CHAPTER 3: THREATS TO NORTHEAST HABITATS AND SPECIES

SWAP Element 3

Descriptions of problems which may adversely affect species identified in the 1st element or their habitats, and priority research and survey efforts needed to identify factors which may assist in restoration and improved conservation of these species and habitats.

Suggested components:

A. The Plan indicates sources of information (e.g., literature, databases, agencies, or individuals) used to determine the problems or threats.
B. The threats/problems are described in sufficient detail to develop focused conservation actions (for example, "increased highway mortalities" or "point-source pollution" rather than generic descriptions such as "development" or "poor water quality").
C. The Plan considers threats/problems, regardless of their origins (local, state, regional, national and international), where relevant to the state's species and habitats.
D. If available information is insufficient to describe threats/problems, research and survey efforts are identified to obtain needed information.
E. The priority research and survey needs, and resulting products, are described sufficiently to allow for the development of research and survey projects after the Plan is approved.

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HOW TO USE THIS CHAPTER

This Chapter provides:

- An overview and background of key regional efforts and classification systems for context
- Identification of the top threats to species on the 2023 RSGCN list:
    - Pollution
    - Climate Change
    - Invasive & Problematic Species, Genes, & Diseases
    - Natural System Modifications
    - Biological Resource Use
    - Residential & Commercial Development
- A section for each of the top 6 priority regional threats with:
    - Description of the general effects on Northeast RSGCN
    - Breakdown of the different ways the overall threat impacts Northeast RSGCN and their habitats, with some species and taxa-specific examples
    - Identification of interactions and synergies with other threat categories
    - Description of useful tools and resources for learning more about the threat
- References and resources
- *Supplemental Information 3* describes the threat classification hierarchy system referred to throughout the chapter

3.0 REGIONAL OVERVIEW

The third required element of State Wildlife Action Plans (SWAPs) describes the problems impacting species and their habitats, priorities for research, and factors that will improve the efficacy of conservation and restoration activities. The Northeast states, through the Northeast Fish and Wildlife Diversity Technical Committee (NEFWDTC), developed a consistent framework for classifying problems and issues (threats), although the adoption of threat ranking criteria varied from state-to-state in their SWAPs. The Northeast Lexicon developed the first classification framework in 2013 and updated the system for 2022 (Crisfield and NEFWDTC 2013 and 2022). The Northeast Conservation Synthesis (TCI and NEFWDTC 2013) and the Northeast SWAP Database (TCI and NEFWDTC 2020a) used this standardized classification framework in their analyses and structure. The 2017 SWAP Synthesis (TCI and NEFWDTC 2017), the 2020 Limiting Factors to Northeast RSGCN report (TCI and the NEFWDTC 2020b), and the Regional Conservation Needs (RCN) program summarized the framework in several reports and projects. NEAFWA's NEFWDTC and Northeast State Wildlife Action Plan Subcommittee, State Wildlife Action Plans, and synthesized regional products provide the foundation to assess and address shared threats collaboratively and prioritize them for action implementation across the region.

This chapter summarizes information about the threats identified through the 14 Northeast State Wildlife Action Plans, which the 2017 SWAP Synthesis analyzed in (TCI and NEFWDTC 2017). It also presents and compares the threats from the 2015 SWAPs to more recent, finer-scale threat information identified and confirmed by regional taxonomic experts for the 2020 Limiting Factors to Northeast RSGCN report (TCI and the NEFWDTC 2020b), as well as additional information from key published data sources and provided by the taxonomic teams during the 2023 RSGCN list review. This chapter then provides greater detail about the top threats in the Northeast and their impacts on species of conservation concern.

There are many challenges confronting fish and wildlife in the Northeast states. Human activities and natural processes that affect wildlife species and habitats in negative or detrimental ways are threats, as are management challenges such as deficiencies in data or resources for particular species or habitats and characteristics of species that may prevent them from responding positively to conservation or recovery actions, referred to as limiting factors. Threats may affect a species or habitat directly or they may be indirect, affecting a species or habitat through one or more intermediary actors or processes. Fish and wildlife management agencies cannot manage these threats independently of one another. Many threats, especially climate change, act synergistically with one another, facilitating or amplifying their combined impact.

3.1 ANALYZING NORTHEASTERN THREATS

There is no comprehensive assessment of threats to fish and wildlife and their habitats across the Northeast region. The Northeast states identified threats to fish, wildlife, and their habitats in their individual Wildlife Action Plans in 2005 and 2015.

The **2007 SWAP Synthesis** report from the Association of Fish and Wildlife Agencies (AFWA) compiled information on priority threats from all 50 states from the original SWAPs in 2005 (TCI 2007). Wildlife diversity program managers and SWAP coordinators provided priority threats cited in their SWAPs. Results were analyzed and presented at national and regional scales. This report indicates that the greatest threats to Northeast wildlife and habitats were Habitat Loss and Degradation from Development, Water Quality from Pollution, Disruption or Alteration of Natural Systems, Invasive and Other Problematic Species, and Climate Change (Figure 3.1).

After the 2015 SWAP revisions, the Northeast region synthesized these results in the **2017 SWAP Synthesis** (TCI and the NEFWDTC 2017). Pollution, Residential and Commercial Development, Natural System Modifications, Wildlife Disease and Invasive Species, and Climate Change emerged as the top regional threats (Figure 3.1). These threats were shared by most states, affected the greatest number of species and habitats, and were cited most frequently in SWAPs.

In 2020, additional threat and vulnerability information was added to the Northeast SWAP Database (version 3.0) for the RSGCN species and presented in the **RSGCN Limiting Factors Report** (TCI and NEFWDTC 2020a, 2020b). This report provided additional context that helped explain why some of these threats were so impactful in the Northeast. Characteristics of life history, behavior, and habitat-specific vulnerabilities, collectively referred to as Limiting Factors, work in concert with threats, amplifying their effects. The top regional threats in the Northeast are intertwined with these Limiting Factors; any conversation involving threats should also acknowledge these factors and consider the complex interactions between them.

As part of the **2023 RSGCN list update** (see *Chapter 1* for more information), the Taxonomic Teams reviewed threat information for RSGCN from the published literature, the 2017 SWAP Synthesis, and the 2020 Limiting Factors Report. Pollution (Threat 9.0), Climate Change (Threat 11.0), Invasive & Problematic Species, Genes, & Diseases (Threat 8.0), Biological Resource Use (Threat 5.0), and Natural System Modifications (Threat 7.0) are the top threats in the region (Figure 3.1). These threats impact the greatest number of RSGCN species.

2007 SWAP Synthesis	2017 SWAP Synthesis	2023 Conservation Synthesis
1. Development	1. Pollution	1. Pollution
2. Pollution	2. Development	2. Climate Change
3. Natural System Modifications	3. Natural System Modifications	3. Invasives, Problematic Natives, Genes, & Diseases
4. Invasives & Diseases	4. Invasives & Diseases	4. Biological Resource Use
5. Climate Change	5. Climate Change	5. Natural System Modifications

Figure 3.1 Comparison of the top five threats to species of conservation concern based on the 2007 SWAP Synthesis, 2017 SWAP Synthesis, and this 2023 Regional Conservation Synthesis. Threats are presented in rank order for each analysis.

From 2007 to 2023, the top threats have remained largely consistent, though their relative ranks have shifted. In fact, results from the 2007 SWAP Synthesis, 2017 SWAP Synthesis, and this 2023 Regional Conservation Synthesis highlight most of the same threats as global wildlife threat prioritization efforts (Wilson 1989, Yiming and Wilcove 2005, Maxwell et al. 2016, Tilman et al. 2017, Bellard et al. 2022). The continued high ranking of the same threats across all regional analyses highlights their importance to conservation in the Northeast. The notable changes in 2023 are Development and Natural System Modifications ranks are lower, while Climate Change, Invasive & Problematic Native Species, Genes, & Diseases, and Biological Resource Use ranks have risen.

The rank shifts reflect the data used to inform each Synthesis product. For the first two Syntheses, data came directly from the SWAPs. As a result, it included threat information on both habitats and species. This 2023 Regional Conservation Synthesis is closely tied with the RSGCN list updates, and as a result, primarily reflects species threat information. The same threats can impact species and habitats differently. For example, Natural System Modifications are a higher rank in the SWAP Syntheses because these are direct threats to many habitats, while largely indirect threats to species. Invasive species impact habitats directly, and species both indirectly through the habitat and directly through competition and predation with other invaders, elevating the importance of this threat from a species lens. Biological Resource Use primarily impacts forested habitats, but species from many different habitats, especially aquatic ones, are imperiled by this threat as it includes harvest and collection. Further investigation of the differential influence of threats on Northeast habitats and species would better inform future management actions and regional planning. The updated regional SWAP Synthesis post-2025 SWAP revisions will enable this analysis.

Ranking the relative importance of threats can be a useful tool for framing these issues. However, it is critical to remember these ranks are highly contextual. The taxon, species characteristic, timescale, and ecosystem under consideration may result in ranks being ascribed to different importance levels (Bellard et al. 2022). All of the threats RSGCN face are important and intertwined. Species conservation will require whole-system approaches that take into account the complex interactions these threats can have on one another.

3.1.1 THREAT CLASSIFICATION IN THE NORTHEAST

States applied the Region 5 USFWS and AFWA SWG Guidance and Best Practices (2012) to define and identify "Key Issues or Threats" to habitats and SGCN. States developed individual approaches to classify these threats inclusively through their internal and external experts and partners but coordinated and collaborated in developing the Northeast Lexicon and Synthesis RCN projects that provided consistent terms, data, and information sharing across the region. In late 2022 AFWA issued a 2nd edition of **Voluntary Guidance for States to Incorporate Climate Adaptation in State Wildlife Action Plans and Other Management Plans**, updating guidance from 2009 (AFWA 2022). The updated guidance includes instructions for incorporating climate change adaptation into the context of the SWAP elements, including tools and examples of adaptive management strategies utilized by some states.

The previous Regional Conservation Synthesis addressed regional threats by summarizing the threats identified in the 2005 Northeast SWAPs and RCN projects conducted to date (TCI and NEFWDTC 2013). The 2005 SWAP threats data were classified using the system jointly developed by the International Union for the Conservation of Nature (IUCN) and Conservation Measures Partnership (CMP), the **Direct Threats Classification System, version 1.1** (Salafsky et al. 2008). Following the development of the 2015 SWAPs the **Northeast State Wildlife Action Plan Synthesis: Regional Conservation Priorities** report synthesized the threats to both species and habitats identified in the 14 revised 2015 SWAPs (TCI and NEFWDTC 2017). These threats were classified with the CMP **Direct Threats Classification System, version 2.0,** which was released in 2016 with minor revisions to the IUCN-CMP version 1.1 classification (CMP 2016).

In December 2019 the IUCN released an updated **Direct Threats Classification System, version 3.2**, with some Level 3 categories to allow for more detailed threats descriptions (IUCN 2019). In 2021 Lamarre et al. (2021) advanced a regional threats classification system consistent with both the CMP Direct Threats Classification System version 2.0 and IUCN version 3.2, releasing the **Standardized Classification of Threats to Biodiversity: Definitions for Quebec's Conservation Data Centre, version 1.0.** This regional classification system includes a third-level hierarchy, providing more detailed threat categories applicable to the NEAFWA region. The new Level 3 threat categories allow for an actionable level of detail, such as specifying a specific source of pollution or a specific invasive species or disease of concern. The Terwilliger Consulting, Inc. team found it necessary to add additional categories to capture threats not fully identified by the Quebec classification system. The full **Quebec classification system with the TCI modifications** is described in *Supplementary Information 3*. The **2022 Northeast Lexicon** recommends the use of this modified regional threat classification scheme for the 2025 SWAPs in the Northeast (Crisfield and NEFWDTC 2022).

In December 2022, IUCN released a draft **Direct Threats Classification System, version 3.3,** with Level 3 threat categories applicable at the global scale (IUCN 2022). This system was introduced too late to be used in this analysis but should be reviewed in the future to determine if it should be incorporated into a Northeast Lexicon update.

The first level of the threat classification hierarchy, which has been largely consistent throughout the various versions, has twelve categories:

- Residential & Commercial Development
- Agriculture & Aquaculture
- Energy Production & Mining
- Transportation & Service Corridors
- Biological Resource Use
- Human Intrusions & Disturbance
- Natural System Modifications
- Invasive & Other Problematic Species, Genes, & Diseases
- Pollution
- Geologic Events
- Climate Change & Severe Weather
- Unknown Cause of Decline

Throughout this document, threats will refer to the associated codes used in *Supplementary Information 3*, e.g., Pollution (Threat 9.0), Agricultural & Forestry Effluents (Threat 9.3).

3.1.2 NORTHEASTERN THREAT DATA SOURCES

There are two primary sources of information for threat data to Northeast priority species. Development of the **Northeast SWAP Database, version 3.0** (TCI and NEFWDTC 2020a) occurred in conjunction with the 2017 SWAP Synthesis to store information from the 14 Northeast SWAPs within the data organization structure described in the original Lexicon (Crisfield and NEFWDTC 2013). This database was created in 2015 and supplemented with information from the 2018 RSGCN list and the 2020 Limiting Factors Report. The second source in the **Northeast RSGCN Database, version 1.0** (TCI and NEFWDTC 2023). This database compiled information from the SWAP Database, NatureServe, IUCN Redlist, state experts, scientific literature, and other sources to generate a preliminary understanding of Northeastern RSGCN to inform and store information from the 2023 RSGCN list update.

Threat information in both of these databases represents a snapshot of the current knowledge and may change in the future as new information becomes available. Information on threats for some of the species on the 2023 RSGCN list, especially invertebrates, is currently lacking. These threat summaries need to be reviewed for consistency and accuracy as a comprehensive review of all species accounts by taxonomic experts will continue as part of the RCN grant program and RSGCN update process. The Northeast SWAP Database reflects similar data deficiencies, especially for invertebrates. Many of the RSGCN and SGCN invertebrate species lacked associated threats in the 2015 SWAPS and therefore the 2017 SWAP Synthesis, though the 2020 Limiting Factors analysis added some additional information for invertebrate RSGCN.

For this Regional Conservation Synthesis, threats from both the Northeast SWAP Database and Northeast RSGCN Database are analyzed and ranked according to the number of species known to be impacted. This measure evaluates the relative importance of each threat in terms of its pervasiveness – how widespread the impacts of the threat are across all RSGCN.

3.1.3 COMPARISON OF THREATS TO RSGCN

Threats in the Northeast SWAP Database and the Northeast RSGCN Database were originally ranked using different criteria in the earlier SWAP Synthesis. To more directly compare the information in both datasets, threat information for the 2018 RSGCN list from the Northeast SWAP Database was ranked using the same methodology as the 2023 RSGCN list from the Northeast RSGCN Database. These results are displayed in Table 3.1 below.

The 2023 RSGCN list includes a combined total of 418 RSGCN and Proposed RSGCN species (see *Chapter 1* for descriptions of these categories). The 2018 list includes 358 RSGCN. The increased numbers in the 2023 list reflect a larger number of invertebrate taxonomic groups reviewed and the ability to include non-SGCN species as Proposed RSGCN in 2023. There is also a difference in data completeness for the two lists. The Northeast RSGCN Database contains at least some threat information for all 418 species, though invertebrate taxonomic groups are likely still data deficient. The Northeast SWAP Database contains threat information for only 169 RSGCN, and nearly 80% of the 149 data-deficient species are invertebrates. The inclusion of many more invertebrate taxonomic groups in the 2023 list combined with greater data coverage may also explain some of the threat differences between the 2018 and 2023 RSGCN lists.

Table 3.1 Number of Northeast species from the 2023 and 2018 RSGCN lists impacted by each Threat Category, based on Lamarre et al. (2021). The 2023 list includes both RSGCN and Proposed RSGCN (see Chapter 1 for more information on these categories). Total species is the total number of species on each RSGCN list. Species with threat information is the total number of species that have any threat information included in the appropriate database (Northeast RSGCN Database for 2023; Northeast SWAP Database for 2018). The top five threats for each RSGCN list are shaded in gray.

Threat Category	*Count of 2023 RSGCN & Proposed RSGCN*	*Count of 2018 RSGCN*
Pollution	338	132
Climate Change	305	116
Invasive & Problematic Species, Genes, & Diseases	228	96
Biological Resource Use	200	118
Natural System Modifications	198	116
Residential & Commercial Development	169	108
Transportation & Service Corridors	144	98
Energy Production & Mining	137	96
Human Intrusions & Disturbance	129	94
Agriculture & Aquaculture	118	75
Other	96	68
Geological Events	1	0
Total Species	*418*	*358*
Species with Threat Information	*418*	*169*

Comparing the two databases reveals remarkably high consistency (Table 3.1). Four of the top five threats are the same across the two groups, despite variance in the species reviewed. Pollution (Threat 9.0) is the top threat for both the 2023 and 2018 RSGCN lists. Climate Change (Threat 11.0) ranked second in 2023 but tied for third in 2018. Invasive & Problematic Species, Genes& Disease (Threat 8.0) ranked third in 2023 but was not one of the top five threats for 2018. Biological Resource Use (Threat 5.0) was ranked fourth in 2023 and second in 2018. Natural System Modifications (Threat 7.0) was the fifth-ranked threat in 2023 and tied for third in 2018. Residential & Commercial Development (Threat 1.0) ranked sixth in 2023 and fifth in 2018.

Residential & Commercial Development ranks for both the 2018 and 2023 RSGCN list is somewhat surprising, considering that development ranked highly in 2007 as well as in most global threat prioritizations (e.g., Wilson 1989, Yiming and Wilcove 2005, Maxwell et al. 2016, Tilman et al. 2017, Bellard et al. 2022). The high degree of development and alteration already present in the Northeast landscape may mute the impacts of development on many species. These species may respond negatively to development, but these impacts are harder to observe because unaltered habitat is generally unavailable for comparison, making it difficult to isolate the impacts of development from other threats.

3.2 THE GREATEST THREATS TO NORTHEAST RSGCN

Despite variations in ranks between the 2023 and 2018 datasets, almost the same set of threats are identified as being high priorities in the Northeast region. This highlights that these threats are widespread across the region and within different taxonomic groups and their habitats. The rest of this chapter will highlight key information about the threat categories that are impacting the greatest number of 2018 and 2023 RSGCN species. This includes the top five threats for the 2023 RSGCN list, plus Residential & Commercial Development as this threat ranked highly in other regional and global analyses. The top threats to Northeast Regional Species of Greatest Conservation Need are:

- Pollution
- Climate Change
- Invasive & Problematic Species, Genes, & Diseases
- Natural System Modifications
- Biological Resource Use
- Residential & Commercial Development

Each of the following sections will provide a general overview of how each threat impacts Northeast RSGCN. It then will break each threat down following the secondary and tertiary levels of the Quebec Threat Classification system, as amended by TCI for the Northeast states, and describe in more detail the various ways each threat can impact priority species, with examples specific to RSGCN. As threats cannot be addressed in isolation, each section also identifies ways that threats are interconnected, providing the context necessary for planning conservation actions. The sections also include descriptions of useful tools and resources for learning more about each threat.

These descriptions are not a complete review of each of these topics. Every species responds differently to each threat in this list, adding significant complexity to the analysis. Additionally, species responses can vary depending on the sex, life stage, or behavior of an individual. Habitat type, condition, and other external factors may also exacerbate species responses. It is not feasible to cover these intricacies for all of the RSGCN and Proposed RSGCN in the 2023 list within this document. Instead, the focus is on highlighting the relative importance and relevance of each threat to Northeast

RSGCN and their habitats, with an emphasis on recent and emerging information. This information will provide a starting point but should be supplemented with more data specific to the species, habitats, and conditions being managed.

3.2.1 POLLUTION

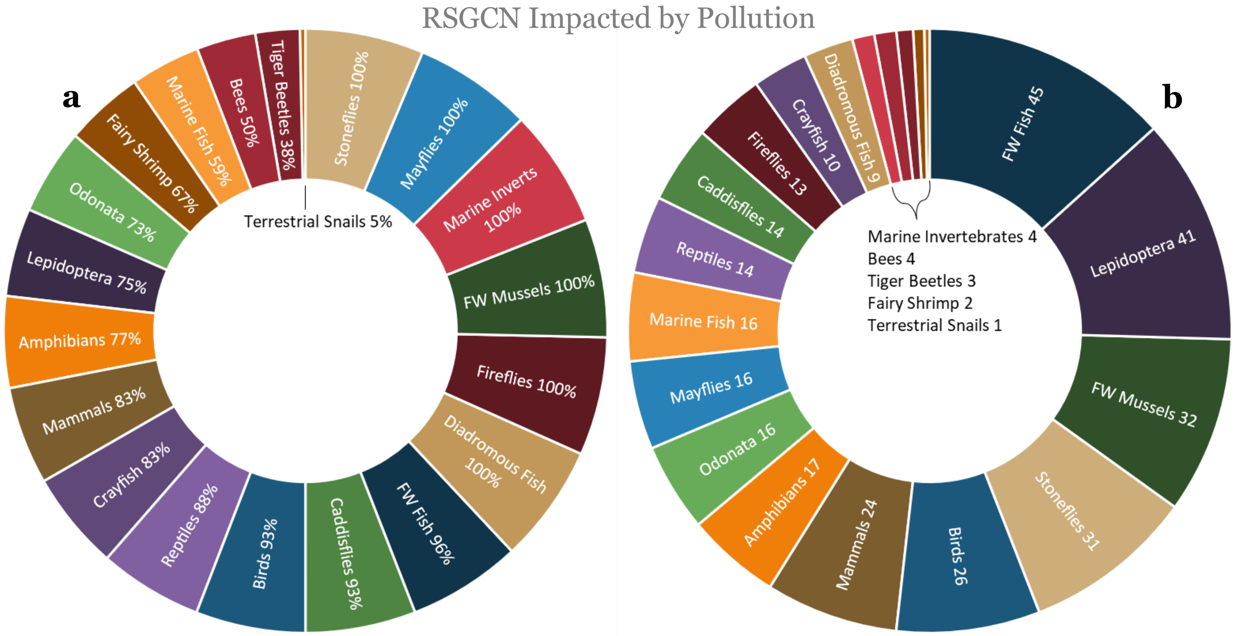

Figure 3.2. Impact of Pollution (Threat 9.0) on RSGCN and Proposed RSGCN. (a) The percentages show the proportion of the species within that taxonomic group known to be impacted by this threat. (b) The total number of species within the taxonomic group known to be impacted by this threat.

Pollution is by far the most common regional threat, impacting 81% (338 species) of the RSGCN and Proposed RSGCN on the 2023 list. Many of the taxonomic groups that are most heavily impacted are aquatic; pollution imperils the entire diversity of the stonefly, mayfly, marine invertebrate, freshwater mussel, firefly, and diadromous fish taxonomic groups (Figure 3.2a). Though pollution does not impact all freshwater fish or lepidopterans, these two groups contribute the largest number of species impacted (Figure 3.2b). For most of the remaining taxonomic groups, the proportion of impacted species is above 50%. The only groups where the proportion is less than 50% are tiger beetles and terrestrial snails. These low numbers are likely the result of data deficiency, rather than indicating that pollution does not impact these groups. Additional research is required to determine if pollution is a concern.

Pollutants come from point and nonpoint-sources. Point-source pollutants can be traced back to a single identifiable discharge point, such as a pipe, ditch, ship, or smokestack. Nonpoint-source pollutants cannot be traced to a single specific source, as point-source pollutants can. Instead, these pollutants come from many sources throughout the landscape. For example, as water moves overland or through the ground, it collects many different pollutants from many different places and brings them all together in more concentrated areas, such as rivers and streams.

Another important aspect of many pollutants is that they can bioaccumulate. Bioaccumulation is the gradual buildup of chemical substances, such as pesticides, in an organism. The body is unable to rid itself of these compounds, so concentrations increase over time, even if the amount of the compound in the environment is very low. As the concentration of the compound in the body increases, individuals may suffer from a wide variety of symptoms, including death, depending on the chemical. Bioaccumulation has important impacts on food webs, as the compounds continue to aggregate in higher tropic levels as predators consume contaminated individuals, a process known as biomagnification.

Many aquatic RSGCN are highly sensitive to pollution: their presence or absence makes them indicators of water quality. Eastern Hellbenders (*Cryptobranchus a. alleganiensis*), mayflies, stoneflies, caddisflies, and mussels thrive in pristine water conditions. Pollution acutely impacts aquatic species because these contaminants are ubiquitous within the habitat. Pollutants are found in the water column, sediments, and potential food sources. By contrast, contaminant distribution is less homogenous in terrestrial systems; combined with the ability of terrestrial species to move away from pollutants, contaminant exposure is a function of concentration and repeated exposure (Smith et al. 2007). In both aquatic and terrestrial systems, exposure from the environment occurs via ingestion, absorption through the skin, accumulation on gills or filters, inhalation, or a combination of multiple pathways (Honda and Suzuki 2020, Smith et al. 2007). Some pollutants, including heavy metals, polychlorinated biphenyls (PCBs), pharmaceutical compounds, and certain pesticides, persist for long periods in the environment, resulting in long-term contamination of the environment and bioaccumulation of these pollutants throughout the ecosystem (McKinney et al. 2015, Ali et al. 2019, Honda and Suzuki 2020).

AGRICULTURAL & FORESTRY EFFLUENTS

Contaminants and effluents from forestry and agricultural activities are known to impact more RSGCN species than any of the other pollutant categories. Though these chemicals can have impacts on species utilizing areas at or near the point of application, the greater impact is their role as nonpoint-source pollutants.

Runoff is the primary culprit in the transport of agricultural and forestry effluents. Rain runs overland and can move faster and gather more pollutants in areas that have lost vegetative cover, as is often the case after agricultural and forestry activities. Additionally, since these pollutants travel downstream, they can still have impacts thousands of miles away from where they entered the water, greatly increasing the area of effect.

The Clean Water Act was implemented as the Federal Water Pollution Control Act in 1948 and expanded in 1972 and regulates pollutant discharges in the waters of the United States. These regulations have increased waterbodies safe for fishing by about 12%, though concentrations in many rivers and streams still exceed water quality standards (Keiser and Shapiro 2019). A major criticism of the Clean Water Act is that it does not have the authority to regulate nonpoint-source pollution, making compliance largely voluntary. This largely reduces the efficacy of this act for managing Agricultural & Forestry Effluents, leading many natural resource agencies to alternative ways of interacting with landowners to achieve pollutant reduction (Ribaudo 2015).

THREAT DESCRIPTIONS AND EXAMPLES

Herbicides and pesticides (Threat 9.3.3) can be highly toxic to non-target species, especially pollinators. Spraying for Spongy Moth (*Lymantria dispar*), a common nonnative forest pest, impacts many of the RSGCN lepidopterans. Neonicotinoid pesticides are known to impact honey bees, but the impacts on wild bee species are largely unknown (Lundin et al. 2015). There are indirect effects on other taxa as well; the loss of insect biomass due to the widespread application of various pesticides imperils insectivorous birds, such as the Eastern Whip-poor-will (*Antrostomus vociferus*). For species dependent on high water quality, including many freshwater mussels and aquatic insects, nonpoint-source pollution may be the most significant threat.

Excessive nutrient inputs (Threat 9.3.1), generally from the application of fertilizers, are primarily a concern for aquatic habitats and species. They can affect stream water chemistry and influence vegetative growth. This growth often benefits invasive species in aquatic habitats and wetlands. High nutrient loads can also lead to algal blooms in larger bodies of water, which can deoxygenate the water, block sunlight, and produce detrimental toxic chemicals, all of which negatively impact many different aquatic species.

Soil erosion and sedimentation (Threat 9.3.2) is a threat that critically impacts aquatic systems. Large sediment loads can settle on the bottom of a water body, smothering some RSGCN directly, such as freshwater mussels, and indirectly impacting other RSGCN by burying important resources. Species will need to seek resources, such as plant and benthic invertebrates, elsewhere if they become buried. Sediments can also alter important structures. Excessive silt and bury spawning shoals and gravel beds for various fish species, smothering eggs and nests. Silt also fills crevices under rocks and other features, leaving species like the Big Stone Crayfish (*Cambarus magerae*) without shelter and protection from predators.

All three forms of agricultural and forestry effluents can influence a species. Atlantic and Shortnose Sturgeon (*Acipenser oxyrinchus* and *A. brevirostrum*, respectively) are vulnerable to nonpoint-source pollution, have the potential to bioaccumulate toxins due to their long lifespan, have some evidence linking reproductive or developmental disorders to chemical pollutants, and require silt-free locations for spawning (Billard and Lecointre 2001).

RELATIONSHIPS WITH OTHER THREATS

Intensive or incompatible agricultural practices without the use of best management practices may have degraded or reduced suitable habitats. Conversion to Annual & Perennial Non-Timber Crops (Threat 2.1), Wood & Pulp Plantations (Threat 2.2), or Livestock Farming & Ranching (Threat 1.3), and Logging & Wood Harvesting (Threat 5.3) leads to the loss of forest cover, grassland habitat, and riparian buffers. These practices also increase runoff from the surrounding areas by removing vegetation, which in turn can increase chemical, nutrient, and sediment inputs. Additionally, Natural System Modifications (Threat 7.0) to the vegetation directly adjacent to water bodies can change water temperature, light levels, and flood patterns.

Climate Change (Threat 11.0) will also exacerbate the impacts of Agricultural & Forestry Effluents on RSGCN. Several taxa were identified as being highly vulnerable and at increased risk from the interactive effects of pollution and climate change, including freshwater mussels and other mollusks, fishes, amphibians, and birds (Pinkney et al. 2015). Climate change is projected to lead to increased frequency and severity of storms. These events intensify the transport of chemicals, nutrients, and sediments into water bodies, enhancing the potential for contamination and eutrophication (Bates et al. 2008; Pinkney et al. 2015). Increasing temperatures due to climate change may alter sensitivity and susceptibility to certain pollutants (Noyes & Lema 2015), increase the risk of hypoxia due to eutrophication and associated algal blooms (Pinkney et al. 2015, Griffith and Gobler 2020), or otherwise alter metabolic processes in ways that alter vulnerability to pollutants (Ficke et al. 2007, Saaristo et al. 2018).

TOOLS AND RESOURCES

The US Geological Service is a repository and resource for many pollution datasets and tools. The **National Water Quality Program** and associated **National Water Quality Assessment Project**[1] track trends and changes in surface water, groundwater, and aquatic habitats. Specific resources relevant to Agricultural & Forestry Effluents include their informational pages on agricultural contaminants[2], nutrients and eutrophication[3], and pesticides and water quality[4]. These pages provide links to additional information, research, and data products related to each topic. Several tools and datasets are particularly relevant. The **Regional Stream Quality Assessment**[5] characterizes water quality factors that are stressors to aquatic life, including contaminants, nutrients, and sediment, to better understand the influence of the stressors in five regions across the United States, including much of the Northeast. These data can be downloaded or explored in their online mapping tool. The **Spatially Referenced Regression On Watershed (SPARROW) attributes**[6] model and its associated products and tools can be used to estimate transport rates of nutrients, sediments, and dissolved solids from inland watersheds to larger water bodies.

The EPA also provides a robust suite of tools and resources related to pollution. The EPA's **National Pollutant Discharge Elimination System**[7] regulates point-source discharge, including forest roads, nutrients, and pesticides. Their resource page includes information about these sources of wastewater and their management.

The EPA **Report on the Environment**[8] tracks more than 80 indicators of human health and ecological condition that show trends in the conditions of the nation's land, water, and air (US EPA 2022). Useful indicators include agricultural fertilizer application rates, nitrate and pesticides in groundwater, nitrogen and phosphorous in streams and rivers, and pesticides in streams. The EPA also has produced other datasets, such as the interactive maps of the **303d Listed and Impaired Waters for the USA**, which identifies waterbodies considered impaired based on pollutant levels exceeding Clean Water Act specifications (US EPA 2015).

Best management practices to protect water quality in adjacent aquatic habitats from agricultural and forestry activities are available from the EPA[9], the US Forest Service[10], and the National Association of State Foresters[11].

DOMESTIC & URBAN WASTEWATER

Similar to Agricultural & Forestry Effluents, Domestic & Urban Waste Water disproportionately impacts aquatic species. These wastewater sources can be point or nonpoint. Due to the wide variety of activities that occur within residential and urban environments, the contaminants are also highly varied. Wastewater is generally collected and treated, but under certain conditions untreated wastewater may be released into water bodies, becoming a point-source pollutant. Once again, nonpoint-source pollution in residential and urban areas carries significant contaminants.

The Clean Water Act was implemented as the Federal Water Pollution Control Act in 1948 and expanded in 1972 and regulates pollutant discharges in the waters of the United States. These regulations have increased waterbodies safe for fishing by about 12%, though concentrations in many rivers and streams still exceed water quality standards (Keiser and Shapiro 2019).

THREAT DESCRIPTIONS AND EXAMPLES

Runoff (Threat 9.1.2) can carry any number of contaminants in it, including those coming from buildings, grassy areas, parking lots, and roadways. Buildings are not a major source of runoff contamination but may have localized inputs such as heavy metals used in paints or construction materials. Grassy areas such as lawns, parks, and golf courses contribute sediments, fertilizers, and pesticides with similar effects to those described above for agricultural effluents. Byproducts from automobiles, such as gasoline residues, break and tire wear, and motor oils, are easily washed from impervious surfaces (Tian et al. 2022). Other chemicals used on roadways, such as salt and sand applied in icy conditions, can be highly detrimental as well (Hintz et al. 2022). In general, runoff negatively impacts water quality in aquatic habitats near developed areas and roadways, impacting any RSGCN with a low tolerance for contamination.

Domestic wastewater (Threat 9.1.1) can add significant nutrient loads to water bodies, especially if untreated sewage is released. The impacts of these releases can be similar to those of excessive nutrient loads described under Agricultural & Forestry Effluents. However, there is also increasing evidence that the presence of various pharmaceuticals in wastewater can be severely disruptive to many species (Holeton et al. 2011, Galib et al. 2018, Petrie 2021).

RELATIONSHIPS WITH OTHER THREATS

Domestic & Urban Wastewater is coincident with Residential & Commercial Development (Threat 1.0) and Transportation & Service Corridors (Threat 4.0), so overlap between these categories is likely. In addition, some of the impacts of Climate Change (Threat 11.0), especially the increased frequency and intensity of storms and precipitation, will further exacerbate the impacts of Domestic & Urban Waste Water. Increased rain frequency means increased overland runoff, resulting in additional transport of pollutants into water bodies (Bates et al. 2008, Pinkney et al. 2018). The combination of increased precipitation frequency, volume, and intensity may overwhelm existing wastewater treatment facilities, potentially resulting in more frequent wastewater releases (Petrie 2021).

TOOLS AND RESOURCES

The USGS is a repository and resource for many pollution datasets and tools. **The National Water Quality Program** and associated **National Water Quality Assessment Project**[12] track trends and changes in surface water, groundwater, and aquatic habitats. Specific resources related to Domestic & Urban Wastewater include resource pages on runoff[13], urban land use and water quality[14], and asphalt sealcoat chemicals[15]. These pages provide links to additional information, research, and data products related to each topic.

The EPA's **National Pollutant Discharge Elimination System**[16] regulates point-source discharge, including municipal and industrial wastewater and stormwater. Their resource page includes information about these sources of wastewater and their management. They also have a **National Menu of BMPs for Stormwater**[17] management to address potential impacts on aquatic habitats from pollution.

The **Waterkeeper Alliance**[18] is a global network of more than 300 local groups dedicated to protecting clean water. The organization monitors water quality, identifies and litigates sources of pollution, advocates for local clean water protections, and conducts education and outreach.

INDUSTRIAL & MILITARY EFFLUENTS

Industrial and Military Effluents impact fewer species than the pollutants discussed above, but their effects are often more acute. These contaminants are generally point-source pollutants. Single pollution events can take an extremely long time to recover from if recovery occurs at all. Because point sources are more easily identifiable and smaller scale, they are theoretically easier to treat and mitigate. Though their impacts may be more limited in scope, these pollutants are highly toxic, persistent, and bioaccumulate and biomagnify. Thus, their influence is severe and long-lasting. Moreover, mitigation is a time-consuming and expensive process. Wind and water currents can disperse chemicals, making them more difficult or impossible to collect efficiently. Additionally, the collected chemicals and contaminated materials must be properly disposed of, or the effects of the pollutant will just be moved to a different location (Kuppusamy et al. 2016).

The Clean Water Act was implemented as the Federal Water Pollution Control Act in 1948 and expanded in 1972 and regulates pollutant discharges in the waters of the United States. These regulations have increased waterbodies safe for fishing by about 12%, though concentrations in many rivers and streams still exceed water quality standards (Keiser and Shapiro 2019).

THREAT DESCRIPTIONS

Oil spills (Threat 9.2.1) are better studied in marine ecosystems and may have wider impacts, but they can also occur in terrestrial or freshwater systems. Because oil spills can happen in any environment, they can impact any species, although they are more commonly thought of as a threat to marine species such as sea turtles, marine mammals, and seabirds. Spills happen during the extraction or transportation of oil, with impacts that vary based on the ecosystem they occur in (Kingston 2002, Baca et al. 2005, Ober 2010). Similar to other pollutants, oil particles have deleterious internal effects on individuals who ingest, inhale, or otherwise absorb them from the ecosystem and can cause mass die-offs of plants, fish, amphibians, birds, mammals, reptiles, and other taxa (Sanders et al. 1980, Piatt et al. 1990, Silliman et al. 2012, Wallace et al. 2017). Oil particles are also harmful externally; they can coat the skin of many species, including turtles, marine and terrestrial mammals, and birds. These oils irritate the skin and interfere with the insulative properties of fur and feathers (Ober 2010). Attempts to preen or otherwise clean the oil off can result in ingestion of the particles. Oil particles collect on filtering structures, such as fish gills, whale baleen, and shellfish ctenidia, clogging these structures and preventing their function, and can coat plant and other food resources, forcing RSGCN to forage for longer times or across longer distances (Ober 2020). Long-term impacts of oil spills are also possible, especially in coastal systems where the residues enter the substrate (Kingston 2002). Oil spills impact RSGCN from many different taxonomic groups, but marine mammals, invertebrates, and turtles were particularly prevalent.

Acid mine drainage (Threat 9.2.2) is a byproduct of many types of mining, though in the Northeast it is primarily associated with coal mining. Mining operations expose various sulfur-containing minerals to surface conditions, where they oxidize and convert into sulfuric acid. These acids, along with associated heavy metals and mining sediments, drain into local ground and surface waters, impacting water quality and pH (Gray 1997, Ray and Dey 2020, Burns 2022). West Virginia may face the greatest threat in the Northeast, with nearly 30,000 miles of streams impacted by coal mining operations. Virginia, the next most impacted state in the region, has 8,000 miles of impacted streams (Burns 2022). Mine drainage is a major concern for several amphibians, mussels, freshwater fish, and crayfish, especially when considering the large number of narrow-range endemics in these two states.

Heavy metals such as **mercury** (Threat 9.2.5) and **lead** (Threat 9.2.6) are highly toxic, persist for long times in the environment, and bioaccumulate throughout the ecosystem (Ali et al. 2019). Bioaccumulation disproportionately impacts higher-level predators due to these characteristics, though they can have severe impacts across many taxa. Mercury can come from several industrial sources, including mine tailings and industrial effluents, and can cause damage to the nervous, excretory, and reproductive systems (Wolfe et al. 1998). Mercury is a particular concern in many piscivores, including predatory fish, birds, and humans, as the longer aquatic food chains allow for more magnification than is present in most terrestrial chains (Chan et al. 2003, Eagles-Smith et al. 2016, Jackson et al. 2016). Two historic but significant sources of industrial lead were the use of lead-based paints and leaded gasoline. The impacts of these sources of lead may be greatest on wildlife living in more urbanized areas where concentrations of lead in the soil are highest (Roux and Marra 2007).

Flame retardants (Threat 9.2.3) are a rapidly growing concern for many wildlife species, though their impacts on Northeast RSGCN and Proposed RSGCN are not yet established. Brominated flame retardants (BFRs) are ubiquitous and include more than 75 different compounds, making it more difficult to identify the impacts on wildlife (Smythe et al. 2022). BFRs are used to reduce the flammability of many products, including textiles, plastics, building materials, and electronics; this widespread use has resulted in their dispersal throughout the environment (Zacs et al. 2018). These chemicals are toxic, persistent, and bioaccumulative, magnifying their impacts throughout ecosystems (Segev et al. 2009, Klosterhaus et al. 2012). They act as endocrine disruptors, carcinogens, and neurotoxins, which has major impacts on human and wildlife health (Segev et al. 2009). In recent decades, several of these compounds have been regulated, which is reducing the output of some of these chemicals, but also contributing to the creation of new ones with unknown impacts (Smythe 2022). Despite significant amounts of research in many different taxonomic groups, significant data gaps exist, including unknown impacts many of the BFRs, a growing body of new compounds, and unclear metabolic pathways (Smythe et al. 2022).

Another group of persistent, bioaccumulative compounds includes polychlorinated biphenys, or **PCBs** (Threat 9.2.4). PCBs share many characteristics with BFRs, acting as endocrine disruptors, immunosuppressants, carcinogens, and neurotoxins, influencing behavior and reproduction (Boyles and Nielsen 2017). Production of PCBs was banned in the United States in 1979 due to concerns about toxicity and chemical stability (Hens and Hens 2018). Several Superfund sites in the Northeast are contaminated by PCBs (Hens and Hens 2018). Even decades after the PCB bans, concentrations remain high in many species, including cetaceans (Jepson et al. 2016), Bobcat (Lynx rufus; Boyles and Nielsen 2017), North American River Otter (*Lontra canadensis*; Carpenter et al. 2014) and freshwater turtles (Adams et al. 2016).

Several **other industrial discharges** (Threat 9.2.7) are also of concern to species on the RSGCN list. Perfluoroalkyl and polyfluoroalkyl substances (PFAS) are a common component in fire suppression foam and other substances used to make products flame, water, oil, or stain resistant. For a review of the impacts of this group of chemicals on wildlife, see Bangma et al. (2022). Similar to BFRs, new PFAS chemicals are being produced, and research is not able to keep pace with these changes. PFASs have been widely produced since the 1950s, but by the early 2000s evidence of the harmful effects of these products on human and wildlife health was becoming more common (Vendl et al. 2021). By 2010, production of many of these chemicals had drastically slowed or stopped as a result of global agreements (Vendl et al. 2021). Consumption of freshwater fish is likely a significant source of the PFAS compound PFOS in much of the United States (Barbo et al. 2023). Pharmaceuticals are another growing concern. Increasing human consumption of these chemicals is resulting in increased pharmaceutical residues in the environment and wildlife (Arnold et al. 2014, Bean et al. 2023). Many of these chemicals enter the environment through wastewater, as sewage is generally not treated for these compounds (Arnold et al. 2014). These compounds may alter activity levels, reproductive success, body condition, stress levels, behavior, and other characteristics in exposed individuals (Arnold et al. 2014). For a review on the effects of different pharmaceuticals on wildlife, see Bean et al. 2023).

RELATIONSHIPS WITH OTHER THREATS

The presence of industrial contaminants is closely tied to the locations where they are produced and used. These forms of pollution often occur in conjunction with Energy Production & Mining (Threat 3.0), Transportation & Service Corridors (Threat 4.0), and Residential & Commercial Development (Threat 1.0). Climate Change (Threat 11.0) may have less of an amplifying effect on this category since these forms of pollution tend to be isolated and episodic, rather than events impacted by changing temperature, precipitation, or weather patterns. Severe weather events may increase the risk of flooding in industrial sites, resulting in an increased risk of spills or other pollution events. In addition, research is just starting to explore how climate change may increase species' sensitivity to various industrial pollutants (McKinney et al. 2015, Pinkney et al. 2015).

TOOLS AND RESOURCES

The USGS is a repository and resource for many pollution datasets and tools. The **National Water Quality Program** and associated **National Water Quality Assessment Project**[1] track trends and changes in surface water, groundwater, and aquatic habitats. Specific resources relevant to Industrial & Military Effluents include their resource pages on sediment-associated contaminants[19], mercury[20], industrial chemicals[21], and emerging contaminants[22].

The EPA administers the **Comprehensive Environmental Response, Compensation, And Liability Act**, informally called Superfund. These are contaminated areas that exist due to improper management of many industrial pollutants. Their Superfund[23] resource page has many resources related to reporting, managing, and remediating superfund sites. They also have datasets and interactive map products for exploring sites in your state, national priority sites, and cleanup operations[24].

NOAA provides scientific expertise, data, tools, training, and assistance related to oil and chemical spill responses in coastal and marine environments. Their **Office of Response and Restoration**[25] focuses on research and tools for ongoing spill events, while the **Damage Assessment, Remediation, and Restoration Program**[26] focuses on cleanup and restoration activities after the initial pollutant containment occurs.

EXCESS ENERGY

Unlike the other pollutants previously discussed in this section, excess energy is not the presence of a chemical or compound that causes direct harm to a species. Instead, byproducts of human presence and activity alter the sensory landscape of an ecosystem, which changes the behavior of species in that environment. Each of these forms of pollution can be an attractant or a deterrent; for some species, it may be both depending on other conditions such as time of year, life stage, or activity type.

THREAT DESCRIPTIONS AND EXAMPLES

Light pollution (Threat 9.6.1) is one of the most common forms of excess energy in the Northeast. Beachfront lighting has long been known to disorient sea turtle hatchlings, but more recent work has also highlighted that excessive light can discourage nesting females and increase hatchling risk of predation (Verutes et al. 2014, Brei et al. 2016, Silva et al. 2017). Excessive nighttime lighting has similar disconcerting effects on migrating birds and can disrupt their circadian rhythms (Cabrera-Cruz et al. 2018). Seasonal "Lights Out" initiatives for both sea turtles and migratory birds are widespread in the United States, but further evaluation of their efficacy may be necessary (Kamrowski et al. 2015, van Doren et al. 2021). Bats, including members of the genus *Myotis*, show mixed responses. They may avoid traveling through areas with artificial lighting and opportunistically forage around light fixtures that are attracting night-flying insects; increased light levels may lead bats to abandon roosting sites and can disrupt circadian rhythms and alter nightly emergence timing (Stone et al. 2015). Some research has indicated that light reduction measures in urban environments can improve conditions for some bat species (Laforge et al. 2019). Nocturnal insects and other invertebrates are also heavily impacted by light pollution (Gaston et al. 2013). Owens and Lewis (2018) and Owens et al. (2020) summarize the many different ways insects respond to artificial lighting. Fireflies are of particular interest as all RSGCN and Proposed RSGCN firefly species are considered threatened by light pollution. Lighting may impact this taxonomic group more than other nocturnal insects because it interferes with their bioluminescent communication signals (Firebaugh and Haynes 2016, Owens and Lewis 2018).

Thermal pollution (Threat 9.6.2) is any deviation from the natural temperature in the ecosystem and is generally a byproduct of certain industrial facilities, such as desalination and power plants. Most commonly, it refers to discharges from cooling systems where the heated water is dumped into a nearby lake, river, or ocean. Other forms of thermal pollution include heat-island effects in urban areas and discharges of cold water from reservoirs into warmer streams. Most aquatic species operate within a limited range of thermal tolerances, which influence many of their biological, chemical, and physiological responses to the environment (Verones et al. 2010). Though these responses are particularly well studied in fish (Beitinger et al. 2000), mussels (Ganser et al. 2015), crayfish (White 1983), and aquatic insects (Herrera et al. 2018, Orr and Buchwalter 2020) are also sensitive the thermal changes. Sudden temperature changes, such as those caused by the discharge of heated water from power plants or cold water from dams, can cause shock in many of these organisms, leading to widespread die-offs (Allman 1998, Clarkson and Childs 2000, Archambault et al. 2014, Buhariwalla et al. 2016). In some unusual cases, species may become dependent on sources of thermal pollution and be negatively impacted if the source of the thermal pollutant is disrupted. Buhariwalla et al. (2016) attributed a temporary maintenance shutdown of a power plant as a contributing factor to Striped Bass (*Morone saxatilis*) mortality in Nova Scotia. The associated pause in warm-water discharge during a cold snap resulted in cold shock, especially among younger year classes. Gradual temperature changes can have more widespread impacts. Warmer water is less oxygenated, which can be a significant physiological stressor. Temperature increases can still be observed hundreds to thousands of miles downstream of the original input, alter mixing and nutrient cycles in lacustrine environments, and reduce ice cover in winter, all of which can result in cascading effects throughout aquatic food webs (Vinna et al. 2017). Since temperatures dissipate more quickly in the air than in water, thermal pollution has less of an impact on terrestrial wildlife. The main exception to this is heat island effects, where high concentrations of buildings and roads re-emit heat from the sun, causing urban and developed areas to be warmer than nearby areas.

Excess noise (Threat 9.6.3) can refer to an increased frequency of high-intensity sound events, such as explosions, or more generalized increases in background noise levels. Species responses to noise pollution vary depending on whether the noise is chronic or intermittent, and can lead to direct or indirect fitness costs (Francis and Barber 2013). Research on the impacts of noise has occurred for just about every taxonomic group, though is disproportionately focused on birds and marine mammals (Shannon et al. 2016). It is also pervasive; Buxton et al. (2017) found that anthropogenic noise doubles background noise levels in more than half of the protected areas in the United States, including more than 10% of designated Wilderness Areas. These effects may be elevated in freshwater and marine environments, as water transmits sound much faster than air. Noise pollution can lead to avoidance of areas with elevated sound levels, alter behaviors in these areas, increase the risk of predation, and interfere with wildlife communication (Shannon et al. 2016, Duquette et al. 2021). Elevated noise levels make vocalizations harder to hear, especially at greater distances, which could heavily impact strongly vocal species such as birds, frogs, and whales. Some terrestrial species, especially birds, respond to increased background level noise by shifting their calls to higher frequencies, but these behavioral adaptations may not be sufficient to overcome the negative impacts of noise (Duquette et al. 2021). For species that echolocate, such as bats and cetaceans, noise pollution interferes with foraging success and can result in increased physiological stress (Holt et al. 2015, Domer et al. 2021). In the Northeast, various Taxa Teams raised concerns about the impacts of certain noise sources on specific RSGCN groups, especially offshore wind installations and marine shipping on marine mammals, sea turtles, seabirds, and diadromous fish. Potential mitigation strategies for various forms of noise pollution have long been a data deficiency, though increasing research is attempting to address the topic (Alquezar and Macedo 2019, Domer et al. 2021, Ditmer et al. 2021, Teff-Secker et al. 2022).

RELATIONSHIPS WITH OTHER THREATS

All three forms of excess energy are intertwined with human activity. Light pollution is closely associated with Residential & Commercial Development (Threat 1.0). Thermal pollution is sometimes a result of development but is more frequently associated with Energy Production & Mining (Threat 3.0) and Natural System Modifications (Threat 7.0). Noise pollution is associated with nearly every form of human activity, including development, energy production, and Transportation & Service Corridors (Threat 4.0). Excess energy, especially light and noise, is intensifying globally, highlighting the need for better management and mitigation of these forms of pollution (Ditmer et al. 2021). The effects of thermal pollution may also be amplified by Climate Change (Threat 11.0), which in turn may exacerbate threats from Invasive Non-native/Alien Plants & Animals (Threat 8.1) by making otherwise inhospitable conditions conducive to invasion (Strubbe and Matthysen 2009, Wolf et al. 2014).

TOOLS AND RESOURCES

Numerous maps of nighttime light pollution levels are accessible online, from a wide variety of data sources. These maps are often developed using remotely sensed data. However, the International Dark-Sky Association is engaging citizen scientists through their **Globe at Night** initiative to track light pollution levels globally (NOIRLab 2023). A recent analysis of this dataset from 2011-2022 has revealed that sky brightness is increasing by 7-10% per year (Kyba et al. 2023). Though the focus of this paper was on implications for astronomy, these light increases will impact nocturnal wildlife as well.

The Bureau of Transportation Statistics recently released a **National Transportation Noise Map** that shows the concentration and relative sound levels of aviation, railway, and highway noise in the continental United States (US DOT BTS 2020). These data could inform background noise level models for local analysis, though responses to episodic sound events (e.g., an airplane taking off) may not be captured. Resources for noise pollution in marine environments are less readily available. Farcas et al. (2020) **validated shipping noise models** in the northeast Atlantic, which may have implications for mapping marine noise in the Northeast region. In addition, a collaboration between researchers at three universities, Meridian, and FishBase has resulted in **FishSounds**, an online database that compiles global information on the effects of sound production on all extant fish species (Looby et al. 2022).

Fewer resources exist for tracking thermal pollution, in part because it is often associated with specific locations and facilities. However, some innovative uses of **remotely sensed thermal imagery** could have applications for tracking thermal pollution in the Northeast (Ling et al. 2017).

AIR-BORNE POLLUTANTS

Atmospheric pollutants can be from point and nonpoint-sources. Often, it is difficult to determine the source of many atmospheric pollutants, making it more difficult to manage them. Airborne pollutants have decreased dramatically in the United States with the introduction of the Clean Air Act in 1970 and its amendments in 1990 (Butler et al. 2001, Murdoch and Shanley 2006, McHale et al. 2021). However, these historic inputs have had long-lasting effects across many habitats and taxonomic groups.

THREAT DESCRIPTIONS AND EXAMPLES

Acid rain (Threat 9.5.1) in particular has altered ecosystems across the Northeast. Acid rain forms when sulfuric and nitric oxides are released into the air by fossil fuel-burning power plants, vehicle emissions, or other industrial plants. These chemicals then react with oxygen and water to form sulfuric and nitric acids before falling back to the ground, where they can drastically alter soil and water chemistry. Amphibians are extremely sensitive to these changes; decreased pH levels impact the success and survival of eggs, larvae, and adults (Pierce 1993). Acidification also impacts the availability of key nutrients such as calcium, which is critically important for shell-forming species such as mollusks and birds. Several authors have investigated the relationship between calcium, terrestrial snails, and birds, highlighting how acid rain can have reverberating effects throughout the food web (Graveland 1996, Hotepp 2002, Mänd et al. 2000). The Central Appalachian Mountains, a hotspot of salamander, mussel, and terrestrial snail diversity received some of the highest rates of acid deposition in the United States (Thomas et al. 2013). The high level of endemism may have exacerbated the impacts of acid rain in this region. The Terrestrial Snail Taxa Team suggested that the historic declines of several species, including the Cherrystone Drop (*Hendersonia occulta*), may have been a direct result of acid rain and should be investigated. Recovery from the impacts of acid rain has been observed in some taxa in the Northeast, including plants (Thomas et al. 2013) and fish (Warren et al. 2017), and other taxa in other regions (Dolmen et al. 2018), but impacts are likely ongoing in both terrestrial and aquatic systems (Jeffries et al. 2003, Lawrence et al. 2020).

Other airborne pollutants, including **smog** (Threat 9.5.2), **ozone** (Threat 9.5.3), and **dust and ashes** (Threat 9.5.4), can impact wildlife species but are not generally considered a major concern for RSGCN in the Northeast. Smog and dust tend to be associated with specific sources, such as a city or forest fire, so their impacts may be more localized.

RELATIONSHIPS WITH OTHER THREATS

Airborne pollution may be intensified by increased Residential & Commercial Development (Threat 1.0), Energy Production & Mining (Threat 3.0), and Transportation & Service Corridors (Threat 4.0). In addition, Climate Change (Threat 11.0) may amplify the effects of these pollutants by increasing the overall stress levels of individuals within impacted environments (Warren et al. 2017). Changing precipitation and weather patterns may also change deposition patterns and rates of airborne pollutants.

TOOLS AND RESOURCES

The **National Atmospheric Deposition Program**[27] has been tracking airborne pollutants in precipitation since 1978. Early programs focused on acid deposition and key nutrients, but additional programs tracking ammonia and mercury have been added over time. More than 50 active monitoring sites are found across the Northeast region, producing extensive data products and maps tracking changes over time.

The **USGS has useful reference pages** on topics including acid rain[28] and volatile organic compounds[29].

The EPA **Report on the Environment**[1] tracks more than 80 indicators of human health and ecological condition that show trends in the conditions of the nation's land, water, and air (US EPA 2022). Useful indicators include acid deposition, air toxins, ozone-depleting substances, sulfur and nitrogen dioxide, and volatile organic compounds.

GARBAGE & SOLID WASTES

According to the EPA, the United States produces 4.9 pounds of municipal solid waste per person per day[30]. These wastes are a variety of substances, including food, yard trimmings, glass, paper, metals, textiles, and plastics. Management of these wastes is a high priority for state and local governments; depending on the type of waste and available management facilities, municipal solid wastes may be recycled, composted, burnt, or deposited in a landfill.

Ideally, the ultimate fate of these wastes is to end up in a waste management facility where they would be treated, processed, or otherwise disposed of. Unfortunately, a portion of these wastes escape during transport and processing, or may be inappropriately disposed of, and never reach a management facility. These escaped wastes enter the environment, becoming a hazard to many wildlife species. Garbage and Solid Wastes may be composed of a variety of substances, but plastics are often a greater concern due to their longevity, durability, and the increasing volume accumulating in ecosystems.

It is important to note that even properly disposed Garbage & Solid Wastes can pose a risk to the environment. For example, processing these wastes can release toxic chemicals into the air when incinerated or recycled, contaminate groundwater leaching out of landfills, and require the conversion of habitat for the construction and expansion of new facilities to keep pace with growing waste production rates. These associated threats are discussed in more detail under Industrial & Military Effluents (Threat 9.2) and Industrial Development (Threat 1.2).

THREAT DESCRIPTIONS AND EXAMPLES

Drifting plastic and entanglement rubbish (Threat 9.4.4) has long been acknowledged as a threat to marine mammals, sea turtles, seabirds, marine fish, and invertebrates (Laist 1997). Sea turtles, whales, and seabirds are known to swallow floating pieces of plastic, resulting in gastrointestinal blockages that they are unable to regurgitate (Wilcox et al. 2015). Individuals that get tangled in discarded debris can drown if it prevents them from surfacing or moving, starve if it reduces their ability to forage, and can become tangled with permanent features. Fishing gear is a particular problem, often referred to as 'ghost fishing.' Not only does ghost fishing gear entangle individuals swimming on or near the surface. When it sinks, it can disturb benthic habitats and species by smothering or abrading surfaces, snagging organisms in the mesh, or translocating individuals as currents cause the gear to drift (Brown and Macfayden 2007, Stelfox et al. 2016, Duncan et al. 2017). In freshwater ecosystems, entanglement with monofilament fishing line is a concern for birds, fish, and turtles, though this phenomenon is vastly understudied (Theijn 2017, Blettler and Wantzen 2019, Azevedo-Santos et al. 2021).

Other types of **garbage** (Threat 9.4.1) are detrimental as species may attempt to ingest or otherwise utilize non-natural materials. Other taxa, such as terrestrial reptiles, freshwater fish, and amphibians likely face similar threats if they opportunistically or accidentally attempt to swallow plastics, though there is far less research in freshwater and terrestrial systems. Some forms of garbage are also entanglement risks, even if they are not in aquatic environments. Plastic netting and erosion control fences and structures have been shown to imperil snakes (Stuart et al. 2001, Kapfer and Paloski 2011, Ebert et al. 2019). Though similar reports for other species are limited, it would be unsurprising if some amphibians, lizards, turtles, and small mammals are similarly at risk. The utilization of plastics and other garbage may also have indirect impacts. This phenomenon has primarily been observed in birds utilizing plastics as nesting materials. The use of plastic may reduce individual fitness by reducing insulative qualities, encouraging parasites or disease, increasing exposure to potential choking and entanglement hazards, or having other unstudied effects (Votier et al. 2011, Blettler and Wantzen 2019, Parthasarathy et al. 2019). Further impacts of plastic utilization among other taxonomic groups still need to be investigated.

The presence of **solid lead** (Threat 9.4.3) impacts a small number of species in the Northeast, primarily apex predators. The primary sources of this form of lead are ammunition and fishing tackle. As was the case for industrial lead products described above, lead products are persistent and have significant health impacts on many forms of wildlife. Solid lead can remain relatively stable in the environment for long periods before breaking down into more soluble compounds that are more easily absorbed by the body, though ingestion of solid lead is also detrimental (Pain et al. 2019). Several different exposure pathways exist, including absorption of soluble lead from the water, soil, or plants, direct ingestion of spent ammunition or fishing tackle, or ingestion of flesh from an animal that was contaminated with lead (Haig et al. 2014) Lead bioaccumulates through the ecosystem, concentrating as it moves up the food chain. Thus, predators and scavengers tend to have the highest concentrations of lead, and the most health impacts. The issue of solid lead has primarily been studied in birds (Haig et al. 2014, Pain et al. 2019) and fish (Truchencki and Radomski 2013), but examples involving mammals are gaining attention (Burco et al. 2012, Chiverton et al. 2022).

Though not a category identified in Quebec’s Standardized Classification of Threats, **microplastic pollution** is of increasing concern globally, nationally, and regionally. Microplastics are defined as plastic particles less than five millimeters in size and include fibers, fiber bundles, fragments, films, pellets or beads, and other inorganic shapes. Nanoplastics are particles less than one millimeter in size and another area of increasing research attention. Most plastics weather mechanically into smaller and smaller fragments instead of chemically weathering into other compositions, and as a result, can persist in the environment long-term to permanently and bioaccumulate. Particles may consist of any plastic chemical composition, plus additives (e.g., phthalates, brominated flame retardants, antimicrobials), potentially introducing toxic or harmful chemical contaminants to the environment (Browne et al. 2016, Tian et al. 2020, Mariano et al. 2021, Fauser et al. 2022). Plastic particles may also absorb persistent organic pollutants, trace metals, and pathogens, accumulating harmful chemicals at higher concentrations than the surrounding water column (Browne et al. 2016) and acting as a vector for environmental contamination (Mariano et al. 2021, Fauser et al. 2022). Environmental microplastic pollution sources include the breakdown of litter and fishing gear, spillage of industrial pellets and powders, wastewater treatment effluent, industrial abrasives, drilling fluids for oil and gas exploration, artificial turf, paint on roadways and vessels, urban stormwater runoff, tire wear, air emissions, and many other sources. Duis and Coors (2016) summarize the primary and secondary sources of microplastics at the global scale.

Microplastic pollution has been documented virtually everywhere it has been tested from mountain peaks to ocean floors, including in:

- Air (Prata 2018, Brahney et al. 2020)
- Soil (Chia et al. 2021, Wang et al. 2022)
- Ground water (Chia et al. 2021)
- Drinking water (Kirstein et al. 2021)
- Surface water (Baldwin et al. 2016, Eerkes-Madrano et al. 2015, Eriksen et al. 2013, Li et al. 2018)
- Marine waters (e.g., Duis and Coors 2016, Grace et al. 2022)
- Beach sediments (e.g., Duis and Coors 2016, Horn et al. 2019)
- Shorelines (e.g., Browne et al. 2011)
- Deep ocean sediments (Jones et al. 2022)
- Mountain glaciers (Stefánsson et al. 2021)
- Rain (Brahney et al. 2020)
- Snow (Aves et al. 2022)
- Numerous human food and drink products (e.g., Kwon et al. 2020, Prata et al. 2020a)

Regionally, microplastic pollution has been documented in the Great Lakes and its tributaries (Baldwin et al. 2016), the Delaware River watershed (Baldwin et al. 2021, Bransky and Chen 2022), the Chesapeake Bay estuary (Yonkos et al. 2014, Murphy et al. 2019), and North Atlantic Ocean sediments (Jones et al. 2022) A new research study to identify microplastic pollution in the Connecticut River watershed was initiated in 2020 by The Connecticut River Conservancy. A recent research study supported by the Delaware River Conservation Fund documented microplastic pollution at 100% of survey sites in the Delaware River watershed, finding up to 250 particles of at least 16 types of plastic per cubic foot of water and 90% of the microplastic particles consisting of fibers (Bransky and Chen 2022). Microplastic fibers typically are the byproduct of laundering synthetic fabrics (e.g., polyester, nylon, rayon), contributed via domestic wastewater streams where one garment can produce more than 1900 microfibers per wash cycle (Browne et al. 2011, Prata 2018).

Limited information currently exists on the ecological and human health effects of microplastic pollution and contamination (e.g., Prata et al. 2020b, Sangkham et al. 2022). It is estimated that humans consume a credit card's worth of plastic weekly as a result of the presence of microplastic in food and drink products (Dalberg Advisors and

The University of Newcastle 2019). Microplastic and nanoplastic particles have been documented in human blood (Leslie et al. 2022) and lung tissue (Jenner et al. 2022).

Recent studies document the ingestion of microplastics and nanoplastics by mammals (Yong et al. 2020), seabirds (Duis and Coors 2016, Lavers et al. 2019, Susanti et al. 2020), fish (Lu et al. 2016, Mattsson et al. 2017, Parks et al. 2019), whales (Kahane-Rapport et al. 2022), turtles (Jung et al. 2018, Ugwu et al. 2019), lobster (Woods et al. 2020), mole crabs (Horn et al. 2019), oysters (Sussarellu et al. 2016), freshwater and marine mussels (Browne et al. 2008, Li et al. 2018), zooplankton (Cole et al. 2013), and many other marine invertebrates (Setälä et al. 2014, Sussarellu et al. 2016, Ugwu et al. 2019). Baldwin et al. (2016) and Mariano et al. (2021) summarize the known impacts of microplastic and nanoplastic ingestion by wildlife, such as the brain damage and behavioral disorders in fish documented by Mattsson et al. (2017). Recent evidence documents that impacts may be severe. For example, Tian et al. (2020) found microplastic particle leachate containing a common antioxidant chemical from tire treads induced acute mortality in Coho Salmon (Oncorhynchus kisutch) in the Pacific Northwest.

Several meta-analyses are now available that summarize the state of knowledge about various aspects of microplastic and nanoplastic pollution. Eerkes-Medrano et al. (2015), Baldwin et al. (2016), and Li et al. (2018) summarize the threat of microplastic pollution in freshwater systems, Foley et al. (2018) on fish and aquatic invertebrates, Ugwu et al. (2021) on marine organisms, Chia et al. (2021) in soil and groundwater, and Prata (2018) in air. Sangkham et al. (2022) conducted a review of the state of knowledge of microplastic and nanoplastic pollution and toxicity in the environment, including exposure routes for humans. The threat of microplastic and nanoplastic pollution and contamination continues to be a focus of new research, with journals like the International Journal of Environmental Research and Public Health, Current Opinion in Toxicology, and Marine Pollution Bulletin devoting special issues to the topic (in 2018, 2021 and 2022 respectively).

Sampling for microplastic pollution is challenged by potential cross-contamination from plastic components in sampling equipment, the clothing of personnel, cleansing materials (e.g., rinse water), and the air. Moreover, concentrations may vary significantly, even at small spatial scales (Boshoff et al. 2023). Mariano et al. (2021) reviewed identification and detection techniques for microplastics and the emerging classification of nanoplastics. The National Oceanic and Atmospheric Administration has developed standardized sampling protocols for microplastic pollution in water, beach sediment, and seabed sediments (Masura et al. 2015). As techniques for identifying and measuring microplastic and nanoplastic pollution continue to advance, conservation actions to address this emerging threat will also emerge but are currently lacking.

RELATIONSHIPS WITH OTHER THREATS

Most forms of garbage are human products, linking them closely with human activities under Residential & Commercial Development (Threat 1.0) and Transportation & Service Corridors (Threat 4.0). Fishing gear and lead ammunition are the waste products of Biological Resource Use (Threat 5.0). Some forms of garbage may also amplify Invasive & Problematic Species, Pathogens, and Genes (Threat 8.0) by facilitating the widespread dispersal of invasive species (Blettler et al. 2021), providing surfaces for pathogenic organisms to colonize (Parthasarathy 2019), and subsidizing native predators (Newsome et al. 2015). Increased storm and precipitation intensity and frequency as a result of Climate Change (Threat 11.0) may result in more forms of garbage flushing into aquatic ecosystems.

TOOLS AND RESOURCES

Few resources and tools are available for tracking solid waste at the regional scale. **State waste management agencies** may have tools useful for looking into this topic. The EPA has a **resource page for solid waste**[31], which may have useful resources for learning more about this topic.

3.2.2 CLIMATE CHANGE

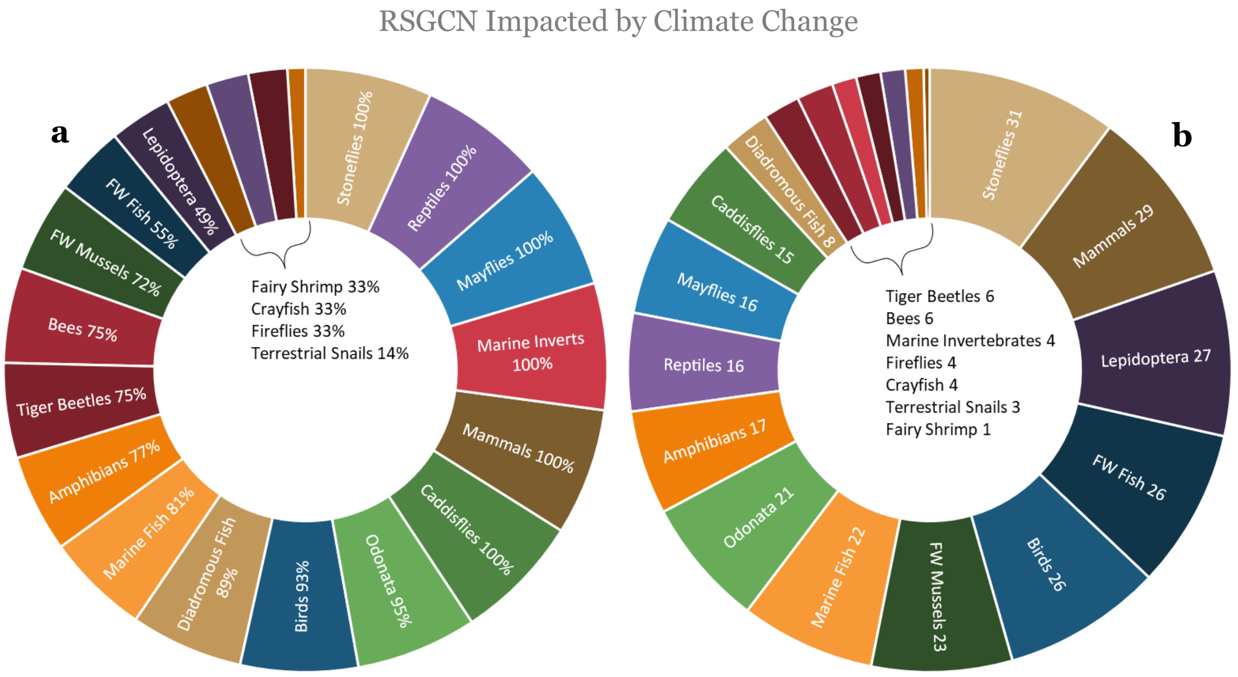

Figure 3.3 Impact of Climate Change (Threat 11.0) on RSGCN and Proposed RSGCN. (*a*) The percentages show the proportion of the species within that taxonomic group known to be impacted

by this threat. (*b*) The total number of species within the taxonomic group known to be impacted by this threat.

Climate Change is a rapidly growing concern in the region, impacting 73% (305 species) of the RSGCN and Proposed RSGCN. All of the species in the stonefly, reptile, mayfly, marine invertebrate, mammal, and caddisfly taxonomic groups are considered vulnerable to climate change impacts, highlighting these groups' sensitivity to future changes (Figure 3.3a). As knowledge of climate change and its impacts on species and habitats is still evolving, it is likely additional species are impacted by this threat in ways we do not yet understand. The low percentages in many of the invertebrate taxonomic groups may increase in the future as new information is uncovered (Figure 3.3b).

At the time of the 2015 Northeast SWAPs, climate change was considered one of the highest priorities of all threats identified. Climate change is considered to be one of the most impactful threats in the Northeast because of uncertainty about the full effects on individual species, variability in species responses, the infeasibility of addressing sources of climate change at local and state scales, and irreversibility of some impacts (TCI and the NEFWDTC 2017).

The Northeast Climate Adaptation Science Center (NECASC)[32], a consortium of USGS and university researchers housed at the University of Massachusetts, Amherst, is a crucial resource for climate-related information, research, and planning in the Northeast. One of the USGS' nine regional Climate Adaptation Science Centers, their goal is to deliver science to help fish, wildlife, water, land, and people adapt to a changing climate. NECASC produced a **regional synthesis** that compiled a summary of the current literature, strategies and actions, tools, and case studies for addressing multiple and simultaneous threats from climate and non-climate stressors to natural and cultural resources into searchable databases[33] (Staudinger et al. 2015). This report analyzed how climate has and is expected to change, the relative vulnerability of fish and wildlife species and their habitats, likely responses of species of concern to these changes, and the approaches, strategies, and actions that could sustain fish, wildlife, and their habitats across the region.

To support the 2025 SWAP revisions, NECASC is developing an **updated Regional Climate Synthesis**[34], which will be available later in 2023 (Staudinger et al. 2023). This updated Climate Synthesis will have six sections, described briefly below:

1. Climate Change Information
    a. Climate projections for multiple climate variables (e.g., temperature, precipitation, sea level rise) across multiple periods (e.g., retrospective, current, and future) and different climate scenarios (e.g., RCP 4.5 and 8.5)
    b. Quantitative visualizations and qualitative descriptions of climate data

    c. Descriptions and guidance on climate model uncertainties and best practices for applying to targets of interest.
2. Species Responses to Climate Change
    a. Review of the climate-change literature for information relevant to the 2023 RSGCN species
    b. Analyze RSGCN range and distribution shifts
    c. Identify data gaps and data deficient species
    d. Generate species profile visualizations that highlight (a) range, depth, elevation, or phenology shifts, (b) describe morphological and population responses, and (c) determine species' climate change vulnerability
3. Climate Vulnerabilities and Risks
    a. Update list and database summarizing regional climate change vulnerability assessments (CCVA) conducted since 2015
    b. Additional vulnerability and comprehensive risk assessment information
    c. Summaries and examples of advances in climate vulnerability assessments and the pros and cons of different approaches to assessing risk
4. Scale-appropriate Adaptation Strategies and Actions
    a. Summaries of adaptive strategies and actions related to NE RSGCN and associated habitat
    b. An updated database of strategies and actions from 2015 that organizes actions for RSGCN around top climate threats
    c. Identify actions with multiple climate and non-climate benefits
5. Case Studies
    a. Describe extreme event result-chains that link system response to multiple threats specific to RSGCN species
        i. Extreme precipitation and pest outbreaks (spongy moth)
        ii. Coastal storms and sea level rise
6. Recent Climate Adaptation Resources

As the updated Regional Climate Synthesis is being released at nearly the same time as the Regional Conservation Synthesis, this document does not go into as much depth on Climate Change as it does for other threats, providing only brief descriptions of the ways climate change can impact species and habitats, synergistic effects of climate change with other threats, and useful partners and resources. The Climate Synthesis will be a far more comprehensive review; managers, biologists, partners, and other users of this document should refer to the Climate Synthesis for the most complete and up-to-date information.

THREAT DESCRIPTIONS AND EXAMPLES

Climate change has the potential to impact nearly every aspect of an ecosystem, including marine (Gruber 2011, Bryndum-Buchholz et al. 2019, Franco et al. 2020), estuarine (He and Silliman 2019, Columbano et al. 2021), terrestrial (Häder and Barnes 2019, Pugnaire et al. 2019), freshwater (Häder and Barnes 2019, Grieger et al. 2020, Woolway et al 2020, Salimi et al. 2021), and atmospheric (Payne et al. 2020) systems Responses are hugely variable across species, making a synthesis of the current trends a complicated endeavor (Staudinger et al. 2013). These impacts are hugely varied, but include:

- Habitat Shifting & Alteration (Threat 11.1), including changing vegetation communities, phenological mismatch, and sea level rise
- Changes in Geochemical Regimes (Threat 11.2) including changes in pH and salinity
- Changes in Temperature Regimes (Threat 11.3) including gradual changes, increased variability, and extremes
- Changes in Precipitation & Hydrological Regimes (Threat 11.4) including gradual changes, increased variability, and extremes
- Severe/Extreme Weather Events (Threat 11.5)
- Other changes in patterns such as altered air or ocean currents

RELATIONSHIPS WITH OTHER THREATS

Climate change is not only a direct threat but often amplifies the negative impacts of many other threats, acting in a synergistic way to increase overall vulnerability (Staudt et al. 2013; Pinkney et al. 2015). Examples of this include:

- Changes in temperature or precipitation make areas more susceptible to the invasion of non-native species or the spread of disease (Burek et al. 2008, Hellman et al. 2008, Rahel and Olden 2008, Dukes et al. 2009, Adlard et al. 2015, Finch et al. 2021, McClure et al. 2022, Tazerji et al. 2022)
- Increased precipitation and storms result in more frequent flooding that increases contaminant loads in runoff (Petrie 2021)
- Sea level rise and coastal development constraining species caught between the two
- Environmental conditions change faster than species can adapt (Sekercioglu et al. 2008, Ralston et al. 2017, Urban 2018)
- Changes in temperature, salinity, or pH increase the stress levels of species, making them more likely to succumb to pollution, competition, or disease (Burek et al. 2008, Ganser et al. 2015, McKinney et al. 2015, Noyes and Lema 2015, Pinkney et al. 2015, Orr and Buchwalter 2020)
- Altered disturbance regimes, especially fire, result in the invasion of non-native species (Bradley et al. 2010, Finch et al. 2021)

- Warmer temperatures and changing nutrient cycles alter the frequency of harmful algal blooms (Chapra et al. 2017, Gobler et al. 2017, Griffith and Gobler 2020, Ralston and Moore 2020)
- Altered temperature or precipitation regimes alter interactions between species (Dallalio et al. 2017)

The complexity and interconnectedness of resources influenced by climate change highlight extensive knowledge gaps and confound conservation planning and implementation of relevant actions. Collaborative initiatives across geopolitical and jurisdictional boundaries help bridge these data deficiencies and allow for a more comprehensive understanding of the impacts of climate change and the responses of species and habitats. With shared concerns related to this global threat, states in the Northeast Region have many opportunities to work together to improve the effectiveness of conservation actions supporting RSGCN on a land- and seascape scale. Addressing sources of climate change (e.g., greenhouse gases) is largely beyond the immediate scope of state resource managers, but implemented actions can be crucial for species adaptation, habitat resiliency, and connectivity. For the near future, site-specific conservation actions that ameliorate non-climate threats are the most immediate options for increasing species viability.

TOOLS AND RESOURCES

Available tools and resources related to climate change are numerous, with additional resources being added frequently. On a national scale, climate change resources include the EPA's **Report on the Environment**[35], which tracks trends in the conditions of the nation's land, water, and air (US EPA 2022). Some of the more than 80 indicators they track, such as greenhouse gas levels, sea and air temperature, and precipitation records, are directly related to climate change.

The importance of non-climate stressors and the interactive effects of climate change has been addressed by the US Global Change Research Program in the **National Climate Assessment**, which is conducted every four years. Development of the Fifth National Climate Assessment is currently underway, with anticipated delivery in 2023. The interaction of climate change with other stressors and the complicated, interacting effects they have on species was a key message in the fourth National Climate Assessment (US Global Change Research Program 2018). This report also has a chapter that summarizes trends within the Northeast region, highlighting the importance of seasonal weather patterns and coastal ecosystems to regional economics and the proactive efforts underway to adapt to future climactic conditions. The US Global Change Research Program is also undertaking a **National Nature Assessment**[36], which is expected to be completed in 2026. This Assessment will take stock of the current status of United States lands, waters, and wildlife and look forwards to how they might change in the future and the implications of those changes on United States economics, human health, and climate.

The **National Fish, Wildlife, and Plants Climate Adaptation Strategy** identified specific strategies and actions for climate-and non-climate threat interactions. Here, the emphasis is to slow, mitigate or reverse the effects of non-climate stressors to increase resilience and allow species to adapt to changing conditions (National Fish, Wildlife and Plants Climate Adaptation Network 2012). In 2021, the National Fish, Wildlife, and Plants Climate Adaptation Network[37] released a new report that describes how climate science had changed over the previous decade, crosswalks the original Strategy with existing conservation plans made at various levels to assess implementation, and provides recommendations for future management actions highlighting the needs and challenges facing natural resource management in the next decade (National Fish, Wildlife and Plants Climate Adaptation Network 2021).

Other regional partners who work together to plan and implement climate-smart planning are the Nature Conservancy's **Center for Resilient Conservation Science**[38] and the **Wildlife Conservation Society**[39]. Mawdsley et al. (2009) identified **sixteen strategies for climate change adaptation**, many of which are in use in Northeastern states. In states where actions to prevent or adapt to climate change are already being implemented, much of the work is done by state fish and wildlife agencies or through partners such as land trusts and through cooperation with other state and federal agencies, including the US Fish and Wildlife Service, National Park Service, and US Forest Service.

3.2.3 INVASIVE & PROBLEMATIC SPECIES, GENES, & DISEASES

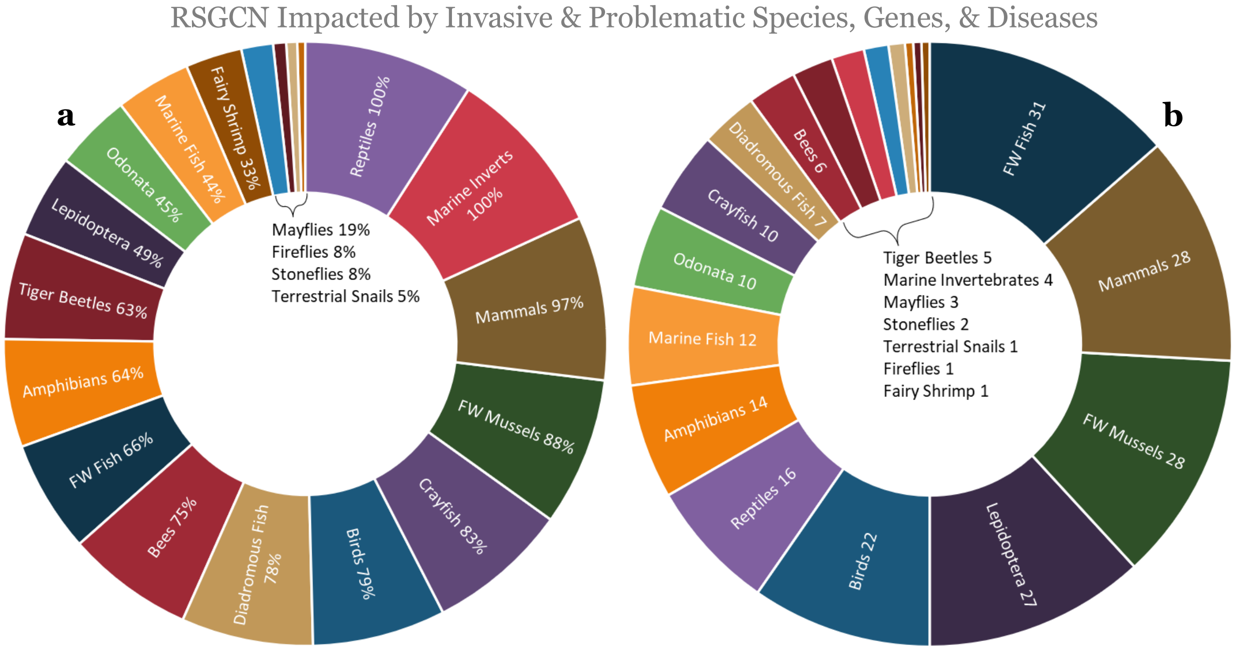

Figure 3.4 Impact of Invasive & Problematic Species, Genes, & Diseases (Threat 8.0) on RSGCN and Proposed RSGCN. (a) The percentages show the proportion of the species within that taxonomic group known to be impacted by this threat. (b) The total number of species within the taxonomic group known to be impacted by this threat.

More than half of the species on the 2023 RSGCN and Proposed RSGCN list – 55%, or 228 species – are imperiled by interactions with invasive or problematic species, face complications due to genetic integrity, are impacted by disease, or have natural biological limitations that reduce recovery potential. This includes all reptiles and marine invertebrates, and all but one mammal (Figure 3.4a). Though not all freshwater fish, mussels, and lepidopterans are associated with this threat, these taxonomic groups contributed as many species, if not more, as mammals (Figure 3.4b). Many invertebrate groups had five or fewer species for which this threat is known to be a cause of decline. This is likely due to data deficiencies and a limited understanding of how these threats impact these groups, rather than an indication that these groups are not sensitive to these threats.

The subjects categorized under this threat are incredibly diverse, touching on invasion ecology, competition and predation, parasitism, population and conservation genetics, epizoology, and other ecological and biological concepts. The breadth of these topics makes it difficult to generalize about the overall trends and patterns within the Northeast region at this topmost level. The impacts of these threats are not concentrated within certain habitat types or taxonomic groups; instead, they are found almost universally. More in-depth descriptions of the different threats and discussions of the trends and patterns in the Northeast are discussed under each threat category below.

INVASIVE NON-NATIVE/ALIEN PLANTS & ANIMALS

The introduction of organisms to novel environments can drastically alter the balance of entire ecosystems. The terminology describing species beyond their native range is complex, including terms such as invasive, introduced, non-native, exotic, alien, and more (Colautti and MacIssac 2004, Falk-Petersen 2006). In this document, the terms invasive and non-native are both used to describe plants or animals that are introduced to a new geographical or ecological system, usually as a result of human activity, and have direct or indirect impacts on the species or habitats native to the system. Invasive species are often considered to have broad, harmful ecological effects that contribute to direct or indirect declines in population health or status of native species (Mooney and Cleland 2001, Clavero and Garcia-Berthou 2005, Doherty et al. 2016, Dueñas et al. 2021), though some authors have suggested that invasions are a symptom, rather than the cause, of these changes (Didham 2005, MacDougall and Turkington 2005, Bauer 2012). Though usually considered a primary driver of ecological degradation in impacted systems, there may be occasions where invasive species may benefit certain native species, though this is usually at the cost of other native species (Rodriguez 2006, Gallardo et al. 2016).

Invasion ecology is a diverse field that is constantly growing. Numerous hypotheses and frameworks exist attempting to describe and explain invasion pathways and the characteristics of a potential invader (Catford et al. 2009, Perkins and Nowak 2013, Gutiérrez et al. 2014). Other researchers have focused on describing the impacts invasive species have on native species, communities, and ecosystems (Thomsen et al. 2011, Gallardo et al. 2016, David et al. 2017, Crystal-Ornelas and Lockwood 2020, Mayfield et al. 2021). The impacts of invasive species are very difficult to monitor, control, or reverse, which is one reason this is a priority threat in the Northeast (Leung et al. 2002, Mehta et al. 2007, Larson et al. 2011, Crowley et al. 2017).

Proactive management at the early stages of invasion involves preventing species from being introduced through policy mechanisms such as state noxious weed lists and importation bans. Proactive management also involves monitoring for new invasions and quickly eradicating them before they spread – a practice known as early detection and rapid response (EDRR; Westbrooks 2004). Preventing or detecting and eradicating invasions early is much more cost-effective than controlling invasions after the species have spread (Leung et al. 2002, Keller et al. 2007). Although proactive prevention and EDRR are the most effective tools for invasive species management, controlling populations at any stage can benefit wildlife. For example, in a meta-analysis of studies from over 200 papers, Bradley et al. (2019a) showed that there is a significant negative, linear relationship between invasive plant abundance (e.g., percent cover, stem count, biomass) and native species diversity. From a management standpoint, this suggests that environmental harm continues to accrue as plant invasions progress. Therefore, reducing invasive plant abundance at any stage of invasion reduces corresponding ecological harm.

In this document, the focus is on three primary roles in which invasive species interact with Northeast RSGCN: consumption, competition, and habitat alteration. Two further potential impacts of invasive species, hybridization with non-native species and infection by non-native diseases, will be discussed below under Introduced Genetic Material (Threat 8.3) and Pathogens and Microbes (Threat 8.4).

Consumption is one of the most direct ways invasive species can impact native species. Generally, consumption refers to examples of predation, but also includes non-native herbivores or insects feeding on native plants and parasitism, including klepto-, nest-, and brood parasites. Invasive predators and herbivores are often more detrimental than native ones because prey species lack co-evolved defenses or evasive mechanisms to protect themselves (Park 2004, Mayfield et al. 2021). Combined with the fact that these invasive species are often generalists whose populations are not impacted by the decline of any one native species, invasive species are released from bottom-up controls preventing their proliferation (Park 2004, Gallardo et al. 2016).

Invasive species can be favored in competitive interactions with native species that occupy the same or similar niches. Competition can be for food, shelter, or other resources; the limited availability of key resources creates these interspecific interactions between native and non-native species. Invaders with biological or behavioral adaptations that amplify their ability to gather or occupy resources will outcompete other species. These invaders are also often released from the pressures of their predators and parasites, allowing populations to grow beyond what native species can achieve and further exacerbating interspecific interactions (Predator Release Hypothesis; Torchin et al. 2001, Catford et al. 2009).

Invasive species often impact native species indirectly by altering habitats. If an invasive species alters or eliminates important niches from the habitat, native species that depend on that niche are also eliminated. For example, Chinese Mitten Crabs (*Eriocheir sinensis*) are extensive burrowers, destabilizing banks that other burrowing crustaceans would otherwise utilize and causing significant erosion and changes in water quality, impacting many aquatic species (Dittel and Epifanio 2009). These species, sometimes termed “invasive engineers” can change the structure, ecosystem function, nutrient cycling, and disturbance patterns of a habitat (Crooks 2002, Cuddington and Hastings 2004, Emery-Butcher et al. 2020).

It is important to note that a single invasive species may fill more than one of the three roles described above depending on the life stage of a native species, or may fit different roles for different native species. Round Goby (*Neogobius melanostomus*) contribute to declines of Mottled Sculpin (*Cottus bairdi*) and Yellow Perch (*Perca flavescens*) twice over by preying upon eggs and competing with young-of-the-year for other food resources and shelter (Zuwerink et al. 2019). Zebra and Quagga Mussels (*Dreissena polymorpha* and *D. bugensis*, respectively), one of the most iconic invasive species in North America, can act as a consumer, competitor, and habitat engineer, depending on which native species are considered. They filter large amounts of plankton out of the water column, which is both direct consumption of the plankton and competition with native mussels and fish for a primary food source, alter water clarity and chemistry, and form dense colonies that exclude other benthic organisms (Strayer 2009).

THREAT DESCRIPTIONS AND EXAMPLES

Invasive aquatic animals (Threat 8.1.3) are known to have wide-ranging effects on many RSGCN (Strayer 2010). The impacts of Zebra and Quagga Mussels are described above but include competition with other species and widespread habitat alteration. Although not as widespread in the Northeast as the two mussels, Asiatic Clams (*Corbicula fluminea*) have similar impacts (Simard et al. 2012). In addition to Roundy Goby, other invasive fish species of concern include Common Carp (*Cyprinus carpio*; Kloskowski 2011), Northern Snakehead (*Channa argus*; Saylor et al. 2012), and Blue and Flathead Catfish (*Ictalurus furcatus* and *Pylodictis olivaris*, respectively; Fabrizio et al. 2018, Schmitt et al. 2019). Most of these fish species are predators; Common Carp and Northern Snakehead are also able to alter their habitats in ways that exclude some native species.

In intertidal systems, concerns about several invasive crustaceans are increasing. European Green and Asian Shore Crabs (*Carcinus maenas* and *Hemigrapsus sanguineus*, respectively), compete with native crustaceans (Griffen and Riley 2015, Zargarpour 2020), prey upon crustaceans and shellfish (Brosseau and Goldberg 2007, Brosseau et al. 2014), and can cause loss of key habitat features such as eelgrass beds (Howard et al. 2019). Chinese Mitten Crabs (*Eriocheir sinensis*) are a more recent transplant in the Northeast region but are known to cause major habitat alterations due to their burrowing habits (Dittel and Epifanio 2009). Spiny and fishhook water fleas (*Bythotrephes longimanus* and *Cercopagis pengoi*, respectively) are a growing concern in the region, where they are already established in the Great Lakes and major watersheds in New York and Pennsylvania. These predatory zooplanktons compete with native species for prey and potentially create conditions beneficial for algal blooms, resulting in cascading effects across all trophic levels (Brown and Balk 2008, Yan et al. 2011, Walsh et al. 2016).

Geographic context is very important for some of the aquatic invaders in the Northeast; some species may be considered invasive only in certain areas. For example, invasive freshwater crayfish are a primary concern for nearly every 2023 RSGCN or Proposed

RSGCN crayfish. Of particular concern in the Northeast region are Virile, Rusty, and Red Swamp Crayfish (*Faxonius virilis, F. rusticus,* and *Procambarus clarkii*, respectively). Though these species are all native to North America, they have been introduced far beyond their home watersheds, largely via bait releases (Lodge et al. 2000, Kilian et al. 2012, Taylor et al. 2019). Their primary impact on native crayfish is as competitors, but some crayfish may have significant impacts on the habitat as well (Lodge et al. 2000, Hale et al. 2016, Kouba et al. 2022). Similarly, some predatory sportfish are native to the Northeast but may be considered invasive in specific water bodies where they have been stocked. Whittier and Kincaid (1999) evaluated the impacts of stocked fish across more than 200 lakes in the Northeast and found that many lakes are now dominated by non-native species. Impacts may be elevated when these predators are introduced to previously fishless waterbodies. For example, the introduction of fish to fishless ponds is known to impact dragonflies (Schilling et al. 2019), fairy shrimp (Leyse et al. 2004), amphibians (Gregoire and Gunzberger 2008), and aquatic macroinvertebrates (Schilling et al. 2009). One of the species on the 2023 RSGCN list is also considered invasive in the region. Rainbow Smelt is the dominant native forage fish in Lake Champlain, where it is imperiled but is considered invasive in the Great Lakes (Bruel et al. 2021). Another species on the 2023 Watchlist, Sea Lamprey (*Petromyzon marinus*), has diadromous populations along much of the Atlantic Coast but is managed as an invasive species in the Great Lakes and Lake Champlain (Hume et al. 2021).

For Northeast RSGCN, **invasive terrestrial animals** (Threat 8.1.1) are a major concern. Non-native mammals have significant impacts on wildlife populations. Feral Cats (*Felis catus*) are of particularly high concern. Predation by free-ranging cats can have major impacts on local vertebrate populations, especially birds and small mammals (Loss et al. 2013, 2022). Cats have been cited as a particular concern for several RSGCN, including Wood Thrush (*Hylochlia mustelina*), Piping Plover (*Charadrius melodus*), Indiana Bat (*Myotis sodalist*), Little Brown Bat (*Myotis lucifugus*), and Block Island Meadow Vole (*Microtus pennsylvanicus provectus*). Off-leash dogs can also disturb local wildlife, especially beach-nesting birds, though these effects are less well-studied (Gibson et al. 2018). Norway and Black Rats (*Rattus norvegicus* and *R. rattus*, respectively) are a concern as potential vectors for disease, predators of small mammals and nests, and competitors with similarly sized omnivores, although these impacts tend to be concentrated around human development (Banks and Hughes 2012). Another invasive mammal in the Northeast is Feral Hogs (*Sus scrofa*). Though more widespread in the Southeast and Midwest regions, several states, including Vermont, New Hampshire, Pennsylvania, West Virginia, Virginia, and Delaware are currently managing Feral Hog populations. Feral Hogs impact forest composition and soil structure with their foraging, rooting, and wallowing activities (Siemann et al. 2009, Meyer et al. 2021). They also can compete with native herbivores and mast-feeding species or prey upon smaller animals; Feral Hogs are particular predators on sea turtle nests in the southeastern United States (Seward et al. 2004, Sieman et al. 2009). The Animal and Plant Health Inspection Service (APHIS) has a National Feral Swine Damage Management Program[40], which has been instrumental in reducing Feral Hog populations and mitigating the damage they cause. This program maintains a website with useful information and resources about Feral Hogs and their management in the United States, including maps of their known distribution.

There are several non-native birds in the region as well. European Starlings (*Sturnus vulgaris*) are widespread across North America and may competitively exclude some cavity-nesting birds, though these effects are not consistent (Koenig 2003, Craig 2020, Meyer et al. 2021). House Sparrows (*Passer domesticus*) are native to Europe and Asia, but have been widely introduced around the world. They are highly adapted to anthropogenic habitats, giving them a competitive advantage in these areas, facilitate the spread of several diseases, and can be aggressive in their competitive interactions with native birds (Hanson et al. 2020). Monk Parakeets (*Myiopsitta monachus*) are native to South America, but escaped and released pets have established breeding populations in several areas in the United States, including southern Virginia and the greater New York City metropolitan area. This species is not known to have any major impacts on native wildlife, but their use of electric facilities as nest sites can cause power outages and maintenance issues (Avery 2020). Another largely urban bird, Feral Pigeons (*Columba livia*) are ubiquitous across much of the Northeast (Carlen 2021). Though they do not tend to compete with many wild bird species directly, these birds are frequently vectors for various diseases that negatively impact wildlife species (Santos et al. 2020). Mute Swans (*Cygnus olor*) are common in much of the region but are native to Europe and Asia. They were introduced largely for ornamental reasons and now are reproducing rapidly (Gayet et al. 2020). This rapid growth is problematic, as the swans deplete food resources, are reservoirs for avian influenza, and aggressively exclude and displace other waterbird species (Gayet et al. 2020). Efforts to control Mute Swan populations are contentious, as attempts to limit the ecological impacts and aggressive interactions with humans are countered by strong public opposition in support of the charismatic species (Hindman and Tjaden 2014, Jager et al. 2016, Gayet et al. 2020). House Finches (*Haemorhous mexicanus*) were confined to the southwestern United States and Mexico until the 1930s when about 100 individuals were released in New York (Britton and Badyaev 2020). Since then, the species has spread throughout the eastern United States where it is now a common feeder bird and an occasional agricultural pest (Britton and Badyaev 2020). Although they do not appear to have major impacts on any native species, the House Finch is susceptible to a form of conjunctivitis, which may be a concern if the disease changes and can infect new host species (Hosseini et al. 2006). Brown-headed Cowbirds (*Molothrus ater*) were originally limited to the prairies of the Midwest, but were able to greatly expand their range in response to the widespread conversion of forests to agricultural areas across much of the United States, and are now considered invasive in the Northeast (Wilson 2020). This species is a nest parasite and can successfully parasitize more than 150 host bird species, including several RSGCN and Proposed RSGCN birds (Wilson 2020).

Terrestrial invertebrates have major impacts on ecosystems as well. The Northeast region has some of the highest concentrations of invasive insects and diseases in the country, a result of elevated opportunities for invasion due to a longer colonized history combined with numerous pathways for human-mediated invasion (Juzwik et al. 2021). Many of these insects, including Spongy Moth (*Lysmantria dispar*), Hemlock Wooly Adelgid (*Adelges tsugae*), Emerald Ash Borer (*Agrilus planipennis*), Winter Moth (*Operophtera brumata*), and Asian Longhorned Beetle (*Anoplophora glabripennis*), either defoliate or kill key tree species in the Northeast, altering key habitats across the region (Juzwik et al. 2021, Meyer et al. 2021). The US National Phenology Network[41] produces short-term phenology forecast maps as a tool to inform management and monitoring actions for all of these invasive forest insects (Crimmins et al. 2020). These Pheno Forecast maps depict the status of the insect's life cycle across the United States and are updated daily. In the southern and western parts of the region, Spotted Lanternfly (*Lycorma delicatula*) is closely associated with another invasive species, Tree of Heaven (*Ailanthus altissima*). While Tree of Heaven is the preferred host, Lanternflies can utilize many different plant species; the current focus is on its impact on agricultural species, but it has major potential to impact forested ecosystems as well (Urban 2020, Barringer and Ciafré 2020).

A growing body of research is highlighting the impacts of invasive earthworm species on forested ecosystems. These earthworms are model invasive engineers, removing leaf litter (Maerz et al. 2009) and altering carbon dynamics (Snyder et al. 2009), nutrient cycling (Bohlen et al. 2004), mycorrhizal relationships (Paudel et al. 2016), and soil structure (Snyder et al. 2013). Native soil invertebrates are impacted either indirectly through the homogenization and alteration of the environment or through direct competition with the worms, which has the potential to cascade up through higher trophic levels (Migge-Kleian et al. 2006, Loss and Blair 2011, Ferlian et al. 2017, Frelich et al. 2019). The taxonomic teams indicated that this is of particular concern for the terrestrial snails, many of which live in the leaf litter. There is some evidence that natural fire regimes may favor native worms, but this research is ongoing, and the full effects are not understood (Meyer et al. 2021).

The primary impact of **terrestrial and aquatic invasive plants** (Threat 8.1.2 and 8.1.4, respectively) on Northeast RSGCN and Proposed RSGCN is as invasive engineers. Invasive plants are a well-known threat to wildlife habitat, altering habitat structure and leading to significant declines in the fitness, abundance, and diversity of native wildlife (Vilà et al. 2011, Pyšek et al. 2012, Buciarelli et al. 2014). Invasive plants have also been linked to increased tick densities, which could alter disease transmission patterns (Williams et al. 2009, Allan et al. 2010, Mathisson et al. 2021). A majority of invasive plants in the United States were introduced intentionally as ornamentals, though other intentional and accidental pathways provide additional routes (Ehan et al. 2013). New introductions through horticulture continue; more than half of the species identified as invasive in the United States are still available for purchase (Beaury et al. 2021). It is worth acknowledging that not all the impacts of invasive plants are negative; some may offer benefits to some wildlife species (Hayes and Horzmueller 2012). There are more invasive plants impacting Northeast RSGCN and Proposed RSGCN than space in this document, but some common and widespread invasive plant species include:

- Phragmites (*Phragmites australis*): a widespread invader of freshwater and brackish wetlands that forms dense colonies which exclude native vegetation, alter hydrology, nutrient, and decomposition cycles, and entangle native species (Meyerson et al. 2000, Hazelton et al. 2014, Cook et al. 2018)
- Japanese Knotweed (*Fallopia japonica*): another widespread, monoculture-forming invader of riparian areas that decreases plant biodiversity, alters streamflow and flooding, and has mixed effects on other taxonomic groups (Vanderklein 2014, Lavoie 2017, Wilson et al. 2017)
- Purple Loosestrife (*Lythrum salicaria*): a wetland plant that alters decomposition rates and nutrient cycling, reduces wetland plant biodiversity, reduces successful pollination in other wetland plants, and changes suitability for wetland specialist birds (Blossey 2001). The introduction of beetles in the genus *Neogalerucella* (*Galerucella*) as biocontrol agents is widely considered effective in many regions, including the Northeast, though the response is variable at different sites (St. Louis et al. 2020, Endriss et al. 2022).
- Didymo (*Didymosphenia geminata*): a diatomaceous alga that can cause large algal blooms that impact fish, benthic invertebrates, and mussels (Clancy et al. 2020)
- Garlic Mustard (*Alliaria petiolata*): an allelopathic forest plant that is of particular concern for butterflies and other pollinators that are dependent on the plants directly impacted via decreased regeneration and growth, disruption of mycorrhizal relationships, or altered nutrient cycles (Stinson et al. 2007, Rodgers 2008)
- Multiflora Rose (*Rosa multiflora*): a plant found in many habitats that was introduced in the United States as an ornamental and for use as “living fences” that forms dense thickets that reduce light and nutrient availability for native plants and may form reservoirs of Lyme disease-carrying ticks (Adalsteinsson et al. 2018, Bowden et al. 2018)

RELATIONSHIPS WITH OTHER THREATS

Invasive species can be introduced to new environments following a large number of different pathways, but many of those pathways are human-mediated (Hulme et al. 2008, Wilson et al. 2009). Residential & Commercial Development (Threat 1.0), Agriculture & Aquaculture (Threat 2.0), Transportation & Service Corridors (Threat 4.0), Biological Resource Use (Threat 5.0), and Human Intrusions & Disturbance (Threat 6.0) have all facilitated the introduction and distribution of invasive species. Furthermore, it is important to highlight the role of disturbance, both natural and anthropogenic, in many invasions. Disturbance creates opportunities by temporarily increasing resource availability, giving invasive species an equal chance to colonize and establish a site without needing to compete with native species (Catford et al. 2009, Meyer et al. 2021). Less intact habitats are more susceptible to invasion, especially by generalist species (Marvier et al. 2004). In the Northeast, the role of anthropogenic activity in invasions is particularly strong for plants (Gavier-Pizarro et al. 2010, Beaury 2021).

In addition, Climate Change (Threat 11.0) will exacerbate the threats of invasives. These changes will impact species at every stage of invasion (Hellman et al. 2008). Many authors have discussed the numerous ways climate change will amplify the impact invasive species have on native species, including:

- Warming temperatures will enhance the winter survival of many invasives, allowing populations to grow and expand their ranges (Rahel and Olden 2008, Hellman et al. 2008, Dukes et al. 2009, Bradley et al. 2010, Mainka and Howard 2010, Staudt et al. 2013, Finch et al. 2021)
- Many invasive species have mechanisms that facilitate rapid dispersal, making them more likely than native species to adapt as climactic conditions shift (Dukes et al. 2009, Finch et al. 2021)
- Increased precipitation and altered streamflow may facilitate the dispersal of invasive plants and animals (Rahel and Olden 2008, Mainka and Howard 2010)
- Climate change alters the frequency, severity, timing, and location of biological disturbances, such as severe storms, fire, and wind events, increasing the likelihood of invasion (Bradley et al. 2010, Staudt et al. 2013, Finch et al. 2021)
- Altered ocean currents may result in increased trans-oceanic transportation of invasives (Mainka and Howard 2010)
- For many forest pests, warming temperatures increase activity levels and the number and duration of breeding cycles, resulting in more frequent outbreaks (Dukes et al. 2009, Finch et al. 2021)
- Stressed ecosystems can’t recover as easily (Staudt et al. 2013)
- Changing climactic conditions will likely shift which areas are at risk of invasion, requiring dynamic monitoring protocols (Allen and Bradley 2016)

Proactively addressing the combined impacts of invasive species and climate change will be necessary for effective management, but additional research and communication of results are necessary (Beaury et al. 2020).

TOOLS AND RESOURCES

Since invasion ecology is a matter of movement of species across borders, invasive species management occurs at many different levels. Numerous resources are available for learning more about this complex issue. The **Global Invasive Species Database**, developed by the IUCN and the Invasive Species Specialist Group (ISSG), provides a summary of the known impacts and potential management strategies for more than one thousand species known to negatively impact biodiversity around the world (ISSG 2015). The ISSG is also working on a **Global Register of Introduced and Invasive Species**, which will develop county-level record information for many invasive species (Pagad et al. 2018). Another online database, the Centre for Agriculture and Bioscience International (CABI) **Compendium of Invasive Species**[42], has many informational datasheets on invasive species, though the focus is more on agricultural pests.

Multiple invasive species management and implementation plans have been developed at the national level. The US Department of Agriculture (2004, 2013) lays out four key elements for the management of invasive species in their **National Strategy and Implementation Plan for Invasive Species Management**: prevention, early detection and rapid response, control and management, and rehabilitation and restoration. The **National Invasive Species Council**[43], under the umbrella of the US Department of the Interior, provides guidance on the prevention, eradication, and control of invasive species, as well as the restoration of impacted ecosystems in their **Management Plan and Annual Work Plans**. The annual workplan frames actions under six themes: climate change, wildland fire and invasive species, early detection and rapid response, information management, outreach and engagement, and interagency dialogues (National Invasive Species Council 2016, 2022). The US Department of the Interior (2021) has a comprehensive agency-wide approach intended to build upon existing plans and serve as an overarching invasive species management strategy in their **Invasive Species Strategic Plan**. The five major goals in this document are to increase collaboration both within and outside of the agency, prevent the introduction and spread of invasive species using cost-effective methods, implement early detection and rapid response efforts in collaboration with other partners, control or eradicate established invasive species using cost-effective methods, and improve invasive species data management. The US Forest Service (2013) has its own **National Strategic Framework for Invasive Species Management** which prioritizes and guides the prevention, detection, and control of invasive insects, pathogens, plants, wildlife, and fish species.

There are invasive species programs and resources within many of the federal natural resource agencies. The **National Invasive Species Information Center**[44] is within the US Department of Agriculture, providing invasive species information from local, state, federal, and international sources. The Center maintains an **Invasive Species Profiles List** for aquatic and terrestrial species declared as invasive, noxious, prohibited, or otherwise harmful or potentially harmful in the United States. The Animal and Plant Health Inspection Service additionally maintains a **noxious weeds program**[45] whose purpose is to prevent the introduction of nonindigenous invasive plants. Plants can be designated under the **Federal Noxious Weed Act**[46], which gives the authority to regulate their import and transport, as well as the ability to seize and destroy plant products if necessary to prevent their spread.

The USGS **Biological Threats and Invasive Species Research Program**[47] monitors several biological threats at the national level. They conduct research intended to inform the protection of public safety, property, and ecosystems from invasive species and diseases. The USGS has produced several **data resources and tools** related to invasive species management (Table 3.2).

The US Fish and Wildlife Service has **programs focused on terrestrial invasive species[48] and aquatic invasive species**[49]; both programs work on the prevention, eradication, and control of biological invaders. The USFWS also has the authority to designate species as injurious[50] under **title 18 of the Lacey Act**, setting importation and transportation restriction on these species. The USFWS and NOAA also co-chair the **Aquatic Nuisance Species Task Force**[51], a group established by Congress by the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990. Their **Strategic Plan** outlines the goals, objectives, and strategies that guide national and regional prevention, early detection and rapid response, control, research, and outreach activities (Aquatic Nuisance Species Task Force 2019). The Task Force works together with regional panels, partnerships of state and federal agencies, academic institutions, environmental organizations, commercial interests, and regional entities collaborating on aquatic invasive species management The **Northeast[52] and Mid-Atlantic[53] regional panels** set regional priorities and work together with the Task Force to develop and implement strategic, coordinated, action-oriented approaches to prevent and control aquatic invasive species.

Non-governmental organizations are also focused on invasive species management. The **North American Invasive Species Management Association**[54] is a network of land managers and other professionals implementing management programs to prevent the detrimental impacts of invasive species across the country. They support invasive species management professionals with training opportunities, inventory and data standards, and outreach and networking events that bring together diverse stakeholders and interest groups. The Association developed a PlayCleanGo brand for outreach materials and a Weed Free Product Standards and Certification Program to prove assurance that noxious weeds are not spread through the movement of forage, mulch, or gravel. The **Reduce Risks from Invasive Species Coalition (RRISC)**[55] is a nonprofit organization dedicated to educating the public on the risks of invasive species to the environment, public health, and the economy and promoting cost-effective strategies to reduce those risks. The organization profiles an Invasive Species of the Month as part of its education and outreach activities. The Coalition recognizes best practices for invasive species management by giving awards for private sector and state government achievements in prevention, control, and risk management.

The **Center for Invasive Species and Ecosystem Health**[56] at the University of Georgia is another group focused on the development, consolidation, and dissemination of information and programs focused on invasive species, forest health, and natural and agricultural management. They have also developed several invasive species tools and data resources (Table 3.2).

Significant amounts of invasive species coordination and management happen regionally. The National Park Service's Northeast, Mid-Atlantic, and National Capitol Area **Invasive Plants Management Teams**[57] have highlighted a list of 18 target species for management and provide the expertise needed to prevent introductions of new species, reduce existing infestations, and restore native plant communities and ecosystem functions at national parks across the region. Other regional organizations such as the **Northeast-Midwest State Foresters Alliance**[58] consider invasive species a key issue and are working to identify and prioritize research needs as well as effective prevention, management, and restoration actions.

Table 3.2 Data resources and tools related to invasive species. For more information on each of these data resources and tools, see the associated citation and link.

Database	*Data Manager*	*Citation & URL*
Plant List of Attributes, Names, Taxonomy, and Symbols (PLANTS) – Invasive and Noxious Species Search	USDA – NRCS	(USDA NRCS 2023) https://plants.usda.gov/home/noxiousInvasiveSearch
US Register of Introduced and Invasive Species (US-RIIS)	USGS	(Simpson et al. 2022) https://www.sciencebase.gov/catalog/item/62d59ae5d34e87fffb2dda99
Nonindigenous Aquatic Species (NAS) Database and Flood and Storm Tracker (FaST) maps	USGS	(USGS 2023) http://nas.er.usgs.gov

Invasive Species Habitat Tool (INHABIT)	USGS	(Englestad et al. 2022) https://gis.usgs.gov/inhabit/
Catalog of US Federal Early Detection/Rapid Response Invasive Species	USGS	(Simpson et al. 2020) https://www.sciencebase.gov/catalog/item/5bf87027e4b045bfcae2ece6
*climatch*R	USGS	(Erickson et al. 2022) https://www.usgs.gov/software/climatchr-implementation-climatch-r
National Institute of Invasive Species Science (NIISS) Database	USDA	(National Institute of Invasive Species Science 2017) https://data.nal.usda.gov/dataset/national-institute-invasive-species-science-niiss-database
Early Detection and Distribution Mapping System (EDDMapS)	Center for Invasive Species and Ecosystem Health	(CISEH 2023) https://www.eddmaps.org/
Invasive and Exotic Species of North America	Center for Invasive Species and Ecosystem Health	(CISEH 2018) https://www.invasive.org/index.cfm
Invasive Plant Atlas of the United States	NPS, Center for Invasive Species and Ecosystem Health	(Swearingen and Bargeron 2016) https://www.invasiveplantatlas.org/
Global Avian Invasions Atlas (GAVIA)		(Dyer et al. 2017) https://figshare.com/articles/dataset/Data_from_The_Global_Avian_Invasions_Atlas_-_A_database_of_alien_bird_distributions_worldwide/4234850

The Great Lakes region has additional programs. The **EPA's Great Lakes program**[59]manages aquatic nuisance species. Their resource page has information on the aquatic invaders present and the work EPA is doing to address them. The Great Lakes Environmental Research Laboratory and NOAA maintain the **Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS)**[60], a one-stop shop for information about aquatic nonindigenous species in the region. GLANSIS provides tools to generate custom lists of species for a geographic area of interest, explore species distributions and data through a map tool, and access risk assessment literature, methods, and project results from partners. The system integrates spatial datasets from collaborators, allowing the exploration of habitat relationships and the creation of custom maps. Partners supporting GLANSIS include the Great Lakes Sea Grant Network, GLRI, USGS, and others.

Several regional tools are also available. The **Invasive Plant Atlas of New England**, which later became the Invasive Plant Atlas of the United States, was one of the first tools that documented both presence and absence data for the region using citizen science (Bois et al. 2011). The **Marine Invader Monitoring and Information Collaborative (MIMIC)**[61] is another citizen science tool that has been searching for marine invaders along the New England Coast since 2006. Another major partner in the region, the **Northeast Climate Adaptation Science Center**[62], coordinates the **Regional Effort on Invasive Species and Climate Change (RISCC) Management**[63] program, an initiative that aims to develop management-relevant research to improve invasive species management in the face of climate change. RISCC produces 2-page management challenge documents that synthesize the current state of knowledge about a topic related to invasive species and climate change, such as identifying **100 plant species likely to invade** the region in the future (Bradley et al. 2020). A similar effort is underway to identify the **top 100 aquatic species likely to invade** the Northeast[64].

Many states are exploring new tools for invasive species monitoring. Larson et al. (2020) **reviewed several tools with significant potential, especially for the early detection of invasive species**, including eDNA, remote sensing, and citizen science. Many states are already using new citizen science-based tools such as **iMap Invasives**[65], **EDDMapS**[66], and **iNaturalist**[67] as reporting systems for invasive species. Some states have more coordinated programs dedicated to invasive species, such as **New York's Partnerships for Regional Invasive Species Management**[68]. States are also attempting to reduce the chances of new invasions by addressing potential invasion pathways. Except for the District of Columbia, every state in the Northeast Region **regulates the sale of some invasive plant species**, though enforcement of these regulations is varied (Beaury et al. 2021). **Education programs and regulations** aiming to reduce the transport of firewood containing Emerald Ash Borer, the release of bait species such as crayfish, worms, or minnows, the movement of any Spotted Lanternfly life stage, and the movement of invasive plants and mussels snagged on boats and trailers between water bodies are widespread across the Northeast. **Native Plant Societies** perform education and outreach about the value of native and the hazards of non-native plants in individuals' gardens and on the landscape.

PROBLEMATIC NATIVE PLANTS & ANIMALS

For most species, interactions with other native species that result in mortality, such as predation and competition, occur at a natural rate that is not a cause of population decline. Native plant and animal species generally become problematic because some other factor acts as either a competitive benefit or a stressor to one of the species in the ecosystem, upsetting the ecological balance with the others. This may mean the impacts of these interactions with native species may result in higher levels of mortality than in less impacted systems.

THREAT DESCRIPTIONS AND EXAMPLES

Increased predation by mesopredators (Threat 8.2.5) is one of the most prominent threats in this category. Many native mesopredators are subsidized by human activities. Humans can create large influxes of resources that release predators from bottom-up controls, allowing predator populations to grow beyond what local prey populations can support (Newsome et al. 2015). Anthropogenic fragmentation may also enable predators to travel greater distances more quickly (Beyer et al. 2016, Gómez-Catasús et al. 2021) or make certain habitats more permeable to predators, and thus prey species more vulnerable (Schneider 2001, Chalfoun et al. 2002). For many turtles and songbirds, increased nest predation by Raccoons (*Procyon lotor*) and Striped Skunks (*Mephitis mephitis*) is a major concern. Freshwater mussels have many native predators, including Raccoons, Otters (*Lontra canadensis*), Muskrats (*Ondatra zibethicus*), turtles, and birds, whose predation rates are compounding declines caused by other threats. The stocking of Striped Bass (*Morone* saxatilis) has contributed to population increases for this species, which in turn is contributing to declines of prey species such as the American Eel (*Anguilla* rostrata). Shorebird species are facing increasing predation following the widespread recovery of falcons (Ydenberg et al. 2017, Hope et al. 2020). Other native mesopredators that are having increasing impacts include Coyotes (*Canis latrans*), Bobcats (*Lynx rufus*), and gulls. Increased predation by large predators (Threat 8.2.6) is much less of a concern in this region, as most large predators, such as Wolves (*Canis lupus*) and Cougars (*Puma concolor*), are considered extirpated from the Northeast.

In marine ecosystems, the primary large predators in the region are seals and sharks. The recovery of these species, especially Harbor and Gray Seals (*Phoca vitulina* and *Halichoerus grypus*, respectively) and White Sharks (*Carcharodon carcharias*), has been a contentious issue in coastal New England, encompassing fisheries management, human safety, and conservation (Bogomolni et al. 2021, Bratton 2022). These top predators can alter fish behavior (Shea et al. 2020) and abundance and may also depredate fish from fishing gear (Jog et al. 2022), sparking concern from commercial and recreational fisheries. Though some research has suggested that the impact of these predators on the local fisheries is minor (e.g., Rafferty et al. 2012), the full impacts of their recovery are still largely unknown.

Interspecific competition with favored species (Threat 8.2.8) can have similar additive impacts on priority species facing other threats. However, identifying and isolating the impacts of competition with other native species from other environmental factors is very difficult. As a result, very few species in the 2023 RSGCN and Proposed

RSGCN lists have this threat tagged as a reason for regional concern. A few of the species identified by the taxa teams include Shenandoah Salamander (*Plethodon Shenandoah*) which competes with Red-backed Salamander (*Plethodon cinereus*) for food and shelter, Atlantic Brant (*Branta bernicla hrota*) which compete with Snow Goose (*Anser caerulescens*) for habitat, Delmarva Fox Squirrel (*Sciurus niger cinereus*) which compete with Gray Squirrel (*S. carolinensis*), and Duskytail Darter (Etheostoma percnurum) which are being displaced by Fantail Darter (*E. flabellare*).

Increased grazing by vertebrate and invertebrate herbivores (Threat 8.2.2 and 8.2.3, respectively) can have direct and indirect impacts on other wildlife species. In the Northeast, White-tailed Deer (*Odocoileus virginianus*) have largely been released from predator pressure and benefit from additional anthropogenic resource availability, resulting in significant population increases. Deer browse defoliates forest understories, altering forest regeneration, species composition, biodiversity, nutrient cycling, and invasive species prevalence (Gill and Beardall 2001, Rooney and Waller 2003, Rawinski et al. 2008, Shelton et al. 2014, McWilliams et al. 2018, Kelly 2019, Hanberry and Abrams 2019). Dobson and Blossey (2015) found that deer browse had less impact than invasive earthworms on smaller plants, but the impact may increase as the plants become larger. These impacts then have indirect effects on forest species from many different taxonomic groups, including small mammals (Flowerdew and Ellwood 2001, Shelton et al. 2014), forest birds (Fuller 2001, Crystal-Ornelas et al. 2021), amphibians (Brooks 1999), and invertebrates (Stewart 2001, Shelton et al. 2014). Pollinator RSGCN include some of the species most impacted by deer browse in the Northeast region because pollinators decline as a result of the loss of key host plants (Miller et al. 1992, Wagner et al. 2003, Rooney and Waller 2003, Schweitzer et al. 2011) or plants responding to deer browse by increasing physical or chemical defenses (Lind et al. 2012). Experiments in Japan have shown pollinator diversity increases when deer are excluded from grassland habitats (Nakahama 2020); experiments in the United States have shown increases in plant diversity and abundance as a result of deer exclusion, but the more direct impacts on priority pollinators have not yet been assessed (Webster et al. 2005, Dávalos et al. 2015).

Relatively few widescale **native insect pest epidemics** (Threat 8.2.4) are of concern in the Northeast. However, similar to concerns for invasive insect species, changing climactic conditions may increase the frequency, severity, or distribution of these outbreaks. Moreover, some invasive insects target the same trees as these native insects. Trees that would otherwise be able to recover from outbreaks of a single insect pest are not able to withstand the combined outbreaks of multiple species. The native and invasive insects could amplify the effects of the other pest if they attack different plant tissues, at different points in the growing season, simultaneously, or asynchronously over a multi-year period, amplifying defoliation rates and stress levels and precluding periods of recovery between outbreaks (e.g., Ward and Aukema 2019).

Generally, the impacts of these insects are indirect; defoliation and mortality of trees result in major habitat modification, which can have cascading effects across multiple trophic levels. Eastern Spruce Budworm (*Choristoneura fumiferana*) is responsible for the largest insect-caused defoliation events of coniferous forests in North America. Budworm outbreaks occur every 25-40 years and can last for a decade, but new information on the factors driving these outbreaks is still being discovered (Pureswaran et al. 2016). Several warbler species may be closely linked to these outbreak cycles, and may even play a role in determining their intensity (Venier and Holmes 2010). Budworm outbreaks and the associated forest mortality may have particular impacts on several RSGCN salamanders and snakes (Mitchell 1991) and Canada Lynx (*Lynx canadensis*; Hoving et al. 2004). Sothern Pine Beetle (*Dendroctonus frontalis*) has long been a management concern in the Southeast but has now been found as far north as Rhode Island and Massachusetts. It is associated with the mortality of hard pine species, especially Pitch Pine (*Pinus rigida*), though the full impact on northeastern pine species is not yet known (Dodds et al. 2018). This beetle may be a particular concern for pitch pine barrens, a rare xeric habitat type associated with many unique species. Pine Beetle outbreaks may represent an increase in resource availability for certain insectivorous species, such as woodpeckers, but these benefits may be outweighed by the loss of critical nesting trees and the changes to over- and understory structure (Tchakerian and Coulson 2011). The Forest Tent Caterpillar (*Malacosoma disstria*) is one of the most widely distributed insects in North America and is a pest of oak, maple, and aspen species (Dukes et al. 2009). Outbreaks of this species are generally shorter, lasting only 3-4 years, but repeated defoliation can result in significant mortality (Dukes et al. 2009).

Ectoparasites (Threat 8.2.7) are another threat that is currently of conservation concern in the Northeast, in part because the effects of many parasites at the individual and population levels are not always well understood. In general, these parasites induce limited mortality in their hosts as they consume relatively small amounts of blood before falling off to complete the rest of their life cycle. However, ectoparasites can cause host mortality if parasite loads become excessive. Winter Tick (*Dermacentor albipictus*) populations have been increasing as a result of warmer, milder winters. Larger parasite loads are resulting in unprecedented mortality rates – greater than 50% – in Moose (*Alces alces*) calves across the southern parts of their distribution (Jones et al. 2019, DeBow et al. 2021). The tick is also reducing female productivity, increasing the likelihood of failed pregnancies, especially in smaller individuals (Pekins 2020). Though Moose are currently Watchlist rather than RSGCN in the Northeast, this parasite is a high priority as managers are still trying to determine the full impacts. Another mammalian ectoparasite, sarcoptic mange, is caused by the mite *Sarcoptes scabiei*. This mite can result in hair loss, skin irritation, and fissuring, and can result in mortality as a result of emaciation or secondary infections of the skin (Niedringhaus et al. 2019). Sarcoptic mange is commonly associated with Red Foxes (*Vulpes vulpes*), Gray Wolves (*Canis lupus*), Coyotes (*Canis latrans*), and American Black Bears (*Ursus americanus*), but can also infect humans and domestic animals (Niederinghaus et al. 2019). This wide host range suggests the mite is highly adaptable and could move to other high-priority species. Gray Fox (*Urocynon cinereoargenteus*) is a Watchlist species that overlaps significantly with several of the other commonly infected species. However, mange is extremely rare in Gray Fox, a phenomenon that is poorly understood and deserves further research (Niederinghaus et al. 2019).

Though currently poorly understood, the potential role of ectoparasites on freshwater mussel declines is being highlighted as a serious data gap that needs to be addressed (Gangloff et al. 2008, Brian and Aldridge 2019, Aldridge et al. 2023). A large group of parasitic copepods, collectively known as sea lice, may be a concern for many marine and diadromous fishes. These parasites exist at low levels in the environment, but can reach harmful levels in fish farms and aquaculture facilities and spread to wild populations (Johnson et al. 2004, Costello 2009, Frazer et al. 2012). The impacts of the louse (*Lepeophtheirus salmonis*) on Atlantic Salmon (*Salmo salar*) are particularly well-studied and include elevated stress levels, reduced recruitment, and mortality (e.g., Krkosek et al. 2013, Ugelvik and Dalvin 2022). This concern is largely tied to farmed fish and closely related species, but monitoring for outbreaks of other sea lice species should continue in high-priority fish.

Habitat alteration by beavers (Threat 8.2.1) can have major impacts on both terrestrial and aquatic RSGCN. Beavers are widely acknowledged as ecosystem engineers as their activities profoundly alter hydrological, geomorphological, and ecological characteristics and processes within their environment, increasing landscape heterogeneity (Rosell et al. 2005, Brazier et al. 2020). Beaver meadows are often associated with high biodiversity; studies have shown increased species richness of plants (Wright et al. 2002, Bartel et al. 2010), birds (Rossel et al. 2005, Nummi and Holopainen 2014), mammals (Rossel et al. 2005, Nelner and Hood 2011), fish (Rosell et al. 2005), and amphibians (Cunningham et al. 2007), and increased habitat suitability for rare butterflies (Bartel et al. 2010), and fish (Rosell et al. 2005, Malison et al. 2014, Bylak and Kukula 2018). For some aquatic species, the presence of beaver dams is detrimental. Beaver-modified landscapes favor lentic species over lotic ones, often inundating stream features such as riffles that are important to many aquatic invertebrates (Rosell et al. 2005, Washko et al. 2022). The inundated water above the dam can be significantly warmer, which influences oxygen levels and can result in die-offs under extreme conditions (Rosell et al. 2005, Kemp et al. 2012). The dams slow water flow rates, which impacts downstream sedimentation and forms a physical barrier to stream connectivity, both of which can have severe impacts on fish and mussel species that are already impacted by stream fragmentation (Rosell et al. 2005, Kemp et al. 2012).

Though not a category identified by the Quebec Standardized Classification of Threats, **harmful algal blooms** are a group of problematic species with significant impacts in the Northeast. Various species of phytoplankton, macroalgae, cyanobacteria, and even some protists are present in fresh, brackish, or marine environments. They form the basis of many aquatic food chains and are a critical food resource for many species, especially during the early spring when few other resources are available (Porter 1977, Sigler et al. 2014). However, under certain conditions, high nutrient loads and warmer temperatures promote excessive algal growth, while wind conditions, tides, and currents consolidate the algae in large colonies, often referred to as bloom (Paerl et al. 2001, Sellner et al. 2003, McGillicuddy et al. 2003, Anderson et al. 2008, Gobler et al. 2017, Griffith and Gobler 2020). These blooms can create floating mats or cloud the water, blocking sunlight from reaching benthic plants and invertebrates and depleting nutrients from the water (Paerl et al. 2001, Gatz 2020). Some forms of algal blooms can become barriers to movement, forcing animals away from important resources (Maurer et al. 2021). They also create anoxic conditions and deplete oxygen levels in the water body either directly by extracting it for photosynthesis or indirectly after the algae die and decompose, which leads to die-offs of fish and mussels (Paerl et al. 2001, Gatz 2020). Some forms of harmful algae produce toxic compounds, which can lead to severe health consequences or mortality when ingested (Nelson et al. 2003, Shumway et al. 2003, Sellner et al. 2003, Broadwater et al. 2018, Gatz 2020). Harmful algal blooms are known to cause mortality in fish (Paerl et al. 2001, Fire et al. 2012, Starr et al. 2017), marine mammals (Simeone et al. 2015, Starr et al. 2017, Broadwater et al. 2018), birds (Shumway et al. 2003, Stewart et al. 2008, Starr et al. 2017, Rattner et al. 2022), sea turtles (Amaya et al. 2018, Ley-Quiñónez et al. 2020), shellfish (Shumway 1990, Griffith et al. 2019), marine invertebrates (Turner et al. 2021), and terrestrial species including domestic animals and humans (Pybus et al. 1986, Shumway 1990, Stewart et al. 2008).

RELATIONSHIPS WITH OTHER THREATS

Human activity in Residential & Commercial Development (Threat 1.0) subsidizes several species, such as Raccoons, by providing additional food resources and allowing their populations to grow far beyond what their prey can support. Agriculture & Aquaculture (Threat 2.0) can also provide additional resources for these human-adapted species, such as White-Tailed Deer feeding in agricultural fields. Transportation & Service Corridors (Threat 4.0) have altered how some animals move through the environment, in some cases creating pathways that enable predators to travel more quickly between habitats and in others causing avoidance of fragmented areas. Species already impacted by forms of development and agriculture, Energy Production & Mining (Threat 3.0), Biological Resource Use (Threat 5.0), Human Intrusions & Disturbance (Threat 6.0), or Natural System Modifications (Threat 7.0), may become more susceptible to other impacts caused by interactions with native species.

Climate Change (Threat 11.0) is altering the ecosystems and interspecific interactions of native species. Species that are better able to adjust to changing temperature and precipitation regimes have a competitive edge over species that are not able to respond as quickly. Climate change is expected to result in many species shifting further north or up in elevation to remain within their preferred climatic conditions (Ralston et al. 2017). However, high elevation and headwater species don't have much space to move into, leaving these species trapped between limited habitat availability and competition from other species moving into their existing range (Sekercioglu et al. 2008, but see Urban 2018). Some of these interspecific interactions are even more complicated; Dallalio et al. (2017) demonstrated that climate change may actually decrease competition between Shenandoah Salamander (*Plethodon shenandoah*), a high-elevation RSGCN, and Red-backed Salamander (*Plethodon cinereus*), but increased water temperatures would largely counteract this potential benefit. Some native insects and arthropods may also benefit from climate change. Historically, winter temperatures in the Northeast restricted the northernmost distributional edge of a species or caused sufficiently high winter mortality to prevent major outbreaks. Warmer, milder winters are allowing the Southern Pine Beetle to expand far beyond its historical range and increasing Winter Tick populations to lethal levels.

Climate Change (Threat 11.0) and Pollution (Threat 9.0) amplify harmful algal blooms. Nutrient inputs from wastewater, fertilizers, aquaculture facilities, and other sources are a major component in bloom formation (Sellner et al. 2003, Anderson et al. 2008). The influx of nutrients supports much larger algal populations than the water body otherwise could. Warmer temperatures allow algae to grow faster, and elevated atmospheric CO_2 levels provide additional resources for photosynthesis that match the increased nutrient availability (Gobler et al. 2017, Griffith and Gobler 2020).

TOOLS AND RESOURCES

Resources for monitoring or tracking problematic native species tend to be localized because the impacts of many problematic native species are context dependent and are not always negative.

The US National Phenology Network[69] produces short-term **Pheno Forecast maps** as a tool to inform management and monitoring actions (Crimmins et al. 2020). These maps depict the status of the insect's life cycle across the United States and are updated daily. Native insect pests that the Phenology Network currently forecasts include Apple Maggot (*Rhagoletis pomonella*), Bagworm (*Thyridopteryx ephemeraeformis*), Bronze Birch Borer (*Agrilus anxius*), Eastern Tent Caterpillar (*Malacosoma americanum*), Lilac Borer (*Podosesia syringae*), Magnolia Scale (*Neolecanium cornuparvum*), and Pine Needle Scale (*Chionaspis pinifoliae*).

The **Assessing Vegetation Impacts by Deer (AVID)**[70] project sponsored by Cornell University and the New York Department of Environmental Conservation engages citizen scientists in monitoring plants for one year to document the impact of deer browsing on forest health.

A diverse suite of resources is available for harmful algal blooms. The US Geological Survey[71,72], Environmental Protection Agency[73], National Oceanic and Atmospheric Administration[74], National Institute of Environmental Health Sciences[75], Center for Disease Control[76], and National Office for Harmful Algal Blooms[77] all have **website hubs with numerous resources, publications, and data** about harmful algal blooms. The National Oceanic and Atmospheric Administration's **National Centers for Coastal Ocean Science** has produced useful tools for forecasting and monitoring algal blooms[78,79], allowing managers to plan for and respond to these events more rapidly. Algae blooms are also tracked globally in the **Harmful Algal Event Database** and the **Harmful Algal Information System** (IOC UNESCO 2023a,b). The Intergovernmental Oceanographic Commission of UNESCO maintains these products and provides access to information on harmful algal events, harmful algae monitoring and management systems worldwide, and maps and data products.

New tools for predicting the impacts of algal blooms and methods for detecting them are also being developed. Chapra et al. (2017) developed a modeling framework for **predicting the effect climate change** is likely to have on reservoirs and highlighted that some of the largest increases in the occurrence of cyanobacterial harmful algal blooms will likely be in the Northeast. Ralston and Moore (2020) reviewed recent studies modeling harmful algal blooms and their response to climate change and made **recommendations for improving future modeling efforts**. Multiple researchers have also been exploring the use of **remote sensing technology** as a tool for identifying, tracking, and understanding harmful algal blooms (Isenstein et al. 2014, Wolny et al. 2020).

INTRODUCED GENETIC MATERIAL

The scientific literature has long acknowledged that the introduction of novel genetic material can have severe impacts on wild populations (Cross 2000, Mooney and Cleland 2001, Araki and Schmid 2010, Valiquette et al. 2014, Todesco et al. 2016, Varney et al. 2018). Sources of genetic variation can be human-altered, human-transported, or natural. Though the source of the introduced genetic material may vary, the overall result is the hybridization of local and novel individuals and the introgression of non-native genes into the broader population. Hybridization is a complex issue, with important implications for conservation (Woodruff 1973, Allendorf et al. 2001, Genovart 2009). It is also important to note that hybridization is largely a natural process and not intrinsically a threat (Barton 2001, Abbott et al. 2013, Adavoudi and Pilot 2022). Hybridization can occur naturally as isolated events (e.g., Hull et al. 2007) or occasionally within hybridization zones, areas of overlap between two species' distributions (e.g., Koen et al. 2014). In these cases, the incidence of hybridization is generally low enough to not have major impacts on the species as a whole. Hybridization is more likely to have negative impacts on a population if it is already facing other stressors that have restricted the total number of breeding individuals or if the population is naturally genetically isolated.

There are three primary ways hybridization can threaten a species: (1) hybrids are fitter than their progenitors, (2) hybrids are less fit than their progenitors, or (3) hybridization changes the genetic landscape for the parent species (Todesco et al. 2016). Hybrids that are fitter than their progenitors competitively exclude one or both of the parent species and may eventually replace them in the landscape in a process referred to as genetic swamping (Wolf et al. 2001, Todesco et al. 2016). Candy Darter (*Etheostoma osburni*), a federally endangered RSGCN, is an example of genetic swamping in the Northeast, as hybridization with Variegate Darter (*E. variatum*) is widespread and still spreading (Gibson et al. 2019). Swamping can also occur with genetic units besides species, such as in island populations of American Marten (*Martes americana*) and translocated mainland populations (Colella et al. 2019) and native subspecies of *Phragmites* with the highly invasive subspecies (Meyerson et al. 2010). Hybrids that are less fit than their progenitors or that carry maladaptive traits can lead to the extinction of the parent species by reducing reproductive success and wasting reproductive effort, referred to as demographic swamping (Wolf et al. 2001, Todesco et al. 2016). Demographic swamping is much less common than genetic swamping and is more frequently observed in plant species (Todesco et al. 2016). The final impact of hybridization, changes to the genetic landscape, are the result of the introgression of new genes into the greater population or species, rather than individual-level interactions.

The impacts of these population or species-level genetic changes can be grouped into four categories: loss of genetic variation, breakdown of localized adaptation, changes to the within-population genetic composition, and simplification of the population structure between populations (Laikre et al. 2010). Decreased genetic variation can occur as a result of a large influx of introduced, very similar genetic material, such as would occur when stocking fish or animals for recreational use. These genetically swamped populations are more susceptible to outbreaks of disease or parasites, which can further decrease genetic variation as the population collapses (Laikre et al. 2010). The spread of non-native genes can interfere with localized adaptation, reducing fitness by replacing alleles with non-adaptive ones (Laikre et al. 2010). In populations that were previously isolated, this can reverse evolutionary trajectories and potential speciation by returning the population to a similar composition to populations elsewhere (Laikre et al.

2010). The genetic composition of a population – the particular mix of alleles present – can change if the introduced genetic material contains alleles that were not previously present (Laikre et al. 2010). Finally, genetic structure – the organization of genetically distinct populations across a landscape or species' range – can be impacted by releases that homogenize the genetic composition between populations (Laikre et al. 2010). In some cases, intermixing of the local and introduced genetics via hybridization is not necessary for these deleterious effects to occur; the introduced individuals could outcompete or prey on native populations or increase the transmission of diseases or parasites that disproportionately impact the native individuals (Weber and Fausch 2003, Bradbury et al. 2020).

The impacts of introduced genetic material are particularly well studied in farmed fish species, such as the Atlantic Salmon (*Salmo salar*; Lage and Kornfield 2006), but the implications are similar for farmed shellfish (Varney et al. 2018), marine species (Kitada 2018), and gamebirds (Evans et al. 2009, Champagnon et al. 2009, Champagnon et al. 2012), as well as for recovery activities for freshwater mussels (Hoftyzer et al. 2008, McMurray and Roe 2017), fish (Minckley 1995, George et al. 2009), and mammals (Pacioni et al. 2019).

THREAT DESCRIPTIONS AND EXAMPLES

Human-altered genes generally come from cultivated sources, such as agriculture (Threat 8.3.1), silviculture (Threat 8.3.2), and aquaculture (Threat 8.3.3). This includes both genetically modified organisms (GMOs) and breeding stock where intentional or unintentional human choices and actions result in artificial selection, such as selecting for more domesticated individuals (Hagen et al. 2019). These genes generally enter wild populations either due to individuals escaping cultivation facilities, broadcast distribution of gametes, such as is the case for wind-pollinated plants or spawning fish or shellfish, or the release of large numbers of captively raised recreational species, often referred to as stocking. **Human-transported genes** are the result of stocking efforts that do not utilize local populations as broodstock, the translocation of individuals from another population in an attempt to bolster a failing population or reintroduce a species to an area where it has been extirpated, or hybridization with non-native species. For stocked species, differentiating between human-altered and human-transported genes can be very difficult, and both may be occurring depending on propagation facility practices.

In the Northeast, cultured or stocked species are a major source of human-transported genetic material. Atlantic salmon are farmed offshore in Maine and have been stocked from many different sources across the region, resulting in very few wild populations with sufficient genetic integrity (Lage and Kornfield 2006). The contamination of their genetics prompted the Fish Taxa Team to specify that only the wild populations should be listed as RSGCN in the 2023 list. Other fish species with a history of stocking that may be influencing wild genetics include Striped Bass (*Morone saxatilis*; Woods et al. 1995, LeBlanc et al. 2019), lake trout (*Salvelinus namaycush*; Krueger and Ihssen 1995, Baillie et al. 2015), and brook trout (*Salvelinus fontinalis*; Perkins et al. 1993, Kazyak et al. 2022), all of which are included in the 2023 list as Watchlist [Assessment Priority] species. Cultured shellfish are known to influence the genetics of nearby populations of Eastern Oysters (*Crassotrea virginica*; Varney et al. 2018) and may also impact Bay Scallops (*Argopecten irradians*; Bert et al. 2011). Northern Bobwhites (*Colinus virginianus*) have a long history of being stocked in the region. Extensive research has been conducted to determine the impact of these introduced individuals on wild population survival rates (deVos and Speake 1995, Sisson et al. 2000), productivity (Eggert et al. 2009), behavior (Hutchins 2003, Eggert et al. 2009), and genetic integrity (Valentine 1997, Evans et al. 2006). Bobwhite populations in the Northeast are heavily impacted by these releases; the Bird Taxa Team suggested that Virginia is the only state that likely still has viable wild populations, supporting their decision to defer this species to the Southeast and Midwest which support more populations with wild genetics.

Hybridization between co-occurring native species is also a concern for some of the species on the 2023 Northeast RSGCN list. Perhaps one of the most famous examples is the hybridization between Golden-winged and Blue-winged Warblers (*Vermivora chrysoptera* and *V. cyanoptera*, respectively), which is contributing to declines in the Golden-winged Warbler (Gill 1980, Vallender et al. 2007). Mallards (*Anas platyrhynchos*) and American Black Duck (*Anas rubripes*) form a species complex, with the genetic distance between the two species decreasing (Heusmann 1976, Mank et al. 2004, Lavretsky et al. 2019). In addition to the Candy Darter, hybridization is a concern for Slender Chub (*Erimystax cahni*; Kuhadja et al. 2009) and Stripeback Darter (*Percina notogramma*; Loos and Woolcot 1969). Saltmarsh Sparrow (*Ammospiza caudacuta*), a species already facing significant impacts due to habitat and sea level rise, may be hybridizing with Nelson's Sparrow (*Ammospiza nelson*; Shriver et al. 2005, Walsh et al. 2011).

RELATIONSHIPS WITH OTHER THREATS

As the source of much introduced genetic material comes from cultivated sources, this threat is tightly tied to Agriculture & Aquaculture (Threat 2). Because these sources of genetic contamination are embedded within the landscape, it is difficult, if not impossible, to prevent all introductions. Many aquaculture facilities attempt to sterilize their crops as a method of reproductive and genetic containment, but these are not always successful (Piferrer et al. 2009, Golpour et al. 2016, Xu et al. 2022). Continued work will be necessary to further improve methodologies for preventing the intrusion of foreign genetic material into native populations. Climate Change (Threat 11.0) may also influence this threat by potentially expanding the ranges of some species, either native or invasive, and increasing the area of the hybridization zone.

TOOLS AND RESOURCES

Several authors have **assessed the success rates of animal translocations** and may provide additional insights into the viability of translocations as a recovery tool for imperiled populations (Griffith et al. 1989, Seddon 1999, Fischer and Lindenmayer 2000). The release of individuals to bolster a species, whether for recreational or recovery purposes, should consider the genetics of both the wild and introduced populations to prevent the introduction of detrimental genetic material. Other important considerations include randomly selecting individuals to prevent artificial selection, ensuring there are sufficient breeders to capture the genetic variability of the population, and not stocking in areas where the wild populations are stable due to natural reproduction rates (Ryman 1991, Jennings et al. 2010). Genetic considerations for recovery work are often complicated by the fact that locally adapted populations may be extirpated or too small to support the removal of individuals for breeding. In these cases, the selection of an appropriate genetic source is a primary consideration, as is ensuring the habitat and other conditions will contribute to the successful establishment of the released individuals and establishing monitoring protocols to track the success or failure of individuals. The IUCN's Species Survival Commission produced the **Guidelines for Reintroduction and Other Conservation Translocations**, a handbook that outlines considerations that should be made before, during, and after any recovery effort (IUCN SSC 2013). George et al. (2009) provide additional **guidelines specific to the propagation and translocation of freshwater fish**.

A growing topic related to stocking is climate-adaptive population supplementation. The idea of this concept is to use stocking practices to align climate-associated traits, such as drought or thermal tolerance, of propagated species with the likely future environmental conditions at the places they are released. The Northeast Climate Adaptation Science Center hosted a **Climate-Adaptive Population Supplementation Workshop**[80] in 2022 that brought together individuals from federal and state agencies, academic institutions, nonprofit organizations, and private companies together to develop this concept and discuss how they could contribute to managing priority populations.

PATHOGENS & MICROBES

Most discussions about pathogens and microbes focus on the negative impacts on their hosts, widespread outbreaks, and their potential role in species extirpation or extinction. However, much like native predators, pathogens and microbes are an integral part of all ecosystems that co-evolved with the community. Through their direct influence on their hosts, they shape populations, communities, and ecosystems (Hudson et al. 2006, Preston et al. 2016). Increasingly, research is demonstrating the importance of these microscopic organisms as sources of biodiversity, mediators of inter- and intra-specific interactions, directors of energy flow and biomass in food webs, modifiers of biogeochemical cycles, sources of disturbance dynamics, and even shapers of evolutionary pathways (Hudson et al. 2006, Thompson et al. 2010, Selakovic et al. 2014, Preston et al. 2016, Hamede et al. 2020).

As was the case with Ectoparasites (Threat 8.2.7), many pathogens and microbes are present in the environment but remain at low enough levels that they do not have much impact. However, under certain conditions, a pathogen or microbe that was previously relatively benign can shift into an emerging infectious disease with severe and widespread impacts (Daszak et al. 2000, Adlard et al. 2015). There are two primary theories for explaining why the characteristics of a disease change: the novel and endemic pathogen hypotheses. The dynamics of novel pathogens share many similarities with invasive species. Novel pathogens are those that have expanded or been introduced into a new area or have evolved a new strain. Thus, their hosts are naïve and highly susceptible to infection (Rachowicz et al. 2005). Endemic pathogens were already present in the environment but have either shifted into a new host, have changed the intensity of their effects due to other environmental factors and stressors, or escaped prior human notice (Rachowicz et al. 2005). Understanding whether a pathogen is novel or endemic has important conservation implications, as the methods for managing the pathogen may differ. The focus for novel pathogens is often on controlling distribution, while endemic pathogen studies often focus on understanding the environmental conditions that have increased the intensity of the effects on the host (Rachowicz et al. 2005). Experimental tests and genetic testing may be able to help identify the pathogen's origins (e.g., Rachowicz et al. 2005, Warnecke et al. 2012).

Much of the earlier study of wildlife diseases was focused on zoo animals and zoonotic diseases, infections that spread between humans and animals. Recent decades have seen an increase in research on emerging infectious diseases in wildlife, driven by increased awareness and advances in the fields of parasitology and epizoology (Daszak et al. 2000, Cunningham et al. 2017). The reason that these pathogens are such great threats to wildlife populations is that they are infectious; healthy organisms can become infected via contact with other individuals of the same or different species or from the environment.

For some infectious diseases, multiple hosts are necessary for different life stages. An example of this is a disease that requires a reservoir species where the disease can survive and multiply, a primary host where the disease reaches sexual maturity, and a vector species that transmits the disease between the two. Lyme disease, one of the most frequently reported vector-caused diseases in the Northeast, is caused by the bacterium

Borellia burgdorferi, for which the primary vectors are ticks in the genus *Ixodes* (Kilpatrick et al. 2017). Tick larvae feed on small vertebrates, including White-Footed Mice (*Peromyscus leucopus*), the primary reservoir for *B. burgdorferi* (Ostfeld et al. 2006). Nymphs and adults feed on a variety of larger mammals, transmitting the bacterium as it feeds. White-tailed Deer are the predominant host for these later life stages, but other animals, including livestock, dogs, and humans, can be infected with Lyme disease. With so many hosts, managing this disease is difficult, especially since we know that climatic and forest masting conditions influence the risk of Lyme disease indirectly by favoring the tick hosts (Ostfeld et al. 2006, Bregnard et al. 2021). In the Northeast, ticks and mosquitoes are the primary vectors of several diseases, and snails are vectors for several wildlife parasites.

Another form of transmission between species is the introduction of a disease into a host it did not previously infect. Most infectious diseases are specific to certain hosts; transmission to other species is unlikely because the disease cannot survive and reproduce in alternative hosts. Under certain conditions, a disease may adapt or mutate, allowing it to be transmitted to a new host species. There are three possible outcomes of transmission to a new species: isolated infection events between the original and new hosts that do not spread (dead-end hosts), infections that spread between the old and the new host across a local population before fading (spillover), and epidemic or sustained transmission between members of the new host species (host-switching) (Parrish et al. 2018). Dead-end hosts are not generally a concern for wildlife management except as a potential signal of an emerging spillover or host-switching event. Often, spillover events happen at the intersection of wildlife and domestic animals, such as the transmission of bovine tuberculosis and epizootic hemorrhagic disease from farm animals to White-tailed Deer, or canine distemper and parvoviruses transmitting between domestic dogs and wild carnivores. Host-switching is one of the biggest concerns in disease ecology, as it can result in the widespread transmission of highly virulent diseases.

Though not a direct threat to wildlife populations, the impacts on human health are a critical component of disease and wildlife management. Increasing human populations, combined with the invasion of natural habitats, are resulting in an increased frequency of zoonotic outbreaks (van der Hoek et al. 2018). In the Northeast, many communities exist within a matrix of wildlife populations, resulting in many opportunities for the transmission of diseases that have major impacts on humans. This includes the recent global COVID-19 pandemic, a zoonotic originally transferred from bats that we now know can also spillover into other wildlife species that act as reservoirs for the disease, including White-tailed Deer in the United States (Kuchipudi et al. 2022). For more information on other zoonotic diseases in the United States, see (US DHHS et al. 2017). Recognition that human, animal, and ecosystem health are intrinsically intertwined has led to the One Health concept, which advocates for holistic and transdisciplinary approaches to disease (Destoumieux-Garzón et al. 2018). One Health is increasingly incorporated into research on wildlife health (e.g., Jenkins et al. 2015, Cunningham et al. 2017, Turner et al. 2021, Kuchipudi et al. 2022), helping to build a fuller understanding of the impacts on target species, implications for human health, and potential management approaches.

All Northeast RSGCN are vulnerable to the threat of infectious disease. Emerging diseases are potentially more urgent and dynamic than other top threats, making them a challenge to manage. The complexity of coping with this threat is apparent when considering that diseases can be introduced and spread through many vectors and then exacerbated by pervasive anthropogenic and environmental factors. Again, similar to invasive species, the most effective management tool for diseases is to prevent their establishment. States must collaborate on this shared threat because of potential rapid transmission beyond state borders and the difficulties of controlling or eradicating diseases once established in native populations. Once established, strategic approaches require regional protocols and planning to react quickly and effectively to minimize the impacts of new and emerging diseases while also working continuously to manage diseases and invasions that are already affecting populations.

THREAT DESCRIPTIONS AND EXAMPLES

Various infectious agents cause diseases in wildlife. This includes **bacterial** (Threat 8.4.1), **viral** (Threat 8.4.2), and **fungal pathogens** (Threat 8.4.3), various internal parasites including **worm-induced** (Threat 8.4.4), and **protozoan-induced diseases** (Threat 8.4.5), and prion diseases (Threat 8.4.6). These infectious agents vary in terms of biology and infection mechanisms[81]. For an in-depth overview of methodologies and techniques applicable to studying wildlife diseases, see Franson et al. (2015).

Wildlife diseases in the Northeast are too diverse to summarize based on infectious agents, general effects, or even impacted species. Instead, the sections below provide a brief overview of high-concern diseases broken out by broad taxonomic groups.

MAMMALS

The pathogens and microbes impacting mammals are better studied than those of many other taxonomic groups in part due to the increased risk of zoonotic disease transference between wildlife, livestock and other domestic animals, and humans and the charismatic nature of many of these species.

White-Nose Syndrome (WNS) is one of the most devastating infectious diseases currently in the Northeast. Caused by the fungus *Pseudogymnoascus destructans*, the disease was first identified in bats in New York in 2006, making the Northeast the epicenter. The disease was highly virulent and spread rapidly, highlighting the need for focused research and monitoring (Blehert et al. 2009). For a more detailed description of the progression of WNS and its impacts on bats, see Frick et al. (2016) and Hoyt et al. (2021). By the time of the 2013 Conservation Synthesis, WNS had been found in every state in the Northeast Region and was the focus of three regionally funded projects (TCI and NEFWDTC 2013). For a description of these projects, see *Chapter 4*. At this time, researchers had determined that White-Nose Syndrome caused skin damage and altered the torpor cycle and metabolism of overwintering bats (Cryan et al. 2010), recognized that the disease was causing precipitous declines in several bat species (Gargas et al. 2009, Frick et al. 2010), assessed key data gaps and methods for addressing them (Foley et al. 2011), determined the mechanism by which the fungus caused mortality (Warnecke et al. 2012), recognized that it could potentially lead to the extirpation of the federally endangered Indiana Bat (*Myotis sodalist*; Thogmartin et al. 2013), and developed tools for detecting the presence of the fungus (Lorch et al. 2013).

Research on White-Nose Syndrome has been extensive since 2013. Though not a complete list, researchers in the last decade have:

- Confirmed that the fungus is native to Europe and was introduced to North America (Leopardi et al. 2015)
- Determined that *P. destructans* is highly persistent, and can remain in the soil for years (Hoyt et al. 2015)
- Found that hibernation, and not birth pulses, are the driver in seasonal infection spikes (Langwig et al. 2015)
- Developed non-destructive tools for determining infection status and severity (McGuire et al. 2016)
- Identified changes in bat genetic structure in the region (Lilley et al. 2020, Gignoux-Wolfsohn et al. 2021)
- Found a relationship between fungal loads and mortality levels, identifying management targets (Hoyt et al. 2020)
- Studied the disease recovery process in infected bats (Fuller et al. 2020)
- Identified high-priority data gaps and research needs (Bernard et al. 2020)
- Determined preferred bat habitat also has higher fungal loads, but over time a greater portion of the population is shifting to ‘refugia’ sites where the pathogen is less prevalent (Hopkins et al. 2021)
- Quantified the scope and severity of WNS to hibernating bats (Cheng et al. 2021)
- Compared the assemblage of skin fungal communities between bat species that are and are not impacted by White-Nose Syndrome and found that impacted species have lower overall fungal diversity, and identified one yeast species that may inhibit *P. destructans* (Vanderwolf et al. 2021)
- Synthesized data from across the United States to identify trends in the response of each impacted bat species to White-Nose Syndrome (Hoyt et al. 2021)

- Evaluated the effect of artificially cooling hibernacula as a potential tool for combating White-Nose Syndrome (Turner et al. 2022)
- Field-tested an antifungal treatment that can be applied to entire bat colonies, rather than individuals, with no apparent detrimental impacts on bat behavior or health (Gabriel et al. 2022)

The White-Nose Syndrome outbreak facilitated an unprecedented level of coordination across the United States. The US Fish and Wildlife Service developed a national plan for managing White-Nose Syndrome, with seven key elements including communication, monitoring, and research (USFWS 2011). This national plan organizes the efforts of the **White-Nose Syndrome Response Team**[82] which, along with similar groups from Canada and Mexico, form the **North American Bat Conservation Alliance**[83]. These groups facilitate communication between the many individuals involved in bat conservation and share important resources such as decontamination protocols and management recommendations, while also continuing to track the spread of White-Nose Syndrome. Other national products include the **North American Bat Monitoring Protocol**, which standardizes survey methods for hibernacula and maternity colony counts and acoustic surveys (Loeb et al. 2015). The US Forest Service and US Geological Survey both have significant resources devoted to White-Nose Syndrome and produce numerous reports and research products on the subject, such as this report describing the impacts of timber harvest on forest management on three species impacted by White-Nose Syndrome (Silvis et al. 2016), or an assessment of the potential risk of transmitting the disease to North American bat populations (Runge et al. 2020). You can find more research and information on their websites.

As of 2023, White-Nose Syndrome is now known to occur in 38 US states and 8 Canadian provinces and is suspected to be present in five more states (WNS Response Team 2022). At least twelve bat species in North America are known to be impacted by this disease, including seven Northeastern species: Indiana Bat (*Myotis sodalis*), Northern long-eared Bat (*M. septentrionalis*), Little Brown Bat (*M. lucifugus*), Eastern Small-footed Bat, (*Myotis leibii*), Tri-colored Bat (*Perimyotis subflavus*), Big Brown Bat (*Eptesicus fuscus*), and Gray Bat (*Myotis grisescens*), of which the first five species are RSGCN (Hoyt et al. 2021). Most states have been tracking population declines with annual surveys. The Mammal Taxa Team indicated that declines in some species were greater than 90%, but other species appear to be stabilizing, which was also confirmed in Hoyt et al.'s (2021) results.

Another highly visible infectious disease in the Northeast is **Brainworm**. Brainworm is caused by the parasitic nematode *Parelaphostrongylus tenuis*. This parasite's primary host is White-tailed Deer (*Odocoileus virginianus*). When the nematode is sexually mature, it lays its eggs in nearby tissues. When the eggs hatch, the larvae migrate to the gastrointestinal system and are shed along with fecal material. Various gastropod species consume the mucus layer on deer pellets, consuming the immature nematode as well. Eventually, White-tailed Deer contract the parasite by consuming vegetation with contaminated snails on it. Brainworm infects the meningeal tissue of White-tailed Deer with relatively little impact. When consumed by other cervids, such as Moose (*Alces alces*), the parasite spreads into and causes significant damage to neurological tissues that results in motor impairment, limb weakness, apparent deafness or blindness, listlessness, circling or weaving movements, fearlessness, and mortality (Anderson 1964, Lankester 2010). The parasite has been found across much of northern and eastern North America since the 1960s (Anderson 1964, Wasel et al. 2003), but has become an increasing concern for Moose in the Northeast only in the last few decades (Lankester 2010, Wattles and DeStefano 2011). Brainworm infection rates in Moose are related to the density of White-tailed Deer, as higher deer populations result in increased prevalence of the parasite (Wattles and DeStephano 2011, Lankester 2018, Ditmer et al. 2020). Winter conditions play a role in controlling the population size of both White-tailed Deer as the primary host and the various gastropod species that act as intermediate hosts (Lankester 2018). As winter conditions in the Northeast get warmer and deer populations continue to grow and expand, the threat of brainworm, as well as other parasites including Winter Tick, will increase, especially on the southern distributional edge for Moose (Murray et al. 2006, Timmermann and Rodgers 2017, Lankester 2018, DeBow et al. 2021).

Another potential risk to Moose is **Chronic Wasting Disease**. Chronic Wasting Disease is a prionic disease of White-tailed Deer and is the only one known to affect free-ranging wildlife. It results in brain degeneration, emaciation, abnormal behavior, and death. For a more complete description of the history, distribution, and ecology of this disease, see Escobar et al. (2020) and other resources available from the National Wildlife Health Center. The Northeastern states have been monitoring for the disease since the early 2000s, where it is known to occur in five states (Evans et al. 2014). While the major concern with this disease is for deer and, in the western United States, elk, there have been a few isolated incidents of wild Moose contracting the disease (Baeten et al. 2007, Pirisinu et al. 2018). Until we have a better understanding of the mechanisms that lead to spillover infections in Moose, we cannot determine if this disease will become an important threat in the Northeast. Continued monitoring of Chronic Wasting Disease in both White-tailed Deer and Moose will be necessary to track the continued spread of this disease and its potential transference into other cervid species (Evans et al. 2014).

A highly contagious disease affecting rabbits and hares, **Rabbit Hemorrhagic Disease**, is of increasing concern in North America. Mortality events involving the original strain (RHDV1) of this virus have been affecting domestic and wild European rabbit (*Oryctolagus cuniculus*) populations around the world since the 1980s (Abrantes et al. 2012). However, around 2010, a new strain (RHDV2) emerged in France that was also able to infect members of the genera *Lepus* and *Sylvilagus* (Asin et al. 2022). The first outbreak of this new strain in North America occurred in captive lagomporph populations in Quebec in 2016, followed by outbreaks in British Columbia in 2018 and 2019 (Asin et al. 2022). In 2020, reports of RHDV2 in wild populations in the American southwest, as well as captive animals in New Mexico and New York, rapidly increased concerns about this disease (USDA APHIS 2020). Since that time, it has continued to spread in wild lagomporphs in the western United States (Asin et al. 2021, Williams et al. 2021). As of 2023, there have been no further records of RHDV2 in captive or wild lagomorphs in the Northeast region. However, this disease is a major concern for the Northeastern lagomorph RSGCN and Watchlist species, New England Cottontail (*Sylvilagus transitonalis*), Appalachian Cottontail (*Sylvilagus obscurus*), and Snowshoe Hare (*Lepus americanus*), as the effects on these species are unknown but likely to be severe. The New England Cottontail working group and mammal biologists across the region are preparing by updating protocols to include decontamination, vaccination, and other methods to protect native rabbits and hares (New England Cottontail Initiative 2021, Pennsylvania Game Commission 2021). Additionally, the US Animal and Plant Health Inspection Service maintains a **map showing the current distribution of known RHDV2 occurrences** (USDA APHIS 2022). Currently, treatment options for this virus are limited, but Bosco-Lauth et al. (2022) have tested a potential vaccine for use in domestic rabbits. While widescale application of this vaccine to wild populations is not reasonable, it could be effective in preventing transmission from captive populations or for inoculating key Northeast populations, such as those in the New England Cottontail captive propagation facilities.

A contributing factor to Allegheny Woodrat (*Neotoma magister*) declines may be infection by the **Raccoon Roundworm** (*Baylisacaris procyonis*). This intestinal nematode is generally benign in its primary host, the Raccoon (*Procyon lotor*), but in woodrats and other species that act as intermediate hosts, the parasite enters the nervous system and causes death either directly or indirectly by making the host more susceptible to predation (LoGiudice 2003). Researchers have confirmed that areas with a lower prevalence of *B. procyonis* tend to have more stable woodrat populations, but additional research will be needed to more clearly separate the impacts of the roundworm from the other threats contributing to woodrat decline (Owen et al. 2004, Smyser et al. 2013*a*, Wolfkill et al. 2021). For a more complete description of these other factors, see LoGiudice (2008). An experimental application of bait containing the medication Pyrantel nearly eliminated *B. procyonis* from treated sites and may be a valuable tool for the protection of existing Allegheny Woodrat populations or improve success in future translocation and recovery projects (Smyser et al. 2013b).

Another parasite may be mediating the interactions of Northern and Southern Flying Squirrels (*Glaucomys sabrinus* and *G. volans*, respectively). The **nematode *Strogyloides robustus*** infects both species. However, Northern Flying Squirrels appear more susceptible to the parasite, which is highly prevalent in Southern Flying Squirrel populations (Pauli et al. 2004). Where the two species overlap in distribution, the Southern species likely introduces the parasite to Northern populations, leading to reduced competitive capability (Pauli et al. 2004). This may prove problematic for the Virginia Northern Flying Squirrel (*G. s. fuscus*) subspecies included on the 2023 RSGCN list.

Several viruses have widespread impacts on northeastern carnivores, and can spillover into domestic cats and dogs. While these diseases can cause mortality events, they tend to be isolated both spatially and temporally, making them generally of lower concern in the Northeast. **Rabies** is perhaps the most infamous example. This virus can infect any mammal species, but raccoons, foxes, skunks, and bats are the most common reservoirs in the eastern United States. Dedicated dog vaccination programs greatly reduced the incidence in pet populations, but translocations helped spread the virus among wildlife populations (Wallace et al. 2014). Oral vaccines are being used to reduce the prevalence and transmission rates of the variant that is widespread across the eastern United States and may in the future be effective in eliminating the disease (Slate et al. 2009). Canada, Mexico, and the United States cooperatively work on managing this disease as part of the **North American Rabies Management Plan** (NARMP 2008). APHIS has a **National Rabies Management Program**[84], which has useful resources related to the disease.

One family of viruses that are the source of disease outbreaks in many species is the **morbilliviruses**. There are seven known morbilliviruses, including human measles. Two morbilliviruses called rinderpest, one of which has been largely eradicated, are primarily a concern for livestock but may occasionally spillover into native ungulate populations and are not a major concern in the Northeast. Feline morbillivirus is primarily a concern in Feral Cat populations, but there is some potential for it to spillover into *Lynx* species in the Northeast. The other three morbilliviruses include canine distemper, phocine distemper, and cetacean morbillivirus. Canine distemper is perhaps the most flexible of these diseases, capable of infecting all families of terrestrial carnivores as well as pinnipeds, while the other two strains tend to be more specific (Deem et al. 2000). All three of these diseases are known to cause mass mortality events, though they do not generally happen with high frequencies (Deem et al. 2000, Jo et al. 2018).

Marine mammals may be particularly impacted by viral infections. For a more comprehensive list of the many viruses known to impact marine mammals, see Bossart and Duignan (2018). Simeone et al. (2015) found that viruses were the most commonly reported source of marine mammal mortality in the Northeast from 1972-2012, comprising more than 75% of all records. Records of mass mortalities of marine mammals due to viruses do not appear to be increasing, but a more reliable, centralized collection of data is needed to better track these trends (Gulland and Hall 2007, Jo et al. 2018). The National Oceanic and Atmospheric Administration maintains the **Marine Mammal Health and Stranding Response Program**[85] and coordinates emergency responses to sick, injured, distressed, or dead marine mammals. As part of this program, they investigate **unusual marine mammal mortality events**[86] in the United States.

Another class of viruses with major impacts on carnivores is the **parvoviruses**. These viruses are organized into three general lineages – feline, canine, and mink – all of which can be found in the Northeast. For a more in-depth overview of this class of viruses, see Steinel et al. (2001). Once again, these diseases can infect domestic animals, but vaccination against them is common for household pets (Kimpston et al. 2022). A new parvovirus was recently identified from Red Foxes (*Vulpes vulpes*) in Newfoundland; though it was not found in a suite of other carnivores, Gray Fox (*Urocynon cinereoargentus*) were not tested and may be susceptible (Canuti et al. 2021).

Many different herpesviruses impact Northeast mammals but do not generally have major impacts. A few other diseases that tend to spillover between wild and domestic animals include feline immunodeficiency virus and the bacteria that cause leptospirosis and tuberculosis.

BIRDS

Birds are a major reservoir for several vector-borne zoonotic diseases in the Northeast (e.g., Zika Virus, Eastern Equine Encephalitis) and have the ability to transfer diseases large distances due to their migratory patterns (Reed et al. 2003, Fuller et al. 2012). Despite this, there are relatively few pathogens and microbes that are of major concern for the management of bird RSGCN in the Northeast.

West Nile Virus (WNV) is one of the most cosmopolitan zoonotic diseases, with confirmed infections in birds, amphibians, mammals including humans, and reptiles, though only avian species appear to support viral loads high enough for transmission to other individuals via mosquito vectors (Pérez-Ramírez et al. 2014). This virus first emerged in the US in 1999 and primarily affected corvids (Friend et al. 2001). In the decades since its emergence, WNV has been identified in more than 300 bird species in the US alone (US CDC 2016) and has been identified as the driving reason behind population declines in many species (LaDeau et al 2007, George et al. 2015). Though many states used to have systems in place to test for WNV in dead birds, many of these programs were discontinued once WNV spread to all states in the continental US in

2012. The disease has been identified as a particular concern for Ruffed Grouse (*Bonasa umbellus*; Eastern Grouse Working Group 2020, Nementh et al. 2021, Kunkel et al. 2022).

Periodic outbreaks of various strains of Influenza A are a rapidly growing concern for bird species. A group of these viruses is referred to as **Highly Pathogenic Avian Influenza (HPAI)**. This group has many different strains which have been a major source of avian mortality worldwide since 1996, though before the early 2000s, most outbreaks were associated with domesticated poultry (Hill et al. 2022, Ramey et al. 2022). The distribution, frequency, and intensity of these outbreaks appear to be increasing, and they are increasingly impacting wild bird species as well as domestic ones (Hall et al. 2015, Ramey et al. 2022). Moreover, the disease has recently spilled over into seals in New England, one of the first population-level mortality events in mammals associated with this disease (Puryear et al. 2022). As this disease evolves rapidly and transfers easily between species, containment and eradication are unlikely and will require structured decision-making within a One Health framework to address at a global scale (Ramey et al. 2022, Harvey et al. 2022). APHIS[87], the CDC[88], and USGS[89,90] all have resources and tools devoted to tracking outbreaks of Avian Flu. However, understanding the role this disease plays with wild bird populations will require sustained, cost-effective investment in standardized sampling, testing, and reporting at national and global scales (Machalaba et al. 2015).

Outbreaks of conjunctivitis, a disease that causes inflammation of the eye tissues, were a cause of serious decline for House Finches (*Haemorhous mexicanus*) in the 1980s (Hartup et al. 2001). The bacterium ***Mycoplasmosa gallisepticum*** was identified as the infectious agent. While House Finches are not native to the eastern United States, this disease is still potentially of concern in the Northeast because it can spill over into wild passerine populations (Hosseini et al. 2006, Sawicka-Durkalec et al. 2021).

Recently in 2021, a mortality event centralized in the mid-Atlantic region generated a regionally-coordinated response. Symptoms included crusty eyes and neurological behaviors, followed by death, across several different passerine species. Consistent and coordinated messaging from state fish and wildlife agencies and local Audubon chapters encouraged reporting of bird mortalities, as well as preventative measures such as removing bird feeders and bird baths until after the outbreak died down. The USGS National Wildlife Health Center, Southeastern Cooperative Wildlife Disease Study, Wildlife Futures Program (University of Pennsylvania), and Indiana Animal Disease Diagnostic Laboratory all worked to identify the cause, and were able to eliminate many of the usual disease culprits (USGS National Wildlife Health Center 2021, Greening et al. 2022). Ultimately, reported cases dropped off late in the summer, leading many of the affected jurisdictional agencies to lift the feeder guidance. In early 2022, many agencies again sent out messaging to ensure feeders were removed or kept clean and to report any further mortalities, but the outbreak did not re-occur. As of 2023, some of the occurrences in Maryland and the District of Columbia have been attributed to an unspecified conjunctivitis bacterium, but results for the rest of the region are still pending (USDA APHIS 2023). A manuscript describing the multi-agency response is in prep and will hopefully be submitted soon (Bryan J. Richards, USGS Emerging Disease Coordinator, *pers. comm.*). Regardless of the ultimate diagnosis, this event is significant because it demonstrated that rapid, collaborative, regional responses to emerging issues are possible, significantly increasing common understanding, collective messaging, and collaboration between many different entities.

There are a handful of other diseases that have caused periodic outbreaks in wild bird species, including Duck Plague, Avian Botulism and Cholera, and Newcastle Disease. For more information, see Friend and Franson (1999) and Friend et al. (2001). One disease currently known from Alaska may become more prevalent in the future. This disease, called Avian Keratin Disorder, causes beak overgrowth in several bird species from across different orders (Handel et al. 2010, Zylberberg et al. 2021). The disease agent has tentatively been identified as a poecivirus. Though most testing for this disease has occurred in Alaska, testing of an individual from Maine was positive for this disease (Zylberberg et al. 2021). This may suggest the disease is more widespread across North America than previously believed, but further study will be necessary to determine if it will become a threat in the Northeast. Finch Trichomonosis, a disease that is currently spreading in Europe, may also become a concern in the future if it is introduced to North America (Lawson et al. 2011).

AMPHIBIANS & REPTILES

One of the most widespread disease-causing agents in amphibians is the fungus ***Batrachochytrium dendrobatidis* (*Bd*)**, a causative agent of the disease chytridiomycosis. For a description of the characteristics of this pathogen and its impacts on hosts, see Voyles et al. (2011). This fungus was first identified in 1997, and has since been confirmed on all continents and is considered a leading cause of amphibian declines and extinctions (Fisher et al. 2009). To date, more than 2500 amphibians have been tested for *Bd* globally and the disease has been found in more than half of the species sampled (Monzon et al. 2020, Olson et al. 2021). The global pattern of *Bd* distribution and impacts suggest it is a non-native pathogen whose spread was anthropogenically facilitated by international amphibian trade (Fisher and Garner 2007, Fisher et al. 2009). The fungus likely originated in Asia, as amphibians in these areas still carry high loads of the fungus, but do not suffer from the virulent effects (Fu and Waldman 2019). However, the eastern United States may represent the site of the historical diversification of the fungus that resulted in the modern *Bd* lineages that are now widespread globally (Byrne et al. 2022).

The biology of this fungus greatly affects its ability to spread and persist in the environment, with important implications for sampling for the disease. First, *Bd* populations vary seasonally, with zoospore density and associated disease prevalence and intensity highest during early-season sampling in the spring (Lenker et al. 2014, Chestnut et al. 2014, Petersen et al. 2016). These results suggest warm and dry summer conditions may help clear up infections, but they also suggest summer surveys may underestimate the actual prevalence of the fungus and highlight the complications with comparing results across different sites and seasons (Petersen et al. 2016). Chestnut et al. (2016) also demonstrated that tests may imperfectly detect the presence of the fungus, which can be alleviated by testing multiple samples from the same site. *Bd* is also able to survive for a sustained time outside of its host, keeping water bodies infective (Johnson and Speare 2003). This longevity combines with water connectivity, as more connected wetlands have greater *Bd* occurrence, which may have important implications for the transmission of this disease across larger areas (Hulting et al. 2022). On the other hand, the long-term presence of *Bd* in aquatic habitats makes it possible to test for its presence using eDNA, rather than needing to capture and sample from potential hosts (Kamoroff and Goldberg 2017, Barnes et al. 2020). For an overview of diagnostic tests and sampling protocols for *Bd* in host individuals, see Hyatt et al. (2007).

Despite its relatively recent discovery and rise as a major source of conservation concern, *Bd* has been present in North America for more than a century. Review of museum records has made it possible to better assess when and where *Bd* has been introduced (Monzon et al. 2020). Talley et al. (2015) found records of *Bd* as early as 1888 in Illinois, currently the earliest known record of the disease. In Florida, Karwacki et al. (2021) detected *Bd* as early as 1928. Similar reviews of museum records have not yet occurred in the Northeast, but may provide valuable insights into the presence and spread of the disease in the region.

Surveys for *Bd* in the Northeast region did not occur for many years, in part because no major amphibian mortality events occurred that prompted more in-depth testing. Gahl et al. (2011) exposed seven common northeastern species to *Bd* and found that these species had different responses to the infection, with some species demonstrating complete mortality and others none; this highlights that some species could act as reservoirs for the disease within the region, promoting the transmission to more vulnerable species. Longcore et al. (2007) surveyed anurans primarily in northern New England and found that chytridiomycosis was widespread in members of the family Ranidae, but absent in other species, a finding that was further confirmed by Richards-Hrdlicka et al. (2013) and their testing of anurans and salamanders in Connecticut. Plethodontid salamanders in the southern Appalachians had a surprisingly low incidence of *Bd* over a 50-year period, less than 1%, suggesting that declines in these species may be due to other sources (Muletz et al. 2014). In contrast, the prevalence of

Bd in some of these same plethodontid species in New Brunswick was quite high, up to 12.9%, highlighting the need for further research to determine if these differences are due to seasonal, geographic, or other sources of variation (Jongsma et al. 2019). Eastern Hellbender (*Crypotbranchus alleghenienisis*), another salamander that has undergone significant declines in recent decades, is also commonly positive for *Bd*, but the fungus may not impact overall individual health (Bales et al. 2015).

Another chytrid fungus that is quickly rising in global importance is ***B. salamdrivorans* (*Bsal***; Martel et al. 2013). Described in 2013, this fungus also appears to have originated in Asia and is the cause of several recent salamander die-offs in Europe (Martel et al. 2013, Gray et al. 2015). Many of the symptoms of *Bd* and *Bsal* are similar, but *Bd* tends to be more pathogenic to frogs and tends to cause thickening of the skin, whereas *Bsal* is more pathogenic to salamanders and usually causes skin ulcerations (Gray et al. 2015). For a more complete overview of the impacts of *Bsal*, known status and distribution, and monitoring protocols for the disease, see North American Bsal Task Force (2022a).

Though *Bsal* has not yet been discovered in North America, it is a major concern for the Northeast, especially the southern Appalachians, as it is a global hotspot of salamander biodiversity, The full impact on Northeastern species is unknown, but laboratory experiments have suggested that Eastern Newt (*Notophthalmus viridescens*) may experience high levels of mortality, while plethodontid salamanders may be somewhat resistant to the disease (DiRenzo et al. 2021). However, as resistance to *Bsal* has been assessed in only ten species so far, much more work is needed to determine the likely susceptibility and potential impacts on North American salamanders (Pereira and Woodley 2021, DiRenzo et al. 2021). Work should also be done to assess the vulnerability of anurans to this disease, as they may also be susceptible (Grear et al. 2021). Additional research has highlighted that the pathogenicity of *Bsal* may be influenced by temperature, suggesting that Eastern Newt populations in the northeastern United States and southeastern Canada may be more at risk than more southern populations (Carter et al. 2021).

Many efforts have focused on predicting and preparing for the invasion of this disease. Numerous authors have highlighted the importance of the amphibian pet trade as the likely distribution pathway of *Bsal* (Richgels et al. 2016, Yap et al. 2017, Grear et al. 2021, Connelly et al. 2023). Yap et al. (2015, 2017) combined a *Bsal* habitat suitability model with salamander richness, identifying four high-risk zones in North America: the highlands of central Mexico, the south coast of British Columbia, the western United States, and the southeastern United States. Richgels et al. (2016) overlaid similar habitat suitability and salamander species richness data with pet trade and import patterns and found the West Coast, Mid-Atlantic, and southern Appalachians were at the greatest risk. Moubarak et al. (2022) conducted a similar spatial analysis based on the ecological niche of *Bsal* in its native range and found that most of the Northeast region falls within the suitable range for *Bsal*, in contrast to other risk assessments that suggested greater impacts further south, but complimenting the results from Carter et al. (2021) suggesting that temperatures in the Northeast may be more conducive for the fungus.

These impact assessments and other calls to action (e.g., Gray et al. 2015) led to the creation of the **North American *Bsal* Task Force**[91]. The Task Force has released two documents to guide *Bsal* monitoring and management in the United States (North American *Bsal* Task Force 2022a,b). The **Strategic Plan** summarizes interdisciplinary scientific and managerial guidance for a successful response to the detection of *Bsal* in North America, following similar concepts to those used in many invasive species Early Detection and Rapid Response (EDRR) programs. The Strategic Plan highlights the importance of having policies in place to restrict the importation of *Bsal*-susceptible species, establish protocols for ensuring imported individuals are disease free and for handling and quarantining infected individuals, identify field mitigation responses for outbreaks, and reduce accidental transmission following future establishment. The Implementation Plan outlines the objectives, goals, and priorities of the eight working groups organized under the Task Force. It is intended to adapt over time as new information, goals, and priorities are identified, and will be updated periodically on the Task Force website.

Ranaviruses are another group of multi-host pathogens with even broader tolerances than the chytrid fungi, as they infect many ectothermic species. Though first identified – and most comprehensively studied – in amphibians, reptiles, and fish are also hosts of this family of viruses (Lesbarrères et al. 2012). Ranaviruses were first identified in the 1960s but have since been identified as the cause of several mortality events in frogs, turtles, and fish on all continents except Antarctica (Lesbarrères et al. 2012). A review of United States amphibian mortality events in the late 1990s and early 2000s revealed that ranavirus infections caused significantly more mortality events than chytrid fungus, though they were often associated with widespread and abundant species rather than species known to be in decline (Green et al. 2002). Other viruses are a concern for some Northeastern freshwater turtle species but do not generally have major impacts in the region. For an overview of these other viruses, see Okoh et al. (2021).

Ranaviruses can transmit between species from different taxonomic classes and have differential impacts on these hosts (Brenes et al. 2014). As a result, some species may act as reservoirs for the disease, maintaining their presence in the ecosystem and repeatedly re-infecting populations that are more sensitive to the disease (Brenes et al. 2014). Additionally, ranaviruses can persist in the environment outside of their hosts in both soil and water, especially at low temperatures, again increasing the chance of transmission (Nazir et al. 2012). As is the case for many other diseases, the severity and prevalence of ranavirus infections can increase in the presence of other stressors in the environment, such as salinity (Hall et al. 2020) and chemical contaminants (Smalling et al. 2022).

Gray et al. (2009) reviewed the ecology and pathology of ranaviruses in amphibians, summarizing the known research, possible reservoirs and transmission pathways, drivers of outbreaks and other stressors that alter infection rates, pathology and diagnostics, rise to global prevalence as an emerging disease, management and conservation strategies, and future research needs. They highlighted the need to better understand the genetics of the various ranavirus species, determine species-specific vulnerabilities to the different ranaviruses, the role of additional stressors in ranavirus virulence, and co-occurrence with other diseases such as *Bd*. Wirth et al. (2018) conducted a similar review of ranaviruses and reptiles, highlighting methods for diagnosing and surveying for the disease, known host ranges and impacts, disease pathology and transmission, likely vectors and reservoirs, immune responses, treatment options, and future research needs. The key data deficiencies for ranavirus in reptiles are their pathogenesis and transmission, as it often involves terrestrial, rather than aquatic species, and host immunity and immune evasion strategies (Wirth et al. 2018). For in-depth discussions on the known ranavirus species and their taxonomy, distribution, replication and transmission, pathology and diagnosis, host impacts, ecology, and antiviral adaptations, see Gray and Chinchar (2015).

In the Northeast region, ranaviruses are known to cause mortality in anurans, turtles, and salamanders, though ranavirus-induced mortality has not yet been observed in hellbenders and plethodontid salamanders (Duffus et al. 2015). A recent report confirmed the presence of ranavirus in the Common Snapping Turtle (*Chelydra serpentina*), the first known occurrence in this species (McKenzie et al. 2019). No ranavirus infections have yet been recorded in North American snakes or lizards. The limited available information about this disease prompted a Regional Conservation Needs project to understand the extent to which ranavirus was impacting amphibians and reptiles in the Northeast (Smith et al. 2016). This project developed a standardized protocol for screening for the disease in Wood Frog (*Lithobates sylvaticus*) larvae across Delaware, Maryland, New Jersey, Pennsylvania, and Virginia, setting the stage for future research and conservation efforts.

Several different diagnostic assays have been used to test for ranavirus (see Wirth et al. 2018). Several methods involve the use of swabs or non-lethal tissue samples, though these methods may underestimate infection prevalence (Gray et al. 2012, Goodman et al. 2013). Improvements in environmental DNA (eDNA) methodologies may make this method highly effective for aquatic species (Hall et al. 2016, Wirth et al. 2018). Moreover, eDNA can be used to test for ranaviruses and *Bd* simultaneously (e.g., Barnes et al. 2020).

Monitoring and management for *Bd*, *Bsal*, and ranavirus are critical in the Northeast due to the wide host range and high virulence of these diseases. The Northeast Partners in Amphibian and Reptile Conservation (NEPARC) have developed **best management practices for disinfecting field equipment** (NEPARC 2014) and **construction machinery** (Julian et al. 2020) to minimize the risk of spreading herptile pathogens. Gray et al. (2017) also discuss considerations for study design, sample collection, biosecurity, and intervention strategies to minimize disease transmission. In addition, attempts to consolidate information, increase multidisciplinary research, and improve understanding of *Bd* and *Bsal* resulted in the creation of the **Amphibian Disease Portal** (Koo et al. 2021). This repository of global chytridiomycosis data enables and accelerates amphibian research and conservation and provides a framework for future research on many different diseases. Similar needs around ranavirus resulted in the **Global Ranavirus Reporting System** (Duffus and Olson 2011). This open-source database contains global detection and non-detection data, providing insights into pathogen emergence patterns and host range and susceptibility, as well as being an archive of ranavirus studies (Brunner et al. 2021).

Starting in 2006, severe and often fatal skin infections were increasingly observed in several snake species across the eastern United States (Lorch et al. 2016). **Snake Fungal Disease (SFD)**, also called ophidiomycosis, is caused by the fungus *Ophidiomyces ophiodiicola* (Lorch et al. 2015). For an overview of the natural history, ecology, and epidemiology of SFD, see Allender et al. (2015b). It was originally observed in Timber Rattlesnake (*Crotalus horridus*) populations, prompting a Regional Conservation Needs grant project to assess the prevalence of the disease in New England (McBride et al. 2015). This project found that overall regional prevalence at that time was around 33%, but even with the relatively high incidence, most individuals were in good health.

Though originally identified in Timber Rattlesnakes, the condition has since been found in a large number of snake species, especially members of the family Colubridae and Viperidae, though the impacts vary depending on the species (Lorch et al. 2016). Most evidence had previously supported the idea that SFD is native to North America, and has recently changed in virulence, potentially as a result of environmental changes (Lorch et al. 2016, Davy et al. 2021). However, recent genetic analysis has revealed that the disease is likely not native but has been introduced multiple times to North America within the last few hundred years, explaining its wide distribution (Ladner et al. 2022).

Snake Fungal Disease can create infections, lesions, sores, and nodules in the skin and, in severe cases, cloudiness of the eyes and facial disfigurement. Often, snakes respond by increasing molt frequency in an attempt to slough off the infected tissues; multiple molts in quick succession may be necessary to fully rid the snake of infection (Lorch et al. 2016). Environmental factors, such as temperature and humidity, may influence infection, which may have important implications for climate change (Allender et al. 2015b, Lorch et al. 2016). Infected snakes demonstrate altered behavior, moving shorter distances and spending more time basking than uninfected individuals (Tetzalff et al. 2017, McKenzie et al. 2021). Though infection status does not appear to have an impact on short-term survival rates, longer-term studies are needed to fully understand the effects on long-term survival and movement (McKenzie et al. 2021).

Effective diagnostic tests for SFD are available (Allender et al. 2015a, Baker et al. 2019). Unfortunately, no effective treatment for SFD in wild populations has been found (Allender et al. 2015b). Prevention is the best countermeasure at this time, though the disease does appear to already be widespread throughout the region (Lorch et al. 2016). Disinfectants for field gear have been tested, setting a baseline of effective methods to prevent transmission of the fungus between individual snakes (Rzadkowska et al. 2016, Gray et al. 2017). Other biosecurity considerations are discussed by Gray et al. (2017).

The rising number of terrestrial herptile diseases has focused the efforts of the **Partners in Amphibian and Reptile Conservation National Disease Task Team**[92]. This team recognizes the importance of collaboration among government and non-government agencies, universities, and the public in responding to disease emergence. This team works to facilitate and guide communication and collaboration amongst the PARC regions, federal and state agencies, and other partners.

Sea turtles face a unique suite of diseases. **Fibropapillomatosis (FP)**, widely thought to be initiated by a herpesvirus, is one of the most important. Originally discovered in Green Sea Turtles (*Chelonia mydas*) in 1938, it has now been found in all seven sea turtle species, though it is most widespread and well-studied in Green Sea Turtles (Jones et al. 2016). FP results in the formation of tumorous growths and lesions on areas of soft skin, especially around the head, flippers, and tail, though they can also form on the carapace and plastron (Jones et al. 2016). Generally, these tumors are considered benign with a high rate of recovery and not a major source of mortality, but depending on location, they can interfere with movement, vision, feeding, and breathing (Patrício et al. 2016, Dujon et al. 2016). Records of the disease from the 1930s indicate that prevalence was low, around 1.5%; starting in the 1980s, outbreaks became increasingly common, with prevalence between 20-60% (Jones et al. 2016). Many researchers have suspected that an external stressor might be associated with the increased emergence of the disease; possibilities have included ultraviolet light exposure, temperature, parasites, pollutants, and harmful algal blooms (Dujon et al. 2021). In their review, Dujon et al. (2021) found that FP was more prevalent in areas with greater exposure to harmful algal blooms with carcinogenic biotoxins present in the algae. Currently, there are no effective treatments for the disease, but managing nutrient loads that promote harmful algal blooms may prevent or reduce disease outbreaks (Dujon et al. 2021).

Sea turtle eggs face additional pathogenic agents. One rapidly emerging disease is **Sea Turtle Egg Fusariosis (STEF)**, discovered only in the last few decades. This disease has been linked to two fungi species within the *Fusarium* (*Neocosmospora*) *solani* complex, *F. keratoplasticum* and *F. falciforme* (Smyth et al. 2019, Gleason et al. 2020). These fungi are distributed globally, with very little known about their ecology and epidemiology (Smyth et al. 2019). The eggs are likely infected by coming into contact with contaminated substrates in and around the nesting site or from contact with gravid females (Gleason et al. 2020). Nests in drier sands appear to be less susceptible, as the fungi prefer warm, moist environments (Gleason et al. 2020). The specific method of transmission between the environment and turtle eggs is not fully understood, as uninfected eggs still occur in the presence of the fungi, suggesting other factors influence infection rates and disease suppression (Gleason et al. 2020). Additionally, the fungi have also been isolated from skin swabs of adult turtles, suggesting they may also play a role in their transmission (Gleason et al. 2020). Recent research has also revealed that these fungi may have impacts beyond the nests; these fungi have been isolated from skin lesions on post-hatchling turtles and may have been the causative agent (Greeff-Laubscher and Jacobs 2022). Additionally, though this disease has long been associated with sea turtles, Carranco et al. (2022) identified it as the cause of hatching failure in an Amazonian freshwater turtle, which may have implications for other freshwater species. Additional research on these fungal agents is necessary to fully understand their impacts on different life stages and implications for Northeastern freshwater turtles.

As all sea turtles in the Atlantic are federally endangered or threatened, the National Oceanic and Atmospheric Administration oversees a **Sea Turtle Stranding and Salvage Network**[93]. State, federal, and private partners work together to gather information on the causes of sea turtle mortality, injury, and illness by collecting data from stranded sea turtles. Data and samples from these turtles inform research on diseases impacting sea turtles, including FP and STEF.

FISH

Research on fish diseases tends to be skewed towards those pathogens and microbes that impact harvested, stocked, and farmed species. Widespread stocking in Northeast rivers and streams, especially of both native and non-native salmonids, has facilitated the distribution of many diseases. In addition, warming temperatures and increasing numbers of aquaculture facilities may be increasing fish vulnerability to disease (Vollset et al. 2021). As research on the impacts of many of these diseases on wild populations is limited, it is not easy to determine if any one of these diseases, or a combination of several of them, is significantly contributing to the declines of any RSGCN or Proposed RSGCN species. Thus, this section provides a very brief overview of several fish diseases that could influence species of conservation concern, but further research is necessary to determine the full impacts.

- **Whirling Disease** is a debilitating disease caused by the parasite *Myxobolus cerebralis*, which has a complicated two-host lifecycle involving an oligochaete *Tubifex tubifex* and a salmonid fish. This disease causes irregular swimming patterns and skeletal and pigment abnormalities in many salmonids including Brook Trout (*Salvelinus fontinalis*), Lake Trout (*Salvelinus namaycush*), and Atlantic Salmon (*Salmo salar*; Sarker et al. 2015). The disease is though to be native to Europe, but has been introduced in North America, where it caused a near-complete collapse of salmonid fisheries in Colorado and Montana (Sarker et al. 2015). Whirling Disease has been detected in several hatcheries and wild populations in the Northeast, though it has not yet caused widespread declines in the region (Sarker et al. 2015). The species' range is continuing to expand, which could impact fisheries in several states (Ksepka et al. 2020).
- **Infectious salmon anemia (ISA)** can be a devastating viral disease in farmed Atlantic Salmon that also spills into wild populations, though they appear to be more resistant to the disease (Nylund et al. 1995).
- **Swim bladder sarcomas** are caused by viruses and are known to impact Atlantic Salmon, though it is not known how widely this disease is distributed in wild North American populations (Paul et al. 2006, Bowser et al. 2006).
- American Eel (*Anguilla rostrata*) are impacted by **the invasive nematode *Anguillicola crassus***, which causes damage to the swim bladder. This damage can influence buoyancy, which could increase mortality at turbines (Pflugrath et al. 2019). Prevalence, abundance, and intensity vary across developmental stages and environmental factors, though more research is needed to determine if this parasite is a significant contributor to eel declines (Warshafsky et al. 2019).
- **Furunculosis** is caused by the bacterium *Aeromonas salmonicida* and is a common, recurring disease in hatcheries and aquaculture facilities worldwide (Dallaire-Dufresne et al. 2014, Baset 2022).
- **Viral hemorrhagic septicemia** is a devastating viral disease of fish globally, found in more than 140 freshwater and marine species, and is expected to continue to expand its range (Escobar et al. 2018).
- Striped Bass (*Morone saxatilis*) are increasingly impacted by the bacterial disease **mycobacteriosis**. Warmer temperatures and decreased oxygen levels increase susceptibility to the disease (Lapointe et al. 2014). In the Chesapeake Bay, incidence and mortality rates are very high; Striped Bass are likely at their thermal maximum in this area, and management will need to incorporate the influence of both disease and temperatures on the species (Groner et al. 2018).
- For a review of other **tumor-causing diseases** in fish, see Coffee et al. (2013).
- For a review of **infectious diseases of salmon species**, see Miller et al. (2014).

INVERTEBRATES

As is the case for many other aspects of invertebrate ecology, knowledge of pathogens and microbes that impact these species is limited. Disease impacts on many invertebrate taxa are unknown and baseline information is lacking in most RSGCN and Proposed RSGCN species. Most of the diseases known to impact Northeast invertebrate RSGCN are those that infect species with economic value and are often studied through the lens of the propagation and culture facilities that raise captive populations of these species.

Declining bumble bee populations have been linked to several pathogens and microbes. ***Nosema bombi*** is a fungal pathogen contributing to the decline of *Bombus* species across North America. Authors suggest that the fungus is native, but its distribution and transmission have been largely facilitated by the use of commercially reared bumble bees in greenhouse operations (Cameron et al. 2016). Researchers isolated this pathogen from 22 of the 36 North American bumble bee species; American Bumble Bee (*Bombus pensylvanicus*), a Northeast Watchlist [Assessment Priority] species, has one of the highest prevalence rates (Cordes et al. 2012). A destructive intestinal parasite, ***Crithidia bombi***, is commonly found in commercial *Bombus* species and is thought to be one of the causes of Colony Collapse Disorder in honeybees and can spillover from commercial bumble bees to native species (Otterstatter and Thompson 2008). Recent research has revealed that transmission of this parasite occurs on flowers where bees deposit fecal matter (Figueoroa et al. 2019). Moreover, the pollen of certain flowers may depress *C. bombi* populations; more research is needed to understand the role of diet in individual health (LoCascio et al. 2019). Some flower flies may be suitable vectors for the parasite, though they are not suitable hosts (Davis et al. 2021). One northeastern species, *Bombus impatiens*, has greatly increased in relative abundance, potentially because this species is resistant to the two pathogens above (Averill et al. 2021).

Eastern Oysters (*Crassotrea virginana*) are sensitive to several diseases. **Dermo**, caused by the protozoan *Perkinsus marinus*, caused significant declines in oyster populations starting in the 1940s. Outbreaks of Dermo are linked to high salinity levels and elevated temperatures (Ford and Smolowitz 2007). Climate change may increase the risk of outbreaks of this disease in the future. Another disease, **MSX**, is caused by the parasite *Haplosporidium nelsoni*. This parasite is not native, originating in the Pacific. Researchers have been trying to understand the dynamics of MSX since the first outbreaks in the 1960s, but research has been hampered because Eastern Oysters are not the primary host; another as of yet unidentified species is present and acting as either the primary host or vector (Ford et al. 2018). Outbreaks of Dermo and MSX in the Northeast in the 1990s prompted the development of disease-resistant lines for use in commercial aquaculture operations (Frank-Lawale et al. 2014). This could have implications for the genetics of wild populations, as disease-resistant strains are now cultured on much of the east coast. Moreover, the population declines may have decreased genetic diversity, making the populations more vulnerable to further impacts (Schulte 2017). Interestingly, populations in Delaware Bay naturally developed resistance to MSX, though they remained susceptible to Dermo (Bushek and Ford 2016). Disease remains a significant impediment to the recovery of Eastern Oysters (Smolowitz 2013, Schulte 2017).

American Lobsters (*Homarus americanus*) suffer from **Epizootic Shell Disease (ESD)**, which first emerged in Long Island Sound in the 1990s. This bacterially-induced disease causes infections in the shell of the Lobster, which result in subsequent infections, interfere with molting, and can cause mortality when infections are severe (Carlon et al. 2018). Warmer temperatures and increased CO2 levels facilitate the disease, increasing individual susceptibility (Barris et al. 2018, McLean et al. 2018). Lobster populations in the southern portions of their range have been decreasing in recent decades as a result of the disease, and the range of the disease has been spreading further north and increasing in prevalence (Groner et al. 2018, Reardon et al. 2018). Climate change is likely to continue increasing the distribution and prevalence of this disease in the coming decades (Rheuban et al. 2017, Groner et al. 2018). This highlights the need for more research and monitoring to determine the likely effects on the Northeast region, especially in the Gulf of Maine, a water body that is heating more rapidly than 99% of the world's oceans (Pershing et al. 2015). Outbreaks of shell diseases are also occurring in other marine crustaceans. A recent outbreak in Jonah Crab (*Cancer borealis*) highlighted the need for more research to be conducted on the topic to determine if the incidence of these outbreaks and associated mortality events are increasing (Carlon et al. 2018).

Sea stars on the Pacific coast have been suffering from widespread outbreaks of a disease called **Sea Star Wasting Disease (SSWD)**, which is causing mass mortality events in several events. The cause is likely a densovirus, but the understanding of this disease remains incomplete (Hewson et al. 2014, Work et al. 2021). In recent years, similar disease outbreaks of disease have been observed in Common Seastar (*Asterias forbesi*) on the Atlantic coast. Current research suggests that the events in the Atlantic are not the result of the same virus associated with the disease in the Pacific (Bucci et al. 2017). A closely related virus is widespread across both infected and uninfected seas stars in the Atlantic, suggesting that the virus is a natural part of these species' microbiome and not the cause of the disease, but again, further research will be necessary to confirm the pathogenicity of these viruses (Jackson et al. 2020).

Interest in **diseases of freshwater mussels** has been increasing in recent years. Carella et al. (2016) and McElwain (2019) provide reviews on the state of knowledge for pathogens of unionid mussels globally. These reviews describe the pathogens and parasites known to impact freshwater mussels, but none of these agents have yet been linked to mussel declines and die-offs in the United States. The limited information available is prompting calls for more coordinated efforts to understand mussel health, especially given the extreme imperilment of this group (Waller and Cope 2019). In addition, some authors have highlighted the importance of considering the potential of transmitting pathogens, microbes, or parasites before utilizing captive propagation or translocation as tools to bolster populations and ensuring the use of best practices to prevent the accidental spread of these threats (Brian et al. 2021).

No diseases were identified as having significant impacts on any RSGCN or Proposed RSGCN in the following taxonomic groups:

- Crayfish
- Fairy, tadpole, and clam shrimp
- Fireflies
- Tiger beetles
- Dragonflies and damselflies
- Mayflies
- Stoneflies
- Caddisflies
- Butterflies and moths
- Terrestrial snails

It is important to remember that this is not an indication that these groups do not have any pathogens or microbes that are impacting populations, just that the current information available for these species has not studied this topic in detail. Further research is needed to understand how this threat may impact Northeast RSGCN and Proposed RSGCN from these taxonomic groups.

PLANTS

Plant diseases can have similar indirect impacts on Northeastern wildlife as invasive and problematic native insects. These diseases defoliate and kill key plant species, altering the structure and composition of many ecosystems, causing cascading effects across all tropic levels. Changing climactic conditions may also increase the frequency, severity, or distribution of these disease outbreaks in the future. Some plant diseases that are current or historic concerns for RSGCN and Proposed RSGCN in the region include:

- **Chestnut Blight**: A fungal disease caused by *Cryphonectria parasitica* that infests American Chestnut (*Castanea dentata*) and is responsible for the near extirpation of this species and significant alteration of eastern forest structure and composition (Hepting 1974). This eliminated a key food resource from eastern forests, which some authors link to Allegheny Woodrat declines (LoGiudice 2008). Efforts to breed blight-resistant American Chestnuts are ongoing. The American Chestnut Foundation[94] and the State University of New York College of Environmental Science and Forestry have regional efforts (Powell et al. 2019). The planting of disease-resistant strains has started. Further monitoring and research will determine if these efforts will successfully re-establish American Chestnuts (Gurney et al. 2011, Clark et al. 2014).
- **Beech Bark Disease**: A fungal disease caused by members of the genus *Neonectria*, especially *N. coccinea*, that infests American Beech (*Fagus grandifolia*), causing tree mortality, bark scarring, and significant root sprouting

(Cale et al. 2017). The Lepidoptera Taxa Team suggested this disease may be a particular concern for the RSGCN butterfly Early Hairstreak (*Erora laeta*), which feeds on beechnuts.

- **Beech Leaf Disease**: This disease is caused by the nematode *Litylenchus crenatae* and has only recently been discovered, so its impacts and distribution are not yet fully understood (Ewing et al. 2019). It is expanding into the region, adding another threat to the already impacted American Beech. Once again, the Lepidoptera Taxa Team is concerned that this disease will negatively impact Early Hairstreak.
- **Eelgrass Wasting Disease**: This disease is caused by the protist *Labyrinthula zosterae* and infests Eelgrass (*Zostera marina*). Increasing ocean surface temperatures appear to be linked to increasing outbreak frequency (Plaisted et al. 2022). The disease was widespread in the region in the 1930s, leading to the extinction of the Eelgrass Limpet (*Lottia alveus*). Several Northeast RSGCN and Proposed RSGCN, such as Bay Scallop (*Argopecten irradians*) depend on Eelgrass beds as nurseries and would be negatively impacted by new outbreaks.

RELATIONSHIPS WITH OTHER THREATS

Pathogens & Microbes are frequently influenced by anthropogenic activity. Residential & Commercial Development (Threat 1.0) and Agriculture & Aquaculture (Threat 2.0) and the resulting environmental degradation can increase species' susceptibility to disease. Habitat fragmentation increases the likelihood of interactions between wildlife in unaltered habitats and wild and domestic animals, such as livestock and pets, in disturbed areas, increasing cross-species transmission (Dobson and Foufopoulos 2001). Agriculture and aquaculture facilities can be major sources of disease outbreaks due to the large numbers of individuals present, which can then spillover into wild populations; this is a particular concern with open-ocean aquaculture facilities (Dobson and Foufopoulos 2001). Developed areas can contain concentrated resources, such as bird feeders or landfills, which concentrate larger numbers of animals together, again increasing inter-individual and inter-species transmission (Oro et al. 2013, Wasi et al. 2013). Higher levels of Pollution (Threat 9.0) can act as a stressor and increase a species' susceptibility and vulnerability to disease (Staudt et al. 2013, Hamede et al. 2020). Some forms of pollution, especially wastewater and agricultural runoff, may contain potent reservoirs for certain diseases as well.

Climate Change (Threat 11.0) is likely to have significant impacts on disease threats. Geographic range shifts may occur for some pathogens, parasites, and disease vectors, increasing their ability to spread (Staudt et al. 2013, Tazerji et al. 2022). Warmer and wetter climates are likely to benefit several fungal pathogens (Dukes et al. 2009, Fisher et al. 2012, Finch et al. 2021) and invertebrate disease vectors (Tompkins et al. 2015, Tsao et al. 2021), increasing their impact. Moreover, climate and pollution may interact synergistically, with severe impacts on wildlife health (Noyes and Lema 2014).

TOOLS AND RESOURCES

Many resources for wildlife health and the intersection with human and domestic animal health are available. Tools and resources specific to a disease or taxonomic group are included in the sections above. Those included in this section are more general tools and resources that are relevant across all taxonomic groups.

The USGS' **National Wildlife Health Center**[95] is dedicated to wildlife disease detection, control, and prevention. They provide information, technical assistance, coordination, and research on wildlife health issues, monitor and assess the impacts, determine underlying causes of outbreaks and transmission, and develop methodologies and technology for disease prevention and control. One of their tools, the **Wildlife Health Information Sharing Partnership-event reporting system (WHISPers)** promotes collaboration and sharing of wildlife health information, providing situational awareness and timely information about wildlife disease threats (Richards et al. 2022, USDA APHIS 2023).

APHIS's **National Wildlife Disease Program**[96] is focused more on the agricultural impacts of wildlife, livestock, and human diseases, but also participates in the monitoring of high-profile wildlife diseases, including Chronic Wasting Disease, Avian Influenza, and Rabbit Hemorrhagic Disease Virus.

The **Wildlife Disease Association**[97] is an international society of scientists from many different backgrounds united in their mission to promote healthy wildlife and ecosystems, biodiversity conservation, and environmentally sustainable solutions to One Health challenges.

The **Southeastern Cooperative Wildlife Disease Study (SCWDS)**[98] was founded as an agreement between the Southeast Association of Fish and Wildlife Agencies and the College of Veterinary Medicine at the University of Georgia as a diagnostic and research service for the specific purpose of investigating wildlife diseases. They provide expertise to state and federal agencies and are a collaborative environment where wildlife managers, state and federal authorities, and researchers come together to ensure the welfare of wildlife, domestic animals, and human health. They also produce the Field Manual of Wildlife Diseases in the Southeastern United States, a pocket-sized reference of field investigation methodologies and descriptions of the primary pathogens and diseases associated with 25 mammal and bird species.

Similar to SCWDS, the **Northeast Wildlife Disease Cooperative (NEWDC)** operated out of Tufts University from 2013 to 2020. This consortium of veterinary diagnostic laboratories provided educational opportunities, wildlife diagnostics, cutting-edge research, and collaboration with fish and wildlife agencies in the region, and disseminated current information regarding fish and wildlife diseases to various organizations in the Northeast United States. The cooperative entered a dormant phase when the Director of NEWDC transitioned to a new position. Moving forward, disease threats will be managed through a coordinator hired by the Northeast Association of Fish and Wildlife Agencies with funding from the US Fish and Wildlife Service. The **Northeast Regional Fish and Wildlife Health Coordinator** will encourage and support the work carried out by fish and wildlife health practitioners to address zoonotic and other wildlife diseases. This position will work with Coordinators from other regions, encouraging collaboration nationally, and helping develop regional strategies for the prevention, detection, control, and eradication of wildlife diseases. This position is anticipated to be filled in March 2023. Until then, inquiries may be directed to the Wildlife Management Institute.

The **Cornell Wildlife Health Lab**[99] works to promote the health and long-term sustainability of wildlife populations through the integration of the fields of wildlife ecology and veterinary medicine. The Lab conducts disease surveillance and collaborative research; develops diagnostic tools; and communicates findings through training, teaching, and public outreach. The lab is based at the Cornell University College of Veterinary Medicine Animal Health Diagnostic Center.

The **Wildlife Futures Program**[100] is a partnership between the Pennsylvania Game Commission and the University of Pennsylvania's School of Veterinary Medicine (Penn Vet). This program is a science-based, wildlife health program that serves to increase disease surveillance, management, and research to better protect wildlife across the Commonwealth of Pennsylvania and beyond. Their Animal Diagnostic Laboratory provides in-depth, rapid diagnostic information to support disease control, health management, and performance of livestock, poultry, wildlife, fish, and companion animals. They provide active surveillance of animal diseases, identification of emerging diseases through the development and application of new diagnostic methods, and training and education for new diagnosticians, veterinarians, and graduate students as proactive measures to ensure the viability of Pennsylvania's animal industries.

INTRINSIC BIOLOGICAL LIMITATIONS

The threats described under this category are not part of Quebec's Standardized Classification of Threats but have been included in this document because they have major impacts on the ability of a RSGCN to recover from historic declines. Even if other threats, such as habitat loss or pollution, are eliminated, recovery cannot occur unless these underlying threats are dealt with. These threats are critical considerations for any restoration actions and methods for addressing them must be incorporated from the initial planning stages.

THREAT DESCRIPTIONS AND EXAMPLES

The first major intrinsic biological limitation is the **loss of genetic integrity**. In many ways, this is the inverse of the threats described under Introduced Genetic Material (Threat 8.5) above. Loss of genetic diversity becomes an independent threat for isolated populations or species already facing precipitous declines (Frankham 2003). Smaller population sizes leave the whole population more susceptible to stochastic events, potentially eliminating important sources of genetic diversity (Kendall 1998, Melbourne and Hastings 2008). As the populations persist, they face two major concerns as the result of reduced diversity: reduced reproductive output due to inbreeding, and reduced adaptive capacity (Frankham 2003, Willi et al. 2006). Inbreeding is caused by the accumulation of deleterious alleles in the population and is known to depress survival, fecundity, and viability across a wide variety of taxonomic groups (Neaves et al. 2015). Over time, fewer and fewer individuals are recruited into the breeding population, further decreasing population size and intensifying the impacts over multiple generations, potentially resulting in extinction (Frankham 2003, Neaves et al. 2015). Adaptive capacity is reduced in small populations due to the limited variation in the gene pool, reducing the likelihood of successfully responding to challenges like environmental change or disease (Nicotra et al. 2015, Ujvari et al. 2018). Some of the impacts of reduced genetic variability are long-lasting, and can still be detected many generations later (Matocq and Villablanca 2001).

In general, RSGCN with greater dispersal capacity, like birds and other migratory species, may be less likely to become limited by genetic diversity, while sedentary species, such as mussels, and species that exist in naturally isolated populations, such as high elevation salamanders, may be more at risk. Fragmentation can also result in decreased diversity, as it reduces connectivity, and the associated gene flow, between populations.

In the Northeast, many of the species threatened by lost genetic diversity are mussels and fish. Historic damming of rivers and streams fragmented and isolated many populations, reducing needed gene flow across the landscape. Mussels may be the most heavily impacted group amongst the 2023 RSGCN: the Mussel Taxa Team identified genetic diversity and small population sizes as a concern for more than 16 species, including Brook Floater (*Alasmidonta varicosa*), Dwarf Wedgemussel (*Alasmidonta* heterodon), Longsolid (*Fusconaia subrotunda*), Golden Riffleshell (*Epioblasma Florentina aureola*), Atlantic Pigtoe (*Fusconaia masoni*), Cumberland and Appalachian Monkeyface (*Theliderma intermedia* and *T. sparsa*, respectively), and Tennessee Bean (*Venustaconcha trabalis*). Diamond Darter (*E. cincotta*), Duskytail Darter (*E. percnurum*), and Bridle Shiner (*Notropis bifrenatus*) are all facing challenges due to their small, isolated populations. One species, the Maryland Darter (*Etheostoma sellare*) may already be extinct as a result of inbreeding depression. The decimation of many bat species by White-Nose Syndrome has raised concerns about the genetic diversity in remaining populations, but further research is needed to determine the overall effect (Foley et al. 2010, Gignoux-Wolfsohn et al. 2020, Lilley et al. 2020). The Bird, Mammal, Crayfish, Bee, and Lepidopteran Taxa Teams also all identified several species where low genetic diversity is a concern.

Another intrinsic biological limitation that threatens some RSGCN is the **decline or loss of a species that the RSGCN is dependent upon**. If sufficient food resources or host species are not present, their dependents cannot persist in the landscape. The types of relationships between these interdependent species and RSGCN vary, as do the underlying cause of the declines. In the case of many pollinators, they are highly dependent on specific plant species or groups as the primary food source for larval life stages and nectar resources. The general impacts of deer browse (Threat 8.2.3) on these lepidopteran hostplants has been described by several authors (e.g., Miller et al. 1992, Rooney and Waller 2003, Schweitzer et al. 2011). Other researchers have directly linked deer browse with pollinator population declines in Frosted Elfin (*Callophrys irus*; Frye 2012), West Virginia White (*Pieris virginiensis*; Davis and Cipollini 2013), Diana Fritillary (*Speyeria idalia*; Wells and Tonkyn 2014), and bumblebees (Sakata and Yamasaki 2015).

Decreased biomass is also problematic for RSGCN that are not dependent on a single key food resource. The Allegheny Woodrat (*Neotoma magister*) consumes a wide variety of forest fruits, seeds, and nuts. Despite their varied diet, one of the factors thought to be contributing to their imperilment is the loss of the American Chestnut as a food resource (Logiudice 2008). Many RSGCN are insectivorous, so the global decline in insect biomass is of grave concern (Wagner 2020). Aerial insectivores such as Eastern Whip-poor-will (*Antrostomus vociferus*) are impacted by decreases in overall insect biomass (Spiller and Dettmers 2019), and decreased availability of plankton or forage fish such as Atlantic Menhaden (*Brevoortia tyrannus*) will have impacts on seabirds, predatory fish, and marine mammals (Friedland et al. 2013, Anstead et al. 2021).

Declines of interdependent species are critical in symbiotic relationships as well. Freshwater mussels are highly dependent on fish for dispersal, as larval glochidia attach to the host's gills before dropping off in new areas. Damming of river systems prevents the movement of fish hosts, which can lead to declines in these critical species (Vaughn 1993, Vaughn 1997). Parasitic relationships, such as the case of cuckoo bees, also put RSGCN at risk. Cuckoo bees infiltrate the hives of other bee species and lay their eggs, leaving them for the host to raise. Ashton Cuckoo Bumble Bees (*Bombus ashtonii*) parasitize other *Bombus* species, including several that are already imperiled and included on the 2023 RSGCN list. Any threats that impact bumblebees, such as loss of floral resources, impact these nest parasites twice over; directly as they also need nectar sources, and indirectly as their host populations decline (Colla et al. 2012, Richardson et al. 2019). Another bee on the RSGCN list, the Macropis Cuckoo Bee (*Epeoloides pilosulus*) is another cuckoo bee that parasitizes *Macropis* bees, including two RSGCN and one Watchlist [Assessment Priority] species, though no research has yet connected analyzing the declines in these species.

The final threat under this category is **recruitment failure**. Recruitment refers to the process of adding or moving individuals to a population or age class and can occur via reproduction and growth or immigration, though this document focuses on reproduction. Critically, recruitment adds individuals to the breeding population to replace individuals that are no longer reproducing or have died. When recruitment failure happens as a temporally or geographically isolated event, it is not likely to have severe impacts on the species as a whole. It is only when recruitment failure happens repeatedly or across a large area that it becomes a threat. While recruitment failure may be the result of other threats, it must be treated independently. Recruitment failure may continue even after the root cause is addressed, as the historic alteration to the structure or composition of the remaining individuals still prevents any reproduction from happening. This is a major concern for some turtles, which are generally long-lived species with very low juvenile survival rates (Iverson 1990, Paterson et al. 2012). Even if adults in the population continue to breed and lay eggs, this reproductive effort is wasted if insufficient numbers of eggs recruit to juveniles and insufficient numbers of juveniles recruit to adults. Many turtle conservation efforts utilize headstarting as a tool for improving juvenile survival. In the Northeast, headstarting has benefited the Massachusetts population of the Northern Red-bellied Cooter (*Pseudemys rubriventrris*; Haskell et al. 1996), Blanding's Turtle (*Emydoidea blandingii*; Buhlmann et al. 2015, Carstairs et al. 2019), Wood Turtle (*Glyptemys insculpta*; Mullin 2019), and Diamond-back Terrapin (*Malaclemys terrapin*; Herlands et al. 2004). Mussels are similarly long-lived with very low juvenile survival, in part due to the specific needs of both their larval and juvenile stages. Relict populations of adult mussels with very few or no juveniles may be the result of a combination of factors that increased stress levels to lethal levels for younger age classes (Strayer and Malcom 2012). Similar to the turtle headstart programs, many imperiled mussels are propagated and grown to larger sizes before being released (Jones et al. 2006, Gum et al. 2011, Haag and Williams 2013), though there have been few attempts to evaluate the success of these efforts. One other species that is potentially impacted by recruitment failure is the American Eel (*Anguilla rostrata*). Decreased eel ladder counts for this species have been linked to recruitment rates, but more research is needed to more completely understand all the factors that may be contributing to the decline (Castonguay et al. 1994, Sullivan et al. 2009).

RELATIONSHIPS WITH OTHER THREATS

The threats described under this category are unusual in that they are very closely linked to or are the compounded result of many other threats. Decreased genetic diversity is frequently a result of fragmentation, which can be caused by Residential & Commercial Development (Threat 1.0), Agriculture & Aquaculture (Threat 2.0), Energy Production & Mining (Threat 3.0), Transportation & Service Corridors (Threat 4.0), Biological Resource Use (Threat 5.0), or Natural System Modifications (Threat 7.0). Pollution (Threat 9.0) can also play a role if it results in large mortality events, decreasing the size of the population. Species interdependence is closely linked to any threat that decreases the availability of an important host or food source, but Invasive & Problematic Species, Genes, & Diseases (Threat 8.0) and Climate Change (Threat 11.0) may be key drivers in shifting relationships. Recruitment failure is often the result of changes wrought by historic threats, and recovery may continue to be hampered by these or other considerations.

TOOLS AND RESOURCES

There are not relevant tools and resources for this threat because these Intrinsic Biological Limitations are species and location specific and highly contextual. In general, any actions that improve connectivity may help reduce the potency of these threats, but more information on alleviating the impacts of these threats is needed.

3.2.4 BIOLOGICAL RESOURCE USE

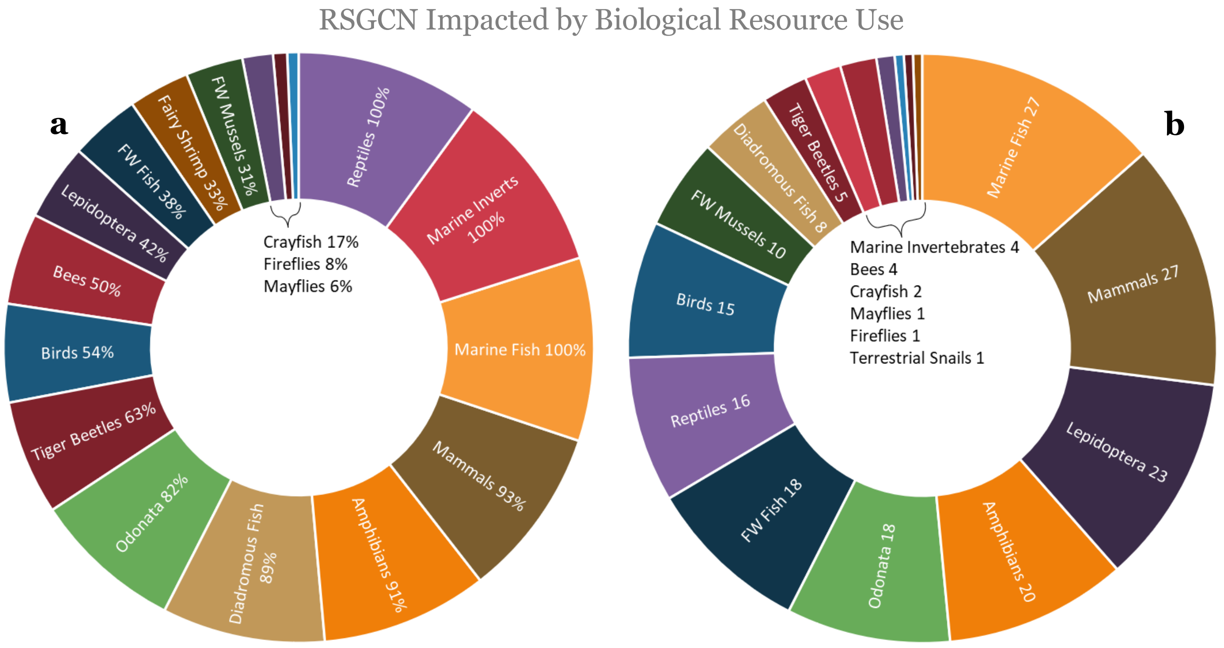

Figure 3.5 Impact of Biological Resource Use (Threat 5.0) on RSGCN and Proposed RSGCN. (a) The percentages show the proportion of the species within that taxonomic group known to be impacted by this threat. (b) The total number of species within the taxonomic group known to be impacted by this threat.

Biological Resource Use impacts 48% (200) of the species included as RSGCN and Proposed RSGCN in the 2023 list. This includes all members of the marine invertebrate, reptile, and marine fish taxonomic groups (Figure 3.5a). Mammals, amphibians, and diadromous fish are also largely included in the species impacted by this threat. Most of the species known to be impacted by biological resource use are vertebrates or are harvested for human consumption. This threat likely has less impact on most terrestrial invertebrate species, but the smaller numbers may also reflect data deficiencies in these groups (Figure 3.5b).

Biological Resource Use refers to the removal of biotic components of the environment for human consumption or benefit. This includes hunting and fishing, bycatch in regulated animal harvest, persecution and management of species considered dangerous or problematic, unregulated collection of wildlife for any purpose, and the harvest of timber and other plant products. The impacts of Biological Resource Use on RSGCN and Proposed RSGCN are often direct, physically removing individuals from the ecosystem. The exception to this is logging, which indirectly impacts many species by removing, fragmenting, and otherwise altering habitat. Regardless, these removals have major impacts on the individual, population, community, and ecosystem levels.

The individuals removed are intended for human use or benefit, as opposed to the mortality of flora and fauna as a result of some other threat factor. These removals can be either intentional, where the species is the target, or unintentional, where the species is collected incidentally along with a target species. Many of these forms of Biological Resource Use are regulated, but some species, especially invertebrates and amphibians, may lack formalized protections at state, national, or international levels. Other species are targeted despite legal prohibitions on their collection. Due to the human dimensions of this threat coordinated actions, consistent messaging, and shared regulatory decisions are needed across the Northeast for successful management.

Historically, many species in the Northeast were negatively impacted by forms of biological resource use. Hunting for sustenance led to significant declines in many iconic mammals and birds in the region (Foster et al. 2002). Persecution of large predators and other “nuisance” species, including bounty systems, led to declines and regional extirpations (Foster et al. 2002). Historic overfishing contributed to population crashes and declines of many marine fish species and coastal ecosystems (Jackson et al. 2001). Logging and the collection of plant species altered habitat on large scales across the region, contributing to widespread species declines and shifting wildlife communities better suited to agricultural landscapes (Foster et al. 2002). Human use of biological resources has had a strong influence on the ecosystems in the Northeast.

HUNTING & COLLECTING TERRESTRIAL ANIMALS AND FISHING & HARVESTING AQUATIC RESOURCES

The collection of terrestrial and aquatic wildlife and wildlife products has been occurring for millennia and continues to be a driver in wildlife declines globally. Removal of individuals from the ecosystem, frequently referred to as take, can occur for several reasons, be intentional or unintentional, and be managed or unmanaged. Regulation of species collection is a state, national, and international management concern, and requires coordination with the many organizations with jurisdiction over fish and wildlife species. Regardless of the type of take, collection can have significant cascading impacts on populations, communities, and ecosystems.

One important consideration for the management of terrestrial animals and aquatic resources is that responsibility may be shared with other agencies. For example, state marine programs usually have jurisdiction over marine plants and animals, though diadromous fish are often shared responsibilities as they transverse both marine and freshwater environments. Some state fish and wildlife agencies may not have authority over all invertebrates. They work closely with those regulatory authorities (e.g., the state Department of Agriculture) and often have cooperative agreements with these agencies.

THREAT DESCRIPTIONS AND EXAMPLES

Consumptive uses of wildlife include both use as food and collection for specific animal parts, such as furs or shells. While species from nearly every taxonomic group are consumed globally, the focus in the Northeast is generally on vertebrate species. In terrestrial ecosystems, most **hunting** (Threat 5.1.1) and **trapping** (Threat 5.1.2) targets mammal and bird species, though a very small number of amphibians and reptiles are also targeted. In aquatic ecosystems, fish and shellfish are targeted by **recreational or subsistence** (Threat 5.4.1) and **commercial fisheries** (Threat 5.4.2). These forms of take are generally regulated and managed by the state or other jurisdictional agencies, such as the regional fisheries management councils, via harvest seasons, quotas, and other regulations.

Overexploitation occurs when species are harvested at rates greater than reproduction and regrowth occur. When a species is overexploited, there are not enough individuals to interact which leads to a downward spiral of decreasing birth rates and shrinking population sizes. Overexploitation has additional impacts beyond the populations of the target species. The effects cascade to higher trophic levels and across the wider community, which can lead to widespread collapses in the ecosystem (Jackson et al.

2001, Humphries and Winemiller 2009). Even if the impacts of overexploitation are reduced, these systems may not have the capacity necessary to recover (Walsh et al. 2006, Humphries and Winemiller 2009). In the United States, overexploitation of bison, elk, and other big game sparked some of the earliest conservation efforts in the country and the development of a conservation ethic that still shapes the management of game species and their habitats (Organ et al. 2010, Heffelfinger et al. 2013).

Harvest of wildlife populations can lead to demographic shifts as individuals with certain characteristics may be disproportionately targeted. Larger individuals and males with more impressive horns, antlers, or plumage are often preferred. As these individuals are often the older members of a population, this can cause shifts in the age structure and sex ratio. As a result, overharvested populations often have lower fecundity and survivorship, increased mortality rates, destabilized social structures and hierarchies, truncated age and size classes, and altered age or size at maturity (Walsh et al. 2006, Milner et al. 2007, Fenberg and Roy 2008, Heffelfinger et al. 2013, Uusi-Heikkilä et al. 2015). These phenotypic changes may also be accompanied by behavioral changes, selecting individuals that are characteristically different than in unharvested populations (Uusi-Heikkilä et al. 2015, Leclerc et al. 2017). Significant research has gone into determining if these demographic and behavioral changes also have a genetic component, indicating human-driven evolution in these populations, though phenotypic plasticity may also account for some of these variations (Harris et al. 2002, Walsh et al. 2006, Fenberg and Roy 2008, Heffelfinger et al. 2013, Pinsky and Palumbi 2014, Uusi-Heikkilä et al. 2015, Festa-Bianchet and Mysterud 2018).

Relatively few RSGCN and Proposed RSGCN species continue to be impacted by regulated, intentional harvest. Many of these historical pressures have been reduced through the reduction of bounty systems, the establishment of conservation measures such as the Marine Mammal Protection Act, and management strategies such as the establishment of seasons, take limits, and size restrictions. These conservation measures have contributed to the recovery of seal populations in the Gulf of Maine (Bogomolni et al. 2021). Careful management can balance the recreational and subsistence uses of these species with the biological requirements necessary to maintain stable populations. For some species, harvest pressure remains high due in large part to practices outside of the Northeast region and the United States. Migratory birds and many marine species migrate in and out of the jurisdictional areas of the region, limiting the ability of Northeastern states to manage overexploitation in seasonal habitats. Fishing in international waters and the harvest of migratory species on their wintering grounds may be contributing to species declines within the region. Management of these threats will require international coordination and cooperation. Finding the balance of sustainability requires close coordination between regulatory agencies and commercial industries, as well as sound, unbiased scientific monitoring.

An additional source of take associated with collection and harvest is the unintentional capture of a species while pursuing a different target species, or **bycatch**. Bycatch occurs when fishing, hunting, or trapping gear are not selective and capture any species that come in contact with the equipment, leading to the capture, wounding, and mortality of non-target species. This phenomenon is particularly well studied in marine ecosystems, where various commercial fisheries incidentally capture numerous species. Marine bycatch contributes to declines in many fish species, sharks, marine mammals, sea turtles, and seabirds (Glass 2000, Molina and Cooke 2012, Senko et al. 2014). Estuarine and freshwater turtles are frequently caught in fish and crab traps (Rook et al. 2010, Bury 2011). Furbearer trapping can capture non-target species, generally other mammalian carnivores (Jachowski et al. 2021, Fogarty et al. 2022).

Bycatch can be reduced by establishing area or seasonal closures that protect vulnerable species or sensitive life stages or changing or modifying gear so that it excludes or deters non-target species or allows for their escape. Glass (2000) describes some of the common net design considerations and modifications used to mechanically sort target and non-target species. Bull (2007) discusses approaches for reducing seabird bycatch. More recent research is exploring the use of sensory deterrents for marine species, especially cetaceans and sharks (Hamer et al. 2012, Jordan et al. 2013, Hannah et al. 2015, Martin and Crawford 2015). Exclusion devices prevent seals and turtles from getting caught in nets and traps (Rook et al. 2010, Bury 2011, Jenkins 2012, Königson et al. 2014). In terrestrial systems, the Agreement on International Humane Trapping Standards has historically been used as a benchmark, but these standards may need to be updated to incorporate modern technology that will improve furbearer welfare, trap efficiency, and selectivity (Proulx et al. 2020).

Both closures and multiple gear modifications should be considered, depending on the target species, vulnerable non-target species, ecosystem, and tradeoffs between non-target species captured and target species released (Senko et al. 2014). Establishing seasonal closures can be very effective for species with very different life histories. However, climate change is shifting the timing of historically predictable recurring life events for many species (Staudinger et al. 2019). This may cause mismatches with these closures, reducing their efficacy under changing conditions. Gear modifications takes advantage of the behavioral or physiological characteristics of target and non-target species to reduce the impact on the non-target species. While these methods may be effective when the bycatch species is extremely different from the target species, such as is the case with sea turtle exclusion devices in shrimp trawls, this method is less successful when the species are more similar. For example, river herring such as American Shad (*Alosa sapidissima*) and Alewife (*Alosa pseudoharegus*) form large multi-species schools with commercially harvested species such as Atlantic Herring (*Clupea harengus*), which can result in many of the river herring species being caught as bycatch. Similarly, American Marten (*Martes americana*) and Fisher (*Pekannia* *pennanti*) have significant overlap in body sizes and similar behaviors, making the Marten susceptible to capture in Fisher traps.

Poaching and persecution of terrestrial animals (Threat 5.1.3) **and aquatic species** (Threat 5.4.4) are increasing concerns in the Northeast. The effects of these forms of take are similar to those for overexploitation described above for fishing and hunting. When it occurs at unsustainable levels, it results in population declines and extirpations, with associated demographic, phenotypic, and genetic shifts (Morton et al. 2021).

Persecution of snakes, especially venomous species like the Timber Rattlesnake (*Crotalus horridus*) has been occurring for hundreds of years, contributing to declines in these species (Montague 2022). Many predatory mammals and birds faced similar persecution, as they were believed to prey on livestock and desirable game species (Foster et al. 2002). Bats have also historically been persecuted due to misconceptions about the species; the spread of COVID-19 heightened concerns that persecution of these species would again increase (MacFarlane and Rocha 2020). Protection of persecuted species and outreach and education about these species has greatly reduced the levels of persecution in the region, though further efforts are needed for some species.

Poaching and illegal wildlife trade are contributing to major declines for several RSGCN and Proposed RSGCN. Export for traditional medicines, food, and pet trade has long been cited as a concern for several amphibians and reptiles (Schlaepfer et al. 2005). Illegal and unsustainable wildlife trade is a complex issue, as it involves global supply and demand, enforcement of state, federal, and international laws and agreements, online marketplaces that are largely not monitorable, and a complex, culturally-driven understanding of the underlying issue (Fukushima et al. 2021). The awareness of and intensity of this threat has increased dramatically in the Northeast for freshwater turtles since 2000, in response primarily to the increasing demand for pet turtles in Asia (Easter et al. 2023). The United States has some of the highest freshwater turtle diversity in the world, with the Northeast and Southeast regions most heavily impacted by the illegal export of turtles (Easter et al. 2023). Widespread recognition of this problem led to the creation of the Collaborative to Combat the Illegal Trade in Turtles[101], which builds relationships between state, federal, and tribal agency biologists, law enforcement, and researchers from academic and non-governmental organizations, allowing them to collaboratively address the needs associated with illegal turtle trade. This group, along with the Partners for Amphibian and Reptile Conservation's Turtle Network Team, works to develop regulations to address current risks, provide resources for law enforcement activities and confiscated turtle care, enhance communication and public outreach, and develop scientifically-informed guidance for the treatment of confiscated turtles. In 2022, the Convention on International Trade in Endangered

Species (CITES) voted to include 21 United States turtle species in Appendix II, providing international trade protections for these species (Center for Biological Diversity 2021).

There are a few other forms of take, though they are not generally considered a major concern in the Northeast. **Non-lethal harvesting of terrestrial animals** (Threat 5.1.3) involves the collection of animal products in ways that do not result in the mortality of individuals, such as the collection of molted feathers, shed antlers, or bat guano. Generally, these activities do not have direct impacts on any species, but in some instances, the collection activities themselves may be disruptive if individuals are still present. **Management and control of terrestrial animals** (Threat 5.1.5) and **aquatic species** (Threat 5.4.4) generally involves the targeted culling of species whose populations are thought to be too large, but the removed individuals are not consumed. Some common examples of this in the Northeast are the application of lampricides in streams to decrease non-native populations of Sea Lamprey (*Petromyzon marinus*) and netting of Common Starling (Sturnus vulgaris) flocks to reduce impacts on crops. Unfortunately, several RSGCN and Proposed RSGCN fish are also sensitive to the lampricides, including American and Northern Brook Lamprey (*Lethenteron appendix* and *Ichthyomyzon fossor*, respectively), Lake Sturgeon (*Acipenser fulvescens*), and Hellbender (*Cryptobranchus alleghaniensis*). Starlings can form flocks with other species, including Rusty Blackbird (*Euphagus carolinus*), which is also trapped by the nets. The impacts of these management strategies need to be carefully considered to develop best practices that reduce impacts on non-target species.

RELATIONSHIPS WITH OTHER THREATS

The exploitation of wildlife species tends to follow patterns, with take occurring in concentrated areas. The location of these areas is often influenced by their proximity to Residential & Commercial Development (Threat 1.0) and Transportation & Service Corridors (Threat 4.0). Because of the direct interactions between humans and wildlife, these threats can facilitate the spread of Invasive Non-native/Alien Plants & Animals (Threat 8.1) and Pathogens & Microbes (Threat 8.4). These activities are also the source of many forms of Garbage & Solid Waste (Threat 9.4), such as lead ammunition, abandoned fishing gear and other entanglements, and garbage. Climate Change (Threat 11.0) is likely to amplify the effects of overexploitation on wildlife species, adding additional stressors to already high-risk environments (e.g., Staudt et al. 2013).

TOOLS AND RESOURCES

State fish and wildlife agencies have tools for tracking hunting and fishing activities in their state through their licensing systems. Many agencies conduct hunter, trapper, and fisherman surveys to determine hunter effort, satisfaction, and opinions. However, these surveys are unique to each state and may collect very different information. It is difficult to analyze these activities consistently across the region due to the individuality of the data collected by each state.

Every five years, the US Fish and Wildlife Service coordinates the **National Survey of Fishing, Hunting, and Wildlife-Associated Recreation**[102] which determines American participation in, expenditure on, and values around these activities. The survey has been conducted since 1955, providing a long-term dataset showing changes in demographics, behavior, and opinion over time. The most recent report on the 2015 survey is currently available; the report for the 2022 surveys should be available in the summer of 2023. The Fish and Wildlife Service also works with state fish and wildlife agencies to administer the **National Migratory Bird Harvest Survey**[103]. This survey has collected information for estimating hunter effort and harvest levels of doves and pigeons, waterfowl, American Woodcock (*Scolopax minor*), and rallid birds since 1955.

Kroodsma et al. (2018) used Automatic Identification System (AIS) data to develop **maps of global commercial marine fishing activity**. AIS are navigational tools used to reduce collisions in open waters. In the last decade, the International Maritime Organization mandated that all vessels greater than 36 meters transmit signals, which can be picked up by ground stations and satellites and analyzed at global scales. The organization Global Fishing Watch[104] hosts an interactive version of these maps, providing tools to look at patterns over time. NOAA Fisheries is also implementing **electronic monitoring of American fishing fleets**[105], adding additional detail to marine fisheries data.

Many organizations participate in the management of Northeast fisheries, including the Great Lakes Fishery Commission[106], Northeast Regional Ocean Council[107], Mid-Atlantic Regional Council on the Ocean[108], New England Fishery Management Council[109], Mid-Atlantic Fishery Management Council[110], and the Atlantic States Marine Fisheries Commission[111]. These partner organizations both manage fish populations and have species and habitat conservation programs to support imperiled species. These groups all have suites of geospatial data and information about fisheries management. For more information about these partners and their products, see *Chapters 2* and *7*.

LOGGING & WOOD HARVESTING

Much of the Northeast was deforested and converted to agricultural land use in the 1800s and early 1900s, though significant areas have been reforested in the century since (Foster et al. 2002). More than half of the land area in the Northeast region is now forested (Anderson et al. 2023). As a result, logging, wood harvesting, and other silvicultural practices have the potential to impact large portions of the landscape.

In recent decades, researchers have recognized that timber harvest is a disturbance factor just like wind and fire. Planning harvest activities so they emulate natural disturbance regimes in terms of scale and frequency may help maintain forest health while simultaneously meeting human needs (Seymour et al. 2002, Long 2009, Kuulkuvainen et al. 2021). Additional research has investigated the carbon storage capacity in forests managed utilizing disturbance-based silviculture (Thom and Keeton 2020). These practices may maintain a diverse forest matrix that can support a wide variety of species' needs (Thom and Keeton 2020, Kuulkuvainen et al. 2021). Research in the Northeast has highlighted the dominance of timber harvest as a disturbance factor in the region and predicted how forest biomass levels are likely to change based on changing climate and future timber harvest projections (Brown et al. 2018). Increasing demand for timber products is likely to elevate harvest intensity and frequency. These increases may slow the accumulation of biomass over the next 150 years, though they will likely not stop it completely (Brown et al. 2018). However, intensified harvest regimes may alter the age structure of the forests, keeping much of the landscape in younger forest age classes (Brown et al. 2018).

In the Northeast, the majority of forests are privately owned, adding additional complexity to the management of these landscapes (Thompson et al. 2017, Butler et al. 2021a). These landowners are driven by a variety of socioeconomic drivers that shape if, when, and how they decide to harvest timber on their properties (Butler et al. 2021a, Sass et al. 2021). Landscape-level management of forested landscapes in the Northeast thus requires understanding the opinions of these landowners and involving them in the development of policies, programs, and management plans to benefit forested habitats (Butler et al. 2021a, Sass et al. 2021).

While forest harvest may result in direct mortality of RSCN and Proposed RSGCN, the primary impact for many species is the loss alteration of habitat. Timber harvest changes the structure, composition, and function of forested ecosystems. The use of heavy equipment has major impacts on the soil, causing compaction and rutting, which in turn alters the properties of the soil, changes nutrient and carbon cycling, and slows plant growth and regeneration (Cambi et al. 2015). The logging roads themselves have additional impacts, fragmenting habitat, facilitating the spread of problematic species, causing avoidance of high traffic areas, impacting water quality, and increasing infiltration of forested areas by hunters or for other recreational uses (Boston 2016). Some native predators also utilize these forest roads, increasing their abundance and predation rates (e.g., Gómez-Catasús et al. 2021). The removal of tree biomass affects nutrient and carbon cycles, which can affect future regeneration (Berger et al. 2013, Ranius et al. 2018). Timber harvest can differ greatly from natural disturbances in the structure it creates; harvested forests tend to have significantly less coarse woody debris and fewer standing dead trees (Berger et al. 2013). Openings are sunnier, supporting different species than would grow in the understory of the surrounding forest.

Nearby aquatic habitats are also significantly impacted. Forest harvest can alter stream flow rates by decreasing evapotranspiration rates and increasing overland runoff (Berger et al. 2013). This runoff simultaneously increases sedimentation rates, and can also carry various nutrients and chemicals (Berger et al. 2013, Boston 2016, Ranius et al. 2018). If harvest occurs in riparian areas, it increases light penetration to the water and can increase temperatures, which negatively impacts many aquatic species (Berger et al. 2013). Harvest practices can also change the influx of woody debris into aquatic systems (Berger et al. 2013).

THREAT DESCRIPTIONS AND EXAMPLES

Forestry harvest practices are diverse to meet a variety of economical, esthetic, and ecological purposes. As a result, they can have variable impacts depending on the harvest intensity, scale, and equipment used. **Complete removal of forest cover** (Threat 5.3.1), such as clear cuts, removes the greatest amount of biomass from the ecosystem. These harvesting practices often result in large, even-aged stands. These cuts can be highly disruptive to some wildlife species, though they may provide habitat for others (Ram et al. 2020). **Partial removal of forest cover** (Threat 5.3.2) allows for the retention of some canopy cover and includes practices such as shelterwood cutting and selection harvesting. The retention of forest patches can provide refuge from the impacts of harvest on local wildlife, as well as being a seed source for the regeneration of the harvested area (Fedrowitz et al. 2014). **Improvement cutting in natural forests** (Threat 5.3.3) is more selective, removing certain trees to improve the growth of those that are left. Common examples of this include pre-harvest thinning, tending felling, and sugarbush management. Importantly, while these practices may retain canopy cover, they can change the composition of the stand by selectively removing species that are undesirable for the management goals of the stand.

Other activities associated with timber harvest can impact wildlife species. **Artificial regeneration of forest stands** (Threat 5.3.4) involves the seeding or planting of harvested areas to reduce erosion and speed up regeneration rates. However, this practice can have unintended ecological impacts. As the seeds or seedlings are generally sourced from nursery stock, they are not locally adapted to the site they are planted, which can interfere with evolution and create monocultured stands that are more vulnerable to disease or insect outbreaks (Ratnam et al. 2014, Liu et al. 2018). Tree planting may also increase fire risk, especially under changing climatic conditions (Hermoso et al. 2021). Researchers have also shown that artificially and naturally regenerated forests have different species diversity, abundance, and assemblages (Kosewska et al. 2018). **Management of cutting areas** (Threat 5.3.5) includes several practices for handling debris from the timber harvest and soil treatments to improve natural regeneration. Traditional harvest typically removes just the bole of the tree, leaving the branches and other debris behind. This debris provides important habitat for numerous species, especially small mammals and amphibians. Piling the debris into piles or windrows greatly increases small mammal diversity and abundance, and also provides important hunting opportunities for predatory RSGCN such as American Marten (*Martes americana*; Sullivan et al. 2017, 2021). Downed logs and debris also create protected microhabitats with higher moisture content, an important component for forest amphibians, especially salamanders (Otto et al. 2013, Clipp and Anderson 2014). Forest harvest practices that ensure the availability of debris benefit many species. In contrast, practices such as whole-tree harvest and harvest for energy production leave far less debris behind, with significant impacts on many ecological components and species (Berger et al. 2013, Ranius et al. 2018). Scarification and other soil treatments can improve germination rates of certain tree species but can also disturb soil biota (Yamazaki and Yoshida 2020, Smenderovac 2023).

Significant research has gone into understanding the reactions of various species to different timber harvest practices. Though not a complete catalog, the following papers include recent reviews of key taxonomic groups and provide a starting point for further research:

- Small mammals: Zwolak 2009, Sullivan et al. 2017, Demarais et al. 2017, Kellner et al. 2019, Larsen-Gray and Loehle 2022
- Birds: Demarais et al. 2017, Castaño-Villa et al. 2019, Kellner et al. 2019, Basile et al. 2019, Ram et al. 2019, Lott et al. 2021, Larsen-Gray and Loehle 2022, Akresh et al. 2023
- Herptiles: Otto et al. 2013, Demarais et al. 2017, Thompson and Donnelly 2018, Kellner et al. 2019, Cordier et al. 2021, Martin et al. 2021, Larsen-Gray and Loehle 2022
- Terrestrial invertebrates: Korpela et al. 2015, Kosewska et al. 2018, Ram et al. 2019
- Aquatic species: Cristan et al. 2016, Warrington et al. 2017, Coble et al. 2019, Schilling et al. 2021, Rajakallio et al. 2021

Sustainable, compatible forest management should incorporate the needs of many different species, anthropogenic uses and purposes, and ecological services. As a result, the managed forest landscape must be dynamic and heterogenous to meet all of these sometimes conflicting needs.

RELATIONSHIPS WITH OTHER THREATS

As is the case with many extractive practices, logging and wood harvesting is influenced by accessibility (Thompson et al. 2017). As a result, these activities are often related to the location of roads (Threat 4.1.1). Logging activities are also associated with the conversion of forested land to other uses, such as Residential & Commercial Development (Threat 1.0), Agriculture & Aquaculture (Threat 2.0), and Energy

Production & Mining (Threat 3.0). Logging roads increase the distribution and mobility of Invasive Non-native/Alien Plants & Animals (Threat 8.1), Problematic Native Plants & Animals (Threat 8.2), hunters (Threat 5.1.1), and recreational vehicles (Threat 6.1.1). Some forest practices may magnify the impacts of Pathogens & Microbes (Threat 8.4), as is the case for bats impacted by White-Nose Syndrome (Silvis et al. 2016). Deforestation can intensify the impacts of Dams & Water Management/Use (Threat 7.2) and increase sedimentation (Threat 9.3.2) and other forms of Pollution (Threat 9.0) in nearby streams. Climate Change (Threat 11.0) is likely to intensify some of these effects, especially hydrology, and may also interact to increase the risk of fire (Threat 7.1.1).

TOOLS AND RESOURCES

The US Forest Service has significant resources for informing forest management nationally. The **Forest Inventory and Analysis (FIA)**[112] program reports on forest status and trends, including species composition, tree size and age, forest health and growth, harvest and wood production, and land ownership. The program has been operating since 1930, producing long-term monitoring and inventory datasets that inform analysis of American forests. One of their products is the **National Woodland Owner Survey**[113], which is implemented by the Family Forest Research Center out of the University of Massachusetts, Amherst. This survey aims to better understand who owns forests in the United States, their motivation for owning forested lands, and their historic and future management objectives. This survey is conducted on a five-year cycle, with the most recent survey completed in 2018 (Butler et al. 2021b). Other data products include tools for analyzing inventory and monitoring programs, state-level summaries of FIA data, urban tree data, and tools for exploring the National Woodland Owner Surveys.

Many best practices for timber harvest and logging operations have been developed. The **Young Forest Project**[114] is a partnership of private, public, tribal, and commercial forest landowners working to enhance and maintain the availability of early successional, young forests and shrublands for wildlife. Their website has best management practices, instructional guides and manuals, and a list of demonstration site projects in the Northeast, Mid-Atlantic, and Midwest. Oehler et al. (2006) produced a book that included sections with **recommendations on improving young forests and forest openings for wildlife**, which could be used to inform timber harvest operations. The US Army Corps of Engineers produced a set of **best management practices for stream crossings**, including temporary crossings utilized in logging operations (USACE 2015). Individual states may also have their own best management practices describing harvest methodology, stream and riparian area protection, and logging road management. **Best management practices to protect water quality** in adjacent aquatic habitats from forestry activities are available from the US Forest Service[115] and the National Association of State Foresters[116].

Other authors focus on species-based recommendations. A RCN project titled **Best Management Practices (BMPs) for RSGCN Species in Northeast Forests** produced field guides and management guides for five forest RSGCN: Bicknell's Thrush (*Catharus bicknelli*), Wood Thrush (*Hylocichla mustelina*), Canada Warbler (*Cardellina canadensis*), Rusty Blackbird (*Euphagus carolinus*), and American Marten (*Martes americana*). For more information on this project, see *Chapter 4*. The White-Nose Syndrome Response Team produced a document outlining **forestry best management practices for bat species** (Taylor et al. 2020).

Other important partners for forest management, including the **National Alliance of Forest Owners**[117], the **National Association of State Foresters**[118], **and the Northeast-Midwest State Foresters Alliance**[119] are described in *Chapter 2*.

GATHERING OF TERRESTRIAL PLANTS OR FUNGI

Most of the threats under this category are not as relevant to Northeast RSGCN, as plants have yet to be included as RSGCN. However, since at least half the Northeast states list plants as SGCN, these threats are still relevant to high-priority species in many states. This is a complicated management issue, as many state fish and wildlife agencies do not have primary jurisdiction over wild plant species; regulatory authority and responsibilities vary by state. Management will require coordination with the state agencies that do have responsibility for plants.

Most of the plants that are collected for uses besides timber are forest species and are often referred to as Non-Timber Forest Products (NTFPs). Collectors of NTFPs include commercial collectors where these products are a primary or supplementary source of income and a rapidly growing number of recreational harvesters and foragers collecting for personal use (Vaughn et al. 2013). Many land managers see NTFP management as a daunting task due to a lack of information about sustainable harvesting practices, unclear regulations and enforcement capabilities, and uncertainty about gatherer culture and mindsets (Vaughn et al. 2013). For a more complete assessment of NTFPs in the United States, see Chamberlain et al. (2018).

A few examples of Northeast commercially and recreationally exploited plant species include:

- American Ginseng (*Panax quinquefolius*) – a medicinal plant that has largely disappeared in the wild
- Ostrich Fern (*Matteuccia struthiopteris*) Cinnamon Fern (*Osmunda cinnamomea*), and Royal Fern (iO. spectabilis) – the source of fiddleheads, a popular wild-harvested food that can be negatively impacted by high-intensity harvest

- Wild Leek/Ramps (*Allium tricoccum*) – another wild-harvested food plant that is frequently overharvested
- Sugar Maple (*Acer saccharum*) – primary species tapped to collect sap for syrup production. Red (*A. rubrum*) and Silver Maple (*A. saccharinum*) also can be tapped, but generally produce less abundant, lower quality sap
- Salt hay (*Spartina patens*) – saltmarsh species collected and sold for a variety of uses, especially as a weed-resistant mulch
- Pine straw (*Pinus sp.*) – fallen needles from various pine species, often in plantation settings, collected and sold as a ground cover and mulch
- Wild berries, fruits, and nuts – collected for consumption and value-added specialty products, such as jams, syrups, and flours
- Evergreen boughs and other greenery – collected for wreaths, winter decorations, and floral arrangements
- Medicinal plants – collected for use in traditional medicine
- Birch bark – collected for traditional crafts and other value-added products
- Wild mushrooms – collected for personal consumption and specialty markets

There are a few instances where the regulated harvest or management of a plant species could have indirect impacts on wildlife. This generally falls into one of two categories: the widespread removal of a plant leads to habitat alteration, or the collected plant is an important host or food resource for a RSGCN or Proposed RSGCN species. The Taxa Teams did not identify any RSGCN or Proposed RSGCN impacted by the threats in this category. The effects may be localized and not widespread enough to be a regional concern or our understanding of how the harvest of these plants impacts RSGCN and Proposed RSGCN species is currently limited. For example, the Ostrich Fern Borer (*Papaipema sp. 2 nr. pterisii*) populations may decrease in areas where their host plant is impacted by collection. Saltmarsh Sparrow (*Ammospiza caudacuta*) and other saltmarsh birds may avoid areas managed for salt hay or may lose nests as a result of management practices such as mowing. More research will be necessary to determine the influence of human exploitation of these plant resources on the RSGCN and Proposed RSGCN that are associated with them.

3.2.5 NATURAL SYSTEM MODIFICATIONS

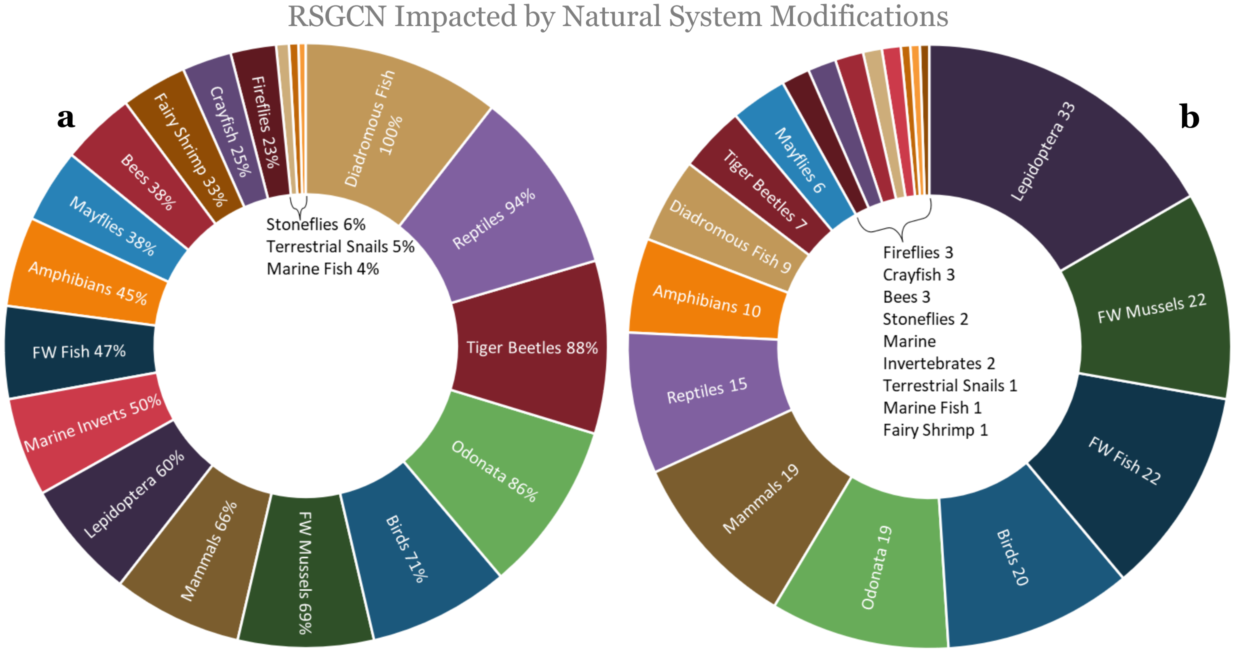

Figure 3.6 Impact of Natural System Modifications (Threat 7.0) on RSGCN and Proposed RSGCN. (a) The percentages show the proportion of the species within that taxonomic group known to be impacted by this threat. (b) The total number of species within the taxonomic group known to be impacted by this threat.

A total of 198 species – 47% –on the 2023 RSGCN and Proposed RSGCN list are impacted by Natural System Modifications. Diadromous fish, reptiles, tiger beetles, and odonates are the most heavily impacted, with more than 80% of the species in each of these groups known to be imperiled by these threats (Figure 3.6a). The largest number of species impacted are lepidopterans, freshwater mussels, and freshwater fish (Figure 3.6b). For the other invertebrate groups and marine fish, very few species are tagged to this threat, both in terms of total numbers and proportion of the taxonomic group. This is likely due to data deficiencies and a limited understanding of how natural system modifications can impact these groups, rather than an indication that these groups are not sensitive to these threats.

Natural System Modifications are a threat to many RSGCN and Proposed RSGCN species because, while they may not eliminate a habitat, they alter the structure and function of these ecosystems. Habitat degradation or other impacts on quality and condition can make some habitats unsuitable for more sensitive species. Some of these modifications can alter important processes, such as disturbance and succession, changing the functionality of a habitat over long time scales. Other modifications may fragment habitats, preventing species movements and isolating populations.

Many species in the Northeast RSGCN and Proposed RSGCN list are considered indicator species, where their presence or absence is indicative of habitat condition at that site. These indicator species can be related to the presence of pollutants or other contaminants (e.g., Evers et al. 2003), management history (e.g., Blossey et al. 2019), or overall ecosystem health (e.g. Edsall et al. 2005, Jones et al. 2009). In particular, aquatic insects such as mayflies, caddisflies, and stoneflies are frequently considered indicators of water quality and are sensitive to changes in streamflow. Many insects, such as the Northern Barrens Tiger Beetle (*Cicindela patruela patruela*) and Buchholz's Gray Moth (*Hypomecis buchholzaria*) are closely associated with pine barrens habitats and often decline in the absence of fire.

FIRE & FIRE SUPPRESSION

In the Northeast region, fire is one of the disturbance factors that shape the landscape along with wind and storms, anthropogenic activity, beavers, and insect outbreaks (Van Lear and Harlow 2002). These disturbances can function independently or interactively with one another, creating complex, dynamic landscapes across the region (Turner 2010, Cannon et al. 2017). An ecosystem's fire regime – the patterns in fire frequency, intensity, timing, size, and duration – determines the vegetation structure and composition, which in turn influences the wildlife communities that form (Archibald et al. 2013). Fire regimes vary across the region. In much of New England and New York, fire tends to occur infrequently, on a timescale of 200 years or more, but when fires do occur, they are often more severe, replacing large swaths of forest (Brown and Smith 2000). Further south, fires tend to happen more frequently, but are generally of lesser intensity, burning the understory rather than replacing the canopy (Brown and Smith 2000). Indigenous burning of forested habitats played a role in shaping the fire regimes in the eastern United States, but our understanding of the intensity and frequency of these burns and their impact on the environment is evolving, suggesting that these burns were not as widespread as previously though, especially in the New England area (Ryan et al. 2013, Oswald et al. 2020). In many cases, our knowledge of historic regimes, current conditions, and likely future changes is limited, as is our understanding of the impacts of prescribed fire on both above-ground and below-ground communities, highlighting the need for additional research in fire ecology (McLauchlan et al. 2020).

Fire can result in the mortality or injury of wildlife, though these impacts are generally considered minor at the population level (Jolly et al. 2022). Exceptions to this are species with limited mobility that are unable to flee or small, isolated populations that cannot depend on immigration from other populations to recolonize the site (Smith 2000). Timing is a critical component in determining the impacts of fire on wildlife. Burns that happen during nesting seasons or while wildlife are immobile, such as overwintering insect pupae or hibernating bats, have much greater impacts on populations (Smith 2000). Many wildlife species, especially those that occur in fire-prone habitats, have developed adaptive behavioral and morphological traits that improve their chances of survival (Pausas and Parr 2018).

THREAT DESCRIPTIONS AND EXAMPLES

Changes in fire regimes have significant impacts on species in ecosystems because they alter key processes that shape plant communities. Some unique habitat types, such as pine barrens, xeric grasslands, and sandplains are dependent on regular fires to maintain the community and prevent the incursion of other species that are not fire-adapted. **Suppression in the fire regime** (Threat 7.1.2) results in the intrusion of plant species that are poorly adapted to fire but are shade-tolerant and able to overtop and shade out fire-tolerant species that require more sunlight (Nowacki and Abrams 2008). Fire-adapted grasslands and open savannah-like habitats gradually transition into closed-canopy forests, which alters ground litter composition, fire fuel accumulation, and moisture levels (Nowacki and Abrams 2008). In the eastern United States, historic fire suppression has resulted in compositional shifts from fire-adapted oak and pine forests to mixed mesic hardwoods (Nowacki and Abrams 2008). It has also caused the age classes to shift and resulted in fewer open areas (Lorimer and White 2003). Species that are dependent on open, xeric, fire-prone habitats are excluded over time as their habitats become rarer. The physical activities of actively suppressing fires, such as creating firebreaks or usage of fire retardants, can also have impacts on wildlife and are summarized by Backer et al. (2004).

Increases in the fire regime (Threat 7.1.1) are also problematic for many species. These impacts are more difficult to summarize and are largely contextual, dependent on which aspects of the fire regime - frequency, intensity, timing, size, or duration – are changing, and which species is under consideration. Changing climactic conditions, such as decreased precipitation and increased temperatures, may make the ensuing fire more intense (Flannigan et al. 2000, Reilley et al. 2022). The history of fire suppression in the region has also resulted in altered fuel loads and forest structure, which can increase the intensity of fires when they occur.

The use of prescribed fires as a habitat management tool in the Northeast is growing (e.g., Harper et al. 2016). Most prescribed burns occur in seasons that are most conducive to safety, rather than aligning with periods when natural fires would have most commonly occurred (Knapp et al. 2009). These associated changes in burn timing and intensity can have severe effects on some species. For example, the Frosted Elfin (*Callophrys irus*) is dependent on plants in the genera *Lupinus* and *Baptisia*, which are fire-adapted species. Burning in these habitats releases nutrients that the plants utilize, providing higher-quality forage to the butterflies. However, if burns occur in the spring, they may damage or destroy pupae located in the leaf litter or near the soil surface, leading to long-term population declines (Jue et al. 2022, Meyer et al. 2023). Planning and timing prescribed fires should consider these aspects of fire and species ecology to minimize impacts on RSGCN and Proposed RSGCN.

RELATIONSHIPS WITH OTHER THREATS

Climate Change (Threat 11.0) is driving many of the changes in fire regimes, as increased temperatures, decreased precipitation, and shifts in the timing of these cycles influence the aspects of fire regimes. Some of the other threats can be ignition sources for fires. Transportation & Service Corridors (Threat 4.0) have started several wildfires, including the deadly 2018 Camp Fire in California, which transmission lines (Threat 4.2.1) sparked. Vehicles on Roads & Railroads (Threat 4.1) can produce sparks, as can equipment used for Logging & Wood Harvesting (Threat 5.3). Residential & Commercial Development (Threat 1.0) may also be a source, especially in low-density areas and campgrounds where human activities, such as campfires, occur close to flammable habitats. Invasive Non-native/Alien Plants & Animals (Threat 8.1) can either invade after a fire or can greatly influence fire conditions, as many species promote increased fire occurrence and intensity (Grace et al. 2001, Brooks et al. 2004, Fusco et al. 2019). Fire may also interact with Pathogens & Microbes (Threat 8.4), shaping the dynamics of diseases and disease vectors (Albery et al. 2021, Gallagher et al. 2022).

TOOLS AND RESOURCES

There are a large number of tools and resources available related to fire monitoring and management. Though far from a complete list, the following resources provide a starting point for learning more about these topics:

- The **National Interagency Fire Center**[120] houses fire management programs from the Bureau of Land Management, National Park Service, US Fish and Wildlife Service, Bureau of Indian Affairs, and the US Forest Service. In conjunction with their partners, this group provides leadership, policy oversight, and coordination to manage the nation's wildland fire programs.
- The National Oceanic and Atmospheric Administration produces several **maps, tools, and other products for wildfire management**, including predictive map products for fire risk, satellites and models for tracking active fires, and forecasting tools for monitoring flood risk after the fire as part of its wildlife program[121].
- The Environmental Systems Research Institute's (ESRI) **Disaster Response Program**[122] has a page devoted to wildfires with maps and other spatial products tracking active fires, air quality, and containment operations.
- The US Forest Service has an **informational page devoted to fire science**[123], including research, fire management, forecasting, and rehabilitation.
- The fire programs of the US Forest Service and the US Department of the Interior jointly manage the **Landscape Fire (LANDFIRE) and Resource Management Planning Tools**[124]. This program provides landscape-scale geospatial products that describe vegetation, wildland fuel, and fire regimes across the United States to support cross-boundary planning, management, and operations.

DAMS & WATER MANAGEMENT/USE

Water management activities have significant impacts on aquatic habitats, altering many of the ecological processes that shape these environments. All of the threats in this category modify the flow of water through aquatic ecosystems by changing a combination of the water volume, speed, timing, temperature, and availability. Human water control structures, such as dams and culverts, directly interfere with the flow, manipulating these characteristics. Activities that withdraw water from the system entirely for human purposes have impacts beyond the water body. The reduction of water from the system can alter local hydrology and lower the water table, which has particular impacts on many upland habitats, especially sensitive areas like ephemeral wetlands and cave systems.

THREAT DESCRIPTIONS AND EXAMPLES

The most commonly cited threat to RSGCN and Proposed RSGCN within this category is **water level management using dams** (Threat 7.2.1). Many natural barriers, such as beaver dams, waterfalls, and canyons, also exist in riverine systems, but the impacts of natural and anthropogenic barriers can differ (Fuller et al. 2015). These impacts vary dependent on the size, purpose, and location of the dam and the species being considered (Fuller et al. 2015, Turgeon et al. 2019). Globally, most river systems are impacted by dams; the United States has some of the highest levels of riverine habitat fragmentation globally, with very few free-flowing river reaches remaining (Nilsson et al. 2005, Grill et al. 2019, Barbarossa et al. 2020).

One of the greatest impacts of dams is as a physical barrier to species movement. Fragmentation can isolate populations and reduce gene flow, leading to long-term population declines and extinction (Reidy Liermann et al. 2012, Fuller et al. 2015, Carvajal-Quintero et al. 2017). Connectivity is one of the most important factors in determining the distribution of fish species globally, highlighting the vulnerability of this group to dams and other barriers (Carvajal-Quintero et al. 2019). Diadromous fish are particularly vulnerable as they often must bypass dams to reach spawning grounds (Waldmann and Quinn 2022). Translocation and passage structures such as fish ladders or elevators may help these species bypass these structures, but are not always effective or sufficient (Roscoe and Hinch 2010, Waldmann and Quinn 2020, Pires et al. 2021). Dams also fragment the habitat for freshwater invertebrates, such as mussels, crayfish, and insects (Vinson 2001, Strayer 2006, Santucci et al. 2005). Freshwater mussels in particular may be doubly impacted, as the dams fragment both the mussel populations and the fish species they depend on (Vaughn 1997).

The physical barrier of a dam causes inundation upstream, transforming lotic habitat to lentic (Friedl and Wüest 2002). This changes water flow velocity, movement, temperature, turbidity, and stratification (Friedl and Wüest 2002, Herbert and Gelwick 2003). Impoundments may also provide habitat for greater numbers of larger piscivores and invertivores, which impacts species from lower trophic levels (Herbert and Gelwick 2003, Gido et al. 2009). Some invasive species may do well in these altered habitats (Nilsson et al. 2005). Nutrient and oxygen levels can be altered in the impoundment (Nilsson et al. 2005). Downstream, the primary impacts are on water quality and habitat condition. Water releases from the dam result in temperature fluctuations, increased sedimentation and turbidity, and bank scour (Lessard and Hayes 2003).

Water management using culverts (Threat 7.2.3) has similar impacts on aquatic connectivity as dams, though they tend to occur in smaller riverine systems (Strayer 2006, Fuller et al. 2015). Generally, the height differential at culverts is less than that at dams, but small sizes, steep terrain, and significantly higher numbers of culverts still make them a significant barrier to movement in higher stream reaches (Fuller et al. 2015, Frankiewicz et al. 2021, Waldmann and Quinn 2022). Habitat improvement for riverine species will require the mitigation of both dams and culverts (Januchowski-Hartley et al. 2013).

In recent decades, interest in dam removals as a method of restoring habitat has increased. The Northeast region has some of the highest concentrations of removed dams in the country, with many of these removals concentrated in Pennsylvania and coastal and northern New England (Foley et al. 2017, Bellmore et al. 2017). Dams in the Northeast are often older than those elsewhere in the country, heightening concerns about potential dam failure (Hansen et al. 2020). Despite relatively high numbers of removals, few studies have evaluated the effects of these actions, especially before-and-after analyses and over longer time scales (Bellmore et al. 2017). Dam and culvert removal and other fish passage projects have been shown to have significant benefits for various diadromous fish (Waldmann and Quinn 2022).

Withdrawal of surface (Threat 7.2.6) and **groundwater** (Threat 7.2.7) can have significant impacts on nearby aquatic ecosystems, including rivers, streams, wetlands, lakes, and ponds. These impacts can spread into upland habitats as well by lowering the water table, which has implications for the vegetation in these areas. Water is extracted for residential or commercial use, irrigation, hydraulic fracking, or other uses. Effects of extraction include decreased volume in aquatic environments, alteration of flow regimes, lowered water tables, drought, and salinization (Bierkins and Wada 2019, Saha and Quinn 2020). The taxonomic teams highlighted these concerns for species that are dependent on ephemeral water bodies or cave systems, as these systems are reliant on water tables remaining stable for at least part of the year, and even small withdrawals can impact water levels.

Beaver dam management (Threat 7.2.2) does not impact very many Northeast RSGCN and Proposed RSGCN. However, the dismantling, removal, or other management of beaver dams and associated water levels can impact or remove beaver meadow habitat from the landscape. Species that are habitat specialists or otherwise dependent on these areas are adversely impacted by these activities. However, management of beaver dams tends to be highly localized, usually an attempt to reduce human-wildlife conflict. As a result, the impacts are also highly localized rather than pervasive across the landscape.

Similarly, **drainage in agricultural** (Threat 7.2.4) and **forest environments** (Threat 7.2.5) reduces the availability of wetlands and moist microhabitats within these environments, which may have impacts on some species in these areas, but does not likely lead to widespread declines across the region. Agricultural drainage is much more common in the Midwest and Southeast than in the Northeast; in these regions, this threat is likely to have a much greater impact (Blann et al. 2009). For a detailed description of the impacts of drainage on aquatic ecosystems, see Blann et al. (2009).

Though not included in the Quebec Standardized Classification of Threats, the taxonomic teams highlighted the importance of **tidal water restriction** as a threat to some species. Tidal restriction occurs when the construction of roads, causeways, bridges, and tidal gates restricts connection points between coastal wetland areas and the open ocean. The limited openings that remain greatly reduce or prevent water from moving back and forth between the two areas. The restriction of tidal water reduces turnover, allowing contaminants to build up, altering salinity and oxygen levels, and preventing nutrient and sediment movement (Portnoy and Allen 2006). Tidal restrictions also change the vegetative community in the wetland, allowing the incursion of species less tolerant of flooding and brackish water (Roman et al. 1984, Hinkle and Mitsch 2005). Restoration of tidal flow can have many benefits, including increased carbon cycling (Wozniak et al. 2006), exclusion of invasive and upland plant species (Smith et al. 2009, Smith and Medeiros 2013), and restoration of microbial (Lynum et al. 2020), plant (Roman et al. 2002, Buchsbaum 2021), fish (Roman et al. 2002), and avian (Buchsbaum 2021) communities.

RELATIONSHIPS WITH OTHER THREATS

Water is managed and extracted for many different human uses and thus interacts with many other threats, including Residential & Commercial Development (Threat 1.0), Agriculture & Aquaculture (Threat 2.0), and Energy Production & Mining (Threat 3.0). Climate Change (Threat 11.0) is also likely to amplify the impacts of threats under Dams & Water Management/Use, as changing precipitation rates and hydrological regimes may result in decreased water availability, especially when coupled with continued and often increasing anthropogenic demand.

TOOLS AND RESOURCES

Several tools and resources are available for learning more about dams and other barriers. Global Dam Watch produced the **Global Georeferenced Database of Dams (GOODD)**, a digitized collection of more than 38,000 dams greater than 15 meters in height, enabling analysis of the impacts of dams on the environment and nearby communities (Mulligan et al. 2020). The US Army Corps of Engineers (USACE) maintains a **National Inventory of Dams**, with information on more than 90,000 dams nationwide (USACE 2022).

Regionally, the **Northeast Aquatic Connectivity Project**, completed in 2012, created a regional inventory of dams, impassable waterfalls, and anadromous fish habitats across the Northeast to inform landscape-level conservation efforts (Martin and Apse 2011). The resulting spatial dataset allows aquatic connectivity to be addressed at the landscape scale and prioritizes barriers for mitigation (Martin and Levine 2017). The **Connecting the Connecticut**[125] project developed an interactive GIS-based application to estimate continuous unimpacted daily streamflow at ungagged locations in the Connecticut River basin.

Other resources for aquatic connectivity include **frameworks developed for selecting, planning, and launching dam removal projects** (Tonitto and Riha 2016, Hansen et al. 2020). The New England District of the USACE also developed **best management practices for stream crossing on both tidal and non-tidal streams** in the Northeast describing new and replacement crossings and culvert extensions to minimize impacts (USACE 2015). Many states have their own best management practices and regulations regarding stream crossings and should be referred to when embarking on any project.

There are numerous resources devoted to dam removal information. The US Geological Survey manages a **Dam Removal Information Portal (DRIP)**[126], which is a tool for exploring dam removal science and research (Wieferich et al. 2021). American Rivers, a non-profit organization devoted to increasing awareness of the importance of rivers, maintains a **map of United States dams removed since 1912**[127]. The Northeast Climate Adaptation Science Center has a project devoted to evaluating the **effectiveness of removing obsolete dams and other structures as a climate resilience strategy**[128].

Many different partners are working on issues related to watershed connectivity, including the **North Atlantic Aquatic Connectivity Collaborative**[129], **Chesapeake Bay Program**[130], **Coalition for the Delaware River Watershed**[131], and the US Fish and Wildlife Service's **Fish and Aquatic Conservation Program**[132]. These partners are valuable resources, with information, data, management guidelines, and established partnerships. For more information on these and other partners, see *Chapter 7*.

OTHER ECOSYSTEM MODIFICATIONS

The threats in this category can be broken into two groups. Natural processes, such as succession and erosion, gradually change landscapes over time, which can lead to the exclusion or addition of certain species as conditions shift. The remaining threats under Natural System Modifications are generally activities that alter or reduce available habitat for human purposes, especially recreation, safety, or aesthetics. These forms of manipulation do not eliminate habitat but can have significant impacts on the quality of the habitat that is available. For species that have specialized requirements or are sensitive to human activities, these modified sites may no longer be suitable.

THREAT DESCRIPTIONS AND EXAMPLES

Vegetation succession (Threat 7.3.2) is a naturally occurring event in any ecosystem. As was discussed above under fire suppression (Threat 7.1.2), the true threat is the lack of disturbance events. Without disturbance, habitat naturally shifts to later successional stages, which is detrimental to species that depend on early successional, grassland, or shrubland habitats (DeGraaf and Yamasaki 2003, Litvaitis 2003). It has also altered the density and openness of many forested areas (Lorimer and White 2003). The northeastern landscape has changed significantly over the last few centuries, with these disturbance habitats largely disappearing and forest composition shifting and homogenizing (Litvaitis 2003, Thompson et al. 2003). Recognition of the importance of these early successional, disturbance-driven habitats to species like the American Woodcock (*Scolopax minor*), Golden-winged Warbler (*Vermivora chrysoptera*), and New England Cottontail (*Sylvilagus transitionalis*) led to the formation of the Young Forest Project[133]. This organization brings together many different partners to create suitable habitats using a variety of management strategies and has resources for managing habitats for key young forest species.

Natural erosion and sedimentation (Threat 7.3.3) is another threat that gradually changes habitats and makes them less suitable for species. Erosion is the physical removal of soils, rock, and other materials from one location, and is the opposite of deposition, which is the addition of those materials at another location. Generally, natural erosion is not a major threat to most RSGCN and Proposed RSGCN because species can move from sites that are being eroded to nearby suitable areas where sediments are being deposited. While the taxonomic teams identified many species where erosion and sedimentation are a concern, all of these examples were cases where the sedimentation was caused by anthropogenic activities or structures, such as deforestation, dams and water management structures, and shoreline protection structures.

Beach habitats on both coastlines and lakes are often heavily modified for human recreation and safety. **Shoreline alteration** (Threat 7.3.1) includes many structures engineered to stabilize shorelines, prevent the loss of sands and other substrates to natural erosion, and protect coastal communities from wave action, storms, and flooding. In the Northeast, Massachusetts, Connecticut and New Jersey have the highest number of coastal engineering structures along marine sandy beach habitats (Rice 2017). The installation of these structures is referred to as shoreline hardening or armoring, as soft sediments are replaced with rock, concrete, and metal. Hardening and armoring have significant ecological impacts. Ironically, although the intent of many of these structures is to prevent erosion, they interrupt littoral drift patterns, the geological process that transports sediments along the shoreline. In natural systems, erosion and accumulation of sediments occur simultaneously, replenishing the beach. When sediments are trapped by these structures, they cannot erode and be transported to a new location. As a result, shorelines in the downdrift area continue to erode but have no sediments available to replace those that are lost. This may have particular impacts on sea turtles, as they return to natal beaches that decrease in size and suitability over time. This also can impact nesting shorebirds and waterbirds, as suitable habitats become less available.

Other ecological impacts of shoreline armoring include altered hydrodynamics, increased scouring and turbidity, and degraded and eliminated nearby habitats (Defeo et al. 2009, Prosser et al. 2018). In addition, some animals, such as Diamondback Terrapins (*Malaclemys terrapin*) can get trapped by armoring structures as they attempt to move between terrestrial and aquatic habitats (Egger and the Diamondback Terrapin Working Group 2016). As a result, armored shorelines tend to have a less complex structure, reduced biodiversity, and lower species abundance (Dugan et al. 2018, Lawrence et al. 2021). Some of these impacts can be lessened by changing the slope and shape of existing structures, adding features such as crevices or pits that increase structure complexity, or attaching additional structures that mimic unique microhabitats such as rock pools (Chapman and Underwood 2011).

Another form of shoreline alteration is the creation of dunes both actively through manipulation with heavy equipment and passively using sand-trapping features such as sand fences. Generally, the manual creation of dunes is less desirable, as these dunes do not function in the same way as natural dunes (Rice 2009). Creating a dune using sand fencing is a much slower process, but effective in creating more natural habitats. Sand fences can become a hazard or barrier to wildlife when they are unburied due to erosion and storms or when they are placed in long, continuous sections without gaps that allow animals to pass through them (Rice 2009). This has been particularly noted as a threat for sea turtles, as it results in females nesting in subpar locations (e.g., Witherington et al. 2011a,b). Research has investigated how the fence material, orientation, and design affect dune accretion (Miller et al. 2001, Grafals-Soto and Nordstrom 2009, Itzkin et al.

2020). Dunes that develop as a result of sand fences do not share all the same qualities as natural dunes, tending to be taller but not as wide and with fewer ridges that support unique microhabitats (Nordstrom et al. 2012). This has shaped best management practices for projects using fencing to re-establish dunes (Rice 2009, Guilfoyle et al. 2019).

Beach development (Threat 7.3.4), as defined by Lamarre et al. (2021) in the Quebec classification system, refers to the creation of beaches, especially the addition of substrate (beach nourishment) and other maintenance activities such as raking. Nourishment is often a response to beach erosion, replacing the sediments removed by waves, tides, and currents with sediments from other locations. Impacts of nourishment are variable, dependent on the timing, location, qualities, and volume of the imported sediments (Defeo et al. 2009). It can directly impact species by burying them or compacting and crushing individuals (Defeo et al. 2009). This is primarily a concern for invertebrates and sea turtle nests. In turn, this leads to indirect impacts on other taxonomic groups, especially birds, as the newly nourished area is depauperate of much of the prey base and can be significantly altered, destroying dune vegetation and nearshore habitat (Peterson and Bishop 2005, Defeo et al. 2009). Best management practices for beach nourishment include limiting the use of heavy equipment, nourishing alternating sections that create small refugia from the impacts, selecting sediments with similar characteristics to those already on the beach, and not sourcing sediments from sensitive areas like nearshore sandbars that reduce the need for replenishment in the first place (Guilfoyle et al. 2019). Other maintenance activities like raking, grooming, and cleaning are generally employed on beaches with heavy recreational use. These practices may remove trash and other litter from the beach, but they also remove young dune plants and wrack, disturb local fauna, and make the sand more vulnerable to erosion (Defeo et al. 2009). Raking can also prevent the formation of complex natural dunes systems with a greater variety of habitats (Nordstrom et al. 2012).

An alternative approach for protecting shorelines and managing beaches that is gaining interest is the construction of living shorelines. These installations incorporate natural and nature-based features, rather than armoring features, for the protection of shorelines and other coastal habitats. When installed, living shorelines provide similar erosion prevention and wave action reduction functions as traditional armoring structures, but additionally create habitat heterogeneity and continuity between upland and aquatic areas (Bilkovic et al. 2016). Living shorelines may also increase the resilience of shorelines to future conditions, including changing climate, when installed in ways that make use of the dynamic nature of these areas (Mitchell and Bilkovic 2019). Authors have reviewed the use of various living shoreline techniques, especially those applicable to New England, highlighting benefits and approaches that may be valuable across the Northeast region (Donnell 2017). Other recent research has highlighted that living shorelines can function similarly to natural marshes, including carbon and nutrient cycling, plant productivity, and habitat availability for numerous taxonomic groups (Isdell et al. 2021).

At this point, living shoreline approaches are still a new concept and most installations have been recent. In recent years, awareness has been growing that living shorelines are not appropriate in all locations or for all conditions (O'Donnell 2017). Areas with high wave action may prevent the successful establishment of plantings without the construction of suitable protection structures (Mitchell and Bilkovic 2019). Some sites, such as areas in front of important infrastructure and developed areas will still require more intensive shoreline protection, though aspects of living shorelines could be incorporated to create protective structures that provide more ecosystem services than traditional structures (O'Donnell 2017). Moreover, shorelines are highly dynamic systems; living shoreline design must consider not just the current desired status, but that the installation must be situated in a way that allows for landward migration in response to sea level rise (Bilkovic et al. 2016, Mitchell and Bilovic 2019). More long-term research and monitoring will be necessary to evaluate living shoreline effectiveness over time and under different, changing conditions and to determine best practices for siting, planning, and design that will ensure their successful installation (O'Donnell 2017, Smith et al. 2020).

Though much of the discussion of shoreline alteration and beach development has been focused on coastal habitats, many of these concepts are relevant to lake environments as well. Research in these locations is more limited, but armoring has demonstrated impacts on fish and macroinvertebrate assemblages in lakes of various sizes (Jennings et al. 1999, Brauns et al. 2007, Chhor et al. 2020). Research in the Great Lakes linked shoreline hardening to bluff recession, altered sedimentation patterns, and deposition rates, with significant, irreversible impacts on nearshore communities and ecology (Meadows et al. 2005).

Sea bottom trawling (Threat 7.3.6) is an alteration that impacts marine environments. Fisheries methods that utilize bottom-dragging equipment impact more global seabed habitats than any other, though trawling appears to be declining globally (Halpern et al. 2008, Halpern et al. 2019). Determining the full extent of trawling is difficult, but new technologies for measuring relative impact are available (Amoroso et al. 2018).

Trawling gear drags along the bottom of the seabed, resuspending sediments in the water column, smoothing the seafloor, removing significant biomass, and causing significant damage to seafloor structures and biota (Hiddink et al. 2017). In turn, this can greatly reduce biomass and biodiversity, as the trawled areas are often relatively barren and take significant amounts of time to recover. Different types of trawling equipment have variable impacts. Otter trawls have the least impact, removing the least total biomass and causing the least disturbance of the seabed, while hydraulic dredges have the greatest impact and impacted communities require longer recovery periods (Hiddink et al. 2017). McConnaughey et al. (2020) reviewed different equipment and management practices, comparing their relative impacts and offering guidance on identifying best practices that meet varying management priorities.

Species with shorter lifespans can recover more rapidly, which may have important implications for the sensitivity and responses of certain communities to trawling pressure (van Denderen et al. 2015, Hiddink et al. 2019). In an attempt to protect these sensitive ecosystems, the United Nations General Assembly released a series of resolutions highlighting the importance of these deep-sea ecosystems and calling for reduced impacts in vulnerable areas (Ashford et al. 2019). In response, the Northwest Atlantic Fisheries Organization has identified Vulnerable Marine Ecosystems, areas that are closed to bottom fishing; as of 2023, 27 Vulnerable Marine Ecosystems have been identified in international waters in the northwest quadrant of the Atlantic (UN Food and Agriculture Organization 2023). While these protected areas have reduced bottom fishing impacts, some research has shown that their current placement may be excluding important unique, high-diversity areas, highlighting the need for these designations to be periodically evaluated (Ashford et al. 2019, Murillo et al. 2020).

Riverine habitats are also often heavily modified for human purposes. Though not identified as a threat under the Quebec Threats Classification System, **stream channelization** greatly alters the structure and function of riverine habitats. Channelization refers to the practice of deepening, widening, and straightening river and stream channels to improve navigability, reduce flood frequency and intensity, or drain moisture from wetlands. Riverine habitats are naturally variable, with variations in flow speed and direction, water depth, substrate, and temperature. Changes to water depth, width, and flow impact aquatic vegetation, substrate, and water quality (Brooker 1985). Channel straightening increases flow speeds compared to more meandering channels, increasing sediment transfer, eliminating pools and riffles, and reducing in-stream vegetation (Brooker 1985, Lennox et al. 2016). Associated removal of riparian vegetation increases erosion, removes cover, and raises water temperatures (Brooker 1985). In general, channelized reaches are less meandering. As a result, these channels are also more homogenous, lacking the microhabitat patches, such as riffles and pools, that are characteristic of other stream habitats (Hohensinner et al. 2018). As a result, channelization changes the diversity and assemblage of plants and animals present in the altered stream reaches (Brooker 1985, Rambaud et al. 2009, Lennox et al. 2016).

An activity often associated with channelization is the **removal of snags in water courses** (Threat 7.3.5). Generally, this refers to the removal of large woody debris or boulders to improve water flow, for esthetic value, or to facilitate navigation. Similar to stream channelization, these activities can increase flow speeds and bank erosion, with similar impacts on the biota of the river or stream (Gippel 1995, Gurnell et al. 1995). Biologists have long recognized that these structures, especially woody debris, serve important roles as a food resource and habitat for many species (e.g., Benke et al. 1985). However, it is only in the last few decades that the importance of in-stream woody debris has been recognized, both as wildlife habitat and for stream stabilization, and incorporated into management activities and planning (Wohl 2014, Wohl et al. 2016).

RELATIONSHIPS WITH OTHER THREATS

As many of the threats in this category are the result of human actions altering natural habitats, these impacts are frequently associated with other anthropogenic threats, especially Residential & Commercial Development (Threat 1.0), Transportation & Service Corridors (Threat 4.0), Biological Resource Use (Threat 5.0), and Human Intrusions & Disturbance (Threat 6.0). Invasive Non-native/Alien Plants & Animals (Threat 8.1) can increase erosion and sedimentation. Some invasive plants destabilize streambanks (e.g., Lavoie 2017), as do species that burrow in streamside areas (e.g., Harvey et al. 2019).

Climate Change (Threat 11.0) will also intensify the effects of some of these ecosystem modifications. Increased precipitation and storm frequency and intensity will increase erosion and sedimentation of both riverine and coastal habitats. Channelized stream reaches will be even more vulnerable, as currents already run faster in these areas. Sea level rise further alters shorelines and beach management activities, and potentially leads to coastal squeeze as shorelines are simultaneously pressured by development and other disturbances inland (Defeo et al. 2009). Changing temperatures and precipitation levels may also alter succession patterns, as changing conditions may favor different species than those that were there historically.

TOOLS AND RESOURCES

As vegetation succession and erosion are natural processes that are happening across all landscapes at all times, it is difficult if not impossible to develop tools to track these forces. Tools and resources related to stream channelization and snag removal are also not available. Instead, most tools and resources focus on tracking human-caused Natural System Modifications.

Marine and coastal ecosystems have the greatest number of tools and resources available. Rice (2009) outlined **BMPs for avoiding, minimizing, and mitigating the adverse impacts of shoreline stabilization** projects on dune, beach, nearshore, offshore, inlet, and estuarine habitats. These BMPs advocate for a “do nothing” approach first, where human structures are pulled back proactively from shorelines in anticipation of sea level rise and climate change-driven weather patterns and utilizing shoreline stabilization only where this is not a viable approach (Rice 2009).

These BMPs were incorporated into conservation strategies for the federally-listed Piping Plover (USFWS 2012) and a technical report developed by the US Army Corps of Engineers that provides **suggested coastal management approaches that minimize impacts on shorebirds and sea turtles** (Guilfoyle et al. 2019).

The National Oceanic and Atmospheric Administration conducted a literature review on the effects of overwater structures, shoreline hardening, and other anthropogenic changes to marine habitats; this document includes summaries of 73 documents published between 2010 and 2021 (Shinn 2021). They also maintain a Digital Coast resource[134] that provides data, tools, and training resources for addressing coastal issues, including data and maps for land cover, sea level rise, elevation, hurricanes, coastal flooding, imagery, socioeconomics, weather and climate, marine habitat and species, ocean uses and planning areas, water quality, infrastructure, and more.

NOAA's Office for Coastal Management developed the **US Great Lakes Hardened Shorelines Classification**[135] data layer, which identifies natural and artificial segments, structure types, and condition (NOAA Office for Coastal Management 2019). The **Center for Coastal Resources Management**[136] produces inventories of shoreline structures in the mid-Atlantic. NOAA's Habitat Blueprint[137] program includes an interactive **map showing the locations of existing NOAA-funded living shoreline project**s[138].

The Program for the Study of Developed Shorelines[139] at Western Carolina University maintains a database that represents the most comprehensive compilation of beach nourishment history in the United States. Their **Beach Nourishment Viewer**[140] contains information on the linear distance, total volume, and cost of each identified coastal beach nourishment project in their system, dating back to 1923. The American Shore and Beach Preservation Association, in conjunction with its partners, developed its own **National Beach Nourishment Database**[141]. This tool contains information on nourishment projects on both coastal and lake shorelines, improving understanding of how anthropogenic activities influence long-term change (Elko et al. 2021).

Partners such as the **Great Lakes Restoration Initiative**[142] and **National Marine Fisheries Service**[143] has extensive libraries of information and data products that can inform decision-making processes for Natural System Modification projects. See *Chapter 7* for descriptions of these and other partners and their resources.

3.2.6 RESIDENTIAL & COMMERCIAL DEVELOPMENT

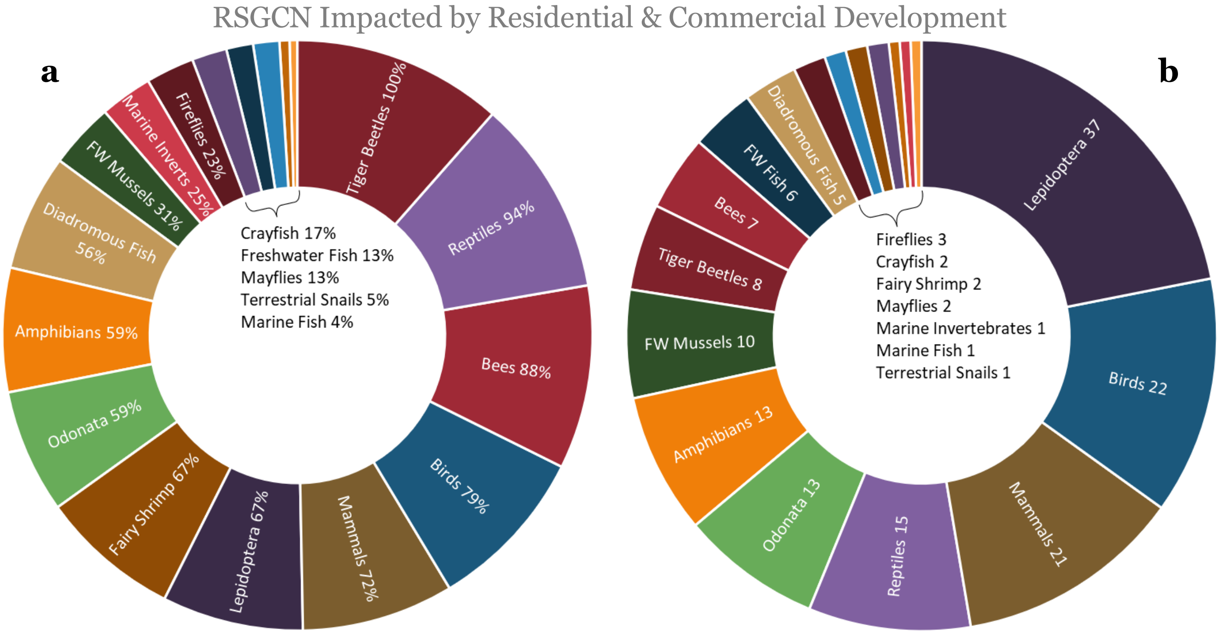

Figure 3.7 Impact of Residential & Commercial Development (Threat 1.0) on RSGCN and Proposed RSGCN. (a) The percentages show the proportion of the species within that taxonomic group known to be impacted by this threat. (b) The total number of species within the taxonomic group known to be impacted by this threat.

Residential & Commercial Development does not rank as highly as the other threats in 2023 discussed in this document. However, it impacts at least 40% (169) of the species on the RSGCN and Proposed RSGCN lists and remains a major concern in the Northeast. All eight tiger beetles are impacted by this threat, as are most reptiles and bees (Figure 3.7a). Lepidopterans, birds, and mammals provide the largest number of species impacted by development, though smaller proportions of these groups are impacted (Figure 3.7b). Aquatic species appear to be less impacted by this threat, potentially since development more directly impacts terrestrial habitats. However, data deficiencies for many invertebrate taxonomic groups likely make it appear that development is not a concern for these species when in reality we are uncertain what the impacts truly are.

The most direct impact of development is habitat loss and alteration. Habitat loss can eliminate key areas or result in decreased habitat area, which in turn restricts the number of individuals and species able to be supported by the remaining habitat. Development also fragments habitats into smaller patches. Fragmentation alters the arrangement of habitat such that it results in reduced habitat area, increased patch isolation, and the creation of more edge habitats. Smaller habitat patches support less diverse wildlife communities and fewer individuals as a result of limited resource availability (Laurance et al. 2002, Haddad et al. 2015). Isolation between patches restricts the movement of individuals between patches, which has consequences for metapopulation dynamics and genetic integrity (Lande 1988, Laurance et al. 2002). Increased edge habitat can change the community structure by altering patterns of energy flows and resource availability while also creating space for unique interactions between species that do not usually interact (Laurance et al. 2002, Ries et al. 2017). All of these changes to habitat structure impact ecosystem processes, such as nutrient cycles, pollination, and succession, and change the resilience of the ecosystem (Haddad et al. 2015).

Studying wildlife interactions with development is complicated because not all species respond in the same way (Birnie-Gauvin et al. 2016). Responses are often contextual and dependent on the reason for habitat loss, the surrounding landscape matrix – the patterns and organization of habitat types – and the intensity of human activity and use. Many species change their behavior in response to development, either avoiding areas of anthropogenic disturbance or changing their behaviors in ways that allow them to utilize these areas (Lowry et al. 2013, Ritzel and Gallo 2020). Others adapt and evolve to be better able to utilize anthropogenically-altered environments (Cheptou et al. 2017, Johnson and Munshi-South 2017). Even in species that can utilize developed areas, factors such as increased stress levels, lesser nutritional content of available food resources, anthropogenic noise interfering with communication, and increased exposure to hazards such as pollution and disease can have negative impacts on individuals (Birnie-Gauvin et al. 2016).

In the Northeast region, the impacts of development are almost ubiquitous. The region contains some of the most densely populated areas in the United States, which have been heavily modified by human land use change since European colonization. Very little of the region remains unimpacted by the effects of development and agriculture, and these impacts are likely to increase over the next few decades (Theobald 2010, Venter et al. 2016). Urban centers are not the only concern. Areas where low-density housing is developed near or intermixed with natural habitats, commonly referred to as the wildland-urban interface, are also widespread in the Northeast (Radeloff et al. 2005). These interfaces alter the risk of fire, vehicle collisions and mortality, invasion of non-native and human-subsidized species, and disease transmission (Bar-Massada et al. 2014, Kreling et al. 2019). In the conterminous United States, a total of ten states have at least 33% of their area within the wildland-urban interface; eight of these states are within the Northeast region (Radeloff et al. 2005). Connecticut, Rhode Island, and Massachusetts are particularly impacted, with more than 65% of their area within the wildland-urban interface (Radeloff et al. 2005). This high level of intermixing has implications for conservation for the region. An analysis of Conservation Opportunity Areas identified in the 2015 SWAP revisions showed that a majority of these sites are vulnerable to future projected development or are constrained by current development

(Carter et al. 2019). Management of this threat will require careful planning to balance the needs of the growing human population in the region and conservation priorities.

HOUSING & URBAN AREAS

The development of Housing & Urban Areas significantly modifies the environment, converting suitable habitats into vast amounts of impermeable surfaces, including buildings, roads, and parking lots. The replacement of local vegetation with concrete, asphalt, and metal raises temperatures by reflecting solar radiation to the areas nearby (Shepherd et al. 2013, Bounoua et al. 2015). Impermeable surfaces also repel significant amounts of water, making management of runoff a critical concern in these areas.

Housing & Urban Areas also alter the sensory environment for wildlife species. Heightened noise pollution levels in these environments can prevent communication in auditory species, increase stress levels, and reduce the detection of predators or other hazards (Slabbekoorn and Ripmeester 2008, Lowry et al. 2013). In turn, this may cause some species to alter how they behave or communicate (Lowry et al. 2013, Ditmer et al. 2021, Duquette et al. 2021). Light pollution is also a significant hazard, interrupting circadian rhythms, disorienting migratory species, and causing avoidance of high-light areas and altered movement patterns (Cabrera-Cruz et al. 2018, Laforge et al. 2019, Ditmer et al. 2021). For more information on how sound and light pollution impacts wildlife, see the section on Excess Energy (Threat 9.6).

Some of these features can be hazardous for wildlife. Bird collisions with man-made structures, especially windows, are a major source of mortality. Estimates suggest as many as 1 billion birds die from collisions annually in the United States alone (Loss et al. 2014). Light pollution compounds the risk of collision, as nocturnally-migrating birds are disoriented by the lights and do not perceive the barrier (Parkins et al. 2015, Lao et al. 2020, van Doren et al. 2021). Researchers trying to understand the characteristics and patterns of collisions identified that the risk is greatest at large buildings surrounded by relatively low levels of development and smaller structures (Hager et al. 2017). Collisions with cars, trains, boats, and aircraft are also a major concern in developed areas. Vehicle-wildlife collisions are a source of both animal and human mortality and injury (Huijser et al. 2008). Because vehicles often are moving at extremely high speeds, wild animals are often not able to detect the vehicle, identify it as a threat, and employ an appropriate escape response in time to avoid collision (Lima et al. 2015). Billions of vertebrates are killed annually in collisions in the United States, and those numbers are likely to increase as development continues to spread.

Residential yards and gardens often incorporate non-native plants, reducing their value as native wildlife habitats and making them a key vector for species invasions (Paker et al. 2014, Pardee and Philpot 2014, Beaury et al. 2021, Larson et al. 2022). Companion animals, especially cats, cause greater mortality than building collisions in developed areas in the United States (Loss et al. 2013). Proximity to domestic animals can increase the transmission of diseases, creating reservoirs in both wild and domestic populations that continue to reinfect one another (Hassell et al. 2017). Humans can also influence disease transmission by providing food resources that aggregate higher numbers of wildlife, such as bird feeders and bird baths (Adelman et al. 2015, Lawson et al. 2018). For more information on how invasive and non-native species and diseases impact wildlife, see the section on Invasive Non-native/Alien Plants and Animals (Threat 8.1) and Pathogens & Microbes (Threat 8.4).

THREAT DESCRIPTIONS AND EXAMPLES

Dense housing and urban areas (Threat 1.1.1) have some of the greatest impacts on wildlife habitats because they generally represent permanent, irreversible changes to the ecosystem. Urbanization transitions the landscape from native habitat types to intensive anthropogenic use, completely altering the structure and function of available habitat.

Urban areas can increase the frequency and intensity of thunderstorms and rain events by altering atmospheric conditions and carbon and water cycles, further exacerbating the issue of runoff (Niyogi et al. 2017, Singh et al. 2020). Urban runoff often contains contaminants, including pollutants from vehicles, litter and household wastes, fertilizers and pesticides, pet waste, and water and chemicals used to clean buildings and other structures (Müller et al. 2020). These pollutants are increasing the salination levels in freshwater resources across the Northeast (Kaushal et al. 2005, Utz et al. 2022).

Suburban areas have less impermeable surfaces, but still greatly alter ecosystem function. The prevalence of intensively managed lawns and other greenspaces in urban and suburban areas can reduce plant and insect diversity. Management practices favor annual plant species and reduce floral resources for pollinators, resulting in cascading effects within ecological communities (Watson et al. 2020). These areas also require significant chemical input in the form of fertilizers, pesticides, and herbicides, which again contribute to pollution rates (Watson et al. 2020). Interestingly, developed areas across the country are more similar to one another than they are to neighboring natural ecosystems, highlighting how anthropogenic management significantly alters these landscapes (Groffman et al. 2014).

Low-density housing areas (Threat 1.1.2) may be less altered than urban and suburban areas, existing within a matrix of less altered habitats. Despite this, many of the impacts on species are largely the same (Hansen et al. 2005, Glennon and Kretser 2013). The effects of low-density development are poorly studied compared to urban areas, and require further research to better understand the impacts on nearby ecosystems and wildlife.

A final threat is the **alteration of features within urban and suburban environments**. While development is a major threat for many species, others have been able to adapt and make use of features within developed areas as replacements for natural habitat features. However, changing practices within developed landscapes may limit the availability of these replacements. For example, many bats can make use of attics and abandoned buildings as roosts and hibernacula. However, concerns related to public health often cause homeowners to evict bats from these spaces and install devices that prevent their return (Arias et al. 2020). Chimney Swifts (*Chaetura pelagica*) have long nested in household and industrial chimneys. The installation of chimney caps has been suggested as a contributor to their declines, though some authors suggest other threats are more critical (Fitzgerald et al. 2014). Vacant lots can support diverse pollinator communities, but these sites often have negative associations and are seen as ‘wasted’ space that needs to be cleaned up, improved, or otherwise altered (Hall et al. 2016, Kim 2016). More research will be necessary to understand the importance of these developed features to RSGCN and Proposed RSGCN species and best practices for their management.

RELATIONSHIPS WITH OTHER THREATS

Development is associated with higher densities of Transportation & Service Corridors (Threat 4.0). Demands for energy and water in these areas can contrite to additional Energy Production & Mining (Threat 3.0) and Dams & Water Management/Use (Threat 7.2). Other forms of Natural System Modifications (Threat 7.0), especially fire suppression (Threat 7.1.1) and shoreline alteration (Threat 7.3.1), are frequently associated with developed areas. Housing and Urban areas are frequently the source of Invasive Non-native/Alien Plants & Animals (Threat 8.1), subsidize Problematic Native Plants & Animals (Threat 8.2), or are reservoirs for Pathogens & Microbes (Threat 8.4). Pollution (Threat 9.0) is closely associated with development. Climate Change (Threat 11.0) is likely to exacerbate some of the effects of urbanization, especially heat island effects and increased storm intensity, especially in areas where precipitation and temperature regimes are already changing (Staudt et al. 2013).

TOOLS AND RESOURCES

Numerous techniques and programs are available to improve Housing & Urban Areas for wildlife. Multiple partner organizations offer **guidance and certification of developed spaces as improved habitats** for birds and pollinators. Others offer programs for urban forestry and canopy trees. Some address specific hazards such as light pollution, collisions with glass, aircraft, or vehicles, and the use of transportation infrastructure by bats. See *Chapter 2* for descriptions of these programs.

Some RSGCN and Watchlist bat species use bridges, culverts, and buildings in developed areas for roosting. Sparks et al. (2019) developed a **manual of BMPs for**

transportation projects to protect bats in developed areas. The manual includes survey techniques, measures to enhance the habitat for bats, and mitigation options for unavoidable impacts.

Maintaining connectivity is a critical issue in a landscape that is increasingly fragmented. Plans for maintaining connectivity for wildlife will need to be grounded in ecological data, establish partnerships with nearby communities, and incorporate sociopolitical and socioeconomic information (Lacher and Wilkerson 2013). As developed and urbanized areas increase in the Northeast, state fish and wildlife agencies will need to work closely with local and state planning and zoning organizations to ensure natural resource areas are sufficiently protected from impacts. Wildlife managers should also consider long-term trends for planning land acquisition and management activities. Local, comprehensive plans are needed to manage the needs of wildlife and human across the landscape. Researchers at Harvard Forest considered **four development scenarios and their potential influence on the Massachusetts landscape**, providing a framework that could help shape discussions on the future of development in the Northeast (Thompson et al. 2014).

COMMERCIAL & INDUSTRIAL AREAS

Commercial & Industrial Areas share several similarities with Housing & Urban Areas: increased impermeable surfaces contributing to changed hydrologic and temperature regimes, elevated pollution levels, altered sensory environments, more physical hazards, and heightened exposure to non-native species and disease. However, commercial and industrial areas may produce greater amounts of different pollutants than housing and urban areas, especially Industrial & Military Effluents (Threat 9.2) and Air-Borne Pollutants (Threat 9.5).

THREAT DESCRIPTIONS AND EXAMPLES

Common examples of **commercial and industrial areas** (Threat 1.2.1) include industrial parks, manufacturing plants, offices, shopping centers, military bases, power plants, seaports, shipyards, and airports. Many of these areas are intergraded with Urbanized & Housing Areas, making it difficult to identify risks that are unique to commercial and industrial areas. One unique threat is the use of wildlife deterrents to reduce populations for human health and safety, such as the various methods used on airfields to reduce bird strikes (Bradbeer et al. 2017, Folkertsma et al. 2017).

Landfills (Threat 1.2.3) consolidate human trash and garbage in small areas, including significant food resources. Many species, especially those that are considered opportunistic scavengers, take advantage of these resources, though diverse communities may be present (Oro et al. 2013, Arnold et al. 2021). Predators in turn are attracted to these sites by the presence of smaller prey species (Oro et al. 2013). Non-native species, such as rats, feral pets, and Feral Hogs (*Sus scrofa*) are often present in these areas (Mayer et al. 2021). While these areas are potential resources for some species, some species experience tradeoffs between survival and reproductive demographics (e.g., López-García et al. 2021). Landfills also facilitate the ingestion of plastics, which can have severe consequences for wildlife (Seif et al. 2018). Landfills pollute nearby water, air, and soil through the release of leachate and toxic gases, which has major implications for nearby habitats and wildlife (Vaverková 2019, Bandala et al. 2021). The decomposition and other chemical reactions occurring within a landfill can also produce heat, causing thermal pollution (Basit et al. 2022).

Two additional commercial industrial areas, **open dump sites** (Threat 1.2.2) such as junkyards and **nuclear waste disposal facilities** (Threat 1.2.4) are not considered major threats to Northeast RSGCN and Proposed RSGCN by the taxonomic teams, but have localized impacts on some species. These sites may have particularly high heavy metal contamination (Wasi et al. 2013). More information is needed to determine if these threats are significant for the region.

Restored and reclaimed landfills and similar industrial sites can provide suitable habitats for many species, especially pollinators and grassland species (Tarrant et al. 2013, Camerini et al. 2014, Gobeil and Gobeil 2014, Webster 2021). Airfields may also be beneficial, though these areas must balance improved habitat benefits for some species against the increasing risk of airplane strikes (Blackwell et al. 2013). Managing these open industrial areas could be beneficial for many species.

RELATIONSHIPS WITH OTHER THREATS

Similar to Housing & Urban Areas, Industrial & Commercial Areas are associated with higher road densities (Threat 4.1.1) and may lead to the development of additional Energy Production & Mining (Threat 3.0). Depending on the type of industrial area, significant Dams & Water Management/Use (Threat 7.2) may also occur. These sites subsidize Invasive Non-native/Alien Plants & Animals (Threat 8.1), Problematic Native Plants & Animals (Threat 8.2), and Pathogens & Microbes (Threat 8.4). Pollution (Threat 9.0) is closely associated with industrial and commercial areas.

TOOLS AND RESOURCES

Many of the tools and resources available related to Commercial & Industrial Areas are similar to those available for Housing & Urban Areas. Partner organizations offer **guidance and certification of developed spaces as improved habitats** for birds and pollinators. See *Chapter 2* for descriptions of some of the programs.

One resource could be particularly useful for landfills, airfields, and other open Commercial & Industrial Areas. Oehler et al. (2006) produced a book that includes sections with **recommendations on improving grassland and shrubland areas for wildlife**, which could be used to inform the management of these industrialized areas.

TOURISM & RECREATIONAL AREAS

Tourism and recreational areas differ from the other forms of development in that they do not usually involve the installation of extensive impermeable surfaces. Nonetheless, the installation of recreational infrastructure can fragment habitats and lead to alteration in how and which species make use of those areas. Human activity and presence may cause some species to avoid these sites, while others may benefit. In general, recreational areas are associated with increased human activity, which results in elevated noise levels, artificial lighting, and litter.

Interest in the impacts of recreational uses on wildlife is rapidly increasing, contributing to the rise of recreational ecology as a field of research. Research attempting to understand the influence visitor numbers and behaviors have on the natural environment tends to focus on four mechanisms: disturbance of individuals, harvest or take, habitat alteration, and the modification of biotic relationships (Sumanapala and Wolf 2019). Balancing the increasing desire for natural recreation and nature-based tourism with the needs of the ecosystems will require careful management (Wolf et al. 2019).

The global COVID-19 pandemic drastically changed the nature of outdoor recreation in the Northeast and across the United States. Many states in the region saw unprecedented increases in state land visitation during the pandemic, while simultaneously dealing with decreased staffing levels and shifted operations priorities, leaving many states unprepared to handle the influx. The Northeast Fish and Wildlife Diversity Technical Committee has expressed an interest in learning more about recreational impacts on wildlife and habitats in the region and determining how these impacts are likely to change in the future.

Many researchers have studied the influence COVID-19 has had on different aspects of outdoor recreation. Many new outdoor recreationists started during the pandemic, but the use of urban spaces and outdoor recreation by those who live in urbanized settings decreased, potentially a reflection of stricter COVID-19 transmission reduction recommendations in these areas (Rice et al. 2020, Taff et al. 2021). COVID-19 forced federal and state land management agencies to shift priorities and change how they communicate and interact with the public (Miller-Rushing et al. 2021, Perry et al. 2021). In the Northeast region, National Forests saw visitation rates increase by as much as 61%, which contributed to negative impacts including overcrowding, vegetation damage, and littering (Ferguson et al. 2022a,b). Understanding the long-term effects of COVID-19 on outdoor recreational sites will require further research.

THREAT DESCRIPTIONS AND EXAMPLES

Docks and marinas (Threat 1.3.5) link shorelines to deeper waters, increasing human access to these areas without the need for a boat. The National Oceanic and Atmospheric Administration conducted a literature review of the effects of overwater structures, shoreline hardening, and other anthropogenic changes to marine habitats; this document includes summaries of 73 documents published between 2010 and 2021 (Shinn 2021). Most research on these threats focuses on estuarine and marine ecosystems, but the implications are similar for freshwater ecosystems as well.

Docks, piers, and other overwater structures change sedimentation rates and organic matter accumulation, which can have impacts on nearby ecosystems (Vasilas et al. 2011). They also limit the growth of seagrasses, algae, and other plants by restricting the amount of sunlight that can reach them, which in turn impacts the communities dependent on these ecosystems (Gladstone and Courtenay 2014, Rehr et al. 2014, Cordell et al. 2017). As a result, the communities surrounding docks and marinas are often significantly different than those in nearby unaltered habitats (Munsch et al. 2014, Pereira et al. 2017). The shadows cast by overwater structures also deter many species, leading to avoidance of these areas (Able et al. 2013, Grothues et al. 2016). Some research has demonstrated that artificial lighting can be used to minimize the avoidance of these areas in some species (Ono and Simenstad 2014). Overwater structures can also alter the relative vulnerability of certain species or age and size classes to capture by recreational fishers (Lamont et al. 2022).

Marinas have some unique impacts. Marinas contain significant infrastructure that supports boating activities, such as fueling and pumping stations, moorings, and repair and cleaning facilities. The presence of these amenities greatly increases boating traffic, pollution, and associated impacts in these areas. Marinas tend to have higher turbidity, temperatures, and pH, which impact the recruitment of various taxa (Rivero et al. 2013). Many marinas contain populations of many invasive species, potentially the result of higher water temperatures and lower oxygen levels (Lagos et al. 2017). These areas are also heavily impacted by many pollutants, which contaminate the water and sediments (Valdor et al. 2019).

Parks and sport fields (Threat 1.3.1) nested within a more developed landscape matrix can provide habitat refuges for urban wildlife, especially pollinators, birds, and mammals. These areas can serve as important habitats and linkages between habitats for many species (Beninde et al. 2015). However, the management practices used in these areas may be detrimental to the species that are attempting to use them. The intensive management of these sites, especially the use of pesticides, is also detrimental to many species, especially pollinators and other invertebrates (Park et al. 2015, Baldock 2020). Pesticide use will also impact invertivores by reducing available food resources for these species. These areas are also often structurally simple, dominated by maintained lawn areas with few floral resources, trees, and shrubs, limiting available microhabitats (Ikin et al. 2013, Eyles et al. 2015). Frequent mowing keeps vegetation short and promotes the growth of annual grasses which are of limited value to pollinators and grassland species (Watson et al. 2020). The particular arrangement and type of structural complexity within these areas influence the communities that exist there (Gallo et al. 2017, Normandin et al. 2017). Encouraging land managers to plan for more complex structure will benefit many urban species (Eyles et al. 2015, Baldock 2020). The taxonomic teams highlighted the management of urban and suburban greenspaces as a particular concern for several RSGCN species, including Yellow-Banded Bumble Bee (*Bombus terricola*) and Eastern Meadowlark (*Sturnella magna*).

Campgrounds (Threat 1.3.2) and **recreational trails** (Threat 1.3.4) can be a particular threat to wildlife because these locations are largely intended to encourage human enjoyment and the use of protected natural areas. Outdoor recreation has long been considered relatively benign to conservation, but evidence showing negative impacts on wildlife species is growing (Larson et al. 2016). Researchers have demonstrated that some wildlife species avoid recreational trails and campgrounds, though these impacts are species- and context-dependent (Larson et al. 2016, Marion et al. 2016, Kays et al. 2017, Naidoo and Burton 2020, Farmer et al. 2022). Use of these recreational areas generally results in trampling, which can have impacts on vegetation, soil, and water that increase with higher intensities of human usage (Monz et al. 2013, Marion et al. 2016). Wildlife can be flushed or startled by human activities, which may cause them to abandon important resources such as food or young (Monz et al. 2013). In some cases, wildlife can alter their usage of these areas in response to seasonal or weekly patterns in human activity levels, but further research is needed to determine if these patterns of avoidance have long-term effects (Nix et al. 2018, Farmer et al. 2022).

The feeding of wildlife at recreational sites, whether intentional or unintentional, can increase the likelihood of conflict between humans and wildlife (Marion 2019). The consistent availability of food resources can habituate animals to human presence in these areas, reducing an animal's fear responses (Hudenko 2014). Unfortunately, reduced fear can lead to increased aggression while pursuing food resources in recreational areas, altered population sizes, and dependency on human-provisioned foods (Marion 2019). These interactions can become particularly dangerous when they involve larger animals such as bears and can result in the termination of problematic individuals (Hudenko 2014, Greene 2016).

For recreational trails, impacts vary by the types of activities they are used for. The impacts of hiking are the most widely studied, but trails utilized for horseback riding, mountain bikes, off-highway vehicles, and snowmobiles have their own impacts (Larson et al. 2016, Sumanapala and Wolf 2019, Naidoo and Burton 2020). These forms of recreation can have more significant impacts on soil conditions and vegetation, especially if the trail is poorly maintained or badly designed (Larson et al. 2016). Regardless of the purpose of the trail, human use can facilitate the spread of weeds and other undesirable plants (Pickering et al. 2016, Pickering 2022). Motorized vehicle use is generally louder than hiking and may thus have a greater impact area, though the increased speed of motorized activities may mean wildlife are not able to respond to the disturbance as rapidly (Marion 2019). Trails for motorized vehicles are also generally wider, which may make them a more significant barrier to movement for some species (Soulard 2017).

Ski resorts (Threat 1.3.3) have significant impacts on the vegetation and soils of alpine and subalpine habitats. The initial construction of ski runs requires the removal of trees and other vegetation and the smoothing of slopes using heavy equipment to machine-grade the area and remove topsoil, boulders, and vegetation (Freppaz et al. 2013, Rixen 2013). These activities often cause compaction, expose mineral soils, and perturb and thin the soil layer, which in turn can lead to significant erosion, alteration of soil chemistry, texture and structure, nutrient cycling, and reduced plant re-growth (Roux-Fouillet et al. 2011, Freppaz et al. 2013). In the winter, snow is compacted by skiers and grooming equipment, which decreases its insulative properties, resulting in decreased soil temperatures that may prevent or delay vegetative and microbial growth (Freppaz et al. 2013, Rixen 2013). The compaction also delays the melting of snow in the spring, which can have impacts throughout the summer (Rixen 2013). The delayed melting can result in shorter growing seasons for high elevation plant species (Meijer zu Schlochtern et al. 2014).

The artificial production of snow can further impact vegetative growth and the overall hydrology of the surrounding ecosystem. Artificial snow has different characteristics compared to natural snow, including a more homogenous structure, additional salts, additives, and other chemicals, and higher pH levels (Meijer zu Schlochtern 2014). While the addition of artificial snow may better insulate the ground, it also will take even longer to melt and may add significantly more water to the system in spring than is otherwise present (Roux-Fouillet et al. 2011, Rixen 2013, Meijer zu Schlochtern 2014). The increased volume of water can result in greater stream flow and erosion (David et al. 2009). Water bodies surrounding ski areas may also impact nearby water quality (Wemple et al. 2007, Kangas et al. 2012).

Ski slopes are also known to have significant impacts on the faunal communities. Ski run construction and management alters the assemblage of small mammals (Hadley and Wilson 2004, Rolando et al. 2013a), arthropods (Kašák et al. 2013, Rolando et al. 2013b), reptiles (Sato et al. 2014), and birds (Rolando et al. 2013a). Some species avoid ski resort areas in winter, likely a response to increased activity at these sites (Slauson et al. 2017). Much of the research on the impacts of ski resorts on wildlife is focused on European species. More work will be necessary to understand the impacts in the Northeast.

RELATIONSHIPS WITH OTHER THREATS

These forms of development are intended to increase human access to natural areas. As a result, they are often coupled with increased Biological Resource Use (Threat 5.0) and Human Intrusions & Disturbance (Threat 6.0). Humans may transport Invasive Non-Native/Alien Plants & Animals (Threat 8.1) when utilizing recreational areas. Human presence also often increases Pollution (Threat 9.0) in recreational areas. Climate Change (Threat 11.0) is likely to have particular impacts on docks and marinas and ski resorts due to changing temperatures and precipitation regimes, but all recreational areas are likely to compound climate-related stress in nearby ecosystems.

TOOLS AND RESOURCES

The EPA has a **resource page**[144] on vessels, marinas, and ports with information on preventing and reducing pollution in these areas. This includes an interactive map of the designated no-discharge zones, areas where boat sewage cannot be released. Many states also have **Clean Marina Programs**. These are voluntary, incentive-based programs that encourage marina operators and recreational boaters to engage in environmentally sound practices. Examples of these practices can be found in the Massachusetts and Rhode Island Clean Marina guides (Massachusetts Office of Coastal Zone Management 2001, Rhode Island Coastal Resources Management Council 2006).

Parks, sports fields, and other developed greenspaces are increasingly recognized as an important part of developed areas as they improve human physical and mental health, protect against flooding, and provide important habitat patches and linkages for wildlife. The Georgia Department of Environmental Protection produced a greenspace best practices document to guide the planning and implementation of these spaces (Georgia Environmental Protection Division 2014). Oehler et al. (2006) produced a book that includes sections with **recommendations on improving grassland and shrubland areas for wildlife**, which could also be used to inform the management and design of parks, sports fields, and campgrounds.

3.3 THREAT AMPLIFIERS AND LIMITING FACTORS

Some species may have characteristics that make them more vulnerable to certain threats. These characteristics can be intrinsic biological traits that affect how that species responds to threats or they can work synergistically with the threat, increasing a species' exposure to a threat and its impacts.

Threat amplifiers and limiting factors are crucial considerations for wildlife management and recovery planning. These amplifiers and factors may limit a species' ability to respond positively to conservation or recovery actions, even if the underlying threat or threats are alleviated. The sections below describe some common threat amplifiers and limiting factors in the Northeast region, using examples from RSGCN and Proposed RSGCN species that illustrate these patterns. These descriptions are not comprehensive lists of threat amplifiers, limiting factors, and affected species. These are only a few examples intended to prompt further consideration and discussion when planning management activities.

SPECIFIC HABITAT REQUIREMENTS

Habitat specificity is a threat amplifier because species that have unique habitat requirements have far less available habitat overall, making even small amounts of habitat loss or degradation a significant impact. Some species are so specialized they require specific habitat features; loss of these features is a threat even if the greater habitat remains intact. Some of the habitat specialists on the 2023 RSGCN and Proposed RSGCN list include:

- Bethany Beach Firefly (*Photuris bethaniensis*): dependent on isolated, freshwater interdunal swales
- West Virginia Salamander (*Gyrinophilus subterraneus*): known only from a single incompletely protected cave system in West Virginia
- Maryland Glyph (*Glyphyalinia raderi*): requires calcium-rich environments, especially near outcrops on steep, forested slopes
- Saltmarsh Sparrow (*Ammospiza caudacuta*): nests along the Atlantic Coast in salt marsh habitats dominated by cordgrass, salt meadow grass, and blackgrass
- Appalachian Tiger Beetle (*Cicindela ancocisconensis*): usually found along rocky mountain streams and small rivers
- Red-cockaded Woodpecker (*Dryobates borealis*): requires older and larger live pine trees in open forests and savannah-like habitats, preferably with some form of heart rot to make excavating nest cavities easier
- Coalfields Crayfish (*Cambarus theepiensis*): preferentially uses sites under large rock slabs as shelter in riverine environments; these areas are some of the first areas filled by sedimentation

Habitat specialists are more sensitive to habitat modification and other forms of degradation (González-Suárez et al. 2013, Rocha-Ortega et al. 2020), are less able to respond to changing climatic conditions (Estrada et al. 2015, Hossain et al. 2018), and have lower adaptive capacity (Ofori et al. 2017), all of which make them vulnerable.

SPECIES INTERDEPENDENCE

Dependence on another species, whether it is as a food resource or a symbiotic host, has similar impacts on habitat specificity. If sufficient food resources or host species are not present, their dependents cannot persist in the landscape. Common examples of species interdependence in the Northeast include mussel glochidia and their associated fish hosts, lepidopteran plant hosts, kleptoparasitic bee hosts, and pollinator nectar resource plants. Examples of this threat amplifier were discussed under Intrinsic Biological Limitations (Threat 8.5); more detailed examples are in the text in this section above.

SEASONAL VULNERABILITIES

Seasonal movement amplifies threats because migrations, whether long-distance or local, bring species into contact with threats that may not be present during more sedentary periods of their life cycle. Of the 418 species included on the 2023 RSGCN list, more than 60 of them are long-distance migrants, present in the region for only a portion of the year. This includes many birds, bats, diadromous and marine fish, marine mammals, sea turtles, and the Monarch Butterfly (*Danaus plexippus*). At least 30 more species are local migrants, traveling shorter distances within the region or between certain habitat features, such as winter hibernacula, breeding pools, and nesting sites. This includes most amphibians and reptiles, cave-dwelling bats, and freshwater fish. For birds and bats, given the increasing number of wind energy installations, it is important to determine migration timing and triggers, routes, and any differences in pattern between sexes so that the impacts of wind turbines can be determined and best management practices can be developed (Northrup and Wittemeyer 2013). Anthropogenic lighting may also be a major problem for nocturnally-migrating species (Cabrera-Cruz et al. 2018). For diadromous fish, the presence of dams and other structures has long been recognized as a barrier to seasonal migrations, which has long-reaching effects on populations (Waldman and Quinn 2022). Even for species that are not long-distance migrants, traveling between different sites for seasonal purposes, such as breeding or hibernating, can be risky. For example, road mortality can result in significant declines in amphibian populations during synchronized overland movements to breeding areas (Gibbs and Shriver 2005).

Migrations also require huge energy expenditures, necessitating resource inputs before and during migration (Myers 1983, Reed et al. 2003, McGuire and Guglielmo 2009). These energy requirements require many species to pause at stopover sites to reprovision, such as the well-studied example of Red Knot (*Calidris canutus rufa*) feeding on Horseshoe Carb (*Limulus polyphemus*) eggs in Delaware Bay. In some ways, the threat of habitat loss is tripled for migratory species; loss of important wintering, stopover, or breeding sites outside of the Northeast can reverberate through the populations of the species impacted within the region (Martin et al. 2007, Thogmartin et al. 2017).

Seasonal activity may also increase the vulnerability of some species to certain threats, especially Climate Change (Threat 11.0). Nearly 150 species on the Watchlist and RSGCN list are known to hibernate, enter sustained periods of torpor, or otherwise overwinter in an inactive manner. Key taxa include most amphibians and reptiles, some freshwater fish and crayfish, insects, and bats. Species that hibernate require specialized habitats or habitat features, and may even need to travel to these sites, exposing them to some of the same threats as migratory species. Once species enter torpor or hibernation, they are highly vulnerable to predation as they are generally operating below optimal metabolic rates (Geiser 2013). Warmer winters may also change the dynamics of certain diseases that impact hibernating species, such as bats and amphibians. Warmer winter temperatures increase the impacts of White-Nose Syndrome on hibernating bats, as the fungal causative agent reproduces more slowly in cooler temperatures (Turner et al. 2022). For insect species that overwinter in egg, larval, or pupal life stages, warming spring temperatures may make these species emerge earlier, leading to phenological mismatches with their environment and important food resources (Scranton and Amarasekarea 2017). Some authors have suggested that the earlier flush of vegetation growth prompted by climate change may shade and reduce temperatures in the soil, preventing the emergence of some butterflies (WallisDeVries and van Swaay 2006).

LIFE HISTORY CHARACTERISTICS

Certain life history characteristics can be limiting factors. These characteristics generally result in reduced genetic variation, leading to many of the problems described under Intrinsic Biological Limitations (Threat 8.5) above. Some key life history characteristics that act as limiting factors include:

- Small populations: Small populations are likely to already be suffering from restricted genetic diversity. Recovery in these populations may not be possible due to inbreeding effects and the accumulation of deleterious alleles. This may be the fate of the Maryland Darter (*Etheostoma sellare*), which is possibly extinct.
- Late maturity: Species that take a long time to reach sexual maturity are vulnerable to being removed from the population before they can reproduce, reducing the overall reproductive output. If individuals are consistently removed from the population before reproducing, recruitment rates can decrease and the overall age structure will shift over time to older, potentially no longer reproductive individuals. This is the case in some freshwater turtle populations that have been exploited for export as pets for long periods.

- Low fecundity: Species that do not produce very many young take much longer to recover from any population declines, putting them at a greater risk of extinction. For example, Shortnose and Atlantic Sturgeon (*Acipenser brevirostrum* and *A. oxyrinchus*, respectively) may go multiple years between spawning.
- Limited dispersal: Species that cannot travel long distances are more sensitive to threats like fragmentation. Isolation of populations can result in decreased genetic diversity, as it reduces connectivity, and the associated gene flow, between populations. Populations with limited dispersal capacity are also more vulnerable to extinction and less likely to be rescued by colonization events.

DATA DEFICIENCY

Data deficiency isn't a species characteristic, but it can threaten imperiled species and restrict fish and wildlife agencies' ability to effectively protect and manage species of concern. These species are often treated as a lower-priority concern because there is no information to support urgency in their conservation (Parsons 2016). This is problematic because trends indicating population declines or other changes may not be noticed until after the species crosses critical imperilment criteria.

In addition, it is not possible to effectively address a threat without knowing what the threat is. While some threats can be mitigated using similar methods, most will require specialized management approaches. A lack of basic ecological and biological information about a species may result in conservation actions having negative consequences for the species they are intended to benefit. Monitoring species before and after changes are made is crucial for developing informed and adaptive management practices.

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3.5 ENDNOTES

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