opportunities for their use offered by the Pennsylvania Department of Conservation and Natural Resources (PADCNR 2015e; PADCNR 2015f). Currently, unknown is the extent of direct and indirect impacts of this threat on SGCN and their habitats. The level of environmental impact will depend on the type, number, and duration of activities, as well as sensitivity of the habitat(s) and species to disturbance.

Urbanization also brings other forms of pollution such as increased artificial nighttime light and noise, although the effects on Pennsylvania's SGCN are not well-known. Artificial light has been shown to affect the function of species in several major taxonomic groups, however effects on populations or ecosystem-level processes such as mortality, fecundity, community productivity, species composition, and trophic interactions are not well understood (Gaston et al. 2013).

Noise can disrupt species interactions, thus indirectly influencing ecological processes (Francis et al. 2009). Increased noise has been found to negatively influence bird populations and communities, yet higher reproductive success was observed which may be attributable to urban-adapted bird species tolerant of noise. Predators that use acoustic cues to locate prey may be less likely to locate nests because of the masking effects of noise. Thus, birds excluded by noisy conditions from habitats that might otherwise be acceptable, were also found with higher rates of nest predation (Francis et al. 2009).

Pesticides

Pesticides are used extensively throughout society, including in households, agriculture, and industry. With this extensive use, it is beyond the scope of this Plan to provide a comprehensive review on the implications of pesticides for SGCN and habitats. However, it is important to acknowledge that pesticides may be a factor influencing a species' status. Among invertebrates, recent public attention has focused on pollinators that are highlighted in this Plan. Declines in the monarch butterfly (*Danaus plexippus*) (Pleasants & Oberhauser 2012) and bees (*Bombus spp*.) including *B. affinis* and *B. terricola* (Pennsylvania SGCN) (Cameron et al. 2010) have been documented. For bees, a potential source of decline is a class of insecticide neonictinoids (Rundlöf et al. 2015). Preliminary evidence has also linked neonictinoids with mortality in monarch butterflies, although additional work is required to fully document this insecticide as a contributing factor in the decline of the species (Pecenka & Lundgren 2015). The decline of these species is complex, involving many factors. However, use of neonictinoids appears to be a common factor.

Pennsylvania-Climate Change Overview

(IUCN Level 1: Code 11)

Introduction

There is diminishing debate in the scientific community regarding human activity as the source of global climate change (also called "global warming") (Oreskes 2004; Cook et al. 2013). Yet, uncertainty remains in the paths of greenhouse emissions as well as global and regional climate responses to those paths; incomplete knowledge in the sensitivity of systems and adaptation options; and uncertainty about other stressors that may interact with climate change (Shortle et al. 2015). In context of this uncertainty, there is expanding scientific literature on current and anticipated effects of a changing climate on habitats and species' distributions globally, regionally (Staudinger et al. 2015a), and in Pennsylvania (Shortle et al. 2015). Given varied and pervasive impacts across multiple habitats and species, we discuss this topic throughout this Plan and, in this section we provide a multi-scale overview of climate change in Pennsylvania.

Pennsylvania Climate Adaptation Strategy

In 2008, passage of the Pennsylvania Climate Change Act 2008 (Public Law-PL 935 No. 70 2008) authorized the Pennsylvania Department of Environmental Protection (PADEP) to "Report on potential climate change impact and economic opportunities for this Commonwealth" and to be revised every 3 years. The Act also required an annual inventory of Green House Gas (GHG) emissions including trends and major sources, establishment of a Climate Change Advisory Committee and development of Climate Change Action Plan (PADEP 2009). With assistance from the Climate Change Advisory Committee (CCAC), the *Pennsylvania Climate Change Action Plan* was produced (PADEP 2009; PADEP 2014b), however, this report did not consider adaptive measures for a broad range of sectors in Pennsylvania that were either currently experiencing, or likely to be impacted by, climate change. In 2010, approval was obtained to produce an adaptation report. Through efforts of 4 working groups (Table 3.18), adaptation recommendations primarily generated by the Natural Resources and Tourism & Outdoor Recreation Work Groups were considered relevant to the 2005 Pennsylvania Wildlife Action Plan.

Table 3.18. Work groups and corresponding sectors encompassed in the Pennsylvania Climate Change Adaptation Strategy. (Source: PADEP 2014b)

Work Group	Sectors
Infrastructure	Transportation, energy, water, buildings, communications, land use
Public Health and Safety	Public health, emergency management
Natural Resources	Forest, freshwater, plants and wildlife, agriculture
Tourism and Outdoor Recreation	Fishing, boating, sports, adventure, golf, skiing, gardening

Reflected in the composition of these 4 working groups, adaptation strategies can have economic and ecological implications across many sectors. To support adaptation of natural resources, natural resource agencies, non-governmental organizations and research that manage and support species and habitats will need to prepare for anticipated changes. To understand awareness of climate change and adaptation strategies, leaders of several Pennsylvania conservation agencies and organizations were interviewed (TNC 2010). These discussion topics included: 1) importance of climate change impacts to their organizational mission; 2) response to climate-change impacts; 3) most important challenges and opportunities; and suggestions for statewide adaptation strategies. Overall, respondents acknowledged that fostering collaboration, communication and knowledge-exchange could be enhanced by including climate-change adaptation actions into organizational strategic plans and through statewide planning for climate change. Implementing these findings also could yield a more accurate assessment of information gaps and conservation action priorities (TNC 2010).

Climate Change in the Pennsylvania Wildlife Action Plan

Climate change was noted as threat in the 2005 Pennsylvania Wildlife Action Plan, yet at that time, the potential impacts to SGCN and their habitats were less understood compared to other threats such as urban sprawl. By 2007, the Intergovernmental Panel on Climate Change (IPCC) had reached a consensus position that human-induced global warming was already causing physical and biological impacts worldwide (IPCC 2007). Climate change research also was finding alterations in climate system patterns were occurring as predicted, but earlier and faster than expected. By 2009, increasing discussion of climate-change legislation within the U.S. Congress highlighted the potential for funding to address this threat. The Association of Fish and Wildlife Agencies (AFWA)-Climate Change Work Group also developed voluntary guidance for states seeking to more thoroughly discuss climate change in their State Wildlife Action Plans (AFWA 2009). Further elucidating the threat of climate change, the Union of Concerned Scientists (UCS) reported on climate change effects to broad sectors of Pennsylvania (e.g., urban areas, agriculture, forests, recreation) (Union of Concerned Scientist-UCS 2008).

In Pennsylvania, increasing interest in climate change motivated development of a minor amendment to the 2005 Pennsylvania Wildlife Action Plan and, in 2010, this amendment was approved by the U.S. Fish and Wildlife Service (PGC-PFBC 2010). The amendment more fully explained the implications of climate change and associated management strategies for Pennsylvania's SGCN and their habitats. In this amendment, the PGC and PFBC committed to "a full inclusion of climate change adaptation priorities and pitfalls in the PA Wildlife Action Plan revision of 2015."

Pennsylvania-Climate Change Impacts on Species and Habitats

Adapted from Ross et al. (2013) and Shortle et al. (2009, 2015)

Introduction

Climate change is recognized as a threat to species and habitats across the Northeast and Midwest (Staudinger et al. 2015a) and, in the years following approval of Amendment #2 to the 2005 Pennsylvania Wildlife Action Plan, the scope and detail of the scientific literature regarding climate change in Pennsylvania has greatly expanded. Although new data and innovative analyses (e.g., downscaled climate models) are expanding the understanding of climate change and implications for SGCN and habitats, uncertainty remains in the severity, timing and scope of impacts. Despite this uncertainty, analysis of these data in the context of Pennsylvania's species and habitats, can guide the design and implementation of conservation actions.

As discussed in other parts of this chapter, numerous threats affect Pennsylvania's species and habitats, yet climate change can worsen the effects of these threats. For example, in aquatic habitats, fragmentation may impede species movement (e.g., fish migration limited by dams on streams) however, when combined with warmer water or altered stream flows, survival may be further diminished. In terrestrial habitats, climate change can further intensify the effects of habitat fragmentation from sources such as increased energy-based infrastructure developments (Energy), invasive species, or other habitat-altering developments.

To provide national support for revising State Wildlife Action Plans, the Association of Fish and Wildlife Agencies AFWA (2012) developed voluntary "best practices" for states to consider when discussing climate change. These "best practices" recommended that states:

- Include climate change impacts as one criterion for selecting and prioritizing SGCN.
- Conduct vulnerability assessments to inform selection of SGCN and conservation actions.
- Link climate impacts to priority actions.
- Integrate key characteristics of climate-smart conservation when developing conservation actions (e.g., consider broader landscape context).
- Consider key adaptation approaches (e.g., reduce non-climate stressors) when developing conservation actions.
- Work with regional partners such as the Landscape Conservation Cooperatives.
- Reach out to diverse partners.

Throughout this Plan, these "best practices" serve as a framework for discussing this threat and associated conservation actions.

In Pennsylvania, multiple ecological features may be affected by climate change and, given the complexity and dynamic state of knowledge, a comprehensive review of the topic is beyond the scope of this Plan. This section, adapted from the reports noted above, and with additional authorship by the 2015 Pennsylvania Wildlife Action Plan Climate Change Committee, provides an overview of key climate change factors and current, or anticipated, impacts to species and habitats.

Temperature

Temperature is ecologically important because it can directly affect a species' survival (e.g., change in life-history patterns, exceed lethal threshold) or alter its habitats (e.g., changing forest structure). Therefore, understanding projected changes in temperature can guide conservation actions that help species adapt or mitigate effects of changing temperature.

Over the past 110 years, Pennsylvania's climate has warmed more than 1.8°F (1°C), with only a brief cooling during the mid-20th century (Shortle et al. 2015). Climate models simulate this pattern of temperature change only when human influences, primarily greenhouse gases (GHGs), are considered (Shortle et al. 2015). In the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), Pachauri et al. (2014) found global warming dominated by human influence in all but one emission scenario (e.g., with the strongest mitigation) (Shortle et al. 2015). In the IPCC-AR5, GHG scenarios are referred to as Representative Concentration Pathways (RCPs) (Moss et al. 2010; van Vuuren et al. 2011; Shortle et al. 2015). As noted in their report, of 4 RCP scenarios, Shortle et al. (2015) primarily based future climate projections for Pennsylvania on RCP 8.5 (i.e., highest predicted GHG concentrations), thus anticipating greater warming of the atmosphere. Among the several reasons for choosing this scenario, RCP 8.5 represents the current global emissions' path, including any approved emissions reduction legislation (Riahi et al. 2011; Shortle et al. 2015). Because RCP 8.5 is based on the higher levels of GHG emissions, it could be considered a worst-case scenario. However, some climate change affects (e.g., decline of Arctic sea ice cover) are proceeding at rates even faster than predicted by models under this scenario (Stroeve et al. 2012; Melillo et al. 2014; Shortle et al. 2015). Under scenario RCP 8.5, by mid-21st century, Pennsylvania will be about 5.4°F (3°C) warmer than at the end of the 20th century.

The IPCC-AR5 report (Pachauri et al. 2014) also produced the next phase (fifth phase) of the Coupled Model Intercomparison Project (CMIP5) (Taylor et al. 2012; Shortle et al. 2015). The CMIP5 served as the primary source of General Circulation Model (GCM) data for the Shortle et al. (2015) report. The main advantage of the CMIP5 is higher horizontal resolution outputs (Shortle et al. 2015). Although improved, the resolution remains too coarse to consider topographic influences, such as mountains. Shortle et al. (2015) compare the CMIP5 with dynamically downscaled and statistically downscaled models, noting their predictive limitations and advantages for temperature and precipitation.

Precipitation

Precipitation is another important factor associated with climate change and, although precipitation is more difficult to model (Shortle et al. 2015), interpreting potential scenarios can assist with understanding how this factor may affect SGCN and their habitats. A change in timing, seasonality, and magnitude of water delivery can alter ecosystems, which may be reflected in changing seasonal patterns of water levels, reduced stream flows during dry periods, larger floods and longer droughts (Moore et al. 1997; Rogers & McCarty 2000; Ross et al. 2013).

Overall, an annual 8% increase in precipitation is expected in Pennsylvania, with a 14% increase in winter months (Shortle et al. 2015). Heavy rainfall events have become more frequent in Pennsylvania (Madsen & Figdor 2007; Ross et al. 2013), but it is difficult to determine if flood frequency or hurricanes has increased due to recent warming (Mills 2009; Ross et al. 2013).

Pennsylvania is projected to receive less snowfall as a consequence of climate change (Kapnick and Delworth 2013; Shortle et al. 2015) (Table 3.19) suggesting that increasing precipitation would occur in liquid form rather than snow (Ross et al. 2013). The likelihood of a meteorological drought (i.e., lack of precipitation for a short duration) (National Weather Service-NWS 2006; Ross et al. 2013) is expected to decrease and the impacts of droughts are likely to be short-term in duration. Yet, even in such situations, wetland degradation and competition could occur across multiple sectors of users (Shortle et al. 2015).

Timing and rate of delivery of water can be crucial to species and habitats. Climate-change studies thus far, generally suggest a slight increase in runoff in the northeastern United States (Milly et al. 2005; Ross et al. 2013). In their analysis, Hayhoe et al. (2007) used a large-scale hydrological model with GCM output (includes precipitation and temperature) along with both historical and future projections for the northeastern United States. Compared to the historical period, projected results showed slight changes in runoff, but the change was not considered statistically significant (Ross et al. 2013). Projections show wetter winters and generally warmer temperatures resulting in an estimated 5% increase in runoff (Milly et al. 2005; Ross et al. 2013). In urbanized watersheds, climate change influences on annual runoff are uncertain, but urban conditions may have more influence on runoff than the effects of climate (DeWalle et al. 2000).

Table 3.19. Summary of projected changes for Pennsylvania's water resources. (Ross et al. 2013; Shortle et al. 2015).

Property	**21st Century Projection**	**Confidence**
Precipitation	Increase in winter precipitation. Small-to-no increase in summer precipitation. Potential increase in heavy precipitation events.	High (for winter); lower for summer.
Snow pack	Substantial decrease in snow cover, extent, and duration.	High
Runoff	Overall increase, but mainly due to higher winter runoff. Decrease in summer runoff due to higher evapotranspiration.	Moderate
Soil moisture	Decrease in summer and fall soil moisture. Increased frequency of short and medium term soil moisture droughts.	High
Evapotranspiration	Increase in temperature throughout the year. Increase in actual evapotranspiration during spring, summer and fall.	High
Groundwater	Potential increase in recharge due to reduced frozen soil and higher winter precipitation when plants are not active and evapotranspiration is low.	Moderate
Stream temperature	Increase in stream temperature for most streams likely. Some spring-fed headwater streams less affected.	High
Floods	Potential decrease of rain-on-snow events, but more summer floods and higher flow variability	Moderate
Droughts	Increase in soil moisture drought frequency.	Moderate
Water quality	Flashier runoff, urbanization and increasing water temperatures might negatively impact water quality.	Moderate
Saltwater intrusion	Increase in saltwater intrusion (in estuaries) due to rising sea levels.	Moderate

Overall, Pennsylvania's current trends in warming and wetter conditions will continue at an accelerated rate in which trends include an increase in months with above-normal precipitation and a decreased likelihood of drought (Shortle et al. 2015).

Forests

With a landscape of more than 60% forested habitats, effects of climate change on Pennsylvania's forests and associated biotic communities are of particular concern. Biotic communities, such as birds, are often associated with specific forest structure (Cullen et al. 2013) and there is potential for changing forest composition under altered climate scenarios (Iverson et al. 2008a, 2008b; Shortle et al. 2009, 2015). To understand more fully potential changes in Pennsylvania's forests, McDill (2009) evaluated 35 tree species, placing them into 6 categories:

- *most at-risk of being extirpated from the state.*
- *most likely to decline substantially in importance in the state.*
- *most likely to decline moderately in importance in the state.*
- projected to either marginally increase or decrease.
- currently relatively common in the state and most likely to increase in importance.
- *currently not common in the state and most likely to increase in importance.*

From this assessment, tree species at the southern end of their range are expected to be lost from Pennsylvania, whereas species at the northern edge of their range (e.g., oaks, hickories, southern pines) are anticipated to advance further northward (Shortle et al. 2009). Aspen (*Populus spp*.) and birch (*Betula spp*.) are among the most vulnerable species for extirpation from Pennsylvania and projected to be extirpated from Pennsylvania under high-emission scenarios and greatly reduced (perhaps eliminated) under low-emission scenarios (Iverson et al. 2008a, 2008b; Shortle et al. 2009) (Table 3.20). Models developed by Iverson are being integrated into Pennsylvania's CCRF/NIACS Vulnerability Assessments and Forest Adaptation workshops and will provide more specific results by December 2016.

In addition to climate change, Pennsylvania's forests have been subjected to many disturbances, including habitat fragmentation, pollution and non-native plants, insects and diseases (Shortle et al. 2009). For example, flowering dogwood, American beech, eastern hemlock and white ash are declining or have already declining, but this loss is attributed to invasive pests and disease and not directly the result of climate change (Shortle et al. 2015). As discussed in Invasive Species, survival of invasive species can be enhanced by environmental changes associated with a warming climate. Confidently understanding the effects of these anticipated changes in forest composition on other biotic communities, such as birds, will require extensive monitoring during the implementation of this Plan.

In addition to forest composition, a significant challenge in the coming decades will be maintaining forest habitat connectivity in the more heavily forested parts of the Marcellus and Utica Shale regions, where natural gas development has resulted in expansion of existing roads, development of new roads, and development of pipeline corridors, all of which have contributed to further fragmentation of the landscape.

Table 3.20. Categories of tree species in Pennsylvania based on projected vulnerability to climate change (Iverson et al. 2008a, 2008b; Shortle et al. 2009, 2015).

Category (for relevance in Pennsylvania)	**Common Name**	**Scientific Name**
Most at-risk of extirpation from the state	Paper birch	*Betula papyrifera*
	Quaking aspen	*Populus tremuloides*
	Bigtooth aspen	*Populus grandidentata*
	Yellow birch	*Betula alleghaniensis*
Most likely to decline substantially in importance in the state	American beech	*Fagus grandifolia*
	Black cherry	*Prunus serotina*
	Striped maple	*Acer pensylvanicum*
	Eastern hemlock	*Tsuga Canadensis*
Most likely to decline moderately in importance in the state	Red maple	*Acer rubrum*
	Sugar maple	*Acer saccharum*
	Eastern white pine	*Pinus strobus*
	Sweet birch	*Betula lenta*
	White ash	*Fraxinus Americana*
	American basswood	*Tilia Americana*
Projected to either marginally increase or decrease	Northern red oak	*Quercus rubra*
	Chestnut oak	*Quercus prinus*
	Yellow-poplar	*Liriodendron tulipifera*
	Sassafras	*Sassafras albidum*
	Pignut hickory	*Carya glabra*
	Blackgum	*Nyssa sylvatica*
	Black walnut	*Juglans nigra*
	White oak	*Quercus alba*
	American elm	*Ulmus Americana*
	Flowering dogwood	*Cornus florida*
Currently relatively common in the state and most likely to increase substantially in importance	Mockernut hickory	*Carya tomentosa*
	Black oak	*Quercus velutina*
	Silver maple	*Acer saccharinum*
	Eastern red cedar	*Juniperus virginiana*
Currently not common in the state and most likely to increase in importance	Loblolly pine	*Pinus taeda*
	Shortleaf pine	*Pinus echinata*
	Common persimmon	*Diospyros virginana*
	Red mulberry	*Morus rubra*
	Black hickory	*Carya texana*
	Blackjack oak	*Quercus marilandica*
	Winged elm	*Ulmus alata*
	Post oak	*Quercus stellata*

Rivers and Streams

Forests are a dominant ecological feature of the Pennsylvania landscape, yet the state's diverse aquatic habitats, which include approximately 86,000 miles of streams (PADEP 2014a) – second only to Alaska in number of stream miles - also are highly regarded resources. For rivers and streams, recent trends strongly support previous predictions of higher flooding potential in Pennsylvania due to higher precipitation. Extreme flows have become more extreme in much of the state except of the southwest quadrant. For some small-to-medium sized streams, increases in high-flow volumes are substantial (>20%), whereas large streams showed only moderate increases (5-20%) (Shortle et al. 2015). With few exceptions, lower stream flow was not observed in summer and fall, rather low-flow discharges also increased. Modeled predictions of higher precipitation are expected to be reflected in increased flooding risks (Shortle et al. 2015).

Reliable statewide projections of stream temperatures were confounded by lack of data, especially on streams with continuous records (Shortle et al. 2015). Analysis showed inconsistencies in summer temperatures, but overall more recording stations showed warmer hottest-day temperatures and longer hot periods. In winter, the warming trend is apparent and substantial. The ecological implications are currently unclear, but could impact native eastern brook trout and other coldwater species (Chisholm et al 1987; Cunjak 1996; Isaak et al. 2011; Shortle et al. 2015). Higher stream temperatures in winter could reduce thermal stress and associated mortality, yet higher summer temperatures could adversely affect spawning (Shortle et al. 2015).

Potential changes in precipitation, noted above, are expected to be observed in higher flooding potential, increased flow variability, especially from decreased snow cover and following storm events (Ross et al. 2013; Shortle et al. 2015). Larger peak flows can contribute to higher rates of sedimentation and increased scouring of stream banks and floodplains, both of which decrease survival and reproductive success for fish and macroinvertebrates (Chapman 1988; Fisher 2000; Nerbonne & Vondracek 2001). No direct evidence was available to establish trends of erosion rates, yet indirectly, larger erosion rates, bank instability and reduced stream health are possible (Shortle et al. 2015).

The greatest impacts of climate change on flow are expected in urban areas with a high percentage of impervious surfaces where runoff is quickly routed to streams (Rogers & McCarty 2000; Shortle et al. 2015). Overall, increased hydrological variability (e.g., larger floods, longer droughts) predicted by climate models could have severe, long-term impacts on both stream and wetland communities (Harper & Peckarsky 2006; Humphries & Baldwin 2003; Shortle et al. 2015).

Wetlands

In Pennsylvania, inland freshwater palustrine wetlands encompass approximately 404,000 acres (163,492 hectares) (PADEP 2014a) and an additional 512 acres (207.2 hectares) of tidal wetlands are found in southeastern Pennsylvania. Freshwater wetlands are critical areas for aquatic ecosystem functions, serving as nursery areas for fish, amphibians and other aquatic life, sources of dissolved organic carbon, critical habitat, and stabilizers of available nitrogen, atmospheric sulfur, and carbon dioxide (Mitsch & Gosselink 2000; Ross et al. 2013). These habitats support diverse biotic communities, including all major taxonomic groups encompassed by this plan. Climate change-induced alterations could have serious implications for species with life histories that include wetland habitats.

As found with streams, hydroperiod defines the structure and function of wetlands, with the amount of water, rate of flow, and timing of delivery influencing the type of organisms present, the cycling and removal of nutrients, and other ecosystem services (Millennium Ecosystem Assessment 2005; Shortle et al. 2009). Altered timing, seasonality, and magnitude of water delivery can severely affect these systems, reflected in changing seasonal patterns of water levels, reduced stream flows during dry periods, larger floods and longer droughts (Moore et al. 1997; Rogers & McCarty 2000; Ross et al. 2013). Some surface-water wetlands, believed to be the most vulnerable to these changes, may disappear completely (Ross et al. 2013).

In degraded wetlands, diminished ecosystem functions, such as reduced nutrient removal or sediment trapping, could have systemic effects across other habitat types such as streams. The type and magnitude of these changes are dependent upon several factors, including the current ecological condition of a wetland and surrounding land use (Brooks et al. 2004; Wardrop et al. 2007; Shortle et al. 2009). Wetlands, streams, and lakes surrounded by agricultural and urban activity often have reduced water quality (Omernik 1976; Lenat and Crawford 1994; Crosbie & Chow-Fraser 1999; Trebitz et al. 2007). Altered timing and quantity of precipitation and increasing temperatures are anticipated for Pennsylvania in future climate scenarios (Shortle et al. 2009; Shortle et al. 2015) and because these factors can influence biotic communities (Poff et al. 2002), shifts in Pennsylvania species and habitats also may be anticipated.

Lakes

Lake habitats can be degraded through enhanced nutrient delivery, as well as rising temperatures, which collectively contribute to occurrences of Harmful Algal Blooms (HABs). These blooms have been attributed to loss of aquatic life due to toxin-producing phytoplankton (Anderson et al. 2002; O'Neil et al. 2011; Michalak et al. 2013). Although the Pennsylvania portion of Lake Erie was not directly involved, the largest HAB event in Lake Erie history occurred in western Lake Erie (Ohio) in 2011, and was consistent with increasing nutrient inputs and warming conditions (Michalak et al. 2013).

In similar eutrophic conditions (e.g., low dissolved oxygen levels, elevated nutrients), occurrence of Type E botulism has been associated with loss of Lake Sturgeon in Lake Erie, but this has only been confirmed in a few specimens (Great Lakes Lake Sturgeon Conference 2004). Also in Lake Erie, spotted gar (*Lepisosteus oculatus*) and tadpole madtom (*Notorus gyrinus*) were noted as effected by algal blooms and associated anoxic conditions from decomposing biomass (see Chapter 1, Appendix 1.4). With projected increases in temperature and precipitation (Shortle et al. 2009), elevated occurrences of HABS in Pennsylvania lakes could be expected, along with potential negative effects on associated aquatic life.

Species Impacts

In aquatic systems, temperature serves a crucial role in behavioral and physiological factors important for survival and growth of nearly all macroinvertebrate and fish species (Sweeney et al. 1991, Ward 1992, Mountain 2002, Harper & Peckarsky 2006, Shortle et al. 2015). Elevated temperatures can contribute to fundamental changes in a species' life history, such as observed with mayfly emergences that are primarily initiated by increases in water temperature (Sweeney et al. 1991; Watanabe et al. 1999; Harper & Peckarsky 2006; Shortle et al. 2015). With consistently warmer temperatures earlier in the year, the long-term health of mayfly populations can be manifested in less growth during the larval period. This reduced growth can contribute to smaller size and lower fertility of adult mayflies (Peckarsky et al. 2001; Harper & Peckarsky 2006; Shortle et al. 2015).

Aquatic communities in rivers and streams are typically associated with the thermal regime. Coldwater streams have been characterized with temperatures < 66.2°F (< 19°C) (Wehrly et al. 2003) and which support native eastern brook trout, as well as thermally intolerant mayfly, stonefly, and caddisfly species (Ross et al. 2013). Increased stream temperatures could negatively impact these organisms by exceeding thermal tolerances, lowering dissolved oxygen concentrations, and biomagnifying toxins (Moore et al. 1997; Mountain 2002; Shortle et al. 2013). Elevated temperatures could therefore contribute to a decline in coldwater communities, along with a simultaneous increase in abundance of less desirable biological assemblages, especially invasive species that may outcompete and decimate native populations (Dukes & Mooney 1999; Rogers & McCarty 2000; Ross et al. 2015).

Coolwater streams typically have temperatures ranging from 66.2 to ≤ 71.6 °F (19 to ≤ 22 °C) and may contain species such as the central mudminnow (*Umbra limi*) and burbot (*Lota lota*) (Wehrly et al. 2003). These streams may be especially susceptible to increasing temperatures (Argent & Kimmel 2013). With sufficient increase in temperature, these systems could transition from coolwater to warmwater, along with an associated shift in biotic community. Streams with reduced thermal protection from forested riparian zones, altered flow regimes from dams, or watersheds with extensive impervious surfaces may be especially susceptible. Warmwater streams have been characterized as streams with temperatures > 71.6°F (> 22°C) (Wehrly et al. 2003) and, although fishes in these habitats are generally tolerant of warmer temperatures, the potential remains for increased loss of species, due to direct thermal effects or other factors contributing to less desirable conditions (e.g., lower dissolved oxygen).

Globally, decreases in the range of native trout have been observed in several places (Comte et al. 2012). For Pennsylvania, models currently indicate that stream temperature and flows are suitable for coldwater species under current conditions statewide, except in southeastern Pennsylvania and in a portion of western Pennsylvania, including Beaver and Lawrence counties (Jones et al. 2013; Shortle et al. 2015). Yet by 2050, models project that much of northwestern and southeastern Pennsylvania will be unsuitable for coldwater fishes. By 2100, all of Pennsylvania is projected to be unsuitable for coldwater fishes except for portions of the Laurel Highlands and Poconos which, under the "cold" climate scenario (B1), are expected to remain stable (Jones et al. 2013; Shortle et al. 2015).

Geographic scale of data and models may be factor in uncertainty about potential impacts to stream biota. For example, recent studies suggest that cold, headwater streams may be less vulnerable than regional models predict (Trumbo et al. 2010; Argent & Kimmel 2013). In southwestern Pennsylvania, temperatures in headwater streams appeared influenced by local riparian conditions and groundwater, suggesting greater resiliency of these streams compared to climate model predictions (Argent & Kimmel 2013). However, a strong relationship was found between air-temperature and water-temperature profiles in the receiving streams of these coldwater systems, which were characterized as coolwater. With increasing air temperatures, concern was expressed about the loss of these coolwater habitats for fish movement and potential genetic isolation of fishes in coldwater tributaries (Argent & Kimmel 2013).

Fine sediments reduce stream insect and salmonid spawning habitats, and lower survival rates of many insect species and salmonid embryos (Chapman 1988; Roy et al. 2003; Nerbonne & Vondracek 2001). Large flood events reduce survival rates for eggs laid alongside stream banks and flood-prone areas, and crush species lacking flood refugia (Karr & Chu 1999; Sedell et al. 1990).

Hydrologic factors can greatly modify fish assemblage structure (Poff & Allan 1995) and loss of seasonally predictable flood events and reduced groundwater recharge would affect many species that have adapted their life cycles to coincide with times of high water (Tockner et al. 2000; Amoros & Bornette 2002; Suen 2008; Shortle et al. 2009). Use of floodplain habitats by some fishes can be associated with the timing and predictability of high-flow events (Humphries et al. 1999). These changes could be seen in mismatched timing of life cycle stages and aquatic habitat availability (e.g., aestivating eggs that rely on inundation to initiate hatching in seasonal wetlands), insufficient duration of inundation (e.g., aquatic life cycle stages dependent on longer hydroperiods), and lack of sufficient habitat refugia (e.g., young insect larvae and fish fry that depend on seasonal backwater areas to escape predation and ensure adequate food supply) (Poff & Ward 1989; Sedell et al. 1990; Firth & Fisher 1991; Sweeney et al. 1991; Bunn & Arthington 2002; Suen 2008; Shortle et al. 2009).

For other species, such as the common toad (*Bufo bufo*), physiological effects of a warmer climate have been observed in reduced female body condition that also was correlated with laying fewer eggs (Reading 2007). Amphibians are especially susceptible to a changing climate because they are sensitive to dry conditions and their habitat is often scattered throughout the landscape (Rodenhouse et al. 2009; Ross et al. 2013) thus making it potentially difficult to find alternative, suitable habitats. As an indirect effect, phenological (timing) changes in prey availability and drying conditions are factors that may affect amphibians (Rodenhouse et al. 2009; Ross et al. 2013).

As noted in regional climate change impacts, the effects of a changing climate on mammals is unclear. Reduced snowpack could increase mortality of small rodents which rely on snow for its insulating properties and warming temperatures may contribute to increased arousal and energy use of hibernating bats (Rodenhouse et al. 2009; Ross et al. 2013; Shortle et al. 2015). Yet, for insectivorous bats, annual survival appears more strongly associated with precipitation and insect abundance rather than a minimum temperature (Frick et al. 2010). Thus, a wetter climate in summer, which is projected for Pennsylvania, could favor insectivorous feeding species.

For birds, the negative effects of climate change for some species is projected to be substantial. For example, of 314 of 588 North American birds assessed (National Audubon Society 2014b), 126 are classified as “climate endangered” and anticipated to lose more than 50% of their current range by 2050. The remaining 188 species are considered “climate threatened” and range loss is expected to exceed 50% by 2080.

Species Shifts

Though the effects are variable, warmer weather has been attributed to earlier arrival and breeding dates for migrating species (Rodenhouse et al. 2009; Ross et al. 2013), and climate change effects also may include a shift in species range or abundance. For example, the ranges of 27 of 38 studied bird species found in the northeastern United States have shifted northwards (Rahbek et al. 2007; Ross et al. 2013). As with species' ranges, changes in species abundances attributed to climate change are variable. Of 25 forest bird species assessed, the abundance of 15 species increased, 5 species showed no change in abundance, and 5 species showed decreasing abundances (Rodenhouse et al. 2009; Ross et al. 2013). In their models, Rodenhouse et al. (2008) projected declining bird species richness in Pennsylvania and western New York, but increasing richness in Maine and western New Hampshire (Ross et al. 2013).

The black-capped and Carolina chickadee are current examples of Pennsylvania species for which ranges have shifted. The former is at the southern end of its range in Pennsylvania and the latter at the northern edge of its range. Both species are moving north and a narrow band of hybridization has developed where they overlap. The zone of hybridization also is shifting north about a kilometer per year (Robert L. Curry, Villanova University, personal communication). Similar shifting of species range has been noted in Wisconsin winter bird community structure that, over a 20-year period, shifted to a warmer climate bird composition (Princé & Zuckerberg 2015). Similarly, hybridization attributable to climate change has been observed between southern flying squirrels (*Glaucomys volans*) and northern flying squirrels (*G. sabrinus*) (Garroway et al. 2010) due to a northerly shift in the range of the southern flying squirrel, contributing to increased opportunity for sympatry. The extent of range shift is not consistent among species and will be contingent upon factors such as vulnerability to a changing thermal regime, availability of suitable alternative habitats, and capacity to move to new habitats.

Phenology

The timing of developmental processes in plants and animals can be initiated by various factors, including seasonal temperature (Badeck et al. 2004) or photoperiod (Körner & Basler 2010). Mismatches in phenology (i.e., timing) between species, such as plants blooming before emergence of associated insect pollinators, or early emergence of insects historically important food for nesting birds, could have serious negative consequences for these dependent species. Climate-associated changes in phenology (i.e., temporal change in a species' life history) have been attributable to earlier spring development in plants (Badeck et al. 2004), ice-out on waterways (Bradley et al. 1999), early bird migration and insect emergences (Visser & Both 2005). As with shifting ranges, responses to a changing thermal regime are not consistent among species, and species not able to adapt to an altered thermal regime or move to new habitats may be lost (Bradley et al. 1999).

Invasive Species

The number of invasive species in Pennsylvania is dynamic (Invasive Species) and a changing climate can make native habitats and species increasingly vulnerable to invasive species. Plant diseases and pests are likely to have a greater impact in a warming climate, allowing them to expand their range into new areas (Dukes & Mooney 1999; Shortle et al. 2009). These pests can alter the community structure of terrestrial and aquatic organisms. For example, in Pennsylvania, the hemlock woolly adelgid (HWA) (*Adelges tsugae*) is killing the native eastern hemlock (*Tsuga Canadensis*) (PADCNR 2015d; USDA-FS

2013) (Fig. 3.25). Because HWA is vulnerable to cold temperatures, the loss of eastern hemlock forests is expected to be enhanced by a warming climate, especially warmer winters (Paradis et al. 2008; Albani et al. 2010; Groffman et al. 2012). Beyond loss of this tree species, biological communities are associated with eastern hemlock. For example, fish communities in eastern hemlock ecosystems, compared to hardwood forests, have been found to hold more eastern brook trout and brown trout (*Salmo trutta*) (Ross et al. 2003). Aquatic invertebrate communities (Snyder et al. 2002) and birds such as the Louisiana waterthrush (*Parkesia motacilla*) are associated with eastern hemlock and also may be harmed by loss of this tree species. Relevance of HWA survival to temperature is just one example of how climate change can be expected to influence habitat and associated species. Given varied responses of native and invasive species to changing temperature and precipitation, continued monitoring will be crucial to more fully understanding the rate of change, climate resiliency of native species, and identify potential conservation actions to support adaptation strategies. The earth's climate is changing and, regardless of discussions about the source of this change or uncertainty in severity or scope, it will be crucial to support adaptation and foster resiliency (e.g., enhance habitats, provide corridors) to reduce risks to species. Many of the same conservation actions that will enhance species' survival of non-climate threats will also support species adaptation to climate change.

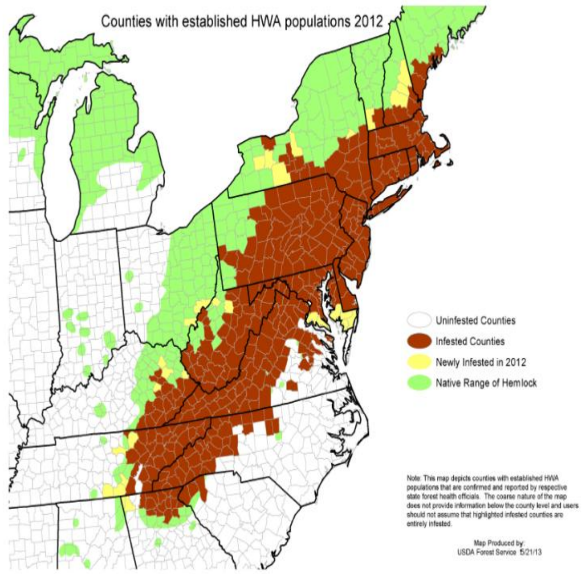

Fig. 3.25. Distribution of Hemlock Woolly Adelgid in eastern United States. (Source: USDA-FS 2013).

Other Threats

Insufficient Information

Expressed as a regional threat, lack of information is an indirect threat to Pennsylvania's SGCN and habitats because it inhibits development and implementation of conservation actions to address known threats. This lack of information goes beyond the knowledge of resource managers and includes public understanding and recognition of threats. Public knowledge also can help identify other potential threats or perhaps highlight needs for outreach. For example, in its survey of Commonwealth residents, Responsive Management (2014) found over one-third of respondents either "didn't know," or considered there to be "no important issue" facing non-game wildlife today in Pennsylvania. However, of those respondents who identified an issue or concern, 16% indicated that "habitat loss/fragmentation/degradation" was the most important concern (Fig. 3.26) followed by both "urban sprawl/over-development" and "population growth" at 6%, and "pollution in general" and "polluted water/water quality" at 5% each. Overall, these responses suggest that various forms of habitat modification are the primary concern for wildlife in Pennsylvania and strongly indicate that residents are unfamiliar with the threats facing Pennsylvania's nongame wildlife (32%) and thus suggest a notable topic for outreach initiatives.

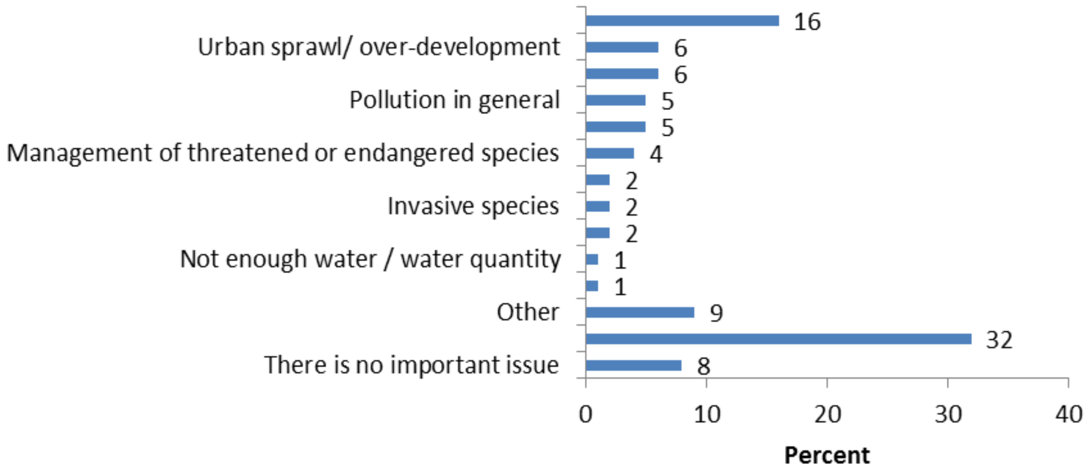

Fig. 3.26. Distribution (percent) of survey responses to an open question regarding the most important issue or concern facing nongame wildlife in Pennsylvania today (Responsive Management 2014).

Summary

Threats to Pennsylvania's SGCN and habitats are substantial and complex, sometimes with synergistic effects. Further confounding our understanding of threats, especially climate change, is the temporal aspect by which data are required to be collected, often for decades, due to delayed responses of some species or ecosystems.

In recent years, in the northeast region and globally, research has provided crucial understanding of threats relevant to fish and wildlife. Increasingly, this knowledge of threat impacts on species and habitats is enhanced through compilation and analysis of disparate datasets. In the northeast region continued collaboration of the NEFWDTC, NALCC, AppLCC, UMGLLCC and NECSC will be vital to more fully understand these threats. Long-term datasets and refined (downscaled) climate models will be useful for informing resource managers in their decisions for designing, implementing and testing conservation actions. The dynamic and often synergistic effects of threats may require development of monitoring strategies and use of novel or untested conservation actions. For these measures, methodically understanding effectiveness of actions may benefit from an adaptive management approach (Stankey et al. 2005).

New research and observations are providing insight into these relationships, but monitoring and investigative work may be required. Ecological responses to disturbances may take decades; therefore monitoring initiatives should be designed to extend well beyond the typical 1- to 5-year grant cycle.

Long-term, science-based projects such as the Long-Term Ecological Research Program (Hobbie et al. 2003) and the Long-Term Resource Monitoring Program (LTRMP) (USGS 2014) can help monitor these changes at scientifically appropriate temporal and spatial scales. Exemplified in this section, recently developed U.S. Geological Survey Climate Science Centers (O'Malley 2012), specifically in the Northeast, the NECSC, and the LCCs (i.e. NALCC, APPLCC, UMGLLCC) provide vital analytical resources, which have been lacking at a regional scale. These entities are providing insights into these threats and the long-term environmental effects on species and habitats. Enhancing the capacity to share data (TNC 2010) and developing localized datasets (Argent & Kimmel 2013), will be crucial further refining and downscaling climate models. For threats such as invasive species, expanding current coordination within Pennsylvania, such as through the Pennsylvania Invasive Species Council, can provide information to the public and allow a more proactive approach to address these threats. This is especially required for this threat given the lack of effective eradication measures for established invasive species.

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Appendix 3.1.

Exhibit 1. List of climate-change vulnerability assessment sources from the northeast and midwest regions of the United States. An expanded table of information with study-specific metadata is available in Appendix 2.1 *in* Staudinger et al. (2015b).

Reference	Overview	State or Region
Adaptation Subcommittee to the Governor's Steering Committee on Climate Change 2010	Assessed the vulnerability of 18 terrestrial and aquatic habitats, wildlife SGCN, state-listed plants and some invasive species	Connecticut
Brandt et al. 2014	Central Hardwoods forest ecosystem vulnerability assessment and synthesis.	Southern Missouri, Illinois, Indiana
L. Brandt, written communication	CCRF assessment in progress of the vulnerability of forests and associated ecosystems in the Chicago urban area. Project progress can be found at: http://www.forestadaptation.org/urban/vulnerability-assessment	Greater Chicago metropolitan area
Butler et al. 2015	Central Appalachians forest ecosystem Vulnerability assessment and synthesis	West Virginia and Appalachian portions of Ohio and Maryland
P. Butler, written communication	CCRF assessment in progress of the vulnerability of forests and associated ecosystems in the Mid-Atlantic ecoregion. Project progress can be found at: http://www.forestadaptation.org/midatlantic	Delaware, Maryland, Pennsylvania, New Jersey, New York
Byers & Norris 2011	Assessed the vulnerability of 185 SGCN, common, and foundational animal and plant species.	West Virginia
Cullen et al. 2013	Assessed the vulnerability of 20 forest songbirds due to climate change, historical deer browsing, and energy development (e.g., hydraulic fracturing).	Pennsylvania
Furedi et al. 2011	Assessed the vulnerability of 85 priority species identified from the PA WAP to climate change, and other abiotic factors.	Pennsylvania
Galbraith et al. 2014	Assessed the vulnerability of 49 North American shorebirds to climate change.	US & Canada
Handler et al. 2014a; 2014b	Northwoods forest ecosystem vulnerability assessment and synthesis.	Northern Minnesota; Northern Lower Michigan and Eastern Upper Michigan

J. Hare, written communication	Northeast Fisheries Climate Vulnerability Assessment (NEVA) in progress of 79 commercially and recreationally exploited marine fish and invertebrate stocks to climate change. Project progress can be found at: http://www.st.nmfs.noaa.gov/ecosystems/climate/activities/assessing-vulnerability-of-fish-stocks	Northeast U.S. Continental Shelf Ecosystem
Hoving et al. 2013	Assessed the vulnerability of 400 SGCN and game species.	Michigan
Janowiak et al. 2014a	Northwoods forest ecosystem vulnerability assessment and synthesis.	Northern Wisconsin and Western Upper Michigan
M. Janowiak, written communication	CCRF assessment in progress of the vulnerability of forests and associated ecosystems in the New England ecoregion. Project progress can be found at: http://www.forestadaptation.org/new-england	Connecticut, Maine, Massachusetts, Rhode Island, New Hampshire, Vermont and Northern New York
Manomet & MADFW 2010	Assessed the vulnerability of 20 SWAP-targeted fish and wildlife habitats to climate change.	Massachusetts
Manomet & NWF 2013	Assessed the vulnerability of 13 non-tidal fish and wildlife habitats to climate change.	New England Association of Fish & Wildlife Agencies region
New Hampshire Fish & Game Department 2013	An amendment to the NH WAP that includes narratives of the vulnerability of 24 critical habitats.	New Hampshire
Schlesinger et al. 2011	Assessed the vulnerability of 119 SGCN.	New York
Sievert 2014	Assessed vulnerability of 134 stream fishes to climate change, and habitat fragmentation.	Missouri
Sneddon & Hammerson 2014	Assessed the vulnerability of 64 species of plants and animals to climate change.	North Atlantic Landscape Conservation Cooperative region

Tetratech 2013	Assessed the vulnerability of 22 upland forest, wetland, river, stream, and lake habitats as well as associated fish and wildlife species to climate change.	Vermont
Whitman et al. 2013	Assessed the vulnerability of 442 SGCN, state-listed, Threatened or Endangered wildlife and plant species, and 21 Key Habitats from the Maine Comprehensive Wildlife Conservation Strategy (ME CWCS)	Maine
B. Zuckerberg, written communication	Assessment in progress of the vulnerability of grassland birds. Project progress can be found at: http://necsc.umass.edu/projects/fitting-climate-lens-grassland-bird-conservation-assessing-climate-change-vulnerability-usi	Eastern U.S.

Appendix 3.2.

Exhibit 1. Predictions of Species-Specific Habitat Shift due to Climate Change in the Northeast. Modified from the Climate Change Bird Atlas, Matthews et al. (2007) http://www.fs.fed.us/nrs/atlas/.

Regional Predictions of Species-Specific Habitat Shift due to Climate Change

(Modified from the Climate Change Bird Atlas, Matthews et al. 2007 - http://www.fs.fed.us/nrs/atlas/)

Common Name	Scientific Name	Model Predictions	Common Name	Scientific Name	Model Predictions
Common Loon	*Gavia immer*	↓	Clay-colored Sparrow	*Spizella pallida*	↓
Mallard	*Anas platyrhynchos*	↓↓	Field Sparrow	*Spizella pusilla*	↑↑
Blue-winged Teal	*Anas discors*	↑	Dark-eyed Junco	*Junco hyemalis*	↓↓
Canada Goose	*Branta canadensis*	↓	Bachmans Sparrow	*Aimophila aestivalis*	↑
White Ibis	*Eudocimus albus*	↑	Song Sparrow	*Melospiza melodia*	↓↓
American Bittern	*Botaurus lentiginosus*	↓	Lincolns Sparrow	*Melospiza lincolnii*	↓
Great Blue Heron	*Ardea herodias*	↓	Swamp Sparrow	*Melospiza georgiana*	↓↓
Great Egret	*Ardea alba*	↑↑	Eastern Towhee	*Pipilo erythrophthalmus*	↑
Snowy Egret	*Egretta thula*	↑	Northern Cardinal	*Cardinalis cardinalis*	↑↑
Little Blue Heron	*Egretta caerulea*	↑↑	Rose-breasted Grosbeak	*Pheucticus ludovicianus*	↓↓
Cattle Egret	*Bubulcus ibis*	↑↑	Blue Grosbeak	*Guiraca caerulea*	↑↑
Green Heron	*Butorides virescens*	↑↑	Indigo Bunting	*Passerina cyanea*	↑
Yellow-crowned Night-Heron	*Nyctanassa violacea*	↑	Painted Bunting	*Passerina ciris*	↑↑
Sora	*Porzana carolina*	↓	Dickcissel	*Spiza americana*	↑↑
American Coot	*Fulica americana*	↑	Summer Tanager	*Piranga rubra*	↑↑
Common Snipe	*Gallinago gallinago*	↓↓	Purple Martin	*Progne subis*	↑↑
Spotted Sandpiper	*Actitis macularia*	↓	Cliff Swallow	*Petrochelidon pyrrhonota*	↓↓
Killdeer	*Charadrius vociferus*	↑	Barn Swallow	*Hirundo rustica*	↑
Gray Partridge	*Perdix perdix*	↑	Tree Swallow	*Tachycineta bicolor*	↓↓
Northern Bobwhite	*Colinus virginianus*	↑↑	Bank Swallow	*Riparia riparia*	↓↓
Ruffed Grouse	*Bonasa umbellus*	↓	Cedar Waxwing	*Bombycilla cedrorum*	↓↓
Ring-necked Pheasant	*Phasianus colchicus*	↓↓	Loggerhead Shrike	*Lanius ludovicianus*	↑↑
Rock Dove	*Columba livia*	↓↓	Red-eyed Vireo	*Vireo olivaceus*	↓↓
Mourning Dove	*Zenaida macroura*	↑	Warbling Vireo	*Vireo gilvus*	↓
Common Ground-Dove	*Columbina passerina*	↑	Yellow-throated Vireo	*Vireo flavifrons*	↑↑
Turkey Vulture	*Cathartes aura*	↑↑	Blue-headed Vireo	*Vireo solitarius*	↓↓
Black Vulture	*Coragyps atratus*	↑↑	White-eyed Vireo	*Vireo griseus*	↑↑
Mississippi Kite	*Ictinia mississippiensis*	↑↑	Black-and-white Warbler	*Mniotilta varia*	↓↓
Northern Harrier	*Circus cyaneus*	↓	Prothonotary Warbler	*Protonotaria citrea*	↑↑
Red-tailed Hawk	*Buteo jamaicensis*	↑↑	Worm-eating Warbler	*Helmitheros vermivorus*	↑
Red-shouldered Hawk	*Buteo lineatus*	↑↑	Blue-winged Warbler	*Vermivora pinus*	↑
Broad-winged Hawk	*Buteo platypterus*	↑	Golden-winged Warbler	*Vermivora chrysoptera*	↑
American Kestrel	*Falco sparverius*	↓	Nashville Warbler	*Vermivora ruficapilla*	↓↓
Great Horned Owl	*Bubo virginianus*	↑↑	Northern Parula	*Parula americana*	↑↑
Yellow-billed Cuckoo	*Coccyzus americanus*	↑↑	Yellow Warbler	*Dendroica petechia*	↓↓
Black-billed Cuckoo	*Coccyzus erythropthalmus*	↓↓	Black-throated Blue Warbler	*Dendroica caerulescens*	↓↓
Downy woodpecker	*Picoides pubescens*	↑	Yellow-rumped Warbler	*Dendroica coronata*	↓↓
Yellow-bellied Sapsucker	*Sphyrapicus varius*	↓↓	Magnolia Warbler	*Dendroica magnolia*	↓↓
Pileated Woodpecker	*Dryocopuc pileatus*	↑↑	Cerulean Warbler	*Dendroica cerulea*	↑
Red-headed Woodpecker	*Melanerpes erythrocephalus*	↑↑	Blackburnian Warbler	*Dendroica fusca*	↓↓
Red-bellied Woodpecker	*Melanerpes carolinus*	↑↑	Yellow-throated Warbler	*Dendroica dominica*	↑↑
Chuck-Wills Widow	*Caprimulgus carolinenis*	↑↑	Black-throated Green Warbler	*Dendroica virens*	↓↓
Whip-poor-will	*Caprimulgus vociferus*	↑↑	Pine Warbler	*Dendroica pinus*	↑↑
Common Nighthawk	*Chordeiles minor*	↑↑	Prairie Warbler	*Dendroica discolor*	↑↑
Chimney Swift	*Chaetura pelagica*	↑	Ovenbird	*Seiurus aurocapillus*	↓↓

Ruby-throated Hummingbird	*Archilochus colubris*	**↑↑**	Northern Waterthrush	*Seiurus noveboracensis*	**↓↓**
Scissor-tailed Flycatcher	*Tyrannus forficatus*	**↑↑**	Kentucky Warbler	*Oporornis formosus*	**↑↑**
Eastern Kingbird	*Tyrannus tyrannus*	**↑↑**	Mourning Warbler	*Oporornis philadelphia*	**↓↓**
Eastern Phoebe	*Sayornis phoebe*	**↑↑**	Common Yellowthroat	*Geothlypis trichas*	**↓↓**
Eastern Wood-Pewee	*Contopus virens*	**↑↑**	Yellow-breasted Chat	*Icteria virens*	**↑↑**
Acadian Flycatcher	*Empidonax virescens*	**↑↑**	Hooded Warbler	*Wilsonia citrina*	**↑↑**
Willow Flycatcher	*Empidonax traillii*	↓	Canada Warbler	*Wilsonia canadensis*	**↓↓**
Least Flycatcher	*Empidonax minimus*	**↓↓**	American Redstart	*Setophaga ruticilla*	**↓↓**
Horned Lark	*Eremophila alpestris*	**↑↑**	House Sparrow	*Passer domesticus*	↑
Blue Jay	*Cyanocitta cristata*	↑	Northern Mockingbird	*Mimus polyglottos*	**↑↑**
American Crow	*Corvus brachyrhynchos*	↑	Gray Catbird	*Dumetella carolinensis*	**↓↓**
Fish Crow	*Corvus ossifragus*	↑	Brown Thrasher	*Toxostoma rufum*	**↑↑**
European Starling	*Sturnus vulgaris*	↓	Carolina Wren	*Thryothorus ludovicianus*	**↑↑**
Bobolink	*Dolichonyx oryzivorus*	**↓↓**	House Wren	*Troglodytes aedon*	**↓↓**
Brown-headed Cowbird	*Molothrus ater*	**↑**	Winter Wren	*Troglodytes troglodytes*	**↓↓**
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	↑	Sedge Wren	*Cistothorus platensis*	↑
Eastern Meadowlark	*Sturnella magna*	**↑↑**	Brown Creeper	*Certhia americana*	**↓**
Orchard Oriole	*Icterus spurius*	**↑↑**	White-breasted Nuthatch	*Sitta carolinensis*	↑
Baltimore Oriole	*Icterus galbula*	**↓↓**	Red-breasted Nuthatch	*Sitta canadensis*	**↓↓**
Brewers Blackbird	*Euphagus cyanocephalus*	↓	Brown-headed Nuthatch	*Sitta pusilla*	**↑**
Evening Grosbeak	*Coccothraustes vespertinus*	**↓**	Tufted Titmouse	*Baeolophus bicolor*	**↑↑**
Purple Finch	*Carpodacus purpureus*	**↓↓**	Black-capped Chickadee	*Poecile atricapillus*	**↓↓**
House Finch	*Carpodacus mexicanus*	**↓↓**	Blue-gray Gnatcatcher	*Polioptila caerulea*	**↑↑**
American Goldfinch	*Carduelis tristis*	**↓↓**	Wood Thrush	*Hylocichla mustelina*	**↓↓**
Vesper Sparrow	*Pooecetes gramineus*	**↓↓**	Veery	*Catharus fuscescens*	**↓↓**
Savannah Sparrow	*Passerculus sandwichensis*	**↓↓**	Swainsons Thrush	*Catharus ustulatus*	**↓↓**
Grasshopper Sparrow	*Ammodramus savannarum*	**↑↑**	Hermit Thrush	*Catharus guttatus*	**↓↓**
White-throated Sparrow	*Zonotrichia albicollis*	**↓↓**	American Robin	*Turdus migratorius*	**↓↓**
Chipping Sparrow	*Spizella passerina*	**↓↓**			

Key

Bold indicates agreement among the majority of the 8 model/scenarios considered (3 GCM models [Hadley, PCM & GFDL] with low (SRES A1FI) and high (SRES A2) emission scenarios).

↑↑ Large expected increase of species-specific habitat abundance in the region.

↑ Moderate expected increase of species-specific habitat abundance in the region.

↓ Moderate expected decrease of species-specific habitat abundance in the region.

↓↓ Large expected decrease of species-specific habitat abundance in the region.