

Ecosystem Vulnerability to Climate Change in the Southeastern United States

Two recent investigations of climate-change vulnerability for 19 terrestrial, aquatic, riparian, and coastal ecosystems of the southeastern United States have identified a number of important considerations, including potential for changes in hydrology, disturbance regimes, and interspecies interactions. Complementary approaches using geospatial analysis and literature synthesis integrated information on ecosystem biogeography and biodiversity, climate projections, vegetation dynamics, soil and water characteristics, anthropogenic threats, conservation status, sea-level rise, and coastal flooding impacts. Across a diverse set of ecosystems—ranging in size from dozens of square meters to thousands of square kilometers—quantitative and qualitative assessments identified types of climate-change exposure, evaluated sensitivity, and explored potential adaptive capacity. These analyses highlighted key gaps in scientific understanding and suggested priorities for future research. Together, these studies help create a foundation for ecosystem-level analysis of climate-change vulnerability to support effective biodiversity conservation in the southeastern United States.



Examples of ecosystems that were analyzed to assess climate-change vulnerability included, *A*, montane grass and heath balds, *B*, granite outcrops, *C*, longleaf pine savannas, and *D*, flood-scoured riparian areas.

Introduction

Assessments of **climate-change vulnerability** (**bold terms** can be found in the glossary) are becoming increasingly important to the conservation of biodiversity. Increasing regional temperatures and changing precipitation patterns are already affecting many plant and animal species, and these effects are expected to become more pronounced in the decades ahead. Ecological effects of climate change have been documented around the world, ranging from changes in species **phenology** to shifts in plant and animal **distributions** to altered wildfire dynamics. To target conservation strategies effectively, natural resource managers need timely and comprehensive information concerning climate-change effects on natural communities, including current assessments and future projections. This is especially true in regions that are rich in plant and animal biodiversity, such as the southeastern United States.

Although climate-change vulnerability assessments for individual species are common and important conservation tools, assessments for whole ecosystems offer a number of important advantages. Ecosystem-level assessments allow for more comprehensive and holistic views of ecological processes and drivers of change than do species-level assessments, for example by incorporating climate-induced changes in **disturbance** dynamics, hydrologic conditions, and geomorphic processes. In addition, ecosystem-level assessments can readily incorporate interspecies interactions, including food webs, competition, pest and pathogen dynamics, and exotic species invasions.

Two recent U.S. Geological Survey reports (Cartwright and Wolfe, 2016; Costanza and others, 2016) collectively address climate-change vulnerability for 19 terrestrial, aquatic, riparian, and coastal ecosystems across the diverse landscapes of the southeastern United States. Ranging from Appalachian mountain tops to Texas canyons to Caribbean mangroves, these ecosystems were assessed by integrating current scientific knowledge on a broad range of factors, including

- Ecosystem biogeography and distribution
- Ecological processes and habitat characteristics
- Plant community types and vegetation dynamics
- Abiotic stress factors such as hydrologic variability, soil and water chemistry, topography, and temperature ranges
- Disturbance regimes including wildfire and riparian flood scouring
- Biodiversity, including plant and animal species of conservation concern
- Human threats, such as resource extraction and land-use change
- Conservation strategies and options
- Knowledge gaps and research priorities

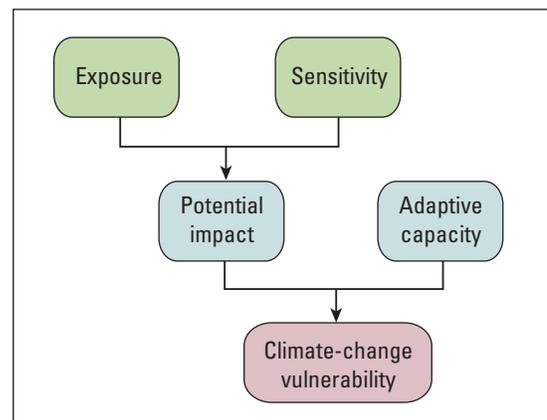
Complementary Approaches: A Question of Scale and Biogeography

Investigations by Costanza and others (2016) and Cartwright and Wolfe (2016) represent a unified effort to develop preliminary frameworks for ecosystem-level climate-change vulnerability

assessment across the southeastern United States; however, the two studies necessarily employed different and complementary approaches. In large part, these approaches were determined by considerations of geographic scale, biogeography, data resolution, and availability of published literature for each ecosystem.

Geospatial Analysis Across Broad Geographic Extents

Costanza and others (2016) assessed **exposure**, **sensitivity**, and **adaptive capacity** to climate change using geospatial analysis for several ecosystems such as wet pine savannas and hardwood forests. Geospatial datasets used in the assessment included climate projections, current and projected land use, elevation, ecosystem **fragmentation**, protection status, sea-level rise and coastal flooding impacts, and models of vegetation dynamics. This approach is well-suited to ecosystems with broad geographic extent, for which such datasets can be obtained and models can be run at appropriate spatial resolution. Where geospatial data to address aspects of climate-change exposure, sensitivity, or adaptive capacity were lacking, Costanza and others (2016) used publications to fill gaps in the analysis.



Ecosystem-level analyses by Costanza and others (2016) were based on a climate-change vulnerability framework incorporating exposure, sensitivity, and adaptive capacity.

Literature Synthesis for Ecological Islands

Cartwright and Wolfe (2016) focused on a set of “insular” ecosystems, characterized by small land area, geographic discreteness (spatially isolated like islands in a sea of contrasting ecosystems), sharply defined boundaries, and biogeographic distributions strongly linked to specific geologic, geomorphic, and soil characteristics. These ecosystems included rock outcrops, insular prairies and barrens, geographically isolated wetlands, and flood-scoured riparian zones. For these systems, existing geospatial data were generally of insufficient spatial resolution to support robust geospatial analysis. Numerous localized, site-specific investigations in these ecosystems over several decades have yielded valuable botanical and ecological information, but this literature has generally remained disconnected and has rarely addressed climate change. Therefore, Cartwright and Wolfe (2016) performed a comprehensive synthesis of the literature for selected insular ecosystems to lay the necessary groundwork for future explorations of climate-change effects on ecosystem function.

Collectively, the analyses by Costanza and others (2016) and Cartwright and Wolfe (2016) incorporate both quantitative and qualitative approaches, draw from a diverse array of data and information sources, and focus on ecosystems ranging in size from dozens of square meters to thousands of square kilometers across the diverse ecoregions of the southeastern United States.

Components and Consequences of Ecosystem Response to Climate Change

Although the analyses by Cartwright and Wolfe (2016) and Costanza and others (2016) employed different approaches and largely addressed different ecosystems, several key findings are common to both studies:

- Climate-change effects on ecosystems are likely to be driven by interactions of multiple processes at local to landscape scales. In addition to regional temperature increases and precipitation change, these processes may include local alterations of disturbance regimes, urbanization, contaminant release, local or regional hydrologic change, and altered interspecies interactions.
- Ecosystem responses to climate change have the potential to adversely affect species of conservation concern, especially rare and range-restricted species such as herbaceous plants **endemic** to insular ecosystems (see photos below).
- Ecosystem fragmentation—whether naturally occurring as in the case of ecological islands or an outcome of land-use change—is likely to degrade the adaptive capacities of ecosystems in response to climate stressors. Fragmentation increases the **dispersal** distances required for species migrations to newly suitable habitats in response to changing climate conditions and increases the potential for edge effects, such as encroachment by competitors and loss of core habitat for sensitive species.
- In many cases, current estimates of ecosystem exposure, sensitivity, and adaptive capacity to climate change are subject to high levels of uncertainty. In particular, differences in projected precipitation patterns across downscaled climate forecasts—combined with knowledge gaps concerning key hydrologic processes such as evapotranspiration and groundwater-surface water interaction—complicate efforts to predict ecosystem-level hydrologic change. In addition, information is lacking for many ecosystems on the relations between climate drivers and key interspecies interactions, such as pollination, food webs, and competition.
- Associations between biodiversity and particular landforms, such as rock outcrops and depression wetlands, highlight the value of conserving **geodiversity**.



Photographs A and C by Alan Cressler, U.S. Geological Survey, Photograph B by Irvine Wilson, Virginia Department of Conservation and Recreation, Photograph D by Nora Murdock, National Park Service.

A number of range-restricted species of conservation concern are endemic to the ecosystems analyzed by Cartwright and Wolfe (2016) and Costanza and others (2016), including, A, Pyne's ground plum (limestone cedar glades), B, Millboro leatherflower (mid-Appalachian shale barrens), C, Spreading avens (high-elevation outcrops of the southern Appalachian mountains), and D, Cumberland false rosemary (riverscour ecosystems on the Cumberland Plateau).

Research Priorities for Future Investigations

To effectively conserve biodiversity in the face of climate change, natural resource managers require timely and accurate predictions of ecological response at the level of whole ecosystems, not just individual species. To improve these predictions, Cartwright and Wolfe (2016) and Costanza and others (2016) proposed a set of research priorities to guide future investigations. In particular, hypothesis-driven empirical investigations are needed concerning (1) effects of hydrologic change on ecosystem function, (2) interactions between multiple types of biotic and abiotic change, for example increased soil temperature combined with increased drought frequency, (3) climatic determinants of interspecies interactions including potential for **phenological mismatch**, (4) climate-change effects on adaptive management options, for example changes in availability of suitable weather conditions for prescribed burning, and (5) effects of scale and spatial resolution on modeled forecasts of ecosystem change. Efforts to address these research priorities will ideally incorporate a variety of methods and approaches, including geospatial analysis, climate and vegetation modeling, literature synthesis, and expert opinion.

References Cited

- Cartwright, J.M., and Wolfe, W.J., 2016, Insular ecosystems of the southeastern United States—A regional synthesis to support biodiversity conservation in a changing climate: U.S. Geological Survey Professional Paper 1828, 162 p., <http://dx.doi.org/10.3133/pp1828>.
- Costanza, Jennifer, Beck, Scott, Pyne, Milo, Terando, Adam, Rubino, Matthew, White, Rickie, and Collazo, Jaime, 2016, Assessing climate-sensitive ecosystems in the southeastern United States: U.S. Geological Survey Open-File Report 2016–1073, 278 p., <http://dx.doi.org/10.3133/ofr20161073>.



Photograph by Alan Cressler, U.S. Geological Survey.

Wildfires and controlled burns are forms of disturbance that are vital to a number of ecosystems of the southeastern United States. The influence of climate change on disturbance dynamics is an important frontier of research.

Glossary

- adaptive capacity** The ability of species or populations to cope with climate change, such as through physiological changes, migration, or exploitation of new microhabitats.
- climate-change vulnerability** The susceptibility of an ecosystem to negative effects from changing climate conditions.
- dispersal** The movement of individual plants or animals or their reproductive structures from one geographic area to another.
- distribution** The spatial arrangement of a plant or animal species across a geographic area.
- disturbance** An event or series of events—such as fires or floods—producing intense environmental stress over a relatively short period of time.
- endemic** Primarily restricted to a particular ecosystem.
- exposure** The magnitude and rate of change in climate variables or sea level experienced by an ecosystem in the future.
- fragmentation** The degree to which an ecosystem is spatially divided into a greater number of small, isolated patches rather than one large, continuous habitat.
- geodiversity** diversity of landforms, topography, soil, and bedrock
- phenological mismatch** A disruption in an interspecies interaction, such as pollination, resulting from changes in phenology.
- phenology** The seasonal timing of life-cycle events, such as bud-burst or nesting.
- sensitivity** The degree to which the ecological integrity of an ecosystem depends upon climate conditions.

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