State of the Sandhills Conservation Targets

Results and Recommendations from Biological Research

2023 Update

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Acknowledgement

This document and much of the work summarized within it was led by ORISE Fellows affiliated with The Nature Conservancy, the US Fish and Wildlife Service, and the North Carolina Sandhills Conservation Partnership between 2013-2023: Ryan Bollinger, Matthew Moskwik, Ana Castillo, Daniel Hannon, and Sarah Hecocks.

Introduction

The North Carolina Sandhills Conservation Partnership (partnership/NCSCP) developed a Biological Monitoring Plan in 2013, a foundational component of the Strategic Conservation Plan (currently under revision, 2023). The monitoring plan aims to guide research and conservation priorities in the NC Sandhills to measure progress towards the Strategic Plan goals. This State of the Sandhills report serves as a synthesis of the past 10 years of efforts by the NCSCP and the knowledge we've gleaned, as well as the knowledge gaps that still exist.

Originating in response to the need increased understanding of the natural communities within the Sandhills longleaf ecosystem, the Monitoring Plan was crafted to contain strategies for quantifying the extent and condition of designated conservation targets, and reaching the envisioned future conditions outlined in the Strategic Conservation Plan. Initially centered around the red-cockaded

woodpecker (*Leuconotopicus* [formerly *Picoides*] *borealis*; RCW) due to its federally endangered status, the scope of the plan was expanded to encompass a broader range of ecological elements. Additionally, the plan aimed to enhance data-sharing among partners and improve overall coordination.

Four conservation targets were identified for focus within the Biological Monitoring Plan: the Longleaf Pine Upland Mosaic, Upland Depressional Wetlands, Blackwater Streams, and Streamhead Pocosins and Seeps. Research efforts are dedicated to a single target per year, although efforts for a given target may extend into subsequent years based on the nature of the project(s). Starting in 2013, the NCSCP conducted research and monitoring within each of the targets and produced a State of the Sandhills report in 2020. As of December 2023, the NCSCP completed a second round of monitoring/evaluation for the Longleaf Pine Upland Mosaic and Upland Depressional Wetlands, and has initiated the next round for Blackwater Streams. Project implementation and data collection is led by the Sandhills Conservation Planner/ORISE Fellow.

Year	Conservation Target/Responsibility
1	Longleaf Pine Upland Mosaic
2	Upland Depressional Wetlands
3	Blackwater Streams
4	Streamhead Pocosins & Seeps
5	Full State of the Sandhills Report

The results from monitoring and management efforts are presented in this report, followed by recommendations. The intent is to not only summarize accumulated knowledge, but also offer insights that can inform present and future efforts focused on preserving ecosystem function and biodiversity.

Summary of Biological Monitoring Efforts

Longleaf Pine Upland Mosaic

Summary of Work

Monitoring of the longleaf pine upland mosaic target has included the evaluation of two widespread and easily detectable indicator species: the red cockaded woodpecker and pinewoods sparrow (formerly Bachman's sparrow; *Peucaea aestivalis),* efforts to map the location and condition of longleaf pine forests, and several partner-led projects outlined below.

In 2014, America's Longleaf (formerly America's Longleaf Restoration Initiative, ALRI) published the Longleaf Pine Maintenance Condition Class Definitions (Table 1), which outlined criteria for ranking quality of longleaf pine forests based on several criteria, largely shaped off the habitat needs of the red-cockaded woodpecker and intended for use towards the ALRI goal of reaching 8 million acres of longleaf pine forest by 2025, with at least 3 million acres in "maintenance" class.

	Metric	Maintenance Condition Class Minimum Standards
Overstory	Longleaf Pine Canopy	Longleaf stand with two-tiered or uneven-aged structure; longleaf pine basal area 40-70ft2/acre *
	Canopy Hardwood or Off-Site Pine	Basal area < 10ft2/acre of canopy hardwoods or off-site pines > 5" dbh
	Evidence of mature characteristics in stand	Large longleaf present (BA at least 20 ft2/acre of trees > 14" dbh class) or flat-top longleaf present in canopy **
Midstory	Shrub Cover	Shrubs average < 30% cover and average < 3' tall
	Canopy Fire-intolerant Hardwood or Off-Site Pine	20% or less midstory cover, with < 5% cover of fire-intolerant hardwood or off-site pine trees > 16' tall
Ground	Herbaceous Indicators	Herbaceous cover > 35% with native pyrogenic species present in stand ***
	Longleaf Pine Regeneration	Advanced longleaf regeneration cover is 5-15% of stand. Includes grass stage or regeneration < 2" dbh
	Non-native Invasive Species	Cover of invasive exotic plant species < 1%
*	Basal areas could be much lower in wet, savanna longleaf types and could also range slightly higher in actively managed forests	
**	Represents presence of mature forest wildlife habitat associations. Tree size may be smaller and, therefore, BA slightly lower in some community types	
***	Wiregrass, Sandhill dropseed, little bluestem, slender bluestem, silver bluestem, etc.	
****	If progress is being made toward satisfying any of the metrics and it can be reasonably assumed that progress will continue, the metric(s) may be checked as being met.	

Table 1. A longleaf stand or area falls in the "maintenance" condition class if all identified metrics are present; otherwise, the stand falls in the "improve" or "restore" condition classes (ALRI, 2014).

Ryan Bollinger (ORISE Fellow 2011-2015), Matthew Moskwik (ORISE Fellow 2015-2018), and Jeff Marcus (TNC) designed and implemented field surveys during the spring and summer of 2015 to assess longleaf Condition Class on 6,936 acres in the Sandhills and 6,965 acres on the NC coast. Over 2/3 of the acres were TNC-owned (~9,618 acres), and the remainder (~4,283 acres) were part of the North Carolina state park system or occurred on other partner lands (e.g. Bladen Lakes State Forest). The survey effort, including data entry, required an intern working for 12 weeks, ~10 workdays from a Conservation Coordinator on the coast, and 41 workdays from an ORISE Fellow in the Sandhills. None of the stands surveyed met all of the maintenance class criteria, indicating one of the shortfalls of the ALRI maintenance class definition as being too restrictive. To address this issue, Jeff Marcus, Matthew Moskwik and Ana Castillo (ORISE Fellow 2018-2020) utilized the habitat metrics collected to develop a habitat quality index (HQI) with groupings of High, Medium and Low quality (Table 2).

Region	Rank	Number of units	% of units within region
Coastal Plain	High (11.1-18)	93	42%
	Medium (8.1-11)	72	32%
	Low (0-8)	57	26%
Sandhills	High (11.1-18)	36	42%
	Medium (8.1-11)	26	31%
	Low (0-8)	23	27%

Table 2. Distribution and number of stands with low (habitat quality index score 0-8), medium (8.1-11), and high (11.1-18) quality from 2015 TNC-led longleaf assessments.

One limitation of the field-based assessments was the inability to cover the entire landscape due to limited access and staff capacity. To expand our understanding of longleaf distribution and quality across NC, Matthew Moskwik, Margaret Fields (TNC), and Ana Castillo conducted an analysis using the National Agricultural Imagery Program (NAIP) imagery and data from the US Forest Service Forestry Inventory Analysis (FIA). By combining field data points and data from FIA longleaf plots for metrics such as trees per acre and basal area, Matthew built a predictive model to for the Longleaf Pine range of North Carolina. Ana Castillo and Jeff Marcus used these data to create an HQI based on the maintenance class criteria outlined by America's Longleaf. The strength of this analysis was that it generated an assessment for the entire historic range of longleaf in NC and was able to accurately map broad-scale patterns of forest quality. Weaknesses include that only a limited number of the America's Longleaf condition class metrics can be measured and that the model cannot distinguish different species of conifers (including other pines and cypress) and as a result, the map probably overestimates the extent of longleaf pine-dominated forests.

The resulting product provided a landscape-level snapshot of where potentially open canopy pine forest with grassy understory might exist within the longleaf pine range of North Carolina (Figure 1). Utilizing this analysis, Dubose et al (2023) found a strong correlation between RCW presence (but not reproductive success) and the NAIP habitat quality index (i.e. RCWs were more likely to be found in areas of high habitat quality, and all RCW territories had high HQI scores).

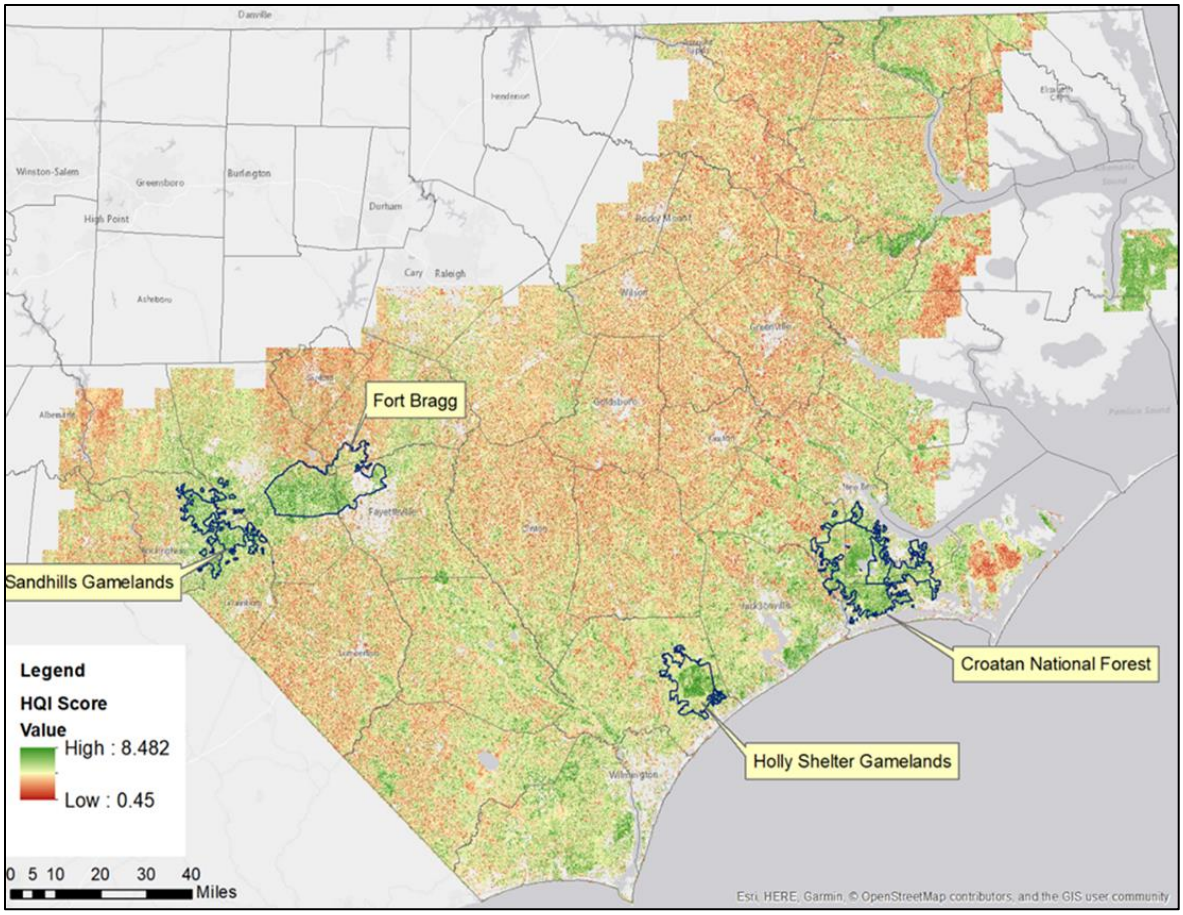


Figure 1. TNC used aerial imagery from the National Agricultural Imagery Program (NAIP) to create a model to predict the occurrence and structure of pine forests across eastern NC. The higher the HQI score, the closer an area is predicted to be to meeting the America's Longleaf Maintenance Class criteria.

To address the limitations of NAIP analysis, specifically in identifying the locations of longleaf stands, the Florida Natural Area Inventory (FNAI) Program devised a protocol for conducting rapid field assessments. This protocol was implemented for the Longleaf Element Occurrence (LEO) project, serving as an improved and expanded version of previous field-based surveys. Leading the project were Amy Knight (FNAI), Carolyn Kindell (FNAI), and Karen Zilliox-Brown (The Longleaf Alliance, LLA). Thus far, the project has successfully documented millions of acres of longleaf across its range. To contribute data from the Sandhills and NC coastal plain to the LEO project, Ana Castillo utilized aerial imagery to delineate polygons representing potential longleaf stands. Additional stands were added to the database from partner timber inventory data and from delineating previously unmapped longleaf stands encountered in the field. Dan Hannon (ORISE Fellow 2020-2022) implemented the rapid assessment field surveys across all 3 NC Local Implementation Team landscapes, in collaboration with partners.

To improve data interpretation and ability to track change over time, the TNC NC chapter developed a metrics-based HQI protocol (Table 3) to accompany LEO rapid assessment surveys based on scoring previously created by NatureServe and by TNC for the surveys conducted in 2015. Combining the habitat quality assessments from the TNC condition class surveys, LEO surveys, and NAIP analysis, we

now have fine-scale condition information for all known longleaf stands in North Carolina (Figure 2). The information obtained provides guidance for how to focus efforts towards achieving greater landscape connectivity between high-quality patches.

LEO habitat quality scoring				
Strata	**Metric**	**Points**	**Weights**	**Max Score**
Overstory	LLP BA	0.00	0.00	0.00
	Total Pine BA	1.00	0, 1, 2, 3	3.00
	Hardwood BA	1.00	0.50	0.50
	LLP Age Classes	1.00	1.00	1.00
	LLP Stand Age	1.00	1.00	1.00
	LLP Flat-tops & LLP ≥ 14" DBH	1.00	1.00	1.00
	Total	-	-	**6.50**
Midstory	Midstory Fire-tolerant HW	1.00	1.50	1.50
	Midstory Fire-intolerant HW	-1.00	1.00	0.00
	Tall Shrub Cover	1.00	0.50	0.50
	Total	-	-	**2.00**
Understory	Short Shrub Cover	1.00	0.75	0.75
	Total Herbaceous Cover	1.00	1.75	1.75
	Pyrogenic Graminoid Cover	1.00	3.00	3.00
	LLP Regeneration	1.00	1.50	1.50
	Invasive Plant Cover	-1.00	1.00	0.00
	Total	-	-	**7.00**
Fire	**Evidence of Fire**	**1.00**	**2.00**	**2.00**

Table 3. Habitat quality scoring created by TNC for LEO RA surveys. Weights were determined by importance of each metric for wildlife habitat. Points were multiplied by associated weights to get a final score for each metric.

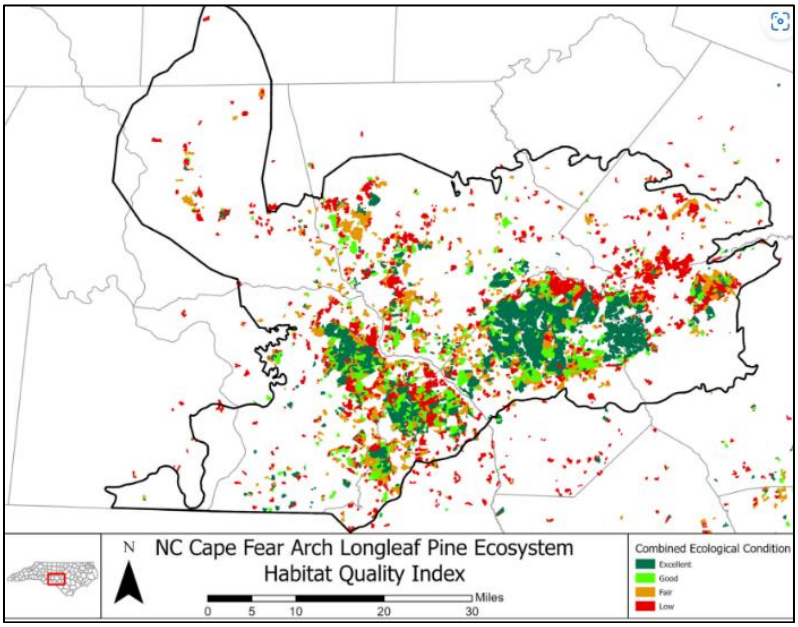


Figure 2. Condition of longleaf pine forests within the NCSCP boundary as of 2020. This map represents the best approximation to date of the location and condition of longleaf forests in the NC Sandhills.

In 2013, TNC NC conducted a resiliency analysis that identified large longleaf habitat blocks that, following protection and appropriate management, would be large enough to support viable populations of area-sensitive species, maintain an appropriate fire regime, sustain functioning hydrology, and be able to recover from disturbances (i.e. hurricanes, pathogens, etc.). When completed, the resiliency analysis defined ten core areas that met a minimum size threshold of 25,000 acres ("Resilient Cores") as well as eight habitat blocks that do not currently meet the resiliency threshold but could be become part of the solution with some effort to increase their size or connect them to other habitat blocks ("Core Enhancement Areas"). When strategic land acquisition bolsters the managed acreage of the core or enhancement areas, and connectivity is achieved between them, the land base will exist to support a resilient longleaf pine ecosystem in North Carolina (Figure 3). Similarly, to guide conservation planning and activities across the range of longleaf pine forests in North Carolina, Matthew Moskwik used a least-cost-path analysis in 2015 to determine the shortest and most important corridors between the Resilient Habitat Core Areas across the most natural land cover and avoiding impediments such as major roads and development (Figure 4).

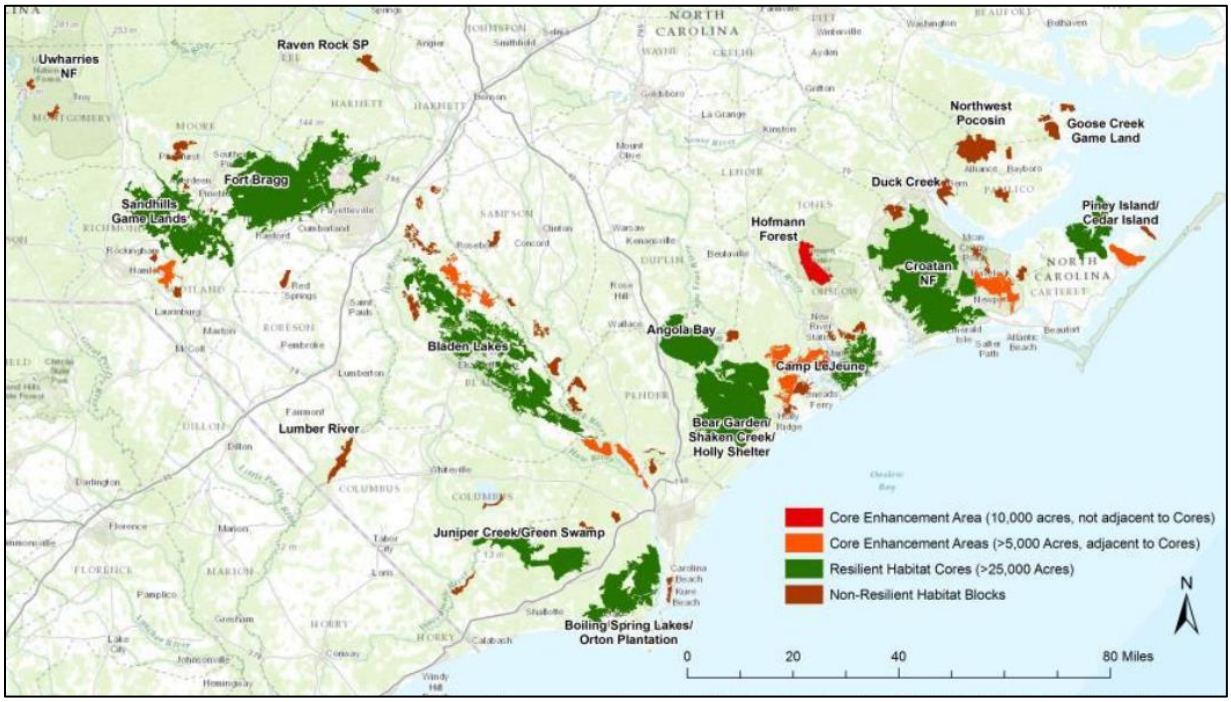


Figure 3. Longleaf pine habitat blocks in eastern NC ranked by resiliency.

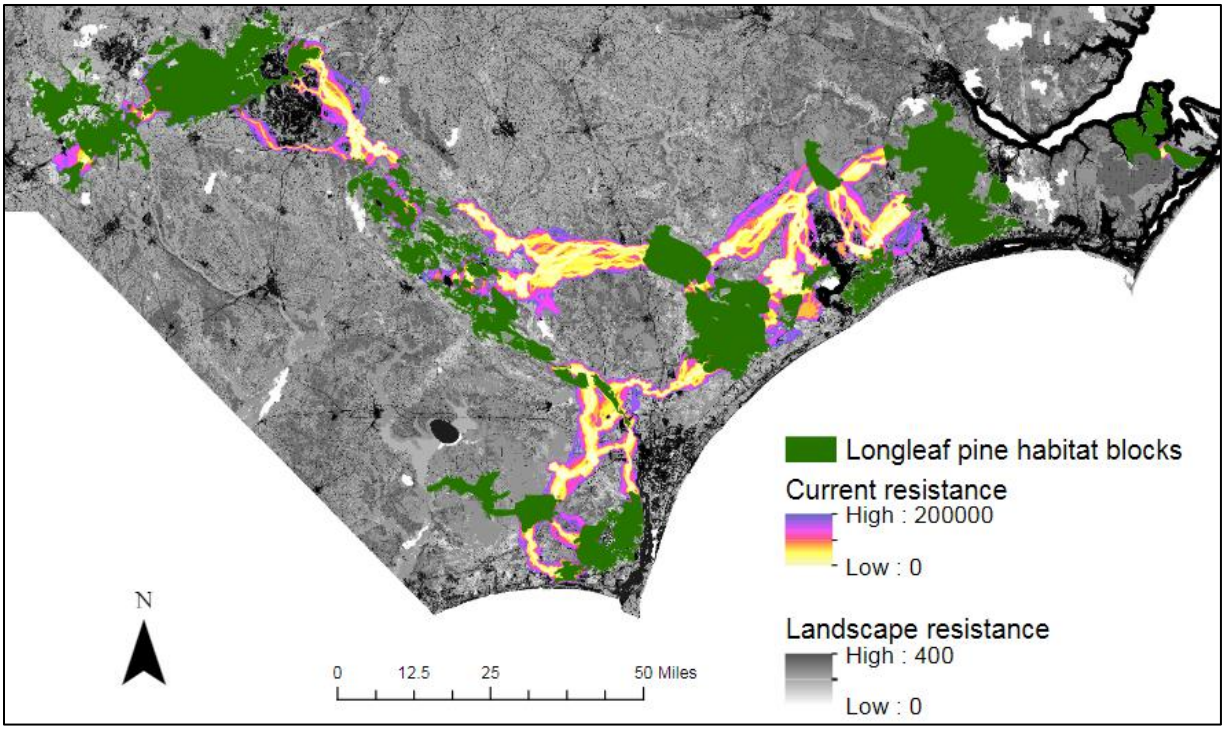


Figure 4. Corridors of least resistance between longleaf pine habitat blocks for conservation prioritization. The lower the "current resistance", the easier it is predicted for species to move across the landscape.

Monitoring of Indicator Species

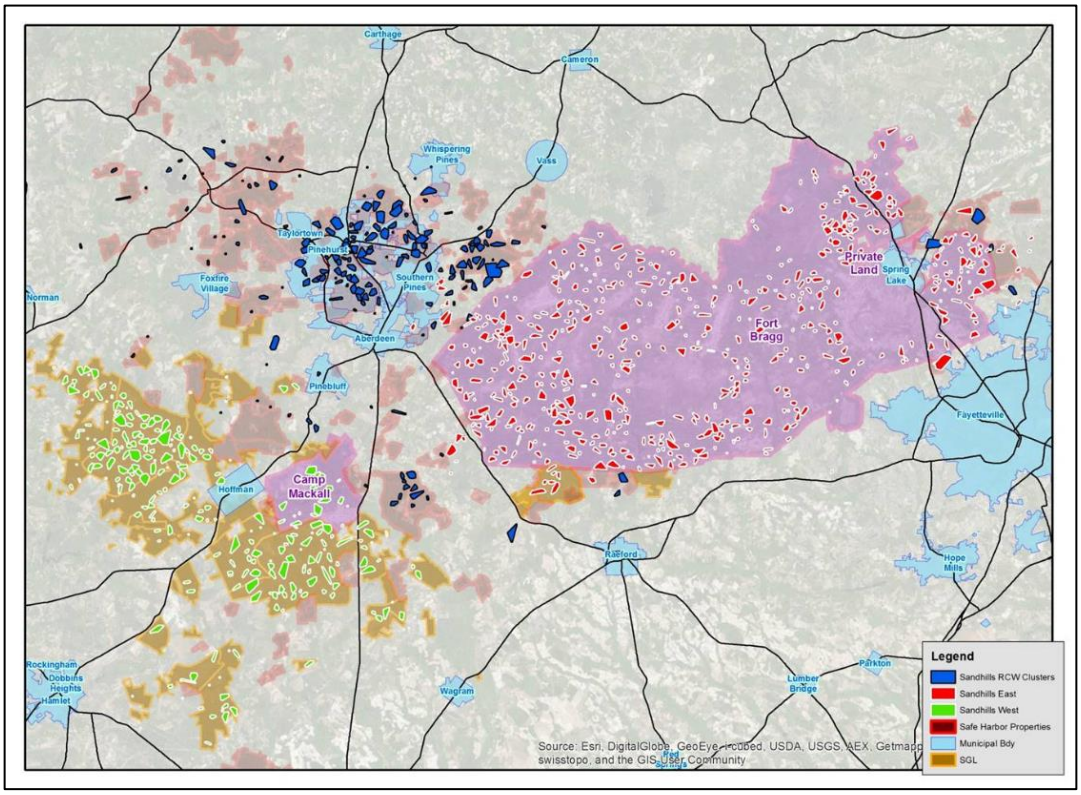
Red-Cockaded Woodpecker

When monitoring began in the 1980s following its federal listing in 1970, under a law that preceded the Endangered Species Act, RCW numbers had plummeted to around 10,000 birds— a sliver of the nearly 1 million birds that previously existed across the longleaf historic range. The RCW's endangered status has enabled sweeping conservation efforts not just for RCW, but for the entire longleaf pine ecosystem. Today, there are almost 20,000 individuals across the southeast, which is most notably due to the creation of artificial cavities, which can be placed in trees RCW normally would not excavate, translocation efforts to increase genetic diversity, effective collaboration across agencies, and improved habitat management, especially on private lands. Although population numbers have shown promise for the recovery of the species, RCW still lack adequate habitat and management to reach stable conditions.

An RCW demographic study initiated by Jeff Walters at North Carolina State University (NCSU) in 1978, and now maintained by the Sandhills Ecological Institute (SEI), is one of the longest-running demographic studies of a wildlife species in North America. The research project has resulted in several publications on RCW behavior and reproductive ecology and has documented the tremendous recovery of RCW in the NC Sandhills (Figure 5A-B). By 2002, the population exceeded the target recovery goal of 450 potential breeding groups (PBG), several years ahead of the target goal date (Figure 5B). In 2017,

the Sandhills East and West subpopulations achieved demographic connectivity ahead of the target date. In 2023, 813 NC Sandhills PBGs were documented.

A.



B.

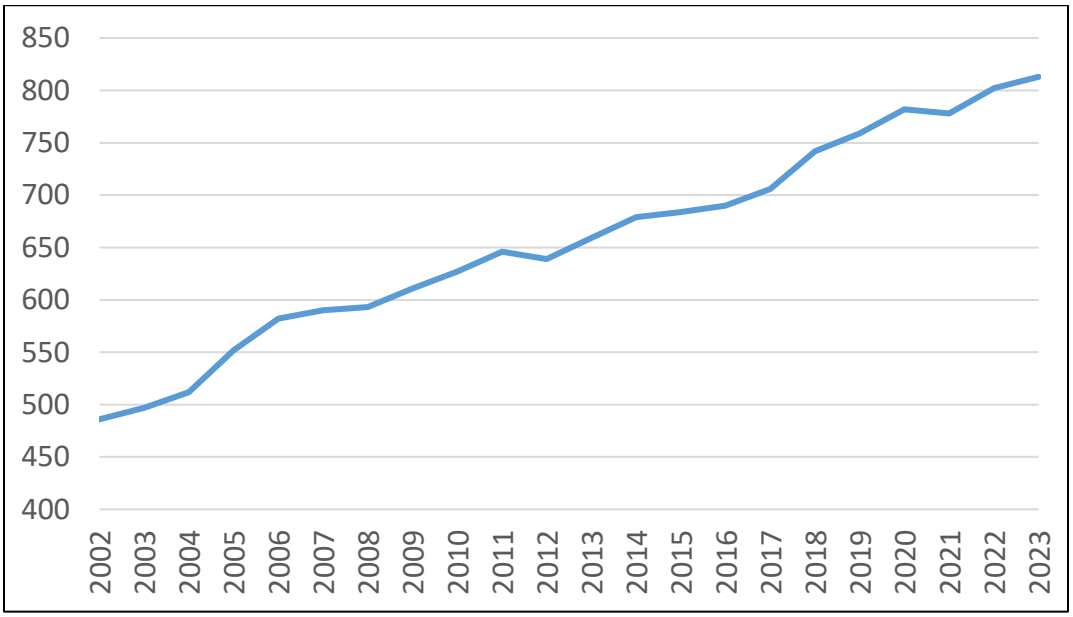


Figure 5. A: RCW clusters (family groups) across the Sandhills geographic range (map credit: Steve Anchor, former SEI biologist, 2010); B: Potential Breeding Groups (PBGs) in the NC Sandhills over time.

Lauren Pharr, a PhD candidate at NCSU, is using the long-term Sandhills RCW dataset to investigate the potential causes of a declining trend in brood production that's been observed in the population. The reductions could be in part due to a changing climate, as we have already seen a correlation between earlier egg laying dates and increasing temperatures. Across 3 study sites (Sandhills Game Lands, Marine Corps Base Camp Lejeune, and Eglin Air Force Base in the western FL Panhandle), Lauren has detected lower reproductive rates and decreasing fledge probability, with Eglin showing the largest decreases.

Pinewoods (formerly Bachman's) Sparrow

From 2012-2014, Jeff Marcus, Scott Anderson, John Carpenter, and Paul Taillie of the NC Wildlife Resources Commission (NCWRC) conducted a state-wide status assessment of for the pinewoods sparrow (*Peucaea aestivalis*). To establish survey locations, the survey team compiled existing observation records, used aerial imagery to identify potential habitat in areas that had not been previously surveyed, and revisited locations with observations >5 years old. Survey points occurred on both private and public lands across a range of habitat suitability. Publications resulting from this work (Taillie et al 2016 and Pickens et al 2017) provide a baseline of distribution and relative abundance of pinewoods sparrows in NC (Figure 6).

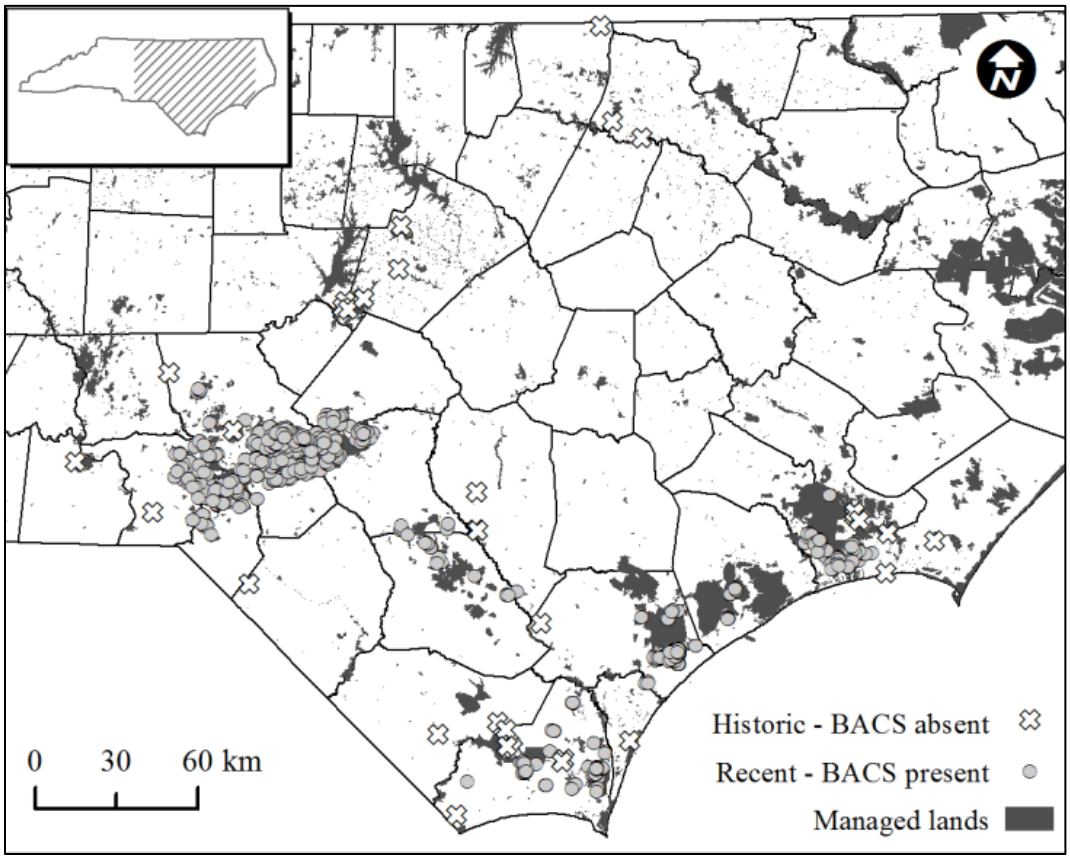


Figure 6. Historic and recent distribution of pinewoods sparrow (previously Bachman's sparrow, BACS) in NC at publication (Taillie et al. 2016).

In the spring breeding seasons of 2020, 2021, and 2022 a subset of the survey points on properties that received management action funded by the National Fish and Wildlife Foundation (NFWF; TNC preserves, Sandhills Game Lands, Uwharrie National Forest, Carver's Creek and Weymouth Woods State Parks, and the Moss Foundation) were revisited by TNC staff to assess how pinewoods sparrows respond to restoration activities such as Timber Stand Improvement and prescribed burning. TNC preserves and WRC game lands that received management funded by NFWF had a 77% increase in acres burned per year resulting in improvements to longleaf habitat available to pinewoods sparrows. Statewide there was a 26% increase in the distribution and relative abundance of sparrows on NFWF-managed lands. The greatest increase was observed in the Sandhills (+76% relative abundance), while a slight decrease was detected on Croatan NF. The increase in the Sandhills highlights the importance of fire-management for pinewoods sparrow and their ability for established populations on large conservation lands to respond quickly to management. However, it is important to acknowledge that this study did not revisit areas that did not receive NFWF support. Therefore, the situation for pinewoods sparrow populations on private lands likely presents a different narrative.

Sensitive upland reptiles

Since 1998, Jeff Beane of the NC Museum of Natural Sciences (NCMNS) has tracked the movements of southern hognose snakes (*Heterodon simus*), northern pine snakes (*Pituophis m. melanoleucus*), eastern coachwhips (*Masticophis* [*Coluber*] *f. flagellum*), and eastern chicken turtles (*Deirochelys r. reticularia*) in the Sandhills using radio telemetry. Most of the work has been conducted on Block B of Sandhills Game Land in Scotland and Richmond counties, as well as some private lands. To date, a total of 23 *D. reticularia*, 22 *H. simus*, 16 *M. flagellum*, and 27 *P. melanoleucus* have been radio-tracked for varying amounts of time (ranging from a few days to 7 years per individual). As of June 2023, he is tracking 4 adult pine snakes (1 male, 3 females) on Block B of Sandhills Game Land. The research has resulted in detailed and long-term information on home range and movement, habitat use, reproduction, ecological interactions, and seasonal and diurnal activity patterns of these rare, cryptic, and largely fossorial animals.

Jeff has also conducted road surveys for southern hognose snakes in the NC Sandhills and Coastal Plain since 1985, data from which has improved our understanding of the species' size, sex ratio, diet, activity patterns, and population trends. Jeff maintains a database of NC occurrences and much of his findings have resulted in publication. Additionally, Jeff has regularly monitored a 0.7-mile stretch of secondary paved road in southern Moore County for >20 years for vehicle mortalities. To date, he has documented >6,000 road-killed vertebrates of 118 species (~73% amphibians, 21% reptiles, and 3% each of birds and mammals). Many of the road-killed specimens are salvaged for genetic resources and NCMNS collections. Similarly, NCWRC conducts road surveys for the southern hognose snake on Sandhills Game Land during the typical breeding season around October.

Protection Recommendations

The improved connectivity between RCW subpopulations suggests that protection strategies aimed at increasing connectivity across the "Gap" between Fort Liberty (formerly Fort Bragg) and Sandhills Game Land have been effective. Protection efforts within the Sandhills should continue focusing on strengthening habitat connectivity across the Gap and between outlying blocks of Game Lands in addition to securing key parcels of good habitat that buffer, connect, or improve management of existing conservation lands (Figure 7).

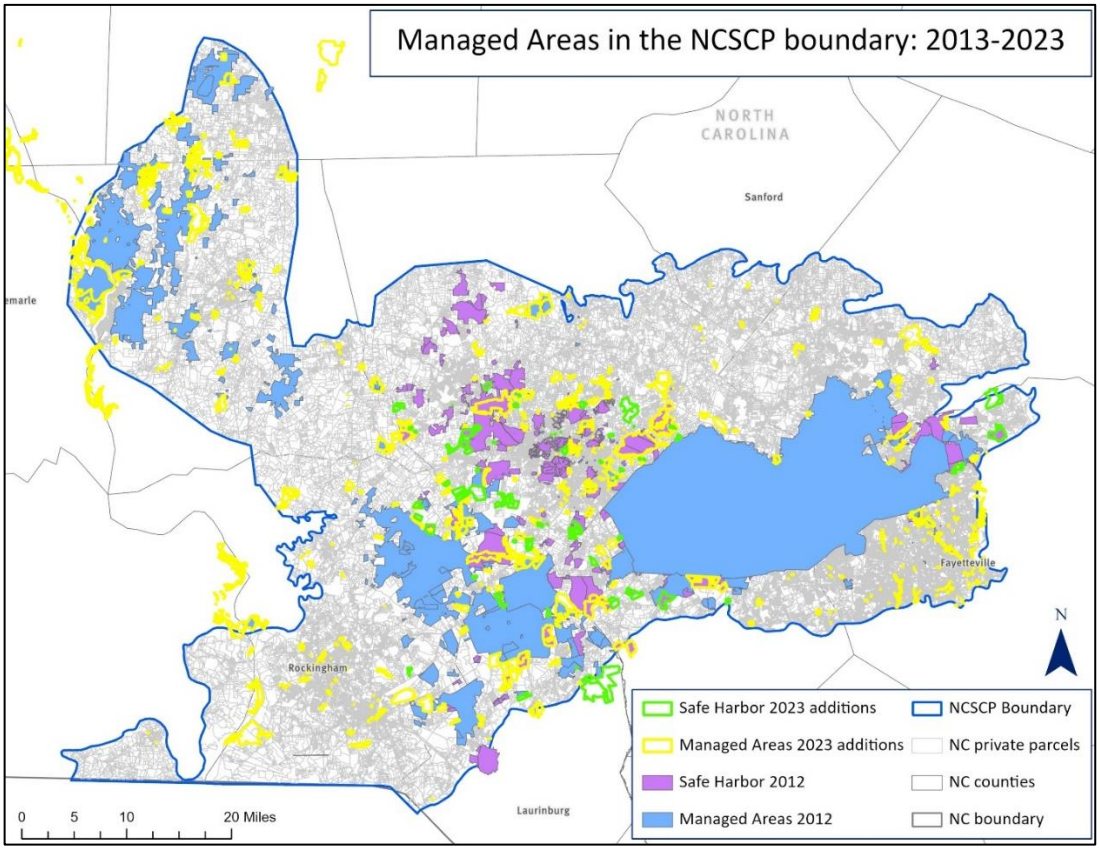


Figure 7. Managed areas in the NCSCP's working boundary from the inception of the NCSCP's Strategic Conservation Plan to 2023. Green polygons represent Safe Harbor properties added between 2012-2023 and yellow polygons represent properties protected (fee simple, conservation easement, Dedicated or Registered land agreement) between 2012-2023. Managed areas include protected lands with a range of management objectives.

Protection efforts should also begin to focus more on connecting core areas in the Sandhills with the Uwharries, the South Carolina Sandhills, and the Bladen Lakes region. In 2021, the Uwharries region was awarded funding through the Joint Chiefs program to restore fire-managed pine habitat on both public and private lands. The goal of the project is to establish a large core area of managed habitat within the Uwharries, centered on Uwharrie National Forest but including partner and private lands to the south, to strengthen connectivity to the Sandhills where many of the rare species associated with this habitat persist. The Joint Chiefs project focuses on land management and would benefit from a

protection strategy and resources to compliment that effort and leverage relationships built with private landowners. Creating landscape connectivity to the SC Sandhills and Bladen Lakes regions will require new initiatives and strategies as there is not currently a concentrated effort for either. All protection efforts should focus on priority areas identified through monitoring and mapping projects and should leverage resources and relationships from neighboring conservation partnerships (Figure 8).

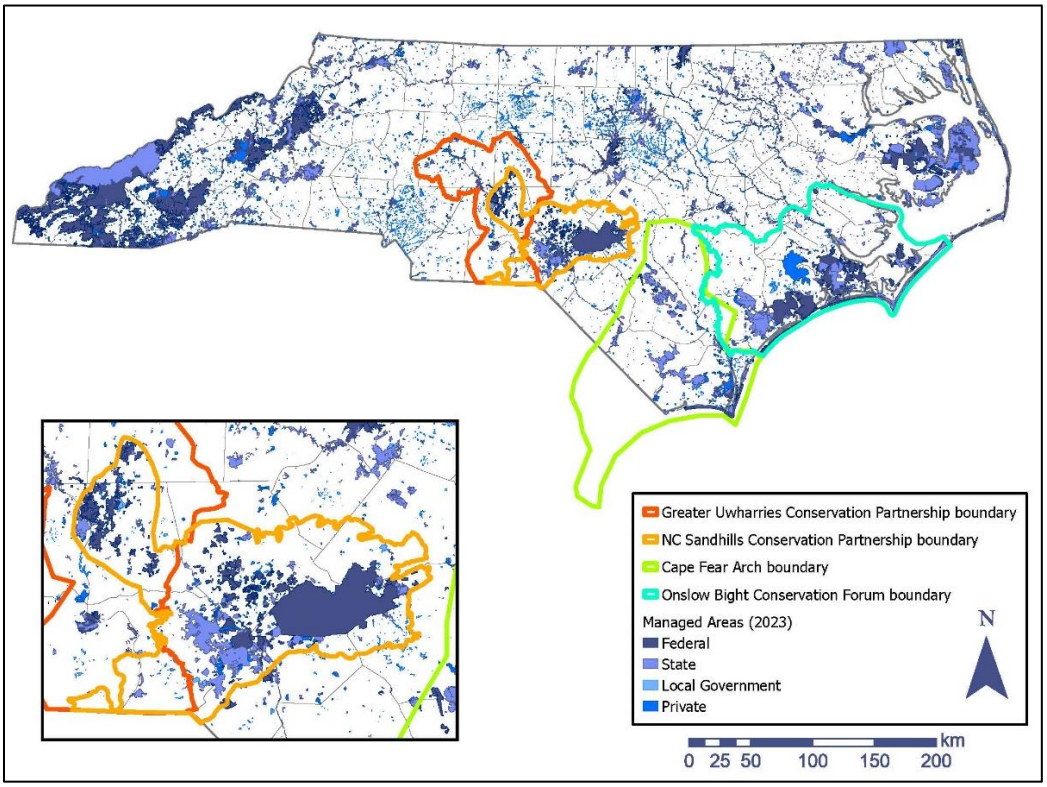


Figure 8. NC Conservation Partnership boundaries.

Protection strategies should also include efforts to influence local land use policies that influence development patterns. The Green Growth Toolbox (GGT), coordinated by the NCWRC, was created in 2010. The GGT is a program that implements the NC Wildlife Action Plan to help minimize development impacts to wildlife habitats through local government comprehensive plans, transportation plans, ordinances, and development designs. The target audience of the GGT is land use and transportation planners, GIS specialists, and planning-related boards in local governments in the Sandhills and across the state. The GGT consists of a handbook, website, training workshops, technical assistance, and modest funding for local governments to implement conservation planning projects. The town of Aberdeen was instrumental in helping the NCWRC craft and fine-tune the GGT to the needs of local governments. Following training, many local governments have used the GGT handbook and conservation data on their own. Although it has not been possible to assess the specific ordinance updates that have been done, most local governments that used the GGT when developing their comprehensive plans included sufficient GGT recommendations to enable ordinance updates that could

implement significant GGT recommendations. Over the years, we have seen that the GGT supported the following activities and results in the Sandhills: 1) Two Joint Land Use Study plans for Fort Liberty, 2) Fort Liberty Sustainable Growth Strategy, 3) Data and recommendations used for comments on major development proposals by the Fort Liberty Regional Land Use Advisory Commission, 4) Aberdeen Comprehensive Plan and ordinance updates, with a Green Growth Assessment required for major development, 5) Moore County Comprehensive Plan and Unified Development Ordinance updates, with the most recent update implementing 45% of the GGT recommendations, 5) Bladen County Comprehensive Plan, 6) Southern Pines ordinance, 6) Consistent interest from Pinehurst in implementing the GGT, 7) Hoke County Planning Department eagerness to learn more about the GGT, but in need of more resources, and 8) Harnett County Comprehensive Plan.

The Regional Land Use Advisory Commission (RLUAC) is an organization that brings together local governments, the military, and the conservation community across the Sandhills to address issues of common interest. In addition to being an information-sharing forum for growth and development issues, RLUAC provides comments and recommendations to local governments on new development, re-zoning, and other land use changes proposed within 5 miles of the boundary of Fort Liberty and Camp Mackall. The Sandhills Conservation Partnership should continue to support RLUAC with data, recommendations, and comments on proposed land use changes.

Management Recommendations

The increasing populations of both pinewoods sparrows and RCW on conservation lands indicate that management efforts focused on longleaf uplands are yielding positive results. To ensure the continuation of this progress and address the impacts of a changing climate, it is crucial to sustain these efforts and adapt management strategies accordingly. One key approach is to foster expanded resource sharing among organizations, including burn crews, equipment, expertise, and data.

Young trees at the time of RCW listing are starting to reach an age of maturity desirable for cavity excavation, which may lessen the need for artificial cavity inserts, but we are still losing mature forests and should continue funding and implementing this strategy. Notably, managing longleaf habitat on private lands remains the most significant hurdle. The accomplishments demonstrated by initiatives like the Sandhills Prescribed Burn Association, NRCS Farm Bill programs, and the Safe Harbor program should serve as foundations to be further expanded and built upon. Following the loss of the US Fish and Wildlife Service (USFWS) Safe Harbor coordinator position in the Sandhills, the ORISE Fellow/Sandhills Conservation Planner has taken on some of these duties, with an emphasis on annual check-ins with high-priority landowners. While this addresses some of the need, a full-time position dedicated to the Safe Harbor program would greatly improve opportunities for strengthening relationships with private landowners and ensuring adequate habitat management is being performed. Many of the early enrollees are advancing in age, and we may miss opportunities for permanent protection of their lands if they are unaware of their options. Additionally, there is a need to continually develop new and improved incentives, motivators, and resources to encourage enhanced forest management practices on private lands.

It is important to recognize emerging developments in the region that have potential to negatively impact the longleaf pine uplands, such as non-compatible solar energy, biomass sourcing, and

housing expansion. North Carolina ranks 2nd in solar energy development. Solar farms have been built in critical habitat areas, at times resulting in large clearcuts of longleaf forest. While we as a nation need to dramatically scale up our transition to renewable energy sources, we also need to be smart about where the technology is sited. TNC and NCWRC have been working to form partnerships with solar companies to help mitigate negative effects to longleaf forests, providing guidance and onsite assistance to improve siting and minimize impacts of solar facilities on wildlife and natural systems. Conservation practices being implemented at sites include benefiting pollinators and/or native vegetation through improved mowing rotations, rehabilitating wetlands on site, and implementing wildlife-friendly fencing. TNC and NCWRC conducted vegetation, insect, and wildlife monitoring at the sites, and produced a report in 2022 that summarized the results of 4 years of monitoring work. This new information helps inform the guidance for solar facilities that was developed by the NC Pollinator Conservation Alliance, and was updated in 2022. A siting workshop was held in Feb 2023, cohosted by Defenders of Wildlife, TNC, and NCWRC, with the intent to bring together interested stakeholders across government agencies, NGOs and industry, and reach consensus on data layers to be included in a siting guidance for NC, with the goal being to avoid social and environmental conflicts when siting renewable energy.

While there are conflicting opinions on the sustainability and carbon footprint of biomass sourcing for wood pellets, the industry has potential to provide income for private and public land-owning entities. Restoring forests that have undergone fire suppression for >5 years often cannot be done with fire alone and requires removal of midstory hardwoods to reach a desirable savanna-like structure with diverse native groundcover. Addressing this midstory issue is one of the greatest challenges in returning prescribed fire to private lands, in part due to its expense. In 2020, the Sandhills Prescribed Burn Association (SPBA) began collaborating with wood pellet companies and the local logging industry to promote their markets as beneficial to entities seeking midstory hardwood removal in restoration forests. In turn, landholders were able to earn a modest amount per acre instead of paying to have it mulched. Giving landowners access to these types of markets could be an effective tool to accomplish range-wide restoration goals and could result in significant cost savings to our state and federal partners who are tasked with wildfire suppression. Converting this midstory challenge from a liability to an asset could be the financial incentive that landowning families need when deciding whether to retain and restore their forests, so long as the sourcing remains in the midstory and does not occur in mature bottomland hardwood forest.

Research, Survey, and Monitoring Recommendations

While monitoring the Sandhills RCW population should continue, we need to evaluate the intensity and extent of monitoring that can reasonably be sustained. The species is being considered by the USFWS for down-listing to Threatened, and the outcome may impact the imperative for monitoring. Key partners, such as NCWRC, have already expressed that personnel resources for monitoring are limited and they may further scale back their monitoring efforts. The RCW Recovery Working Group of the NCSCP will meet after a listing decision has been made to identify the key attributes and sample size for continued monitoring.

The results of the longleaf habitat quality surveys can be used to inform current protection and management priorities, serving as field validation of corridors identified from mapping efforts that use remotely sensed data. This information could also inform a new way of implementing cost-share

programs. Instead of paying for actions, we could pay for results. We could prioritize landowners that continually meet our habitat objectives, such as paying them for improvement or paying them for maintaining longleaf that's already in good condition. This would incentivize landowners to manage for habitat, and thus we would get closer to meeting our goal of 3 million acres of longleaf in maintenance-class condition.

We should consider repeating LEO surveys at periodic intervals to track trends for longleaf habitat. Presently, North Carolina stands as the sole state with comprehensive and high-quality information on all known longleaf populations. Although reaching this level of data collection requires a substantial investment of time and effort and does not cover the entirety of the landscape, the data obtained results in a standardized baseline for future planning throughout the species' range. Therefore, we recommend selecting a statistically relevant and stratified sample of longleaf stands for repeated surveys. Additionally, it may be beneficial to revisit the NAIP analysis in the future to obtain updated statewide information; importantly, this would require the dedication of a specific position and approximately 1 year to complete. Alternatively, as of December 2023 the Longleaf Alliance is exploring options to get long-term habitat quality monitoring data from the Forest Inventory Analysis program.

If resources allow, it would be valuable to extend the pinewoods sparrow monitoring by replicating baseline surveys on private lands and unmanaged areas. This approach would offer a more comprehensive overview of the shifts in sparrow distribution and abundance throughout the entire NC Sandhills region, and not just on conservation lands which boast optimal habitat and larger populations.

Other upland longleaf-associated species that could benefit from additional surveys and monitoring include northern pine snake and southern hognose snake. Better data, specifically on habitat characteristics of their home ranges (e.g. size and plant composition), could help determine conservation status and needs, and the species could serve as additional indicators for tracking progress on conservation of upland longleaf habitats. Monitoring generalist understory plant species (e.g. wiregrass and little bluestem) could also serve as indicators of managed longleaf. However, before sinking funding into monitoring efforts, we should remember that acquisition of habitat is most crucial, followed by management of existing parcels, then research. Monitoring of indicator species is irrelevant if the areas they persist within become degraded or destroyed without proper management or protection, especially within movement corridors.

Upland Depressional Wetlands

Summary of Work

The Upland Depressional Wetland (UDW) conservation target includes water bodies that are hydrologically isolated, such as ephemeral pools, small depressional ponds, and Carolina bays. Because they are free of predatory fish, UDWs provide critical breeding habitat for many rare herpetofauna. UDWs also support many rare plants and associated pollinators. Some of the greatest threats to UDWs are habitat destruction and alteration (e.g. through agriculture), both of which are increasing due to diminishing or eliminated federal and state legal protections for isolated wetlands. The North Carolina Ecosystem Enhancement Program was enacted in 2003 to partially address this issue and include isolated wetlands; however, the system did not address conservation of terrestrial landscapes surrounding wetlands that are important for dispersal of amphibians outside of their breeding periods.

Additionally, because the open nature of these wetlands is reliant on growing-season fires when the wetland basin is dry, most have been fire-suppressed and suffer from dense hardwood encroachment.

Wetland Connectivity

Among the biggest concerns for amphibian species of greatest conservation need (SGCN) are the effects of habitat loss and fragmentation, which can drastically limit dispersal and geneflow between populations. The dissertation work of NCSU student Will Fields (Fields 2011) on Fort Liberty revealed that the quality of dispersal habitat was more important for dispersing ornate chorus frogs (*Pseudacris ornata*) than was extent of isolation from breeding habitat, and that the spatial context of the landscape was most important in determining paths of dispersal. He also found that frogs reared at low densities moved more rapidly through poor-quality dispersal habitat than did frogs reared at high densities, which may suggest that understanding the effects of larval conditions on the dispersal behavior of juveniles could be as influential as the quality of dispersal habitat when assessing landscape connectivity.

In 2016, Matthew Moskwik analyzed a 15-year dataset of breeding records for at-risk species to better understand 1) the overall condition of and spatial relationship between known UDWs in the Sandhills region, and 2) how isolation and fragmentation affects breeding events and species richness. The dataset included data for 6 amphibian SGCN at 26 wetlands on Sandhills Game Land and Fort Liberty. Wetland habitat condition (indicated by canopy, mid-story, shrub cover, number of logs, etc.) was assessed in the field during winter and spring of 2016. Wetland isolation was defined by the number of and distance to neighboring wetlands. To classify barriers to migration, percent of forested area up to 500m from a given wetland edge was calculated using the National Land Cover Dataset (NLCD, 2011).

Results from this study indicated that decreases in species richness and breeding could be attributed in part to increased fragmentation and, therefore, reduced migration between wetland locations (Figure 9). There was a negative relationship between the observed number of amphibians and the average distance to the nearest wetland. Extirpation rate also increased with increasing average distance from wetlands within 10km. Because the target amphibian SGCN analyzed in this study are maintained as metapopulations, maintaining adequate connectivity between diverse and high-quality wetland sites is crucial to their persistence in the landscape. This is especially relevant with a changing climate, as prolonged drought and infrequent but extreme flood events are already occurring in the Sandhills and altering suitability of breeding sites. Findings from this study, in part, led to TNC's acquisition of the Jordan Tract, 2020 acres linking Blocks T, C, and B of Sandhills Gameland within the corridor of high potential movement between Block T Pond and the 4 wetlands to its south (western edge of Figure 9C). This tract, and the wetlands on it, will eventually be transferred to NCWRC and integrated into Sandhills Gameland.

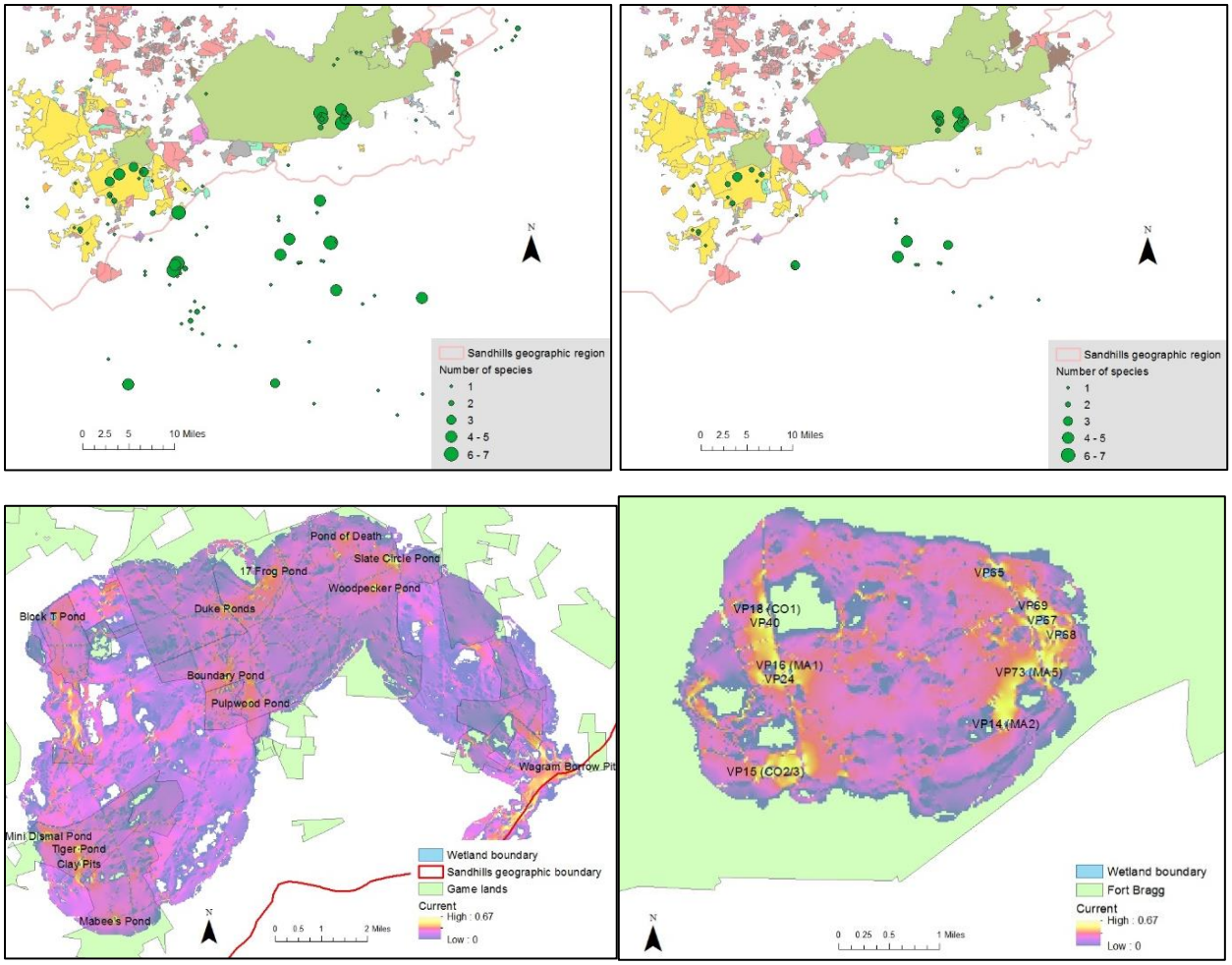


Figure 9. Top left: Historic occurrences of amphibian SGCN. The larger the dot, the greater number of occurrences. Top right: Current (as of 2015) occurrences of amphibian SGCN. The 2015 assessment found fewer ponds supporting any SGCN and most of the others with reduced numbers of species present. Bottom left: Potential corridors between UDWs on Sandhills Gameland. Bottom right: Potential corridors between UDWs on Fort Liberty. Yellow areas are regions of concentrated flow, where dispersal of species is more likely to occur because it is the closest distance between ponds and/or dispersal options are limited to a narrow corridor. Purple areas represent more diffuse flow of dispersing amphibians where there are wider areas of opportunity for movement. Blank areas represent dispersal barriers where no dispersal is predicted to occur.

Wetland Restoration and Mapping

Building on this knowledge, the NCWRC has embarked on ambitious wetland restoration and creation projects across various sites, which has led to increased biodiversity post-restoration, including several rare plants and amphibian species such as tiger salamanders, Mabee's salamanders, chicken turtles, oak toads, Carolina sandhills salamanders, and gopher frogs. Concerted efforts to restore degraded isolated wetlands in the NC Sandhills have largely taken place on Sandhills Gameland and a few on TNC's Calloway Preserve. Restoration is ongoing at most sites, but many are now in a maintenance phase and can largely be managed with growing season fire alone. Projects include Block T

Pond (timber harvest, root rake, broadcast herbicide), Chris's Pond (tree removal), Narrow Pond (tree removal, minor ditch fill), Hill Pond (tree removal), Slate Circle Pond (tree removal, contouring), Watson Pond (tree removal), Block O Pond (timber harvest, ditch fill), Little Dismal Pond (timber harvest, ditch fill/water control structure), Mini Dismal Pond (tree removal), Wildfire Pond (tree removal), Woodpecker Pond (tree removal), Helipad Wetland (tree removal, ditch fill), Mail Route Wetland (tree removal and contouring), and Smilax Wetland (contouring).

Following wetland restoration at Block T Pond, NCWRC partnered with the NC Zoo to head-start gopher frogs and ornate chorus frogs from egg masses collected in natural wetlands to later release as tadpoles and metamorphs to assist in broader establishment of the species. NCWRC has released a total of 44 ornate chorus frog metamorphs, 968 gopher frog metamorphs, and ~664 gopher frog tadpoles over five years (2018 and 2020-2023) into Block T and 17 Frog Ponds. While there have been no detections of returning adults since these releases, our knowledge of their movements and survival following release has greatly improved. Through radiotelemetry in 2017 and 2019, researchers discovered that invasive fire ants were consuming dispersing metamorphic gopher frogs, which prompted the creation of artificial release burrows. So instead of releasing metamorphs into the pond, releases are concentrated into artificial burrows located near the pond and several are monitored with cameras. Preliminary findings indicate that these refugia not only improve the short-term survival of released gopher frog metamorphs, but also offer a cost-effective alternative to radiotelemetry. Experimental treatment of fire ant mounds has been implemented at 17 Frog Pond with limited success.

In addition to restoration efforts, the NCWRC pioneered the creation of a wetland in 2013 (Liner Pond, designed by Tom Biebighauser) that, despite challenges, stands as a model for the establishment of similar ecosystems. While the creation of Liner Pond necessitated using a plastic liner to mimic a natural clay lens, wetland creation may not universally require the incorporation of a pond liner. Instead, strategic planning based on compatible soils could potentially reduce material costs while facilitating the achievement of desired conditions. The need to remove extensive cattail growth in Liner Pond from 2017-2018 led to the realization that it is crucial to proactively plan for vegetative control in the aftermath of wetland creation, recognizing that this process extends over a decade or more.

The growing imperative and interest in isolated wetlands spurred a series of wetland restoration workshops. In September 2019, a workshop hosted by the NCSCP attracted attendees from across the southeastern region, signaling a widespread recognition of the significance of wetland restoration efforts. Building on this momentum, a subsequent workshop in September 2022 centered around wetlands in the Bladen Lakes region further emphasized the increasing need for knowledge and collaboration not only in small depressional pools, but Carolina bays as well. In September 2023, the NCSCP organized a field trip to two restoration sites on Sandhills Game Land: Block T, which is near-maintenance condition, and Sarah's Pond, a new site identified through mapping efforts conducted 2022-2023. Positive feedback from attendees noted the value and diversity of information provided, and their increased confidence to implement strategies in wetlands on properties they oversee.

In line with the NCSCP's goal to increase spatial knowledge of isolated wetlands in the Sandhills landscape, Sarah Hecocks (ORISE Fellow 2022-Present) worked with Natalie Paparone (Duke Master's student) in collaboration with the Swenson Lab at Duke University's Nicholas School for the Environment from 2022-2023 on a project to map the locations of UDWs on Sandhills Game Land. The goals of the project were to: 1) compile the locations of known wetlands into a region-wide database, 2)

develop predictive models using remotely-sensed aerial imagery and machine learning in GIS to locate previously unknown UDWs, 3) create a user-friendly tool for land managers to expand the work elsewhere, and 4) take restoration action in prioritized sites to improve available SGCN amphibian breeding habitat. The model was trained using known UDW point locations, LiDAR-derived digital elevation models (DEMs) and models of vegetation structure, soil maps, and multi-season aerial imagery to capture seasonal hydroperiods. By classifying land cover, presence and seasonality of water, a map of high-probability potential wetland sites was produced. In tandem with sinks identified by Quisheng Wu's Depression Analysis Toolbox, locations were field-validated and classified based on size, condition, and proximity to other wetland locations.

The models identified 461 potential wetland locations on Sandhills Game Land, including the correct prediction of several previously known sites. The combined model had a 45% success rate in identification, with 211 locations confirmed in the field to be true wetlands; however, 116 of those locations were drainage sections dammed by an impoundment structure (e.g. a road), resulting from the high variability in wetland types contained in the known wetland database that was used during model training. Thirteen locations were previously undocumented, naturally occurring, non-floodplain depressional wetlands. Going forward, models should be trained only using the target wetland type(s).

Products resulting from this project include a region-wide GIS database of wetland polygons with relevant management information (Figure 10), a how-to document for model adaption to other properties, and a list of high-priority sites for restoration on Sandhills Game Land with specific management recommendations (Figure 11). Sarah also expanded the model efforts to predict potential UDW locations within the entire NCSCP boundary (Figure 12). Efforts are currently underway to field-verify and incorporate locations on Fort Liberty, Uwharrie National Forest, TNC lands, and Safe Harbor properties into the regionwide wetland database.

Sarah also ground-truthed several wetland locations provided by Charles Lane and Ellen D'Amico of the EPA, predicted using the National Wetlands Inventory and a National Hydrography Dataset buffering process to mask potential isolated wetlands. The EPA dataset mostly predicted locations of seeps and drainages, which may be more useful for identifying those conservation targets.

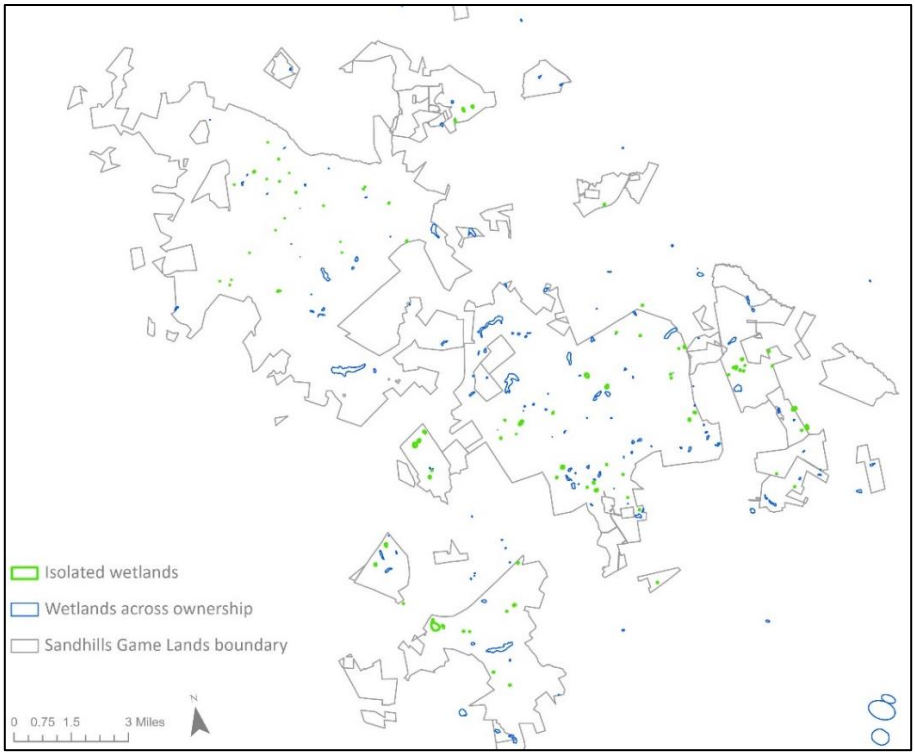


Figure 10. Known wetland locations on Sandhills Gameland, where UDWs are indicated in green.

#	Wetland Name	Acres	Block	Specific Restoration Actions	Control needed		Justification	Prior investment	Effort required
					Veg	Soil			
1	Block T Pond	5.48	T	sweetgum control in basin perimeter (large spatial scale & needs to be intensively controlled during growing season consistently over time)	Y		size, currently supporting SGCN, excellent uplands, connectivity to high quality sites, ease of management due to past restoration	High	High
2	Slate Circle Pond	1.5	B	evaluate pond basin & burms, potential soil control (recontouring road), vegetative control (sweetgum)	Y	Y	size, reliable hydroperiod, historical observation of gopher frog at the site	High	Medium/High
3	Block O Pond	2.29	O	vegetative control (sweetgum, ti ti, loblolly; Fecon & herbicide)	Y		currently supporting SGCN, reliable hydroperiod	High	Medium
4	Watson Pond	2.28	B	remove all loblolly, leave some larger hardwoods in canopy to a level that fire can penetrate, & control resprout of sweetgum after thinning	Y		size, possibility of becoming SGCN breeding site to support only other known breeding site on the property (Mabee's Salamanders)	Low	Low/Medium
5	Sarah's Pond	1.56	O	sweetgum control (Fecon & herbicide)	Y		Likelihood to support SGCN, ease of maintenance after vegetative control	Low	Low/Medium
6	Seeder Pond	2.83	T	tree removal (sweetgum & loblolly; Fecon & herbicide)	Y		Likelihood to support SGCN, ease of maintenance after vegetative control, logistically simple to manage alongside Block T Pond & Chris's Pond, proximity to established restoration wetlands currently supporting SGCN and focus of establishing gopher frogs	Low	Medium
7	Chris's Pond	1.92	T	hardwood control, possibly cattail control	Y		Currently supporting SGCN (tiger salamander), close to maintenance once vegetative control is sufficient, logistically simple to manage alongside Block T Pond & Seeder Pond	Low/Medium	Low
8	Marston East Wetland	4.42	B	pine canopy control (including removal of some longleaf) followed by hydrologic monitoring to assess hydroperiod (taproots may have affected clay lens)	Y		High priority for establishing current and anticipated breeding sites for SGCN (gopher frogs)	Low	Low
9	Strausburg Road Pond	3.21	B	vegetative control & road removal/recontouring followed by hydrologic monitoring	Y	Y	Proximity to primary breeding site of gopher frogs and tiger salamanders	Low	High
10	Little Dismal Pond	23.8	C	hardwood control	Y		SGCN breeding site (oak toad), only site in Richmond County known to have little grass frogs (heard once without the tools to document - Mike Martin, Nathan Shepard, Jeff Hall)	High	High
11	Duke Pond West	0.26	B	soil control, vegetative control (pine tree)	Y	Y	Breeding site for tiger salamanders that is positioned on a wide gap in the species' current distribution between Block B, Block T, and Jordan Tract. Could use tree removal and sculpting to better accommodate wetland plants to aid in egg-laying among amphibians)	Low	Medium-High
12	Boundary Pond	3.18	B	vegetative control (tree/shrub)	Y		Encroaching vegetation is on the verge of taking over the wetland basin, can be maintained with fire otherwise	Low	Low
13	Pitcher Pond	0.36	B	soil control (fill ditch)		Y	Could possibly support nearby SGCN sites (oak toad, Mabee's salamander)	Low	Low/Medium
14	Still Pond	0.36	B	soil control (fill ditch), vegetative control (privet)	Y	Y	Could possibly support nearby SGCN sites (oak toad, Mabee's salamander)	Low	Medium
15	Maple Pond	0.76	F	hardwood control (maples in basin)	Y		Providing connectivity for wetland-dependent amphibians in a gap where multiple degraded wetlands exist that could support SGCN species	Low	Medium-High
16A	Bare Pond	0.47	D	vegetative control	Y		Could likely serve wetland-dependent SGCN species in a gap, with this basin being proximal to multiple other degraded wetlands	Low	Medium
16B	15-501 Pond	0.4	D	hardwood removal	Y		Could likely serve wetland-dependent SGCN species in a gap, with this basin being proximal to multiple other degraded wetlands	Low	Low
17A	Jordan Preserve 1	0.4	between T & C	soil control followed by hydrologic monitoring, & longleaf restoration in uplands		Y	Likelihood to support SGCN species, provide connectivity between Blocks B & T	Low	High
17B	Fennel Pond	0.89	C	vegetative control (dog fennel dominates basin, sweetgum on perimeter)	Y		Likelihood to support SGCN species, provide connectivity between Blocks B & T	Low	Medium
18	Sassafras Borrow Pit	0.38	B	soil control followed by hydrologic monitoring	Needs Assessment	Y	Appears to possibly be an isolated wetland degraded/damaged in the construction of nearby fishing impoundment. Could serve as a priority site to expand habitat suitability for Mabee's salamanders	Low	High
19	Carrington Field Pond	0.37	F	vegetative control, canopy thinning and fire implementation needed along southeastern forested edge	Y	Needs Assessment	Potential to serve as breeding site for SGCN species in gap, bringing SGL's Mabee salamander population closer potential connectivity with extant population eastward (close to Wagram)	Low	Med
20	Spradley Pond	0.52	south of B	sweetgum removal in boundary & hydrologic monitoring. Also disjunct from main SGL blocks, so fire might be highest priority	Y		Added support for SGCN species farther south into the Carolina bays region	Low	Med

Figure 11. Map (top) and accompanying information (bottom) for high-priority restoration sites on Sandhills Game Land. Wetlands highlighted in yellow were discovered in 2023.

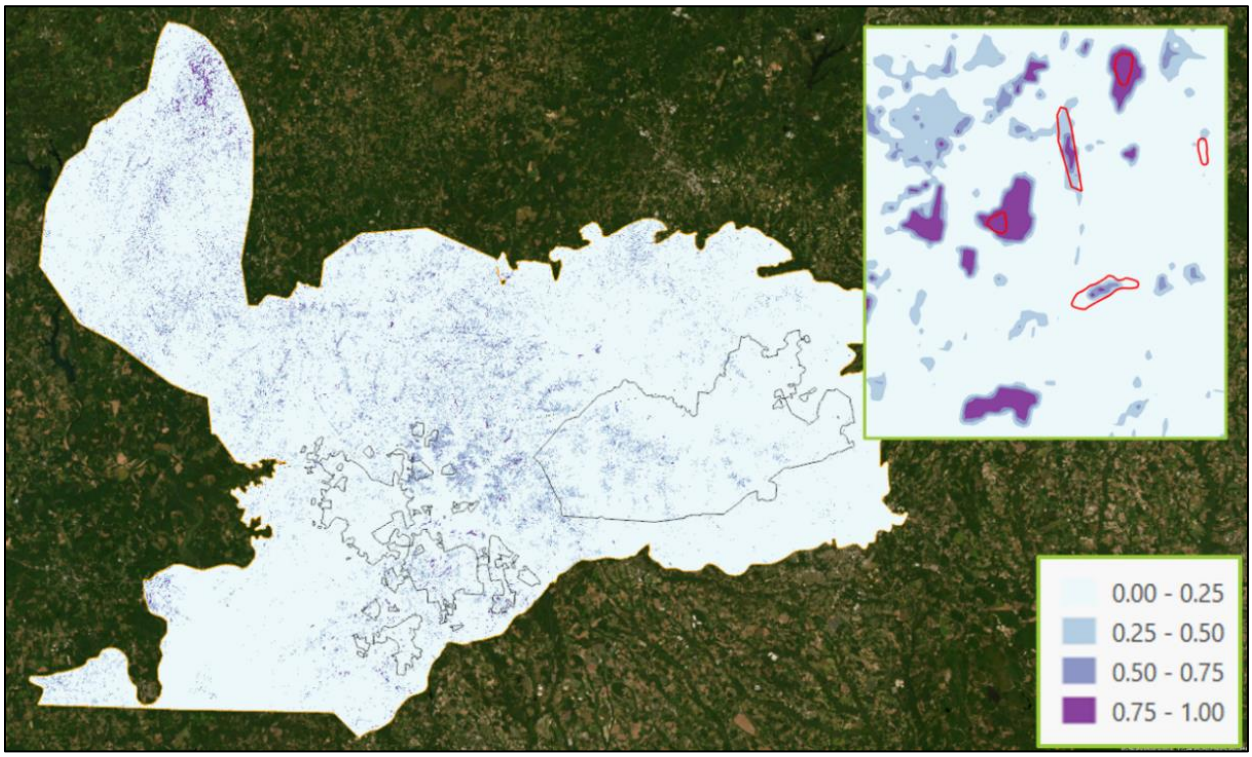
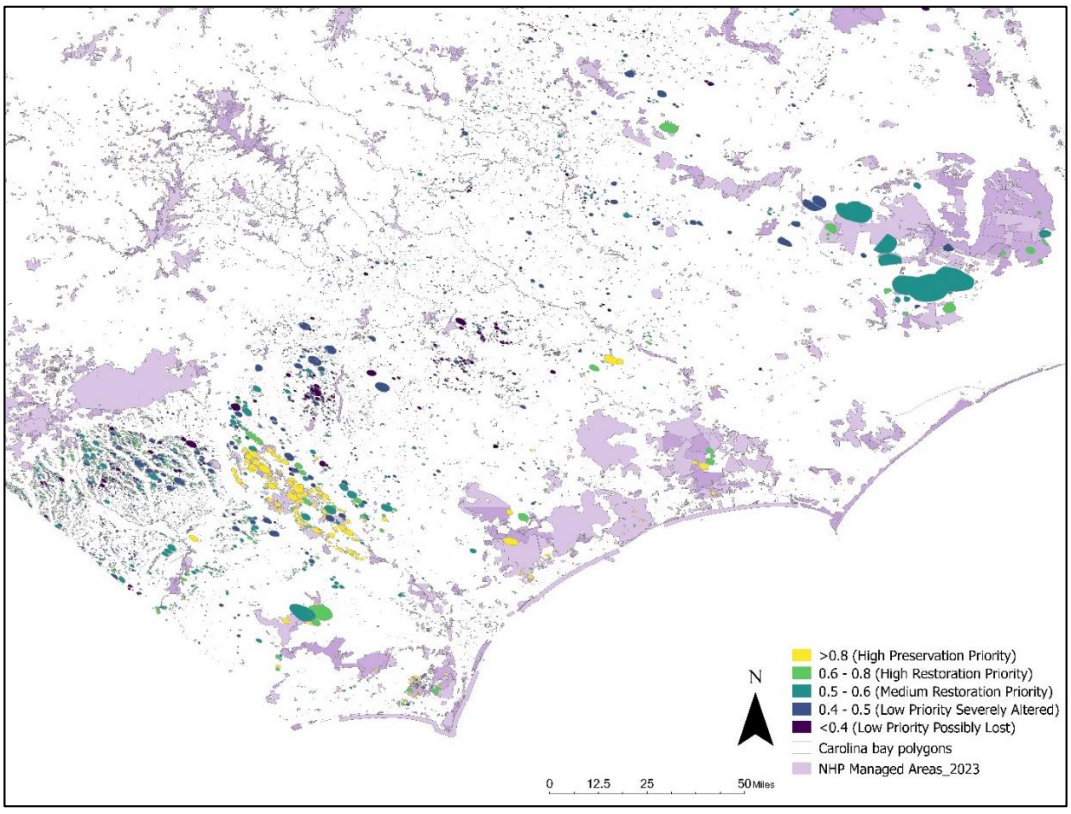


Figure 12. Map of potential wetland locations within the NCSCP boundary. The darker the color, the higher the probability of wetland occurrence. Sandhills Game Land and Fort Liberty have been outlined in gray. Known wetlands are outlined in red.

To better understand the quality and quantity of Carolina bays in NC for prioritizing conservation efforts, in 2023 Sarah Hecocks performed a simple weighted overlay in GIS to rank each bay and the 1km buffer around each bay based on land cover class, climate resiliency, NHP's biodiversity and wildlife habitat assessment, the predicted distribution of 4 SGCN amphibians (gopher frog, tiger salamander, Mabee's salamander, and ornate chorus frog), landscape connectivity (distance from currently managed area), and conservation practicality (number of landowner parcels contained). The unfortunate results from this analysis confirm that most bays, which once dominated the SE coastal plain landscape, have been severely degraded or lost. However, there is still opportunity to preserve what's left, especially within the Bladen Lakes region which contains many high-quality bays and intact upland buffers, some of which occur on conservation lands (Figure 13A). Sarah repeated this analysis for South Carolina in 2023 to guide conservation efforts initiated by Longleaf Alliance and Savannah River Ecology Laboratory (Figure 13B).

A.



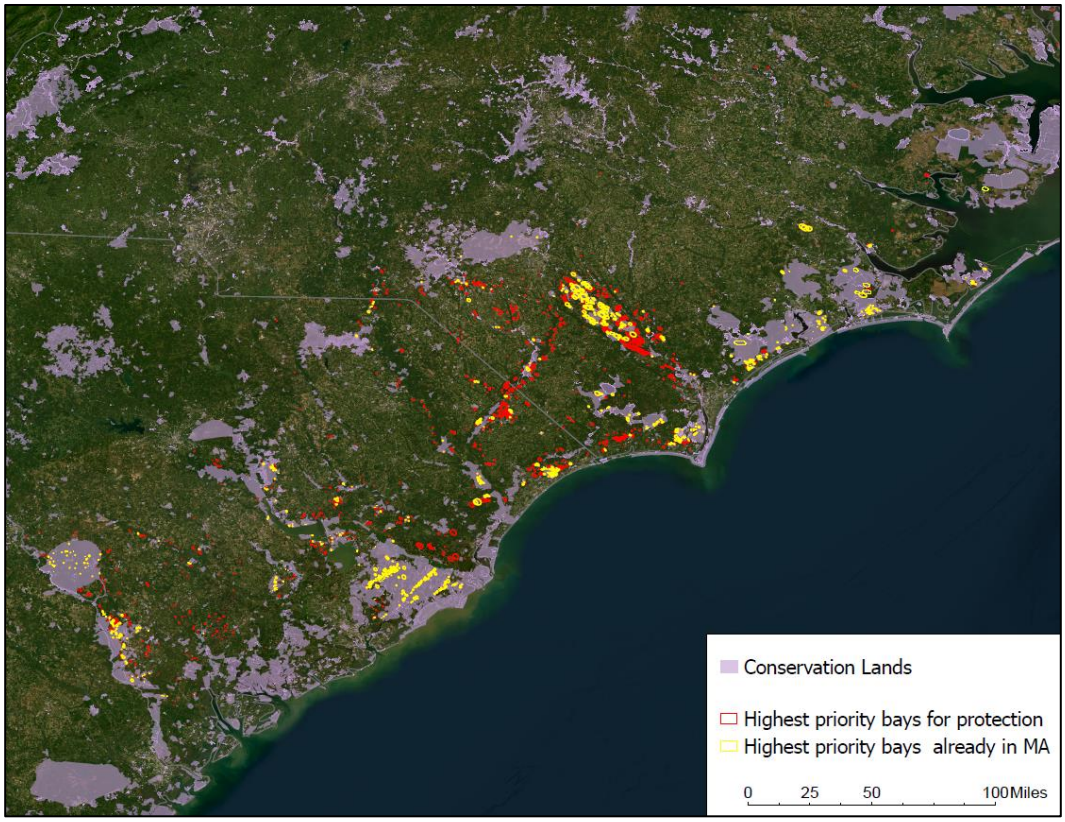
B. 

Figure 13. A: Carolina bays in NC ranked by conservation priority; B: Highest-ranking bays in NC and SC.

Monitoring of Indicator Species

Winter-breeding Amphibians

Jeff Humphries, Mike Sisson, and Mike Martin of NCWRC, Nathan Shepard of NCWRC and the NC Natural Heritage Program (NCNHP), and Jeff Beane and Alvin Braswell of the NC Museum of Natural Sciences (NCMNS) have contributed the most to our understanding of the relative abundance and activity of herp species that breed in the Sandhills. NCWRC has conducted species surveys at over a dozen sites on Sandhills Game Land. Survey methods for winter-breeding species have included counting egg masses, dip netting, and collecting auditory information either through listening or via deployment of remote acoustic recording devices. The most intensively studied site is 17 Frog Pond due to its historic success in supporting SGCN; at the site, NCWRC conducts annual egg mass surveys for the Carolina gopher frog and tiger salamander, collects incidental observations from herp-enthusiasts, and, in the past, conducted a study on gopher frog movement using drift fences and telemetry, where we learned that gopher frogs travel up to 3.5km between the breeding pond and a summer refugium (Humphries and Sisson 2012). NCWRC and Jeff Beane of NCMNS also lead long-term mark recapture studies of several snake species on Sandhills Game Land as well as opportunistic monitoring of gopher frogs, eastern tiger salamanders, Mabee's salamanders, and other rare herps in UDWs and Carolina bays on both protected and private lands.

Protection Recommendations

Across their range, UDWs are becoming increasingly isolated due to habitat destruction and intensified development which poses irreversible barriers to migration. Land protection projects should prioritize sites that contain UDWs and other "small patch" natural communities. Our highest priority should be to protect wetlands ecologically connected to known wetlands on conservation lands. The condition of UDWs should be taken into consideration, with greater focus on intact sites or those requiring less restoration effort. Priority should also be placed on providing connectors of upland habitat between wetlands, particularly for sites less than 10km apart.

The clay-based Carolina Bays found in the SE portion of the Sandhills and upper coastal plain (concentrated around Hoke, Scotland, and Robeson counties) require an updated protection strategy and new resources and partners to meet the conservation need. Protection strategies should focus first on completing protection of partially protected bays, next on protecting and restoring adjacent uplands, then on connecting functioning bays. Protection of new sites should prioritize locations where the entire basin and sufficient uplands can be protected, and sites where the hydrology and vegetation are as unaltered as possible. There are a limited number of sites that meet these criteria.

Management Recommendations

Without immediate intervention, species reliant on UDWs for breeding will inch closer towards extinction. Survival of gopher frogs head-started by the NC Zoo and released on Sandhills Gameland remains limited but does provide a source of reproductive output in years when no reproduction occurs in the wild or when focusing on establishing a population at an unoccupied site. Restoring and creating artificial wetlands is an area of experimentation in need of consistent collaboration, and we should seek to improve the processes of site selection, vegetation management, and burn regime. The high-priority restoration list provided to NCWRC for wetlands on Sandhills Game Land has proven to be a useful prioritization tool, as WRC managers have already begun implementing the recommendations. Efforts like this should be replicated once ground-truthing is complete for the remaining locations identified in the NCSCP boundary. Importantly, whether undertaking the creation of new wetlands or restoring existing ones, periodic monitoring and assessment are imperative to address emerging issues, particularly concerning vegetative response and the control of invasive species. In the meantime, the protection and appropriate management of known suitable (i.e. in good or excellent condition) breeding and adjacent dispersal habitat is crucial to sustain existing populations and should be our top priority. Ideally, prescribed fire should take place during the growing season in wetland areas to best mimic historic regimes and avoid amphibian mortality.

Fire ants are a serious problem in wetlands across conditions. While it's unlikely we will ever be able to completely eradicate them, we can mitigate their expansion by reducing ground disturbance, which is exacerbated through the creation and maintenance of fire breaks and food plots, logging, and other activities that disturb the soil. The use of pesticides to control fire ants near wetlands should be limited because of the risk of these chemicals entering the wetland and the high susceptibility of amphibians to pesticides. NCWRC has tested pressure-injecting hot water into fire ant mounds around 17 Frog Pond on Sandhills Game Land, with mixed results. The treatment removes the colonies, but they often rebuild quickly, resulting in more dispersed colonies of smaller size. The ground disturbance

created by this technique may also aid in further fire ant establishment. WRC concludes that this technique may not be worth it in the long run. Additionally, studies by Dr. Lisa Kelly and her students at UNC Pembroke have detected invasive Asian needle ants (*Brachyponera chinensis*) displacing fire ants and native ants at longleaf savannahs in the NC coastal plain. This species can cause painful bites for people and is able to colonize both disturbed and natural sites. The conservation community should be trained in identification of these ant species, and we should seek to find management solutions to infestations. Read more here.

The NCSCP is particularly well positioned to contribute greatly to the conservation and restoration of UDWs. The NCSCP has a history of work in these communities and institutional knowledge held within its members. We should continue hosting restoration workshops that promote collaboration and provide a space to share challenges and takeaways. Species at high risk of extirpation (e.g. the gopher frog) are still present on protected lands, though successful breeding events are becoming increasingly rare and unpredictable. Of all the conservation targets, UDWs appear to be the conservation target of highest need and urgency as evidenced by continued declines in habitat and breeding events. There are still great needs to focus protection and restoration efforts for Carolina bays, and a group of stakeholders may be convened in 2024 to further discuss this.

Research, Survey, and Monitoring Recommendations

There is still a need to fill knowledge gaps on amphibian SGCN life history and appropriate prescribed burn regimes, both of which are crucial for successful management. Therefore, NCWRC should be encouraged and supported in pursuing continued monitoring of UDWs and SGCN. Continued monitoring of Block T Pond following restoration and introduction of ornate chorus frogs and gopher frogs should be prioritized to document the outcomes of NCWRC's efforts. The wetlands and surrounding uplands on the Jordan Tract should also be assessed for amphibian use, restoration potential, and potential for creating artificial wetlands and stump-holes. Because the Jordan Tract links Blocks T, C, and B of Sandhills Game Land, each of which contains UDWs supporting SGCN, restoration and enhancement of habitat there can improve demographic linkages between populations. It will also be valuable to improve our knowledge of the distribution and status of amphibian SGCN on Fort Liberty, including populations within impact areas. Opportunistic species inventory surveys on private lands will help to deepen our understanding of these species and where they persist on the landscape, and could present opportunities to increase awareness of amphibian SGCN among private landowners.

The remaining high-potential wetland sites predicted by the model produced by Sarah Hecocks and Natalie Paparone should be field-validated and incorporated into the regionwide database. The database should also be made more readily available to partners so that site-specific data is regularly updated as monitoring and management continues. Sarah created an ArcGIS online-based web map that can be accessed in the field using ESRI's FieldMaps application, but adequate training and support needs to be provided to partners before there will be widespread use of the app. The how-to document for reproducing the model in similar landscapes has been shared with neighboring partnerships, and we should continue to provide guidance on an as-needed basis.

Blackwater Streams

Summary of Work

The Blackwater Streams conservation target encompasses all Sandhills waterways, including the Drowning Creek, Lower Little River, and Hitchcock Creek watersheds, each of which support notable biodiversity and provide drinking water to surrounding communities. Land use changes pose many direct and indirect threats to stream systems. To better understand how land use changes have affected the quality of Sandhills streams over time, Matthew Moskwik conducted an analysis in 2011 using NCNHP fish and invertebrate occurrence data in tandem with ~20 years of water quality data from the US Geological Survey (USGS), Environmental Protection Agency (EPA), and land cover data from the National Land Cover Database (NLCD). Results of the analysis indicated that water quality and aquatic biodiversity remain average to good across much of the Sandhills region, with some streams still excellent and relatively few in poor or highly degraded condition. These findings highlight the important need to maintain good waterways, while proactively addressing current and emerging threats.

Urbanization and changes in land-use are not occurring as rapidly in the Sandhills as other regions of the Southeast, however substantial loss of natural and forested landcover has occurred across the range and is especially evident in the Southern Pines and Fayetteville areas. Sub-watersheds downstream of Fayetteville show the greatest signs of impairment, while watersheds immediately downstream of Southern Pines show signs of deteriorating quality. Common hydrologic issues identified include declining flows, decreased oxygen, increased nutrients (in particular, nitrogen and phosphorus), and increased turbidity and water conductance, all of which negatively impact native fish species like the Sandhills chub (*Semotilus lumbee*) which is endemic to the North and South Carolina Sandhills and requires clear, cool streams with little vegetation. Consistent with similar research elsewhere in the world, results showed that macroinvertebrate and fish communities are positively correlated with natural/forested landcover, and negatively correlated with impervious surface. The macroinvertebrate and fish classes in protected areas generally ranked Excellent to Good-Fair; however, several sites on Fort Liberty ranked Fair to Poor in the fish community class (Figure 14).

Long term monitoring data indicates relatively stable baseflows in most Sandhills watersheds (Figure 15). Despite increases in nitrogen and phosphorus, Drowning Creek stands out as a particularly important and high-quality waterway, and shows the most drastic trend of declining baseflow as compared to other Sandhills streams. Increased nitrogen and decreased dissolved oxygen were observed in the Lower Little River, while increases in total suspended solids, turbidity, and conductance were observed in Flat Creek of the Hitchcock Watershed. These increases can be partially attributed to agriculture and damming of waterways, activities which often degrade habitat by affecting flow rate and increasing siltation and nutrient load, leading to increased algal growth and decreased available oxygen for native fish (Figure 18).

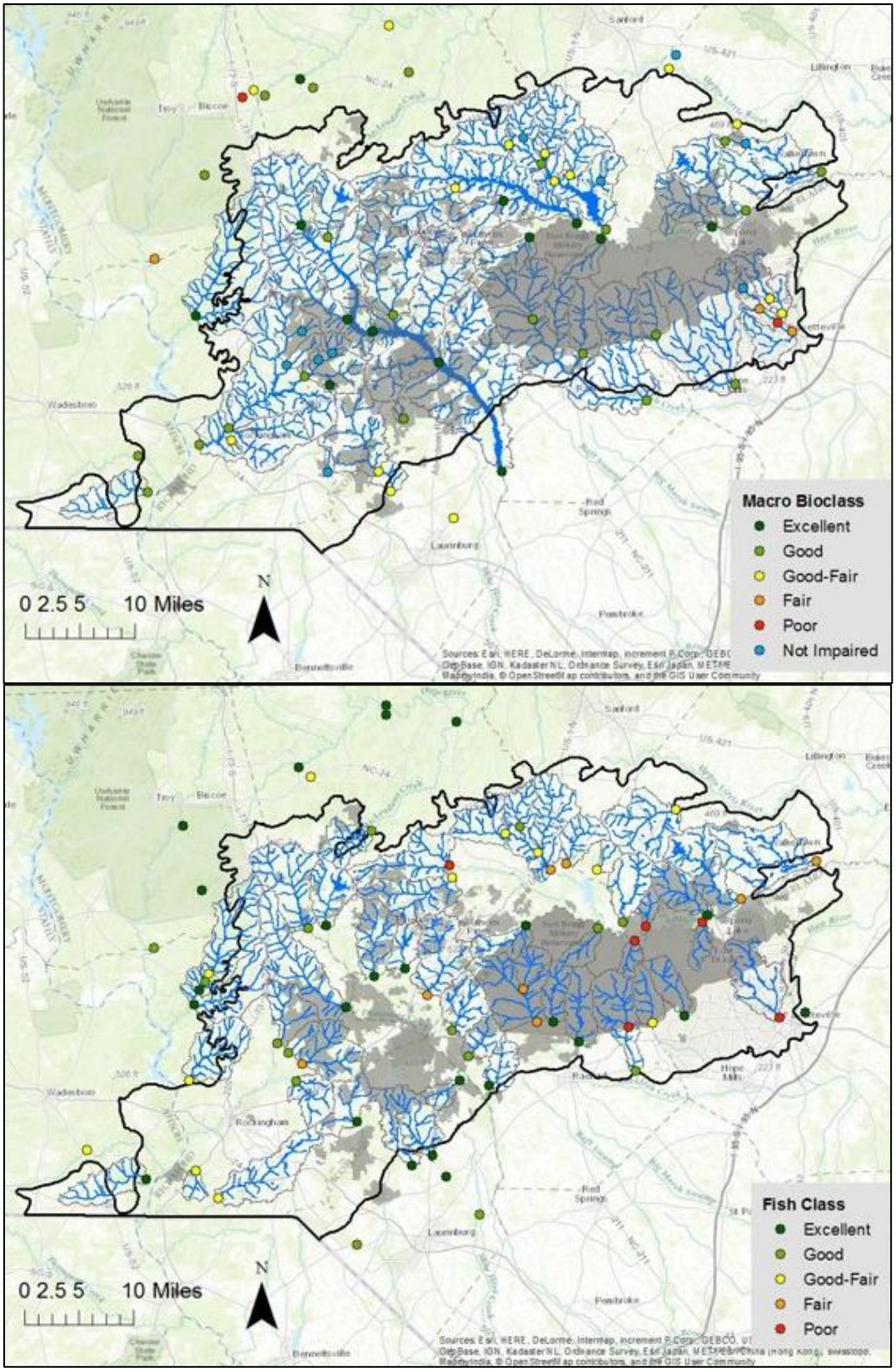


Figure 14. Top: Macroinvertebrate class locations and condition. Bottom: Fish class locations and condition.

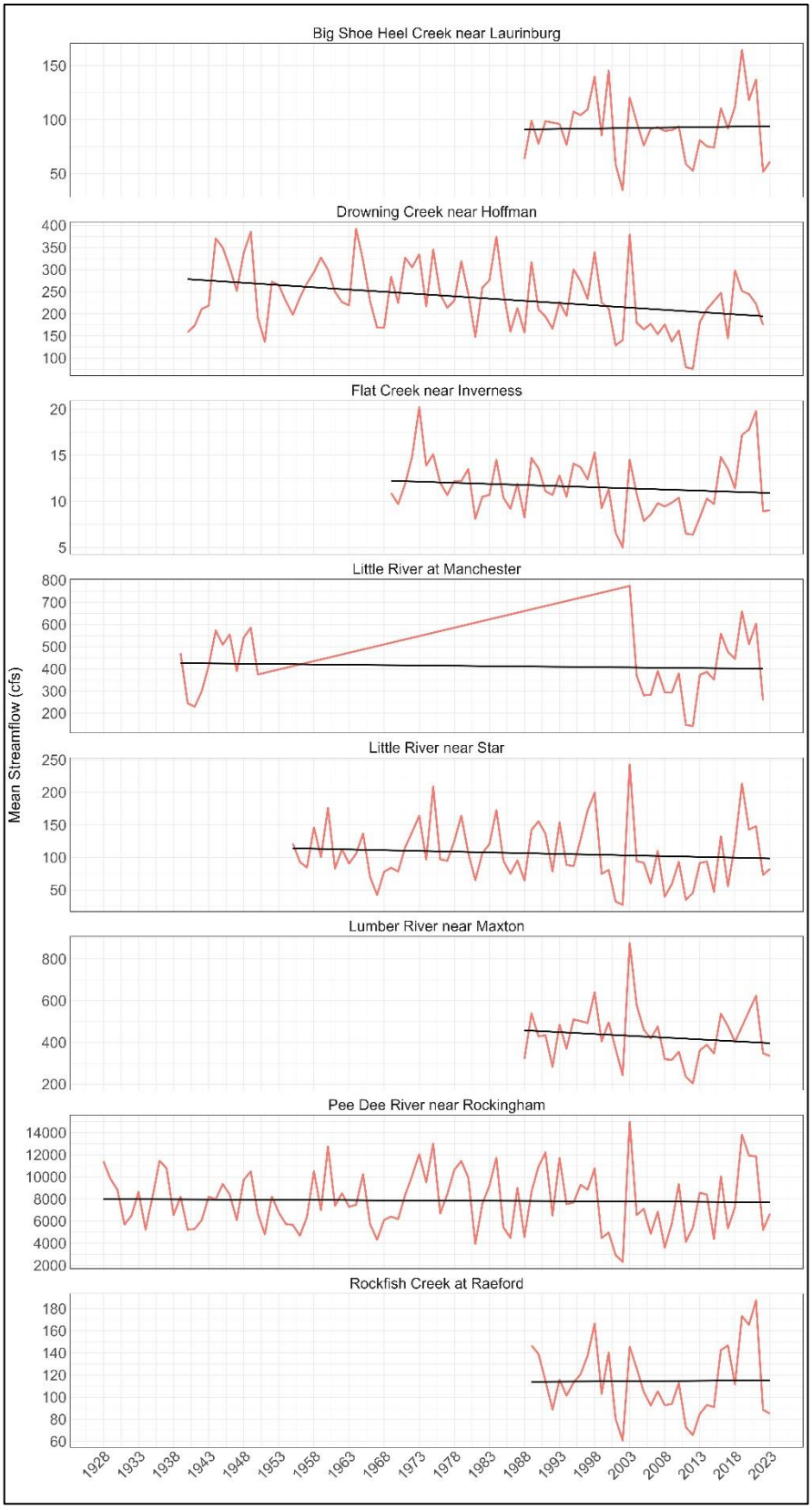


Figure 15. Flow rates in cubic feet per second (cfs) from 1940-2023. Years are shown in increments of 5.

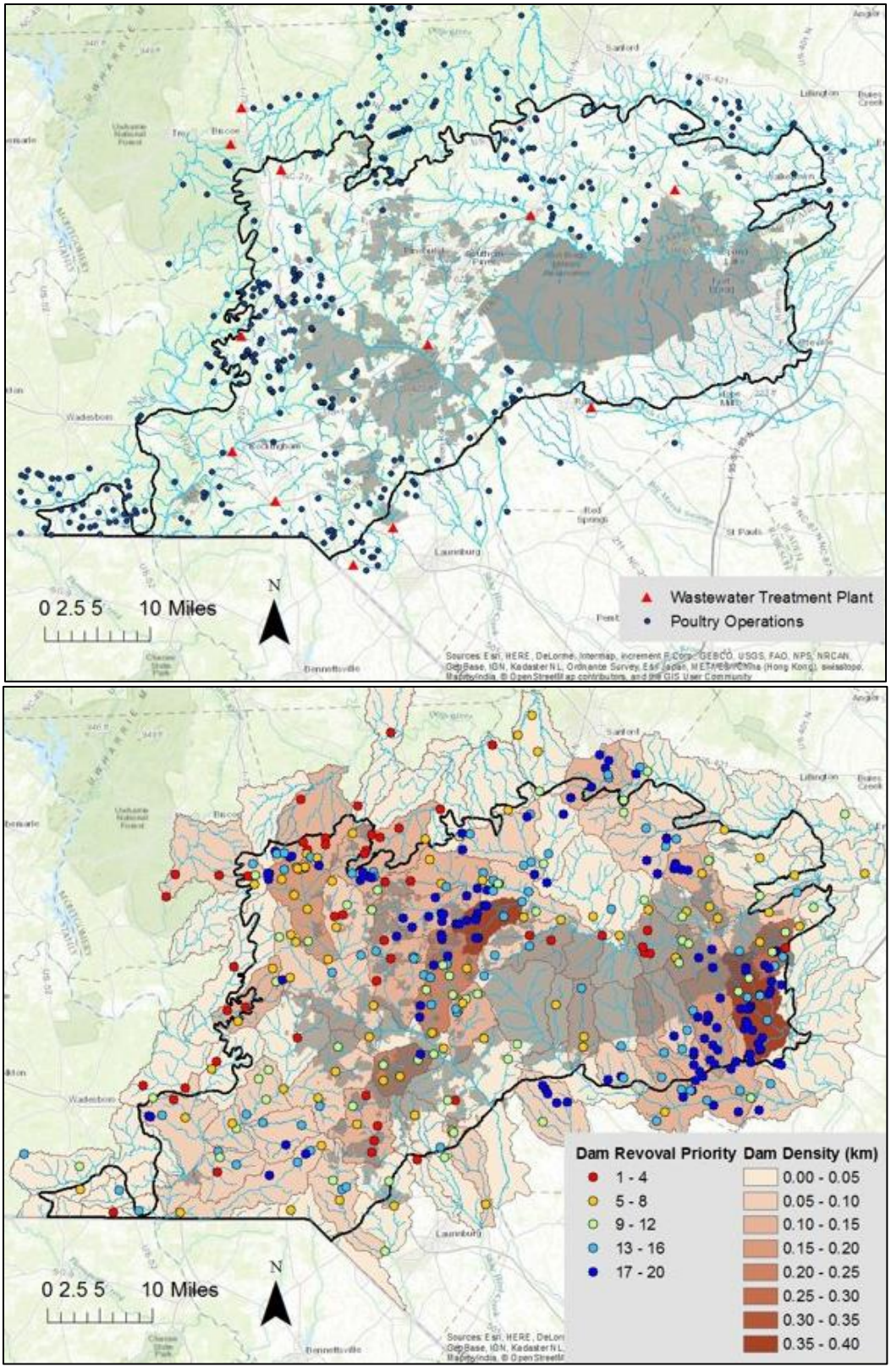


Figure 16. Top: Pollution point sources along Sandhills watersheds. Bottom: Dams prioritized for removal by density and location along watershed. Polygons in gray indicate NHP managed areas.

Research by the Younger Lab at the Jones Center at Ichauway revealed that longleaf forest restoration through fire and thinning not only increases streamflow, but also decreases flood risk, despite previous ideas that more trees on the landscape would do so. TNC has been using the USDA's SWAT (Soil and Water Assessment Tool) to develop watershed models that identify wetland and forest areas of floodplains to prioritize for restoration and protection based on their current or potential resilience to extreme flooding and drought— events that affect concentration of pollutants and are increasing in frequency and intensity due to climate change. These efforts confirm that the conservation work already being done within the NCSCP is key in preserving water quality, streamflow, and resiliency as the climate and land-use change continue to alter Sandhills waterways.

In 2023, TNC initiated an effort on behalf of the NCSCP, with support from the REPI Challenge program, to study the root causes of declining base flows in Drowning Creek and severe flood events on the Lower Little River. TNC hosted a meeting with several stakeholders to share knowledge and discuss ideas for potential causes, and is now in the investigation phase of the project.

Monitoring of Indicator Species

Currently, there is a lack of regular monitoring in the Sandhills region, as staffing and logistical capabilities are insufficient to facilitate meaningful, systematic monitoring of all priority species. The focus of NCWRC is largely dictated by dedicated funding, external assistance from partners (such as federally listed species or collaborations with groups like Duke Energy and State Parks), and similar triggers that prioritize specific projects. While the Department of Water Resources (DWR) within the NC Department of Environmental Quality (NC DEQ) has a statewide systematic monitoring program for fish communities, the program's capacity across sites was significantly reduced since the fish community program and the fish tissue contaminant program coordinator positions were combined in 2017.

Freshwater mussels

While there are native mussels present in the Lumbee River, none of the populations present are listed (E/T/Special Concern). However, detection probability for mussels is low and the absence of a listed species record does not mean the animal is necessarily absent. It is very common for both individuals and species to be missed during surveys, even by experienced surveyors, and results are very dependent on the time investment and number of repeat surveys. Additionally, regular monitoring is not conducted in the Sandhills region. There are a couple species of rare crayfishes present, including the Waccamaw Crayfish (state Special Concern; endemic to Lumbee/Waccamaw/ Little Pee Dee drainages of the Carolinas) and the Santee Crayfish (currently just on NHP Watch List; endemic to Coastal Plain of the Carolinas).

Sandhills Chub

NCWRC is currently working with two graduate students from Coastal Carolina University who are leading a project on Sandhills Chub movement and population genetics under a Competitive State

Wildlife Grant awarded in 2022. They are also documenting distribution, so we are learning a lot more about the species as a result.

Protection Recommendations

Water quality issues are some of the hardest to address, as they are influenced by multiple factors across the large area of a river basin, and require extensive collaboration between multiple parties that differ wildly in their objectives. Development is the biggest single source of aquatic habitat degradation and is largely irreversible, which makes land protection and forest management the most effective tools in sustaining aquatic biodiversity and water quality. By continuing to protect and restore longleaf pine forests, the NCSCP contributes towards overall watershed health. These efforts not only benefit the greater aquatic ecosystem, but they also help maintain a critical ecosystem service for the Sandhills communities that source drinking water from these streams. The NCSCP can actively highlight these services when conducting outreach to the community regarding increasing development.

While land protection is important for protecting water quality, it is impractical to do in the Sandhills at the scale required to protect major waterways. It is imperative to the future health of the blackwater streams target that we continue working with interested parties and promote use of the Green Growth Toolbox to ensure the amount and patterns of development is compatible with protection of water quality and quantity. It is important to minimize the negative impacts of development by advocating for stream buffers, improved stormwater management, and other BMPs that reduce runoff from impervious surfaces.

Management Recommendations

We need to improve our understanding of the relative contributions of impairments and other threats before making management recommendations to address them. Future management recommendations could include dam removal, streambank stabilization and restoration, encouraging living with beavers and/or creating beaver dam analogs in headwaters, managing releases from dams, promoting stream buffers, managing ground and surface water withdrawals, and improving Best Management Practices for pollution sources.

Research, Survey, and Monitoring Recommendations

The landscape-level watershed analysis conducted in 2015 should be repeated every 10 years. Results can be used to highlight trends and target areas of concern that may require more intensive monitoring and conservation action. For example, the long-term trend of declining flows in Drowning Creek, which provides drinking water for Southern Pines, warrants concern. We don't yet have an adequate explanation for why this is, how much of a threat it poses, or what can be done about it. A study is underway as of December 2023 to better understand root causes of this problem and potential solutions. Additionally, the Strategic Environmental Research and Development Program (SERDP) developed ecological reference models that specifically quantify fish and macroinvertebrate

communities and hydrogeomorphic conditions, which can be used to identify degraded sites in need of restoration. More info here.

The Sandhills aquatic communities would also benefit greatly from a systematic monitoring initiative. Currently, the NCWRC's Aquatic Wildlife Diversity program lacks the capacity to undertake such an effort independently. If collaborative partners were willing to join forces, NCWRC would gladly offer technical guidance to support such an endeavor. Upon inquiry about the status of the DWR monitoring program and to emphasize the need for such work in the Sandhills, the monitoring program coordinator, Jeff Deberardinis, said to reach out if there are stream sites that the Partnership thinks need specific DWR attention for either fish community or benthic macroinvertebrate assessment.

Streamhead Pocosins and Seeps

Summary of Work

Streamhead Pocosins and Seeps (SPS) are biodiverse natural communities associated with areas where groundwater is forced to the sandy soil surface by a clay layer. The quality of the habitat and the species these wetlands support is highly dependent upon the hydrology and management history. Like many natural communities in the Sandhills, SPS have suffered from fire suppression and other land use changes. Some of the best remaining examples of Sandhills seeps occur in powerline cuts.

The NCNHP hosts the best available spatial database for these community types across the Sandhills (largely on Sandhills Game Land and Fort Liberty); despite this, we still have a very limited understanding of how to best characterize and manage them. Until a few years ago, many of the Element Occurrences (EOs) identified by NCNHP were not accurately mapped and hadn't been revisited in over a decade. In 2019, Ana Castillo sought to improve our knowledge on the quality and extent of Sandhill Seeps by revisiting and establishing photo points for known EOs on Sandhills Game Land, Calloway Forest Preserve, Bonnie Doone, the Walthour Moss Foundation and other partner lands. Rapid assessments, modeled after NatureServe's Ecological Integrity Assessment framework, were conducted at each site to estimate quality and restoration potential (Figure 17). Data collected were integrated into the NCNHP database and have since provided a baseline for identifying restoration opportunities.

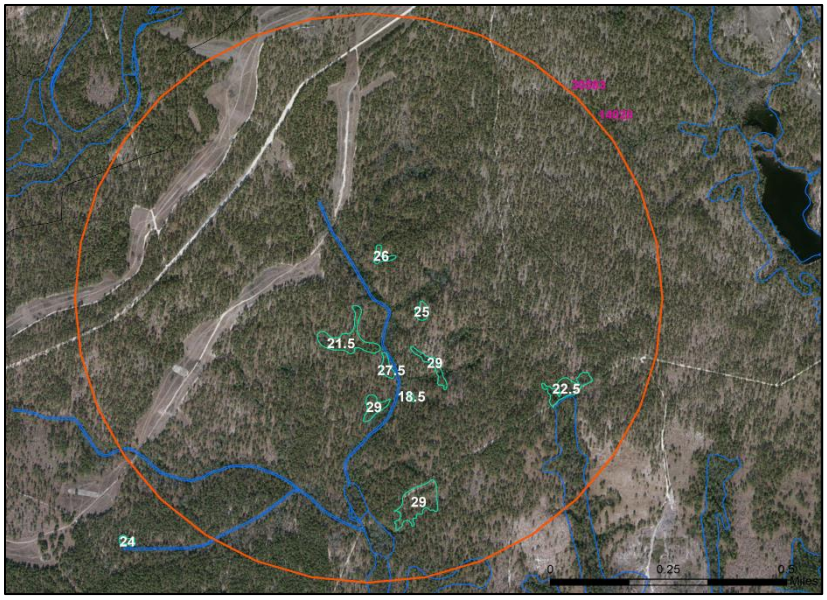


Figure 17. Seeps mapped and scored on Sandhills Game Lands Block A in 2019, previously surveyed in 1998.

A 2016 publication (Gray et al. 2016) provides insight on how to manage canebreak systems, noting that canebreak area increases as fire-return intervals decrease, but that increase begins declining as fire return intervals become more frequent than every 2 years. The publication contains extensive information on plant species supported by canebreaks, many of which are increasingly rare. Black Creek on Fort Liberty contained some of the highest species diversity observed in the study (201 species), where canebreak area has increased over time (Figure 18).

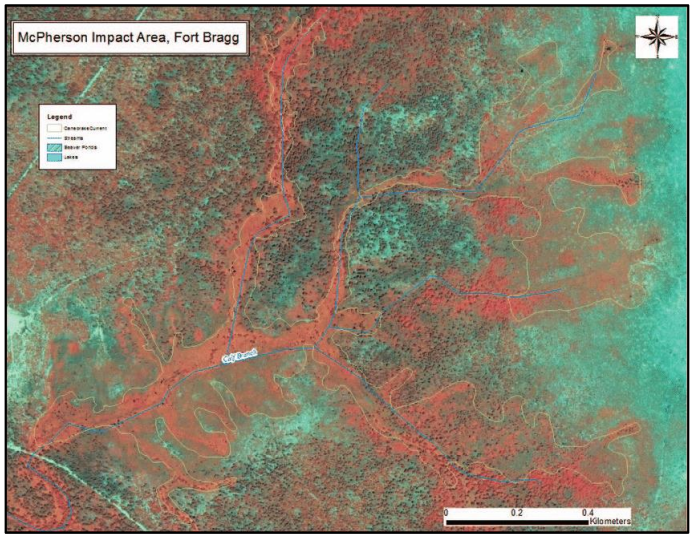


Figure 18. Calf Branch on Black Creek, Fort Liberty. Outlined, light-salmon color areas indicate the canebreaks. Canebreaks have a unique spectral signature that can be easily distinguished from other land cover types in a near-infrared image. From Gray et al. 2016.

Monitoring of Indicator Species

Saint Francis' satyr

The critically endangered Saint Francis' satyr (*Neonympha mitchellii francisci*; SFS), found in only a few streamside sedge meadows on Fort Liberty, relies on two disturbance regimes to persist. The wet, open sedge meadows it inhabits need maintenance from regular flooding and drying caused by beaver dam activity, and localized fire, which occurs frequently on the military base following heavy artillery use. Following natural succession and encroachment by woody vegetation, SFS will disperse to adjacent habitat; however, without frequent disturbance, adjacent habitat is unavailable and population loss is inevitable. Additionally, SFS have limited ability to disperse over long distances, highlighting the need for adequate habitat connectivity.

Via SERDP, the Haddad Lab at Michigan State University has been monitoring SFS since 2002 and conducting habitat restoration (including re-restoration) outside of the Impact Area since 2011. Restoration consists of manual removal of woody vegetation in 30x30m plots connected by 5m-wide corridors. To assess restoration success, the lab monitors habitat quality, SFS dispersal, and demography over time. Monitoring following restoration shows that positive response of vegetation and SFS declines as time since restoration approaches 10 years (Figure 19). While survival of deployed eggs has proven to be high in the wild, larval survival is much lower over winter than between flight periods.

In collaboration with TNC, the lab also created 9 15x15m plots on TNC's Calloway Forest Preserve through dam installation, woody vegetation removal, and seeding and planting of sedges, which was the first attempt at creating new potential SFS habitat outside of Fort Liberty. To date the plots on Calloway have not developed into high quality SFS habitat, largely due to the hydrology not being right.

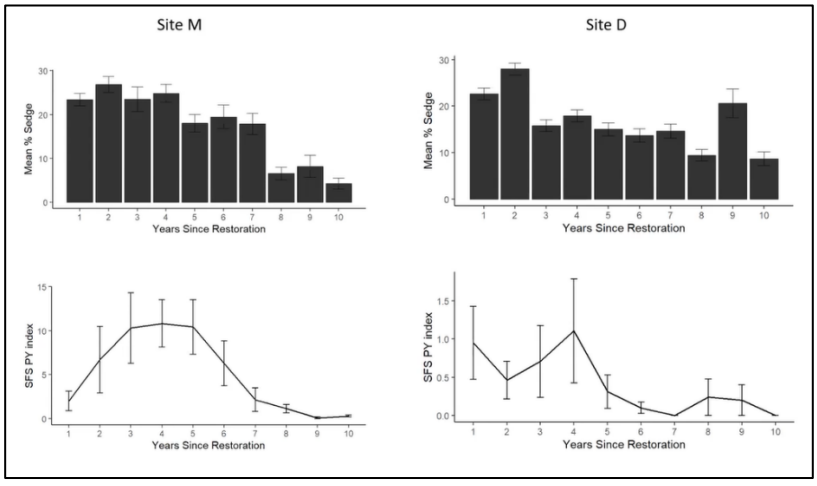


Figure 19. Response of sedges and SFS following restoration in areas outside of Impact Area on Fort Liberty. Percent sedge cover and quantity of SFS decrease as years since fire increase.

Venus flytrap and other sensitive plants

Surveys have been conducted by the NCNHP, Plant Conservation Program (PCP) and Fort Liberty Endangered Species Branch for the Sandhills lily (*Lilium pyrophilum*), Venus flytrap (*Dionaea muscipula*; VFT), rough-leafed loosestrife (*Lysimachia asperulifolia*) and other rare species associated with SPS to inform locations of high-quality sites.

Venus Flytrap populations in the Sandhills are currently only known on Fort Liberty. Research by SERDP on growth, survival, and recruitment showed that the optimal fire return interval for maximizing VFT population growth rate is around 10 years (Figure 21). Importantly, this does not mean that the larger landscape should be burned every 10 years; rather, because VFT occur in wet microsites within the larger longleaf landscape, it's likely that, while the surrounding landscape should be maintained with a 1-3 year fire return interval, highly productive VFT sites are only being burned once every 10 years on average. Climate modeling efforts suggest that VFT population growth rates increase under future climate scenarios, and that VFT sites should burn once every 12 years on average. Additionally, experimental work suggests that positive fire effects on population growth rate are driven in part by competitor removal and addition of ash immediately following fire (Louthan et al. 2022). Other biologists and land managers familiar with VFT consider the results of this study suspect, as field observations suggest that VFT populations are negatively impacted by fire return intervals greater than ~4-5 years and that populations flourish on conservation lands burned every 2-3 years.

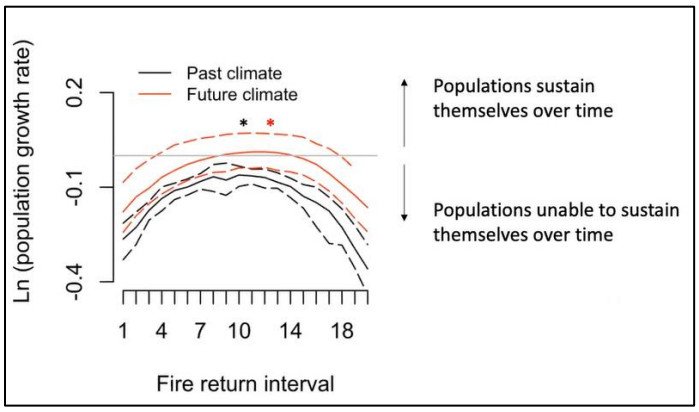


Figure 21. Fire return interval of 10 years is ideal for VFT population growth rate under past climate scenarios, while 12 years is ideal under future climate scenarios, according to Louthan et al. 2022. Other biologists and land managers suggest that much more frequent fire return intervals are required.

Other threats to VFT include habitat loss or degradation (often through fire suppression), land conversion (e.g. agriculture), illegal harvest, nitrogen pollution, and climate change (e.g. drought, coastal flooding from sea level rise). While populations small in either size or geographic range tend to be especially vulnerable to these threats, SERDP concluded that drought and high nitrogen levels from industrial pollution have negative effects on plant growth that are consistent across the VFT's range. This finding may mean that considering source population may be irrelevant when planning

reintroduction efforts. Fort Liberty was identified to be the driest in comparison to coastal locations, which may mean that VFT on Liberty are more sensitive to extreme drought; many populations on the installation have already disappeared, potentially in part due to prolonged drought.

Pine Barrens Tree Frog

NCWRC regularly conducts inventory surveys for the pine barrens tree frog (*Dryophytes andersonii*, PBTF; Figure 20) and has collected telemetry data in the past.

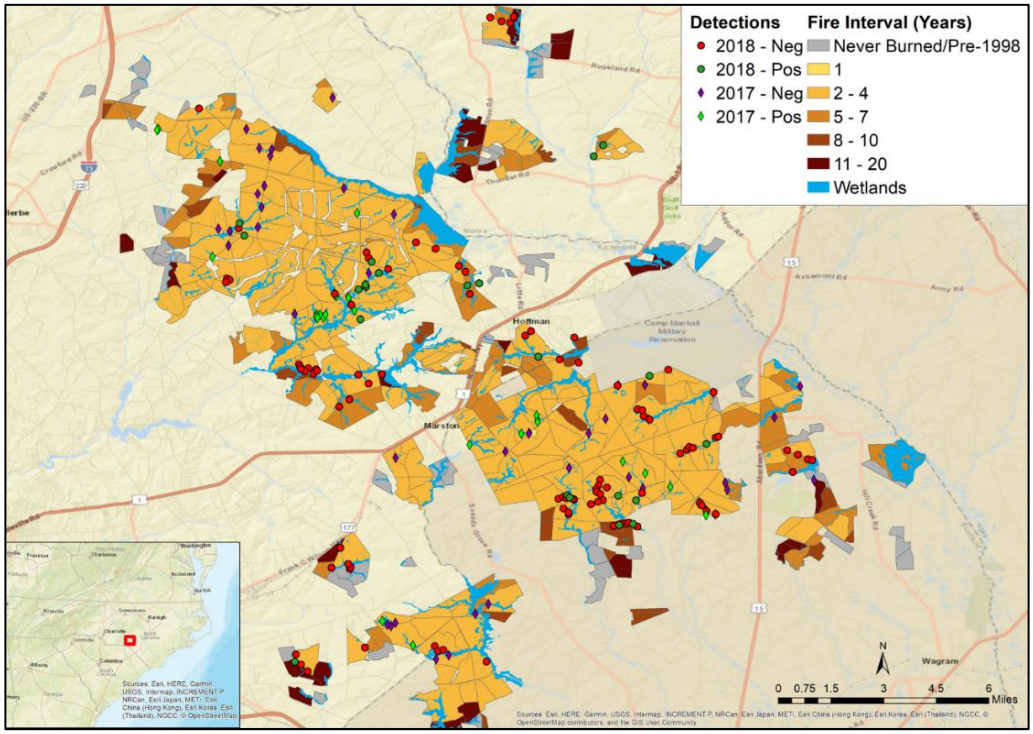


Figure 20. Results from pine barren tree frog monitoring on Sandhills Game Land 2017-2018.

Protection Recommendations

The presence of a high quality streamhead pocosin or seep habitat on a parcel should elevate its priority for protection. Likewise, it should be an elevated priority to protect land that connects known high quality seeps and drains, and/or improves ease of management with fire.

Management Recommendations

Although high quality SPS are increasingly rare due to continued fire suppression, the community types appear to respond well to reintroduction of fire as well as mechanical clearing of vegetation. For example, Bonnie Doone hosts a few small, fire-suppressed seeps that the land manager,

Wendy Dunaway, keeps open via hand-clearing, and they sustain an impressive amount of plant diversity. However, the best and most extensive SPS are found on conservation lands where there is regular prescribed burning. Since these communities are embedded in the longleaf ecosystem, management through fire can be achieved as part of a whole-system approach. To do so successfully, it is important to encourage fire to spread through drains and ensure that fire lines are not constructed in a way that would impede fire from doing so. Where feasible, burn units should be designed or modified to burn from ridge to ridge rather than from drain to drain. The ecotone between the uplands and the drainages is where many of the plant SGCN are found, and where vegetation is prone to becoming overcrowded. Fire that occurs during the growing season is the least likely to cause mortality of sensitive winter-breeding amphibians and dormant or larval overwintering insects.

Research, Survey, and Monitoring Recommendations

Going forward, the NCSCP should seek to better understand how fire affects plant community structure. Although some species are intrinsically rare, many others show strong responses to fire, yet we don't know enough about the effects that fire frequency, seasonality, and intensity have on altering species assemblages. NCWRC has had issues managing rough-leafed loosestrife on the Game Lands, and the PCP has lingering questions about Sandhills lily management on Eastwood Preserve.

The NCSCP should also consider investigating the ecological role and importance of connectivity between seeps and drainages. There is a need to understand more about the distribution, status, and dispersal potential of pitcher plant moths (*Exyra semicrocea*). This species has a metapopulation dynamic and depends on dispersal from connected populations to re-colonize habitat after fire.

It would also be beneficial to better understand the dispersal capability and survival of PBTF. Specifically, how far will individuals travel between suitable habitat patches? Do they migrate over uplands or follow drainages? How do they survive prescribed fire, and how quickly are sites recolonized if local populations are extirpated? When habitat is degrading from long term fire suppression, will they eventually attempt to leave the site and colonize a new site? At what point does the habitat become unsuitable? How long can a PBTF live?

Climate Change

Although the NC Sandhills are known for being especially adapted to high summer temperatures and frequent fire, the region is not immune to the growing climate crisis that is affecting our planet. Future projections for the region indicate likely additional warming of 2-4 degrees Fahrenheit by mid-century and potentially up to 8 degrees by the end of the century. Nights where temperatures don't drop below 75 degrees will become more common, with about an extra month of these nights per year. Average summer high temperatures could approach 95-100 degrees, further exacerbating the region's status as one of the hottest parts of the state. There will be more intense but less frequent rainfall events, leading to higher evaporation due to rising temperatures and more severe drought. Extended wildfire seasons are expected, starting earlier in late winter and early spring and potentially lasting later into the summer, leading to a 74% increase in lightning-caused fires across the state and decreased prescribed burning opportunities. The region will also experience weather whiplash, with heavy drought

followed by heavy flooding and vice versa, affecting aquatic species and pond-breeding amphibians. There is less confidence in model ability to predict the number of landfalling hurricanes, coastal winter storms, freezing rain/ice storms, and near-surface ozone formation conditions.

While longleaf pine is predicted to be one of the forest types more resilient to climate change, negative impacts are still predicted. As temperatures rise, weather patterns shift, and extreme events become more frequent, the delicate balance of this ecologically significant area is increasingly at risk. The consequences of climate change, including more intense droughts, increased wildfire risk, and altered precipitation patterns, pose significant challenges to the region's conservation efforts. Amid these challenges, addressing the climate crisis in the Sandhills region has become an urgent priority, necessitating a comprehensive approach to mitigate its impact.

The best way to inoculate Sandhills habitats from climate stressors is to ensure as many habitat areas are in “maintenance class”. Frequently burned sites have lower fuel loads, can be prescribed burned under a wider range of conditions, and can go longer between burns without losing biodiversity. Increasing the number and quality of wetlands and connectivity between them will help to ensure that at least some suitable breeding areas will be available and accessible under a range of conditions and more species that depend on these habitats will persist on the landscape. Priorities going forward should include maximizing efficiency and extent of prescribed burns within narrower weather windows, evaluating opportunities for resilience through remote sensing and nature-based solutions, ramping up longleaf pine restoration efforts to increase streamflow and enhance regional resilience to drought, preparing for future invasions of nonnative species, and continuing to address issues related to urbanization. Protection efforts should focus on enhancing habitat connectivity and ease of management. NCSCP should also prioritize restoration of fire-managed pine habitats in the Uwharries, as the Uwharries are predicted to have higher than average climate resilience and could become a climate refuge for some species. Interdisciplinary collaboration among experts in biology, ecology, climatology, and related fields is vital to provide a holistic approach to addressing climate and biodiversity challenges.

Conclusions

The collective biological monitoring efforts outlined in this report provide foundational knowledge of the NCSCP’s conservation targets and a pathway for their continued management and conservation within the longleaf pine whole system. In part due to these efforts, the NCSCP has had many notable accomplishments including meeting the RCW NC Sandhills recovery goal, increasing prescribed fire on private land, and restoring and protecting many acres of longleaf forest in the NC Sandhills region. As the next iteration of the biological monitoring program continues, it is important to acknowledge and think critically about how to build upon these great accomplishments and further develop the monitoring program. Of the animal groups receiving attention, the invertebrate taxa have been heavily neglected, and are probably one of the last groups that are in justifiable need of basic monitoring. To this end, the NCSCP should consider establishing a dedicated invertebrate monitoring program to improve decision-making when identifying areas and management actions for conservation and habitat restoration that favor these species. In considering where to expand efforts and increase connectivity

and resiliency, the NCSCP can refer to TNC's Longleaf Action Map: a range-wide prioritization that incorporates biodiversity, climate resilience, landscape context, and opportunity (Figure 22).

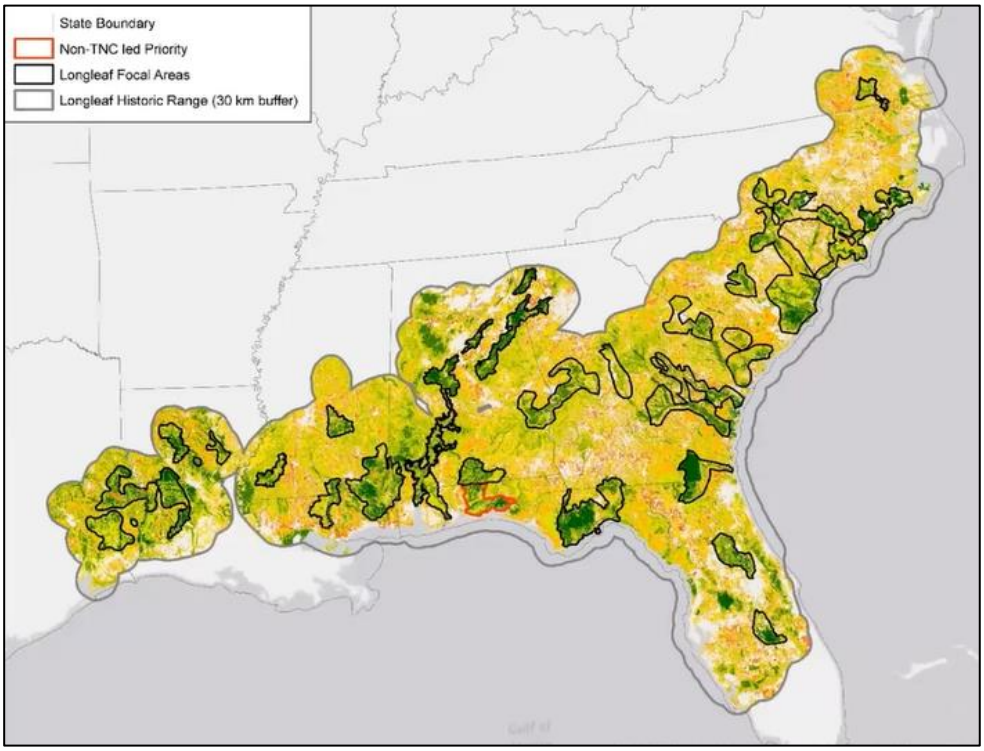


Figure 22. TNC-identified focal areas for conservation within the longleaf pine whole system. Total acreage of TNC focal areas is 32,212,700 acres.

Although the Biological Monitoring Plan was structured within an annual framework, where the ORISE Fellow would focus on one conservation target per year, the 5-year timeline to repeat target assessments is often delayed. This is in part due to turnover of the ORISE Fellows, each of whom arrive to the position with their own unique skillset and limited tenure, but also due to the nature and scope of each project. Before the next iteration of the biological monitoring cycle, it is recommended that the NCSCP forms a subcommittee to review this report, update the plan and timeline, and discuss strategies for coordination and funding.