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Final report for CISA Mini-Grant to the NCSU Tree Physiology and Ecosystem Science Lab

Project title: Influence of historical drainage on coastal ecosystem resilience to rising sea level – Implications for natural resources management and terrestrial carbon storage of the Alligator River National Wildlife Refuge

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Associated students (funded by multiple sources): Charlton (Chase) Brown, Andrew Radecki, David Zietlow, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695

Associated research associate (funded by a different source): Jonathan Furst, field site operations manager

Proposal/award number: 2013-0190/13-2322

Funding amount: $20,216

Project duration: 01/01/13 to 08/31/15

Reporting period: 01/01/13 to 12/31/15

Introduction

When it was established in 1984, much of the 154,000 acre Alligator River National Wildlife Refuge (ARNWR) in Dare County, North Carolina, was a pocosin, characterized by poorly drained soils high in organic matter. With the continuing rise in sea level, drainage in the refuge is becoming progressively impeded, leaving the soil wetter for a longer period of time throughout the year. We hypothesize that changes in soil water dynamics, and possibly salinity, associated with sea level rise (SLR) have led to a cascade of ecosystem transitions affecting wildlife habitat quality of the Refuge (Figure 1A). In many places, marsh communities are replacing the native forest ecosystems, which is the predominant ecosystem type across much of the Refuge (Figure 1b). It is likely these changes in habitat are also leading to changes in animal species distributions and wildlife habitat quality, which is why our project is of interest to the USFWS.

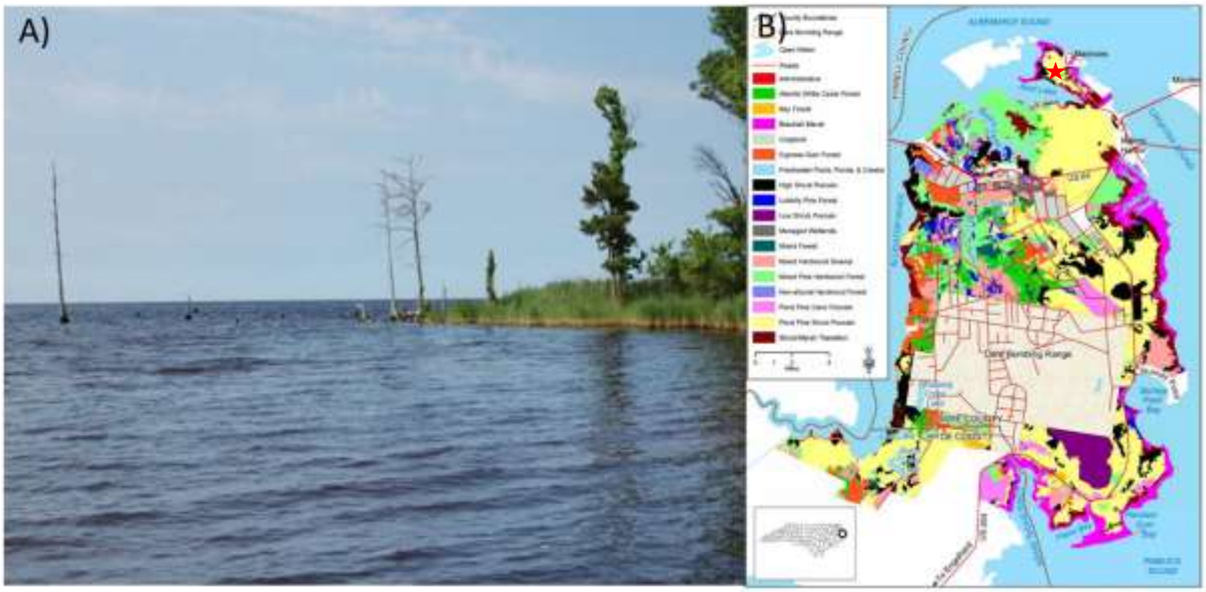

Figure 1. A) Habitat in transition from forest to marsh to aquatic ecosystems due to rapid sea level rise at Alligator River National Wildlife Refuge (ARNWR) in Dare County, North Carolina. Photo credit: John King. B) Vegetation map of ARNWR showing the large area of the Refuge occupied by pond pine pocosin (yellow). Source: US Fish and Wildlife Service. The red star indicates location of Master of Natural Resources student Chase Brown's field site.

In 2012, we submitted a mini-grant proposal to the Carolinas Integrated Sciences and Assessments program (CISA) to quantify thresholds of hydroperiod (number of days saturated soil per year) and salinity stimulating transition between the major ecosystem types occurring at the Refuge (Table 1). This new project would complement existing terrestrial carbon (C) cycling work ongoing at the Refuge.

Table 1. Major ecosystem types to be monitored at the ARNWR ecosystem transition transects.

Ecosystem	Dominant species	Location	Soils	Environment
Brackish marsh	*Juncus roemerianus* *Spartina patens* *Phragmites australis*	Shoreline	Anaerobic muck	Saline to brackish
Freshwater marsh	*Typha sp.*	Very near shore	Organic muck	Freshwater
Low shrub pocosin	*Ilex glabra* *Lyonia lucida* *Cyrrila racemiflora*	Near shore	Organic muck	Freshwater
Pond Pine pocosin	*Pinus serotina* *Magnolia virginiana* *Persea borbonia*	Near shore	Organic muck or histic-mineral	Freshwater
Mixed pine-hardwoods	*Pinus taeda* *Quercus rubra* *Liquidambar styraciflua*	Interior	Mineral or histic-mineral	Freshwater
Forested wetland	*Taxodium* sp. *Nyssa* sp. *Acer rubrum*	Interior (flux tower) Riparian	Organic muck	Freshwater

In transects that spanned the transition zones between adjacent ecosystems (Table 1), we proposed to measure C storage in vegetation and soils, volumetric soil water content (VSWC), salinity, and depth to ground water table (GWT) using permanent sampling wells. It was hoped that quantification of the points as at which changes in these driving variables resulted in ecosystem transition would allow extrapolation to other parts of the Refuge and to similar physiographic settings across the U.S. Southeast coastal plain. Further, as roadside ditches permeate the lower coastal plain and alter hydrology, we wanted to compare ditched and non-ditched systems. Finally, we proposed to conduct a community outreach workshop to communicate the importance of climate change and sea level rise to local communities, and how science is essential to provide the information needed to formulate sound public policy to sustain coastal environmental quality and economic well-being.

Cumulative project accomplishments and problems (compared to original objectives)
In retrospect, the amount of work proposed for the available funds was overly optimistic but it was hoped that by leveraging existing resources we would be able to make significant progress towards achieving our objectives. The work was to be performed by a postdoc (primarily funded by another project), but early on she decided the field work at ARNWR was more of a challenge than she wanted to take on. That left the project unstaffed until a new person could be found and resulted in the request for a no-cost extension from a 2- to a 3-year project. Eventually, we recruited a student, Mr. Charlton (Chase) Brown, to work on the project as part of his Master of Natural Resources program here at NCSU. It was also hoped that this project would allow us to collect enough data to demonstrate proof-of-concept and contribute to ongoing research at ARNWR, helping to attract further funding needed to move the work forward. This has indeed been the case.

Although we originally proposed to work in six ecosystem transitions sites (Table 1), Chase quickly determined that was too much work for a single person to complete in two years, given the significant obstacles to field work inherent at ARNWR. We therefore made the decision to focus on doing a good job at a single site rather than dilute efforts at multiple sites across the Refuge. We chose to focus on pond pine because it is a dominant ecosystem at the Refuge (Figure 1B), that is severely threatened by climate change/SLR. Over the two years, Chase established transects at ditched and non-ditched pond pine poscosin sites in the northern part of the Refuge, installed GWT wells, and quantified C storage in the vegetation and soils. His transects ran from the water's edge to the forest interior. Significantly, while Chase sampled the soil he found several strata of coarse woody debris (CWD) at distinct depths, separated by layers of organic sediments, that spanned the length of the transects (~ 1 km). Further inspection revealed that the chunks of wood were evidence of previous forests that were in equilibrium with past, lower sea-levels. Support from this CISA project allowed us to have the wood layers ^{14}C-dated, which indicated that the approximately 2.5 m of organic soil had accumulated over the past 1,800 years. Thus, this system has been characterized for the last ~2,000 years by alternating periods of stable sea-level resulting in establishment of coastal forest ecosystems (indicated by the buried, dated wood layers), with periods of rapid change (ecosystem transition) in which the forests were replaced by accreting marsh in equilibrium with rapidly rising sea level, which resulted in the formation of the organic deposits between the wood layers. The currently dying pond pine forest at ARNWR (Figure 2) is merely the latest in a recurring series of ecosystem transitions that has occurred at this site at least 4 times over the past two millennia. The comparison of the ditched and non-ditched ecosystems revealed that road construction practices typical of the lower coastal plain significantly increased the rate of pond pine forest dieback, accelerating the transition to marshland.

Figure 2. Dead pond pine forest in the northern reaches of Alligator River National Wildlife Refuge near the location where this CISA project was conducted. Note the raised roadbed and roadside ditch which are ubiquitous across the Southeast lower coastal plain. This type of infrastructure alters the hydrology, increasing vulnerability and accelerating dieback of coastal forest ecosystems in response to sea level rise and storm surges. Photo credit: John King.

We believe understanding the mechanisms and chronology of ecosystem response to historic sea level rise, stored in the C profiles of the vegetation and soils discovered in this study, will prove useful to a wide range of constituencies. Understanding the dynamic nature of wildlife habitat at ARNWR, in time and space, and what causes it to change, will help Refuge managers fulfill their mission of protecting the Nation's wildlife resources in perpetuity. Results will surely benefit other land managers (forest products industry, farmers, NC Forest Service, etc.), as forestry and farming practices must adapt to the changing conditions (or move). It will enrich the lives of local communities, including K-12 education, by broadening their sense of place and understanding of how dynamic, and linked, the climate, geology, and vegetation really are in this coastal environment. Understanding long-term ecosystem responses to changing sea level will also serve as a tool to local planners and decision makers by guiding appropriate development, decreasing occurrence/costs of future disasters. Finally, we believe results of this project will be of keen interest to the scientific community because it contributes information on past, current and future C storage of coastal forested wetlands that are severely under-represented in assessments of global ecosystem C stocks (and responses to the changing environment).

For these benefits to be realized requires dissemination of results, which is the current phase of the project. The first phase of this dissemination was a workshop held at the ARNWR Visitors Center in Manteo, NC, for stakeholders and community members on December 5, 2014 (Appendix 1). Sixty-five participants signed up for the workshop, however only 50 people actually attended. The morning session included a field trip with three stops at the Refuge, educating participants about eroding shorelines and the role of changing hydrology causing rapid ecosystem transition. A locally-caught, locally-prepared seafood lunch was served to the enjoyment of all. The afternoon session hosted a list of invited speakers educating stakeholders on variety of research projects being conducted in the area to help local communities understand and prepare for rapid environmental change of the NC lower coastal plain. Six NCSU graduate student interns assisted with logistics of the workshop, presented research findings on how the changing environment will impact the upcoming NC64 Highway Improvement Project, and earned course credit communicating science to the public. The workshop ended with breakout sessions where stakeholders participated in facilitated discussions on events of the day and created prioritized lists of future needs for research and public engagement. Participant contact information was collected and a workshop website was created to facilitate interactions among attendees and advertise future workshop events: http://coastalenvironmentalchange.weebly.com/. We received a lot of positive feedback from participants that the workshop was very informative, and the public appreciated the opportunity to contribute to the science. The Refuge management was very pleased with how the workshop turned out.

The second phase of results dissemination is publication of results. The first "published" product will be Chase's Master of Natural Resources thesis (Appendix 2). He defended his research and submitted a draft of his thesis to his committee in January, 2016. He is currently working on revisions, but otherwise has completed all requirements of his program, with an anticipated graduation in May. His thesis will be available to the public through the NCSU Library (draft attached). In addition, we are in the process of preparing several manuscripts for publication in the peer-reviewed scientific literature, and coincident with that, we hope to develop several popular science articles targeted to local/state non-specialist audiences. Finally, results of this project will be incorporated into grant proposals to continue and expand upon the work.

Enumerated lists of project accomplishments to date follow. Future products (e.g. publication reprints, popular articles) will be forwarded to CISA program staff. We sincerely appreciate all of the support of our work provided by the CISA program!

Project/associated project outputs:

Publications

Noormets A, Epron D, Domec JC, McNulty SG, Fox TR, Sun G, King JS (2015) Effects of forest management on productivity and carbon sequestration: A review and hypothesis. *Forest Ecology and Management* 355: 124-140.

Domec J-C, King JS, Ward E, Oishi C, Palmroth S, Radecki A, Bell DM, Miao G, Gavazzi M, Johnson DM, McNulty SG, Sun G, Noormets A (2015) Conversion of natural forests to managed forest plantations decreases tree resistance to prolonged droughts. *Forest Ecology and Management* 355: 58-71.

Miao G, Noormets A, Domec JC, Trettin CC, McNulty SG, Sun G, King JS (2013) The effect of water table fluctuation on soil respiration in a lower coastal plain forested wetland in the southeastern USA. *Journal of Geophysical Research - Biogeosciences*, 118: 1748-1762.

Students graduated/theses

Brown C (2016) *Federal wetland policy and climate change impacts*. MNR Thesis, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC, p. 56.

Zietlow D (2014) *Energy and water balance of changing wet land use in the lower North Carolina coastal plain,* MS Thesis, Department of Forestry and Environmental Resources, North Carolina State University, p. 34. (with A Noormets)

Radecki A (2014) *Why eco-hydrologically based management plans that promote ecosystem resilience as well as beneficial ecosystem services through better soil water management are going to be an important tool to address both the ecological and economic concerns of terrestrial ecosystem management in the coming decades.* MS Thesis, Department of Forestry and Environmental Resources, North Carolina State University, p. 103. (with J-C Domec)

Miao G (2013) *A Multi-scale Study on Respiratory Processes in a Lower Coastal Plain Forested Wetland in the Southeastern United States*. PhD Dissertation, Department of Forestry and Environmental Resources, North Carolina State University, p. 209. (with Asko Noormets)

Undergraduate students employed

Jameson Boone, James Williamson, Christian Owen, Abigail Kutcha, Dominic Manz, Collin Powers, Thomas Harris

Presentations

King JS (2016) Forest stewardship. Greenhouse Gas Mitigation Workshop, USDA Forest Service Southeast Regional Climate Hub Webinar, 20-21 January.

King JS, Brown C, Noormets A, Domec J-C, Minick K, Li X, Miao G (2016) Understanding rapid environmental change at Alligator River National Wildlife Refuge. USGS Carolinas Integrated Sciences and Assessment Webinar, 8 January.

Noormets A, Epron D, Domec J-C, Nouvellon Y, McNulty S, Chen J, Sun G, King J (2015) Effects of management on productivity and carbon sequestration: A review and hypothesis. American Geophysical Union Annual Meeting, San Francisco, CA, 14-18 December.

King JS, Brown C, Noormets A, Domec J-C, Minick K, Li X, Miao G (2015) Understanding rapid environmental change at Alligator River National Wildlife Refuge, Cape Fear Arch Conservation Collaborative Quarterly Meeting, 9-10 November.

King JS, Noormets A, Domec J-C (2014) ARNWR's role in global monitoring of environmental change-Flux tower project. Healthy Communities and Sustainable Ecosystems: Understanding and Adapting to Coastal Environmental Change stakeholder workshop, Alligator River National Wildlife Refuge, Manteo, NC, 5 December.

Noormets A, Miao G, Domec J-C, Trettin CC, Sun G, McNulty SG, King JS (2014) Partitioning ecosystem respiration in a coastal plain forested wetland in the southeastern USA: Hydrologic effects and implications in climate change. Ameriflux Annual PI Meeting, Potomac, MD, 4-5 May.

Miao G, Gavazzi M, Wightman M, McNulty SG, Sun G, King JS, Domec J-C, Noormets A (2014) Loblolly pine plantation and natural forested wetland sites in eastern coastal area. Ameriflux Annual PI Meeting, Potomac, MD, 4-5 May.

Dome J-C, Noormets A, King JS, Radecki A, Sun G, McNulty S, Miao G (2014) Aquaporin-mediated reduction in loblolly pine root hydraulic conductivity impacts whole-stand water use and carbon assimilation. International Symposium on Evapotranspiration: Challenges in measurement and modeling from leaf to the landscape scale and beyond. American Society of Agricultural and Biological Engineers. Raleigh, NC, 7-10 April.

Radecki A, Noormets A, King J, Miao G, Domec J-C (2014) Partitioning ecosystem canopy transpiration to evaluate the sensitivity of stomatal conductance to changing climate indicators. International Symposium on Evapotranspiration: Challenges in measurement and modeling from leaf to the landscape scale and beyond. American Society of Agricultural and Biological Engineers. Raleigh, NC, 7-10 April.

Zietlow D, Noormets A, Sun G, Gavazzi M, King J (2014) Energy and water balance of contrasting wet land uses in the North Carolina coastal plain. DOI Southeast Climate Science Center Grand Opening, David Clark Labs, NCSU Raleigh, 22 January.

King JS, Noormets AN, Domec J-C (2013) Assessing hydrologic and salinity thresholds driving ecosystem transition at Alligator River National Wildlife Refuge. Managing Forested Wetlands with Fire in a Changing Climate, USDA Forest Service Joint Fire Sciences Program Symposium, Alligator River National Wildlife Refuge, Manteo, NC, 19-21 November.

Leveraged funding

Noormets A, King JS, Domec J-C (09/15/14-6/30/19) Partitioning ecosystem evapotranspiration by canopy strata, and the contribution of hydraulic redistribution of deep soil water to understory drought tolerance. USDA Forest Service, $25,000.

King JS, Domec J-C, Noormets A (09/01/14-08/31/17) Improved observation of belowground carbon cycling and net ecosystem exchange in natural and managed forested wetlands in the U.S. Southeast. Multi-Agency Carbon Cycling Science Program (NASA/NIFA/DOE), $925,093.

King JS (08/06/13-05/31/18) Regional Assessment of Threats, Opportunities and Ecological Sustainability in Managed and Unmanaged Forests of the U.S. Southeast, USDA Forest Service, $124,078.

Noormets A, Domec J-C, King JS (10/01/2013-09/01/2016) Ameriflux core site cluster. US DOE LBNL, $745,000.

Workshops

Healthy Communities and Sustainable Ecosystems: Understanding and Adapting to Coastal Environmental Change, Stakeholder Workshop, Alligator River National Wildlife Refuge, Manteo, NC, 5 December, 2014.

APPENDIX 1

December 5, 2014, Stakeholder Workshop Program

Healthy communities and sustainable ecosystems: understanding and adapting to coastal environmental change

A participatory workshop to find out what we know and what we need to study to plan for the future

Organizing committee:

John King[1], Charlton Brown[1], Jessica Whitehead[2], and Dennis Stewart[3]

1. Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC
2. NC Sea Grant Program, NCSU Centennial Campus, Raleigh, NC
3. Alligator River National Wildlife Refuge, U.S. Fish and Wildlife Service, Manteo, NC

Time and place:

8 AM to 5 PM, Friday December 5, 2014

US Fish and Wildlife Service Visitors Center, 100 Conservation Way, Manteo, NC 27954

Workshop goals and themes:

Evidence of rapid environmental change abounds all along the eastern U.S. seaboard, yet sometimes we don't see it or fail to understand what it is we do see. The Alligator River National Wildlife Refuge in Dare County, NC, provides important ecosystem services such as public recreation and education, rearing grounds for commercially valuable marine species and migratory waterfowl, protecting coastal communities from flooding and tide surges associated with storms, and cycling vast amounts of carbon and freshwater. The Refuge is critically threatened by rapid environmental change, and thanks to the strong support for science the U.S. Fish and Wildlife Service we are beginning to understand the causes of ecosystem transition and the implications for surrounding communities. However, the science is incomplete if it does not incorporate first-hand knowledge and concerns of local residents whose livelihoods and well-being are directly tied to the health of the coastal environment. Our working premises for this workshop are that 1) Coastal ecosystems and communities are in a state of rapid environmental change; 2) More scientific research is needed on terrestrial, riverine, and estuarine systems to understand the mechanisms driving ecosystem transition; 3) Future public planning that incorporates scientific understanding of coastal dynamics will simultaneously protect environment quality and foster sustainable economic development resulting in a high quality of life for generations to come. The objective of this workshop is to bring together scientists, natural resources managers, state and federal agencies, local decision makers, natural resources-based businesses, and the public to share insights on what is known about coastal environmental change and what information is still needed to best protect and manage North Carolina's coastal treasures in a rapidly changing world.

Program:

8:00-8:30	Pickup meeting materials
8:30-8:40	Welcome and overview of the days' program/safety/workshop objectives Dr. John King, North Carolina State University
8:40-8:50	Welcome to USFWS Alligator River National Wildlife Refuge Mike Bryant, Refuge Manager, US Fish and Wildlife Service
8:50-9:00	Witness to thirty years of rapid environmental change at ARNWR Dennis Stewart, Refuge Biologist, US Fish and Wildlife Service
9:00-10:00	ARNWR Field Trip Stop 1 Mashoes Pond Pine Forest Decline Charlton Brown, MS Candidate, North Carolina State University
10:00-10:30	ARNWR Field Trip Stop 2 Effects of US 64 on Hydrology and Surrounding Forests Dr. Gary Blank's Environmental Assessment class, NCSU
11:00-12:00	ARNWR Field Trip Stop 3 Research on Adaptive Management and Hydrology Aaron McCall, NE Regional Steward, The Nature Conservancy
12:00-1:30	Lunch at ARNWR Refuge Headquarters Locally caught-prepared seafood festival!
1:30-1:45	ARNWR's Role in Global Monitoring of Environmental Change-Flux Tower Project Drs. John King, Asko Noormets, J-C Domec, North Carolina State University
1:45-2:00	Erosion and the changing estuarine coast of North Carolina Drs. Reide Corbett and J.P. Walsh, UNC Coastal Studies Institute/ECU
2:00-2:15	Sixty-five years of a fisherman Terry Pratt, retired commercial fisherman of the Albemarle Sound
2:15-3:00	Public comment period Open-microphone time for all participants who wish to do so to ask questions, express view points, provide insights. Time will be limited to 3-5 minutes per person.
3:00-3:15	Coffee Break

3:15-4:15 Breakout groups of facilitated discussions to identify and prioritize future scientific research, natural resources conservation, public planning/policy, and economic development

4:15-5:00 Open Discussion and Synthesis – Next steps
-Summarize results from all breakout groups
-Preparation of a meeting summary article to appear in the popular press
-Web archive of meeting materials and exchange of contact information of participants

Sponsors:

Southeast Climate Hub

And

Forest Service Southern Research Station

****If you would be interested in becoming a sponsor of the workshop please contact John King at NCSU (john_king@ncsu.edu).**

APPENDIX 2

Federal Wetland Policy and Climate Change Impacts

by

Charlton Brown

A thesis submitted to the Graduate Faculty of

North Carolina State University

in partial fulfillment of the

requirements for the Degree of

Master of Natural Resources

Raleigh, North Carolina

January, 2016

Approved by:

John S. King
Professor

Gary B. Blank
Associate Professor

Introduction

Wetland protection in the United States has been a sustained source of contentious deliberation for some time, at times pitting environmentalists against government agencies, federal agencies against one another, government agencies against landowners, and politicians against agency administrators. Legislative and administrative haggling have been complicated by judicial rulings and jurisdictional inconsistencies. Now, potentially confounding all preceding understandings and questions, discernible climate change impacts could prompt serious issues concerning regulatory enforcement. This paper proceeds from a few assumptions: 1- that most people do not realize the relationships among scientific, legislative and judicial interpretations of wetland status; 2- that recognizing historic steps producing our current regulatory situation might help us avoid further decades of confusion; and 3- that examples on the ground better illustrate questions ahead than do theoretical speculations. Thus, this paper examines history behind current enforcement of the Clean Water Act's Section 404 and then focuses on a specific landscape where the wetland boundary between marine and terrestrial components is migrating and is likely to continue migrating for a very long time. The story encompassed here is tangled, with historic strands braiding together natural resource extraction, natural resource conservation, politics, economics, science and legal interpretation.

Wetland Protection

In the United States, discharging refuse into waters of the US has been offensive since the Rivers and Harbors Act passed the United States Congress in 1899. Such offensive behavior was a mere misdemeanor, though it is not clear to what extent such misdemeanors were punished. The Rivers and Harbors Act, nevertheless, was the first statutory environmental law concerned with aquatic conditions in the United States. Further action at the federal level to protect water quality did not occur until 1948, with passage of the Water Pollution Control Act, but this act essentially had no teeth and only addressed interstate pollution. Meanwhile, mires (such as swamps, marshes, fens and bogs) were still being drained or filled and converted to whatever uses landowners felt were desirable. The main value most people associated with wetlands was providing habitat for waterfowl and other species that could be trapped or hunted. This value eventually brought wetlands within the aegis of the USDI Fish and Wildlife Service.

The Ramsar Convention, an international meeting held in 1971, elevated wetland conservation to global attention. Subsequently, amendments to the U.S. Water Pollution Control Act in 1972 included section 404, making permits necessary for dredging and filling operations in waters of the US. Regulations affecting wetland protection have been contentious in the United States since the early 1970s.

Chapter 1- History of National Wetland Policy Development

The collision of U.S. federal policy toward wetland management with the potential effects sea level rise may have on coastal landscapes poses an interesting set of questions that may need to be addressed relatively soon. Addressing those questions will require better knowledge of the regulatory apparatus and the biological systems at the center of the collision. While defining wetland boundaries has been contentious for several decades, wetland ecology--the study of wetland functions--has been developing at least that long. So the contentiousness of claims for and against regulatory oversight of wetlands management depends greatly on the perceived values associated with wetlands.

Throughout most of United States history, wetlands have been considered worthless land which should be converted to other uses, an attitude common throughout the developed world. Mires, as Europeans tend to call them, exist in a variety of landscape conditions. Large wetland areas were a hindrance to travel and could not be used for growing most crops without draining them. Because of this perspective, America lost over 50% of its wetlands due to drainage for agricultural and other uses since the 1600's. From the mid 1950's to the mid 1970's, 87% of the wetland area lost in the U.S. was due to conversion to agriculture (11). Not until relatively recent history (~1970's) did a policy shift occur so wetlands began to be protected because of a major shift in people's perceptions of the value of wetlands. Benefits that wetlands bring us through flood storage, pollution storage and conversion, and aquatic nursery areas finally began to be realized.

Wetlands are very important to society and the environment for a variety of reasons. Through physical and chemical processes wetlands are able to store and break down pollutants that otherwise could enter our drinking water and have negative impacts on wildlife that need near pollutant-free water to survive. One of the biggest groups of pollutants that wetlands can trap and dissipate into the atmosphere is NOx derivatives that come from fertilizers and airborne emissions. Through the process of nitrification and then denitrification, bacteria in the anaerobic conditions found in wetlands are able to transform harmful types of nitrogen compounds into harmless N2 gas. If these nitrogen compounds instead go directly into water bodies, they can have devastating effects on the aquatic environment. For example, waters at the mouth of the Mississippi River are so high in nitrates from farming operations far up river that there is now a huge "dead zone" from red tide algae blooms that absorb all the oxygen from the water (5). Because this deoxygenated water does not support fish and other aquatic species, fish kills in this area can be very large.

Wetlands also have a very large capacity to store flood waters. Wet soils are able to absorb water faster than dry soils are, and are able to store this water longer due to large pore spaces from accumulated organic material. Wetland areas around streams are able to trap and hold water during a flood event and allow the water to drain from them slowly, preventing flooding in other areas that may be populated by humans.

Many species of plants and animals rely on the specific conditions found in certain wetlands. Many species of frogs use pools found in some wetland types as breeding pools. These vernal pools usually dry up later after the breeding season, so there is not a chance for fish to invade the pools, making these areas safer for frog eggs and tadpoles. (9). Certain species of trees have developed evolutionary traits to use flood waters to spread their seeds, along with many other adaptations that allow them to survive in anaerobic soils (12). Coastal wetlands such as salt marshes and mangroves provide nursery habitat for many fish and other aquatic ocean species (13). In the US, 75 percent of fisheries species rely on these intertidal habitats (14). These ecosystems provide safe environments for many juvenile aquatic species to mature. It is because of these reasons that our perception of wetlands went from negative to the realization that these areas are very important.

Timeline

Table 1.1 on the next page shows the combination of wetland legislation, litigation, executive orders, agency rules, and other important related wetland occurrences that have formed the increasingly convoluted web of wetlands policy. It is useful to refer to this table throughout the paper to keep from getting lost in the back and fourth battle over our nations wetlands. Chapter one walks through this table in greater detail in a less linear way.

Date	Title	Synopsis
1899	Rivers and Harbor Act	Misdemeanor offense to discharge Refuse Matter into Waters of US. First statutory environmental law
1946	Administrative Procedure Act (APA)	Reined in powers of Agencies, made rules of how to implement new regulations
1948	Federal Water Polution Control Act	Precursor to Clean Water Act
1971	Ramsar Convention	Ramsar, Iran-International convention/treaty for conservation of wetlands
1972	Federal Water Polution Control Act Ammendments of 1972 (CWA)	Section 404- Permit needed to dredge or fill Waters of the United States
1975	Natural Resource Defense Council vs. Callaway	Ruled that some wetlands were protected under the Clean Water Act
1977	Clean Water Act Amendments	Amended 1972 CWA, further defined "Waters of the United States", now included wetlands by definition
1977	Presidential Executive Order No. 11990- Jimmy Carter	Stated federal agencies must protect and enhance wetlands
1979	Memorandum of Agreement	EPA has final say in wetland delineation over USACE
1983	First National Wetlands Inventory	Found that between 1950s and 1970s, wetland loss averaged 439,000 acres per year. First calculation of wetland loss in the US
1985	United States v. Riverside Bayview Homes, Inc.	Questioned definition of "waters of the United States"
1985	Food Security Act- Swampbuster Provision	Protections for wetlands on or near agriculture lands. Special rules for farming these wetlands
1986	Council on Competitiveness	Started by President Regan with the goal of US economic competitiveness in the world by cutting bureaucratic red tape
1986	Soil Conservation Service Wetlands Delineation Manual	Response to Swampbuster provision
1987	USACOE Wetlands Delineation Manual	Response to US v. Riverside Bayview
1987	National Wetlands Policy Forum	"No Net Loss" should become policy. EPA suggested the Conservation Foundation to convene forum
1988	"No Net Loss" - George H. W. Bush	Campaign Promise, Boston, Massachusettes
1989	Federal Manual for Identifying and Delineating Jurrisdictional Wetlands	USACE, EPA, SCS, FWS agreed on Delineation Manual
1989	North American Wetlands Conservation Act	Encourages partnerships and grants to protect and enhance wetlands
1991	"Quayle Council"	Vice President Dan Quayle placed as head of Council on Competitiveness- tried to amend the 1989 manual
1991	91 Wetlands Manual	Amendments to '89 manual
1991	Energy and Water Development Appropriations Act of 1992- Public Law 102-104	Legislated out the '89 and '91 manual by using APA
1991	Energy and Water Development Appropriations Act of 1992- Public Law 102-104	shot down '89 manual. Stated any future manual must follow APA guidelines (including '91). USACE to use 1987 Delineation Manual.
1993	Executive Order	SCS, USACOE, EPA, FSW ordered to develop consistent administration of wetland programs
1993	Executive Order	Abolished the Council of Competitiveness as official government council (Still exists today as a nonprofit orginazation)
1994	Delineation MOA	SCS becomes responsible for wetlands on agricultural land
2001	Solid Waste Agency of Northern Cook County v. US Army Corps of Engineers	waters and wetlands adjacent to navigable waters, interstate waters, or their tributaries are "waters of the United States"
2006	Rapanos v. United States	John A. Rapanos, et ux., et al., Petitioners v. United States; June Carabell, et al., Petitioners v. United States Army Corps of Engineers, et al.
		Supreme court was split 4-4-1, Uncertainty over which ruling to follow. SCOTUS essentially turned it over to lover courts to decide

History Timeline of Legislation and Manuals 1970-1995

The Clean Water Act (CWA) passed in 1972 and amended in 1977 began a conversation in the United States about the exact definition of a jurisdictional wetland. The CWA allowed the federal government the right and responsibility to protect the waters of the United States. Section 404 of the CWA gave control of creating dredge and fill guidelines to the Environmental Protection Agency (EPA), which creates the guidelines that the United States Army Corps of Engineers (USACE) has to follow to implement permitting of dredge and fill activities. Regulations issued in 1977 by the EPA laid out categories of jurisdictional waters of the United States. These were meant to help clarify what waters of the United States are, but instead they created more questions.

Also in 1977, President Jimmy Carter signed Executive Order No. 11990, which ordered federal agencies to minimize the destruction of wetlands, and that they should also protect and enhance wetlands when their actions have effects on those lands. This order also amended the National Environmental Policy Act with regards to wetlands, to mandate that federal agencies should consider the effects of projects on wetlands and should not degrade or destroy wetlands unless there is no other “practicable alternative” to the construction, and all practicable measures should be taken to minimize the impacts to the wetlands as much as possible.

After the 1977 amendments to the CWA were passed, USACE began the process to create the rules for what would constitute as a jurisdictional wetland. In 1978, the USACE assigned the task of developing a wetlands delineation manual to the Environmental Laboratory at the Waterways Experiment Station (part of the USACE Research and Development Center). A two volume manual consisting of wetland indicators in one volume, and delineation techniques in the other, was developed and was circulated for review in 1982. It was combined into one manual and reviewed again in 1985 and 1986. In January of 1987, the Army Corps of Engineers Wetlands Delineation Manual was published. It laid out the range of characteristics that an area must have to be considered a wetland (10). Three parameters in this manual are used to determine wetland boundary: soil, vegetation and hydrology. This manual has been slightly modified with clarifications and added data as science has progressed, but it is still the main source used to delineate wetlands. The definition of a jurisdictional wetland, that the EPA and USACE came up with is stated in the 1987 manual as:

> Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas.
>
> (2)

In 1980, the EPA began to develop their own delineation manual and also issued interim guidance for identification of wetlands. After revisions in 1983, a draft manual was prepared in 1985. In 1988, the EPA released its official version of a delineation manual. The *Wetland Identification and Delineation Manual* was slightly different than the USACE 1987 manual. It expanded on the hydrology indicators of the 1987 manual and also allowed simpler delineation in routine cases or where obligate or upland species are present. This manual was short lived due to passage of the 1989 federal manual, which the EPA was a partner in creating (10).

In 1986, after passage of the Swampbuster provision in the 1985 Food Security Act, the Soil Conservation Service (SCS) implemented the Food Security Act Wetlands Delineation Manual. The Swampbuster provision did away with incentives and subsidies for farmers that converted wetlands to agricultural purposes. The passage of this bill was a huge success. Wetland conversion to agriculture prior to 1985 was 235,000 acres per year, but by 1992 the conversion rate was down to 27,000 acres per year (1). The manual was developed to enable the Soil Conservation Service to delineate the boundary between wetland and non-wetland for the purpose of determining if wetlands had been converted to agricultural use, or if areas could be converted without any penalties to farmers. This manual was never intended to be used to delineate for section 404 permitting in the Clean Water Act.

George H.W. Bush- No Net Loss

In 1988, during a campaign speech in Boston, MA, then candidate George H. W. Bush first promised a policy of "no net loss" on a boat in the Boston Harbor while attacking Michael Dukakis for failing to clean up the harbor. "No Net Loss" was the major recommendation from the Conservation Foundation's "National Wetland Policy Forum" that occurred earlier that year. The Conservation Foundation was selected by the EPA to hold the forum. The main proponent of "no net loss" at this meeting was William K. Reilly, who was later selected by President H.W. Bush to be administrator of the EPA. When George H. W. Bush did become president in January of 1989, "No Net Loss" of wetlands became policy in the United States (7)

In an attempt to make one delineation manual to be used across all government agencies, the EPA, USACE, SCS and FWS came together to create the 1989 Federal Manual for Identifying and Delineating Jurisdictional Wetlands. This manual was a combination of the previous manuals, including the Fish and Wildlife Service rules, and it greatly expanded the definition of a jurisdictional wetland. The 1989 manual roughly doubled the acreage of jurisdictional wetland in the United States from previous manuals. Developers and landowners were irate about the new rules that possibly took away control over their land (8).

In 1991, major revisions to the 1989 *Federal Manual for Identifying and Delineating Wetlands* were proposed by the H.W. Bush Administration. These recommendations ultimately came from a group started in 1986 under President Reagan as the Council on Competitiveness. The Council on Competitiveness was formed as an advisory group to the White House to find ways to cut regulation to make the government work more smoothly and boost the economy. President H.W. Bush appointed his Vice President, Dan Quayle, to the head of the committee, which then became known as the "Quayle Council." The workings and discussions of the council became very secretive, and even Congress could not subpoena information or members for questioning. This is the group President H.W. Bush entrusted to come up with a new delineation manual.

Revisions to the 1989 manual would make it similar to the federal manual passed in 1987 in the way it was used, but it held key proposed revisions that set different standards for what constituted wetland soils, hydrology and vegetation. In these new standards, large areas that were wetlands under the 1987 and 1989 manuals would not be wetlands under the 1991 manual. During the public comment period held by the EPA on the new proposed changes to the manual, 50,000 letters and 80,000 phone calls were taken from concerned citizens, most of them highly critical of the proposed changes (7).

In 1991, Congress passed the Energy and Water Development Appropriations act (for the 1992 fiscal year), which was signed into law by President Bush on August 17, 1991. This act stated:

> None of the funds in this Act shall be used to identify or delineate any land as a 'water of the United States' under the Federal Manual for Identifying and Delineating Jurisdictional Wetlands that was adopted in January 1989 (1989 Manual) or any subsequent manual not adopted in accordance with the requirements for notice and public comment of the rule-making process of the Administrative Procedure Act. (Public Law 102-104)

The Administrative Procedure act, that became law in 1946, applies to all federal agencies and sets forth procedural guidelines that they have to follow. The Energy and Water Development Appropriations act for the 1993 fiscal year states:

> Furthermore, the Corps of Engineers will continue to use the Corps of Engineers 1987 Manual, as it has since August 17, 1991, until a final wetlands delineation manual is adopted. (Public Law 102-377)

In 1993 congress approved funding for the National Academy of Science via the National Research Council to make recommendations for a new wetlands manual that would go through the rules laid out in the APA and would replace the 1987 manual. A 17 member committee was selected in the summer of 1993, and spent two years discussing definitions of wetlands, the science behind wetland functions, and regional variations. The recommendations released in

1995 concluded the 1987 manual should be redone with changes that would lead to a broader definition of what constituted a jurisdictional wetland, but found the process of delineation was scientifically sound (10).

Clearly Congress was expecting another delineation manual to come out at some point, but more than 20 years later this has not happened. Inaction by the Clinton administration due to the subject being a political liability and political partisanship that has driven a wedge between parties has ensured that the 1987 Wetlands Delineation Manual will continue to be the manual used by the Army Corps of Engineers.

The 1994 Memorandum of Agreement established the SCS as the agency in charge of delineating wetlands on or surrounded by agricultural lands, defined in the Food Security Act Manual. These include “Prior Converted Wetlands” and also “Farmed Wetlands”. Prior converted croplands are areas of wetlands that were converted to cropland prior to the 1985 Food Security Act, and are not regulated under section 404 of the CWA.

<u>Discussion of Manual Differences</u>

Starting in 1986, multiple federal agencies began to implement different manuals for delineating wetland boundaries (Table 1.2). These manuals varied because of how they were developed and the policies they were supposed to help implement. For example, the SCS manual was used to follow regulations for the National Food Security Act Swampbuster regulations. The other manuals were developed to deal with Section 404 of the Clean Water Act. Each manual differed by one or more of the three primary tests characteristic of wetlands: hydrology, vegetation and wetland soils.

Table 1.2- Federal wetland delineation manuals and dates.

Manual Name	Year
National Food Security Act Manual (SCS)	1986
Corps of Engineers Wetlands Delineation Manual	1987
EPA Wetland Identification and Delineation Manual	1988
Federal Manual for Identifying and Identifying Jurisdictional Wetlands (FWS, SCS, USACE, EPA)	1989
Amendments to Federal Manual	1991

The differences in the manuals meant that the wetland areas that would be considered as jurisdictional under each different manual would vary. This variation caused the problems seen earlier this chapter. Differences in the manuals are shown in the tables below. The EPA manual was short lived and very similar to the USACE 1987 manual, and it has not been included in the tables and discussions below.

During the five year period starting in 1987, three manuals were developed, only to end up with the first manual developed in 1987. The USACE manual in 1987 was the first manual used to delineate wetland boundaries for the purpose of section 404 of the Clean Water Act. The 1989 manual was developed during collaboration among the FWS, SCS, EPA and USACE. In order to meet the needs of all the agencies, the definition of federal jurisdictional wetland was expanded. This expansion meant that more land was protected under the 1989 manual than the 1987 manual. However, in 1991, the Bush administration proposed amendments to the 1989 federal manual that would cause less area fall to under government jurisdiction as protected wetland, which helped landowners and also helped meet the goal of “no net loss”. Due to backlash from the public and environmental groups, however, Congress did not pass the amendments to the 1989 manual and told the USACE to go back to the 1987 manual (3,10).

More specific differences in the manuals are found in how the manuals treated hydrology, vegetation and soils. Table 1.3, for example, shows that jurisdictional land was expanded from the 1987 manual to the 1989 manual by shortening the growing season requirement and in some soil types making it possible for the water table to be deeper and still fulfill the requirements. The opposite can be seen between the 1989 manual and the 1991 amendments. Differences in vegetation are also shown below in tables 1.4 and 1.5. Table 1.6 shows reasons why new manuals were developed and why they all failed except for the 1987 manual.

Table 1.3. Differences in Hydrology Indicators (10)

Shortened Manual name	**growing season length**	**depth to water table**	**length of inundation during growing season**
SCS 1986	soil temp above biological zero	surface	15 days for most areas
USACE 1987	frost-free days (Air temperature)	12 inches	>12.5%
Federal Manual 1989	above biological zero 20 in. below ground	.5 to 1.5 ft depending on soil type	7 days
1991 amendments	3 weeks before to 3 weeks after first/last killing frost	surface	15 days

Note: biological zero is 5^{o}c

Table 1.4- Differences in Vegetation Indicators (10)

Shortened Manual name	Definition of Wetland Vegetation
SCS 1986	Plants growing in water or in a substrate that is at least periodically deficient in oxygen during the growing season as a result of saturation or inundation by water.
USACE 1987	...macrophytic plant life that occurs in areas where the frequency and duration of inundation or soil saturation produce permanently or periodically saturated soils of sufficient duration to exert a controlling influence on the plant species

	present.
Fed. Manual 1989	macrophytic plant life growing in water, soil or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content
1991 amendments	plants that live in conditions of excess wetness… macrophytic plant life growing in water or on submerged substrates, or in soil or on a substrate that is at least periodically anaerobic (deficient in oxygen) as a result of excessive water content.

Table 1.5 Hydrology Criteria (10)

Shortened Manual Name	Hydrophytic Prevalence Index less than 3.0	>50% dominate species OBL, FACW, or FAC	Both
SCS 1986	Y	N	N
USACE 1987	**N**	**Y**	N
Federal Manual 1989	Y	**Y**	**Y**
1991 Amendments	Y	N	N

Note: 1989 Manual used both index *or* % coverage.

Because the 1989 federal manual was able to consider both tests for wetland vegetation, it expanded the area that could be considered as jurisdictional wetland. Clearly this expansion was not well received by many landowners.

Table 1.6. Comparison of the CWA related manuals (3,10)

Manual	Sought to improve	Why it was changed
1987 USACE	First manual used to Delineate wetlands for CWA purposes	Desire to create single manual for all agencies
1989 Federal manual FSW, SCS, EPA, USACE	was supposed to standardize delineations across different agencies	Protected too much land as jurisdictional wetland. People lost control of their land overnight
1991 amendments to 1989 manual	tried to scale back amount jurisdictional wetland, making it easier to meet "no net loss" goal	Congress did not pass amendments, instead legislated that the USACE go back to the '87 manual. EPA followed suit

<u>Litigation- Court Cases</u>

<u>Natural Resource Defense Council vs. Callaway 1975</u>

In 1975, the Natural Resources Defense Council (NRDC) brought a suit to the United States District Court for the District of Columbia against the Secretary of the Army for dredge and fill permits that the Army Corps of Engineers had allowed. The permits were for the Navy to dredge a 7.5 mile stretch of the Thames River in Connecticut to accommodate a new, larger class of submarine. The NRDC did not take issue with the dredging of the river itself, but rather where the dredged material was to be put. The dredging operation required removal and disposal of approximately 2.8 million cubic yards of highly polluted material containing volatile solids from the river bottom. The USACE selected the New London Dumping Site for the dredge spoil.

The NRDC claimed that the areas selected for deposition were not free from the possibility that this toxic sludge could be spread by ocean currents or by storm surges into coastal wetlands. The NRDC also claimed that the EIS completed by the navy was inadequate because it failed to look at different possible dumping sites, and also that the USACE should have been in charge of the EIS because they were in charge of the dumping site. The USACE argued that the only Clean Water Act-section 404 guidelines set forth by the EPA at that time were for ocean dumping and did not cover inland waters. (No. 916, Docket 75-7048.United States Court of Appeals, Second Circuit)

The District Court ruled that the EIS was sound, but the goal of the 1972 Clean Water Act was to expand the jurisdiction and protections of waters of the United States as far as possible. The court ordered the USACE to rewrite its regulations to include protecting wetlands under section 404 of the Clean Water Act. The new protections defined qualities of wetlands that were now going to be protected (10).

i Wetlands are those land and water areas subject to regular inundation by tidal, riverine, or lacustrine flowage. Generally included are inland and coastal shallows, marshes, mudflats, estuaries, swamps, and similar areas in coastal and inland navigable waters. Many such areas serve important purposes relating to fish and wildlife, recreation, and other elements of the general public interest. As environmentally vital areas, they constitute a productive and valuable public resource, the unnecessary alteration or destruction of which should be discouraged as contrary to the public interest.

ii. Wetlands considered to perform functions important to the public interest include:

a. Wetlands which serve important natural biological functions, including food chain production, general habitat, and nesting, spawning, rearing and resting sites for aquatic or land species;
b. Wetlands set aside for study of the aquatic environment or as sanctuaries or refuges;
c. Wetlands contiguous to areas listed in paragraph (g)(3)(ii) (a) and (b) of this section, the destruction or alteration of which would affect detrimentally the natural drainage characteristics, sedimentation patterns, salinity distribution, flushing characteristics, current patterns, or other environmental characteristics of the above areas;
d. Wetlands which are significant in shielding other areas from wave action, erosion, or storm damage. Such wetlands often include barrier beaches, islands, reefs and bars;

e. Wetlands which serve as valuable storage areas for storm and flood waters; and
f. Wetlands which are prime natural recharge areas. Prime recharge areas are locations where surface and ground water are directly interconnected.

This court ruling was the first test of the 1972 Clean Water Act, which expanded the protections of waters of the United States. Because of this ruling, wetlands adjacent to waters of the United States became protected. This court case ultimately led Congress to further define waters of the United States in the 1977 Clean Water Act Amendments (Table 1.1)

Riverside Bayview Homes, Inc. vs United States 1985

In 1985, the United States Supreme Court took up the case United States vs. Riverside Bayview Homes Inc. (RBH). In 1976, this home building company began to fill wetlands on its property in preparation for new home building. The USACE brought a suit against RBH because, in the Corps' opinion, the company was filling adjacent wetlands which under the Calloway opinion required a permit from the USACE to fill these wetlands.

The district court ruled in favor of the USACE, stating that the wetlands that were filled were in fact adjacent wetlands and therefore needed a permit. The Court of Appeals ruled against the district court's opinion and stated that the USACE must have a narrower definition of waters of the United States to keep from overstepping their bounds and to keep from *taking without just compensation* under the 5th Amendment. The Supreme Court overturned the Court of Appeal's decision, and stated that needing a permit to fill in the lands, or even a denial of a permit, would not constitute a *take* by the government. The Supreme Court upheld the lower district court's opinion that the wetlands were adjacent, making it once again required that filling wetlands required a permit. (United States v. Riverside Bayview 474 U.S. 121 (1985) (4).

SWANCC vs US 2001

In 2001, the Supreme Court took up the case of Solid Waste Agency of Northern Cook County v US Army Corps of Engineers (531 US 159, 2001). The Solid Waste Agency of Northern Cook County (SWANCC) wanted to use an excavated mine area for a new landfill for non hazardous baled solid waste. The 533 acre mine had not been used since the 1960s. Since the abandonment of the mine area, multiple areas had filled in with water and had become ponds, some of which were several acres large. SWANCC obtained all necessary local and state permits, but was denied permits by the USACE due to the presence of migratory birds that used the ponds.

In 1989, in an attempt for the USACE to clarify what wetlands were considered jurisdictional after the Riverside Bayview decision, they included language that became the "Migratory Bird Rule". This basically said that isolated waters that are or would be used as habitat by migratory birds protected by Migratory Bird treaties were considered jurisdictional wetlands.

Initially the USACE concluded that it had no jurisdiction over the site, but after the Illinois Nature Preserves Commission informed the USACE that there were migratory birds observed at the site. The USACE asserted jurisdiction over the site and denied a permit to SWANCC citing the Migratory Bird rule, even after SWANCC developed plans to mitigate the displacement of the migratory birds.

The Supreme Court ruled that when congress passed the Clean Water Act, they never intended for that law to cover abandoned mines under section 404 permitting, and the Migratory Bird rule exceeded authority granted to the USACE. The outcome of this court case limited the ability of the USACE to define by themselves what constituted as a jurisdictional wetland (6).

Rapanos v. US, US v. Carabell, 2006

In 1989, John A. Rapanos filled 54 acres of wetland area in Michigan for development purposes. The three areas he had filled were for a shopping complex. The Michigan Department of Environmental Quality warned Mr. Rapanos that the areas he was filling in were protected under section 404 of the Clean Water Act. After ignoring cease and desist orders from the EPA, Rapanos was informed by the USACE that he was in violation with Section 404 of the Clean Water Act for the filling of "Waters of the United States." After 10 years of prosecution by the justice department, in 2001 fines in the amount of $185,000 and 3 years of probation were levied against him. The Justice Department also won a civil suit against Mr. Rapanos in 2005 and sought $10 million in fines and $3 million in fees, along with requiring Mr. Rapanos to set aside 80 acres in permanent wetlands. The case was fought all the way to the United States Supreme Court, that took up the case in 2006.

Section 404 protects Waters of the United States from dredge and fill operations. Waters of the US are navigable waters, including adjacent tributaries and wetlands to these navigable waters. "Adjacent wetlands include those bordering, contiguous to, or neighboring waters of the United States even when they are separated from such waters."

The problem here was with the lack of definitions of terms, and how one definition uses words that need further defining. The wetlands that Mr. Rapanos filled were beside a man-made ditch that eventually led to a major river. The ditch was dry, and the wetlands adjacent to the ditch were separated by a berm that was found to prevent a hydrological connection with the ditch. The river was obviously protected as a "Water of the United States," but the question was at what point does protection of a tributary stop. This was one of the main problems that the Supreme Court had with this case. Prior to this case, the USACE assumed it was a matter of its discretion to determine what qualified as a protected tributary.

Some justices inferred that the intention of the Clean Water Act was to protect the waters of the United States; and gave an example that if poison was placed in this dry ditch, rain could wash it into the river eventually, so the ditch should be protected. Other Justices argued that by that standard, almost all land would be protected under the Clean Water Act due to the propensity of water to run downhill into a tributary, and then into a water of the United States.

(Supreme Court Decision- https://www.law.cornell.edu/supct/html/04-1034.ZS.html, Oral Argument- https://www.oyez.org/cases/2005/04-1034)

The lack of action by the executive and legislative branches on this issue has largely left it up to the judicial system to clarify the meanings of the current wetland protection laws. The courts can only do so much though. They can only interpret parts of the law that are being called into question in that case. They cannot review other parts of a law, even if they know that in the future it will be brought back to them to rule on. Without help from the other branches, the courts can only do so much interpreting before they overstep their authority. This is creating a constant battle between different levels of the courts that has led to two major Supreme Court rulings in the first decade of this millennium alone.

Conclusion

The attempt to protect wetland ecosystems in the United States has been a back and forth battle to define what a wetland is and also to determine the reasons for wetlands protection. President H. W. Bush attempted to further the protections for wetlands by promising a policy of "no net loss", which ended up being a promise he could not keep. In the process of attempting to change what would be considered a jurisdictional wetland, he ended up angering land owners and environmentalist alike, all while greatly failing to reach the goal of "no net loss". This attempt to solve the problem of wetland destruction showed how hard it was to implement a viable plan on an environmental issue that would be accepted by both sides. It also showed that the political climate had changed from the green movement, where many environmental protections were implemented. Because of these changes, after H. W. Bush's term, both congress and President Clinton seemed to not want to revisit the issue and risk the political fallout. Since then, politics in the United States have consistently gotten more and more partisan, making it harder to reach any compromise on anything. Until there is a major change in the current political climate, nothing more will be done by congress or by a president to help clarify the laws and goals of protecting wetlands in the United States.

Climate change could eventually be the political driver of change to wetland legislation. As sea level is expected to rise, coastal wetland ecosystems will become more inundated with water. Forested wetlands will transition to grass dominated ecosystems as the water table rises. Coastal flooding will become more and more of a problem, which will make the value of wetlands increase due to the need for flood control and storm surge protection. Understanding how climate change will affect coastal areas, including wetland ecosystems, is already becoming a major focus for scientists. This will create more policy issues that will need to be addressed by the government. As the sea level rises, land that is currently dry will become wetland. Property owners will begin to lose control over their property to the federal government. Future problems created by climate change will eventually not be a partisan issue, and solutions will follow.

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Chapter 2: Brief History of Wildlife Refuges and Site Characteristics and History of the Alligator River National Wildlife Refuge

Brief History of Wildlife Refuges

Often times wildlife refuges are located in vast areas of wetlands. The reason for this is that the main value of a wetland is in it being left alone to provide storm protection, flood control, pollution reduction and wildlife habitat. There are also not many easy uses for wetlands from any construction stand point, especially after legislation passed that protects them. This lack of profitable use of wetlands makes it easy for the US government to obtain large swaths of this land to create wildlife refuges. Many national wildlife refuges are located in major migratory bird flyways (figure 2.1).

Figure 2.1- US Wildlife Refuge locations. Note the amount along the coast line.

Many of these migratory birds are water fowl that need wetland areas to rest and feed along their journey. Many other plants and animals are well adapted to life in wetlands, from mega flora and fauna to rare and endangered species. These are reasons why so many wetlands are located within national wildlife refuges and vice versa. Wetlands are key to having vibrant, healthy national wildlife refuges.

Refuge History

In 1903, President Theodore Roosevelt created the Pelican Island National Bird Preservation in Florida, which was the first wildlife refuge in the United States. Management of this preservation was charged to the Division of Biological Survey. In 1940, the US Fish and Wildlife Service was created by combining the Bureau of Biological Sciences and the Bureau of Fisheries (9). A year before this merger, there were a total of 37 wildlife refuges created in 1939 alone. There was an influx of refuges created starting in 1935, but quickly fell off at the start of World War II (Figure 2.2 and 2.3).

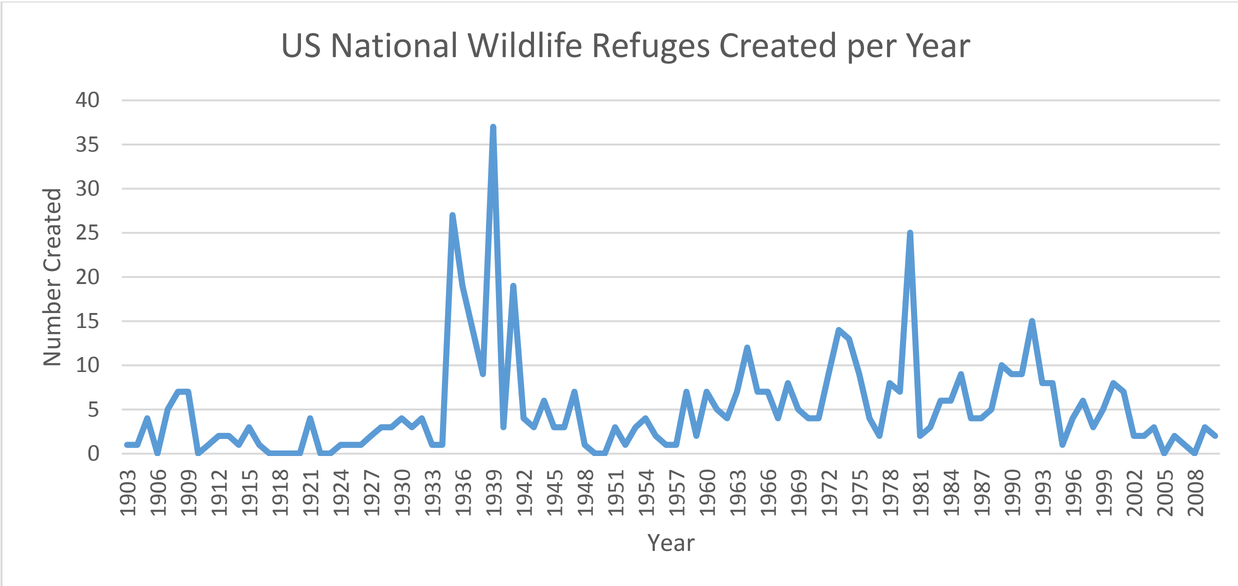

Figure 2.2- Wildlife Refuges created each year. Data extrapolated from
http://training.fws.gov/history/ListsRefugeDates.html

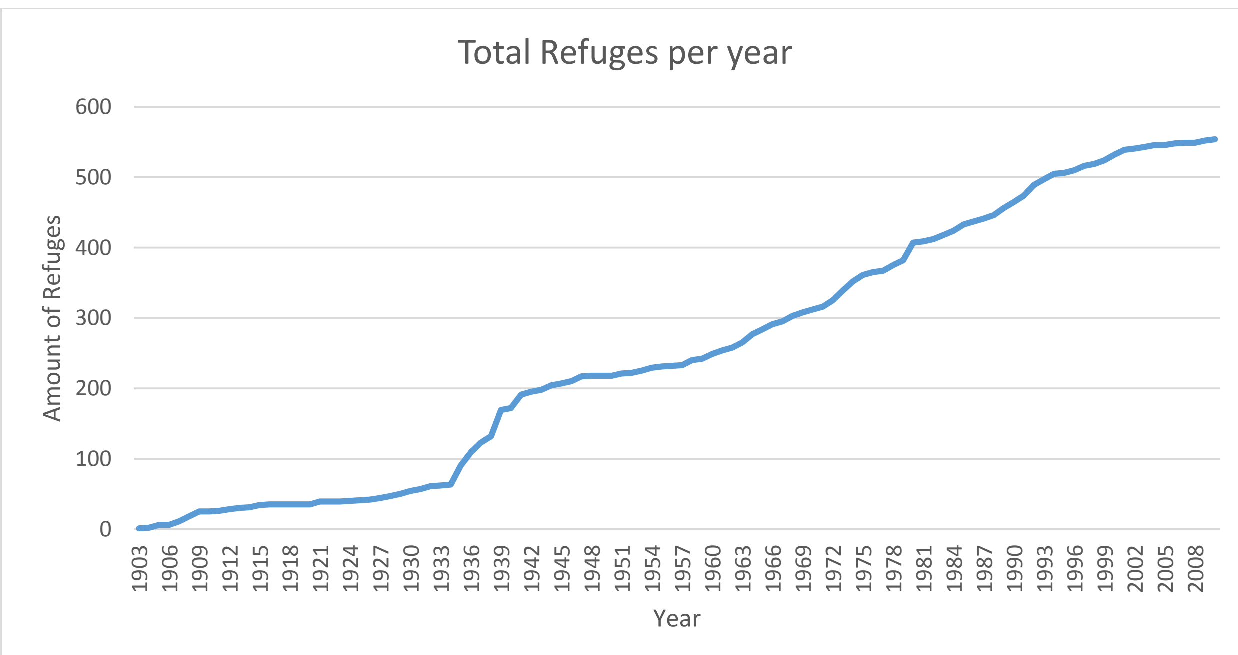

Figure 2.3- Total US Wildlife Refuges in existence each year. Data extrapolated from
http://training.fws.gov/history/ListsRefugeDates.html

As of 2010, there were 554 refuges total, 513 of these are in the 50 US states and 41 are in US territories. North Dakota has the most wildlife refuges at 62 (Figure 2.4). North Carolina has a total of 10 wildlife refuges, one of which is the Alligator River National Wildlife Refuge created in 1984. Five other US wildlife refuges were created that same year.

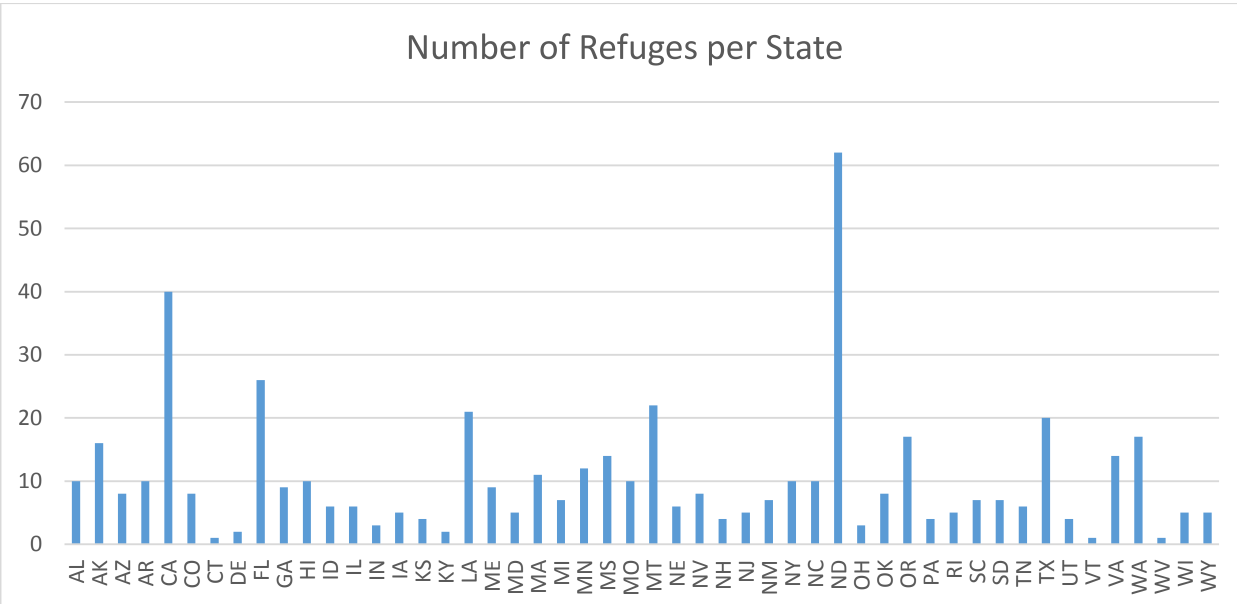

Figure 2.4- US Wildlife Refuges in each state. Data extrapolated from http://training.fws.gov/history/ListsRefugeDates.html

Site Characteristics and History of the Alligator River National Wildlife Refuge

Introduction

Wetland ecosystems provide the environmental benefits of flood control, pollution control and nutrient cycling, and crucial habitat for plants and animals that rely on wetland conditions to survive. Another major benefit found in coastal wetlands is in their ability to weaken hurricanes and tropical systems as they come over land and greatly slow the amount of erosion during these major storm events. Because of these benefits, and the rapid loss of wetland ecosystems in the past, the United States changed its policies to protect wetlands over decades from the 1970's to the 1990's.

The draining of wetlands for various reasons persisted well into the 1970's, and has only slowed within the past 30 years. Reasons for draining wetlands include flood control, mosquito prevention, and making the land viable for crop and timber production (7). Some ditches were also used to float trees out of the swamp and to saw mills. One such area that had been extensively ditched and drained over many years is an area now encompassing the Alligator River National Wildlife Refuge (ARNWR) located near Manteo, NC. The Refuge spans 152,260 acres and is the site of the red wolf recovery program in NC (1).

Prehistory

The wetlands and peninsula that compose ARNWR is a product of post Wisconsin Glaciation factors (1). Roughly 15,000 years ago the sea level was near or at its lowest point, exposing large areas of the continental shelf. With a larger difference in elevation than seen today, fast flowing rivers cut channels throughout the landscape. As the sea level began to rise, the rivers began to slow down due to the terrain elevation becoming more and more uniform. Sediment began to settle as it flowed out of the mouths of the rivers surrounding the Albemarle Sound. These sediments formed what is today the wetland area that the refuge is located in. These wetlands have accrued more soils from plant material that has fallen and has not completely decomposed.

Soils

Some areas of the refuge are up to 5 meters deep of muck soils. The soil type that is most common in the refuge is Ponzer, which has a muck depth of about 30 inches and covers about 73,000 acres of the refuge (1). The organic soils of the refuge sit on top of a marine sediment mineral layer. Roper soil is an organic soil with only around 16 inches of muck with vegetation similar to mineral soils. Roper is one of the most productive soil types in the area when drained. Mineral soils make up around 15,000 acres of the refuge land. Most mineral soils are more productive than the organic soils for crops and trees. The mineral soils found here are considered prime farmland soils. The following table lists the other soil types found in the refuge along with their water table depth, muck depth and flooding frequency.

Udorthents soil is also located in the refuge which comes from dredged soils from the Inter-coastal Waterway (1). This soil type is very well drained and extremely droughty due to there not being any organic material and it being mostly sand. The volume of peat in the refuge is roughly half of the original amount due to drainage ditches, agriculture and fire. Drainage of the swamp has led to the loss of around 1/3 of the peat due to shrinkage, decomposition and fires because of the dry peat.

Climate

The climate of ARNWR is influenced largely by airflow from the west (1). Although the refuge is largely surrounded by bodies of water, the wind that comes from the mainland causes larger fluctuations between day and night than some marine environments that are regulated by water temperatures. Winter storms can bring large amounts of prolonged rain. Snow is not very common in the refuge.

Spring sees a change from rain events to thunderstorms. Thunderstorms make up the majority of rainfall in the late spring and throughout the summer. Autumn is the dry season here, with warm days and cool nights. Average annual precipitation is 144.76 cm per year (1). Average snowfall is 4.8cm per year. 68.6 cm of rain falls in the growing season between May and September and the average growing season is 265 days.

Vegetation

In spite of human activity through harvesting of trees and agriculture, much of the refuge has remained a forested wetland ecosystem that is important to many types of wildlife for habitat because of the ecological resources provided (1). The refuge has vast amounts of non-riverine swamp lands along with fresh and saltwater marshes (1,6). The pond pine shrub pocosin makes up the largest area of the refuge with roughly 50,000 acres. The croplands present are considered prior converted wetlands. The main wetland types are forested palustrine, emergent palustrine and intertidal estuarine (6).

History

The history of the Refuge has spanned more than 200 years. Communities and settlements have existed at different times and in different places. Some of these communities that are fishing villages still exist today such as Manns Harbor and Stumpy Point. Others that were reliant on the timber industry collapsed and the people there moved on.

Beechlands

Before the civil war, farmers converted 5,000 acres of what is today refuge land in a settlement known as Beechlands in the Milltail Creek area (4,5). It was a hidden community that seemed to choose to be cut off from the rest of the world. Theories about why they wanted to remain secluded include avoiding US taxes, laws, and military drafts (5). Not much seems to be known about Beechlands, but there is much speculation and legend behind this small community. The community disbanded in the 1840’s after a “black tongue” disease almost wiped out the entire settlement (5). There are a few theories as to what this disease could have been, including cholera, bubonic plague, or anthrax.

The stories that have been passed down from the past few generations before they were written down all involve tales of Indians that lived in Beechlands, some that had blue eyes (5). It seems as though there were Europeans that were living in the community as well. All the families seemed to have English surnames. In 2009, a report was released by Roberta Estes that found information in the US census and tax records that disproved or at least didn’t agree with some of the stories (4). It seemed from her work that there was a drop in population in the 1840’s, but that there were families that did stay in the area. This also contradicted that the people wanted to be cut off from the rest of society since they were listed in the tax information. There was evidence that the Beechlands Creek was the earliest settlement in Dare County, as early as 1786, but there is still no evidence that points to when the settlement was originally founded (4).

Buffalo City

After the Civil War in 1885, the Buffalo Timber Company of New York bought 168,000 acres of what is today largely refuge property (1). The town of Buffalo City was located on the north part of Milltail Creek, not far from Beechlands. 3,000 people lived in this community, which included 300 Russian employees (3,8). Buffalo Timber Company logged the entire area which included some White Cedar trees with 6 foot diameter trunks (3). This was the sought after species at this time for cedar shingles and siding. After one massive harvest was complete, Buffalo Timber Company left and so did a large portion of the residents. In 1907, Dare Lumber Co. bought the forest and brought back the logging community. A pulp mill was built near the East Lake, and railroads were cut through the woods. Locomotive engines were brought in by boat to carry timber out of today's refuge land. The trains carried the trees to barges in Milltail Creek where they were taken to saw mills elsewhere in the country. When Prohibition went into effect, Buffalo City's logging operation had already begun to slow. The community, being in a swamp that was hard to get to, turned to moonshining to make a living. Barges carried jugs of moonshine to Elizabeth City about 2 times a week, and brought back as much sugar as possible. Everyone in town would always sign that they ordered 100 pounds of sugar so the authorities could not pin it on any one family. The city still harvested Atlantic White Cedar into the 1940's when a mixture of diseases caused the population to drastically collapse to fewer than 100 individuals. At that time the local sawmill closed, and so was the end of Buffalo City.

Company Holdings

Richmond Cedar Works bought the Buffalo City land shortly thereafter the closure of the sawmill, but soon sold it to Prulean Farms, which was a subsidiary to McLean Farms and Prudential Life Insurance Co. (1,3) This became the agriculture area of the Refuge and made up about 5,200 acres. West Virginia Pulp and Paper Company (WestVaCo) acquired the larger part of the forested wetland, which was then sold to Prudential Life insurance Co. In 1984, Prudential Life Insurance Co. obtained all the land from Prulean Farms and then donated the land to the US Government which became the Alligator River National Wildlife Refuge in March of that year.

Bombing Range

In 1965, the US Air Force built a bombing range in the middle of what is refuge land today (1). It was first leased from WestVaCo, and then from Colony Farms, who then gave the land to the Air Force in 1978. 41,200 acres of the 46,000 acre bombing range is managed by the North Carolina Wildlife Commission as a game land.

Ditches and their Effects

The many ditches implemented throughout the Alligator River National Wildlife Refuge have had long lasting effects on the plant communities right around them. The ditches were dug out, and the soil was piled up on one side of the ditch or the other and is typically packed down to make a road. This caused changes in the groundwater hydrology, and caused different effects on both sides of the ditch. Typically, on the side of the ditches that does not have the road, the trees are either dead or dying while on the other side of the ditch the trees usually look much healthier. This effect can be seen hundreds of feet away from the ditch. The suspected reasons for this are that the depth to groundwater is different on one side of the ditch compared to the other, and this is caused by the ditches. It is also suspected that these ditches allow salt water to flow up into the surrounding ecosystems that are not salt tolerant, which has a negative impact on the vegetation there. This happens during strong wind events such as hurricanes, and other tropical or major low pressure systems. Without the ditches, the salt water may not have been able to reach certain parts of the refuge that it can due to the ditches.

Not all the ditches are as obvious as the ones that have roads on them. Some small shallow ditches exist throughout the refuge that were dug to harvest one area but were not maintained after the harvest. Some of these ditches were dug with slave labor by hand and were used to float out trees with oxen dragging the tree through the ditch (5). These ditches have filled in over the years and have been overgrown by the surrounding forest. These ditches have not killed the trees on one side like the larger road ditches, but they may still cause differences in the vegetation around the ditches there, particularly in the understory.

Sea Level Rise

With the current sea level rise estimates at 3mm per year, the low elevation of the Refuge makes it a "canary in a coal mine" to the effects of sea level rise. By the year 2100, at the projected sea level, more than half of the refuge could be under water (2). By studying the ditches now that are allowing water into the interior of the refuge, a look into what the rest of the refuge will transition into can be acquired. These ditches are the first areas to see the effects of increased sea level, but eventually the rest of the refuge will follow suit in being flooded more and more with more salt intrusion.

The Nature Conservancy is working with Refuge officials to come up with ways to adapt to climate change. One project on Point Peter Road has implemented pipes that allow water in the ditches to flow out of the refuge, but are designed to close when the direction of the water reverses during storm surge (2). The idea is to limit as much as possible the amount of saltwater intrusion into the Refuge forest through the drainage ditches. Another project is the implementation of an artificial oyster reef off of the coastline of one of the more heavily eroded beaches in the refuge (2). The reef is supposed to slow down wave energy which will hopefully slow the rate of erosion currently happening. Neither of these projects is meant to curb the effects of sea level rise completely, but the main goal is to slow the process allowing plant communities and animals a chance to transition over a larger amount of time. The Nature Conservancy is also active in planting salt tolerant tree species in some parts of the refuge that are, or are expected to see salt water intrusion.

Conclusion

The past usage of ditches in the Alligator River National Wildlife Refuge is still felt today. The ditches that were once used to harvest timber still leave their mark on the environment by changing environmental conditions away from the ditch itself. The ditches that remain today are one part of multiple small communities' effects on the ecosystem around where they existed. The specific climatic conditions that were present along with the soil and vegetation types present dictated what the local people were able to do with the land. Man is not able to do whatever he wishes with the land as nature has its own rules, but must instead abide by these rules and use them to his advantage.

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Chapter 3: Effects of Canals and SLR in the Alligator River National Wildlife Refuge

Vast areas of wetlands are located along the coastline. Because of their low elevation and close proximity to the ocean, coastal wetlands are prime locations to study the effects of sea level rise associated with climate change. As stated in chapter 2, often wildlife refuges are located in wetlands. Many of these wildlife refuges are also along the coastline, as is the case with the Alligator River National Wildlife Refuge. Signs of sea level rise can be seen in various forms across ARNWR, including effects on vegetation communities found there. Information learned from studying the wetlands here can be used to predict what may happen in other lower coastal plain areas.

The global sea level has been rising since the end of the last glacial maximum roughly 20,000 years ago, though the rate of sea level rise has been relatively stable over roughly the last 4000 years (3). It now seems that our planet is transitioning back into a period of more rapid sea level rise. There is much consensus within the scientific community that the Earth's climate is warming at a geologically unprecedented rate. It is largely believed that human burning of fossil fuels is a major contributing factor to this rate of warming. By the year 2100, the mean temperature of the earth could rise by 2.8^{o}C with ocean temperatures following a similar rise (5). This increased temperature will cause glaciers and icecaps at the poles to melt, along with thermal expansion of ocean waters. This is expected to cause sea level to rise by .35 m by the year 2100 (4). Regardless of the causes, this new period of rapid sea level rise is occurring and the effects can already be seen. Studies need to be done on these effects so that coastal communities are able to better prepare for coming changes.

Sea level rise of a third of a meter would have drastic consequences on coastland areas. The very low (less than 1m), flat terrain of the lower coastal plain in North Carolina makes it a prime location to observe the effects of sea level rise over short time periods. This area is in constant movement over geologic time. The Alligator River National Wildlife Refuge is in the prime location to study these expected effects of sea level rise. This chapter focuses on current and past changes to the ecosystems found in ARNWR.

As stated previously in chapter 2, in these deep peat coastal wetlands that cover ARNWR, roads are often built by removing the organic soil beside the road bed and “borrowing” the mineral soil underneath, which is piled on top of where the road is supposed to go. This operation creates a large canal beside almost all roads inside the Alligator River National Wildlife Refuge. These borrow canals are not meant to remove water from the refuge but are there as remnants of the road construction. Because of the compaction of the mineral soils to build the road, a dam is in effect created that does not allow water to pass from the borrow canal to the forest on the road side. The forest on the borrow canal side, however, is much more susceptible. In this chapter, “canal side” will refer to the forest that is more susceptible to inundation by the canal, and “road side” will refer to the forest that is more protected from the effects of the canal (Image 3.1).

Image 3.1- Ghost forest can be seen on the left (north of the borrow canal), healthier forest on the right (south of the road). Picture taken looking east between plot 7A/B.

Objectives and Methods

In this study we set out to estimate how much carbon was stored in defined plots on two sides of a historical drainage ditch. Our hypothesis is that there is a difference in the amount of carbon stored on each side of the ditch where the ghost forest can be observed (Image 3.1), and that the carbon that is stored there is found in different parts of the forest. We also hypothesize that as one moves towards East lake from the inner forest, the amount of carbon stored decreases.

Study Site

In the northern part of the refuge, close to where the Alligator River, East Lake and the Albemarle Sound all meet, there is a fire road that was built in 1965 called the Ed Sawyer Road. This road was constructed by using a borrow canal (Image 3.2). The borrow canal and road run in a northeast direction at a heading of 80 degrees from East Lake. The water level of the canal is controlled by wind direction and rain storms, and this level can fluctuate quickly throughout the day based on a change in wind direction or storm.

Image 3.2- East Lake is the water body to the west of the Study Area. "Tower" is the location of other ongoing studies with the NCSU Tree Physiology and Ecosystem Science Lab.

The forest at this site is largely a pond pine pocosin, that transitions into a marsh grass ecosystem towards east lake to the west. The death gradient approaching the canal from the north and approaching east lake can easily be seen. "Death Gradient" refers to the ecosystem transition zone phenomena where as you approach a body of water or borrow canal in the refuge, the overstory trees appear sicker, then begin to die off, then you are left with snags and mid story species that then change over to marsh grasses.

Paired plots were laid out along both sides of the borrow canal (FigureX:3). Seven plots were established north of the canal; 8 plots were established south of the canal. The objective of this design was to cover the death gradient that is seen as you approach the canal from the north on the canal side, and also the death gradient that is seen on the road side as one moves west towards East Lake.

Figure X:3- Plot 7A1 and 5A1 are about 50m into the woods from the road (for scale)

Vegetation

The amount of carbon stored in the overstory, midstory and understory were estimated by different methods for each layer to determine biomass, which was then converted to carbon content by assuming that 50% of the live biomass is carbon. Dead overstory biomass carbon was estimated using different percentages shown below.

Overstory

Tree heights and diameters were measured for all plots at a 15m fixed plot radius using a Nikon laser hypsometer and D-tape. Species type and decay class were also recorded. Allometric biomass equations for several species were used to estimate the biomass of each tree. The allometric equation for Pond Pine (*Pinus serotina*) could not be found, so an allometric equation for pitch pine was used instead. Pitch pine (*Pinus rigida*) is very closely related to pond pine, and some classify pond pine as a variety of pitch pine (*Pinus rigida var. serotina*) (1). Biomass allometric equations need to be created for pond pine.

There were 4 types of overstory tree allometric equations used to estimate biomass; Pitch Pine (*Pinus rigida*, substituted for pond pine), red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), and bay trees (swamp bay, sweet bay, loblolly bay ect.). The bays were all assumed to be one species due to the difficulty in identification, especially when dead or decayed. The pitch pine equation used was Y=10^(2.0171+2.3373*LOG(DBH)) /1000*0.5, where DBH is the diameter at breast height and Y is the amount of Carbon in kg ha-1 (6). The red maple equation used was Y= 2.52363*((DBH^2)^1.19648)*0.5/2.2, where DBH is the diameter at breast height and Y is the amount of Carbon in kg/ha. The sweetgum equation used was Y= 1.82108*((DBH^2)^1.2635)*0.5/2.2, where DBH is the diameter at breast height and Y is the amount of Carbon in kg/ha. The bay equation used was

Y= (-13.388+6.82*(DBH^2)*0.5)/2.2, where DBH is the diameter at breast height and Y is the amount of Carbon in kg/ha (2). The mass of carbon of dead and decaying trees was multiplied by the corresponding percent of carbon left after decay, found in table 3-1 below, along with the description of each decay class.

Table 3-1: Decay classes and percentages

Decay Class	Qualification	% C Left After Decay
0	Alive	100
1	Dead but still has small branches attached. Knife would not penetrate wood.	97
2	No small branches left but still has large branches	97
3	Large branches gone, but tree height generally still intact	86
4	Top broken off, very decayed	53

http://www.arb.ca.gov/cc/capandtrade/offsets/copupdatereferences/harmon_2011.pdf

The amount of carbon stored in each plot was also calculated under a possible future scenario with assumptions that all dead trees had completely decomposed and all carbon was lost, and over this time of total decomposition no alive trees died. These assumptions would be incorrect in reality as some carbon will most likely become apart of the organic soil, and some of the alive trees will mist likely die as well. Though these assumptions are incorrect, they still provide an interesting estimate of future overstory carbon mass stored.

Midstory

Allometric biomass equations were developed for woody plants that compose the midstory layer. Fifty midstory plants ranging in size and by representative species were harvested, heights were measured along with diameters and total mass of the tree. Cookies were cut from each tree, and green to dry mass ratios were developed to determine the total dry mass of each tree (Figure 3:1)

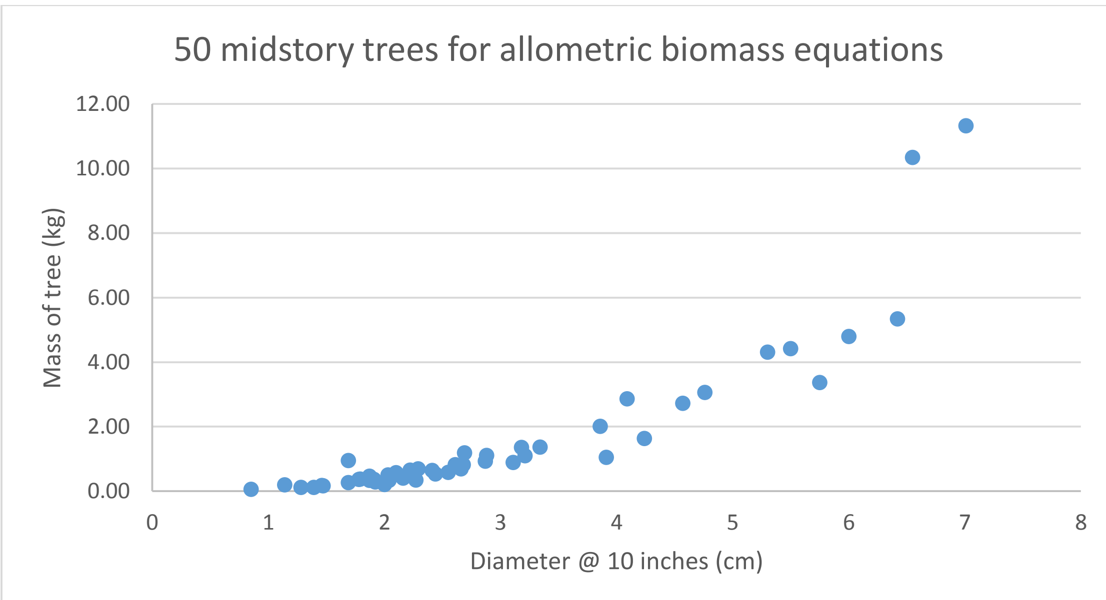


Figure 3-1: Diameters vs. mass of trees

Three equations were used to estimate the mass of carbon stored in this layer in each plot using diameters at 10 inches. At smaller diameters, linear equations gave negative weights, so an exponential equation was better suited. At larger diameters, the exponential equation quickly heads towards infinity, so the linear equations are a better estimate (Table 3:2).

Table 3-2: Allometric equations used for specific diameter ranges.

Range	Equation Used	R^2
0-1.94	y = 0.0944e0.7102x Exponential	0.891
1.94-2.35	y = 0.9342x - 1.4388 No outliers	0.901
2.35+	y = 1.3229x - 2.3518 All data	0.778

Plots were sampled using a 5m radius fixed plot design in each plot. Woody plants up to 10cm diameter were measured at 10cm off the ground.

Understory

The understory biomass was estimated by taking 1x1m clip plots in the dense but uniformly vegetated areas of the understory composed of non woody species. These clip plots were converted to kg*C/ha.

Soils

Soil samples were taken with a Mccauley auger at 10cm increments to a depth of 1 meter in each plot. Bulk densities of these samples will be calculated, and percent carbon will be found at a later date to determine amount of carbon stored in the soil.

Underground Wood Samples

Putting in ground water monitoring wells led to the discovery of buried wood in multiple places across the landscape. It seemed that these wood layers were located at 2 or 3 different depths. Using a bucket auger, samples from these wood layers were recovered at the varying depths and in different plots. Sixteen of these samples were cleaned, processed, and sent off for 14Carbon dating at the National Ocean Sciences Accelerator Mass Spectrometry Facility at the Woods Hole Oceanographic Institution.

Results and Discussion

A statistical difference between the road and canal plots were found in the amounts of carbon stored in the overstory and midstory layers, but not in the understory and total carbon. There is more carbon stored in the overstory on the canal side, but more carbon stored in the midstory on the road side. The amount of total carbon was actually found to be 11.5 Mg C ha-1 more than on the road side (table 3.3). However, the much higher decomposition rate on the canal side (table 3.4), and 56.3% of 687 trees ha-1 of overstory carbon being stored in dead trees (figure 3.3, table 3.4) suggests that as these trees continue to decay, the amount of carbon on the canal side will decrease over time. The largest coefficient of determination (r^2) for forest stand structure was .72 comparing distance to open water to overstory height on the road side.

Table 3.3- Above ground carbon storage. All information in this table excludes data collected from plot 2A. "Road average – Canal Average" is the subtraction from canal side data from road side data. Positive values show the road side is higher, negative values show the canal is higher. Statistically significant P-values are highlighted in yellow.

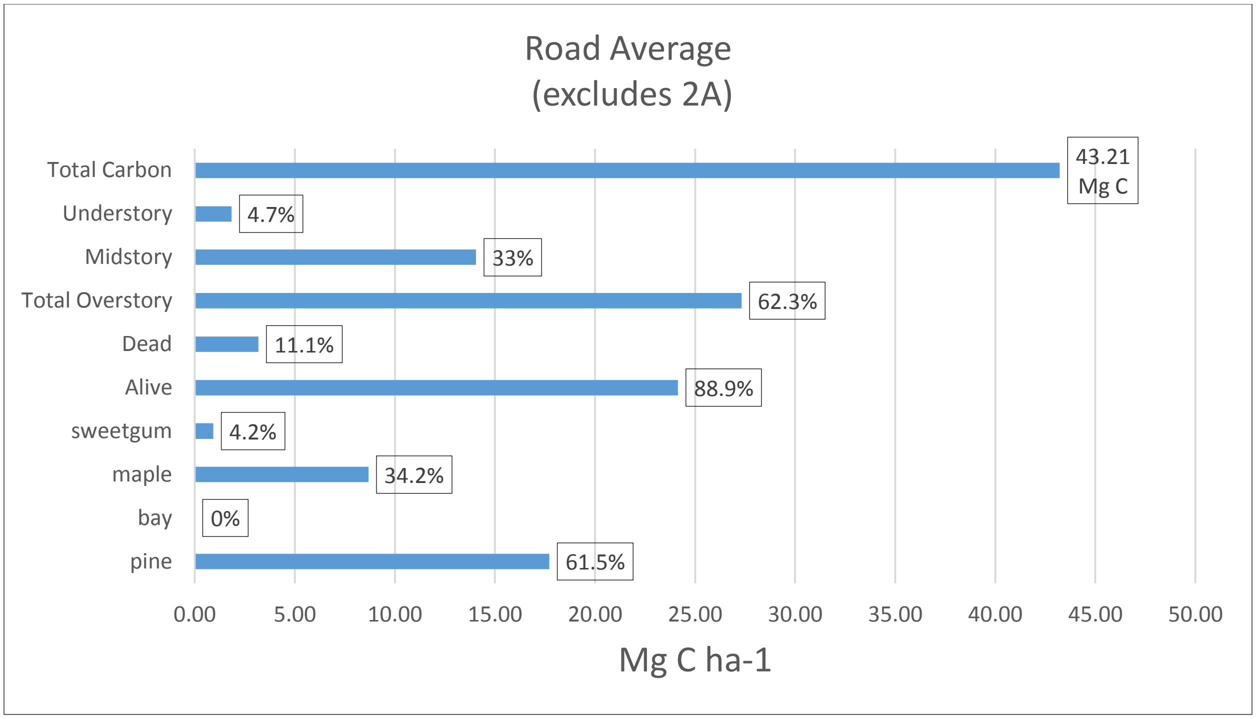
	Mg C Ha-1						r^2 for distance to open water		r^2 for distance to road/canal	
	Road Average	Road Stdev	Canal Average	Canal Stdev	Road Average - Canal Average	p- Value	Road	Canal	Road	Canal
Overstory	27.325	11.637	49.025	15.301	-21.700	0.0297	0.48	0.08	0.03	0.28
Midstory	14.057	7.298	3.652	2.696	10.405	0.0199	0.38	0.11	0.26	0.07
Understory	1.832	0.641	2.059	0.704	-0.227	0.5959	0.15	0.19	0.70	0.02
Total Carbon (Mg/ha)	43.215	12.694	54.736	15.924	-11.522	0.2706	0.09	0.10	0.01	0.31

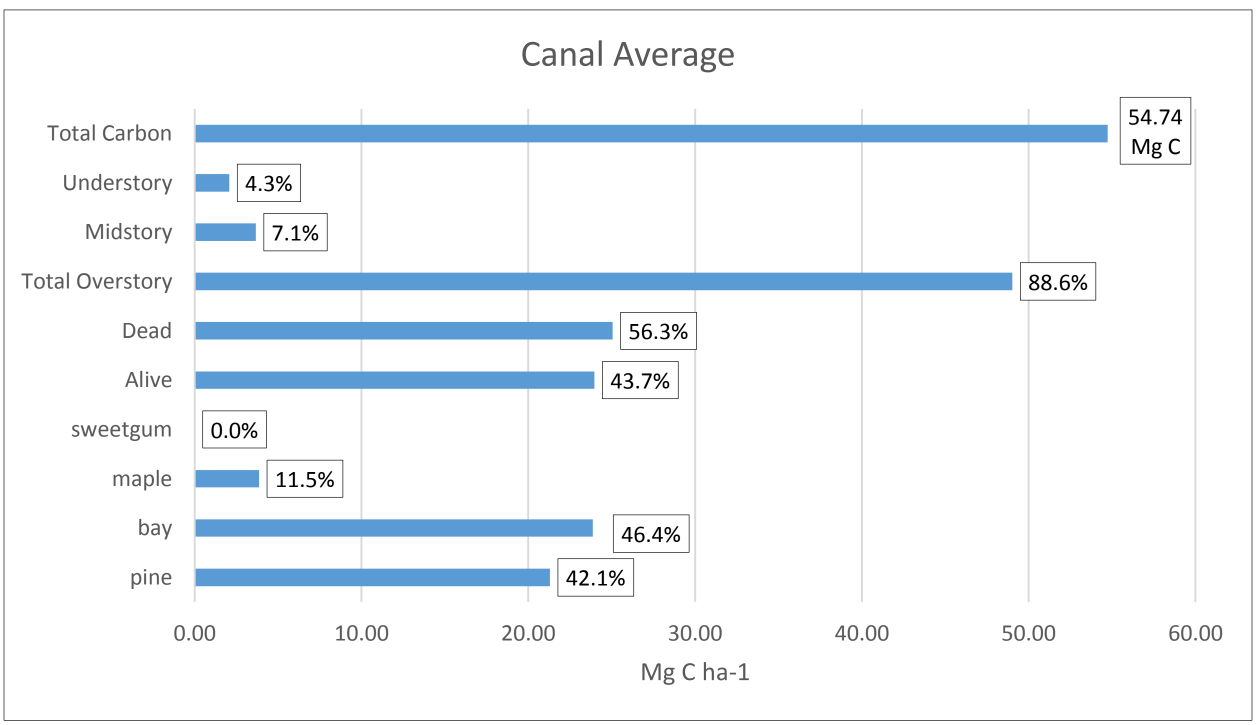
Table 3.4- Forest Stand Structure. averages, p-values, and coefficient of determination (r^2) for road and canal sides. Does not include plot 2A. "Road average – Canal Average" is the subtraction from canal side data from road side data. Positive values show the road side is higher, negative values show the canal is higher. Statistically significant P-values are highlighted in yellow.

	Mg C Ha-1						r^2 for distance to open water		r^2 for distance to road/canal	
	Road Average	Road Stdev.	Canal Average	Canal Stdev.	Road Average - Canal Average	p Value	Road	Canal	Road	Canal
Overstory Diameter (in)	9.802	1.077	7.892	0.427	1.910	0.0085	0.05	0.31	0.01	0.36
Over Height (ft)	35.463	2.572	26.665	5.028	8.797	0.0093	0.72	0.03	0.00	0.40
Overstory Decomposition	0.379	0.321	1.764	0.850	-1.385	0.0026	0.06	0.04	0.58	0.24
overstory # trees/ha	264.737	165.117	687.105	199.868	-422.367	0.0063	0.46	0.13	0.00	0.09
midstory # stems/ha	8603.441	3485.241	4456.328	3321.822	4147.113	0.1094	0.16	0.13	0.21	0.01

The overstory composition on the road side is mainly pine at 61.5%, and mainly bay at 46.4% on the canal side. The road side overstory is 89% alive, while the canal side overstory is 56% dead (Figures 3.2 and 3.3).

Figures 3.2 and 3.3- Averages for both sides of the canal. Road averages exclude plot 2A. Charts for each specific plot can be found in the appendix. Understory, Midstory and Total Overstory percentages are of Total Carbon. Dead, Alive and the tree species percentages are of Total Overstory.





No overstory bay trees were found on the road side, but 192 bay trees were found on the canal side across all plots. More maples were found on the road side, especially in plots closer to East Lake (table 3.6). This could suggest that the canal that was dug 50 years ago quickly killed off the overstory pine forest, which favored bay regeneration, while the slower change on the road side from East Lake favors red maple. Pine total and alive on the road side and pine dead on the canal side show the highest coefficient of determination values (r^2), all at .70+ (table 3.5). This indicates a strong linear correlation in pine decreasing as one approaches East Lake (table 3.6).

Table 3.5- Overstory Composition averages, p-values, and coefficient of determination (r^2) for road and canal sides. Does not include plot 2A. "Road average – Canal Average" is the subtraction from canal side data from road side data. Positive values show the road side is higher, negative values show the canal is higher. Statistically significant P-values are highlighted in yellow.

						r^2 for distance to open water		r^2 for distance to road/canal	
	Road Averages	Canal Averages	Average differences Road-Canal	Total differences Road-Canal	p value	Road	Canal	Road	Canal
Pine Total	13	19	-5	-36	0.3677	0.70	0.46	0.00	0.29
Pine alive	10	6	4	31	0.3895	0.74	0.00	0.04	0.04
Pine Dead	3	13	-10	-67	0.0097	0.36	0.75	0.24	0.28
Bay Total	0	27	-27	-192	0.0003	-	0.08	-	0.05
Bay Alive	0	13	-13	-88	0.0094	-	0.04	-	0.38
Bay Dead	0	15	-15	-104	0.0041	-	0.24	-	0.14
Maple Total	5	3	2	14	0.1975	0.47	0.65	0.03	0.43
Maple Alive	4	1	4	25	0.0093	0.50	0.15	0.01	0.02
Maple Dead	0	2	-2	-11	0.2621	0.16	0.44	0.40	0.37
Sweetgum Total	1	0	1	5	0.3559	0.23	-	0.01	-
Sweetgum Alive	1	0	1	5	0.3559	0.23	-	0.01	-
Sweetgum Dead	0	0	0	0	-	-	-	-	-
Total Alive	16	19	-4	-27	0.5695	0.39	0.02	0.07	0.22
Total Dead	3	29	-26	-182	0.0005	0.43	0.41	0.20	0.04
Total	19	49	-30	-209	0.0063	0.46	0.13	0.00	0.09

Table 3.6- Overstory composition Totals. Numbers are in trees per plot. Totals for the road and canal are listed to the left.

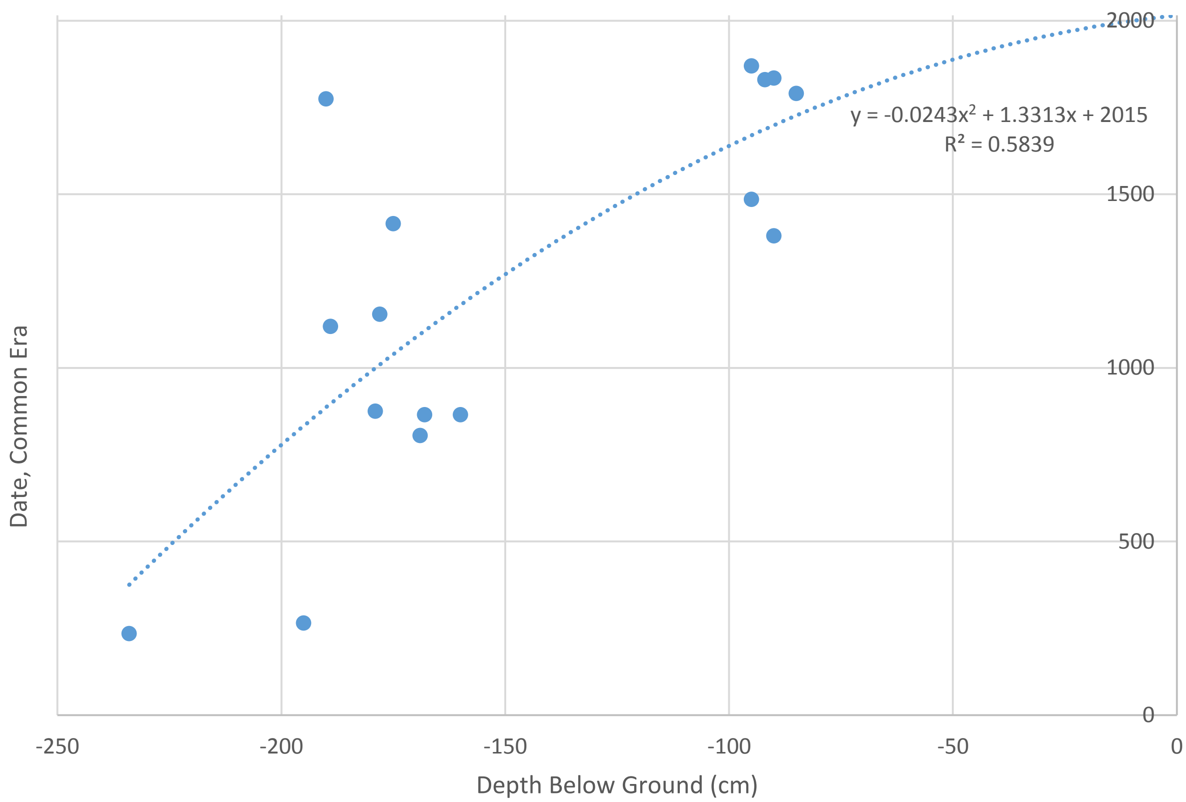
	7A1	7A2	6A	5A1	5A2	4A	3A	Road Totals
Pine Total	40	15	16	4	11	2	6	94
Pine alive	29	15	11	3	11	1	3	73
Pine Dead	11	0	5	1	0	1	3	21
Bay Total	0	0	0	0	0	0	0	0
Bay Alive	0	0	0	0	0	0	0	0
Bay Dead	0	0	0	0	0	0	0	0
Maple Total	3	3	3	2	6	10	5	32
Maple Alive	3	2	3	2	6	10	5	31
Maple Dead	0	1	0	0	0	0	0	1
Sweetgum Total	0	0	0	0	0	5	0	5
Sweetgum Alive	0	0	0	0	0	5	0	5
Sweetgum Dead	0	0	0	0	0	0	0	0
Total Alive	32	17	14	5	17	16	8	109
Total Dead	11	1	5	1	0	1	3	22
Total	43	18	19	6	17	17	11	131

	7B1	7B2	6B	5B1	5B2	4B	3B	Canal Totals
Pine Total	17	24	28	22	18	17	4	130
Pine alive	1	3	16	7	5	10	0	42
Pine Dead	16	21	12	15	13	7	4	88
Bay Total	27	23	33	39	29	32	9	192
Bay Alive	5	10	14	10	23	25	1	88
Bay Dead	22	13	19	29	6	7	8	104
Maple Total	0	0	2	3	0	4	9	18
Maple Alive	0	0	1	2	0	3	0	6
Maple Dead	0	0	1	1	0	1	9	12

Sweetgum Total	0	0	0	0	0	0	0	0
Sweetgum Alive	0	0	0	0	0	0	0	0
Sweetgum Dead	0	0	0	0	0	0	0	0
Total Alive	6	13	31	19	28	38	1	136
Total Dead	38	34	32	45	19	15	21	204
Total	44	47	63	64	47	53	22	340

Figure 3.4 below shows the relationship between the depth at which wood samples were located, and the common era date the carbon in the wood was stored. The trendline is the best fit for the data. The curve in the trend line could either be due to rising sea level rise, compaction of deeper organic soils, or some combination of the two. More research is needed to explain the meaning of the curvature to the trend line.

Figure 3.4: C14 Analysis and the depths the 16 wood samples were found. Y intercept is 2015. Depest sample (-234 cm) was found in a burried A horizon. All other samples were found in peat.



Another issue that arises due to the soft organic soil is the possibility that a limb can fall from a tree deep into the soil. This would make the wood sample be from deeper in the soil, but much younger than expected. This is the case with the sample found at 1.90m deep, but was only found to be 240 years old. Using the trendline equation, a wood sample found at 1.90m should be around 1390 years old; 1150 years off of the 14C date for this outlier.

The wood sample found at -234cm below the surface was pulled out of a stump located in dark A horizon clay in plot 3A. The age of this sample was 1780 years old. This would have probably been the remnants of a forest that existed before the area had been inundated by water and the current wetland began to form. This means that the wetland has accumulated 2.34 meters of organic soil in 1780 years; a rate of 1.31mm per year. Assuming the wetland accumulated organic soil at the same rate as sea level rise, the rate of sea level rise of the surrounding water bodies was also 1.31 mm/year over the past 1780 years. Accumulation rates for other wood samples can be calculated, but until the effects of organic soil compaction at this site are better understood, these accumulation rates may not be accurate.

Conclusion

There is clear evidence that at this site there were forests present when sea level was lower than it is today. With the rate of sea level rise currently at a higher rate of rise than the average rise since this wetlands formation, new changes to the environment are easily seen. These changes will only continue to be more prominent not only around these historical drainage ditches, but across the Alligator River National Wildlife Refuge and lower coastal plain. It is important for local natural resource managers to understand that the areas around these historical drainage ditches will be affected by sea level rise earlier and at a more rapid rate than areas sheltered from the effects of these ditches. The faster rate of transition favors bay trees instead of maples, and the pond pine overstory will die off much faster in the short term. Further in the future, large areas of forest die off is expected. Beyond that a transition to marsh grass is expected, which will store significantly less carbon in the ecosystem.

Future projects such as the widening of hwy-64 through the refuge will also have significant impacts. Already along hwy 64 the same effects of the canal can be seen. Widening the road along with larger canals will lead to more pond pine die off and more rapid ecosystem transition along the corridor.

Though wetland policy seems to have been relatively stable in recent years, climate change will pose new problems that will need to be addressed. Along with wetland ecosystems expected to change into other wetland types, low lying areas that are currently not wetlands will begin to flood as the ocean rises. These areas will soon have the potential to become wetlands as well and will present different types of ecosystem transitions. This will also pose questions for the future about jurisdiction over land that was once dry land that switches into wetland. These questions will need to be addressed in the future by the federal government to determine jurisdiction and justification behind that jurisdiction.

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