Benefits of Wetland Hydrology Restoration in Historically Ditched and Drained Peatlands: Carbon Sequestration Implications of the Pocosin Lakes National Wildlife Refuge Cooperative Restoration Project

Pocosins are unique wetlands, also known as southeastern shrub bogs. These peatlands are characterized by a very dense growth of mostly broadleaf evergreen shrubs with scattered pond pine (Figure 1). The typically thick layer of peat soils (Histosols) underlying pocosins are chemical sponges over geologic time, locking-up metals, carbon, and nitrogen in vegetation and the deepening soil layer. Under normal saturated hydrologic conditions, decomposition in organic soils is minimized due to a lack of oxygen, allowing for accumulation of organic carbon in peatlands worldwide. Millions of hectares of former peatlands in the U.S. have been drained and converted to agriculture and forestry. North Carolina's Albemarle-Pamlico peninsula is the site of the greatest pocosin acreage in the U.S. (Richardson et al. 1981). As pocosins southeast of Lake Phelps, North Carolina were drained for now defunct farming and peat mining operations, their ability to retain carbon (a known source of global climate problems) was diminished resulting in releases of carbon to the atmosphere and adjacent waters. When these lands became part of Pocosin Lakes National Wildlife Refuge (NWR) in 1990, managers began restoring water levels. Restoration is returning the lands to a more natural state and is expected to sequester tons of carbon while providing other important habitat benefits.

Figure 1. Healthy pocosin wetlands have important wildlife habitat, nutrient storage and water quality functions. Their peat soils store tons of nutrients like nitrogen, and carbon. Photo: Dale Suiter

There are important opportunities to expand restoration of drained peatlands, on-and off-refuge, because millions of acres of these lands have been degraded in North Carolina (Figure 2) and nationwide. The following discussion provides 1) a summary of the benefits of peatland hydrology restoration, 2) a discussion of the climate change implications of peatland restoration (with focus on the estimated carbon retention capacity of restored lands), 3) an update of the ongoing hydrology restoration project at Pocosin Lakes NWR, and 4) details regarding additional opportunities for restoration on- and off-refuge.

Benefits of Peatland Hydrology Restoration

Pocosins are extremely flat and generally removed from large streams so that their natural drainage is poor. Poor drainage and organic matter input (leaves, sticks, etc.) over thousands of years causes soil genesis dominated by organic material accumulation in the surface layers. Pocosins are characterized by deep organic soils, or Histosols, with a minimum of 20-30% organic matter and a depth of organic matter > 40 cm, but up to as much as 4 meters in eastern North Carolina (USDOE and NCEI 1982). With abundant organic matter, these soils are approximately 42 to 49 percent carbon (Dolman and Buol 1967, Thompson et al. 2003). Over time, many of these areas were drained for agriculture (Figure 2). Draining organic soils promotes aerobic decomposition and the loss of soil carbon via gaseous carbon dioxide emissions and as both inorganic and organic carbon in surface and groundwater, resulting in peat oxidation and subsidence. Accordingly, artificial drainage alters the carbon balance such that peatlands that historically sequestered carbon now are a source of carbon to the atmosphere and runoff water (Figure 3). Restoring peatlands through re-introduction of wetland hydrology, however, stops the loss of carbon from these soils and, in fact, converts them from a source of carbon to a sink. The most immediate and predictable net benefit from restoring drained peatlands is the interruption of carbon dioxide release to the atmosphere that results from reversing peat oxidation.

In addition to the carbon benefits realized through peatland restoration, replacing hydrology conditions provides other important benefits to water quality and wildlife habitat. Artificial drainage of peat wetlands contributes to off-site water quality impacts by speeding the pace of runoff and increasing discharge peaks (Kirby-Smith and Barber 1979, Daniel 1980, Gregory et al. 1984). There is well-documented concern that drainage-enhanced oxidation of soils re-mobilizes mercury (Lodenius et al. 1987) and nutrients (Brinson 1991). Accordingly, restored sites retain and prevent runoff of metals, nutrients and other soil constituents into adjacent estuaries. Restoration of pocosin hydrology has also been a longstanding management goal of the U.S. Fish and Wildlife Service (Service). Because drained peat soils do not support the same type and diversity of vegetation as the natural, un-drained organic soils, hydrology restoration enhances this unique wildlife habitat.

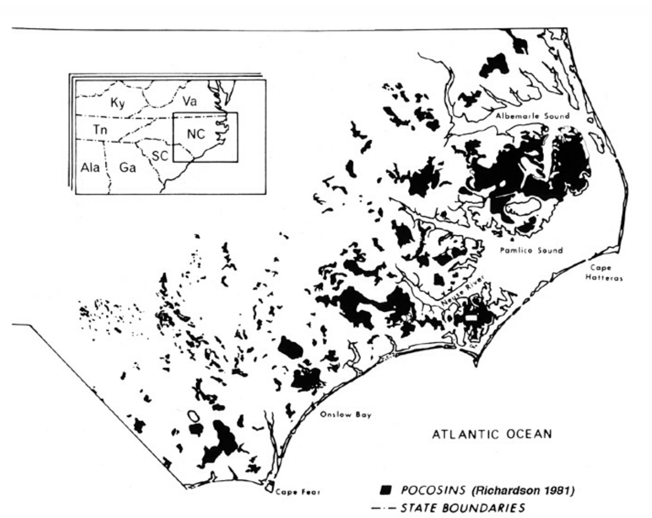


Figure 2. Distribution of pocosins and Carolina bays in North Carolina. Total area was estimated to be 2.2 million acres by Wilson in 1962, but declined to 0.7 million acres by 1980 (Richardson 2003). Restoration of degraded peatlands has great potential carbon and nitrogen sequestration benefits.

Pocosin restoration also plays an important role in reducing the frequency and severity of wildfires, which exacerbate soil loss and off-site transport of soil constituents. The drained, drier peat is highly combustible providing fuel for catastrophic wildfires (such as the 1985 Allen Road and June 2008 Evans Road Fires) and resulting severe ground fires which burn carbon-rich soils. Based on an estimated burned area and depth of peat burned in the Evans Road Fire, the carbon loss likely exceeded 6 million tons of carbon (or the carbon in 22 million tons of CO_2). Saturation of the soils limits the potential for peat ground fires to burn intensely while still allowing the above ground vegetation to burn (a necessary component of pocosin ecosystems).

Finally, restoring hydrology conditions stops the loss of peat soils (via oxidation) while allowing soil generation and biomass accumulation to resume, resulting in increasing elevation of previously drained pocosins with time. By preventing incremental (via oxidation) and catastrophic (via burning) soil loss while generating a deeper soil layer, hydrology restoration in drained coastal peatlands like those in eastern North Carolina provides an adaptation mechanism to sea level rise.

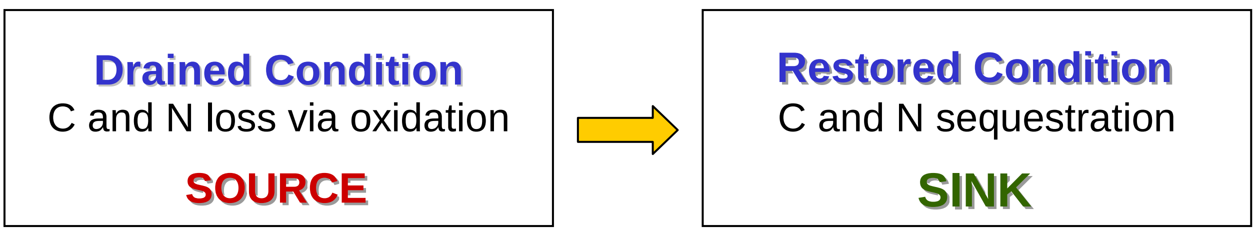


Figure 3. Restoring wetland hydrology in peatlands stops carbon loss from peat soils and converts them from a source of carbon to a sink as aerobic (drained) conditions return to an anaerobic (restored) state.

<u>Carbon Sequestration Potential of Peatland Restoration</u>

The total nitrogen and carbon sequestration estimate for restored peatlands has three primary components: a) the amount retained in peat soils once soil genesis is re-established, b) the amount retained that would otherwise be lost without hydrology restoration (or the stop loss component), c) and the amount sequestered in the above ground biomass (Table 1). The expected benefits are illustrated in the following peer-reviewed calculations:

Table 1. Estimated nitrogen and carbon sequestration capacity of pocosin wetlands with completed hydrology restoration.

Components of Sequestration Estimate	Sequestration (lb/ac/yr)	
	Nitrogen	Carbon
a) Carbon and nitrogen retained in peat soils	7	230
b) Amount retained which would otherwise be lost without hydrology restoration	190	6100
c) Amount sequestered in the above ground biomass	0.6	140
TOTAL	**200**	**6500**

a) Carbon and nitrogen retained in peat soils

Bulk density (kg/ft^3) X Peat depth (ft) X Peat age (yr) X Peat N or C content (%) X CF = **7 lb N/ac/yr** or **230 lb C/ac/yr** sequestered

- Bulk density range[1] from 0.049 to 0.347 g/cm^3 (assume mid-range of 0.2 g/cm^3, or 5.66 kg/ft^3)
- Depth of peat lens[2] northwest of Pungo Lake = 7.6 feet
- Age of peat soils[2] northwest of Pungo Lake = 7500 y
- Peat nitrogen content[3] 0.9 to 2.4% N d.w. (assume mid-range N content of 1.35% N d.w.); Peat carbon content of 42.56%[2]
- CF = conversion factors for ft^2/ac and lb/kg

b) Amount retained which would otherwise be lost without hydrology restoration

Rate of peat loss (ft/yr) X Bulk density (kg/ft^3) X Peat N or C content (%) X CF = **190 lb N/ac/yr** Or **6,100 lb C/ac/yr** sequestered

- Rate of peat loss in current drained state[2] = 0.8 cm/yr
- Bulk density range[1] from 0.049 to 0.347 g/cm^3 (assume mid-range of 0.2 g/cm^3, or 5.66 kg/ft^3)
- Peat nitrogen content[3] 0.9 to 2.4% N d.w. (assume mid-range N content of 1.35% N d.w.); Peat carbon content of 42.56%[2]
- CF = conversion factors for ft^2/ac and lb/kg

c) Amount sequestered in the above ground biomass

Above ground biomass (lb/ac) X Biomass N or C content (%) X Age of mature vegetation (yr) = **0.6 lb N/ac/yr** or **140 lb C/ac/yr** sequestered

- Above ground biomass in tall pocosins[4] range from 3300 to 4700 g/m^2 (assume conservative low-range value of 3300 g/m^2)
- Mean percent nitrogen in live tissue from wetland bog habitat[5] = 0.85% N d.w. with range reported 0.08 – 2.08% N d.w. Individual studies referenced indicate that shrub pocosin habitat vegetation within this category fall at the low end of this range (e.g., 0.082 and 0.096% N d.w. for fetterbush (*Lyonia lucida)* and zenobia (*Zenobia pulverulenta)*, respectively). Conservatively assume 0.09% N d.w., mid-range from shrub pocosins.
- Conservatively assuming that 50% of tall pocosin habitat is wood (and cellulose and lignin comprise 69 and 28% of wood, respectively), and the carbon content of cellulose and lignin is 44 and 64%, respectively
- Age of mature vegetation stand in tall pocosins = 50 years (conservative)

[1] Thompson et al. 2003, Walbridge 1991, Ingram and Otte 1981
[2] Dolman and Buol 1967
[3] Thompson et al. 2003, Ingram and Otte 1981, Bridgham and Richardson, 1993
[4] Christensen et al. 1981 as cited in Sharitz and Gibbons 1982
[5] Bedford et al. 1999

Importantly, the Service and partners will implement a carbon balance verification project starting this year in the restored peatlands at Pocosin Lakes NWR. This project will provide the science to document the carbon benefits of pocosin restoration estimated through these calculations.

The total retention potential in restored peatlands is estimated as 200 pounds of nitrogen/acre/yr and 6,500 pounds of carbon (the amount of carbon in ~24,000 lbs of CO_2) per acre annually

Status of Ongoing Restoration at Pocosin Lakes NWR

The wetland hydrology restoration at Pocosin Lakes NWR is achieved by installing water control structures to raise the water table, encourage the more natural sheet flow (Daniel 1980) (rather than channelized flow from the artificial ditches) and attenuate runoff. In eastern North Carolina, the use of these water control structures to attenuate flows and mitigate off-site water quality impacts is well documented; it is among the most frequently used and encouraged best management practice in the highly altered hydrologic network of eastern North Carolina. Prior work (by the Service's Division of Refuges and Coastal Program) has installed most of the needed water control structures in a 16,000-acre area of the refuge where ditching and draining impacts were most severe. In order to facilitate sheet flows, maintain access, and manage water levels in responsiveness to neighbors, remaining hydrology restoration work involves raising strategic sections of the roads (about 2 feet above their prior elevation) to enhance their levee-effect within the restored wetland blocks allowing water levels within the leveed area to be elevated with continued access for refuge management purposes (Figure 4). Road raising material is obtained from canal dredging (removing accumulated sediments from the bottom of the canal), dredge spoil placement on the adjacent roads, dredge spoil drying, and road re-grading. When road-raising is complete, implementation of conservation easements or other landowner agreements will be necessary in order to achieve appropriate seasonal water levels on refuge areas adjacent to private lands.

Figure 4. Raised roads act as levees to re-flood historically drained peatlands. Water control structures, like the one shown here, are used by refuge managers to maintain optimum saturation conditions.
Photo: Sara Ward, USFWS

A Hydrology Restoration Plan is already in place at the refuge. The NC Department of Environment and Natural Resources (NCDENR) and the Service initiated a partnership in 2006 to enhance restoration in a subset of the most severely drained portion of the refuge. To date, Phases I and II of the project (consisting of 14.5 miles of roads raised to serve as water management levees) have been completed through the NCDENR partnership (Table 2). These roads allow managers to raise water levels and re-saturate peat soils over time in a 7,500-acre degraded portion of the refuge. Ideal hydrology conditions are returning gradually as rainfall raises water levels in the hydrology management units (Figure 5). Figure 6 illustrates the portions of the refuge where hydrology restoration work is now complete as a result of the NCDENR partnership.

Table 2. Estimated nitrogen and carbon sequestration of already completed hydrology restoration at Pocosin Lakes National Wildlife Refuge

Project Phase	Anticipated Acres Restored	Nitrogen Retained (lbs/ year)	Carbon Retained (lbs/ year)
Phase I	3,520	704,000	22,880,000
Phase II	3,980	796,000	25,870,000
OVERALL	**7,500**	**1,500,000**	**48,750,000**

Additional Opportunities for Peatland Restoration

a) Pocosin Lakes National Wildlife Refuge

Of the 16,000 acres of severely drained pocosins at the Pocosin Lakes NWR, restoration of 3,100-acre (prior Service projects) and 7,500-acre (NCDENR partnership) tracts are complete leaving 5,400 acres yet to be restored in this severely drained area (Phase 3 of the ongoing project). Work to complete Phase 3 includes 13 miles of road-raising (with a projected funding need of $390,000). An additional 10,200 acres is targeted for restoration in “Watershed 2” comprising less severely degraded lands bound by Evans Road to the West and Western Road to the east (Phase 4). Work to complete this portion of the restoration includes 12 miles of road-raising (with a projected funding need of $540,000). A synopsis of future restoration opportunities and projected funding needs is provided in Table 3. Portions of the refuge targeted for hydrology restoration in Phases 3 and 4 are shown in Figure 6.

Figure 5. Ideal hydrology conditions, shown in this saturated block adjacent to a levee at Pocosin Lakes National Wildlife Refuge, are anticipated at the completion of the restoration effort. Under normal saturated hydrologic conditions in peatlands, decomposition in organic soils is minimized due to a lack of oxygen, allowing for accumulation of organic carbon.
Photo: Eric Hinesley, NCSU

Table 3. Future opportunities for hydrology restoration at Pocosin Lakes National Wildlife Refuge and projected funding needs.

Future Restoration Project Area	Proposed Miles of Road Raised	Anticipated Acres Restored	Projected Cost	Nitrogen Retained (lbs/year)	Carbon Retained (lbs/year)
Phase III	13	5,400	$390,000	1,080,000	35,100,000
Phase IV	12	10,200	$540,000	2,040,000	66,300,000
OVERALL	**25**	**15,600**	**$930,000**	**3,120,000**	**101,400,000**

When road raising work is complete for all phases of the restoration at Pocosin Lakes NWR, conservation easements or landowner agreements will need to be executed in order to manage water to desired levels on refuge areas adjacent to private lands without negatively impacting adjacent landowners. Neighboring lands where agreements or acquisition will be necessary are highlighted in Figure 6 and correspond to 915 acres of in-holdings in private ownership (with an estimated purchase cost of approximately $1 million) as well as a 300-ft buffer along 10 miles of the refuge boundary (with an estimated conservation easement purchase cost of about $220,000).

Based on remaining levee work and land and easement purchases, completion of the project can be achieved at a cost of $130/acre and would be equivalent to a cost of $11/ton of CO_2

Based on our experience with the restoration at Pocosin Lakes NWR, we have estimated a range of costs for similar projects on conservation lands in eastern North Carolina. Although the needed infrastructure for peatland restoration can vary considerably based on several site-specific factors (including the degree of impact associated with draining, the site watershed area, access requirements, and the size of onsite ditches and canals), the range of costs for the Pocosin Lakes NWR restoration project are likely comparable or greater than those anticipated for other sites based on the extent of ditching and the size of the impacted watersheds at the refuge.

There are four components to the estimated cost of peatland restoration: hydrology restoration planning, water control structure acquisition and installation, levee construction, and conservation easement acquisition / land purchase. Costs associated with restoration oversight (including staff time for contracting, permitting, and implementation, etc) have not been quantified and are not included. To date, the total cost of restoration efforts in the 16,100-acre severely-drained portion of the refuge is over 2.2 million dollars (or about $140/acre). The overall cost for restoration has been discounted by completing a significant portion of the work (including water control structure installation and levee establishment) "in house". Refuge staff estimates that the project cost of approximately 5 million dollars if all restoration work was completed through external contracts. **Accordingly, a conservative cost range for peatland restoration on conservation lands is between $140 (in-house) and $310 (contract) per acre (or equivalent to between $11 and $26/ton of CO_2)**.

If a project were completed on lands not currently in conservation ownership, the restoration cost would rise depending on the purchase cost of the land. **Based on cost estimates for cleared ($1000-$1500/ac[6]) and vegetated ($500-1000/ac[7]) drained peatlands, restoration costs on lands not currently in conservation ownership would range between $810 and $1810/ac (applying the contract restoration rate above plus the purchase cost estimates per acre).** Costs to investors interested in the carbon benefits of the work could likely be offset through partnerships with entities interested in the habitat and wildlife benefits of peatland restoration.

b) Alligator River National Wildlife Refuge

The Service recently partnered with The Nature Conservancy to address climate change adaptation opportunities on the Albemarle-Pamlico Peninsula in eastern North Carolina. A primary focus of that partnership is restoring the hydrologic regime and associated wetland systems on portions of the Alligator River NWR as an adaptation strategy to address anticipated sea level rise. Restoring hydrology conditions is anticipated to stop the loss of soil (via oxidation) while allowing soil genesis and biomass accretion to resume under anaerobic conditions, thereby raising the elevation of the currently drained pocosins over time and providing an important adaptation mechanism to sea level rise. The NC Division of Coastal Management (NCDCM) wetlands data indicate that there are approximately 34,750 acres of degraded pocosin wetlands on Alligator River NWR with restoration potential (NCDCM 2002). Initial stages of the partnership effort will be focused on developing a hydrology management plan (similar to the one used as a blueprint for restoration at Pocosin Lakes NWR). When planning is complete, it is anticipated that new funding sources will be needed to implement hydrology restoration at the refuge; carbon benefits of that restoration can be estimated with available data and verified upon restoration.

c) Off-Refuge Peatland Restoration

In addition to opportunities for restoration at Pocosin Lakes and Alligator River NWRs, substantial areas of degraded peatlands with restoration potential exist off-refuge. Recall that significant pocosin wetland drainage had occurred in eastern North Carolina by the early 1980s. The NCDCM developed a procedure for mapping sites with wetland restoration and enhancement potential using existing geographic information system data (NCDCM wetland type, NRCS soil, landuse/land cover, and USGS hydrography data coverages). **The resulting NCDCM dataset for pocosin wetlands with restoration and enhancement potential identifies nearly 500,000 acres of degraded pocosin wetlands needing restoration (Figure 7a). Notably, about 200,000 acres (or over 40 percent) of these pocosin wetlands identified for restoration are currently managed for conservation and open space (including recreation, wildlife habitat, water quality, and farmland preservation)** (Figure 7b). Given that the cost of acquisition of lands for restoration often dwarfs the cost of restoration implementation, restoration of lands currently in conservation ownership

[6] Washington County tax records, http://taxweb.washconc.org/
[7] Pers. Com., USDA - Natural Resource Conservation Service

could be achieved at a discounted rate. Despite the potentially higher restoration cost, consideration of restoration opportunities on lands in private ownership is warranted because sizeable contiguous tracts of degraded peatlands (e.g., Open Ground Farms property in Carteret County) offer substantial environmental benefits. Costs to investors interested in the carbon benefits of the work could likely be offset through partnerships with entities interested in the habitat and wildlife benefits of peatland restoration._Table 4 presents the basin-specific acreage totals for degraded pocosin wetlands with restoration and enhancement potential based on NCDCM datasets. The carbon benefits of that restoration can be estimated with available data and verified upon restoration.

Table 4. Degraded pocosin wetlands with restoration or enhancement potential in eastern North Carolina

River Basin	Acreage Needing Restoration in Conservation Ownership	Acreage Needing Restoration in Private Ownership	Total Acreage Needing Restoration
Cape Fear	23,599	57,279	80,878
Chowan	0.17	0	0.17
Lumber	2,914	37,440	40,354
Neuse	14,891	40,463	55,354
Pasquotank	98,367	55,095	153,463
Roanoke	310	0	310
Tar	50,736	74,243	124,978
White Oak	20,738	22,455	43,193
TOTAL	**211,556 (42%)**	**286,975 (58%)**	**498,531**

With nearly a half million acres of degraded pocosin wetlands in need of restoration in eastern North Carolina, there is potential to sequester millions of tons of carbon per year. While significant restoration opportunities are available in the State (and many offer cost savings for project implementation based on their existing conservation ownership), there appear to be abundant opportunities for peatland restoration nationwide as well. Peat wetlands characterized by Histosol soils are distributed throughout the eastern states, the upper Midwest, the Pacific Northwest, and Alaska (USDA 1999, Figure 8). Restoration of disturbed United States peat wetlands may be an attractive source of credits as global carbon markets expand. Many existing carbon sequestration projects that are creditable in carbon exchange markets presently do not offer substantive wildlife habitat improvements; consequently, restoring hydrology conditions in peat wetlands offers carbon benefits of substantive magnitude (based on site-specific estimates previously outlined and currently undergoing field verification) and scale (based on the distribution of peat wetlands in need of restoration in North Carolina and beyond) while also benefiting fish and wildlife resources.

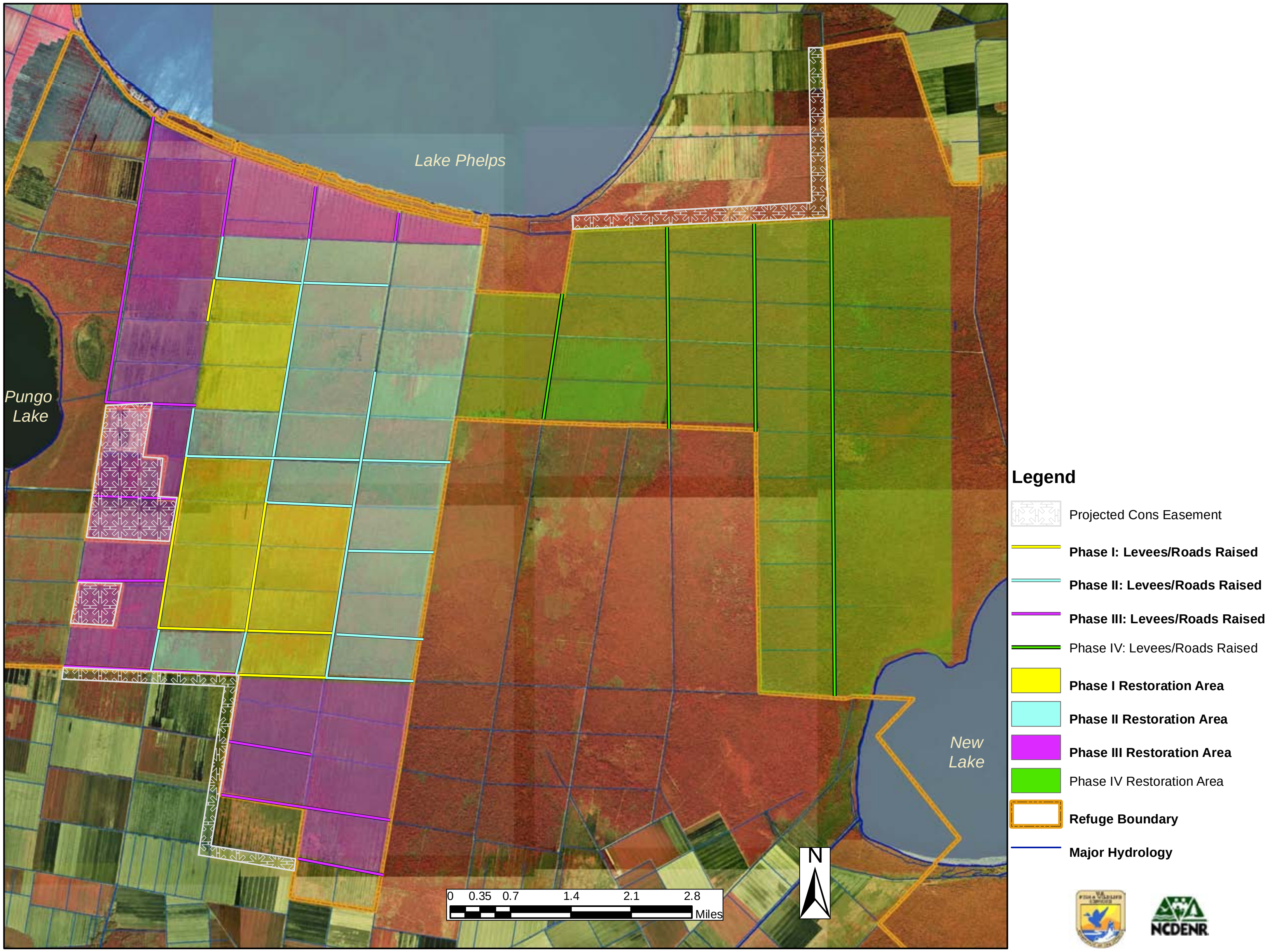
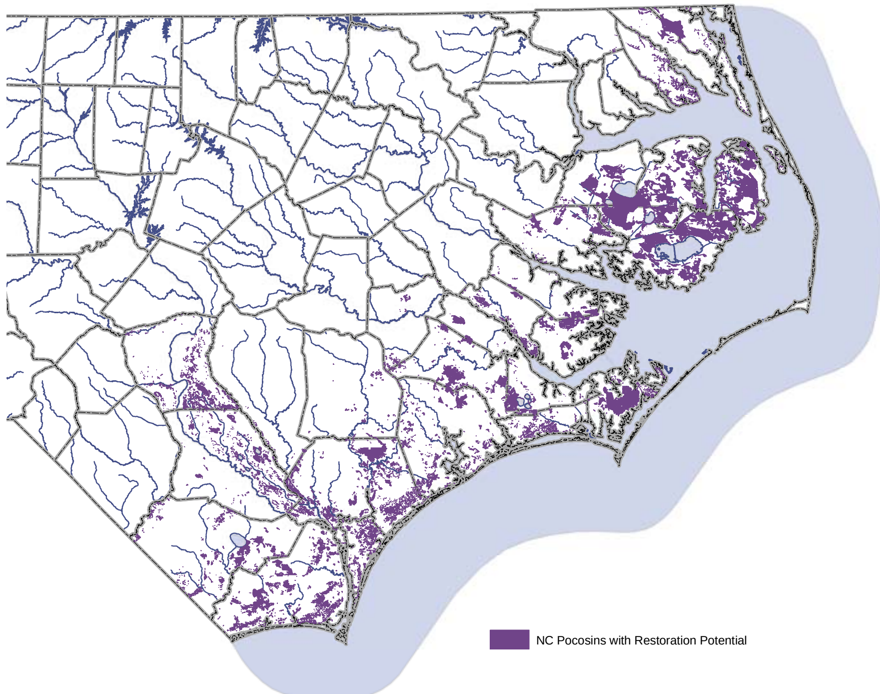


Figure 6. Pocosin Lakes National Wildlife Refuge hydrology restoration project work completed (Phases I and II) and proposed (Phases III and IV).

a)



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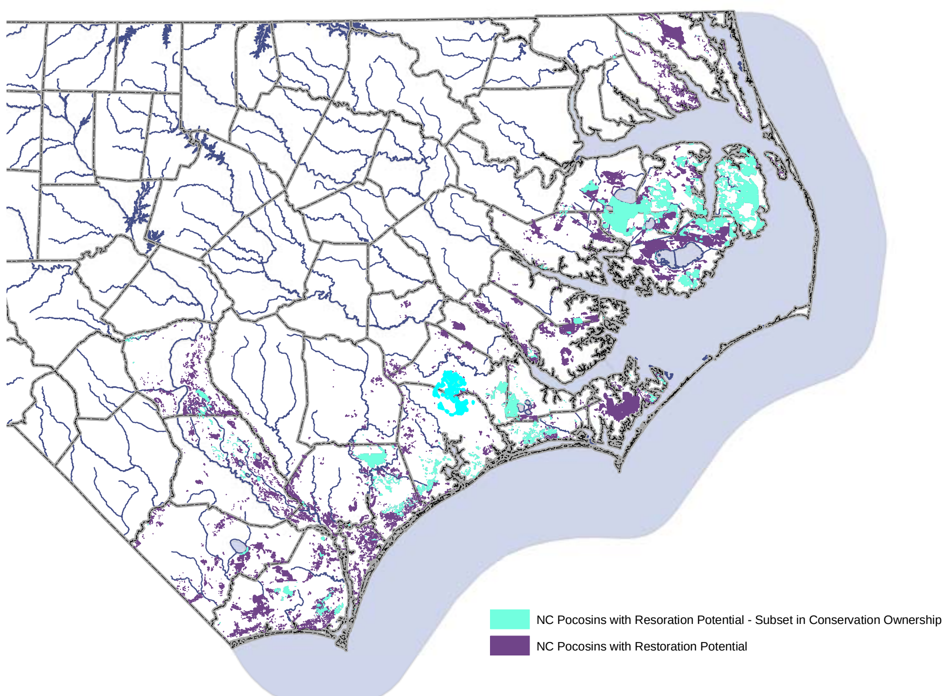

Figure 7. Degraded pocosin wetlands in eastern North Carolina with restoration or enhancement potential identified based on NC Division of Coastal Management data sets (2002). a) All disturbed pocosins. b) Subset of disturbed pocosins on lands currently managed for conservation and open space.

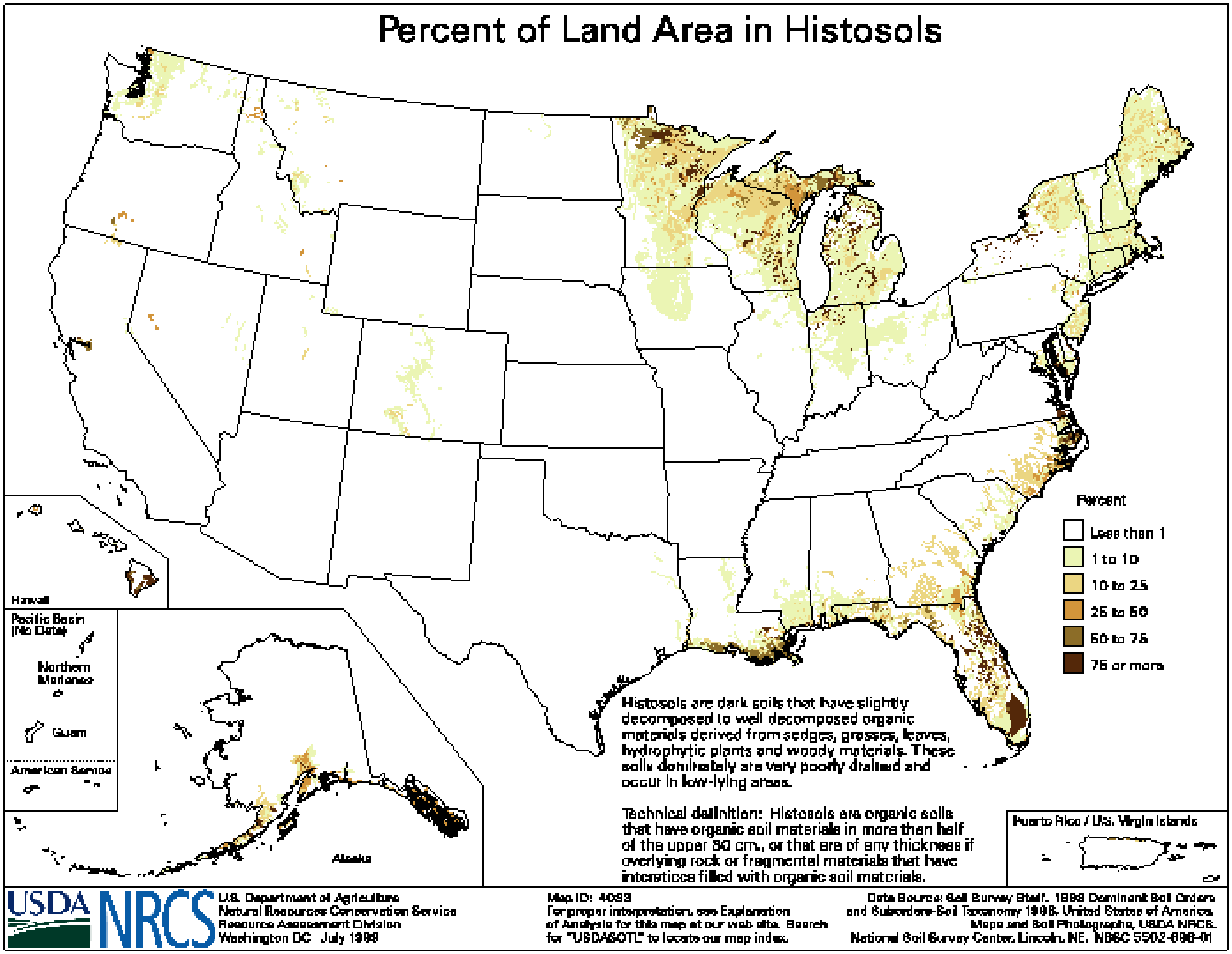

Figure 8. Distribution of peat (Histosol) soils (as percent of land area) in the United States. (USDA 1999)

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