Final Report

SE CASC Project 028
Vital Futures: Conservation Adaptation Planning for Landscape and Climate Changes in the Southeast

1. ADMINISTRATIVE:

Report Date: 1 January 2020
Cooperative Agreement Number: G15AP00162
Principal Investigators:
Dr. Nils Peterson (Department of Forestry and Environmental Resources, North Carolina State University, 919-229-9519, nils_peterson@ncsu.edu)
Dr. Bruce Stein (Chief Scientist and Associate Vice President, NWF)
Dr. Kirstin Dow (Professor, USC Dept. of Geography; Director, Carolinas Integrated Sciences & Assessments [CISA])
Dr. John Kupfer (Professor and Chair, USC Dept. of Geography)
Dr. Kirsten Lackstrom (Research Associate, CISA)
Dr. Ross Meentemeyer (Professor, NCSU Dept. of Forestry and Environmental Resources)
Dr. Adam Terando (Research Ecologist, Southeast Climate Science Center)

Project fiscal contact:
Jeffrey M. Cheek
Associate Vice Chancellor, Research Administration/SPARCS
2701 Sullivan Drive, Admin Services III; Box 7514, Raleigh, NC 27695-7514
(919) 515-2444 - phone, (919) 515-7721 - fax
sps@ncsu.edu
Other cooperators and partners: Dr. Ryan Boyles; SE CASC staff
Project duration: 14 September 2015 – 1 December 2019
Total project funding requested from SECSC: $1,015,588
Actual total cost: $978,782.68

2. PUBLIC SUMMARY:

The Southeast is currently undergoing high rates of population growth, urbanization, and land use change while also experiencing climatic changes. These changes are threatening, and will continue to threaten, wildlife and their habitats. Most existing conservation programs and activities, however, focus on maintaining systems in their current condition, or returning them to a historic state, rather than enabling systems to adapt to projected changes. This project was designed to support the Southeast Conservation Adaptation Strategy (SECAS) effort in developing a collaborative network of conservation partners, shared conservation goals, and regional strategies to manage fish, wildlife, and other natural resources into the future. The project team conducted a detailed review and evaluation of southeastern State Wildlife Action Plans and determined that while states share a collective concern about the threat of climate change, adaptation strategies tended to be general and often vague, and

wildlife management goals tended to emphasize the persistence of species and habitats rather than managing for future system changes. We recommended a variety of steps to enhance cross-state and regional wildlife conservation that better accounts for future change. This included initiating a successful state-based effort to develop a list of Regional Species of Greatest Conservation Need (RSGCN). Future urban development, fire hazards, and climate shifts were mapped to demonstrate how these impact conservation goals and objectives with respect to plausible future scenarios of land and climate change impacts. Project products include reports on the assessment findings, RSGCN list, and content for the SE CASC Global Change Forum, and visualizations of scenarios of change in the Southeast.

3. TECHNICAL SUMMARY:

The overarching purpose of the Vital Futures Project was to provide scientific support for the Southeast Conservation Adaptation Strategy (SECAS), an ambitious state-federal initiative designed to develop and implement a collaborative vision for future-oriented wildlife conservation across the Southeast. The original project design included 3 goals: (1) assess conservation and resource management plans for existing goals and objectives, (2) evaluate existing goals and objectives with respect to scenarios of future climate and land change, and (3) facilitate development of climate-aligned goals, objectives, and strategies and develop principles and propositions for managing change in the Southeast. Goal one was met by conducting systematic thematic analysis of all State Wildlife Action Plans in the Southeast, and the final report is available on Science Base here: https://www.sciencebase.gov/catalog/item/5bf43d1fe4b045bfcae15da5. We coordinated a drill-down analysis focused on longleaf pine management plans, and the final publication in Journal of the Southeastern Association of Fish and Wildlife Agencies advanced regional conservation planning knowledge, and is available here: https://faculty.cnr.ncsu.edu/nilspeterson/wp-content/uploads/sites/17/2018/09/Clarketal151-168_SEAFWA_2018.pdf . We addressed goal two by mapping future impacts of urban development, fire hazards, and climate shifts to demonstrate how these impact conservation goals and objectives with respect to plausible future scenarios of land and climate change impacts. Maps and deliverable outcomes were published in the *International Journal of WIldlife Fire* and is available here: https://www.publish.csiro.au/wf/pdf/WF19198. Final project reports, data, and assessments of future change scenarios were linked on the SE CASC website, secasc.ncsu.edu, for open, one-stop access. We addressed goal three in multiple ways that were specifically aligned with the evolving nature and needs of the SECAS initiative. In 2015, we organized a facilitated workshop at Southeastern Association of Fish and Wildlife Agencies (SEAFWA) annual conference designed to solicit and craft climate-aligned goals, objectives, and strategies from state wildlife management agencies and their federal and non-governmental partners. We built on this effort through a multi-year participation in the monthly SECAS Lead Coordination Team, advising that body on integrating adaptation principles and propositions into the development of that regional initiative. This included organization of a project symposium ("Peering into the Future") at the 2017 SEAFWA annual conference to present on details of project analyses and studies, and outline potential future directions for climate-informed conservation in the region. We collaborated on an additional drill-down assessment, with the Florida Fish and Wildlife Conservation Commission and U.S. Fish and Wildlife Service, that focused on identifying adaptation options for listed endangered species in the

Florida Keys. Scientific support for SECAS continued in 2018 with the initiation of a Regional Species of Greatest Conservation Need assessment, a process that was viewed as a high priority for promoting cross-state and regional conservation, and which was formally adopted by SEAFWA Wildlife Diversity Committee for full implementation. The project concluded with a symposium at the 2019 SEAFWA conference that reported on the successful completion of the RSGCN process and a summary of other Vital Futures project results.

4. PURPOSE AND OBJECTIVES:

This project addressed the broad issue of conservation planning in the face of global change in the Southeast region. The project primarily served the wildlife conservation and forest management communities. We focused on working with state wildlife agencies in the context of the Southeast Conservation Adaptation Strategy (SECAS), including to help them refine goals and objectives for addressing climate change in their wildlife conservation planning and action. Because of evolution in the organization and needs of the SECAS initiative over the duration of the project (4+ years), we adaptively managed our work to ensure that it continued to be responsive to and meet the needs of the SECAS initiative and its state, federal, and non-governmental partners. This necessitated minor shifts relative to the original research proposal (submitted in 2014), but the three primary goals – (1) assess conservation and resource management plans for existing goals and objectives, (2) evaluate existing goals and objectives with respect to scenarios of future climate and land change, and (3) facilitate development of climate-aligned goals, objectives, and strategies – did not change. The minor changes centered on conducting two detailed case studies (longleaf pine management and Florida Keys adaptation options) rather than three, and adding the Regional Species of Greatest Conservation Need assessment component to the project. These changes were responsive to input from the project advisory board, from project stakeholders engaged through the SWAP analysis and project SEAFWA workshops, and particularly from SECAS initiative leadership and partners.

5. PROJECT COMPONENT APPROACHES, ANALYSIS, RESULTS, AND FINDINGS:

Because of the breadth and scope of the Vital Futures project, below we offer an integrated discussion of "organization and approach", "project results", and "analysis and findings" for each of the following four project components: Climate Analysis of SE State Wildlife Action Plans; Case Studies (Longleaf Pine and Florida Keys); Projections of Future Change; and Regional Species of Greatest Conservation Need.

<u>Climate Analysis of SE State Wildlife Action Plans</u>

To assess how climate change was incorporated into the 17 State Wildlife Action Plans (SWAP) that cover the SEAFWA region, the project team developed an overarching conceptual framework based on a modified version of the "climate-smart conservation" planning framework, along with a series of questions that addressed the full range of opportunities for incorporating climate change into the plans. The team conducted a detailed and structured document review, coding, and analysis, which allowed for comparison across plans. The team then carried out a series of structured interviews with SWAP coordinators and/or other staff involved in the plan development to validate our interpretations and draft findings. The approach, results, and findings were published in a comprehensive 39-page

document (Lackstrom et al. 2018, "Climate Change and Conservation in the Southeast: A Review of State Wildlife Action Plans") as well as in a 4-page "Report Summary".
Results/Findings: Based on our analysis of the plans and follow-up interviews, we identified several "key observations", including that: states applied a diversity of climate-related planning approaches; there was minimal interstate and regional collaboration; states share a collective concern about the threat of climate change; adaptation strategies tend to be general and vague; goals tend to emphasize persistence rather than managing for future change; and there is broad support for climate-informed monitoring and evaluation. Based on those key observations, the project team developed a series of recommendations for state wildlife agencies to use in their 2020 plan revisions, including: enhance collaborative planning by drawing on regional resources/expertise; advance the application of state and regional impact and vulnerability assessments; facilitate development of adaptation strategies; foster adoption of climate-informed goals; and enhance monitoring and evaluation efforts

Two detailed case studies were carried out as part of the project, one which focused on an analysis of climate change in regional plans relevant to longleaf pine conservation and restoration, and another that used a workshop-based approach to identify adaptation strategies for federally listed endangered species in the Florida Keys.

Longleaf Pine Case Study
Longleaf pine (LLP, *Pinus palustris*) has been reduced to 3-5% of its original range, but may be particularly resilient to conditions associated with climate change including drought, severe storms, and increased prevalence of pests. Despite the critical role of LLP in building climate resilient ecosystems, little is known about how landscape managers in the region have considered climate change in planning efforts. We gathered 79 publicly accessible natural resource management plans from the southeastern United States that included management of LLP ecosystems between 1999 and 2016. We used document analysis to identify how plans addressed climate change threats on LLP, considered climate change in identification of LLP ecosystems and linked climate change to planned conservation actions for LLP ecosystems. Newer plans and plans from state agencies tended to include greater consideration of climate change than older plans, federal plans, and those developed by nongovernmental organizations (NGO) or Joint Venture partnerships. Additionally, state wildlife action plans and forest action plans tended to score higher than other types of plans, such as plans from the Department of Defense, U.S. Forest Service and NGOs. Considering climate vulnerability in planning efforts of LLP ecosystems is an opportunity because LLP represents a hopeful context for conserving vulnerable wildlife species as ecosystems adapt and evolve. Limited consideration of climate change as a criterion for identifying or evaluating LLP ecosystems may result from climate discourse focusing on negative outcomes versus positive outcomes. Improvement in the plans over time may reflect increased application of best practices and planning tools in natural resource planning, and specific climate-related mandates for some planning processes. A stronger focus on climate change in longleaf pine community restoration may help forest managers promote sustainable forests in the southeastern United States. The approach, results, and findings were published in a comprehensive manuscript in the Journal of the Southeastern Association of Fish and Wildlife Agencies

(https://faculty.cnr.ncsu.edu/nilspeterson/wp-content/uploads/sites/17/2018/09/Clarketal151-168_SEAFWA_2018.pdf).

Florida Keys Adaptation Case Study

Approach: The Florida Keys case study used a series of structured expert and stakeholder workshops, to assess the future exposure and vulnerability of listed species in the Florida Keys to different scenarios of sea level rise and identify adaptation/management options that might be capable of reducing those risks and enhancing the viability of the species or populations. The Vital Futures project contributed technical expertise on adaptation planning to the first of those workshops, and was a part of the workshop design committee for a subsequent workshop on identifying and overcoming barriers to adaptation implementation. This workshop adopted a modified STAPLEE framework (originally developed by FEMA, and consisting of the following: social, technical, administrative, political, legal, economic, and environmental) to assess barriers, and assessing barriers to implementation, and used MeetingSphere technology to allow participants to score and comment on adaptation options and rank perceived barriers.

Results/Findings: A project report (Benedict et al., 2018) prepared by the Florida Fish and Wildlife Conservation Commission summarizes the key results, including: most focal species will lose 90% or more of their current range in a 2' sea level rise scenario; feral cats pose a more immediate threat for small mammals and ground-nesting birds in the Florida Keys than climate change; for many species there are no good long-term solutions for survival within the Florida Keys. The results of the "barriers" workshop consisted of species-specific discussions of adaptation actions (e.g., lower Keys marsh rabbit, Miami blue butterfly), barriers to implementing them, and methodologies to overcome those barriers. The workshop highlighted the many and varied challenges (biological, legal, social) to adopting and carrying out innovative and novel adaptation strategies that focus on future conditions and managing for change.

Future Change Projections

Approach: The calculation of climate velocity requires input values for a: 1) spatial gradient, which represents the 'complexity' of the climate landscape, and 2) temporal gradient, which captures the rate of change of a variable (e.g., temperature) through time. The spatial gradient was defined using the 30 year normal mean values of a climate variable (e.g., winter minimum temperature) from 1981-2010 from the PRISM dataset. Our study area included the entire Southeast within the continental footprint of SECAS, and all analyses were performed using an 800 m spatial resolution. For the temporal gradient, we used statistically downscaled GCM projections from the MACAv2-METDATA dataset (https://climate.northwestknowledge.net/MACA/), which downscales GCMs from the Coupled Model Intercomparison Project 5 (CMIP5) utilizing a modification of the Multivariate Adaptive Constructed Analogs (MACA) method. We downloaded data for 12 GCMs to use in our calculations (Table 1). For each GCM, we used the downscaled climate model output for two greenhouse gas emissions scenarios or Representative Concentration Pathways (RCPs): RCP 8.5, which represents a higher emissions pathway and often serves as a scenario that does not include any specific emissions reduction target, and RCP 4.5, a lower emissions scenario that assumes reductions that stabilize emissions, atmospheric greenhouse gas concentrations and radiative forcing of the climate system.

Comparing the results from multiple scenarios is important because of the uncertainty involved as climates are projected farther ahead in time. We mapped climate velocity for two climate variables (winter minimum temperature and summer maximum temperature) for the period from 2006 to 2065. The projections contained in our datasets are the multi-model means for all GCM's under either RCP 4.5 or RCP 8.5.

Results/Findings: **T**he following datasets / coverages from climate velocity modeling were uploaded into Science Base (https://www.sciencebase.gov/catalog/item/5cfc103fe4b0312686a7f64b).

Spatial gradient
Winter minimum temperature
Summer maximum temperature

Temporal gradient
Winter minimum temperature, RCP 4.5
Winter minimum temperature, RCP 4.5
Summer maximum temperature, RCP 8.5
Summer maximum temperature, RCP 8.5

Climate velocity
Winter minimum temperature, RCP 4.5
Winter minimum temperature, RCP 4.5
Summer maximum temperature, RCP 8.5
Summer maximum temperature, RCP 8.5

It is important to note that in the time since we performed these calculations, alternative (and generally better) methods for calculating climate velocity have been developed, and multiple sources now exist for directly downloading climate velocity data for areas of interest. Users should consider, for example, the Dryad dataset, which is freely available from: https://doi.org/10.5061/dryad.q8d7d: https://datadryad.org/stash/dataset/doi:10.5061/dryad.q8d7d. There are also now algorithms available in R, MATLAB, and Python for calculating climate velocity and associated climate metrics given appropriate datasets.

More detailed results are available in Appendix 1.

Longleaf Prescribed Fire Management

Approach: Prescribed burning is a critical tool for managing wildfire and protecting wildlife, but requires specific meteorological criteria (a 'burn window') to be met. We evaluated the impacts of climatic change on burn windows in the southeastern United States by modeling temperature, relative humidity and wind speed in relation to projections from an ensemble of Global Climate Models under different greenhouse gas emission scenarios.

Results/Findings: The percentage of days when burning was possible did not change during winder but decreases in summer largely due to rising temperatures. These results suggest seasonal shifts in burning from summer to cool-season burns will be required. Additional details are available in a project supported publication available at: https://www.publish.csiro.au/wf/pdf/WF19198. These results also supported initiation of another research project focused on how stakeholders perceive risks to prescribed fire as a management tool. This follow up study is using surveys to elicit information on criteria for prioritizing burn sites,current burning practices and constraints, expectations for future constraints, with an emphasis on perceptions related to urbanization and climate change.

<u>Regional Species of Greatest Conservation Need</u>

Approach: To develop a list of Regional Species of Greatest Conservation Need, the project team worked together with Terwilliger Associates (who provided technical support for a similar effort in the Northeast) to develop a proposed assessment framework, which included three basic criteria: a) level of conservation concern (i.e., extinction risk); b) regional stewardship responsibility (i.e., importance of the Southeast in conservation of the species); and c) biological or ecological significance (e.g., unique evolutionary lineages). This framework was presented to the SEAFWA Wildlife Diversity Committee to gain their buy-in and endorsement of the initiative, as well as refinement in the framework based on state perspectives. The Vital Futures team was successful in getting WDC endorsement, which included a commitment of state agency experts to participate in the RSGCN assessment process on various "taxa teams," as well as the commitment of additional financial resources to fully implement the assessment. More than 100 scientific experts from across the region engaged in the taxa teams, which covered vertebrates (mammals, birds, reptiles, amphibians, and fishes) as well as several better known groups of invertebrate animals (freshwater mussels, crayfish, and bumblebees). These teams reviewed existing information (published literature, unpublished data, and personal knowledge) and evaluated the full set of SGCN species against the established criteria to identify the subset that were flagged as RSGCNs. In addition, the teams characterized the level of conservation concern for each RSGCN, ranging from moderate, high, and very high concern.
Results/Findings: Of the approximately 6,700 Species of Greatest Conservation Need, nearly 2,100 SGCN were evaluated. Of that, 960 species met the RSGCN criteria. Nearly one-third of the RSGCN were considered Very High Concern, 44% High Concern, and the remaining 25% were Moderate Concern. Not surprisingly, the RSGCN list has large numbers of aquatic species. Freshwater fish, with 281 species, represent the group with the greatest number of regional priority species, followed by crayfish (172) and freshwater mussels (136). Together these three groups of aquatic organisms represent nearly two-thirds (61%) and if amphibians are included, many of which depend on freshwater habitats, the proportion of aquatic species on the regional priority list rises to 72%. More than half (55%) of regional priority species are shared by three or more states, and are therefore prime targets for cross-state conservation collaborations. The remaining 45% of species have narrow ranges, being found in just one or two states. Not surprisingly, a greater proportion of narrow-range species are of "very high concern" than more broadly distributed species (43% vs. 20%). The full list of RSGCNs is available here: https://airtable.com/shrDBqYvc0WlUIfh7.

8. CONCLUSIONS AND RECOMMENDATIONS:

One general challenge involved the fact that many of the states do not actively and explicitly discuss and consider "climate change" – while we found many staffers who were interested in or working toward addressing climate change, the political-social environment can inhibit open discussion about the issue. This was revealed in the documents as well as in interviewee comments (particularly those who did not want to be cited for the report). This feeds into recommended next steps – mechanisms and resources to support regional coordination and dialogue (v. individual states going it alone) may help to make climate conversations and adaptations more palatable. There is a need for resources to enhance monitoring and evaluation of climate impacts, as well as conservation strategies and actions. This type of information will help to improve understanding of (climate-related) ecological thresholds and tipping points and the factors that contribute to favorable (or unfavorable) conservation outcomes.

9. MANAGEMENT APPLICATIONS AND PRODUCTS:
This project was designed specifically to inform wildlife management and conservation decisions in the Southeast, both through the broader SECAS initiative and through working with individual state fish and wildlife agencies across the region.

Climate Analysis of State Wildlife Action Plans. Our review of southeastern Wildlife Action Plans ("Climate Change and Conservation in the Southeast: A Review of State Wildlife Action Plans") was designed to inform how state wildlife agencies conceive of and develop the 2025 revisions of those plans. In analyzing how climate was integrated into the wildlife action plans, the project team had direct interactions with the state agency staff most directly involved in planning and developing of the 2015 version of the plans. This resulted in developing a series of recommendations for states to consider in their 2025 revisions. The evaluation and recommendations were also presented at the Spring 2019 meeting of the Association of Fish and Wildlife Agency's Climate Change Committee.

Florida Keys Adaptation Case Study. This study was carried out in collaboration with the Florida Fish and Wildlife Conservation Commission and U.S. Fish and Wildlife Service, which have direct management responsibilities for listed species in the Keys. Additionally, the structured workshops engaged a variety of other land and resource management agencies, as well as local planners and other decision makers from Monroe County.

Regional Species of Greatest Conservation Need. The development of a list of RSGCNs is also designed to have a direct effect on wildlife conservation planning decisions being made by state and federal agencies. By winnowing down the list of overall SGCNs across the region from more than 6,700 species to a far more manageable 960 species, this list is already being used to refine the SECAS blueprint and target conservation investments being made at the state and federal levels. The value that managers put in the RSGCN process is indicated by the level of engagement and commitment made by the state agencies – with more than 100 state agency staff from across the region serving on assessment "taxa review teams." Additionally, Vital Futures investments in the assessment process were matched by financial contributions from the US Fish and Wildlife Service as well as individual state agencies, including the Tennessee Division of Wildlife Resources. This final list of RSGCNs is now available for use online and is being hosted by the Georgia Department of Natural Resources on behalf of the SEAFWA WDC. Based on the success of this effort, the midwestern fish and wildlife agencies are working to launch a similar effort, which would be complementary to the Southeast and Northeast RSGCN listings.

Quote from stakeholder in the project: "The RSGCN project led to a product that will greatly facilitate conservation in the Southeast. It will inform the annual work plan of the SEAFWA Wildlife

Diversity Committee, guide state actions related to listed and petitioned species, help states identify shared conservation priorities and opportunities, and support the development of competitive multistate grants.   This prioritized species list is an important component of the Southeast Conservation Adaptation Strategy." Dr. Jonathan Ambrose, Chief of Wildlife Conservation, Wildlife Resources Division, Georgia Department of Natural Resources.

Jonathan Ambrose, Ph.D.
Chief, Wildlife Conservation
Wildlife Resources Division
(706) 557-3301 | M: (404) 291-8196
Facebook • Twitter • Instagram
Check out our Biodiversity Data Portal!

A division of the
GEORGIA DEPARTMENT OF NATURAL RESOURCES

10. OUTREACH:
Results have been communicated to managers, decision-makers, and the public through research articles, conference presentations, webinars to the SECAS Governance group ………………
The plan evaluation tool, evaluation scores, and publications are publically available in the USGS Repository and on the NCASC Science Base. Work completed for this project contributed to a master's thesis, and doctoral dissertation; these documents are available through the NCSU Electronic Thesis and Dissertation Repository (https://repository.lib.ncsu.edu/bitstream/handle/1840.20/34877/etd.pdf?sequence=1&isAllowed=y), and USC (https://scholarcommons.sc.edu/cgi/viewcontent.cgi?article=6389&context=etd). A list of the types of outreach we conducted as part of this project is below.

Conference Sessions and Workshops

- 2015 SEAFWA Annual Conference, Vital Futures Stakeholder Engagement Workshop,   (Nov. 4, 2015)
- SECAS Leadership Planning Workshop (Jan 7-8, 2016)
- 2016 SEAFWA Annual Conference, SECAS Summit. Stein presentation of high-level Vital Futures project findings (Baton Rouge, LA)
- 2016 SEAFWA Annual Conference. Terando presentation of climate velocity findings.
- National Adaptation Forum. NWF organized symposium: "When Resistance is Futile: Adaptation in the Face of System Transformation" (Minneapolis, MN, May 8, 2017)
- 2017 SEAFWA Conference. Vital Futures Symposium: Peering into the Future (Louisville, KY, Oct. 31, 2017)
- Poster presentation at International Symposium on Society and Resource Management in June 2017, Umeå, Sweden. Poster titled, "Evaluating Climate Change Planning for Longleaf Pine Ecosystems and Wildlife Conservation in the Southeast United States". Authors: Kalysha Clark, Erika Chin, Nils Peterson, Kirstin Dow, Kirsten Lackstrom, and Fred Cubbage.

- Florida Keys Terrestrial Climate Adaptation Workshop (February 28 – March 1, 2017), hosted by Florida Fish and Wildlife Conservation Commission. Stein presentation on "Principles and Propositions for Climate Adaptation in the Florida Keys."
- Overcoming Barriers to Climate Adaptation Implementation and Managing for Change, Orlando, FL (June 12-13, 2018) - Vital Futures/NWF co-sponsor of workshop with Florida Fish and Wildlife Conservation Commission.
- Climate Adaptation Training for Florida Fish and Wildlife Conservation Commission, Live Oaks, FL (January 24-25, 2018) collaboration of US Fish and Wildlife Service, Wildlife Conservation Society, and National Wildlife Federation.
- 2019 North American Wildlife Conference. Briefing on Vital Futures wildlife action plan evaluation and RSGCN work to AFWA Climate Change Committee (Denver, CO, March 7, 2019).
- 2019 SE Climate Adaptation Science Center Regional Science Conference, SECAS Symposium. Stein presentation on Vital Futures Project (New Orleans, LA, Nov. 13, 2019).
- October 2019 Blog Post on SECAS website announcing availability of Regional Species of Greatest Conservation list, also re-posted on SE CASC website; reposted on SE CASC website.

Publications

Benedict, L., Glazer, B., Bergh, C., Stys, B., and J. Evans. Florida Keys case study on incorporating climate change considerations into conservation planning and actions for threatened and endangered species. Project Report for USFWS Cooperative Agreement F16AC01213. 152 p.

Clark, K. E., E. Chin, M. N. Peterson, K. Lackstrom, K. Dow, M. Foster, and F. Cubbage. (2018). Evaluating Climate Change Planning for Longleaf Pine Ecosystems in the Southeast United States. Journal of the Southeastern Association of Fish and Wildlife Agencies 5: 151–168.

Foster, M., Peterson, M. N., Cubbage, F., & McMahon, G. (2019). Evaluating natural resource planning for longleaf pine ecosystems in the Southeast United States. Forest Policy and Economics, 100, 142-153.

Kupfer John A., Terando Adam J., Gao Peng, Teske Casey, Hiers J. Kevin (2020) Climate change projected to reduce prescribed burning opportunities in the south-eastern United States. *International Journal of Wildland Fire* 29, 764-778.

Lackstrom, K., P. Glick, K. Dow, B.A. Stein, M.N. Peterson, E. Chin, and K. Clark. 2018. Climate Change and Conservation in the Southeast: A Review of State Wildlife Action Plans. Raleigh, NC: National Wildlife Federation, University of South Carolina, North Carolina State University.

Lackstrom, K., P. Glick, K. Dow, B.A. Stein, M.N. Peterson, E. Chin, and K. Clark. 2018. Climate Change and Conservation in the Southeast: A Review of State Wildlife Action Plans. Report Summary. Raleigh, NC: National Wildlife Federation, University of South Carolina, North Carolina State University.

Appendix 1. Climate Velocity Summary for Vital Futures: Conservation Adaptation Planning for Landscape and Climate Changes in the Southeast

Dr. John Kupfer, Department of Geography, University of South Carolina

The Vital Futures project was designed to support the development of the Southeastern Conservation Adaptation Strategy (SECAS) by assessing the implications of climate change and other drivers of landscape change for existing conservation goals and management objectives. Many of the concerns regarding the future of species and ecosystems in the Southeast stem from the high rates of population growth, urbanization, and land use change that the region is expected to see over the remainder of the 21st century. Such changes will be taking place at a time when the region is also expected to experience significant shifts in climate patterns; the interactions of these various changes are expected to pose serious challenges for threatened species, wildlife communities, and habitats. Many existing conservation plans, programs, and activities focus on protecting and managing systems to maintain their current state or return to a desired, historic state. With large, landscape-scale transformations already occurring, adaptive conservation strategies that can account for changing conditions are needed along with tools and approaches for synthesizing the interactive impacts of various stressors on species and habitats of concern.

Ecological responses to climate change are numerous, complex, and multifaceted. From the perspective of identifying and addressing future conservation goals and management objectives, it is important to understand how climate changes affect the occurrence of suitable conditions for species. As climate changes, the current distribution of conditions will be rearranged, with some climates disappearing entirely and new climates with no current analog emerging (e.g., Williams et al 2007). For species to survive, they must be able to keep pace with the 'movement' of climates. Such responses have occurred throughout geological time (e.g., range adjustments following the end of the Pleistocene), but the rate at which climate is changing and is projected to change in upcoming decades is thought to be unprecedented within Earth's recent past. Further, understanding the processes that underpin range shifts and predicting their potential outcomes is not only necessary to inform conservation plans; it is crucial for helping to reduce risks to food security, human health, and the viability of numerous industries that depend on ecosystem services, including forestry, fisheries, and ecotourism (Brito-Morales et al. 2018).

Responses of biodiversity to climate change have traditionally been quantified using transfer functions and correlative approaches and by modeling rates of warming or cooling (e.g., temperature anomalies: e.g., Parmesan 2006). What these simple indices do not convey is the *relative likelihood* that a species might escape the threat of climate change by shifting its distribution. A promising solution that retains generality, but conveys more ecologically relevant information, is the velocity of climate change or, more simply, climate velocity (e.g., Ordonez and Williams 2013; Dobrowski and Parks 2016). Climate velocity has emerged in the last decade as a common tool in assessing the vulnerability of species and protected areas to climate change and as a means for guiding conservation and management (e.g., Hamann et al 2014; Carroll et al. 2015; Heikkinen et al. 2020).

Climate Velocity

As initially conceptualized, climate velocity is a vector that describes the speed and direction that a point on a gridded map would need to move to remain static in climate under climate change (Loarie et al. 2009). From an ecological perspective, climate velocity can be conceptualized as the speed and direction in which a species would need to move to maintain its current climate conditions under climate change (Brito-Morales et al. 2018). For this reason, climate velocity can be considered to represent the potential exposure to climate change faced by a species if the climate moves beyond the physiological tolerance of a local population. It is, nonetheless, important to bear in mind that climate velocity is based solely on environmental variables, not on species data (Fig. 1).

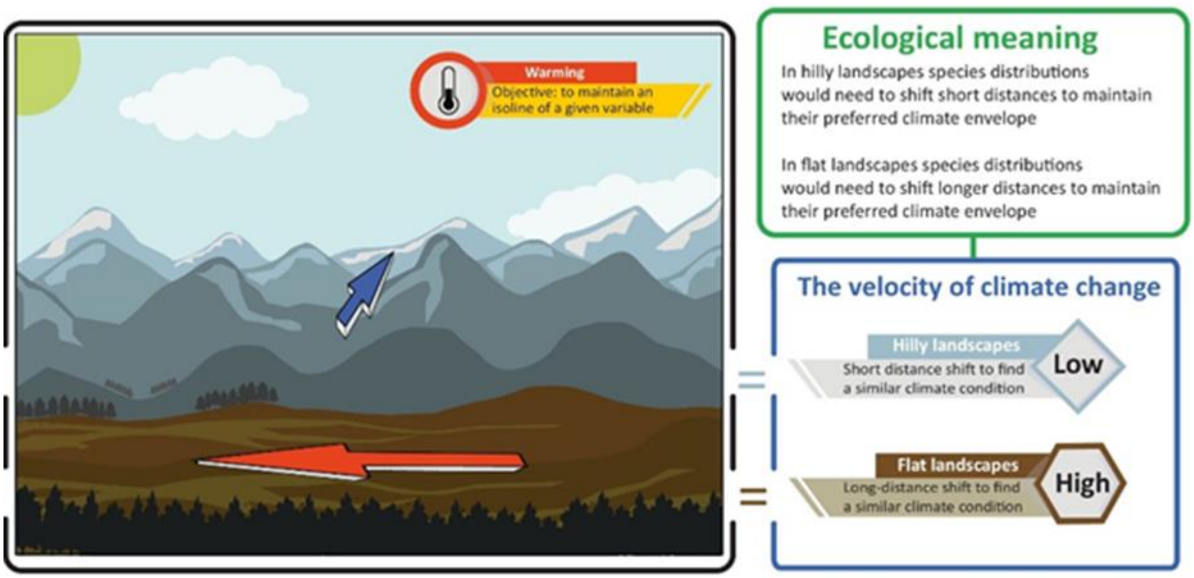


Figure 1. Understanding climate velocity and its associated ecological meaning (modified from Brito-Morales et al. 2018).

Computationally, two approaches to calculating climate velocity have emerged: local climate velocity and climate-analog velocity (Figure 2). In this project, we used local climate velocity as originally proposed by Loarie et al. (2009). This approach has been favored by ecologists when where there is a small number of main variables driving ecological change and response, so that local climate velocity can be constrained by species requirements for particular habitat features. A concise and useful summary of this method is provided by Brito-Morales et al. (2018: 442):

"To calculate local climate velocity at a location – how far and in which direction the isoline of an environmental variable would move – only the rate of change of a variable (e.g., temperature) through time (i.e., the trend, usually estimated as the regression slope) and the corresponding spatial gradient of that variable are needed. The spatial gradient represents the complexity of the climate landscape – its magnitude calculated as the length of a vector resulting from the weighted sum of the latitudinal and longitudinal pairwise differences in values of the climate variable between a focal cell and its nearest neighbors. The associated angle of the vector gives the direction of the spatial gradient. Directions of climate velocity are reversed relative to those of the spatial gradient to reflect response expectations (e.g., in a warming climate, movement towards cooler locations). It is this dependence on neighboring (local) cells for the estimation of the spatial gradient in climate that gives local climate velocity its name."

Climate-analog velocity considers the distance between points at a particular point in time and their future climate analogs, divided by the time difference. This can be calculated as either forward analog velocity, which is the straight-line speed and direction required to reach a given climate-analog destination at some point in the future (usually a single destination for any origin under consideration), or backward analog velocity, which considers a destination and asks which points (usually several) of origin might eventually feed into the destination (Brito-Morales et al. 2018). This approach lends itself to greater ecological realism in complex environments with contrasting climatic gradients and is favored by ecologists dealing with species whose ranges are controlled by a mix of interacting environmental factors (e.g., Barber et al. 2016). More details on these methods can be found in Ordonez and Williams (2013).

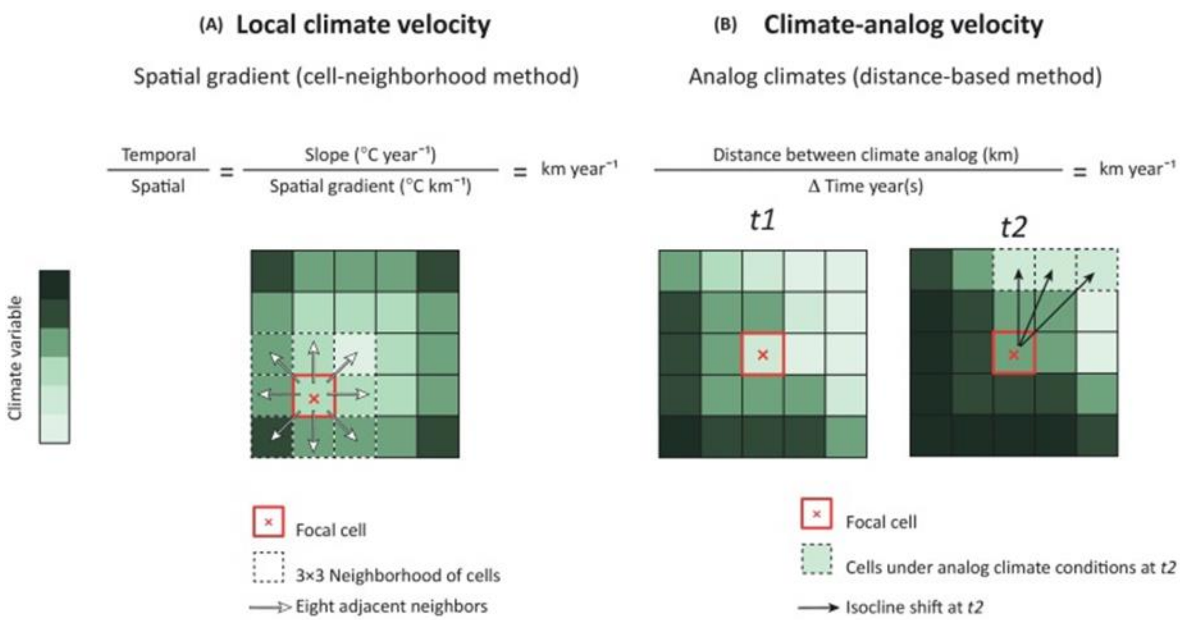


Figure 2. Mathematical and graphical differences between (A) local climate velocity, and (B) climate-analog velocity (from Brito-Morales et al. 2018).

Table 1. GCMs used in climate velocity ensemble

Model Name	Model Country	Model Agency	Atmosphere Resolution (Lon x Lat)
bcc-csm1-1-m	China	Beijing Climate Center, China Meteorological Administration	1.12° x 1.12°
BNU-ESM	China	College of Global Change and Earth System Science, Beijing Normal University, China	2.8° x 2.8°
CanESM2	Canada	Canadian Centre for Climate Modeling and Analysis	2.8° x 2.8°
CCSM4	USA	National Center of Atmospheric Research, USA	1.25° x 0.94°
CNRM-CM5	France	National Centre of Meteorological Research, France	1.4° x 1.4°
GFDL-ESM2G	USA	NOAA Geophysical Fluid Dynamics Laboratory, USA	2.5° x 2.0°
HadGEM2-ES	UK	Met Office Hadley Center, UK	1.88° x 1.25°
inmcm4	Russia	Institute for Numerical Mathematics, Russia	2.0° x 1.5°
IPSL-CM5A-MR	France	Institut Pierre Simon Laplace, France	2.5° x 1.25°
MIROC-ESM-CHEM	Japan	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	2.8° x 2.8°
MRI-CGCM3	Japan	Meteorological Research Institute, Japan	1.1° x 1.1°
NorESM1-M	Norway	Norwegian Climate Center, Norway	2.5° x 1.9°

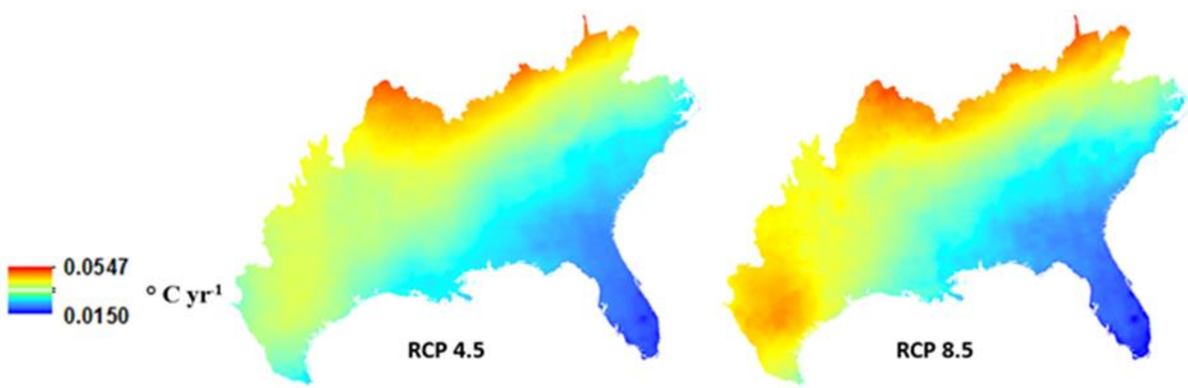


Figure 3. Temporal gradient of winter minimum temperature used to calculate climate velocity for the study area. The results demonstrate that the temporal gradient is greatest along the northern edge of the SECAS area and decreases to the south and east.

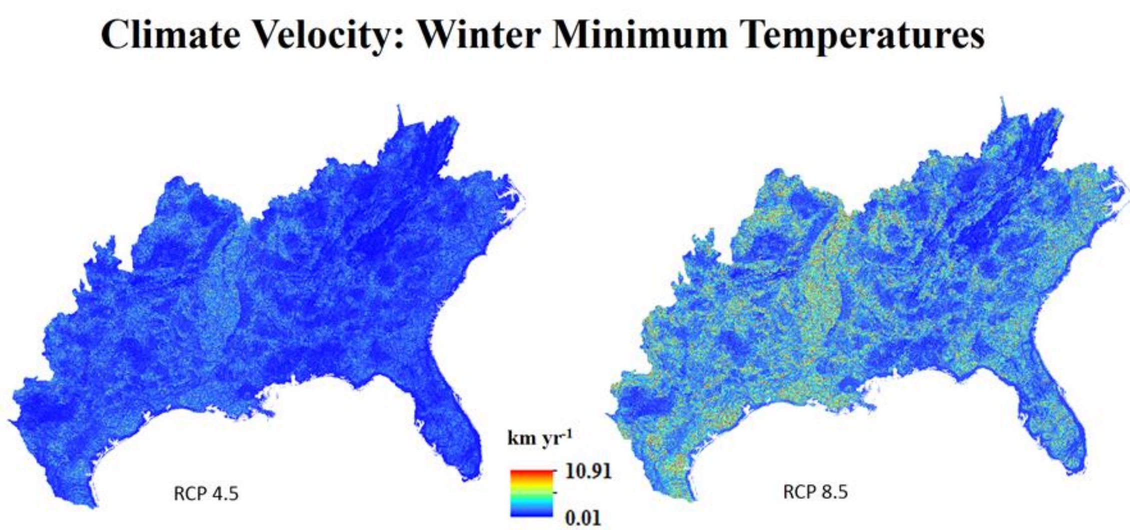
Climate Velocity and Southeastern Climate Change

The calculation of climate velocity requires input values for a: 1) spatial gradient, which represents the 'complexity' of the climate landscape, and 2) temporal gradient, which captures the rate of change of a variable (e.g., temperature) through time.

The spatial gradient was defined using the 30 year normal mean values of a climate variable (e.g., winter minimum temperature) from 1981-2010 from the PRISM dataset. Our study area included the entire Southeast within the continental footprint of SECAS, and all analyses were performed using an 800 m spatial resolution.

For the temporal gradient, we used statistically downscaled GCM projections from the MACAv2-METDATA dataset (https://climate.northwestknowledge.net/MACA/), which downscales GCMs from the Coupled Model Intercomparison Project 5 (CMIP5: Taylor et al. 2012) utilizing a modification of the Multivariate Adaptive Constructed Analogs (MACA) method. We downloaded data for 12 GCMs to use in our calculations (Table 1). For each GCM, we used the downscaled climate model output for two greenhouse gas emissions scenarios or Representative Concentration Pathways (RCPs): RCP 8.5, which represents a higher emissions pathway and often serves as a scenario that does not include any specific emissions reduction target, and RCP 4.5, a lower emissions scenario that assumes reductions that stabilize emissions, atmospheric greenhouse gas concentrations and radiative forcing of the climate system. Comparing the results from multiple scenarios is important because of the uncertainty involved as climates are projected farther ahead in time (e.g. Hawkins and Sutton 2009).

Using the method described by Loarie et al. (2009), we mapped climate velocity for two climate variables (winter minimum temperature and summer maximum temperature) for the period from 2006 to 2065. The projections contained in our datasets are the multi-model means for all GCM's under either RCP 4.5 or RCP 8.5. Sample output from these analyses is included below (Fig. 4.)



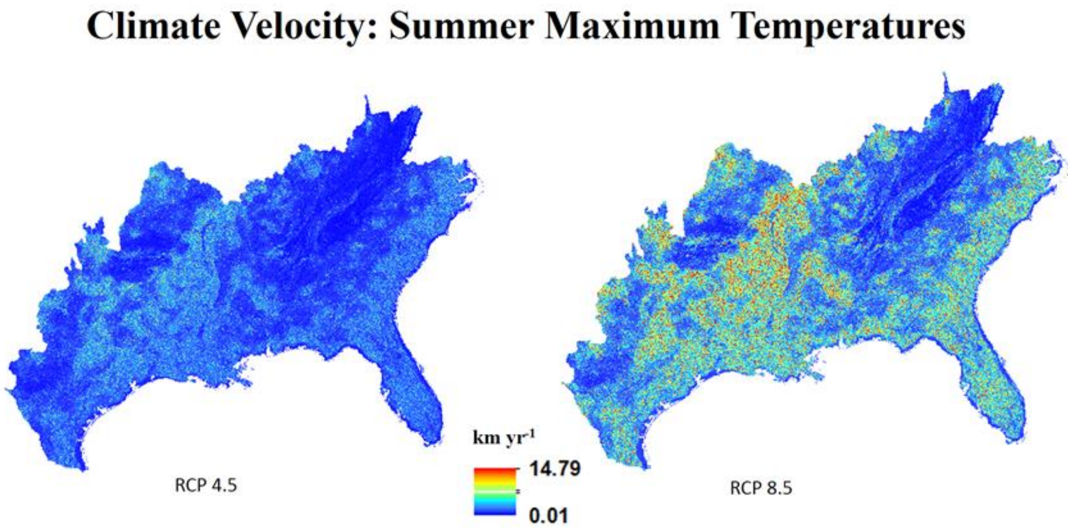


Figure 4. Climate velocity (km yr^{-1}) for two variables under two representative concentration pathways.

Deliverables

Included with this report are the following datasets / coverages:
Spatial gradient
Winter minimum temperature
Summer maximum temperature

Temporal gradient
Winter minimum temperature, RCP 4.5
Winter minimum temperature, RCP 4.5
Summer maximum temperature, RCP 8.5
Summer maximum temperature, RCP 8.5

Climate velocity
Winter minimum temperature, RCP 4.5
Winter minimum temperature, RCP 4.5
Summer maximum temperature, RCP 8.5
Summer maximum temperature, RCP 8.5

It is important to note that in the time since we performed these calculations, alternative (and generally better) methods for calculating climate velocity have been developed, and multiple sources now exist for directly downloading climate velocity data for areas of interest (e.g., Adaptwest Project 2015). Users should consider, for example, the Dryad dataset (Carroll et al. 2016), which is freely available from: https://doi.org/10.5061/dryad.q8d7d: https://datadryad.org/stash/dataset/doi:10.5061/dryad.q8d7d. There are also now algorithms available in R, MATLAB, and Python for calculating climate velocity and associated climate metrics given appropriate datasets (e.g. García Molinos et al. 2019).

References

AdaptWest Project. 2015. Gridded climatic velocity data for North America at 1km resolution. Available at adaptwest.databasin.org.

Barber, Q.E., Nielsen, S.E. and Hamann, A. 2016. Assessing the vulnerability of rare plants using climate change velocity, habitat connectivity, and dispersal ability: a case study in Alberta, Canada. *Regional Environmental Change* 16: 1433–1441.

Brito-Morales, I., García Molinos, J., Schoeman, D.S., Burrows, M.T., Poloczanska, E.S., Brown, C.J., Ferrier, S., Harwood, T.D., Klein, C.J., McDonald-Madden, E., Moore, P.J., Pandolfi, J.M.. Watson, J.E.M., Wenger, A.S., and Richardson, A.J. 2018. Climate velocity can inform conservation in a warming world. *Trends in Ecology & Evolution* 33: 441-457.

Carroll, C., Lawler, J.J., Roberts, D.R., and Hamann, A. 2015. Biotic and climatic velocity identify contrasting areas of vulnerability to climate change. PLOS ONE 10(10): e0140486.

Carroll, C., Lawler, J.J., Roberts, D.R., and Hamann, A. 2016. Data from: Biotic and climatic velocity identify contrasting areas of vulnerability to climate change, Dryad, Dataset. https://doi.org/10.5061/dryad.q8d7d

Dobrowski, S.Z. and Parks, S.A. 2016. Climate change velocity underestimates climate change exposure in mountainous regions. Nature Communications 7: 12349.

García Molinos, J., Schoeman, D.S., Brown, C.J., and Burrows, M.T. 2019. VoCC: An r package for calculating the velocity of climate change and related climatic metrics. Methods in Ecology and Evolution 2019; 00:1-8.

Hamann, A., Roberts, D.R., Barber, Q.E., Carroll, C. and Nielsen, S.E. 2014. Velocity of climate change algorithms for guiding conservation and management. *Global Change Biology* 21:997–1004.

Hawkins E. and Sutton, R. 2009 The potential to narrow uncertainty in regional climate predictions. *Bulletin of the American Meteorological Society* 90: 1095–1107.

Heikkinen, R.K., Leikola, N., Aalto, J., Aapala, K., Kuusela, S., Luoto, M. and Virkkala, R. 2020. Fine-grained climate velocities reveal vulnerability of protected areas to climate change. *Scientific Reports* 10: 1678.

Loarie, S., Duffy, P., Hamilton, H. *et al.* 2009. The velocity of climate change. *Nature* 462**:** 1052–1055.

Ordonez, A. and Williams, J.W. 2013. Projected climate reshuffling based on multivariate climate-availability, climate-analog, and climate-velocity analyses: implications for community disaggregation. *Climatic Change* 119: 659–675.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology and Evolutionary Systematics* 37: 637–669.

Taylor, K.E., Stouffer, R.J. and Meehl, G.A. 2012. An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society* 93: 485–498.

Williams, J. W., Jackson, S. T. & Kutzbach, J. E. 2007. Projected distributions of novel and disappearing climates by 2100 AD. *Proceeding of the National Academy of Sciences* 104: 5738–5742.