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New York Natural Resource Navigator

Final Report

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New York Natural Resource Navigator

Final Report

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The summary report is also available at the webpage listed as well as at: http://www.naturalresourcenavigator.org/resources-page/project-reports/.

For the online mapping tool: The Nature Conservancy. 2016. Natural Resource Navigator: Charting a Smart Future for a Changing Climate. Available at http://www.naturalresourcenavigator.org/

Abstract

The Natural Resource Navigator is an online, interactive mapping tool that is designed to integrate climate change into decision-making for natural resource managers. The Navigator is designed to facilitate the development of actionable strategies for new and existing resource management projects at a variety of scales. It incorporates a wide variety of datasets that are useful to informing management of forest and stream resources within New York State, as well as a wide range of species models and some ecosystem services. These data are paired with decision support tools that help users interpret the data and develop resource management strategies. This report provides a description of the decision support framework and the methods used to create synthesis maps of habitat condition, future threats, and climate sensitivity and exposure. Regional summaries of key findings are provided, as well as maps of priority areas for regional climate adaptation, demonstrating some of the ways the Navigator can be used to identify important places for species conservation, habitat restoration, land protection, and threat abatement.

Keywords

climate change; natural resource management; adaptation; planning; decision support

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Summary

With the ever growing threats of coastal flooding, sea level rise, larger and more frequent storms, and changes in expected temperatures and precipitation, among others, climate change is arguably the greatest challenge facing the sustainability of our world. Even with the uncertainty around the extent and magnitude of the impacts, change is inevitable, and managing for it is a necessity. The **Natural Resource Navigator** (the Navigator) is an online tool (www.naturalresourcenavigator.org) that uses the best available science to provide recommended strategies for how to conserve natural resources in New York State, given the threats posed by climate change. The Navigator has two primary components: the Map Tool and the Guidebook.

The Navigator provides a wealth of information about forest and water resources across the State and the vulnerability of these resources to climate change. It is primarily geared toward natural resource professionals to help them make management decisions. Further, the resources in the Navigator specify actions and activities that can be taken to enhance the resilience and sustainability of these critical natural resources in the face of climate change impacts. Natural resource professionals can take a variety of approaches to prepare for climate change impacts depending on their tolerance for risk and uncertainty and the management options available to them. Assuming that active intervention is necessary, a manager may improve a system's ability to adapt and recover, proactively facilitate anticipated changes, or choose to resist change. In some cases, management can include changing goals or locations.

The Navigator focuses on forest and stream habitats generally and species specifically. Taken together, these natural resources support much of New York's well-being and economy including providing clean air, clean water, protection from floods, stable and productive soils, food, and timber, among other benefits. Understanding the vulnerability of these resources to the changing climate and the actions that can be taken to reduce the impact to these resources allows users to make choices for a sustainable future. A sampling of the types of questions that the Navigator helps answer includes:

- What is the current condition of New York's forest and water resources?
- What is the risk these resources face from climate change?
- What potential actions are best to reduce these risks in different places?
- Are there general patterns across the State that could be improved through policies or local land use decisions?
- What is predicted to happen to species given climate change?

The Navigator assesses the condition of New York's forest and stream habitats and both climate-related (sensitivity to climate change and exposure/vulnerability to climate change) and non-climate-related threats. Using the Map Tool, users can look across the State at how "climate ready" these natural resources are. Similarly, the Navigator assembles available models of species distributions under current-day and future climate and land use scenarios, as well as assessments of condition, non-climate threats, and climate vulnerability, to help guide decision-making both for individual species and biodiversity in aggregate.

The Navigator combines the results of the condition and threat analyses to produce a set of recommendations, which is displayed spatially on a map through the Map Tool. These four high-level recommendations provide a guide for how to proceed in terms of resource management in the area:

- **Maintain** - areas with good current condition and low future non-climate threats so likely to maintain current condition with relatively limited intervention.
- **Reduce threats** - areas with good current condition but some future non-climate related treats so some intervention needed to prevent decline.
- **Restore** - areas with poor current condition but relatively low future threats to potentially good places to invest in restoration and active management.
- **Reduce threats and restore** - areas with poor current condition and further threatened in the future so likely to require ongoing investment with more uncertain outcomes.

Within each of these recommendations, the result is evaluated for degree of climate risk due to exposure and sensitivity. For example, an area might get a recommendation of maintain but have high risks from climate compared to a similar area receiving a maintain recommendation but with minimal climate risk.

For most of the State's stream habitats, the Navigator recommends to "maintain" as they are, although within that recommendation most of those systems stand to suffer from some level of climate risks that need to be prepared for to avoid unanticipated changes in freshwater condition. There were some notable exceptions to this generalization. Across the State, and particularly in the Lake Plain, some stream reaches were low condition and high threat, indicating that in these areas restoration needs could be substantial and greatly complicated by climate change so a focus on adaptation is particularly necessary.

Forests, in general, statewide are in poorer condition. Although most of the Adirondacks and Tug Hill forests fell into the "maintain" recommendation category because of good condition and low overall threat, they were the exception rather than the rule. Places such as Long Island and the Lake Plain had no forest areas where the recommendation was "maintain." As with streams, there were few forest areas where the recommendation was a sole focus on reducing threats. Many of the forest areas in the State need threat reduction and restoration, particularly on Long Island. In addition, about half of these forested areas have a high climate risk, which makes management of these forests particularly challenging and uncertain.

The availability of habitat for rare species is projected to decline fairly dramatically with climate change. Overall, 88 percent of modeled rare species will lose more than half of their suitable habitat due to climate and land use changes. Whereas about half of the species also gain new suitable habitat, in most cases, expansion into new areas will not be sufficient to counteract losses, resulting in 36 percent of rare species at risk of extirpation and another 51 percent with net declines in suitable habitat area. A handful of rare species (13 percent) are projected to see substantial net increases in suitable habitat - reptiles and amphibians, in particular, have a higher proportion of increasing species than any other taxonomic groups.

These results provide a tremendous opportunity for policymakers and decision-makers because they play a significant role in shaping how New York's resources respond to climate change. Thus, it will be important to maintain the factors that are keeping the majority of New York's streams in good condition, and it will be critical to work to improve poor conditions in places such as on Long Island and Southern Lake Ontario. The results from the Navigator suggest New York needs to pay closer attention to restoring and connecting forest resources statewide. Or, given climate change exacerbations, the condition of those forests may worsen.

The scope and diversity of the data provided in the Navigator are potentially useful to natural resource managers and planners working and making decisions at various scales:

- Local-level planning and zoning - to identify places and actions that maintain the connectivity of land and stream habitats, thereby enhancing ecosystem services such as flood attenuation for their communities.
- State-level resource management - provides a wealth of data that could be layered onto existing data to help inform the development of management plans that deliberately and clearly factor in climate change.
- Regional-level spatial prioritization - can help inform high-level planning efforts and prioritize locations for management, by providing a regional perspective on where different conservation actions are particularly important.

1 Introduction

1.1 Project Background

The changing climate has wide-ranging implications for New York's natural resources. Droughts that lead to declines in water quality and quantity, as well as intensity storms and sea level rise that result in flooding and coastal habitat loss, are both expected to increase in the coming decades. Drought, heat waves, and new invasive species will stress New York's forest ecosystems. Vulnerable species will be forced to move in search of more suitable habitats, reshuffling and impoverishing ecological communities. Natural resource managers are responsible for making decisions that will shape the nature and degree of the impacts from these changes for the coming decades. Unfortunately, many of the staff in state agencies, municipalities, and nonprofit organizations are uncertain about how to best prepare to climate change. Although data on climate projections are becoming increasingly available at a scale that is useful to managers, it is not always clear how to incorporate that information into planning or ongoing projects. The available guidance on climate adaptation strategies tends to be general principles that, while useful, can be difficult to translate to work on the ground. Doing so often requires additional information on local resources, and their regional context, that managers have limited time and resources to find and analyze. As a result, addressing climate concerns are often pushed off by more urgent matters, and adaptation efforts get stuck by uncertainty in the planning phase.

To help address this gap, The Nature Conservancy developed the New York Natural Resource Navigator (the Navigator), an online, interactive mapping tool that was designed to integrate climate change into decision-making for natural resource managers. The Navigator is designed to facilitate the development of actionable strategies for new and existing resource management projects at a variety of scales. By providing easy access to the necessary data, paired with decision support features and guidance, the goal for the Navigator is to lower the hurdles that prevent managers from preparing for climate change, so that they can take the actions needed now.

1.2 Audience

The Natural Resource Navigator is useful for natural resource decision-making by:

- State and federal agencies.
- Municipal planners.
- Floodplain and forest managers.
- Land trusts.
- Watershed groups.
- Not-for-profit organizations.

The information and adaptation decision support are designed to be helpful to people who do land protection, habitat management, species management, outreach and education, policy work, and/or planning and capacity building for freshwater and terrestrial resources. Municipal planners, businesses, and others who need to understand natural resources and the variety of factors that impact those resources will also find components of the tool useful.

1.3 Uses

The Navigator provides a structured process for managers to select the most appropriate climate adaptation options for their particular area or target.

The Navigator enables users to:

- Access a comprehensive collection of terrestrial and freshwater spatial data and analyses.
- Determine where to work and what to do in light of climate change.
- Explore resources for implementing climate adaptation strategies for natural resources.
- Create custom map images to support planning and communications.

The Navigator is intended to support a range of users with varied needs and goals. Users can enter the Navigator through a number of use modes, based on the natural resource of interest, geographic scope, and planning needs. Users can use the Navigator to develop new strategies as well as evaluate the climate risk of existing projects. It can be applied at many spatial scales, whether for a single location (a stream reach or park area) or at large scales to select priority places to apply a particular strategy. Similarly, the species data may be used to identify priority species or develop plans for a single species, both within a single occurrence or statewide.

Currently, the decision support materials contained within the Navigator supply instructions for the following planning modes:

- Evaluate the most appropriate strategy for a project area.
- Evaluate an existing project to see if its goals and strategies are "climate smart."
- Decide where to work on a particular strategy.
- Decide what species to focus on.
- Decide what to do for a particular species.
- Understand freshwater flooding dynamics and risks in a community.

1.4 Limitations

Figure 1 gives an overview of the type of data included in the Navigator. The Map Tool currently contains comprehensive data for stream and forest habitats in New York (some data are also available for the full extent of major watersheds that cross NY). It does not thoroughly treat wetlands, shrub or grasslands, or coastal habitats, although basic information on these habitats types is included and could be expanded in future versions. Sea level rise projections for the Hudson River Estuary and Long Island/New York Harbor are included, but the tool does not support examination of direct changes to marine or open water Great Lakes systems. Visit http://maps.coastalresilience.org/newyork to see the Coastal Resilience Tool for more complete assessment of climate change in marine coastal systems.

Figure 1. Natural Resource Navigator Data: Inclusions (+) and Exclusions (-)

The Navigator DOES provide:

- Contain comprehensive data for stream and forest habitats in New York.

- Limited data for full extent of major watersheds in New York.

- Sea level rise projections for Hudson River Estuary and Long Island/NY Harbor.

- Habitat distribution data for species that had models available at the time of the development of the Navigator.

The Navigator DOES NOT:

- Thoroughly treat wetlands, schrubs, grasslands or coastal habitats.

- Support examination of direct changes to marine or open water Great Lakes systems.

- Evaluate beyond modeling of land use change and carbon sequestration on agricultural and urban lands.

- Include extensive data on demographics, infrastructure, working lands, economic or social values.

- Support exploration of different models or emission scenarios.

Because the focus of the Navigator is on natural resources, agricultural and urban lands are not evaluated beyond modeling of land use change and carbon sequestration. It also does not include extensive data on infrastructure, demographics, working lands, economic values, or social data, although these may be added in the future. The species data in the Navigator is limited to those species that had habitat distribution models available at the time of development, and is not intended to provide a comprehensive inventory of all species present in the State.

The Navigator is not intended to support exploration of different climate models or emissions scenarios. To simplify the process of considering climate change impacts, all future forecasting of climate data relied on outputs from an ensemble of regional climate models run with the a “high” (A2) emissions scenario for the 2050s. The goal in using this single climate change projection was to help users understand the process of evaluating climate-related risks and opportunities, and provide them with a starting point for incorporating climate change along with all of the other factors they are already evaluating. Users interested in exploring a range of climate projections are encouraged to explore online climate data portals, such as Climate Wizard (http://www.climatewizard.org/) and the related Climate Change Knowledge Portal (http://sdwebx.worldbank.org/climateportal/) for projections from the Fourth IPPC assessment. The ClimAID report (https://www.nyserda.ny.gov/climaid) provides projections specifically developed for New York State. A wide range of information and resources on climate change in New York State can be found on the New York Climate Change Science Clearinghouse (https://www.nyclimatescience.org/). The Northeast Regional Climate Center at Cornell University also has a wide range of information and resources on climate change in the Northeast (http://www.nrcc.cornell.edu/).

2 Structure of the Navigator

The Navigator is made up of several components, which work together to create a comprehensive planning support tool. The primary components are the Natural Resource Navigator Map Tool (Map Tool) and the Natural Resource Navigator Guidebook (Navigator Guidebook).

2.1 Navigator Guidebook

The Navigator Guidebook is comprised of four sections that may be used to support different phases of the planning process:

- **Wayfinder** - Provides step-by-step instructions for using the Map Tool in combination with the Course Adjustment Worksheets to provide a process for users deciding on what and where to work, what to do, and/or evaluate climate risk for existing projects.
- **Course Adjustment Worksheets (Worksheets)** - Worksheets to help refine conservation objectives to more specific strategies in light of climate change, using data in the Map Tool as well as local knowledge and professional judgment.
- **More to Explore** - Contains additional information on planning for climate change, and highlights resources to help plan and implement climate projects.
- **Tactics Toolbox** - A searchable database of specific tactics that could be used to prepare natural resources for climate change, and modify existing strategies to account for climate change risk.

2.2 Map Tool

The Map Tool provides the spatial data needed to complete the planning process laid out in the Navigator Guidebook. The Map Tool consists of a structured database of statewide map layers, coded and symbolized to interpret and translate the data into common language, and standard tools for navigating and layering spatial data. In addition, the Map Tool features applications that allow users to summarize and customize the spatial data. Currently, the Map Tool supports the following applications:

- **Map Layers** contains the complete catalog of spatial data available, and can be used to create custom maps.
- **Habitat Explorer** creates summary indices based on selected indicators for stream and forest habitats. Users can adjust the weightings of these indicators to create a custom assessment. The indices are combined to generate a map of recommended objectives for resource management.
- **Species Explorer** generates a list of species modeled to have habitat within selected areas, and allows users to customize the list and view detailed information and modeled distributions for each species.

3 Data and Analysis

3.1 Habitats

3.1.1 Geophysical Settings

Recent studies (Anderson and Feree 2010, Beier and Brost 2010, Beier et al. 2015) support the idea that physical diversity can be used as an indicator of likely biological diversity in conservation planning, and that conserving a variety of geophysical settings can help protect biodiversity as a whole, even as individual species shift across the landscape. For this forest assessment, information on geology and elevation from The Nature Conservancy's ecological land units was incorporated with the habitat types in the Northeast Terrestrial Habitat Classification, to identify unique combinations of setting and habitat type. These settings were then evaluated and further prioritized for rarity and protection status.

3.1.2 Stream and Forest Habitat Assessment

The Navigator pulls together a wide variety of data sets that are useful to informing management of forest, and stream resources within New York State. To improve the usefulness of these data to decision-making, it employs a structured framework to organize information and help users apply it in the context of resource management decisions. This framework is most applicable to spatially explicit planning to support conservation goals for habitat targets. However, to improve the usefulness of these data to decision-making, its structured framework organizes information and applies it to identify resource management strategies. Although this framework is most applicable to spatially explicit planning for habitat targets, it has also been applied it to structuring the assessment of species, and for evaluating ecosystem functions, as piloted for the freshwater flooding data.

The framework is based on the evaluation of four primary types of information that are key to identifying appropriate climate change strategies:

- **Current Condition -** current health or status of the target. Condition directly or indirectly measures the existing degree of human modification of the system, which alters conditions beyond a range of naturally occurring variation. Natural systems with high condition are expected to be more diverse and productive, with greater ability to sustain function over time without intervention.

- **Future Threat -** the expected trend in condition due to human activities through the 2050s. Future threats may be *ongoing* (having contributed to a past decline in condition that is expected to persist or get worse) or *new* (not previously encountered or significant but expected to cause future declines in condition). The threats can include indirect impacts of climate change, such as increased severity of nutrient pollution impacts due to warmer water temperatures, but direct climate change exposure, such as drought stress on forests, is considered separately under Exposure. Users are encouraged to think about the interactions between their threats and climate change within the decision support Worksheets.
- **Direct Climate Change Exposure -** the degree of direct changes in climate, such as temperature or moisture regime, that the location or target is predicted to experience. Exposure is evaluated as amount of change, independent of direction. Exposure to temperature change most likely represents an amount of warming, as most places in New York are expected to be exposed to temperature increases. However, projections for precipitation change are much more variable over space, and the same degree of exposure can represent conditions becoming wetter or drier.
- **Sensitivity to Climate Change -** the degree to which the target is likely to change in response to climate change, based on both inherent attributes of the system or species, and additional risk factors related to the landscape or management context. Sensitivity is separate from exposure, in that it represents attributes of the target system or species. If climate conditions change but sensitivity is low, then a lesser degree of climate change impacts is expected. Thus, sensitivity is not a direct prediction of specific climate impacts, but indicates the relative risk of experiencing impacts if exposure changes. Sensitivity may be considered the inverse of what is often referred to as "resilience" to climate change. Many frameworks for assessing vulnerability to climate change further distinguish between inherent sensitivity factors, such as temperature thresholds related to mortality (i.e., in freshwater fish) that are relatively fixed, from others that may indicate "adaptive capacity" or potential to vary or respond in a way that promotes adaptation. These "adaptive capacity" factors may be the focus of efforts to influence through management actions the likelihood of adaptation. Both sets of indicators were rolled into the sensitivity index to make a high-level assessment of climate risk; the components of this composite score can then be examined for a variety of opportunities to reduce sensitivity through management activities.

The Navigator evaluates each of these four factors separately because challenges in each can be addressed through very different types of actions, and with very different types of outcomes. The approach was to use all four types of information to inform planning, and to identify a general objective for resource management based on the status of these four factors. For this approach, each factor was defined for each habitat type using a set of indicators that were selected based on data availability, best available science, and expert opinion. The selected indicators were then scored, normalized, and combined into an index. Where possible, this scoring is based on ecological thresholds and the natural range of variation. When these thresholds are not well-established, the data were scored relative to the possible range of values or the range of values occurring in the project area. In these cases, the assumption is that the full range of conditions exists within the project area, and that the trait varies linearly without critical thresholds.

Once the indicator scores were assigned to defined occurrences of the target, the indicators were then equal weighted and combined to calculate an average summary score for each factor of Condition, Threat, Exposure, and Sensitivity. These scores ranged from 0-100 and represented a unitless index of the status of each factor for each occurrence within the project area. Thresholds were applied to designate classes for "high" and "low" values of the index, as shown in Table 1. The higher threshold was assigned a "high" condition rating and a lower threshold was assigned a "low" condition. These thresholds were purposely biased to increase the sensitivity of the analysis to problems with condition and threat, such that a small number of low-rated condition indicators would lead to a "low" overall score for condition, and a small number of high-rated threat indicators would lead to a "high" overall score for threats.

Table 1. Rating Thresholds for Component Scores

The Condition, Threat, Exposure and Sensitivity scores were rated as either "low" or "high" based on these ranges, which were designed to increase the sensitivity of the assessment.

Factor	Low Score Range	High Score Range
Condition	0 - 66	67 - 100
Threat	0 - 32	33 - 100
Exposure	0 - 49	50 - 100
Sensitivity	0 - 49	50 - 100

These low and high classes were used to identify a general conservation objective (based on the Current Condition and Future Threat) and the relative level of climate risk (using Climate Change Exposure and Sensitivity). The matrix found in Appendix A illustrates how the classes for each of the four factors were combined to assign one of 16 possible management objectives. These recommendations, which are described in more detail in the Appendices, are based on the authors' understanding of the literature and own expertise, and are intended only as a general guide and screening tool. (Citations for each individual recommendation are not included, but literature reviewed to develop this approach are included in the

Literature Cited for this report.) In particular, due to the uncertainties in the underlying data and the averaging nature of the summary algorithms, these recommendations should not override local knowledge or expertise. The Course Adjustment Worksheets in the Navigator Guidebook provide a methodology for refining these objectives based on other information in the Navigator, additional data that may be available to the user, and the user's own professional judgement.

In general, the principles underlying these recommendations are straightforward. Condition and Threat can first be considered independent of climate change. Areas that are currently in a good condition and have low future threats are assumed to be functional and self-sustaining, requiring little intervention beyond monitoring and maintenance activities. A maintain objective does not imply that the resource should be held in a static state and prevented from changing, but rather that any change that occurs is expected to follow natural ecological dynamics. Areas that are in good condition now, but that have modeled threats that could meaningfully reduce condition in the future, are recommended to focus on threat reduction strategies to secure the long-term status of the resource. If conditions are poor, but the sources of degradation no longer occur and future declines are not predicted, then the recommendation is to focus on restoration of condition. If conditions are poor and there are ongoing or new threats predicted to cause further declines, restoration will have limited benefit unless managers also address the threats or plan for ongoing active management in the long term. Either way, management of these areas is likely to be difficult and resource-intensive.

These four general recommended objectives are then refined to account for the level of climate change risk. Climate risk was used to describe both the risk of potential negative impacts from climate change, and the risk of uncertain outcomes for management, due to both the changing climate and the unpredictability of ecological response. A risk level was assigned based on sensitivity and exposure, whereby risk is lowest when both sensitivity and exposure are low, and highest when both are high. When only one factor is high, sensitivity was weighted higher than exposure for two reasons. First, high exposure is expected to have less impact if sensitivity is low. Second, for species or systems that are sensitive, even small changes in exposure can lead to important impacts. Further, only one climate scenario was included from an ensemble of models, and especially for changes in precipitation, the amount of change for any specific area is likely to be underestimated due to averaging of models, contributing to the ensemble average. The authors had greater uncertainty in their measures of exposure because they are rated on a relative basis, and there is inherent uncertainty in the underlying climate models. For these reasons, the authors chose to take a conservative approach that if exposure is higher than predicted, then having a high sensitivity will greatly increase risk.

Although this framework has been discussed in terms of application to occurrences of a particular habitat type using multiple quantitative indicators, the principles could be generalized to be applied to a species, taxonomic group, ecosystem service or function, or any kind of defined resource that is the target of management action and for which the four factors could be evaluated. However, the more generally defined or coarsely spatially delineated the resource is, the more difficult it becomes to make a meaningful assessment. Similarly, the framework could be applied using whatever qualitative or quantitative data were available and with any number of indicators, as long as the assessment was done consistently across the project area and the results were interpreted in context of the quality of the data.

3.2 Species

3.2.1 Habitat Distribution Models

To manage habitats for biodiversity and individual species, it is beneficial to know both the current habitat availability and condition, and what locations are expected to provide suitable habitat in the future. By incorporating future climate and future land use into species distribution models, data can be provided on which species are likely to expand or contract in range or shift to entirely new locations. Combining these models for multiple species helps to indicate which locations will be the most important to support a large number of species in the future.

The Navigator incorporates models of suitable habitat from four different data sources, which are summarized in Table 2.

Due to the different model sources, in some cases there are multiple models available for a species. These have been synthesized into a single map for each species showing locations of current suitable habitat and areas that are expected to persist, decline, or become newly suitable in the future. Descriptions of the methods used by each of the modeling sources are provided in the Data Documentation, available on-line (http://www.naturalresourcenavigator.org/resources-page/data/). It should be noted that, in general, all the included models predict likely suitable habitat, but make no assertions as to the actual presence of populations or the ability of a species to disperse to new habitats in the future.

Table 2. Species Distribution Models Sources

These data sources were used to obtain models of suitable habitat for various species groups under current and future climate conditions.

Species Group	Source	Present Habitat	Future Habitat
Rare plants and animals	New York Natural Heritage Program	Yes	Yes
Terrestrial animals	USGS GAP	Yes	No
Fish	USGS Aquatic GAP	Yes	Pending
Trees	USFS TreeAtlas	Yes	Yes

3.2.2 Spatial Climate Change Vulnerability Index (CCVI-S)

A species' vulnerability to climate change is often assessed at large scales, such as states or entire species ranges. These assessments are useful for comparing among species, but are less helpful in deciding which parts of a species range are most likely to persist or are particularly vulnerable. A fine-scale, spatially explicit model of climate change vulnerability was built by combining predicted habitat suitability information with nonspatial sensitivity factors from the New York species vulnerability (Schlesinger et al. 2011). These data give us an estimate of relatively how much change the species would experience, how easily it could disperse to other locations, and how likely it would be to establish new populations, for each location within the current habitat range. The combined result is a species-specific, spatial climate change vulnerability index (CCVI-S) for 50 rare animals in New York State. The CCVI-S will help managers prioritize conservation actions both among species at particular locations and among locations for particular species. The species selected were based on the availability of input data, and represent a range of taxonomic groups and climate vulnerability ratings. The resulting maps are viewable in the Map Tool.

3.2.3 Habitat Migration Models

When species distribution models show a movement of suitable habitat from one area to another over time, the question is often asked whether it is possible for the species to move between the habitat patches, and what areas in the intervening landscape are most important to protect and maintain that ability. Without modeling numerous time increments to track the shift in range, this question proves difficult to answer. The Navigator piloted methods to address this issue using the current and future suitability models, by applying the least cost path modeling approach between delineated current and future habitat patches. The resulting modeled linkage zones can highlight potentially critical areas for habitat shifts in the modeled species. This model improves on generic connected habitat models by identifying specific source and destination patches, basing the resistance to movement on species-specific modeled suitability, and incorporating movement over time as conditions change in the landscape. However, as with all landscape-based connectivity models, it does not determine whether the species will actually be able to move through the modeled area or be able to establish a functional population in the destination patches. Although the limited pilot set of 13 species does not allow for meaningful assessment of commonalities between the models, it does help refine a methodology that may be applied to additional species of interest in the future.

3.2.4 Species Assessments

In addition to the previously described spatial data, the Navigator includes a database of nonspatial species information that is informative for wildlife management planning. These data are used within the Species Explorer application for some of the filters, to populate the 'Details' display, and the full database is provided for download. The database includes, where available for each species in the Map Tool, rarity ranks, listed status, climate vulnerability assessments from New York Natural Heritage Program (rare species), Audubon (bird species), and New York State Department of Environmental Conservation (other wildlife), threat assessments, range information, and habitat associations. The data included are compiled from a variety of sources, as detailed in the Data Documentation. The status, threat, and climate vulnerability data are summarized in a three-part rating designed to parallel the habitat framework, and the same matrix can be used to identify outcomes and strategies for a species.

Because this information was most consistently available for those species included in the State Wildlife Action Plan as Species of Greatest Conservation Need (SGCN), that subset of species was used to demonstrate how the framework could be applied. Within the list of SGCN species, three lists were generated: 1) species with low condition and low threat, most suited to restoration, 2) species with high condition and high threat, most suited to threat reduction, and 3) species with low condition and high threat, designated as "high risk" species. Because the climate vulnerability assessments were missing for many species and were based on three different, potentially inconsistent, methodologies, the climate risk portion of the framework was not applied to this group.

3.3 Connectivity

Connectivity of habitats and species populations is an oft-cited and potentially important aspect of climate adaptation. Connections among habitats support the movement of energy and nutrients that sustain ecosystem functions, and allow the free movement of wildlife and plant propagules that can be essential to supporting local populations (i.e., by providing access to foraging habitat or sites for plant establishment) and can support adaptation by allowing gene flow among populations. Longer range connectivity improves the likelihood of successful “extreme” dispersal events, in which an individual can travel much farther than average in search of mates or new habitats. These long-distance movements potentially become much more important in light of climate change, when changing habitat suitability may force more species and individuals to roam more broadly to find the resources and habitats they need. The scale of the connectivity needed to support these movements depends on the mobility of a species and the method and average distance of its dispersal events.

The Navigator includes several pieces of information that are useful to determining what places are currently more likely to be supporting local and regional connectivity, and where restoration of connectivity functions may be needed. These data sets are not collected in a single directory in the Map Layers within the Map Tool, but may be found under their associated habitats, either under condition, climate sensitivity, or supporting data. Information about connectivity for species and range shifts can be found under the individual species within the Map Layers hierarchy.

Beyond the simple identification of high connectivity areas, it is important for planners to know which areas are most important to prioritize for management actions. To ensure connectivity for species range shifts due to climate change, the focus centered on long-range connectivity between intact habitat areas, specifically the linkages between large forest blocks. Although these modeled linkages have relatively low resistance to movement, it is unknown whether the linkages can support functional connectivity for any particular species. Given that this assumption will likely require years of detailed field data collection to verify, during which time further habitat fragmentation may occur, a conservative approach might be to assume that the linkage needs at minimum to be maintained at current levels and ideally should be restored to improve any lower connectivity areas within it. To this end, maps were created using data provided in the Navigator, of priority areas to protect, maintain, and restore to secure the connecting function of these linkages. Although this analysis focused on forest connectivity, note that aquatic connectivity is equally vital to climate adaptation, and believe that a similar approach could be used to identify critical locations for dam and culvert removal or restoration. In addition, there is increasing evidence that movement of species ranges northward and upslope is already occurring with climate change (Chen et al. 2011, Zuckerberg, et al. 2009), and that preference should be given to enhancing those connections in particular.

3.4 Ecosystem Services

In addition to habitats and species, the Navigator can be used to manage for desired ecosystem services, or functions and products of ecological systems that have value to human communities. Data was included on the current and future provision of two ecosystem services, carbon storage and nutrient retention, as well as an ecosystem function with potential impacts to human communities, and freshwater flooding. Carbon sequestration may partially offset greenhouse gas emissions and reduce climate change impacts, and can be maintained through protection and responsible management of forest lands. Nutrient retention by vegetation and soils may become more important with climate change, as extreme precipitation events become more frequent and more severe, and the consequences of nutrient pollution within streams become more severe due to warming temperatures. For both of these ecosystem services, statewide maps of current provision of the service were created using InVest, a modeling program developed by the Natural Capital project (http://www.naturalcapitalproject.org/), which creates spatially explicit estimates based on land cover and standard coefficients from the literature. Using the land use change model, we also made projections for future service provision and calculated the change in services between now and 2050. These maps can be used to identify areas of high service delivery either now or in the future that could be maintained, areas of current low service delivery that could be improved, or areas of declining services that may need protection. These data are provided in the Map Tool and detailed methods can be found in the Data Documentation, available on-line (http://www.naturalresourcenavigator.org/resources-page/data/).

Flooding along the inland rivers and streams of New York creates a significant hazard for communities across the State. Although watersheds and floodplains can help to slow and store floodwaters and reduce the severity of flood events, flooding is a natural disturbance process that is important to stream health. However, as a result of past historic building practices, many communities have a large number of residences and critical infrastructure located within the floodplain. For these areas that have always struggled with periodic floods, the expected increases in frequency and magnitude of precipitation under climate change will only make the problem worse. Some areas that have not historically flooded may also experience new flooding problems as higher peak flows push the boundary of the current floodplain. To prepare for and mitigate these impacts, resource managers and community planners need to know how projected land use and climate changes might impact flood conditions, and how sensitive the community is to flooding.

For the analysis of freshwater flooding, this function was treated in much the same way as a natural habitat, organizing the data into Condition, Threat, and Climate Sensitivity and Exposure groups. In this context, the condition indicators describe the current risk of damaging floods, based on past trends and watershed conditions. Increases in flooding can be due to future land use change, described under threats, or increases in amount and frequency of extreme precipitation under climate change, described under exposure. Sensitivity to flooding is based on how well exposed properties are covered by flood insurance. Although the data was not scored and summarized in the same way as the habitat assessments, these pieces of information can be used to identify opportunities to implement strategies that reduce runoff, improve floodplain function, and reduce risk to infrastructure. The Flood Mitigation Worksheets in the Navigator Guidebook provide a structured process for interpreting and using the flooding data sets. For users interested in coastal flooding and sea level rise impacts, use the Coastal Resilience tool for Long Island (http://maps.coastalresilience.org/newyork/), or Scenic Hudson's sea level rise mapper for the Hudson Estuary (http://www.scenichudson.org/slr/mapper).

3.5 Land Use Change

Many factors that influence stream and forest conditions, species viability, and ecosystem services are a function of the patterns and amounts of cover types and land uses. To capture a detailed picture of the current landscape, two available data sets were combined: The Northeast Terrestrial Wildlife Habitat Classification (NETWHC), developed by The Nature Conservancy in 2013, and the 2011 National Land Cover Dataset (NLCD) from USGS. The NETWHC provides detailed mapping of natural habitat types, using the NatureServe ecological classification, but at the time it was developed the 2006 NLCD was used as the basis for mapping non-natural cover types. Since the 2011 NLCD was released during the course of this project, the authors wanted to incorporate the updated and more detailed information on non-natural land uses. Merging the two data sets provided the best of both in one comprehensive "hybrid" land use/land cover (LULC) map.

To understand how New York's natural resources are likely to fare by 2050, it was important to consider the likely changes in habitat extent and distribution and the impacts of habitat loss and development. Starting with the hybrid LULC map, the authors applied a number of projections for various types of land use change to create a predicted 2050 LULC map, which could then be used as an input for a number of other models. The core set of land use transitions were based on models run with the ArcGEOMOD module of the Integrated Assessment Toolbox developed by SUNY-ESF (http://www.esf.edu/cue/integratedmodeling/). Spatially explicit projections of the rate and location of development of agriculture or natural lands, conversion of natural cover to agriculture, and the succession of agriculture to natural cover, were modeled for each of the subregions of New York (Hall and Weng 2013). These projections were then combined and applied to the "hybrid" map.

Additional projections were applied for the transition of ruderal shrubland to forest, based on the dominant surrounding forest types, and a variety of endpoints for abandoned agriculture based on the timing of transition and soil types. Future development was assigned to one of the four NLCD development classes based on the current surrounding development types. The authors did not attempt to predict transitions within development types for currently developed lands, or to assign future agriculture classes, because these transitions would be dependent on economic factors that could not be forecast. Areas at risk of inundation were added based existing sea level rise models for Long Island, NYC, and the Hudson River. Other types of flooding or changes in lake levels were not incorporated. The classification of natural cover types was not altered to reflect climate change because the time frame of analysis compared to the generation time of the dominant vegetation was too short to result in habitat transition (with the exception of ruderal shrubland as previously described). All transitions other than sea level rise were excluded on protected lands because these lands are protected from conversion and likely to be managed to maintain their current cover types.

The resulting map of 2050 LULC provides one potential future scenario, which is based on a number of assumptions and models, and is best interpreted as a "business as usual" scenario. It assumes that past rates of change and drivers of change will continue into the future. We recognize that both the amounts and locations of realized future land use change will vary from what has been modeled as a result of changing economic and social drivers, public policies, natural resource management actions, and climate change. The regional approach taken for the transition models, which was done because of computational limitations, also introduced potential error, both by creating artificial (county-based) edges to the modeled projections, and by smoothing out potential variation in transition rates and drivers within regions. Other

potential sources of error are the reliability of the input land cover classifications, and the mapped values of predictive drivers of land use change. Overall, the confidence statistics for the GEOMOD models generally ranged from 0.50 to 0.97, with the lowest confidence in the transition from agriculture to natural, and the greatest confidence in the models of new development. See the report from Hall and Weng (2013) for a complete discussion of the methods and limitations of those models.

4 Decision Support

The Navigator Guidebook, in combination with the Tactics Toolbox spreadsheet, can be used to apply the data and analyses in the Map Tool to develop project-specific tactics for the management of natural resources in light of climate change. Users can select their entry mode within the Wayfinder to get detailed instructions on how to work through the process. The following instructions refer the user to one or more Worksheets, depending on the use mode and the applicable recommended objectives.

4.1 Course Adjustment Worksheets

The worksheets are found in the Navigator Guidebook. They can be used in several different ways and different combinations to help answer different types of planning questions. One set of Worksheets are intended to be used in conjunction with the Habitat Explorer application and/or the Recommended Objective maps. Each worksheet supports further planning around that particular objective:

- **Maintain** - identify tactics and additional considerations for maintaining resources that are in good condition and not under significant threat.
- **Reduce Threats** - determine which threats are most important to address and whether or not it is feasible and worthwhile to invest in threat reduction strategies. This worksheet includes sections both for selecting what to do and identifying where to work among several locations.
- **Improve Condition** - determine which conditions are most important to address and whether or not it is feasible and worthwhile to invest in restoration strategies. This worksheet includes sections both for selecting what to do and identifying where to work among several locations.
- **Reduce Threats and Restore** - identify whether and what conservation work to focus on in areas hampered by both poor current condition and high future threat, including consideration of whether the area provides important benefits to nature or people.

The second set of worksheets can be used to address non-habitat management interests:

- **Incorporate Species** - use the Species Explorer to identify species present in a project area now OR in the future (based on models of suitable habitat under climate change) that might benefit from conservation attention.
- **Assess Species** - use the species data in the Navigator to identify species or habitat locations appropriate for different strategies, or for identifying actions to implement for conservation of a particular species.
- **Flood Mitigation** - use the data layers in the Navigator to think about strategies to mitigate flooding impacts.

A third group of worksheets are referenced by all of the other worksheets, and are advised to be completed for all projects:

- **Priority Places** - helps identify focal areas that are important to regional and statewide climate adaptation. This may be used to identify higher priority locations within an existing project area and/or to identify new areas of importance to incorporate into a project.
- **Protection -** helps evaluate whether formal protection, and what level of protection, might be required, and helps identify potential tactics for that protection work.
- **Preparing for Climate Change** - helps determine what kinds of climate changes to anticipate and what approaches and actions might be taken to reduce risks.

In most cases the worksheets simply provide a structured way to think about and document standard planning considerations, while assisting the user in finding relevant data within the Navigator Map Tool. However, the Preparing for Climate Change Worksheet draws upon and synthesizes existing guidance to provide a novel framework for developing strategies to address climate change risk, which is described in more detail in the following section.

4.2 Preparing for Climate Change

Managers can take a variety of approaches to prepare for climate change impacts depending, among other things, on their level of activity and their tolerance for change and uncertainty. If the resource is currently in good condition and unthreatened, and projected climate changes do not put valued resources at risk, a hands-off approach may be appropriate. If active intervention to address climate change is deemed necessary, a manager may choose among a variety of actions that improve a system's ability to adapt and recover, proactively facilitate anticipated changes, or resist or reduce the impacts of change. In some cases, management goals may be better served by changing locations or targets, or goals may need to be reconsidered in light of likely future circumstances. These approaches are not exclusive categories but rather represent a spectrum from resisting to promoting change, as well as a range of degrees of active intervention and control of future conditions. More than one approach may be pursued within a single project as appropriate for different areas or resources.

In developing this guidance, the authors drew upon many excellent resources that have been developed to help resource managers evaluate climate change vulnerabilities, and update conservation planning and resource management in light of this information. In particular, the work has incorporated concepts and approaches from collaboratively-developed frameworks, such as the ACT Framework (Cross et al. 2012), the Yale Framework (Schmitz et al. 2015), guidance from The Nature Conservancy (Poiaini et al. 2011), vulnerability assessment and adaptation planning work by the National Wildlife Federation

(Glick et al. 2011, Stein et al. 2014), and forest-focused resources from the USFS's Northern Institute of Applied Climate Science (Swanston and Janowiak 2012). The authors also drew from synthesis documents from the Northeast Climate Science Center (Staudinger et al. 2015).

The Navigator guides users through the process of developing strategies to prepare for climate change using a simple process:

1. **Determine the overall climate risk or vulnerability of the resource of interest.** This information aids both in determining an adaptation approach and how urgently climate concerns need to be addressed.
2. **Determine sources of climate risk**. The actions taken to prepare for climate change depend on whether the risk is due to the impact of a particular climate variable, or a characteristic of the system that increases sensitivity to change. Poor condition in general can also create climate sensitivity because stressed or degraded systems may be less adaptable, so currently poor conditions or future threats that may reduce condition should also be considered.
3. **Think about what kind of approach to take in response to climate change.** To determine where on the spectrum of climate response approaches they fall, managers need to consider their climate risk, the amount of change and uncertainty they are willing to tolerate, and whether active management of change is either feasible or desirable. The Navigator includes several checklists to aid managers in selecting an approach.
4. **Identify possible actions**. By identifying the particular sources of climate risk and choosing a suitable approach, managers can select appropriate actions from among the numerous climate change strategies that have been proposed or piloted by the natural resource community. The Navigator provides a compiled list of these potential strategies and associated tactics in the Tactics Toolbox, and organizes them to be easily extracted for any combination of issue, approach, and objective.

4.2.1 Climate Change Approaches

Resisting change may not be possible for the long term and can be resource intensive. However, there may be situations when resisting change is necessary to protect a resource or service that has high value or is not easily replaced if lost or altered. Resistance strategies may be most appropriate in situations where the system is already intensively managed, or there is a desire to control how and when changes occur. Keep in mind that resistance strategies may not be effective if climate change is more rapid or extreme than predicted, and should only be used in the short term. Resistance actions are ideally easily adjusted or reversed if needed, and do not restrict options for future adaptation.

If you do not have a compelling need to resist change, then you should consider strategies to manage for change. Approaches to managing for change span a wide variety of levels of control and intervention. Examples include passively monitoring change as it happens, reducing barriers to adaptation by improving conditions and resilience, proactively anticipating change, and guiding the system toward an anticipated future state.

You might choose to actively facilitate change when there is limited opportunity to reduce sensitivity and changes are likely to be extreme and/or rapid. These approaches are more appropriate in circumstances where the system is already under active management, and uncertainty is undesirable. Actions that support adaptation are more appropriate when change is likely to be more gradual, sensitivity and adaptive capacity can be improved, and uncertainty is acceptable. When active management of the system is not feasible or necessary, more passive approaches can be employed to monitor for climate change impacts and adaptively manage any changes that may occur.

In some circumstances, neither resistance nor managing for change is feasible within the existing project area. If the expected climate changes will interfere with the ability to achieve key conservation outcomes, and these changes cannot be resisted or accommodated, it may be necessary to reassess the project. In some cases, the project goals may be better served by focusing on other locations or targets, or goals may need to be altered to reflect the likely future scenario.

4.3 Tactics Toolbox

The final step in the planning process is the selection of a strategy and identification of potential tactics that might be pursued. By incorporating climate change explicitly into the planning process, entirely new strategies may be identified that focus on reducing climate exposure of sensitivity. In other cases, traditional management strategies may need to employ new tactics or adjust where or how they are implemented in light of climate change. Many papers, reports, and case studies have been published describing various tactics to address climate change impacts on natural resources. The Navigator assembles a large collection of these tactics into a spreadsheet and organized them to be easily filtered based on resource type, management objective, issue of concern, and/or climate approach. In addition, climate factors to be considered in the implementation of each tactic are highlighted, and links to additional resources are provided.

The Tactics Toolbox are largely compiled from existing resources (see list in Section 4.2), supplemented with additional suggestions from conservation professionals. The categorized filter structure was based on the professional judgement of project staff. The Toolbox is intended to be an aid to managers who are looking for examples of the kinds of tactics they might consider, and who want to think about climate consideration that might affect the implementation of their existing activities. While some tactics have been demonstrated in case studies, others have only been proposed based on the logic of identifying pathways of exposure and indicators of sensitivity. At this time, most climate change strategies have not been around long enough or even tried, so there are few evaluations of effectiveness. As such, the Tactics Toolbox only offers suggestions with no guarantee of success for any particular project. The list of tactics is also not intended to be comprehensive, or fully tailored to the specifics of application in a particular place, and will hopefully be added to over time as more climate change projects are implemented.

5 Habitat Assessment Results

For the purposes of this report, the results of the statewide habitat assessment are summarized by drainage basin for stream habitats (Figure 2) and by state subregions for forests (Figure 3). The drainages are the Ecological Drainage Units (EDUs) from the NY Freshwater Blueprint (http://nynhp.org/FBP). The subregions are derived from the county-based climate regions used in the ClimAid report (Rosenzweig et al. 2011), modified by splitting the Mohawk Valley from the Eastern Hudson Valley. These zones were used to summarize and describe the general spatial patterns in our Condition, Threat, Exposure, and Sensitivity Scores for each habitat type, as well as the representation of each of the Recommended Objectives.

Figure 2. Ecological Drainage Units Used for Summarization of Results for Stream Habitats

This map also represents the freshwater extent of analysis, although not all data were available for the full extent.

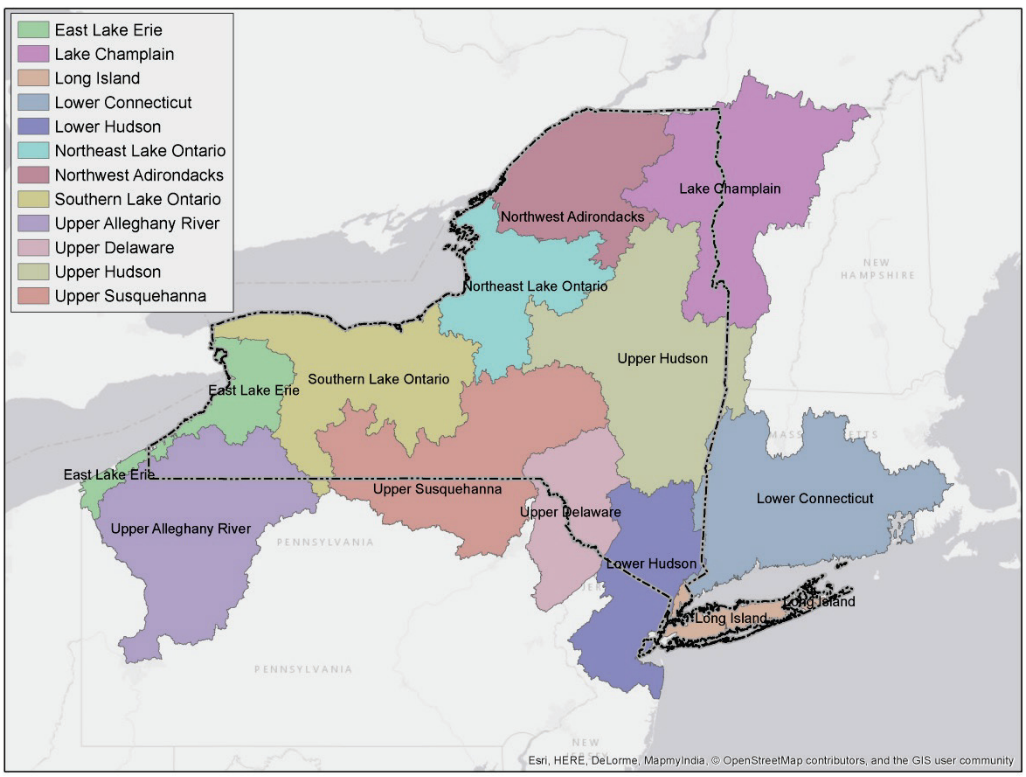
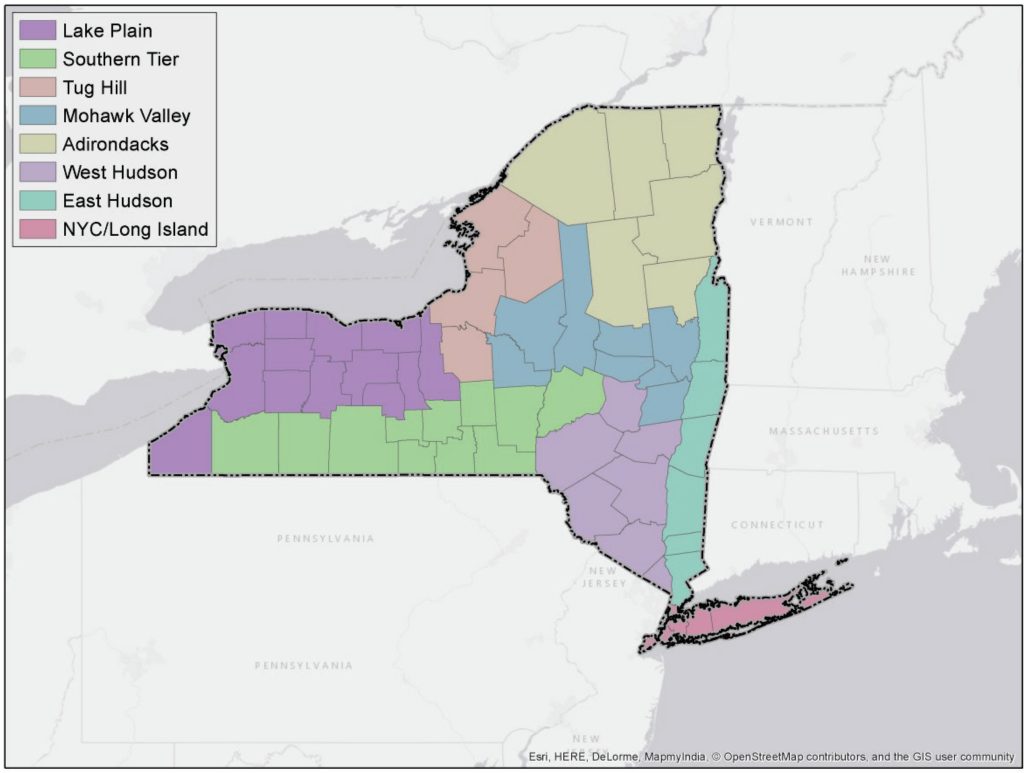


Figure 3. Subregions of New York Used for Summarization of Results for Forest Habitats

Regions were defined by county boundaries and are based on boundaries used in the ClimAid assessment. For this analysis, we split the Mohawk Valley from the Eastern Hudson Valley. These regions were also used for the land use change assessment, although that analysis further divided the northern and southern Adirondacks.



5.1 Regional Patterns in Condition

5.1.1 Streams

Most streams in the study area had high ratings on the condition indicators, with 64 percent of stream miles statewide getting an overall condition score greater than 67, which was the authors' threshold for "good." Two watersheds scored generally lower on stream condition; Long Island and Southern Lake Ontario had average condition scores of 48 and 62, respectively. East Lake Erie and the Lower Hudson also tended to have lower conditions, with only around half of stream miles in those watersheds earning a good condition score. The Lake Champlain, Northwest Lake Ontario, and Northwest Adirondacks watersheds had the highest condition scores on average (Figure 4 and Figure 5).

Figure 4. Condition Scores for Streams

This map shows the condition score assigned to each stream reach based on an equally weighted average of a number of scored indicators.

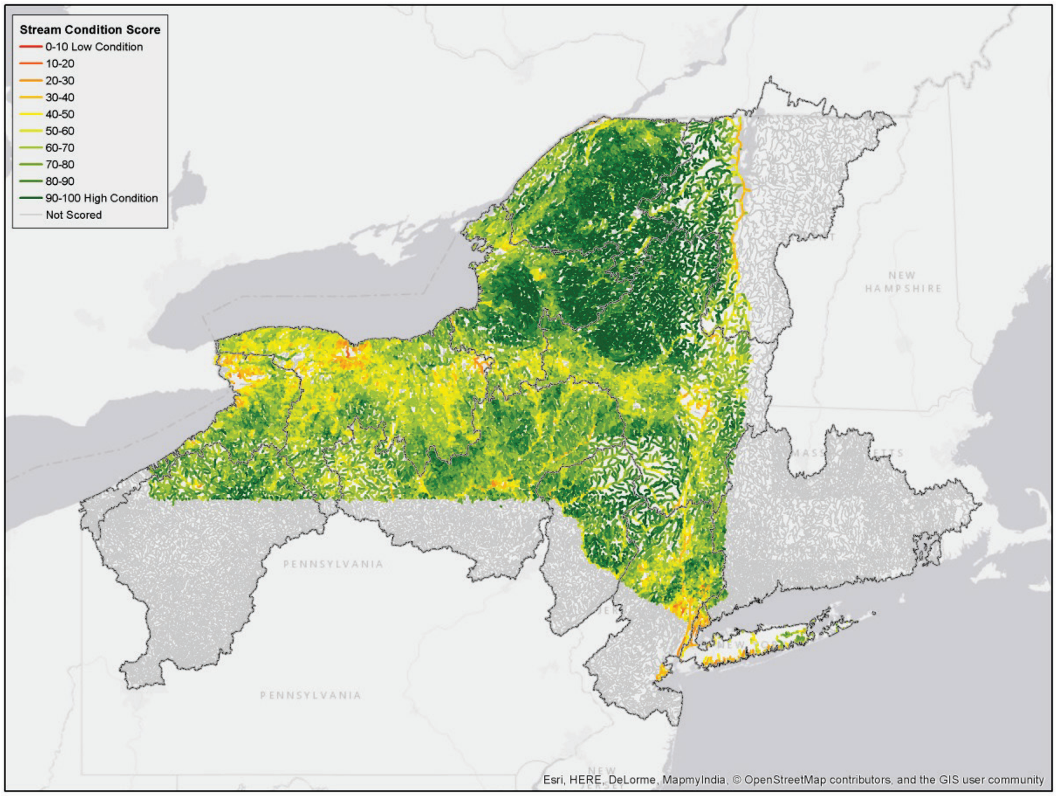
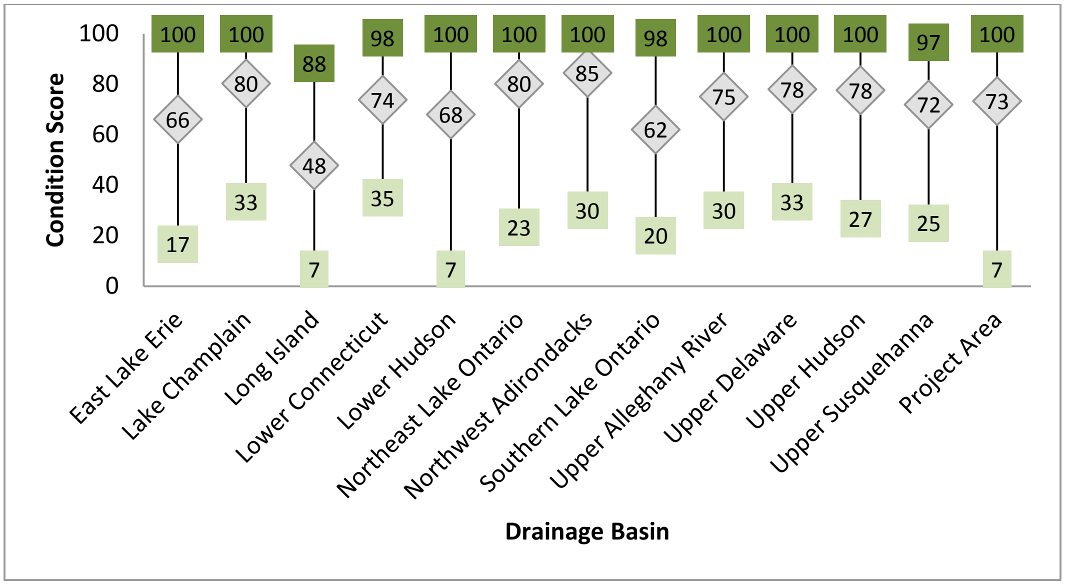


Figure 5. Regional Patterns in Condition Scores for Streams

The min, max, and average condition scores are provided for each drainage basin. Conditions were generally high, but low values occurred in every region.



5.2 Forests

Forest condition scores were generally lower than stream condition scores statewide, with both lower minimum scores and fewer instances of maximum scores. Statewide, only 35 percent of the forest was scored as in "good" condition (67 or greater), and the average forest condition score was 60 out of 100. All regions of the State except the Adirondacks and Tug Hill had less than 30 percent of their forest acres reaching a score of 67 for "good" condition. The maximum condition score on Long Island was a 47, resulting in no good ratings in that region, and the Lake Plain region had just one percent of its forest in good condition. The best-condition forests were in the Adirondack region, with 75 percent of forest acres scoring good or better (Figure 6 and Figure 7).

Figure 6. Condition Scores for Forests

This map shows the condition score assigned to each forest pixel based on an equally weighted average of a number of scored indicators.

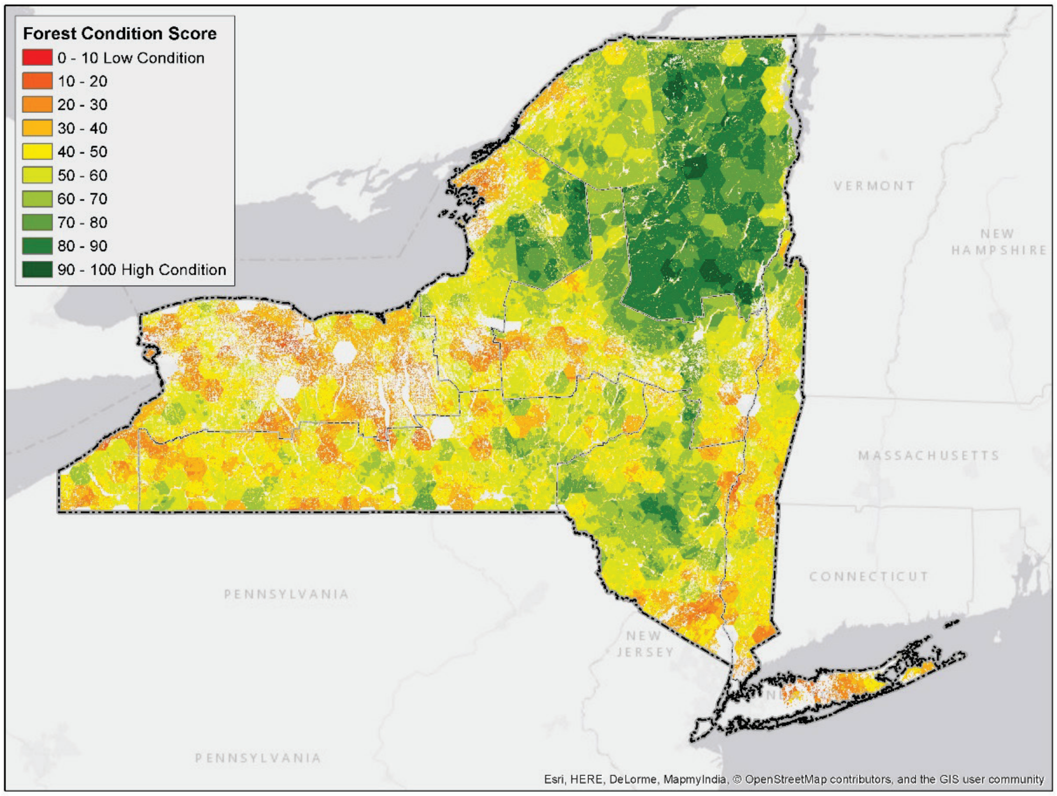
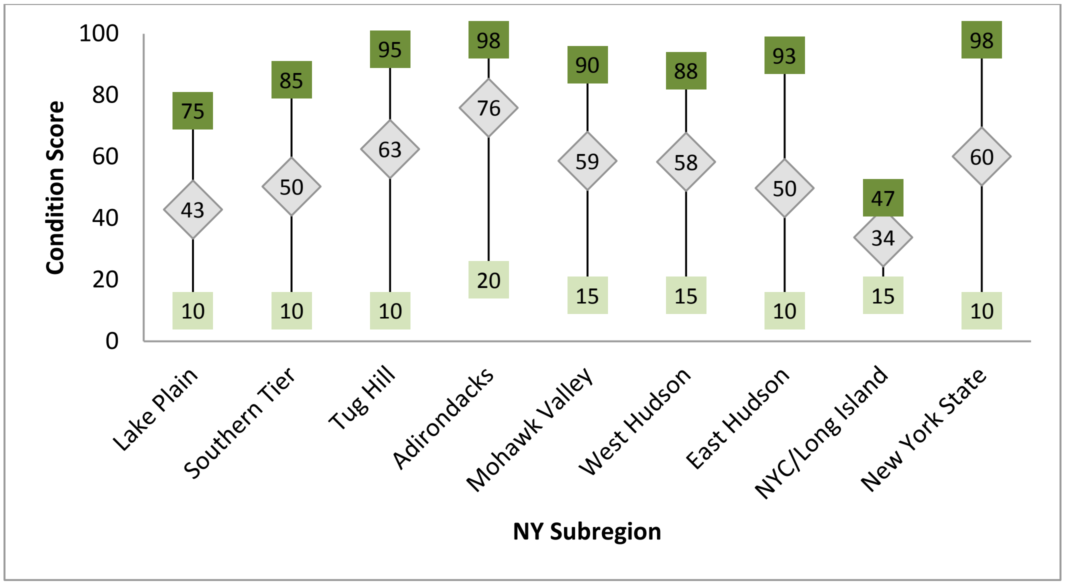


Figure 7. Regional Patterns in Condition Scores for Forests

The min, max, and average condition score are provided for each subregion. Average conditions were low in several regions, but high in the Adirondacks.



5.3 Regional Patterns in Threat

5.3.1 Land Use Change

Land use change is an underlying driver for many of the estimates of future threats included in the analysis. The net effect of these changes statewide was an 11 percent increase in developed lands, a net increase of 2.4 percent in agricultural lands, and a 0.9 percent decline in natural cover (not including inundation). A majority (70 percent) of the losses in natural cover were due to new agriculture, but this loss was more than balanced by gains in natural cover from reverted agricultural land in other areas. More than three quarters of new development occurred on natural lands, with the rest occurring on agricultural land (Table 3).

Table 3. Patterns of Land Use Change

The net change in amount of natural, agricultural, developed, and inundated lands statewide is summarized by transition type. Loss of natural cover is mostly due to agriculture, and is largely but not entirely replaced by agricultural abandonment.

	Natural	Agriculture	Developed	Inundated
Total Lost (ha)	**403,882**	**216,217**	**4,623**	**0**
Percent Lost	**5%**	**8%**	**0.03%**	**-**
To inundation	3%	0.14%	100%	-
To development	27%	15%	-	-
To agriculture	70%	-	0%	-
To natural	-	85%	0%	-
Total gained (ha)	**327,845**	**283,891**	**141,570**	**16,064**
From development	0%	0%	-	29%
From agriculture	100%	-	23%	2%
From natural	-	100%	77%	69%
Net Change	**-0.9%**	**+2.4%**	**+11%**	**n/a**

Some habitat types lost more cover than others. The largest net declines occurred in coastal habitats and shrub/grasslands, which lost 21-74 percent of their existing cover. A large proportion of the loss of coastal habitats was due to inundation, although new development also had an impact, particularly on Coastal Plain Swamps. Most of the losses of grass/shrubland were due to succession to mature forest, which may have been overestimated because timber harvests were not included in the model. Floodplain forests and central hardwood swamps also had net declines more than 10 percent, both largely due to new agriculture. Northern hardwood-conifer forests had a small net gain in area of 0.4 percent, while central oak-pine forests declined 5 percent. Alpine and boreal habitats had no net change in cover.

Land cover change affects habitat conditions both through direct loss of natural areas but also through fragmentation of the remaining habitat. The change in our model disproportionately affected small and medium sized habitat patches, with very minor losses or even net gains in the size of patches over 10,000 acres. The largest losses were from patches between 1,000 and 10,000 acres, which lost nearly 250,000 acres, or 1.9 percent of the existing habitat (Table 4).

Table 4. Habitat Fragmentation Due to Land Use Change

Natural cover mostly occurs in patches ranging from 100 to 10,000 acres in size (spanning two classes in the Table), with a small amount in very small or very large patches. Total net acres lost due to modeled land use changes is also greatest from these moderately sized patches, but on a percentage basis the impacts of habitat loss are slightly greater in the smallest patch class (<100 acres, with patches less than 50 acres not evaluated). The largest patches actually gained a small amount of acreage.

Patch Size Class (acres)	2011 acres	2050 acres	Change in acres	Percent Change
50-100	1,479,612	1,440,461	-39,151	-2.65%
100-1000	14,879,885	14,684,099	-195,786	-1.32%
1000-10,000	13,235,381	12,986,747	-248,634	-1.88%
10,000-100,000	5,282,801	5,280,175	-2,626	-0.05%
>100,000	1,504,128	1,504,660	+532	+0.04%
Total	36,381,808	35,896,143	-485,665	-1.33%

5.3.2 Streams

Stream threats were generally low across the State, and most watersheds had less than 5 percent of stream miles with a threat score of 33, which was the threshold for high threat. Long Island and the Lower Hudson watersheds had the highest average threat scores (22 and 14, respectively) and more than 10 percent of stream miles in each drainage had a high threat rating. The Upper Alleghany and Upper Delaware watersheds had the lowest levels of threat to stream habitats (Figure 8 and Figure 9).

5.3.3 Forests

Maximum threat scores for forests were much higher, although the average forest threat score was still low statewide. Long Island had by far the highest levels of threat, with an average score of 48 and two-thirds of the forest area in high threat. The Southern Tier and East and West Hudson regions also had higher threats, with more than 25 percent of forested area in a high rating. The lowest average threat ratings were in the Adirondacks and Tug Hill regions (Figure 10 and Figure 11).

Figure 8. Threat Scores for Streams

This map shows the threat score assigned to each stream reach based on an equally weighted average of a number of scored indicators.

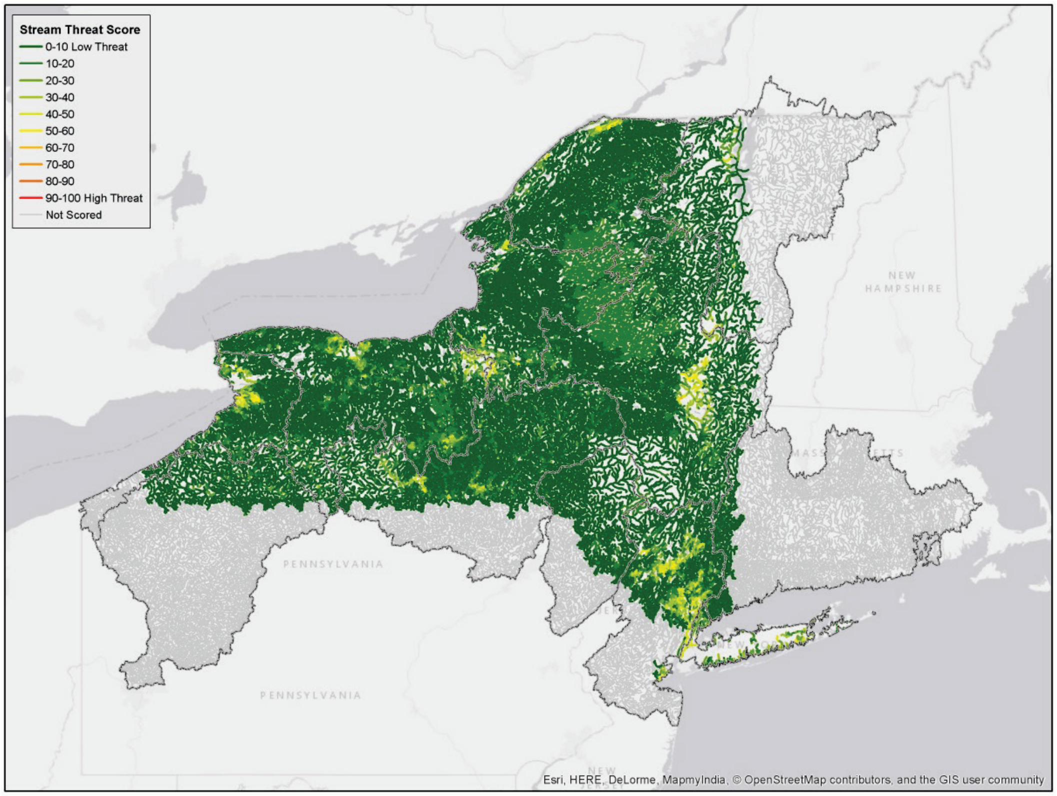


Figure 9. Regional Patterns in Threat Scores for Streams

The min, max, and average threat scores are provided for each drainage basin. Average threats were very low across the state, with slightly higher threat levels on Long Island.

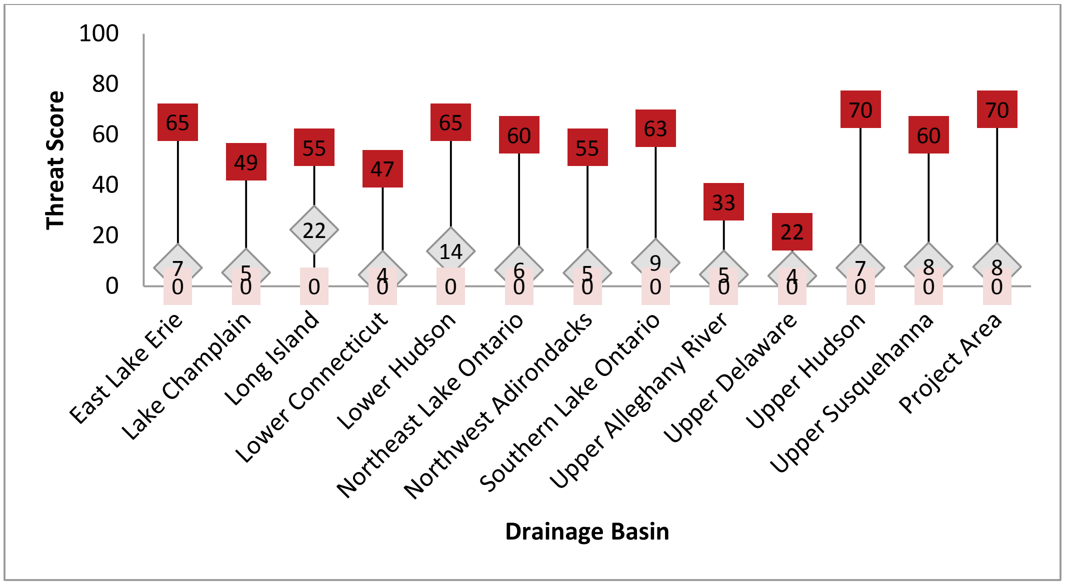


Figure 10. Threat Scores for Forests

This map shows the threat score assigned to each forest pixel based on an equally weighted average of a number of scored indicators.

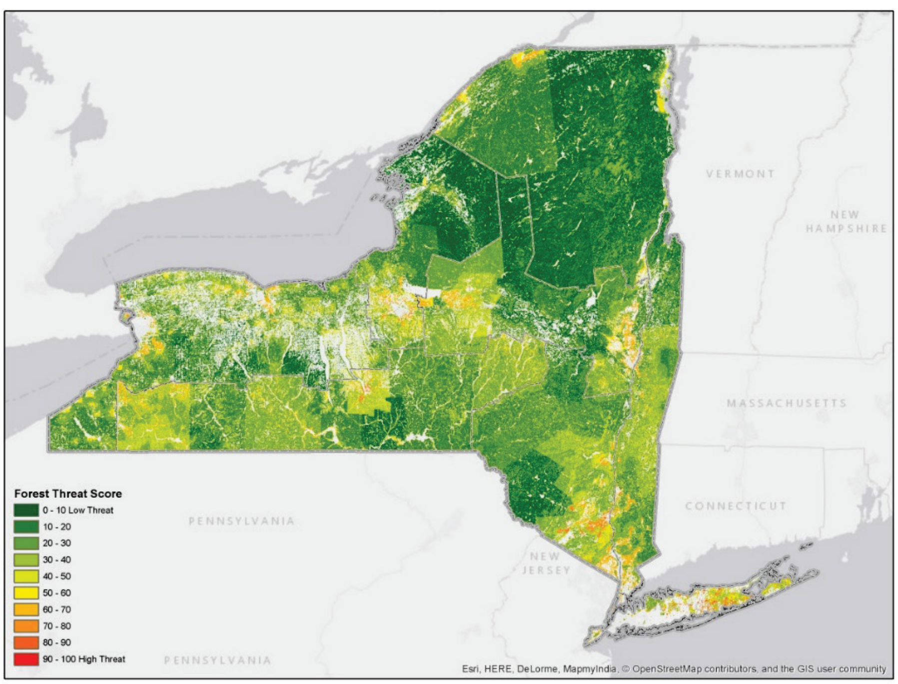
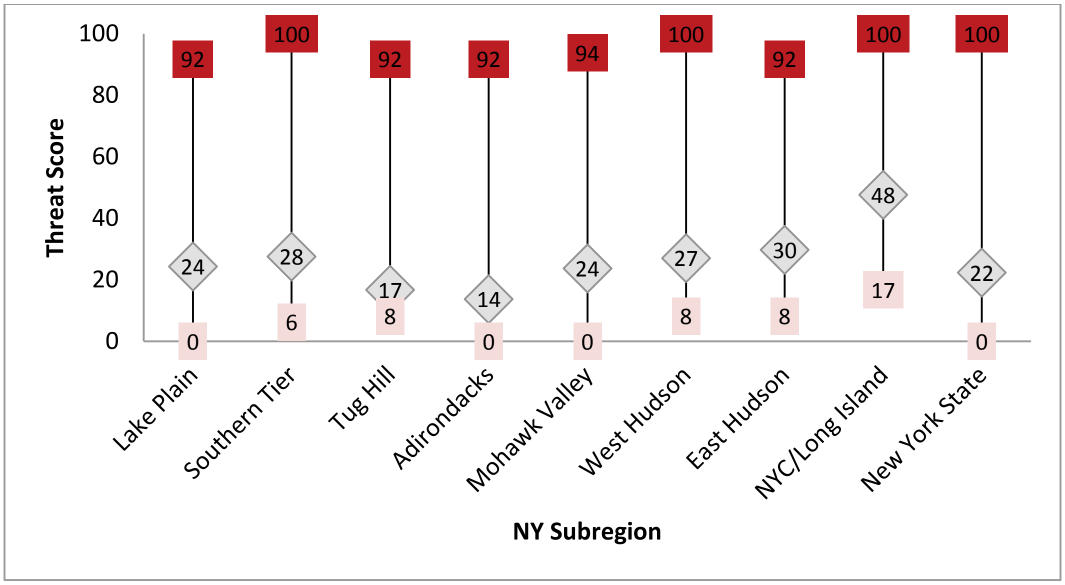


Figure 11. Regional Patterns in Threat Scores for Forests

The min, max, and average threat score provided for each subregion. Average threats were somewhat low across the State, with higher threat levels in NYC/Long Island.



5.4 Regional Patterns in Climate Sensitivity

5.4.1 Streams

Every watershed in the state had at least some stream segments with a maximum score for stream sensitivity to climate change. On Long Island, all stream miles in the region exceeded the score of 50 to get a high sensitivity rating. The Upper Alleghany and Upper Delaware watersheds had the lowest climate sensitivity, with average scores around 38 and with around one-third (2836 percent) of the stream miles in a high rating (Figure 12 and Figure 13).

5.4.2 Forests

With the exception of the Lake Plain and NYC/Long Island regions, most regions of New York had average climate sensitivity scores very close to the statewide average of 45 out of 100, with a high degree of variation within each region. The Lake Plain, with a slightly higher average score of 57, had 77 percent of forest area in the high sensitivity class (score greater than 50) (Figure 14 and Figure 15). The NYC/Long Island region had no forest acres at the lowest end of the sensitivity scale and 87 percent of the forest area was in the high sensitivity class (Figure 14 and Figure 15).

Figure 12. Climate Sensitivity Scores for Streams

This map shows the sensitivity score assigned to each stream reach based on an equally weighted average of scored indicators.

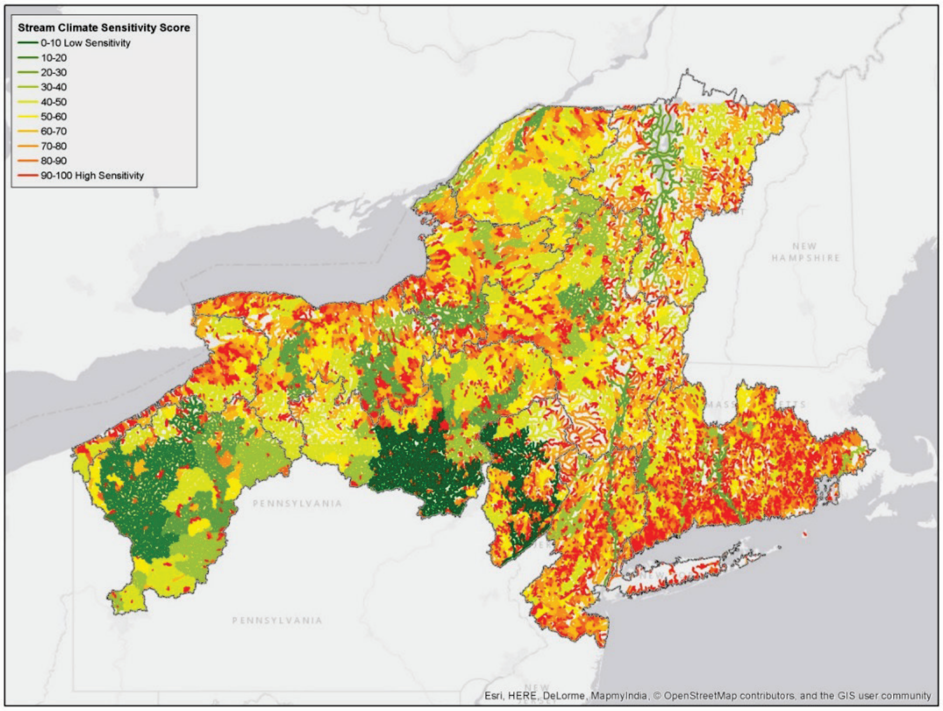


Figure 13. Regional Patterns in Climate Sensitivity Scores for Streams

The min, max, and average sensitivity score provided for each drainage basin. Sensitivity reached maximum values in all basins in the state, and was very high on Long Island.

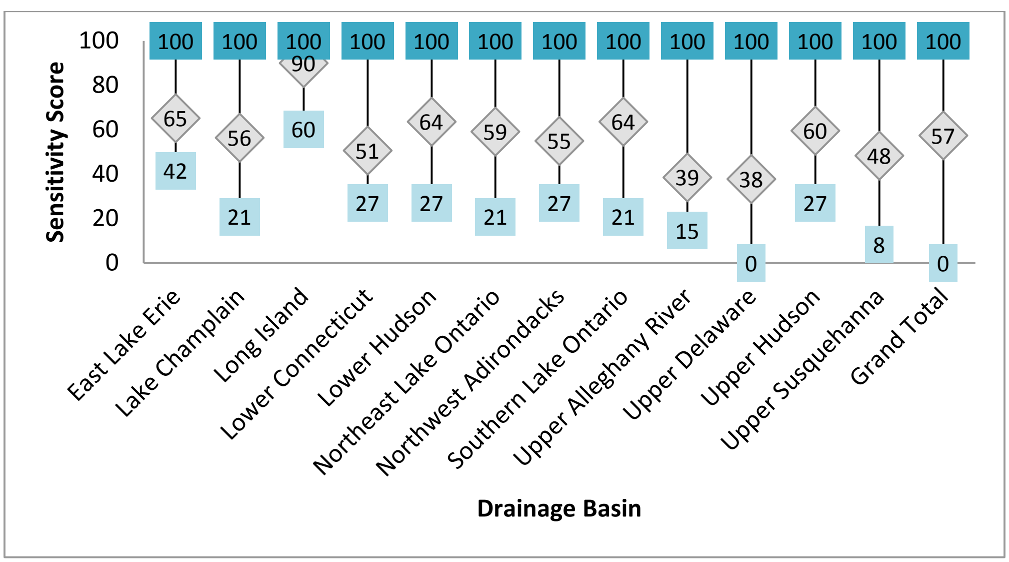


Figure 14. Climate Sensitivity Scores for Forests

This map shows the sensitivity score assigned to each forest pixel based on an equally weighted average of scored indicators.

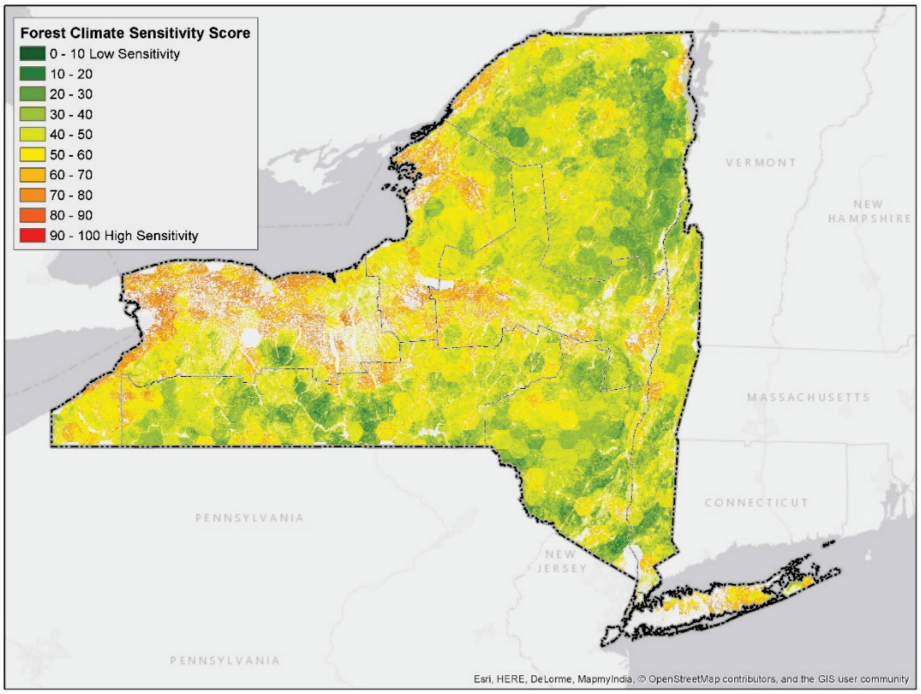
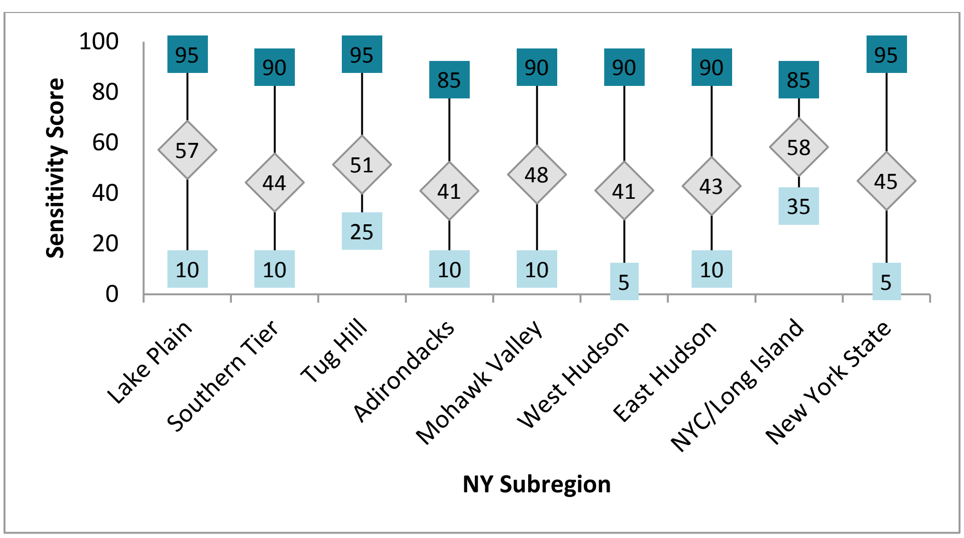


Figure 15. Regional Patterns in Climate Sensitivity Scores for Forests

The min, max, and average sensitivity score provided in each subregion. Sensitivity varied widely across regions, but did not show strong variation between regions.



5.5 Regional Patterns in Climate Exposure

5.5.1 Streams

Climate change exposure scores did not vary greatly across the State or within regions, likely due to the coarse nature of the climate analyses and the relative nature of the indictor scoring. Even so, some regional differences can be detected. The lowest climate exposure for streams within the study area occurs in the Lake Champlain and Northwest Adirondack watersheds. The highest climate exposure is in the western part of the State, with the East Lake Erie, Northeast and Southern Lake Ontario, Upper Alleghany, and Upper Susquehanna watersheds all rating a high exposure (score greater than 50) on more than 75 percent of the stream miles (Figure 16 and Figure 17).

5.5.2 Forests

Forest climate exposure was also generally higher in the western part of the State, with the highest average and maximum exposure scores in the Lake Plain and the Southern Tier. The Tug Hill and Hudson regions also had relatively high exposure, with half or more forest area in a high rating. The lowest climate exposure for forests in the state occurred in the Adirondacks, with an average score of 27 and only nine percent of the forest area rated as high exposure (Figure 18 and Figure 19).

Figure 16. Climate Exposure Scores for Streams

This map shows the exposure score assigned to each stream reach based on an equally weighted average of scored indicators.

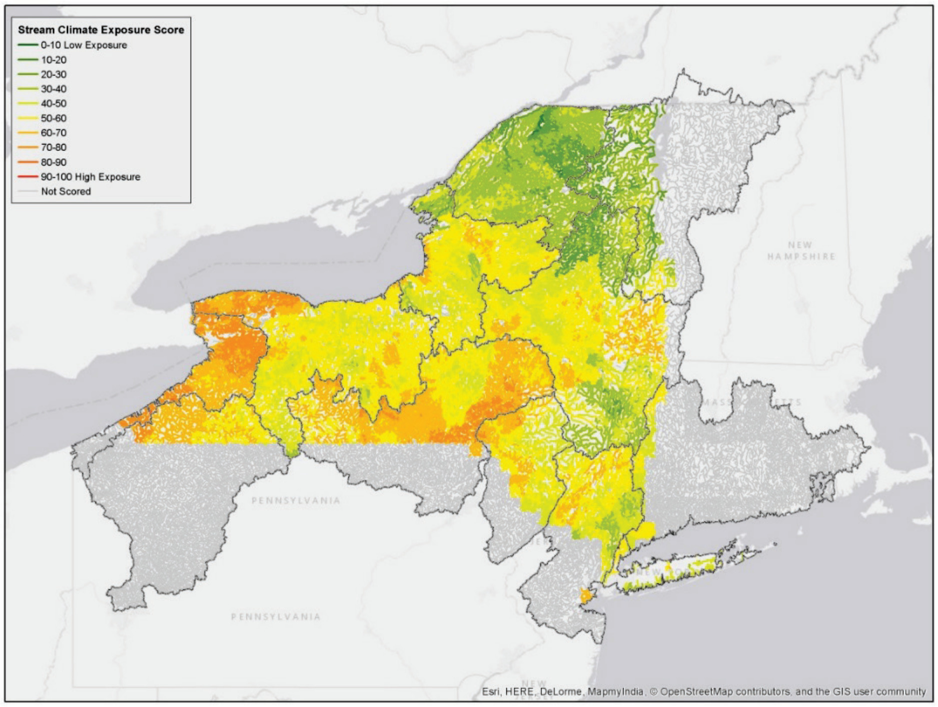


Figure 17. Regional Patterns in Climate Exposure Scores for Streams

The min, max, and average exposure score provided for each drainage basin. Exposure varied little within most regions. It was highest in Lake Erie and lowest in the Adirondacks.

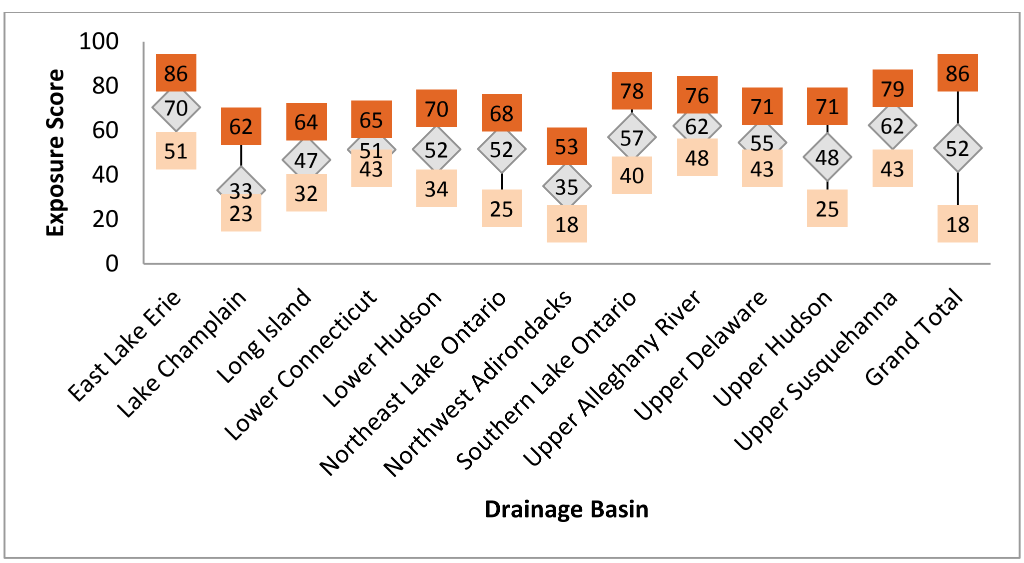


Figure 18. Climate Exposure Scores for Forests

This map shows the exposure score assigned to each forest pixel based on an equally weighted average of scored indicators.

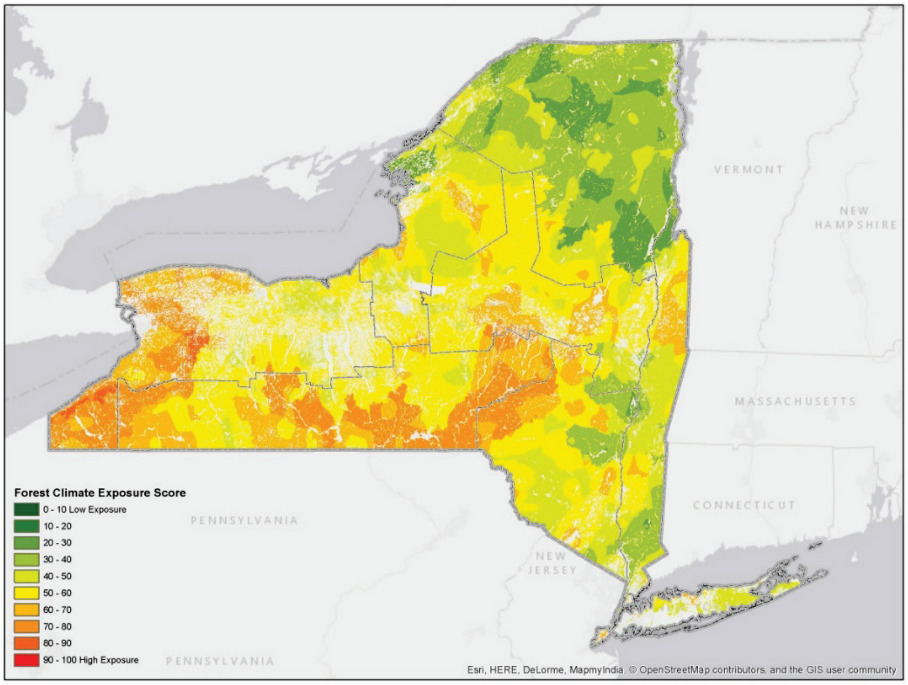
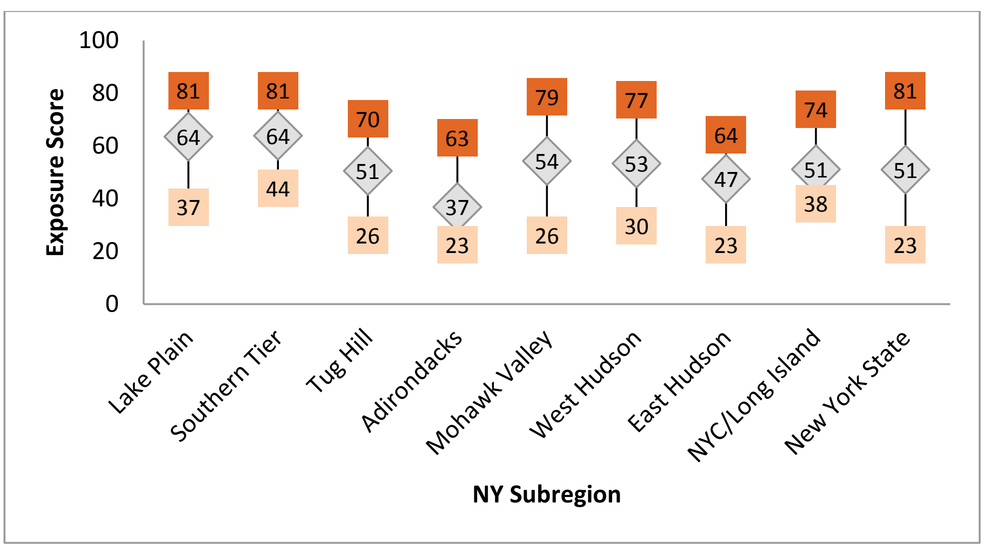


Figure 19. Regional Patterns in Climate Exposure Scores for Forests

The min, max, and average exposure score provided for each subregion. Exposure varied little within most regions. It was highest in western New York and lowest in the Adirondacks.



5.6 Recommended Objectives

5.6.1 Streams

The distribution of recommended conservation objectives in each watershed reflects the trends seen in the component scores above. A small number of stream segments, mostly in the Lower Hudson and Long Island, have the combination of high current condition and high future threat to receive a "reduce threats" class. The majority of areas with high threats statewide also have challenges with their current condition, meaning that we are likely to see intensification of impacts from ongoing stressors in those areas. However, there are also significant portions of some watersheds that are in the "restore" class, where conditions may be more stable and efforts to improve condition may have more success. For most watersheds in the State, the majority of the streams are in "maintain" class, which means they are in generally good condition and are not at risk from new threats other than climate change. Because the highest risk of impacts from climate change occurs in regions of the State where more of the streams are in impaired conditions, restoration efforts in those areas will need to select realistic restoration goals, and should try to incorporate climate adaptation into those restoration practices. Even places in the "maintain" class generally have some level of climate risk, which should be monitored closely for unanticipated impacts (Figure 20 and Figure 21), and may have one or more elements of condition that are impaired or on the verge of becoming so, and managers should consider addressing these, particularly if improving them might help facilitate adaptation.

Figure 20. Recommended Conservation Objectives for Streams

The objective (color) and climate risk (shade) are based on condition, future threat, climate exposure, and sensitivity.

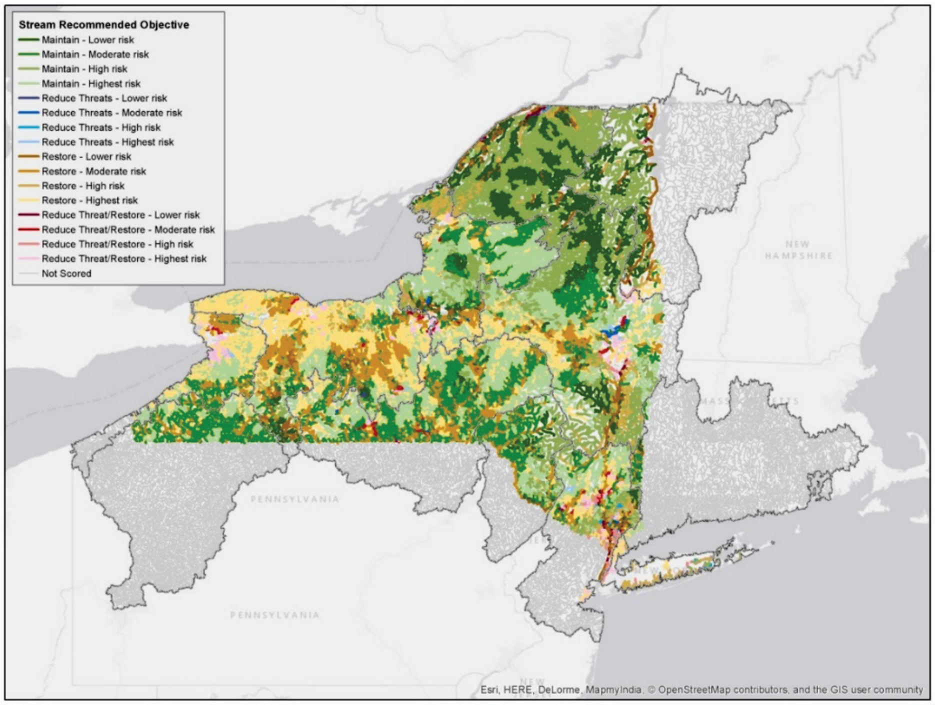
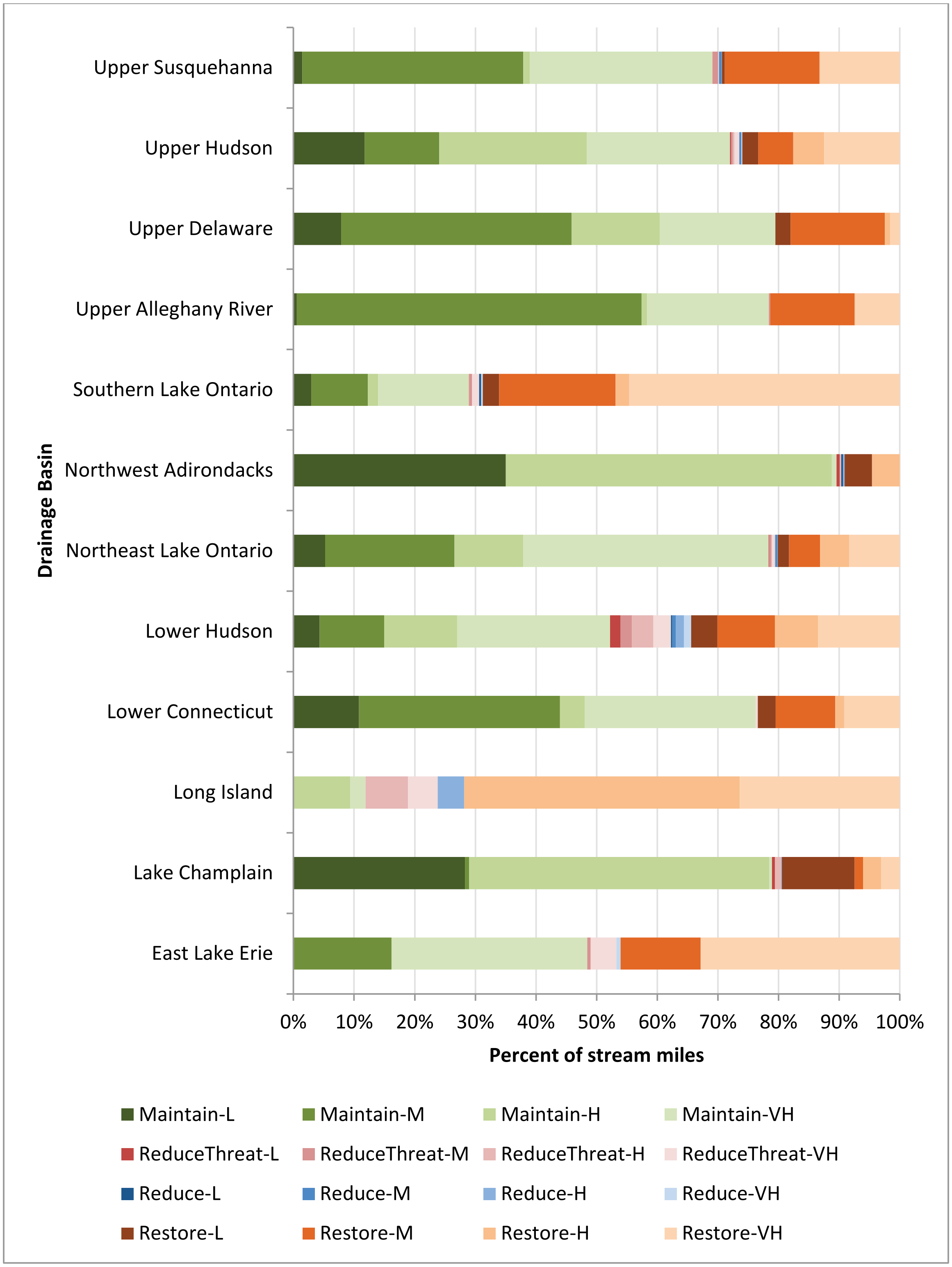


Figure 21. Distribution of Recommended Conservation Objectives for Streams

The proportion of the resource in each recommendation is shown by drainage, using the same color scheme as Figure 20.



5.6.2 Forests

Compared to the streams, the forest assessment revealed much less area in a “maintain” class, outside of the Adirondack and Tug Hill regions. Both the Lake Plain and Long Island had basically no forest areas in a maintenance state. Areas recommended for “reduce threat” were again a fairly minor component, because most of the threats are expected to occur in areas that already have impaired condition. This result creates significant areas of forest in the “reduce threats and restore” class, particularly on Long Island. About half of these areas also have a high climate risk, making the management of these forests particularly difficult and uncertain. Climate change is not as much of a concern for the high-condition “maintain” forests, which also tend to have low to moderate climate risk. But the high climate risk to forests in western New York combined with the predominant “restore” recommendation, again creates a particular need for climate-adapted restoration practices in those areas (Figure 22 and Figure 23).

Figure 22. Recommended Conservation Objectives for Forests

The objective (color) and climate risk (shade) are based on condition, future threat, climate exposure, and sensitivity.

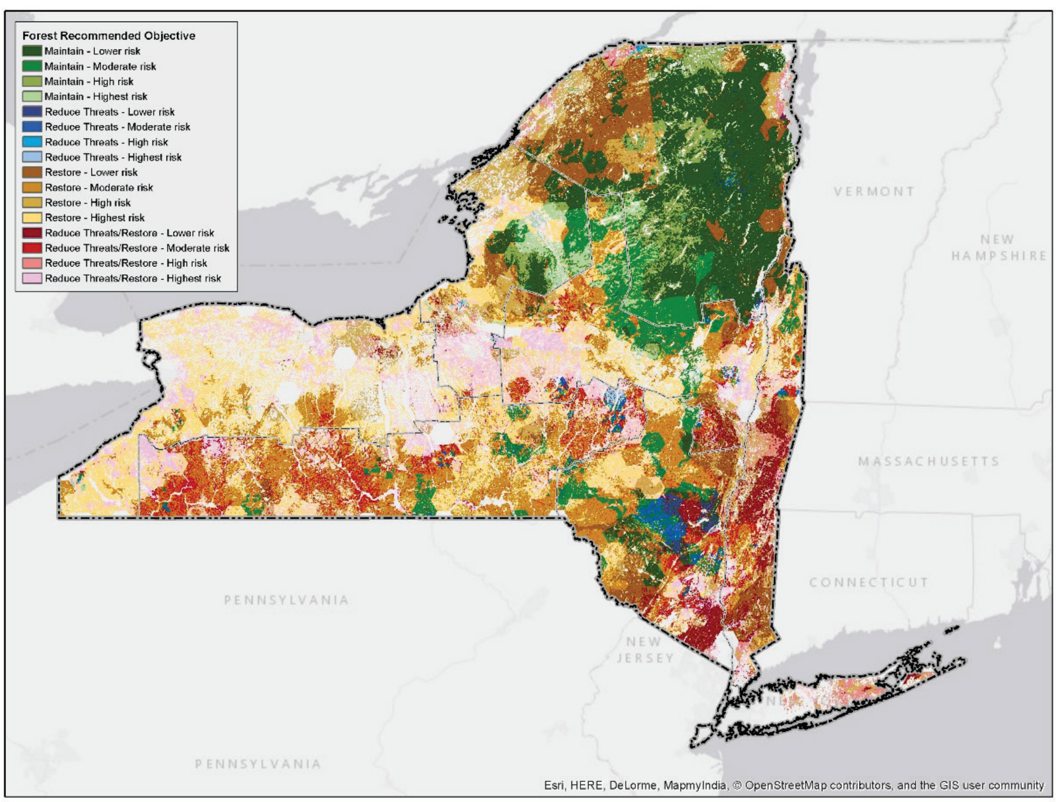
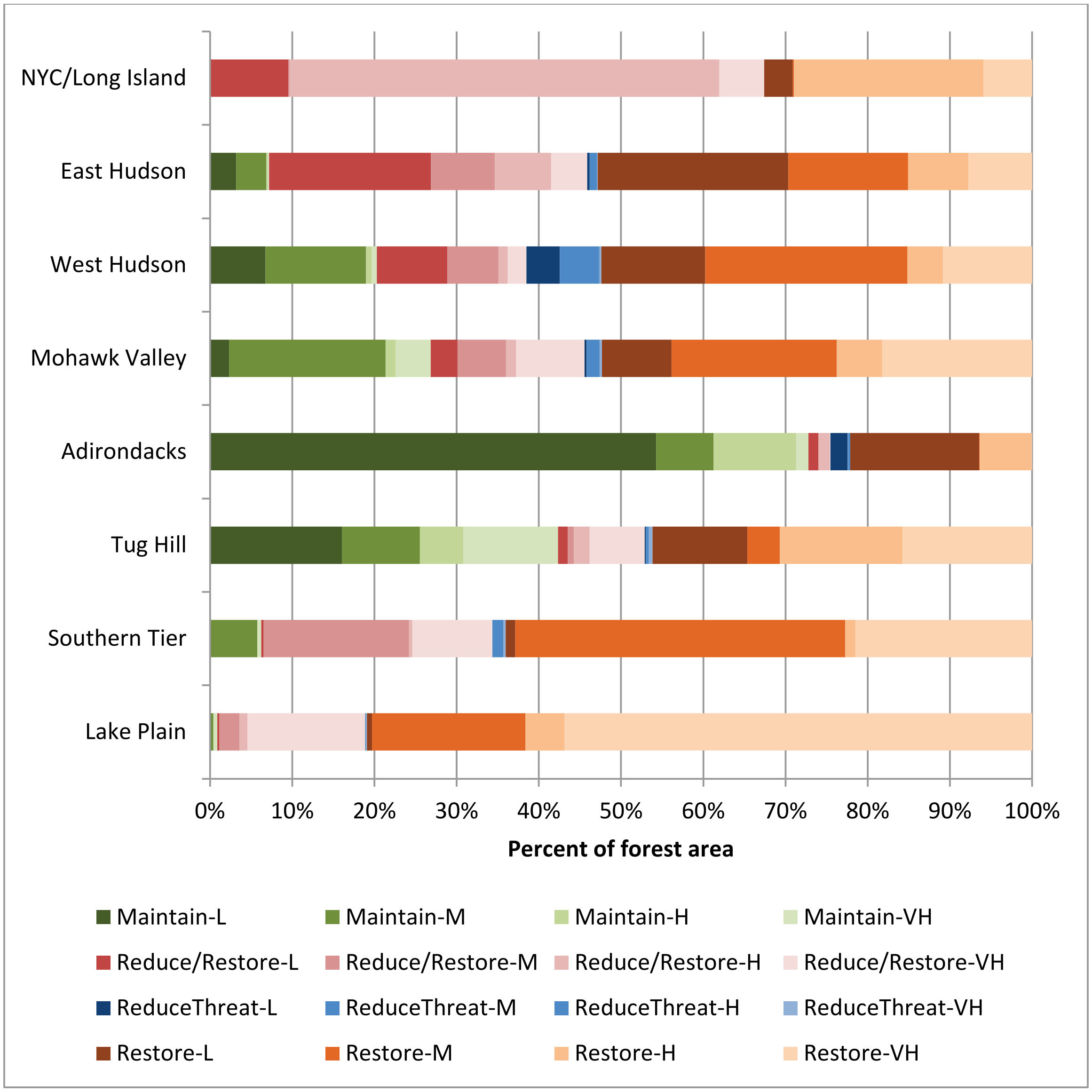


Figure 23. Distribution of Recommended Conservation Objectives for Forests

The proportion of the resource in each recommendation is shown by subregion, using the same color scheme as Figure 22.



5.7 Priority Areas

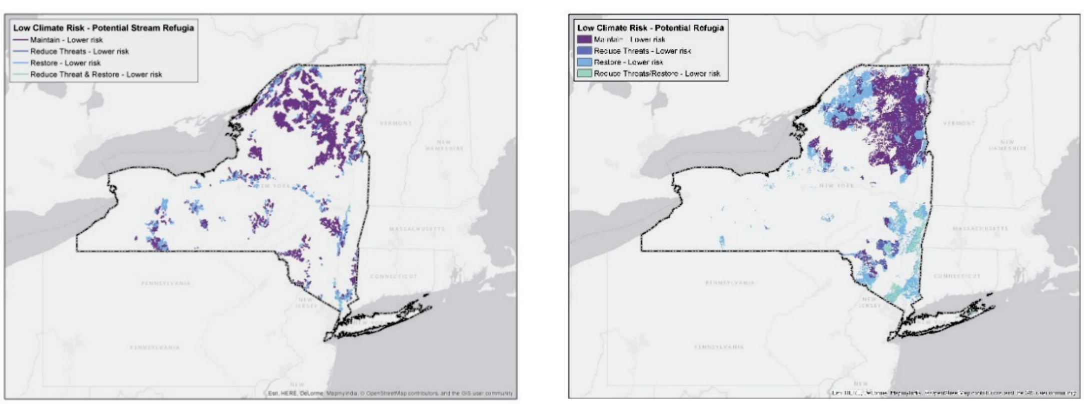
5.7.1 Conserve Potential Refugia

In addition to identifying management actions that can be taken to lower the climate risk in a particular location, the Navigator can also be used to identify places that contribute to large-scale adaptation of ecosystems and regional biodiversity. One of the frequently recommended strategies to this end is the identification and protection of areas that have the potential to act as refugia for species, allowing them to persist in pockets of habitat that in some way allow them to avoid the impacts of climate change, and where they may persist despite general declines elsewhere. Although there is evidence that such refugia helped species survive past climate events, it can be difficult to predict exactly where these might occur in the future.

Criteria for what defines refugia are not widely agreed upon, and vary by scale and purpose (Ashcroft et al. 2010). Refugia may be created by small scale variations in exposure, such as a north-facing crevice, that are beyond the resolution of the Map Tool. Protecting the diversity of heterogeneous sites should increase the probability of capturing these types of refugia. Refugia may be species specific, and include locations both within the current range that will remain stable or those places outside the current range that may become suitable. The future species habitat models and CCVI-S maps provided in the Navigator could be used to identify these potential refugia for individual species.

A third concept called macrorefugia (Saxon et al. 2005) was applied in the Map Tool to identify places that are expected to experience relatively lower climate change impacts and so may provide greater habitat stability. Using the habitat analysis, the lowest climate risk category was extracted for each objective to highlight locations of these potential macrorefugia for forests and streams (Figure 24). The information on objectives provides additional information to prioritize within these low-risk areas. Highest priorities were those places in Maintain status, as they likely provide the greatest chance of persistence. Lower priority but still worth considering were those places that could serve as stable refugia if their threat or restoration concerns were addressed. Lowest on the priority list were the Reduce Threat and Restore areas that may have more stable climate conditions, but suffer from ongoing non-climate challenges that reduce the viability of the site.

Figure 24. Priority Areas for Conserving Potential Refugia in Stream (left) and Forest (right) Habitats



5.7.2 Represent a Diversity of Settings

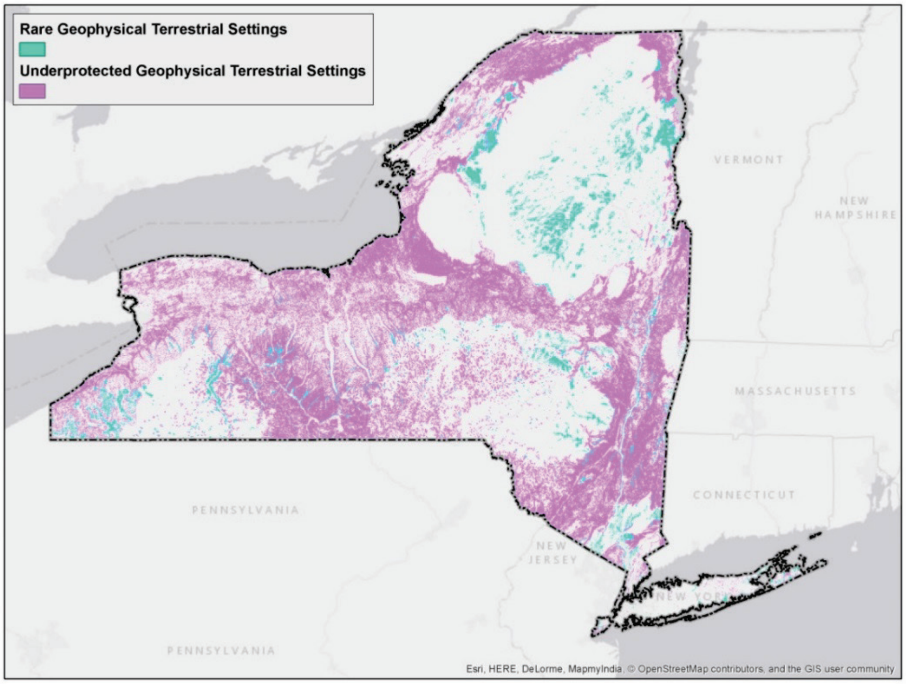
Using the geophysical settings within each terrestrial habitat, places were identified that are either rare or underrepresented within New York (Figure 25). Rare settings were defined as those making up less than one percent of the total area of each habitat type. The percent of total New York area that had some formal level of permanent protection (United States Geological Survey's Gap Analysis Program (GAP) protected area status 1-3) was calculated in each setting-by-habitat combination; habitats with less than 10 percent protection were classed as underprotected.

Rare settings generally occur in small patches, and represent a relatively small amount of area statewide. In many cases, these rare settings are already well-protected, but some are underrepresented in the State's protected lands. These locations should be protected from conversion because they are more irreplaceable. Protection projects could be designed to capture a number of these settings in close proximity.

Underprotected settings cover a surprisingly large proportion of New York State. Because large-scale land protection efforts have tended to occur in a few mountainous regions of the State, valley settings and non-forested habitats are particularly underrepresented. Many of these areas are more at risk of conversion because urban and agricultural development also favors these settings. To strengthen the State's land protection portfolio, State officials could include more of these habitat and geophysical types and prioritize adding diversity.

Figure 25. Rare and Underrepresented Geophysical Settings for Terrestrial Habitats

These locations should be prioritized for conservation to ensure various habitats are represented across the State.



5.7.3 Restore and Maintain Connections

The assessment of priority areas for regional forest connectivity identified a number of areas that would benefit from either protection or restoration of forest habitats. Figure 26 shows places to maintain current existing connectivity between and around large, unfragmented forest areas within the State. Because threats to connectivity were not evaluated beyond direct fragmentation, some of these places may be at risk of other types of degradation, such as forest pests, deer overbrowse, and invasive plants, that could also affect connective function.

Figure 26. Priority Areas to Support Connections Among Forested Habitats

Large unfragmented forests, least-cost linkages between them, and a well-connected landscape are all part of an important connected network.

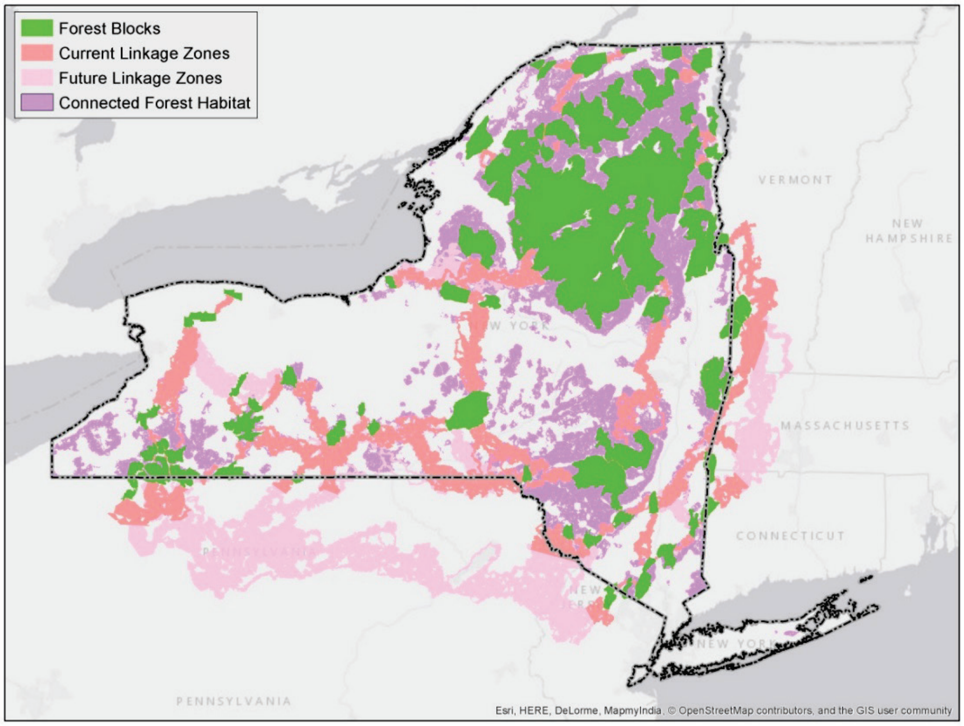


Figure 27 shows areas within the set of highly connected lands that may be at risk of losing connectedness due to new urban or agricultural development, according to the land use change model. Figure 27 highlights mostly limited areas in the Southern Tier and the Hudson Valley as candidates for potential zoning or other non-acquisition strategies to prevent conversion.

Figure 27. Areas at Risk of Losing Connectedness

The areas in gray are predicted to have declines in local connectedness due to land conversion. Areas where these overlap with the connected network should be prioritized.

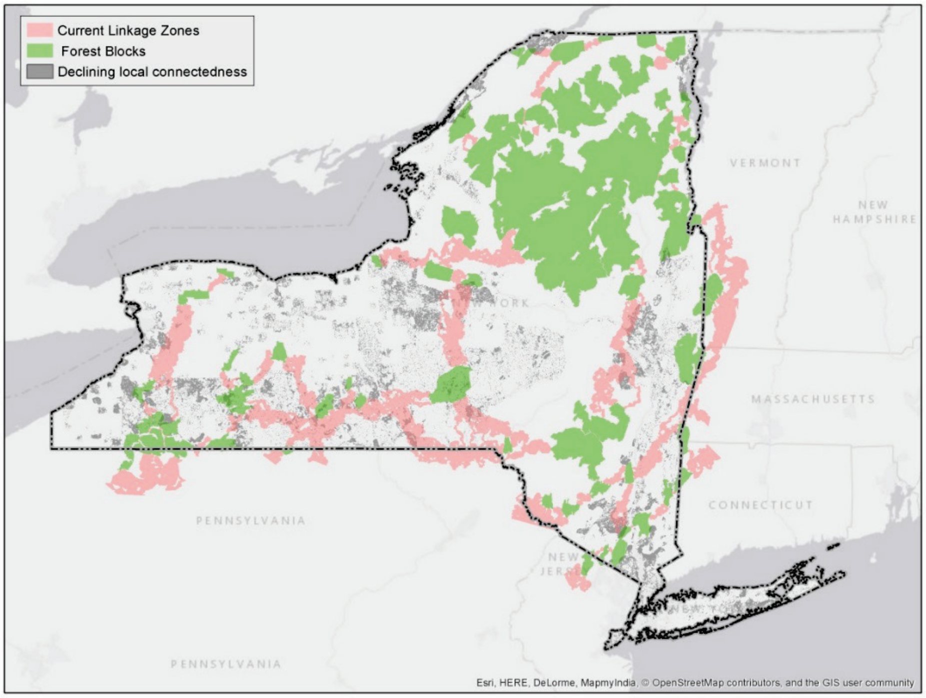
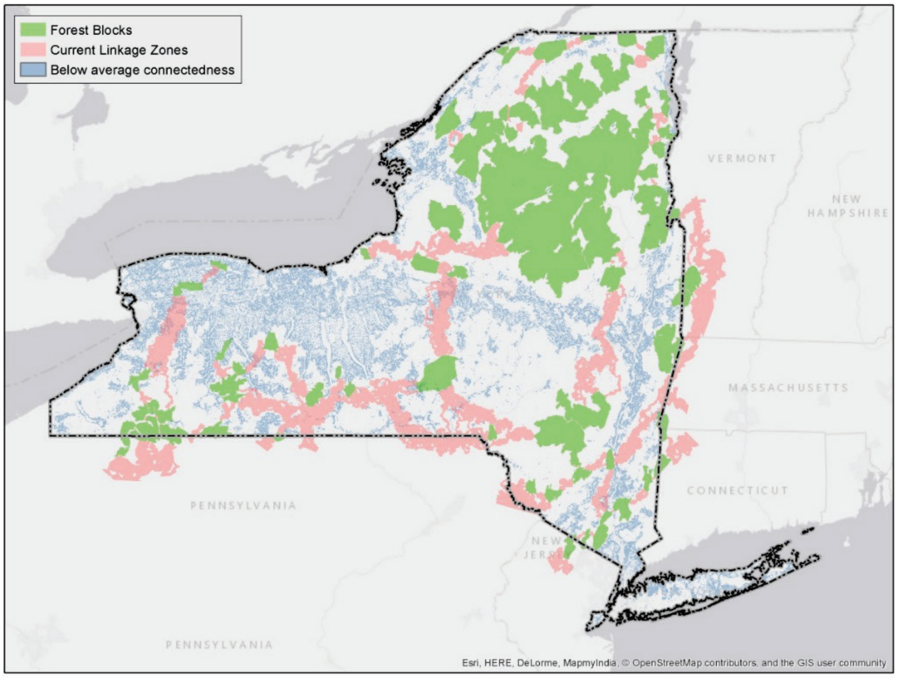


Figure 28 displays those places that are within a linkage or other part of the connection network, and currently have low local connectedness. This analysis identified more total area for restoration than was identified for protection (Figure 27), but the spatial patterns were similar with most of the areas in the Southern Tier or Hudson Valley. Interestingly, some locations within the matrix forest blocks were also selected.

Figure 28. Areas that Currently Have Low Connectednesss

The areas in blue have low current connectedness. Where these overlap with the connected network are priorities for restoration of connectivity.



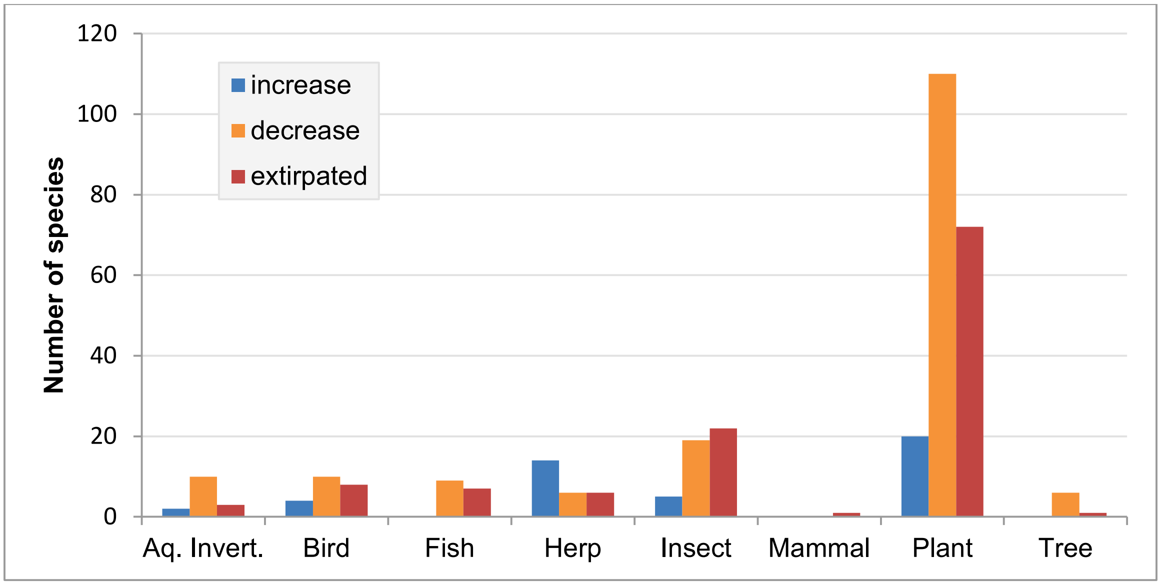
6 Species Assessment Results

6.1 Rare Species

Overall, 88 percent of modeled rare species in New York will lose more than half of their suitable habitat due to climate and land use changes. Although about half of modeled rare species also gain new suitable habitat, in most cases, expansion into new areas will not be sufficient to counteract losses, resulting in 36 percent of rare species at risk of extirpation from the State, and another 51 percent with net declines in suitable habitat area. Among declining species, the average net loss is 80 percent of current habitat area. A handful of rare species (13 percent) are projected to see substantial net increases in suitable habitat area, with the average increasing species gaining four to 50 times the current habitat extent. Herpetofauna in particular have a higher proportion of increasing species than any other taxonomic groups (Figure 29).

Figure 29. Trend in Rare Species by Type

In most taxa, declining and extirpated species outnumber increasing species, except among herpetofauna.



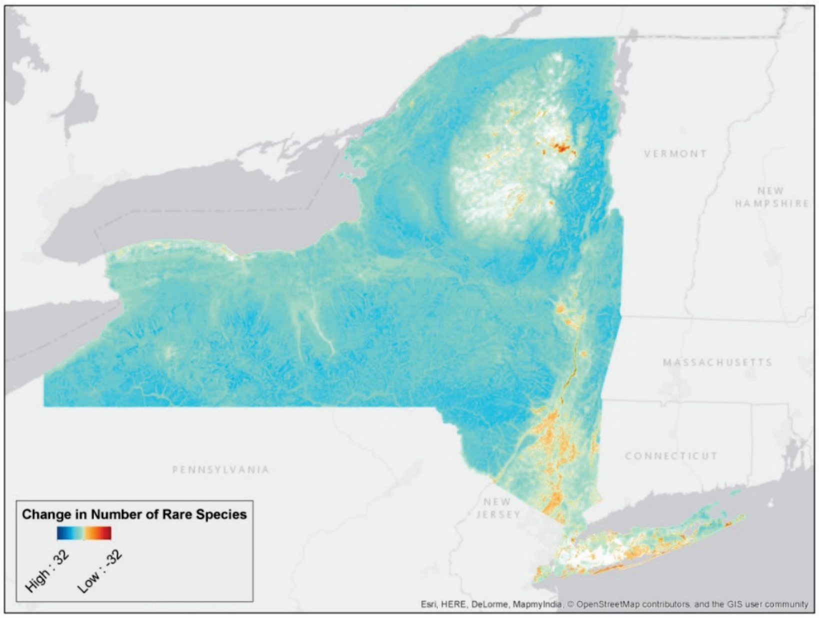
In terms of regional variation, most regions see net increases in rare species richness with climate change, with a few exceptions in the currently high-richness regions of the Hudson Valley, Long Island, and in the High Peaks of the Adirondacks (Figure 30). This result may seem counterintuitive, given the previously described levels of species loss. The difference exists because many of the extirpated species have fairly small distributions, while many of the increasing species, again mostly herpetofauna and birds, expand significantly from currently restricted southern ranges to become suitable in large areas of the State.

A number of cautions must be noted in interpreting these findings. First, an inherent limitation of the species distribution models used here is that the input occurrences of suitable habitat were all from within New York (as a result of the restrictions on Natural Heritage data). Therefore, some species may be modeled as becoming extirpated from New York when the same species happily occurs well to the south of the State. It is important to keep in mind that the models are predicting not actual species presence but rather the distribution of habitat matching the characteristics of current day New York occurrences. Modeled habitat maps beyond New York that are available from U.S. Geological Survey are included in the Navigator for reference. Species with significant southern distributions may not fare as poorly as indicated by the future models.

Second, the analysis of future habitat accounts for changes in both climate and land use, but it does not make any assumptions about the species being able to reach newly suitable habitat areas. For many of these species, dispersal ranges are limited. It is still possible that the rate of climate change, combined with fragmented landscapes, may prevent these species from fully occupying these modeled habitats. Users who want to further explore the role of connectivity in species range shifts should consult the Navigator's various connectivity data sets, as well as checking to see if a spatial vulnerability or migration model has been run for a particular species of interest. Third, because these models were created for rare and potentially threatened species, current populations may not be stable or abundant enough to generate emigrants to find new populations, particularly if the current habitat is modeled to decline in suitability. Modeled increases in a species' distribution should not be taken as evidence to support a reduced investment in the conservation of that species.

Figure 30. Change in Number of Rare Species

Aggregated current and future species habitat models show a decline in total number of rare species in Long Island and the Hudson Valley, but increases in the rest of the State.



6.2 Species of Greatest Conservation Need

The spatial distribution of Species of Greatest Conservation Need (SGCN), as identified in the NY State Wildlife Action Plan, has the greatest richness of these species occurring on Long Island, followed closely by the southern Hudson Valley and the St. Lawrence Seaway. These areas may be good for projects intending to conserve a large number of species, or biodiversity in general.

Reviewing the subsets of this species group using the nonspatial species attributes to identify 1) species to restore, 2) species to reduce threats, 3) and high risk species revealed some interesting patterns are revealed. There are 23 SGCN species that have complete assessments and are assigned to the “restore” group (Table 5). Among this list, species that had a climate vulnerability assessed are all in the low or moderate categories. Looking at the spatial distribution of where these species occur, the eastern side of Long Island in particular stands out as an area where multiple species could perhaps benefit from the same activities. Note that the status rating is based on the rarity ranks and listed status, and so most directly reflects population size and abundance, as opposed to other measures of condition. Because of this fact, the types of restoration needed for these species is likely a combination of habitat restoration and population recovery, but the specific need will depend on the species.

Table 5. Species of Greatest Conservation Need that May Benefit from Restoration

These species have low conservation status, but future threats are also low.

Blackchin Shiner (Notropis heterodon)	Short-headed Gartersnake (Thamnophis brachystoma)
Glossy Ibis (Plegadis falcinellus)	Jutta Arctic (Oeneis jutta)
New England Bluet (Enallagma laterale)	Ohio Lamprey (Ichthyomyzon bdellium)
A Noctuid Moth (Chytonix sensilis)	Northern Map Turtle (Graptemys geographica)
Rapids Clubtail (Gomphus quadricolor)	A Noctuid Moth (Eucoptocnemis fimbriaris)
Mantled Baskettail (Epitheca semiaquea)	Streamline Chub (Erimystax dissimilis)
Brook Snaketail (Ophiogomphus aspersus)	Tricolored Heron (Egretta tricolor)
Arrowhead Spiketail (Cordulegaster obliqua)	Snowy Egret (Egretta thula)
Comet Darner (Anax longipes)	Little Blue Heron (Egretta caerulea)
Waxed Sallow (Chaetaglaea cerata)	Tiger Spiketail (Cordulegaster erronea)
Spatterdock Darner (Rhionaeschna mutata)	Common Goldeneye (Bucephala clangula)
Pink Sallow (Psectraglaea carnosa)	

Table 6 provides the list of assessed SGCN species with high status but high threats, which may benefit from threat reduction strategies. This list includes several more-abundant, and even common, species than the restoration list. As a result, the richness map looks very different for this species with many areas of the State highlighted as having the highest richness values, making it more difficult to identify priority areas.

Table 6. Species of Greatest Conservation Need that May Benefit from Threat Reduction

These species have higher conservation status but high future threats.

Snapping Turtle (Chelydra serpentina)	Smooth Greensnake (Opheodrys vernalis)
Eastern Meadowlark (Sturnella magna)	Common Loon (Gavia immer)
Northern Bobwhite (Colinus virginianus)	American Kestrel (Falco sparverius)
Canada Warbler (Wilsonia canadensis)	Muskellunge (Esox masquinongy)
Bobolink (Dolichonyx oryzivorus)	Red-shouldered Hawk (Buteo lineatus)
Blue-winged Warbler (Vermivora pinus)	American Bittern (Botaurus lentiginosus)
Louisiana Waterthrush (Seiurus motacilla)	Ruffed Grouse (Bonasa umbellus)
American Woodcock (Scolopax minor)	American Shad (Alosa sapidissima)
Brook Trout (Salvelinus fontinalis)	

Species that had both high threat and low current status were classed as high risk, meaning that maintaining those species is likely to require high and ongoing investment. The full list of 117 species is too long to provide here, but Table 7 lists 33 species within this group that also had high climate vulnerability.

The spatial distribution of areas with large numbers of high risk species, regardless of climate vulnerability, partly reflects the distribution of high SGCN diversity in general, but the Southern Tier region has lower numbers of these species than expected. In general, resource managers should consider the feasibility of working on biodiversity conservation in areas where many of the SGCN species fall into this category.

Table 7. Species of Greatest Conservation Need that Are Likely to Require High and Ongoing Investment

These species have low conservation status and high threat ratings, as well as high climate vulnerability.

American Eel (Anguilla rostrata)	Hessel's Hairstreak (Callophrys hesseli)
American Three-toed Woodpecker (Picoides dorsalis)	Incurvate Emerald (Somatochlora incurvata)
Atlantic Salmon (Salmo salar)	Inland Silverside (Menidia beryllina)
Bald Eagle (Haliaeetus leucocephalus)	Marbled Salamander (Ambystoma opacum)
Bay-breasted Warbler (Dendroica castanea)	Mucket (Actinonaias ligamentina)
Black Skimmer (Rynchops niger)	Northern Harrier (Circus cyaneus)
Bog Turtle (Glyptemys muhlenbergii)	Olive-sided Flycatcher (Contopus cooperi)
Brook Floater (Alasmidonta varicosa)	Piping Plover (Charadrius melodus)
Cape May Warbler (Dendroica tigrina)	Roseate Tern (Sterna dougallii)
Cattle Egret (Bubulcus ibis)	Round Pigtoe (Pleurobema sintoxia)
Coastal Heathland Cutworm (Abagrotis nefascia benjamini)	Round Whitefish (Prosopium cylindraceum)
Dwarf Wedgemussel (Alasmidonta heterodon)	Saltmarsh Sharp-tailed Sparrow (Ammodramus caudacutus)
Eastern Hog-nosed Snake (Heterodon platirhinos)	Seaside Sparrow (Ammodramus maritimus)
Eastern Pearlshell (Margaritifera margaritifera)	Spruce Grouse (Falcipennis canadensis)
Eastern Spadefoot (Scaphiopus holbrookii)	Tennessee Warbler (Vermivora peregrina)
Frosted Elfin (Callophrys irus)	Threeridge (Amblema plicata)
Green Floater (Lasmigona subviridis)	

7 Conclusion

Climate change impacts are already occurring in New York, and the people responsible for managing the State's natural resources will need to incorporate climate change risk into their planning if they are to sustain those resources, and their associated benefits, into the future. The Natural Resource Navigator supports this process by providing and synthesizing relevant spatial data. It also informs decisions by providing guidance to interpret the results and generate actionable strategies.

The data in the Navigator indicate that, in general, the State's stream habitats are in good or moderate condition with low threat, but climate sensitivity is very high in many areas, including areas where exposure is also relatively high, creating a high risk of extreme impacts and unpredictable outcomes for management. Also, the Navigator does not yet incorporate information on current water withdrawals and in-stream flow, and consequently may underestimate condition impairments. Statewide stream conservation should focus on maintaining good conditions where they occur, and identifying ways to reduce and mitigate climate impacts. For forests, current conditions are generally lower, particularly outside of the large State-owned preserves, meaning that private forest management and restoration will be needed to improve the adaptive capacity of these systems. Threats from habitat conversion are generally limited in scope, but threats from invasive plants and pests and pathogens are more widespread and likely to be exacerbated by climate change. Climate risk for forests is highest in western New York and the Mohawk Valley, where both exposure and sensitivity are high.

Within these generalizations, a wide range of conditions exist at local scales that run the full gamut of management scenarios. Resource managers should use a combination of these data within the Navigator, local data, and their own judgement to generate their own plan of action. Managers should consider a range of approaches when planning for climate change impacts, factoring in the degree of climate risk, the value of the resource, and the capacity and need for active management and control of outcomes. The Navigator data help to identify priority areas that should receive particular attention due to their role in regional climate adaptation, by providing refugia for sensitive species, connectivity to support range shifts, and a diversity of settings that raise the probability of persistence.

The data provided in the Navigator are limited to data sets that could be assessed and mapped statewide, and are shown at the best available spatial resolution. However, there will always be limits to the accuracy of large-scale and modeled data. The user should focus on general trends and patterns, as opposed to focusing on specific values at very small scales. There are also many important factors influencing resource conditions that are either local in scope or are not available to be mapped, and were left out of this assessment. Therefore, these findings should be interpreted with caution, and in context of other information available to decision-makers. Improvements in the accuracy, scale, and availability of natural resource data are needed to further help managers make informed decisions. As pointed out earlier, information on water use and the current and potential future condition of instream flow/water quantity will be important to consider when it is available in the next few years. Better spatial data on the future location and severity of freshwater flooding is one major data gap of interest to many users that would be particularly valuable to fill.

Any attempt to forecast data into the future will inherently introduce uncertainty, and the data on threats and climate exposure are presented as a single scenario of what the future could look like, albeit one that the authors think is likely unless interventions are made. Greater emphasis was placed on the direction, degree, and general spatial patterns of change than in the specific amounts or locations of change forecast by these models. This simple way of incorporating climate change can be useful for decisions that are focused on near-term goals, and for systems that are less sensitive to climate change or are facing more immediate threats.

The authors have attempted to incorporate the consideration of climate change risk in a way that does not require the highly reliable and specific forecasts of impacts. However, people that are planning for more sensitive systems, or more complex interactions between multiple climate change factors or other threats may need more specific information on future conditions. Those users are encouraged to explore a wider range of climate change projections and to evaluate how differences in those projections might influence project success. Workflows within the Navigator can help in these more in-depth assessments, although users will need to consult other sources for additional climate change projections.

Preparing for climate change is an adaptive process. The information provided in the Navigator is based on the best available science and recommendations from a wide variety of sources. As research continues and climate change progresses, common knowledge may change and some of the assumptions may become incorrect. It is important that practitioners use the Navigator as a jumping off point from which to set a direction and spur action, but that they continue to seek out new information and learn from others' experiences. The authors support efforts to document case studies, share lessons learned, and monitor and evaluate the effectiveness of actions to continuously adapt and improve our practices. In this spirit, it is critical that the usefulness of tools such as the Navigator also be evaluated, and the needs of users incorporated into future iterations. The authors have piloted several new analyses and planning approaches with this project that, if successful, could be expanded to other habitat types, species, and/or geographies. The Freshwater Flooding dataset and worksheet module represent one potential model for how to think about an attribute that is important to both ecosystem function and community resilience.

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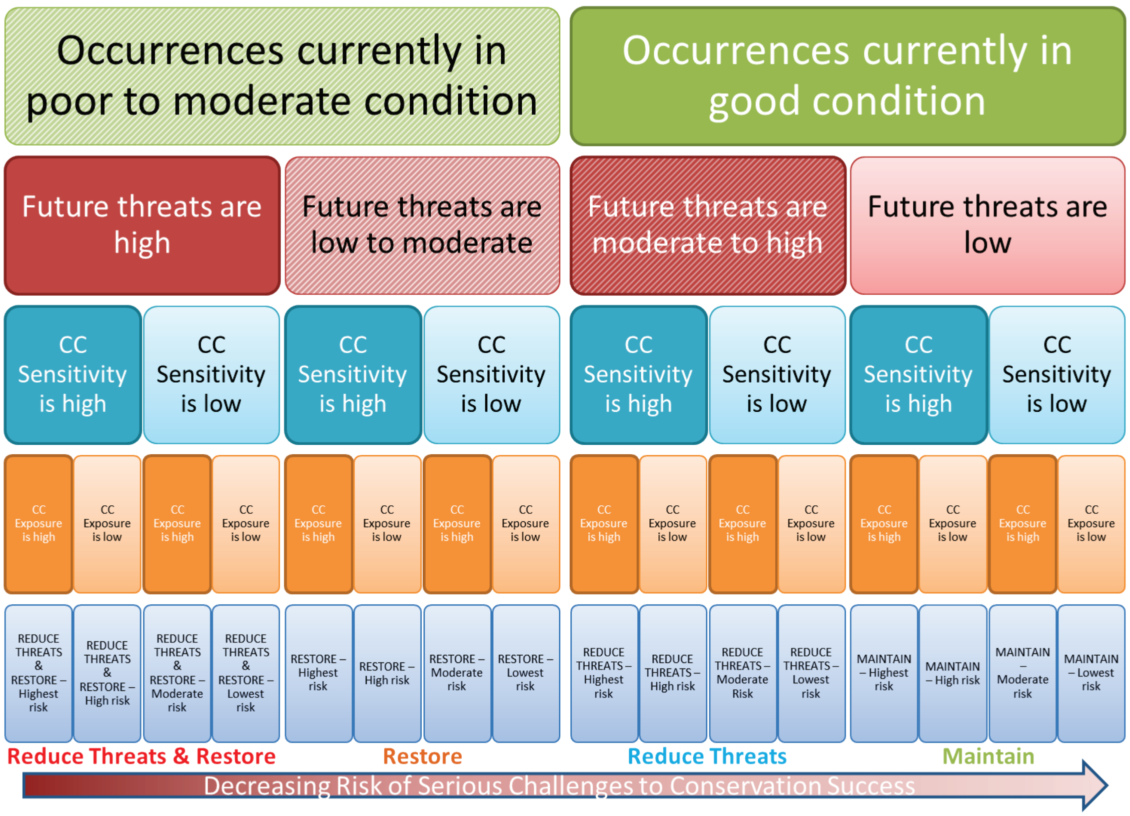
Appendix A: Conceptual Matrix Used to Generate Recommended Conservation Objectives Maps

In the boxes below, "CC" is an abbreviation for "climate change."



Appendix B: Management Recommendations

B.1 Maintain

Due to their good current conditions and low future non-climate threats, these places are more likely to maintain their current conditions with minimal intervention. These places may also be best equipped to accommodate climate change because there are no other significant challenges that need to be addressed.

Objective	Relative Climate Risk	Exposure	Sensitivity	Recommendations
MAINTAIN Current Condition = High, Future Threat = Low	Maintain – Lowest risk	Low	Low	Consider protection tactics if there is a risk of conversion. Maintain low threat and good condition, and monitor for unexpected changes. May serve as refugia for species; possibly important to maintain connection to places with higher climate risk.
	Maintain – Moderate risk	High	Low	Prioritize locations that add to regional representation. Maintain condition and ensure sites or populations are sufficiently large and connected to be self-sustaining. If the impacts of climate change can be reduced here, it may be possible to resist or slow change. Best sites for evaluating whether low sensitivity decreases the realized impacts of climate change on habitats, species and services.
	Maintain – High risk	Low	High	Look for ways to reduce sensitivity. Consider facilitating adaptation through active management. Look for replication and representation of other settings, try to build a connected network and connect to places with lower sensitivity. Be sure to maintain condition, and monitor for unexpected new threats.
	Maintain – Highest risk	High	High	Maintain the site and monitor for unexpected new threats. Consider cost/benefit of resisting change vs. allowing natural shifts to occur.

B.2 Reduce Threats

With good current condition but moderate to high non-climate threats, these places will likely require intervention to prevent future declines in condition. Some threats may be exacerbated by climate change; if threats can't be abated, the combined impacts of climate change and non-climate threats may have extreme and unanticipated consequences. However, because of their good current condition, these places may also be a high priority for intervention.

Objective	**Relative Climate Risk**	**Exposure**	**Sensitivity**	**Recommendations**
REDUCE THREATS **Current Condition = High, Future Threat = High**	Reduce threats --- Lowest risk	Low	Low	This is the highest priority for threat reduction, and possibly a priority for protection if there is a risk of conversion. May serve as refugia for nested species if threats can be abated. Consider the pros and cons of connectivity, depending on the nature of the threat.
	Reduce threats -- Moderate risk	High	Low	Reduce threats and consider resisting or reducing climate change if feasible and buys time for threat reduction. Monitor for climate impacts to learn whether low sensitivity really helps in high exposure situations.
	Reduce threats – High risk	Low	High	If threat can't directly be reduced, steps should be taken to reduce sensitivity if possible. Ensuring connections for movement out to places with lower threat and lower sensitivity.
	Reduce threats -- Highest risk	High	High	Be alert to climate changes that worsen the threat. Consider resisting or reducing climate change (if feasible) long enough to allow threat reduction. Consider relocation or at least ensuring connections for movement out to places with lower threat and lower sensitivity.

B.3 Restore

Places with poor to moderate current condition but relatively low future threat are good places to invest in restoration or ecological management. Recognize that poor condition also increases vulnerability to climate change; management activities may provide opportunities to reduce climate sensitivity. If climate risk is high, consider using non-historical reference conditions to guide management.

Objective	Relative Climate Risk	Exposure	Sensitivity	Recommendations
RESTORE **Current Condition = Low, Future Threat = Low**	Restore – Lowest risk	Low	Low	Top priority for restoration. Could consider maintaining current species compositions for longer, or manage a slower transition to future compositions. Be alert for signs of decline from ongoing or new threats.
	Restore – Moderate risk	High	Low	Consider confidence in your threat and sensitivity evaluations before investing, particularly if it will take a lot of work to restore condition. Focus on restoring function/structure since composition may change.
	Restore – High risk	Low	High	Consider confidence in your threat evaluations and whether or not sensitivity could be reduced before investing in restoration. Restoration could provide opportunities to reduce sensitivity.
	Restore – Highest risk	High	High	Maintain connectivity to places with lower risk/better condition. Focus on restoring function/structure since composition may change. May want to anticipate future composition, take advantage of opportunities to reset the system trajectory.

B.4 Reduce Threats and Restore

Poor to moderate current condition and high threat of further decline in the future means that these places are likely to require greater ongoing investment and have more uncertain outcomes. Consider feasibility of intervention and whether to adjust goals or intended strategy, particularly if climate risk is high.

Objective	Relative Climate Risk	Exposure	Sensitivity	Recommendations
REDUCE THREATS & RESTORE Current Condition = Low, Future Threat = High	Reduce Threats & Restore -- Lowest Risk.	Low	Low	If threat can be reduced and the location is a priority for regional representation, restoration may still be worthwhile. Consider delaying connection work until condition and threat are improved, so that it does not become a sink. If condition and threat status are due to the same ongoing source, may be able to address both simultaneously.
	Reduce Threats & Restore – Moderate Risk.	High	Low	If it is deemed achievable in the short to moderate term, focus on restoring condition first, particularly aspects that might improve adaptive capacity. Consider whether it makes sense to facilitate compositional change given the landscape and regional context. Monitor if low sensitivity helps with high exposure even when target is very compromised otherwise.
	Reduce Threats & Restore – High Risk.	Low	High	Consider whether it makes sense to facilitate compositional change given the landscape and regional context. If need to artificially maintain a high-value resource, focus on restoring condition aspects that will reduce sensitivity to climate and/or other threats.
	Reduce Threats & Restore— Highest Risk.	High	High	Consider whether it is possible to change objective, repurpose the site, or facilitate transition even if original target is lost. If need to artificially maintain a high-value resource, focus on restoring condition aspects that will reduce sensitivity to climate and/or other threats.

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