Albemarle-Pamlico Ecosystem Assessment 2012

National Estuary Partnership

2012 Albemarle-Pamlico Ecosystem Assessment

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Albemarle-Pamlico National Estuary Partnership

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Our Mission

To identify, restore, and protect the significant resources of the Albemarle-Pamlico estuarine system.

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Albemarle - Pamlico
National Estuary Partnership

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List of Acronyms

APES	Albemarle-Pamlico Estuarine Study/ System
APNEP	Albemarle-Pamlico National Estuary Partnership
CASTNet	Clean Air Status and Trends Network
CCMP	Comprehensive Conservation Management Plan (APNEP)
CPUE	Catch per unit effort
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
FMP	Fisheries management plan (NCDMF)
HUC	Hydrologic unit code
IGNS	Independent gill net survey (NCDMF)
LMBV	Largemouth bass virus
MGD	Million gallons per day
MMU	Minimum mapping unit
MRLC	Multi-Resolution Land Characteristics Consortium
MSX	Oyster disease caused by Haplosporidium nelsoni
NADP	National Atmospheric Deposition Program
NAWQA	National Water Quality Assessment (USGS)
NCCR	National Coastal Condition Report (USEPA)
NCDENR	North Carolina Department of Environment & Natural Resources
NCDMF	North Carolina Division of Marine Fisheries (NCDENR)
NCDWQ	North Carolina Division of Water Quality (NCDENR)
NCDWR	North Carolina Division of Water Resources (NCDENR)
NCMFC	North Carolina Marine Fisheries Commission
NCWRC	North Carolina Wildlife Resources Commission
NLCD	National Oceanographic & Aeronautic Administration
NPDES	National Pollutant Discharge Elimination System (USEPA)
RSL	Relative sea-level
SAV	Submerged aquatic vegetation
STAC	Science & Technical Advisory Committee (APNEP)
SVCV	Spring viremia of carp virus
TAC	Total allowable catch
TNC	The Nature Conservancy
TSS	Total suspended solids
UNC	University of North Carolina
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USHCN	United States Historical Climate Network
VDEQ	Virginia Department of Environmental Quality
VDGIF	Virginia Department of Game & Inland Fisheries

Chapter 1 - Introduction

Chapter 1: Introduction

The Value of Environmental Assessment

The Value of Environmental Assessment

In a very concrete way, the health and wealth of humankind are fully dependent on the natural resources and ecological processes of the earth. Eons ago, the earth's atmosphere was a cauldron of noxious gases, uninhabitable by all but the hardiest of bacteria. Over time, geological and biological processes have shaped the environment familiar to us today, both in the Albemarle-Pamlico region and across the globe. As human knowledge and technology have advanced, we have learned to harness our natural resources in increasingly innovative ways. Geological resources form the basis of our manmade materials and most of our energy, providing a foundation for the world's $70 trillion annual economy. Ecological processes like the cycling of water and the creation of oxygen also support life-sustaining processes in ways that cannot be measured in dollars alone.

In the course of human progress, it has become evident that human activities can alter the very processes that support our way of life. In response to this reality, government agencies and other organizations implement policies and invest billions of dollars maintaining and improving the quality of our environment. The value of a healthy environment is also reflected through voluntary stewardship efforts undertaken by individuals and businesses and in efforts to teach the next generation about the beautiful complexities of the natural world.

The successful management of our natural environment is predicated on our ability to define and measure the things that make it healthy. Environmental managers have long measured elements of the ecosystem germane to their areas of expertise, and scientists have likewise conducted focused studies to better understand ecological processes. However, efforts to monitor broader ecosystems across a landscape scale traditionally suffer from a lack of coordination, information, and resources. Where these assessments have been conducted, ecosystem-scale efforts designed to address areas of weakness have only been conducted in an ad hoc way.

Monitoring and assessment serve a number of purposes. Analogous to a routine doctor's visit, taking measures of ecosystem health provides objective information about the status of the environment for managers and policymakers to consider. It helps prevent a shifting baseline by providing quantifiable information about the way things were in the past. Assessments tell us whether efforts to protect the environment are working and are absolutely essential to ensure accountability for natural resource management agencies. Finally, comprehensive and routine ecosystem-scale assessments will be required if ecosystem-based management efforts are to effectively take hold in the Albemarle-Pamlico region.

Assessment's Role in APNEP

In parallel with efforts to develop the Albemarle-Pamlico National Estuary Partnership's first new strategic plan since 1994, the program has also worked with its partners to develop this updated ecosystem assessment of the Albemarle-Pamlico Estuarine System. This introduction begins by explaining the role of "assessment" in the adaptive management cycle and the importance of future APNEP assessments. In addition to the role of ecosystem assessments in APNEP's management approach, we review various broad-scale assessments involving the Albemarle-Pamlico region that have been conducted since APNEP's founding. Finally, we conclude by describing the protocol and format used in constructing this 2012 ecosystem assessment.

Priorities for research, management, and policy cannot be developed effectively without a clear understanding of how the ecosystem may be changing. Increasing impacts to the region's natural resources require those interested in the health and long-term resilience of the region to demand periodic integrated resource assessments. Information from these assessments, based on high quality scientific information, will help address the following policy-based questions of condition, diagnosis, and forecast for any particular ecosystem component:

- Magnitude: what is the condition of the ecosystem component?
- Extent: over what geographic area does the component extend?
- Trend: how has condition and range of the component changed over time?
- Cause: what stressors are believed to be responsible for changing trends?
- Source: what agents are responsible for stressor intensity?
- Vulnerability: what is the likelihood of stressors causing a loss in human well-being or ecological integrity over the coming decade and beyond?
- Solutions: what combination of approaches and tools are the most effective and efficient to reduce impacts from stressors?

These integrated assessments will support APNEP's planning and program processes and other policy and program planning activities including the North Carolina Coastal Habitat Protection Plan (CHPP), Wildlife Action Plan, and North Carolina and Virginia basin-wide planning. To evaluate the success of program efforts guided by this plan, APNEP must provide a reliable environmental baseline of the ecosystem. Most importantly, however, these assessments will help answer two of four basic stakeholder questions posed in APNEP's *Comprehensive Conservation Management Plan 2012-2022* (CCMP):

- What is the status of the Albemarle-Pamlico Estuarine System?
- What are the greatest challenges facing the Albemarle-Pamlico Estuarine System?

The importance of ecosystem assessment has been stressed at the international and national level. Over a decade has passed since The *Millennium Ecosystem Assessment* began a four-year international work program designed to meet the needs of decision-makers regarding links between ecosystem change and human well-being. It was launched in 2001 at the United Nations and involved leading scientists from more than 100 nations under the direction of a diverse Board. Following the spirit if not the letter of the Millennium Ecosystem Assessment conceptual framework, APNEP intends that this assessment and future efforts can aid the region by:

- Integrating information from both natural and social science;
- Facilitating ecosystem-based management;
- Evaluating the compatibility of policies established by institutions at different scales;
- Identifying and evaluating policy and management options for sustaining ecosystem services and harmonizing them with human needs;
- Integrating economic, environmental, social, and cultural aspirations;
- Deepening understanding of the relationship and linkages between ecosystems and human well-being; and
- Demonstrating the potential of ecosystems to contribute to poverty reduction and enhanced well-being.

Earlier this decade, the US Environmental Protection Agency's Science Advisory Board also noted that better information is a prerequisite for better decision making about ecological resources. As a result, they recommended a comprehensive framework to guide the assessment and reporting of ecological conditions (USEPA, 2002). APNEP, through this interim assessment, demonstrates its intention to chart this course with the support of its partners in the region.

History of Assessments in the Albemarle-Pamlico Region, 1991-2011

Given the crucial role of assessment in supplying planners with information that informs the prioritization of plan actions (Figure 1-1), one might assume the synthesis and integration of assessment products would receive priority from environmental and natural resource decision-makers. For example, any new EPA National Estuary Program must conduct an ecosystem assessment before developing a management plan. In APNEP's case, this initial task was addressed by nearly 100 research products and a summative Albemarle-Pamlico Status & Trends assessment funded by the 1988-1994 Albemarle-Pamlico Estuarine Study (APES). Yet despite its importance, assessment of ecological system health is scientifically complex and difficult to accomplish with limited resources (USEPA, 2002). Filling information gaps is always a challenge, and this has been the case with APNEP. Despite an intent for the 1991 assessment to be a "living document" (APES, 1991), over two decades have passed without an update. This interim assessment begins to fill that gap, with an intention that future assessments will be produced more routinely and build upon the information presented here.

Despite the passage of time without an APNEP-sponsored assessment, other important broad-scale regional analyses of environmental condition by APNEP partners have been published in the interim. In addition to the overview of the 1991 assessment that follows, a sample of post-

1991 assessments sponsored by APNEP partners is featured as well. The summaries of each are meant to illustrate their format and scope, with special attention given to their environmental metrics, each of which are worthy for consideration as APNEP expands its suite of indicator metrics (see "Additional Indicators", Chapter 6). Those interested in the analysis of each featured ecological assessment are encouraged to read the source documents, all publicly available. These sample assessments include a substantial Albemarle-Pamlico ecosystem component and have geographies that are included within or overlap significantly with the Albemarle-Pamlico region.

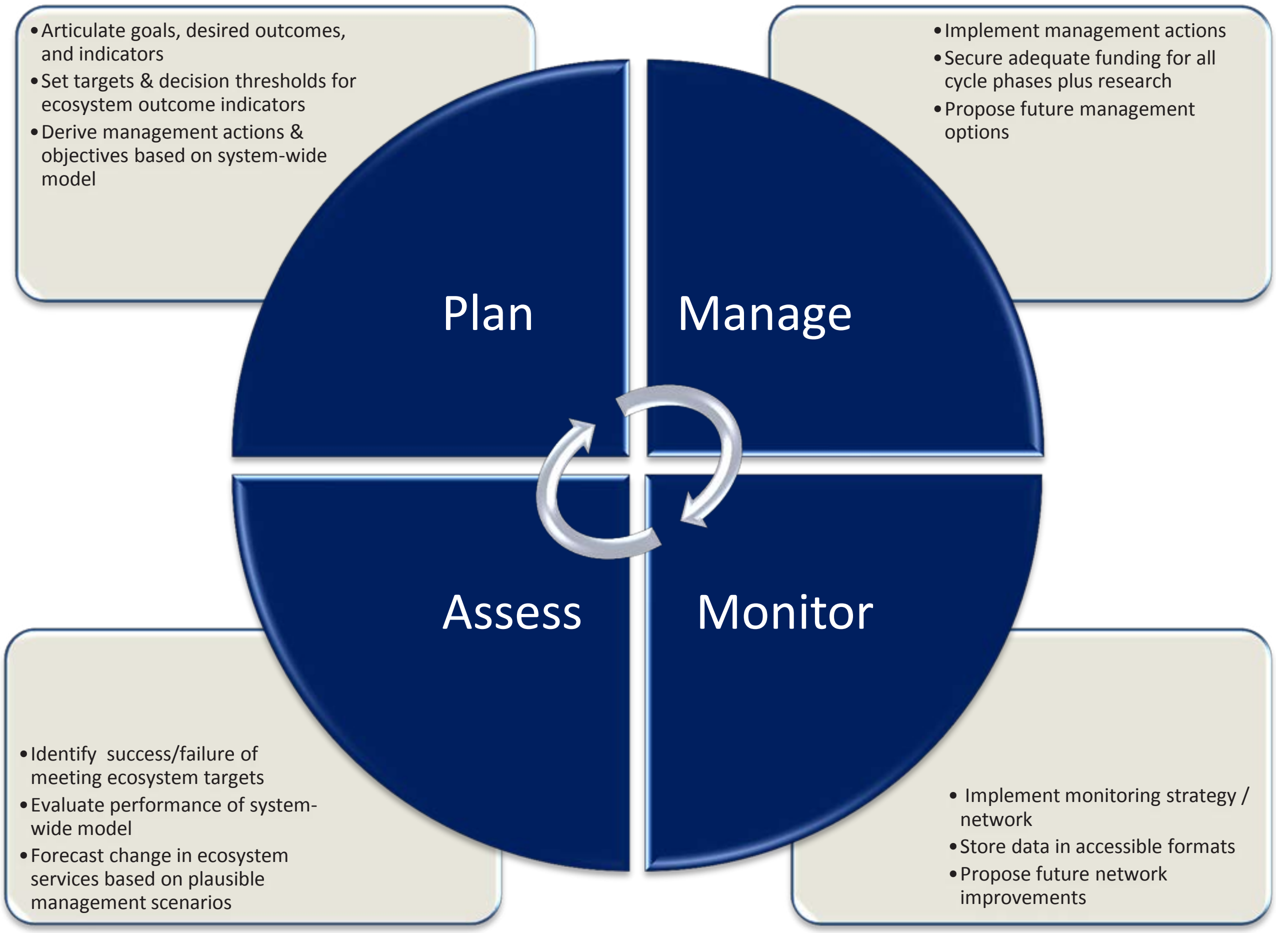

Figure 1-1. The role of assessment in APNEP's adaptive management cycle.

Albemarle-Pamlico Estuarine Study's Status & Trends Assessment (1991): The inaugural Albemarle-Pamlico status and trends assessment, coming at the midpoint of the APES phase of this program (1988-1994), synthesized existing information about the Albemarle-Pamlico Estuarine System and assessed the status and trends of probable causes in the system. The estuarine system was addressed in four core chapters: Critical Areas, Water Quality, Fisheries, and Human Environment. Within each core chapter multiple assessment themes were addressed. Each theme generally featured four main sections: description, status of information, trends, and management/regulatory status and trends. Indicators (explicit or implied) featured within each theme are featured in Table 1-1.

Table 1-1. Indicators featured in the 1991 APES Status & Trends Assessment

CHAPTERS	THEMES	INDICATORS
Critical Areas	*Submerged aquatic vegetation*	areal extent of submerged aquatic vegetation (SAV)
	Wetlands	areal extent of wetland types (tidal marsh, nontidal marsh, freshwater marsh, scrub-shrub wetlands, pocosin forests and related, riparian/alluvial forested, nonriparian forested)
	Special fisheries habitats	bay scallop beds, hard clam beds, American Oyster beds, nursery area, anadromous species spawning beds
	Barrier islands	land cover types
	Rare species and natural communities	federally-listed endangered, threatened, and candidate species; state-listed endangered, threatened, and candidate species by state and global rank
Water Quality	*Freshwater drainage and estuarine circulation*	flow rates, tidal elevation, salinity, wind field, tidal velocity
	Nutrients	N and P loading rates, N and P concentrations in water column
	Metals and toxicants in the water column and sediments	critical trace element concentrations
	Point sources and nonpoint sources	% of total degraded stream distance, land use, large farm animal inventory, poultry inventory, population with secondary wastewater treatment, fertilizer use, chlorophyll a, dissolved inorganic N, ortho P, dissolved oxygen, pH, suspended-solids concentrations, total NH_3 + organic N concentration, total P concentration
Fisheries	*Critical fisheries habitats*	species composition of primary and secondary nursery area trawl surveys
	Status of major species	14 species with the highest commercial landings by weight: river herring, bluefish, catfish, croaker, flounder, weakfish, American shad, spot, striped bass, white perch, shrimp, blue crab, hard clam, oysters
	Status and trends of major fisheries	juvenile fish abundance via primary nursery area surveys: Atlantic croaker, spot, southern flounder, weakfish, brown shrimp, blueback herring, striped bass; CPUE for YOY striped bass; adult menhaden; total commercial landings by principal fish gears; shrimp; 20 species composition and abundance by long haul seine fishery; CPUE for croaker, spot, weakfish, total via long haul seine fishery, species composition of marine recreational fishery statistical survey; number of interviews, angler trips, total fish caught, and mean fish per trip; number of licensed commercial fishing vessels by license categories
	Effects of fishing practices on habitat	None
	Disease problems	finfish diseases via viruses, bacteria, fungi, parasites, shellfish diseases
Human Environment	*Population*	permanent human population, recreational human population
	Direct uses of estuarine resources	total and deflated dockside values for commercial fisheries, total annual vessel licenses, number of processing firms, benefit estimates for sport-fishing trips, saltwater fishing trips, days of fishing, fishermen, mode of fishing, marinas, travel and tourism expenditures
	Indirect uses of estuarine resources	average value of real payroll by economic sector, harvested cropland area, fertilizer tonnage shipped, production of hogs, cattle, and chickens, vehicle registration
	Public sector activity	legislative programs, education and public awareness

USGS's Albemarle-Pamlico Drainage Study Unit of the National Water Quality Assessment (NAWQA, 1991): NAWQA is an ongoing program of the U.S. Geological Survey, conducted in approximately decadal cycles, to assess the status of the Nation's streams and ground-water quality, assess trends in water quality, and examine the processes that control water quality. Assessment of the Albemarle-Pamlico study area (ALBE) began in 1991 and continued through 2001. Cycle I began with compilation and synthesis of existing data and then design of subsequent data collection networks to address specific project objectives. Data were collected between 1993 to 2001, with the most intense period of surface water, groundwater, and ecological data collection between 1993 and 1995. Sampling included ground-water flow path sampling, random statistical sampling of groundwater in agricultural land-use settings in the Inner and Outer Coastal Plain, and monthly surface-water sampling at three sites selected for long-term trend evaluation. Water chemistry, hydrology, stream habitat, and aquatic life data from more than 65 streams and water chemistry from more than 50 wells throughout the study area resulted from this study (Table 1-2).

Whereas the scope of the first cycle was synoptic monitoring covering the entire study area, activities of the second cycle focused on process modeling within the Neuse River Basin. Intensive sampling began again in 2002 (Cycle II), with a focus on evaluating the effects of urban development on ecology and water quality (Effects of Urbanization on Stream Ecosystems (EUSE)), nutrient source and delivery modeling (Spatially Referenced Regressions on Watershed Attributes (SPARROW) modeling), and studying water quality of the Castle Hayne and Piedmont aquifers. Planning for a third NAWQA cycle (2011-2020) for ALBE is currently underway.

USEPA's Ecological Assessment of the Mid-Atlantic Region: A Landscape Atlas (Jones et al. 1997): This 1997 environmental assessment by USEPA's Office of Research & Development was focused on the Mid-Atlantic Region, extending as far south as the Virginia-North Carolina border. Reporting units for all indicators were 8-digit hydrologic unit code (HUC) resolution. Indicator reporting was relative through classifying reporting units into quintile classes (bottom 20%, lower middle 20%, middle 20%, upper middle 20%, upper 20%). Status and some trends included the land-based indicators whose major criterion for selection was that measurements were derived from satellite imagery and spatial data bases (Table 1-3).

North Carolina Division of Water Quality's Basin Assessments (2000-Present): NCDWQ's Basin Assessments present assessments of ambient water quality for North Carolina's major river basins on a rotating basis, with reporting for the first basin in the Albemarle-Pamlico region being the Roanoke (2000), followed by the White Oak (2000), Neuse (2001), Chowan & Pasquotank (2002), and Tar (2003). During the second cycle (2005-2008), the Chowan and Pasquotank had separate assessments. During the third cycle (2009-Present) a basin assessment involves separate reports for biological and physiochemical data.

To provide an example of the ecological indicators featured in the most recent (third) assessment cycle, the Chowan Basin (2011) is featured in Table 1-4.

Table 1-2. Indicators featured in 1991-2001 USGS' NAWQA publications.

TYPE	GROUP	METRICS
Ground Water	*Nutrients*	Dissolved: ammonia N (NH4), nitrite N, phosphate (PO4) , nitrite plus nitrate N (NO2 + NO3), ammonia plus organic N, ammonia N, P, orthophosphate P Total: ammonia plus organic N
	Pesticides	2,6-deithyl aniline, acetochlor, alachlor, alpha BHC, atrazine, benfluralin, butylate, carbaryl, carbofuran, chlorpyrifos, cyanazine, dcpa, deethyl atrazine, diazinon d10, diazinon, dieldrin, disulfoton, eptc, ethalfluralin, ethoprop, fonofos, HCH alpha D6, linden, linuron, malthion, methyl azinphos, methyl parathion, metolachlor, metribuzin sencor, monlinate, napropamide, parathion, pebulate, pendimethalin, permethrin cis, phorate, prometon, pronamide, propanil, propargite, propchlor, simazine, tebuthiuron, terbacil, berbufos, terbuthylazine, thiobencarb, triallate, triflurlin, p,p' DDE
	Organics	1-napthol, 2,4,5-T, 2,4-D, 2,4-DB, 3hydroxy carbofuran, acifluorfen, aldicarb sufone, aldicarb sulfoxide, aldicarb, bdmc, bentazon, bromacil, bromoxynil., carbofuran, choramben, chlorothalonil, clopyralid, dacthal monoacid, dicamba, dichlobenil, dichlor, dinoseb, diuron, dnoc, esfenvalerate, fenuron, fluoeturon, linuron, mcpa, mcpb, methiocarb, neburon, norflurazon, oryzalin, oxamyl, picloram, propham, propoxur, silvex, triclopyr
	Major Inorganics	Dissolved: total alkalinity (CaCO3), Br, Ca, Cl, F, Fe, Mg, Mn, K, Si, Na, SO4; solids residue, specific conductance
	Radionuclides	Radionuclideson 222, tritium, dissolved U, total U
	Field Measurements	dissolved bicarbonate (HCO3), dissolved oxygen, pH, instantaneous discharge, water temperature, total hardness, dissolved hardness, Na adsorption, % Na, acid neutralizing capacity, dissolved CO2,
Surface Water	*Nutrients*	Dissolved: ammonia N (NH4), nitrite N, P (PO4), nitrite plus nitrate N (NO2 + NO3), ammonia plus organic N, P, orthophosphate P Total: ammonia plus organic N
	Pesticides	2,6-deithyl aniline, acetochlor, alachlor, alpha BHC, atrazine, benfluralin, butylate, carbaryl, carbofuran, chlorpyrifos, cyanazine, dcpa, deethyl atrazine, diazinon d10, diazinon, dieldrin, disulfoton, eptc, ethalfluralin, ethoprop, fonofos, HCH alpha D6, linden, linuron, malthion, methyl azinphos, methyl parathion, metolachlor, metribuzin sencor, monlinate, napropamide, parathion, pebulate, pendimethalin, permethrin cis, phorate, prometon, pronamide, propanil, propargite, propchlor, simazine, tebuthiuron, terbacil, berbufos, terbuthylazine, thiobencarb, triallate, triflurlin, p,p' DDE
	Organics	1-napthol, 2,4,5-T, 2,4-D, 2,4-DB, 3hydroxy carbofuran, acifluorfen, aldicarb sufone, aldicarb sulfoxide, aldicarb, bdmc, bentazon, bromacil, bromoxynil., carbofuran, choramben, chlorothalonil, clopyralid, dacthal monoacid, dicamba, dichlobenil, dichlor, dinoseb, diuron, dnoc, esfenvalerate, fenuron, fluoeturon, linuron, mcpa, mcpb, methiocarb, neburon, norflurazon, oryzalin, oxamyl, picloram, propham, propoxur, silvex, triclopyr
	Major Inorganics	Dissolved: total alkalinity (CaCO3), Ca, Cl, F, Fe, Mg, Mn, K, Si, Na, SO4; solids residue, specific conductance
	Field Measurements	dissolved bicarbonate (HCO3), dissolved oxygen, pH, instantaneous discharge, water temperature, dissolved carbonate (CO3), dissolved organic C, suspended organic C
Ecological	*Fish Communities*	Fish species, abundance, mean length, deformities, lesions, tumors, parasites
	Tissues	Trace elements in redbreast sunfish livers, trace elements in Asiatic clam soft tissues, organochlorines in redbreast sunfish (whole), organochlorines in Asiatic clam soft tissues

Table 1-3. Indicators featured in the 1997 USEPA Landscape Atlas.

CATEGORIES	METRICS
Endpoints and stressors (Dual role)	land cover, forest land cover, vegetation change among watersheds (changes in NDVI), human population density, human use index (% of urban and agriculture land cover)
Stressors	roads (road density), air pollution (atmospheric wet deposition of nitrate and sulfate, W126 ozone index), forest and agricultural land cover along streams, roads along streams, agriculture on steep slopes, nitrogen and phosphorus export to streams, soil loss, forest fragmentation index, forest edge habitat, forest interior habitat, largest forest patch in relation to the amount of forest land cover, vegetation change within watersheds (changes in NDVI), vegetation loss on steep slopes

Table 1-4. Indicators featured in the 2011 NCDWQ Chowan Basin Assessment.

CATEGORIES	METRICS
Biological	macroinvertebrate (EPT) taxa richness (EPTS)
Lake & Reservoir	chlorophyll a, pH, dissolved oxygen, water temperature, turbidity, surface metals, Secchi depth, % dissolved oxygen saturation, algal blooms and/or fish kills, problematic aquatic macrophytes

EPA's National Coastal Condition Report Series (2001-Present): EPA's National Coastal Condition Reports (NCCRs) describe the ecological and environmental conditions in U.S. coastal waters. EPA has produced four reports in the series. NCCR I (2001) assessed the condition of the nation's coasts using data collected from 1990 to 1996. NCCR II (2004) provided information similar to the information covered in the NCCR I, but contained more recent (1997–2000) data. NCCR III (2008) examined national and regional trends in coastal condition from the early 1990s to 2002. Data collected as late as 2006 are presented in the fourth *National Coastal Condition Report* (NCCR IV) released in 2012.

The ecological indicators featured in the most recent (2012) NCCR are featured in Table 1-5. The Albemarle-Pamlico coastal region overlaps with the northernmost section of NCCR IV's Southeast Region (Chapter 4), which includes the coasts of North Carolina, South Carolina, Georgia, and Atlantic coast of Florida.

Table 1-5. Indicators featured in the 2012 USEPA National Coastal Condition Report.

CATEGORIES	METRICS
Water Quality Index	nitrogen (DIN), phosphorus (DIP), chlorophyll a, water clarity, dissolved oxygen
Sediment Quality Index	sediment toxicity, sediment contaminants, total organic carbon (TOC)
Benthic Index	total number of species and integrated measures of species dominance, species abundance, abundance of pollution-sensitive taxa
Coastal Habitat Index	wetland area
Fish Tissue Contaminants Index	total polycyclic aromatic hydrocarbons (PAHs), total polychlorinated biphenyls (PCBs)

A year prior to releasing NCCR III, USEPA released the National Estuary Program Coastal Condition Report (2007), which applied the same five indices at finer spatial scales, including the Albemarle-Pamlico Estuarine Complex. The NEPCCR provided the percentage estuarine area achieving a rating (good, fair, poor, missing) for each index and each indicator component, based on data collected in 1997-2003. To the extent these coastal, estuarine, and marine indices are adopted by APNEP in the future, these NCCR assessments can be used to evaluate condition and trends in the Albemarle-Pamlico Estuarine System.

TNC Carolinian Marine Ecoregion Assessment (DeBlieu et al., 2005): The Nature Conservancy's objective for this assessment was to derive principal conservation targets and threats in order to identify priority action areas within the Carolinian Marine Ecoregion. The boundaries of this region extend from northern Florida to southern Virginia, and its sub-units include the Pamlico Sound-Outer Banks Estuarine Complex and the Outer Banks Ocean Complex. The Carolinian Marine Ecoregion Assessment overlaps partially with the boundaries delimitated for TNC's Mid-Atlantic Coastal Plain (Terrestrial) Ecoregion. Indicators (explicit or implied) featured within these conservation themes are listed in Table 1-6.

Table 1-6. Indicators featured in the 2005 TNC Carolina Marine Ecoregion Assessment.

CATEGORIES	METRICS
Conservation targets	seagrass ecosystems, shellfish ecosystems, shoreline types, wetland ecosystems, sea turtle concentrations, shortnose sturgeon habitat, shorebirds and colonial waterbirds, benthic types
Principal threats	dredge activity, port activity, shipping lanes, NPDES, roads, hardened shorelines, dredge disposal sites, Superfund sites, population increases

North Carolina's Forest Resources Assessment (Bardon et al., eds. 2010): The objective for this 2010 assessment was to conduct a statewide analysis of the past, current, and projected future conditions of North Carolina's forest resources to support state forestry strategic planning. The motivation for this assessment and planning activity, like that for a concurrent effort in Virginia (see below), was US Forest Service implementation of supporting state assessments and resource strategies. This approach, integral to the US Forest Service's State and Private Forestry (S&PF) Redesign, was required as an amendment to the Cooperative Forestry Assistance Act (CFAA) enacted in the 2008 Farm Bill. Forest resources were addressed in four core chapters of the assessment: Conserving Working Forest; Threats to Forest Health; Enhancing the Benefits of Forests; and Goals, Objectives & Strategies. Indicators (explicit or implied) featured within these natural resources themes are listed in Table 1-6.

Table 1-6. Indicators featured in the 2010 North Carolina Forest Resources Assessment.

CATEGORIES	METRICS
Forest	land area by forest type; timberland area by major species group, forest-type group, forest-management type, and ownership; volume of live softwood and hardwood trees by stand origin, species, diameter class on timberland; average net annual growth and removals of live softwood and hardwood trees
Declining forest types	total area of longleaf pine and longleaf-scrub oak types by ownership type, area of longleaf establishment by federal and state cost-share programs, area of Atlantic white cedar forestland by stand age, area of shortleaf pine forest and shortleaf pine-oak forest types by stand age
Family and minority forests ownership	forest area by ownership category, number of farms by race, minority population density
Population growth and land-use change impacts	human population level by development intensity (rural, urban), human population density by census tract, housing units, area per housing unit, % of land developed, area of forest management practices by ownership, urban and forest management plans developed and area impacted by management or assistance, area reforested by cost-share program, forest development project number and area accomplished by management practice, area treated with herbicides for forestry purposes, prescribed burning area by purpose, forestry site inspections for forest guidelines practice
Emerging markets in ecosystem services	federally-listed species occurrences, estimated forest carbon biomass per area (above- and below-ground)
Insects, diseases, and non-native invasive plants	major plant pathogens, major insect pests, major non-native invasive plants
Fire and fire exclusion	fire occurrences per area, % vacant homes
Climate, atmosphere, and natural disasters	relative sea level, tropical storm and hurricane frequency, annual freezing rain event frequency
Water quality/quantity	% impervious surface cover
Forest wildlife habitat	longleaf pine area
Urban forests	urban housing density

Virginia's Forest Resources Assessment (VDOF 2010): The objective for this 2010 assessment was to conduct a statewide analysis of the past, current, and projected future conditions of Virginia's forest resources to support state forestry strategic planning. The motivation for this assessment and planning activity was analogous to that for the concurrent effort in North Carolina (see above). Forest resources were addressed in three core chapters of the assessment: Virginia Forest Trends and Conditions, Program Areas within the Virginia Department of Forestry, and Multi-State Issues and Priority Areas. Indicators (explicit or implied) featured within these natural resources themes are listed in Table 1-7.

Table 1-7. Indicators featured in the 2010 Virginia Forest Resources Assessment.

CATEGORIES	METRICS
Forest Land	forestland area by timber type, % forestland area by ownership, forest volume by wood type, common tree species by volume and number, % land-use change from/to forestland, cumulative Gypsy Moth defoliation, southern pine beetle hazard, forest patches by patch size
Forest Management	area of tree planting, forest development projects by number and area, number and area of timber harvests, number of attendees and classes for logger education
Landscapes	extent of conserved land, wildfire risk, insect and disease risk
Landscape Management	number of communities with wildlife protection plans

2012 Assessment Protocol and Format

This 2012 initial assessment is a beginning snapshot of the Albemarle-Pamlico Ecosystem. It is not a comprehensive analysis of the regional ecosystem, nor is it a report on whether the region's natural resources are being used sustainably. In part, this limitation exists because APNEP has far fewer resources to dedicate to assessment than it did in 1991. APES' primary function was the assessment of the ecosystem, but now APNEP utilizes many of its resources on protection, restoration, and engagement initiatives across the region. Furthermore, many important indicators are not rigorously monitored and we have much to learn about how ecosystems function. These limitations notwithstanding, this report makes the most of resources and knowledge at hand to share the status and trends on a limited suite of indicators for three ecosystem types: System-Wide; Coasts, Sounds, and Near Marine; and Fresh Waters (Chapter 2).

Although the need to re-activate assessment activities has long been acknowledged, the push to create this assessment began in earnest during mid-2010 with this product being a top priority in the STAC's 2010-2012 Action Plan. APNEP contracted with UNC-Chapel Hill's Institute of Marine Science for Dr. Lindsay Dubbs to be project coordinator in spring 2010. Dr. Dubbs' initial task, with assistance from APNEP Program Scientist, Dr. Dean Carpenter, was to facilitate the production of individual assessments by STAC members and other authors who had volunteered to develop one or more individual assessments. Twelve STAC and six non-STAC members contributed as authors, with many STAC authors contributing to multiple assessments. Without these authors' willingness to volunteer their time and resources to APNEP, this assessment would be much less comprehensive and information rich. Dr. Carpenter assumed project coordinator role when Dr. Dubbs completed her post-doc in fall 2011, but Dr. Dubbs continued with multiple authorship responsibilities and editorial support until the assessment was complete.

The assessment's reporting format was modeled after that used in the continental-scale assessments by the H. John Heinz III Center. The Heinz Center in 2008 released their second *State of the Nation's Ecosystems* report on the condition and use of U.S. ecosystems. Of the 109 indicators in this report, six were new, ten had been redesigned, and 46 had been refined since the first assessment.

In addition to the question-based format of individual assessments (Chapters 3-5), the APNEP assessment framework is similar in the following aspects:

- Assessment is based on current, high-quality, scientifically credible information (HCSEE, 2008a:1).
- Indicators provide "big picture" insights into the regional ecosystem (HCSEE, 2008a:5).
- Indicator selection is based on gauging ecosystem health and is not limited to those that are currently monitored (HCSEE, 2008a:3).

- A broad array of partners was given the opportunity to contribute information during indicator selection, data compilation, and assessment (HCSEE, 2008a Executive Summary:11; HCSEE, 2008b:6).
- While data must be of high-quality, its origin should not be a limiting factor (HCSEE 2008a:xv).
- The assessment will have four levels of conceptual organization:
    - Level 1: Ecosystem Condition (seven ecosystem types)
    - Level 2: Major Categories (same four categories for each ecosystem type)
    - Level 3: Ecosystem Characteristics (2-3 different subcategories for each)
    - Level 4: Indicators (22-32 different indicators each)

  While this interim assessment is missing the third level and the number of indicators for each major category, future assessments will attempt to achieve this standard.
- The initial technical assessment will be a status and trends assessment only. Diagnosis and forecasting will be considered in subsequent versions (HCSEE, 2008a Executive Summary:16-17).

The following chapter will discuss the scope of this assessment, including the determination of what significant resources are addressed in this interim product.

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Chapter 2 - Region’s Ecosystems

Chapter 2: The Region's Ecosystems

While the previous chapter shares the motivation and approach of APNEP to develop this ecosystem assessment, this chapter provides an overview of the assessment's content. Topics addressed include the region's setting, an overview of the featured ecosystems and indicators, how climate change is addressed, and the challenges of incorporating changes in indicator metrics and associated ecosystem services into the policymakers' language of economic value.

The Albemarle-Pamlico Region

The content of this section was adopted from a similar section in the 1991 Albemarle-Pamlico status and trends assessment (APES, 1991), which solely focused on the resources of the estuarine system and Coastal Plain. Future editions of this publication will include descriptions of resources within the Piedmont and Mountain provinces where appropriate.

Geography and Boundaries

The Albemarle-Pamlico Estuarine System is one of the largest and most important in the United States. Covering approximately 7,530 square kilometers (2,900 square miles) (Table 2-1), the waters of the system comprise the second largest estuarine system on the East Coast of the United States, exceeded in area by only the Chesapeake Bay.

Table 2-1. Comparison of Albemarle and Pamlico Sounds (APES, 1991:3).

Item	Albemarle	Pamlico
Area km^2 (mi^2)	2,330 (900)	5,200 (2,000)
Watershed km^2 (mi^2)	47,552 (18,360)	32,427 (12,520)
% area of state inshore total	26	56
Freshwater inflow (cfs)	17,000	32,000
Volume of sound MAF (BCF)	5.3 (23.1)	21 (91.5)
Time for inflow to replace volume	6 weeks	14 weeks
Salinity	low	moderate/high
Fisheries	anadromous/fresh	marine/anadromous

The Albemarle-Pamlico Estuarine System is comprised of an extensive complex of creeks, rivers, swamps, marshes, and open water sounds dominating northeastern North Carolina (Figure 2-1). Tributaries originating in the mountains and piedmont serve as conduits from a major portion of North Carolina and southern Virginia. Albemarle Sound is the drowned portion of the Roanoke River and its extensive floodplain.

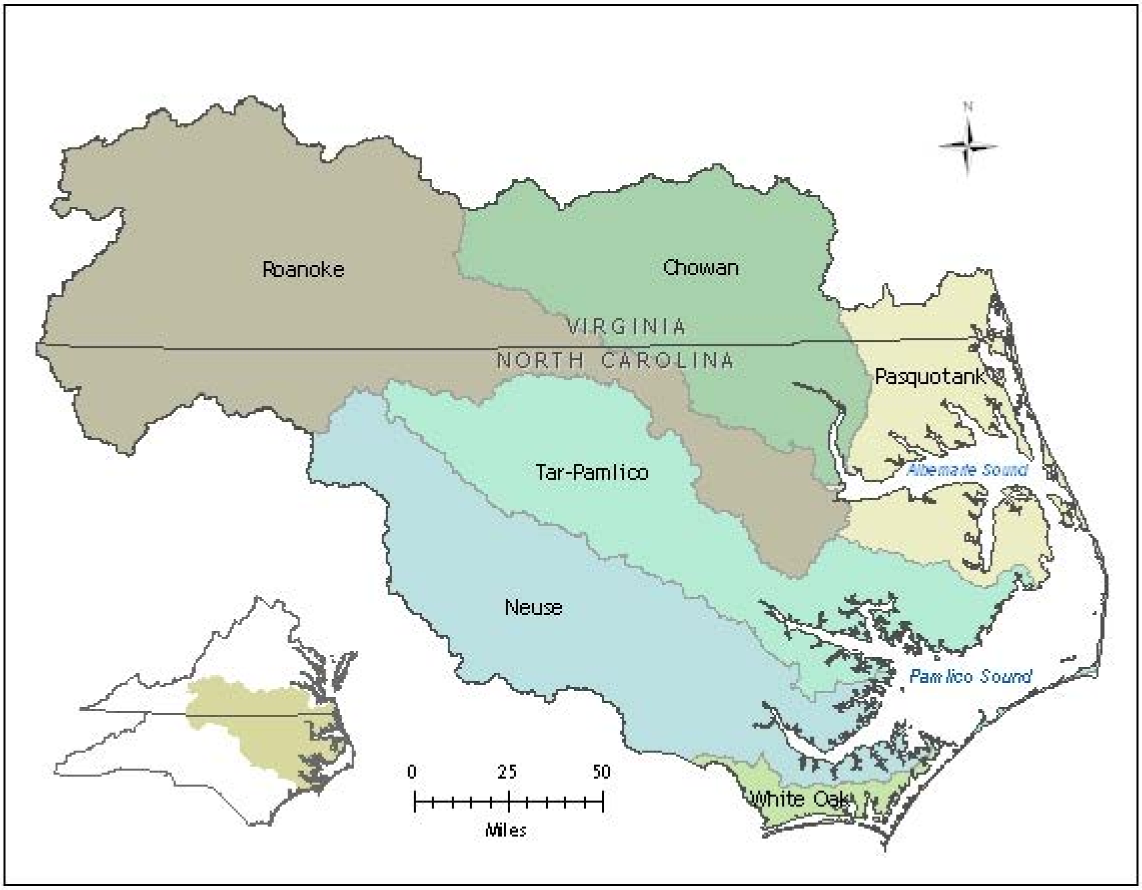

Figure 1. River basins and major sounds of the Albemarle-Pamlico Estuarine System.

Other major lateral tributaries of the Albemarle Sound include the Chowan, Perquimans, Little, Pasquotank and North Rivers in the north; and the Scuppernong and Alligator Rivers in the south. Pamlico Sound is the drowned portion of the Tar and Neuse Rivers and their extensive floodplains. Several small lateral tributaries drain off the low, flat, swampy coastal area, the largest one being the Pungo River in the north.

Neither sound is directly connected to the Atlantic Ocean; both lay behind an extensive chain of barrier islands referred to as the "Outer Banks". Albemarle Sound has three open-water estuaries at its eastern end that are parallel to the Outer Banks: the freshwater Currituck Sound to the north, and brackish Croatan and Roanoke Sounds to the south. Albemarle Sound is connected to the ocean only through the Croatan and Roanoke Sounds via Pamlico Sound. As a result, Albemarle Sound is strongly influenced by freshwater flows and only marginally by the Atlantic Ocean. Pamlico Sound is connected to the ocean through several inlets including Oregon, Hatteras, and Ocracoke. These tidal connections exert considerable oceanic influence on Pamlico Sound.

While the Albemarle Sound and Pamlico Sound, as well as Currituck, Core, Back, and Bogue Sounds and the Back Bay together comprise the estuarine waters for the Albemarle-Pamlico Region, the region also encompasses the adjacent marine (near-coastal) waters as well as the entire 73,300 km^2 (28,300 mi^2) drainage basin for the Albemarle and Pamlico Sounds.

Geological Origin

Sediments and sedimentary rocks of marine origin underlie the entire sound region (Brown et al. 1972). These sediments were deposited when the ocean covered portions of the coastal plain on top of the same type of crystalline rocks that occur in the Piedmont. As the coastal system migrated back and forth across the coastal plain-continental shelf over the last 100 million years, layers of stratified rock were formed. The marine sediments range in thickness from 600 m (1969 ft) at Washington, North Carolina, to 1500 m (4921 ft) near Swanquarter, to over 3000 m (9843 ft) at Cape Hatteras.

While each in the series of formations has a distinctive textural, mineralogical, and fossil composition, and while each was deposited during a specific period of geological time, these formations have little direct bearing on the present-day functioning of the Albemarle-Pamlico Estuarine System. Only the uppermost veneer of unconsolidated sediments has a direct bearing on the modern estuary. These sediments dictate the general characteristics of the estuarine margins, bottoms, topography, soil types, water drainage, and use of the adjacent land areas.

Sediments of interest for the current Albemarle-Pamlico Estuarine System include those from the Upper Miocene to the Pleistocene and Recent. The Miocene sediments (roughly 250 million years old) contain several fossil layers and comprise the sediments from which the phosphate mining industry along the Pamlico River is derived. The Pliocene sediments, deposited during the time of rapidly changing sequence in coastal environments (25 to 1 million years ago), are extremely complex and include gravel, sands, clays, peats, and all possible combinations of these (Hartness, 1977). Most of these units do not contain fossils or, if they did, the fossils were partly or completely leached out by acidic groundwater moving through the surface aquifers. The Pliocene and Pleistocene sediments range in thickness from a few meters up to 20 or more meters throughout the inner and middle estuarine areas, increasing to 15-25 m under the outer portions of the Albemarle-Pamlico Estuarine System.

Recent sediments were formed during the Ice Ages of the Pleistocene, when the advancing and retreating ice sheets brought about worldwide fluctuations in sea level. When the last major glacial advance reached its maximum about 17,000 to 18,000 years ago, the edge of the continent was about 40 km east of Cape Hatteras. The land surface sloped gently seaward and was dissected by rivers and associated tributaries with moderately deep channels and broad flood plains. Climate and vegetation were such that maximum surface water discharge and sediment erosion occurred (Whitehead, 1981). The products of such an environment are the coarse sands and gravels deposited on the North Carolina Coastal Plain.

The most recent rise of sea level began around 17,000 years ago when the climate began to warm and glacial ice masses receded. The sedimentary and physical character of the present sound system began to be defined at that time. As the climate continued to warm, the vegetation slowly evolved into the hardwood and pine forests that characterize the southeastern United States today. Also, the estuarine system impinged landward across the continental shelf to its current position.

A major geomorphic feature known as the Suffolk Scarp or Arapahoe Ridge trends north and south across the western portion of the Albemarle-Pamlico Estuarine System, dividing the area into two distinct geomorphic provinces. The prominent sand ridge rises to 6-9 m of elevation and represents an old barrier island shoreline formed by the sea during the previous Pleistocene interglacial period when sea level was higher than it is now. West of the Arapahoe Ridge, the terrain gently rises to the Piedmont. To the east lies the Pamlico Terrace, which has a low, poorly drained land with extensive swamps and pocosins composed of peat soils that generally thicken eastward.

Climate and Land

The climate in the area of the Albemarle-Pamlico Estuarine System is moderately mild and moist, creating a good environment for agriculture, forestry, and fisheries. Northeastern North Carolina and southeastern Virginia generally receive 120-142 cm (47-56 in) of rain per year, though spatial and temporal variation are great (Wilder et al., 1978). Dry years average about 89 cm (35 in) while wet years may receive up to 200 cm (78 in) of rainfall. Seasonal distribution of precipitation is relatively uniform, with the highest precipitation occurring in association with summer thunderstorms and the lowest occurring during fall and spring. Temperature is moderate. January temperatures average between 6 and 8 °C (43 and 46 °F); the low seldom falls below -12 °C (10 °F). Summers are hot and humid, with the average daytime temperature often exceeding 32 °C (90 °F) in July and August. Although winds are variable, the prevailing winds are from the S-SW with average velocities of 15-16 km/hr (9-10 mph) (Clay et al., 1975), making it an attractive resource for the wind energy industry. Special situations arise with northern winds of high velocities (most common during the winter), and localized thunderstorms, hurricanes, and tornadoes (most common during spring, summer, and fall).

Historically, the area directly surrounding the Albemarle-Pamlico Estuarine System has been heavily forested. In 1982, 33% of the land cover area in counties surrounding the sound system was forested, 16% was cropland, 15% was wetlands, and 2% was urban land cover (Table 2-3). Land use studies in the early 1990s confirmed small urban areas and a generally rural setting, with changes primarily from forest to agricultural uses rather than urban development. Almost a quarter-century later in 2006, of the land cover area in sub-basins (not counties) surrounding the sound system, 20% was in forest, 29% was in cropland, 33% was in wetlands, and 7% was in urban land cover (Table 2-4).

Table 2-3. Land area and 1982 land cover (in acres) in the counties surrounding Albemarle-Pamlico Estuarine System (US Soil Conservation Service National Resources Inventory) (APES, 1991:8).

County	Total	Urban	Cropland	Forest	Wetlands
Beaufort	612,980	20,800	131,300	333,000	43,700
Bertie	471,379	2,100	95,600	333,800	93,300
Camden	203,770	300	40,400	93,900	69,100
Carteret	673,625	22,400	53,000	93,500	48,800
Chowan	154,784	3,300	49,100	55,800	11,900
Craven	487,213	21,900	76,400	250,500	69,800
Currituck	281,082	2,800	54,200	55,400	31,200
Dare	800,601	15,800	5,200	33,978	58,078
Hyde	871,136	800	117,000	170,800	121,600
Pamlico	368,186	2,900	36,700	138,700	50,900
Pasquotank	185,203	5,800	76,100	46,400	26,400
Perquimans	208,845	2,200	96,500	52,400	11,800
Tyrrell	383,143	200	61,900	187,000	187,000
Washington	264,486	2,000	81,400	115,800	47,200
Total	5,966,433	103,300	974,800	1,958,978	870,778
Percent		2	16	33	15

Table 2-4. Land area and 2006 land cover (in acres) in the sub-basins surrounding Albemarle-Pamlico Estuarine System (see "Land Cover Extent" assessment in Chapter 3).

Sub-Basin	Total	Urban	Cropland	Forest	Wetlands
Albemarle	1,701,240	114,105	533,611	133,011	797,979
Chowan	547,537	31,157	156,547	176,268	113,405
Lower Roanoke	834,815	51,350	218,077	217,254	247,856
Pamlico Sound	280,277	9,933	51,573	17,747	139,570
Pamlico	739,623	30,713	226,644	155,319	212,968
Lower Tar	614,297	52,791	236,566	126,056	112,854
Lower Neuse	752,149	48,021	146,430	217,089	230,227
Middle Neuse	681,419	59,921	233,315	136,297	147,821
White Oak River	385,256	37,186	60,371	100,159	125,851
Total	6,536,613	435,177	1,863,134	1,279,200	2,128,531
Percent		7	29	20	33

Hydrography

The Roanoke and Chowan Rivers are the main sources of freshwater for Albemarle Sound (Giese et al. 1979). Of the approximately 481 cubic meters per second (17,000 cfs) net, annual average freshwater inflow to Albemarle Sound in the late 1970s, over half (249 cms or 8,800 cfs) is from the Roanoke River. Major sources of freshwater into Pamlico Sound are Albemarle Sound (481 cms or 17,000 cfs), the Pamlico (Tar) River (153 cms or 5,400 cfs), and the Neuse River (173 cms or 6,100 cfs); the average annual inflow is 898 cms (31,700 cfs) (Giese et al. 1979). Freshwater input is not evenly distributed throughout the year; the highest runoff occurs during the late winter and early spring, and the lowest occurs during the fall.

The total annual average outflow from Albemarle Sound is larger relative to the sound's volume (about 481 cms and 5.3 MAF, respectively) than the out flow from Pamlico Sound (906 cms and 21 MAF, respectively). This difference gives rise to a much shorter time for inflow to replace the volume of water in the Albemarle Sound from the ocean, resulting in much lower salinity conditions than in the Pamlico Sound.

Wind is the most important factor influencing short-term circulation in the Albemarle-Pamlico Estuarine System, with astronomical tides and freshwater inflows from tributaries playing secondary roles (Giese et al., 1979; Pietrafesa et al., 1986). The embayed lateral tributaries are very responsive to wind tides. Winds blowing downstream may often drive most of the water from the embayment (Overton et al., 1988), and wave action usually eliminates vertical stratification (especially in Albemarle Sound) except under certain calm or high-freshwater-inflow conditions.

Groundwater Resources

Abundant groundwater occurs in the unconsolidated sedimentary deposits (Health 1980), which range in thickness from a few meters along the fall line to more than 3,000 m (9,800 ft) at Cape Hatteras. Most of the groundwater available in the Coastal Plain is from the upper aquifer and the limestone aquifer (Wilder et al., 1978). The upper aquifer yields the most water and is the one most susceptible to contamination by land use activities. The water table lies very close to the surface in much of the low-lying areas around the sounds.

Roughly 20% of the annual Coastal Plain precipitation (112-142 cm or 44-56 in) recharges the groundwater system in the Coastal Plain (Winner and Simmons, 1977). Most of the water recharged to the groundwater system moves laterally through shallow aquifers and discharges to streams, thereby constituting a major part of surface water baseflow. Less than one inch per year of the recharge typically reaches the deep aquifers in the Coastal Plain.

The Estuary and Society

Native Americans called Albemarle Sound "Weapemeoc" and lived around the area prior to the arrival of European settlers in the sixteenth century. Albemarle was first explored by Sir Walter Raleigh's colonists under the leadership of Ralph Lane during spring 1586. Lane's Albemarle Sound expedition encountered bad weather, natives fiercely proud and defensive of their territory, and conflicts over presumed rights. While the details and characters have changed, people in the four centuries since have been and are the product and continuation of historical Albemarle Sound (Stick, 1982).

The size and isolation of the Pamlico Sound limited early settlement by colonists. Beginning with the settlement of Jamestown, Virginia in 1607, early settlement began north of the Albemarle Sound and later spread southward. Settlers built homesteads along the shores, produced crops for export, and sailed their crafts from sound to sea through the inlets of Currituck and Roanoke in the 1600s. Throughout the seventeenth century, the Albemarle Sound was the hub and heart of North Carolina, and Edenton, one of the Colonial capitols, was the center of trade (Stick, 1982). Numerous communities and small towns were established near the water, and land was cleared in ever-increasing acreage for agriculture. Fishing thrived and timber provided raw materials for local use and export. Southern migration continued, leading to the establishment of Bath on the northern shore of the Pamlico River Estuary in 1704. The sounds served as important highways for the transport of goods in colonial North Carolina and Virginia.

Even with the addition of a modern tourism economy, coastal North Carolina is still very dependent upon agriculture, forestry, and fishing just as it was 400 years ago. The Albemarle-Pamlico Estuarine System has dominated eastern North Carolina and southeastern Virginia for centuries and is bound to continue to do so.

Selection of Featured Ecosystem Indicators

APNEP defines an indicator as a numerical value derived from actual measurements of a pressure, state or ambient condition, exposure, ecological condition, or measure of human health or wellbeing over a specified geographic domain, whose trends over time represent or draw attention to underlying trends in the condition of the environment in the Albemarle-Pamlico Region.

The purpose for developing APNEP indicators is to gauge and communicate the status of and trends in environmental conditions in the Albemarle-Pamlico Region, in order to:

- measure the success of protection, restoration, and engagement programs at meeting CCMP outcomes;
- identify and fill knowledge gaps, including information needed to establish a science-based rationale for management actions;
- improve management of the natural and human resources of the region; and
- build constituencies for enhanced management success.

Indicators considered may include simple measures or complex indexes, to the extent that they meet the criteria below. The criteria listed below should guide selection of an array of indicators adequate to communicate key messages to target audiences. These criteria are not intended to be proscriptive, but they provide a framework for evaluating candidate indicators. Resource constraints may preclude some indicators that otherwise fit these criteria from being adopted, and some indicators that fulfill an important function may be monitored despite not fully meeting the criteria.

- The indicator is useful. It addresses a key process or property and answers or sheds light upon an important question about conditions in the Albemarle-Pamlico Region.
- The indicator is objective. It is developed and presented in an accurate, clear, complete, and unbiased manner.
- The underlying data are characterized by sound collection methodologies, maintained by data management systems adequate to protect informational integrity, and comply with quality assurance procedures.
- To ensure utility, data necessary to support the indicator are available and timely or will likely be available in the future.
- Trends depicted in the indicator accurately represent the underlying trends in the target population.
- The indicator is clearly defined and reproducible. The specific data used and the specific assumptions, analytical methods, and statistical procedures employed are clearly stated.

This interim assessment of the Albemarle-Pamlico ecosystem reports on the status and trends of ecosystem indicators representing three of five ecosystem categories. The five categories together represent a comprehensive survey of regional ecosystem condition. Some featured indicators represent characteristics of the entire Albemarle-Pamlico regional ecosystem, termed "system-wide" (Chapter 3), while the remainder represent one of two substantial aquatic-dominated components thereof: "coasts, estuaries, and near-marine" (Chapter 4) and "fresh waters" (Chapter 5). The remaining two categories to be incorporated in the next version of this assessment are addressed in "Next Steps" (Chapter 6).

The 24 indicators featured in this assessment (Table 2-1) were selected from a much larger set of candidate indicators, the latter approved by APNEP staff in late 2007 for consideration in APNEP's integrated monitoring strategy work to begin soon thereafter. The candidate set was the product of initial development by the APNEP Science & Technical Advisory Committee (STAC) in 2005-2006, followed by further refinement by an APNEP Indicator Steering Committee in 2006-2007. While it was important to have indicator development rooted in science and hence the STAC leading the first phase, equally important was the role of the Indicator Steering Committee to then broaden the perspectives contributing to indicator refinement. Therefore, STAC representatives on the indicator committee were joined by

Table 2-1. APNEP indicators assessed in Chapters 3 to 5. Origin legend: S&T = Addressed in 1991 APES status & trends report, O = STAC's 2010 proposed metrics that are not S&T, N = Proposed metrics to align with new CCMP.

					Reporting Scales			
					Space		Time	
Type	Category	Indicator	Origin	Units	Extent	Resolution	Extent	Frequency
System-Wide	Extent & Pattern	**Human Population**	O	persons	region	basin & sub	1990-2010	10 years
		Land Cover Extent	S&T	acres	region	basin & sub	1992-2006	5-9 years
	Chemical & Physical	**Ambient Air Temperature**	O	degrees	4 stations	Station	1895-2009	annual
		Storm Frequency & Intensity	O	count, F scale	region	storm track	1950-2010	60 years
		Ground-Level Ozone Concentration	O	W126 Index	11 stations	Station	1993-2010	annual
		Total Inorganic Nitrogen Deposition	O	kg-N/ha	5 stations	Station	1980-2009	3-yr moving average
		Dissolved Metal Concentrations	S&T	ug/L	state (VA)	Basin	1998-2011	1-48 months
		Dissolved Oxygen Concentration	S&T	mg/L	region	Basin	1980-2010	monthly
		Chlorophyll-a Concentration Violations	S&T	ug/L	region	Basin	1980-2010	1-96 months
	Biological	**River Herring Abundance**	O	count, biomass	2 basins	Basin	1972-2010	annual
		American Shad Abundance	O	CPUE, relative F	region	Basin	2000-2010	annual
		Sturgeon Abundance	O	CPUE	region	Basin	1990-2011	annual
Coasts, Sounds, and Near-Marine	Extent & Pattern	**Submerged Aquatic Vegetation Extent**	S&T	acres	region	Census	2006-2008	2-yr average
		Phragmites australis Extent	N	acres	13 stations	Station	Various within 2009-2010	annual
	Chemical & Physical	**Relative Sea Level**	O	mm	4 stations	Station	Various within 1953-2010	annual
		Ocean Shoreline Migration	O	m/yr, m	region	Station	Various within 1933-2009, 1996-2009	57-76 years, 13 years
		Estuarine Shoreline Migration	O	feet/yr	region & sub & 5 stations	sub & km	? & 1958-1998 & months	? & 40 years & months?
		Estuarine Salinity Concentration	S&T	ppt	region	Sub	1980-2009	10 years
	Biological	**Shellfish Closures**	S&T	% closed	region	Region	1980-2010	annual
		Unusual Fish Mortalities	S&T	count	state (NC)	Basin	1997-2010	annual
Fresh Waters	Chemical & Physical	**Streamflow**	S&T	cfs	basin	Station	Various within 1930-2008, 1996-2010	annual, 14-yr average
		Point Source Discharges	S&T	discharger number, tons	station	Station	1960-2008	2-10 years
		Riverine Transport of Nitrogen & Phosphorus	S&T	tons, tons/mi2, cfs	basin	Station	1997-2008	annual
		Suspended Sediment	S&T	tons, tons/mi2, NTU	region	Basin	1980-1992, 1980-1989	9-12 years

members from APNEP's three other standing advisory bodies at the time: Policy Board, Management Advisory Committee, and Citizens Advisory Committee.

To support their 2010-2012 Action Plan to produce a preliminary assessment, STAC members were asked to cull the aforementioned 2007 list of candidate indicators and narrowed the selection to many of those featured here. There were three main factors influencing an indicator's selection: (1) whether it was featured in the 1991 APES status and trends assessment, (2) whether data sets were available representing at a minimum the period mid-1990s (publication of original CCMP) to present, and (3) whether a STAC member was willing to serve as lead author or facilitator.

For reasons more pragmatic than scientific, a small number of deletions and additions to the resulting indicators list occurred during 2011. Because the referenced criteria focused less on policy relevance and more on expediency, those candidate indicators not selected for this interim product remain highly desirable for incorporation into future APNEP assessments.

Addressing Climate Change

With the Coastal Plain of the Albemarle-Pamlico Region being widely recognized as among this nation's most vulnerable landscapes to relative sea level rise and associated climate phenomena, one may ask why this first assessment is an ecosystem assessment rather than a vulnerability assessment to climate change and/or other stressors. APNEP has prioritized ecosystem condition indicators over stressor indicators for this initial assessment phase (CCMP Question 2). In future assessments, APNEP would like to further develop its diagnostic capabilities and more fully evaluate the effects of various stressors on the ecosystem (Chapter 6), which includes but is by no means limited to climate change (CCMP Question 3). Despite APNEP's focus on ecosystem condition, the indicators "ambient air temperature," "storm frequency and intensity," and "relative sea level rise" all offer insights into the influence of climate stressors on the Albemarle-Pamlico ecosystem.

Challenge of Economic Valuation

Andrew G. Keeler[1] and Lindsay Dubbs[2]

The economy of the Albemarle-Pamlico Region features several sectors that are highly dependent on the quality of the region's environment. Ecosystem services, which can be defined as results of ecosystem processes that confer benefits on human society, is the appropriate concept for evaluating the economic importance of the Albemarle-Pamlico Region's natural resource base. Data and analysis that show how changes in the region's ecosystems affect human welfare should be the goal of meaningful indicators that measure the connection between the region's environment and economy.

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Such data and indicators do not currently exist on a region-wide basis. In this section we provide insights on the challenges that arise from economic valuation using the economic product data available, which includes overall output levels and the monetary value of production in the agriculture, silviculture, and fisheries natural resource-based sectors. The available data provide an indication of how these activities have fared over time and the amount of income they produce for the region's residents. Similar statistics on the increasingly important set of activities related to recreation and tourism that are strongly dependent on the region's natural resources are unavailable.

These data are useful, but they do not provide a clear picture of the state of economic welfare provided by the region's natural resource base. The output of these sectors relies not only on the condition of the natural ecosystem, but also on national and international trends in commodity prices, changes in technology, and choices made in the use of fertilizers, pesticides, herbicides, and irrigation, which may boost yields but detrimentally impact the overall ecosystem condition. Advances in fishing methods can increase yields that may not be sustainable in the long-term if fish stocks decline as a result of short-term harvest increases. Ideally this report would include measures of the stock of natural capital and of the ecosystem services flowing from that capital stock. Such measures are difficult and time-consuming to estimate for both practical and conceptual reasons, but have the potential to give a much clearer picture of the economic value of the natural environment in the Albemarle-Pamlico Region.

The challenge presented by interpreting agricultural production and monetary value data: The amounts of livestock and crops produced in the Albemarle-Pamlico region are correlated with the land and water used in their production, and therefore provide some rough information on the ecosystem's agricultural productivity. However, yields are a very imprecise indicator of ecosystem service productivity; holding everything else constant, better soils and air quality improve agricultural yields. This is confounded by the fact that agricultural technology generally improves yields over time, and that changing the mix and levels of inputs can increase yields. Some categories of input use – fertilizers and water – can increase yields at the same time they increase the stress on ecosystems and reduce the future level of ecosystem services.

The monetary value of agricultural production is an indicator of how important agriculture is to the economy of the region. It is not particularly informative about the productivity of the ecosystem since it depends on land area under cultivation, crop choice, commodity prices, and input use as well as ecosystem service utilization.

Production of agricultural products and monetary values provide a very incomplete picture of both the economic dimensions of agriculture and the way it depends on and affects the regional ecosystem. For a better picture of economic importance, ideally we would have data on net incomes from agriculture, average wages or returns to labor per hour, and contributions to percentage of family income. To really begin to shed light on the issues of managing the estuaries for economic well-being, it would be necessary to begin to assess and quantify specific ecosystem service flows that support agriculture as well as the flows out of agriculture that affect the estuary and its continuing productivity.

The challenge presented by interpreting total wood harvested, total growing stock, and monetary value of silviculture products data: Monetary value gives an indication of the importance of forestry to the economy of counties within the Albemarle-Pamlico region. Yields in any given year are trickier to interpret, since they depend on harvest decisions that can in turn be influenced by annual market conditions and historical patterns of harvest and replanting. The reported indicators on total growing stock are probably a better indicator of the overall economic value of managed forests in the region.

Data on land conversion – forestry to agriculture, agriculture to forestry, forestry to urban – would help to give a picture of the effects of economic decisions about forestry on the landscape. Data on both gross and net returns to timber per acre over time would be helpful in assessing economic importance.

The challenge presented by interpreting major yields and monetary value of fishery products data: Yields and values of fisheries products are highly informative about the productivity of the fishery and its economic importance to the region. The trends in yield for particular species over time can give an indication of the health and sustainability of the fishery for that species.

However, the data do not show the cost of and time spent fishing, the net incomes of fishermen, the catch and value by species, or the impact of regulation and restrictions governing various fisheries. The data also do not distinguish between commercial and recreational fishing. Data on the net income of commercial fishermen, the economic benefits of recreational fishing, and the state of fish stocks over time would help to give a more accurate picture of how well the region's environmental system is contributing to the economic value of the fishery.

Recreation and Tourism: Recreation and tourism are clearly very important sources of economic value in the Albemarle-Pamlico region that depend very directly on the natural resource base. This sector is particularly important to include for a meaningful evaluation of environment – economy interactions because some ecosystem services provided to agriculture, silviculture, and commercial fishing can result in decreased services to recreation and tourism. For example, increased water use in agriculture can result in decreased water quality and reduced ecosystem services to water sports enthusiasts, wildlife viewers, etc. Increased timber harvesting and commercial fisheries catches can also result from changes in natural capital that decrease the flows of resources to recreation and tourism.

These conflicts are not inevitable – natural capital can be managed in a way that enhances the total value of ecosystem services. The point we wish to emphasize in this section is that evaluating the tradeoffs inherent in management choices – or understanding the effects on the economy that result from external drivers like changes in economic demand or climatic drivers – requires indicators that reflect the relationship between changes in ecosystems and changes in the full set of ecosystem services they provide. Enhancing the data and analysis of this set of broad and complex relationships is the highest priority for providing useful information about the economic importance of the Albemarle-Pamlico Region's environment.

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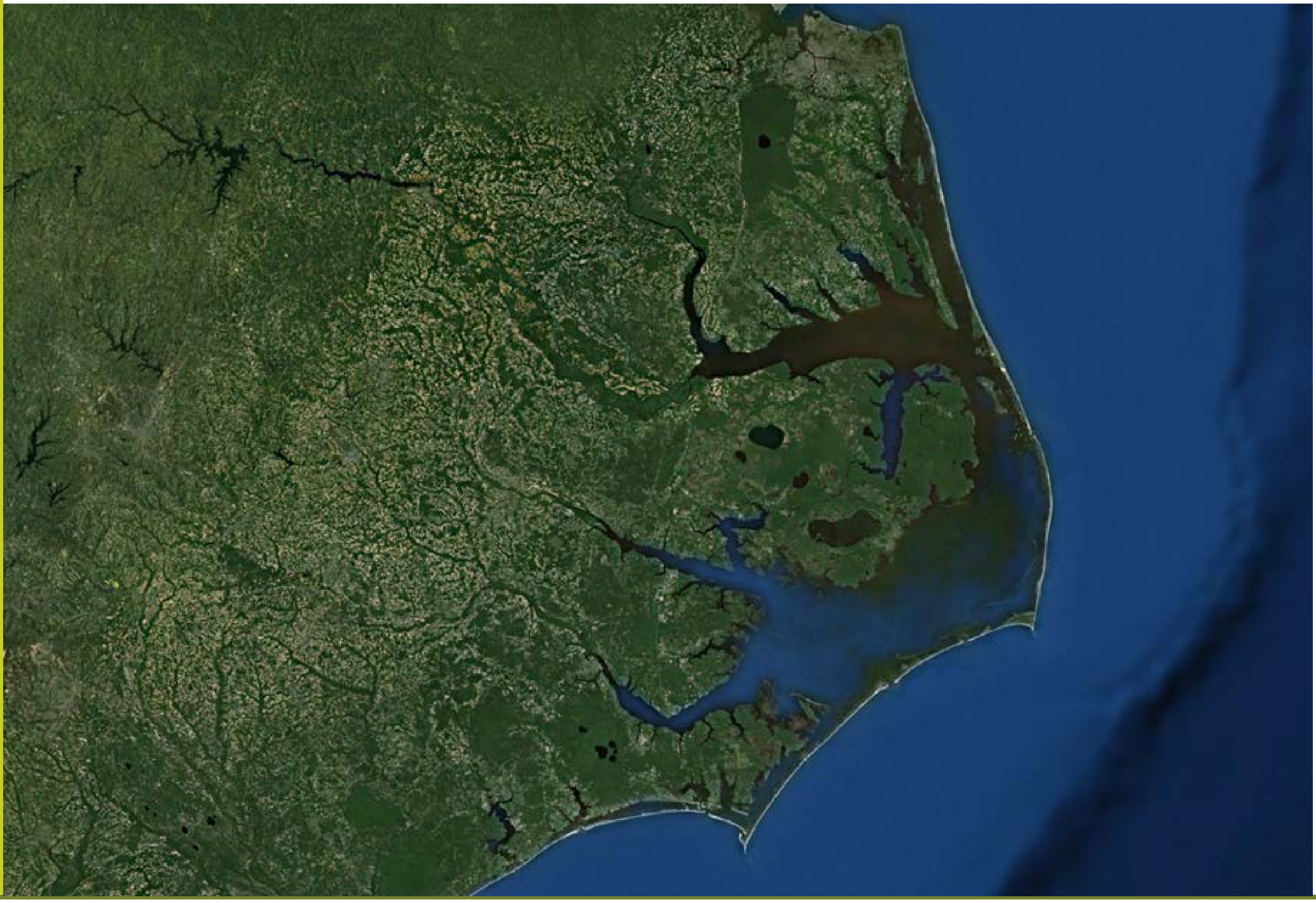
Chapter 3 - System-Wide

Chapter 3: System-wide

This chapter features twelve assessments of the broadest ecosystem type "System-wide", including assessments of:

- two indicators of the major category "Extent and Pattern":
  - Human Population,
  - Land Cover Extent;
- seven indicators of the major category "Chemical and Physical Characteristics":
  - Ambient Air Temperature,
  - Storm Frequency & Intensity,
  - Ground-Level Ozone Concentration,
  - Total Inorganic Nitrogen Deposition,
  - Dissolved Metals Concentrations,
  - Dissolved Oxygen Concentration Violations,
  - Chlorophyll-a Concentration; and
- three indicators of the major category "Biological Components":
  - River Herring Abundance,
  - Shad Abundance,
  - Sturgeon Abundance.



HUMAN POPULATION

Thomas Crawford[3]

Why Is Human Population Important?

All else being equal, a larger human population contributes to larger environmental impacts and stresses on natural resources within the Albemarle-Pamlico region. Each individual necessarily occupies space(s), consumes natural resources, produces waste and thereby leaves an ecological footprint that alters the natural environment locally, regionally, and even globally with increased globalization. Of course "all else" is rarely if ever equal as different human populations with varying characteristics can contribute differently to impacts and stresses. Human ecologists have framed this problem using the "IPAT" equation $I = PAT$, where I represents an environmental impact or stress that results as a function of human population P, affluence A, and technology T. Human populations alter the environment in myriad ways. Selected impacts associated with human population and their behaviors include: loss of natural land covers (e.g. wetlands and forests), natural habitat fragmentation, increased impervious surface, point and non-point source water pollution, water withdrawal, air pollution, greenhouse gas emissions, and reduced health of terrestrial and aquatic species populations.

Historical evolution of settlement patterns is driven by multiple factors such as demographic processes (i.e. human fertility, mortality, and migration), geographical accessibility, land economics, natural landscape environmental opportunities and constraints, and institutional land policies governing where settlement may occur. The spatially varying nature of these factors causes an uneven distribution of human population such that it is important to report human population patterns at multiple geographical scales of increasing spatial resolution that range from the entire Albemarle-Pamlico Basin to individual sub-basins (Figures 1 and 2).

What Does This Indicator Report?

- Population size: Total human population summarized by state, basin, and sub-basin for the years 1990, 2000, and 2010.

- Population change: Total and percent human population change summarized by state, basin, and sub-basin for the periods 1990-2000, 2000-2010, and 1990-2010.

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What Do the Data Show?

Regional Human Population

- Total human population numbers (Table 1) indicate 2010 human population levels of approximately 3.7 million with North Carolina housing a much greater share of the population.

- Total human population change for 1990-2010 (Table 2) indicates an increase over twenty years of approximately 1.0 million with North Carolina receiving an overwhelming majority of this growth.

- Percent population change for 1990-2010 (Table 3) indicates a percent increase over twenty years of 36.0%. North Carolina had nearly three times the growth rate of Virginia. Virginia experienced a growth rate in the 1990s substantially less than North Carolina that declined substantially in the 2000s. North Carolina's decadal growth rates were constant during both decades at about 20.0%.

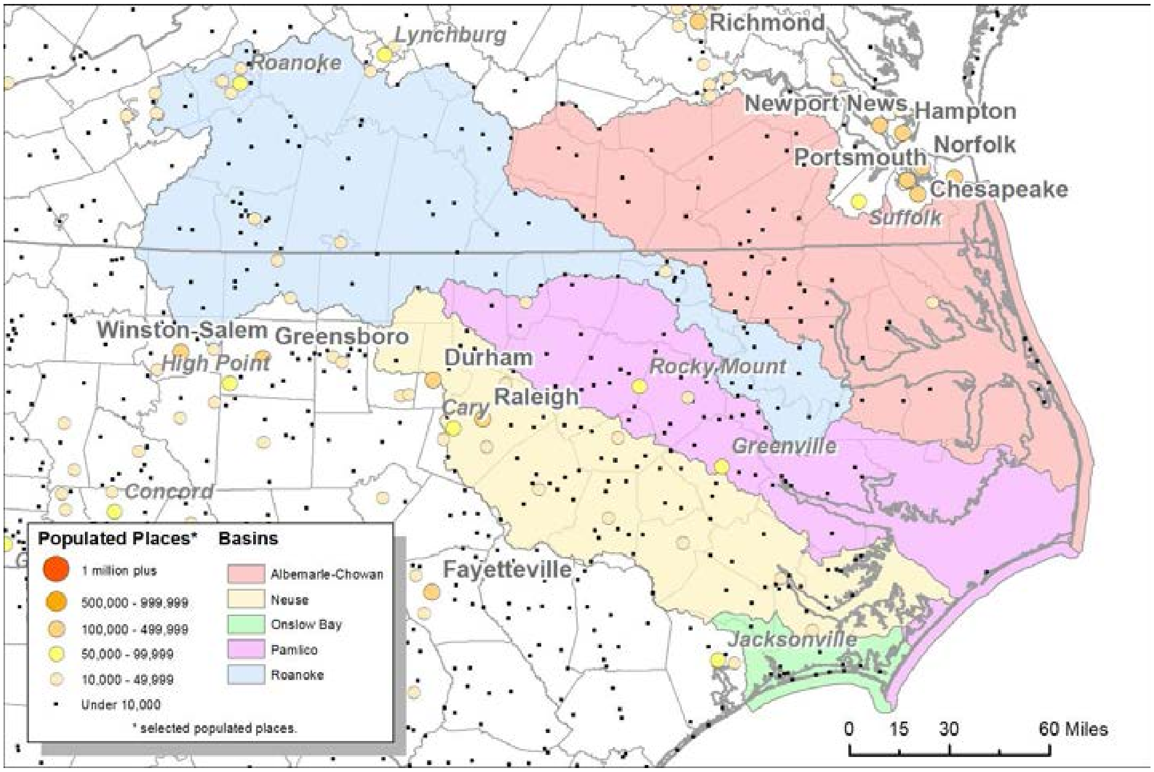

Figure 1. Basins and selected populated places.

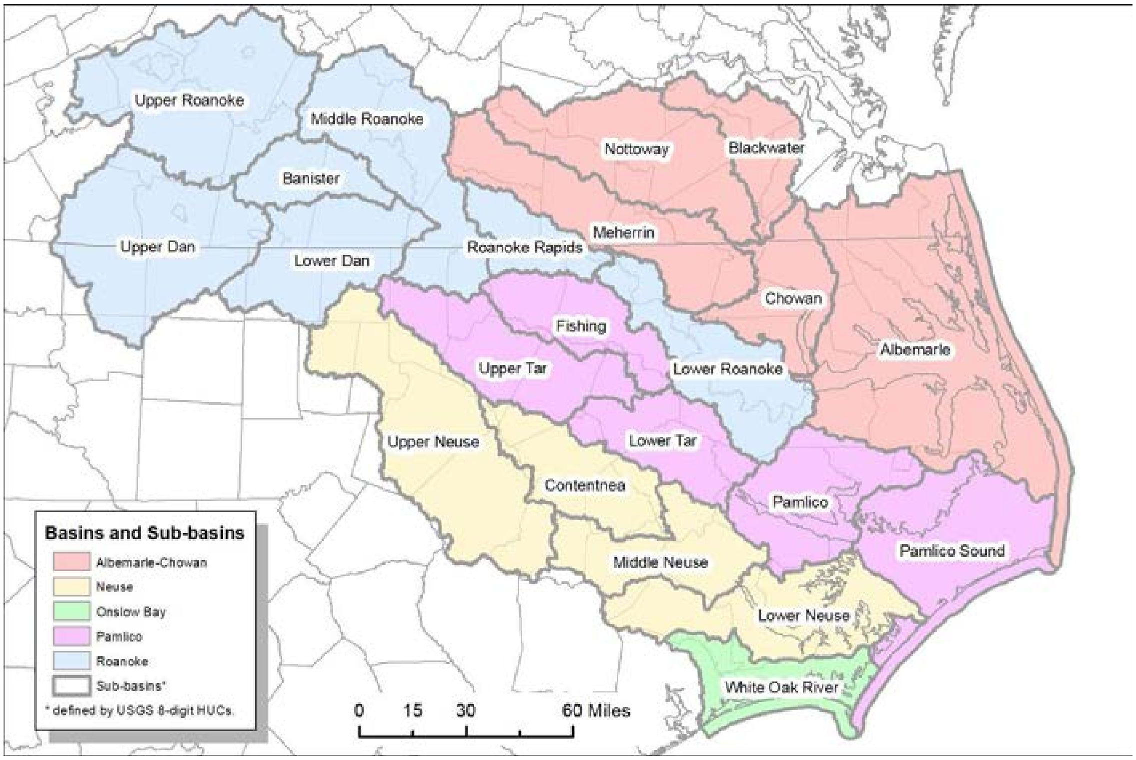

Figure 2. Basins and sub-basins.

Table 1. Human population by state.

Region	1990	2000	2010
Albemarle-Pamlico	*2,762,409*	*3,267,706*	*3,756,019*
NC portion	1,868,298	2,267,795	2,715,169
VA total	894,111	999,911	1,040,850

Table 2. Human population change by state.

Region	Change 1990-2000	Change 2000-2010	Change 1990-2010
Albemarle-Pamlico	*505,297*	*488,313*	*993,610*
NC portion	399,497	447,374	846,871
VA total	105,800	40,939	146,739

Table 3. Percent human population change by state.

Region	% Change 1990-2000	% Change 2000-2010	% Change 1990-2010
Albemarle-Pamlico[1]	*18.3*	*14.9*	*36.0*
NC portion	21.4	19.7	45.3
VA total	11.8	4.1	16.4

Basin and Sub-Basin Human Population

- The 2010 human population in the Neuse basin was approximately 1.7 million which was by far the largest basin population (Table 4). The Roanoke basin ranked second at approximately 970,000. Other basin human populations in 2010 were substantially smaller at approximately 560,000 or less.

- The 2010 human population in the Upper Neuse sub-basin was approximately 1.2 million which was by far the largest sub-basin population (Table 4). The Albemarle sub-basin ranked second among sub-basins within the Albemarle-Pamlico Region at approximately 340,000. The majority of remaining sub-basins had substantially smaller human populations of less than 100,000.

- The Neuse basin had the highest percent increase over the twenty-year (1990-2010) period at 65.8% (Table 5). The Roanoke basin is notable for having the lowest growth rate over this period.

- Percent increase was generally consistent during both the 1990s and 2000s for the Neuse, White Oak, and Pamlico basins (Table 5). Percent increased declined from higher values during the 1990s to lower values during the 2000s for the Albemarle-Chowan and Roanoke basins.

- The Upper Neuse sub-basin had the highest percent increase over the twenty-year (1990-2010) period at 86.3% (Table 5). The next highest ranking sub-basins having growth rates of at least approximately 30% were the Albemarle (42.6%), White Oak River (39.1%), Contentnea (33.8%), and Lower Tar (29.6%).

- Percent increase was generally consistent during both the 1990s and 2000s for the Upper Neuse, Lower Neuse, White Oak River, Lower Tar, and Upper Tar sub-basins. Most other sub-basin experienced changing growth rates for each of the respective decades.

Table 4. Human population by basin and sub-basin.

Basins and Sub-basins	1990	2000	2010
Albemarle-Chowan	*432,830*	*514,986*	*561,443*
Albemarle	240,867	306,606	343,392
Blackwater	43,613	46,303	48,768
Chowan	36,841	38,325	40,816
Meherrin	62,322	65,799	66,842
Nottoway	49,187	57,953	61,625
Roanoke	*878,853*	*947,166*	*969,715*
Lower Roanoke	77,392	78,988	78,503
Roanoke Rapids	22,567	28,259	28,615
Middle Roanoke	66,942	73,045	74,354
Upper Roanoke	338,049	371,163	309,902
Banister	26.571	28,352	28,605
Lower Dan	117,168	120,318	116,552
Upper Dan	230,164	247,041	244,184
Pamlico	*368,492*	*408,261*	*447,943*
Pamlico Sound	9,005	9,444	9,666
Pamlico	38,331	40,076	40,983
Lower Tar	125,623	141,465	162,763
Upper Tar	160,276	180,432	197,886
Fishing	35,257	36,844	36,645
Neuse	*1,017,817*	*1,320,194*	*1,687,332*
Lower Neuse	88,432	98,963	108,606
Middle Neuse	141,692	152,827	172,358
Upper Neuse	671,670	931,013	1,251,126
Contentnea	116,023	137,391	155,242
White Oak	*64,417*	*77,099*	*89,586*
White Oak	64,417	77,099	89,586

Table 5. Percent human population change by basin and sub-basin.

Basins and Sub-basins	% Change 1990-2000	% Change 2000-2010	% Change 1990-2010
Albemarle-Chowan	*19.0*	*9.0*	*29.7*
Albemarle	27.3	12.0	42.6
Blackwater	6.2	5.3	11.8
Chowan	4.0	6.5	10.8
Meherrin	5.6	1.6	7.3
Nottoway	17.8	6.3	25.3
Roanoke	*7.8*	*2.4*	*10.3*
Lower Roanoke	2.1	-0.6	1.4
Roanoke Rapids	25.2	1.3	26.8
Middle Roanoke	9.1	1.8	11.0
Upper Roanoke	9.8	7.5	18.0
Banister	6.7	0.9	7.7
Lower Dan	2.7	-3.1	-0.5
Upper Dan	7.3	-1.2	6.1
Pamlico	*10.8*	*9.7*	*21.6*
Pamlico Sound	4.9	2.3	7.3
Pamlico	4.6	2.3	6.9
Lower Tar	12.6	15.1	29.6
Upper Tar	12.6	9.7	23.5
Fishing	4.5	-0.5	3.9
Neuse	*29.7*	*27.8*	*65.8*
Lower Neuse	11.9	9.7	22.8
Middle Neuse	7.9	12.8	21.6
Upper Neuse	38.6	34.4	86.3
Contentnea	18.4	13.0	33.8
White Oak	*19.7*	*16.2*	*39.1*
White Oak	19.7	16.2	39.1

What Is Not Shown by This Indicator?

By describing total human population and human population change, this indicator does not describe characteristics of human population. Indicators of socio-economic characteristics of the Albemarle-Pamlico human population would provide richer information to assess environmental stressors using an IPAT framework where factors describing human population beyond human population size and change are included. Socio-economic attributes of human population rely on either expensive primary data collection or secondary data sources such as the US Census. Decennial US Census data at the county level can be used to assemble a richer set of indicators but their use is hampered due to the fact that the Albemarle-Pamlico watershed boundaries do not align with administratively defined county boundaries.

Census blockgroups provide a finer level of spatial resolution that helps alleviate this problem. Relatively detailed socio-economic data are reported at the blockgroup level in the 1990 and 2000 census and will soon be released in the 2010 census. Due to these limitations associated with assembling socio-economic indicators of the Albemarle-Pamlico human population, only total human population and human population change indicators for 1990, 2000, and 2010 are reported. These indicators were assembled from census blocks which provide the finest spatial resolution census data publicly available. Socio-economic characteristics are not included in census block data due to privacy and confidentiality issues.

Understanding the Data

Human population and human population growth is unevenly distributed (Figures 3 and 4). 2000 human population and growth during 1990-2010 is most concentrated in the Upper Neuse sub-basin. This sub-basin is home to the Raleigh and Durham urban centers and the Research Triangle region more generally which is one of the fasting growing metro regions in the United States. A secondary though smaller node of human population and human population growth is located in the Albemarle sub-basin. While visually this sub-basin is more areally expansive, it is important to note that much of this area is comprised of large estuary water bodies. This sub-basin houses parts of the Virginia-Beach/Norfolk metropolitan area, the Elizabeth City urban region and the northern Outer Banks. A third node is located in the Upper Roanoke sub-basin associated with the Roanoke metropolitan area.

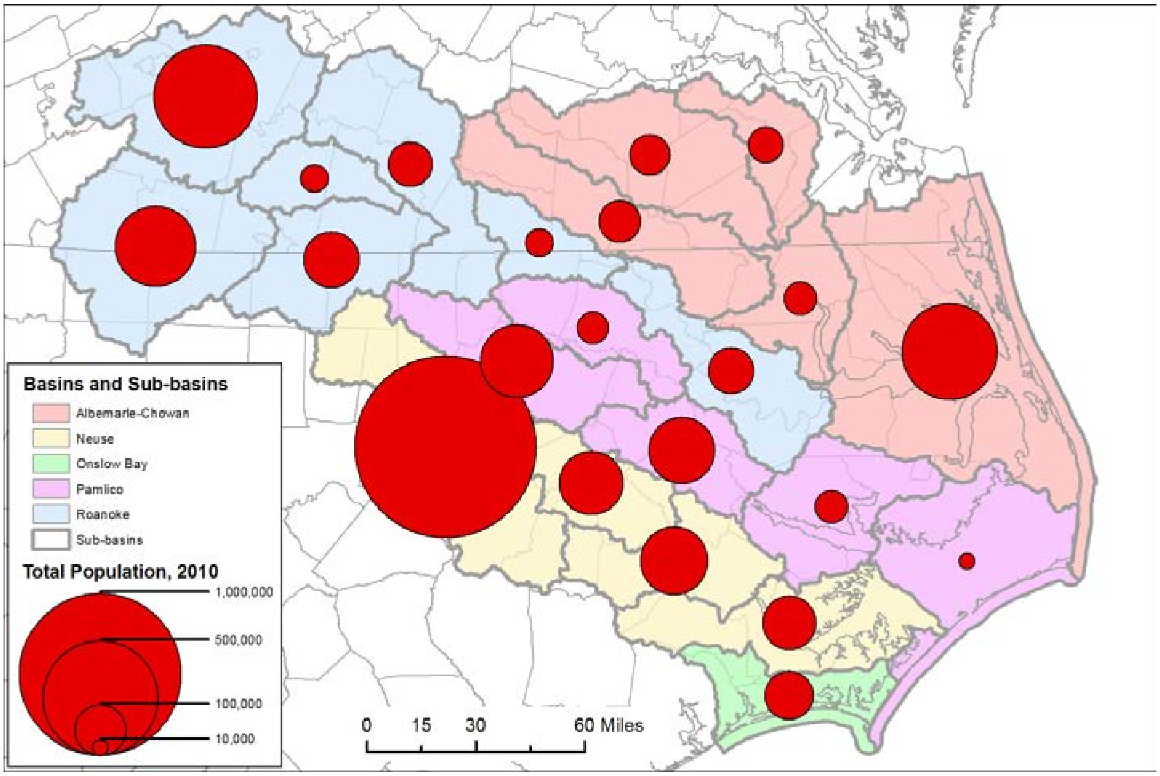

Figure 3. Total human population, 2010.

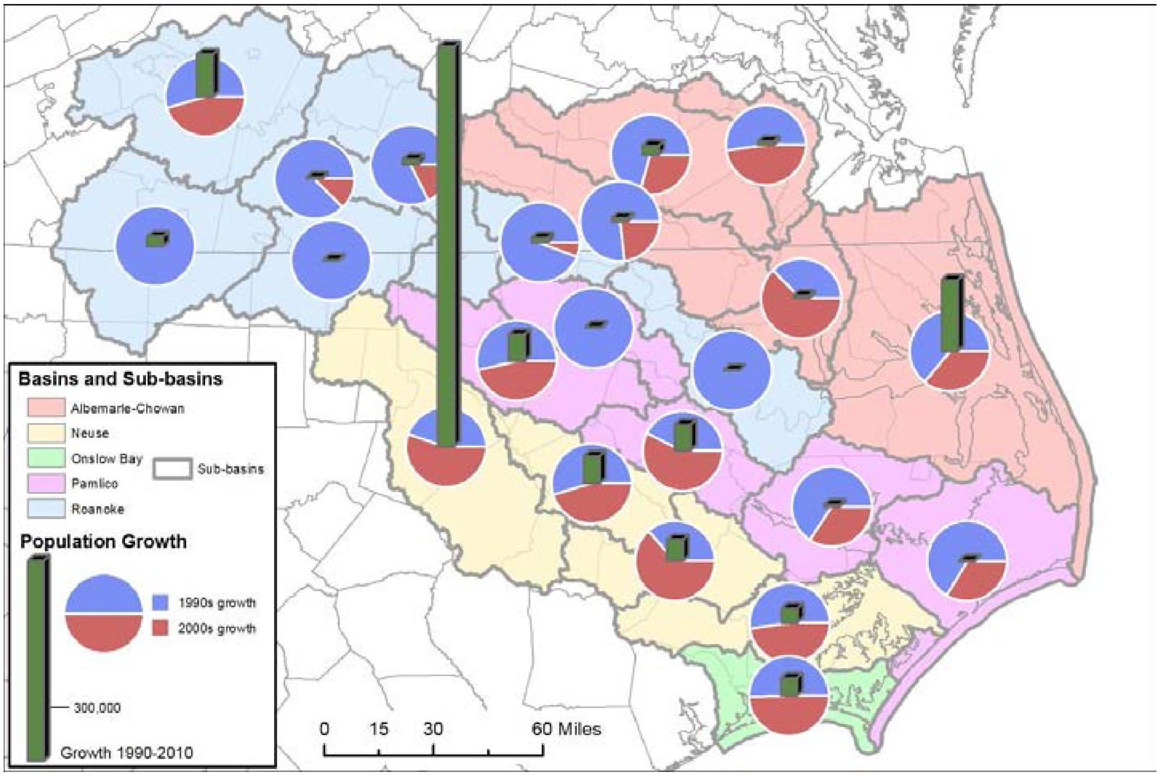

Figure 4. Human population growth 1990-2010: green = raw growth, blue = share of raw growth during the 1990s, red = share of raw growth during the 2000s.

EXTENT OF LAND COVER TYPES

Thomas Crawford[4] , Silvia Terziotti[5]

Why Is the Area of Different Land Cover Types Important?

The regionwide amounts and spatial patterns of particular land cover types, like wetlands or forests, describe basic characteristics of the overall landscape that contribute to the overall health of regional ecosystems and the ecosystem services and functions provided within the region. Land cover change can result from anthropogenic conversions such as from forest or farmland to urban development. Land cover change may also occur due to environmental processes such as climate change or forest succession, albeit over longer time horizons. Indicators reported here focus on amounts and spatial variation of land cover and land cover change but do not provide information on the habitat quality of ecosystems comprised of the various reported land cover types.

What Does This Indicator Report?

• Land Cover Patterns: Area and percentages of land cover types summarized by basin and sub-basin for the year 2006 (Figures 1-2).

• Land Cover Change: Total acres and percentages of change for selected land cover types summarized by basin and sub-basin for change occurring during 1992-2001 and 2001-2006. Changes within the entire basin for 2001-2006.

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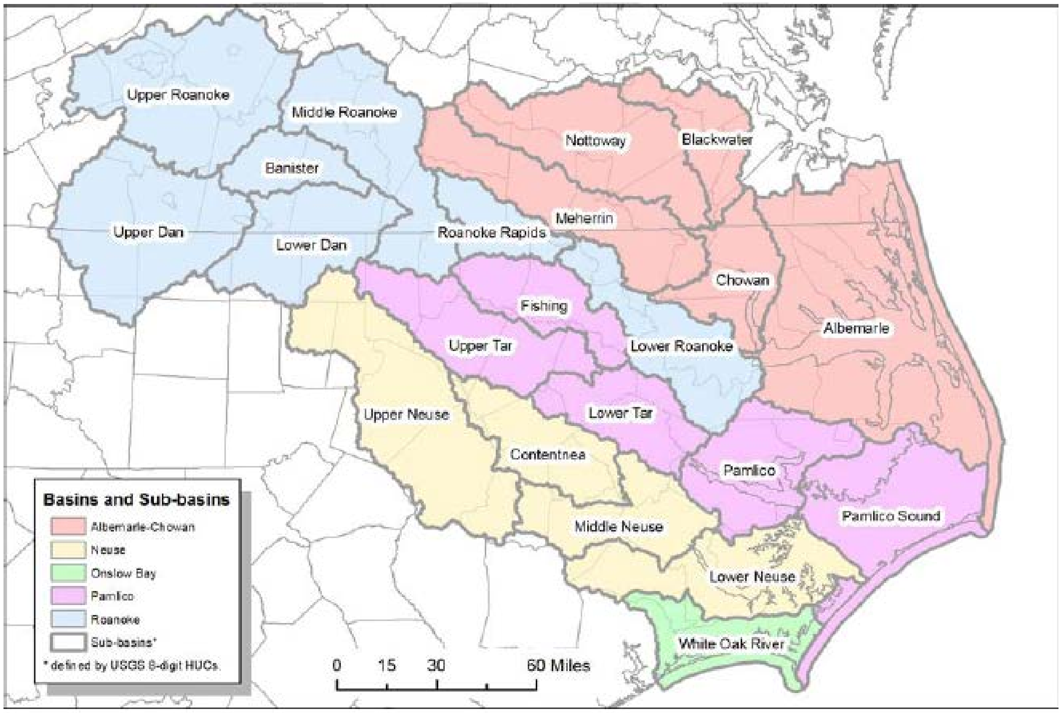


Figure 1. Sub-basins of the Albemarle-Pamlico Basin.

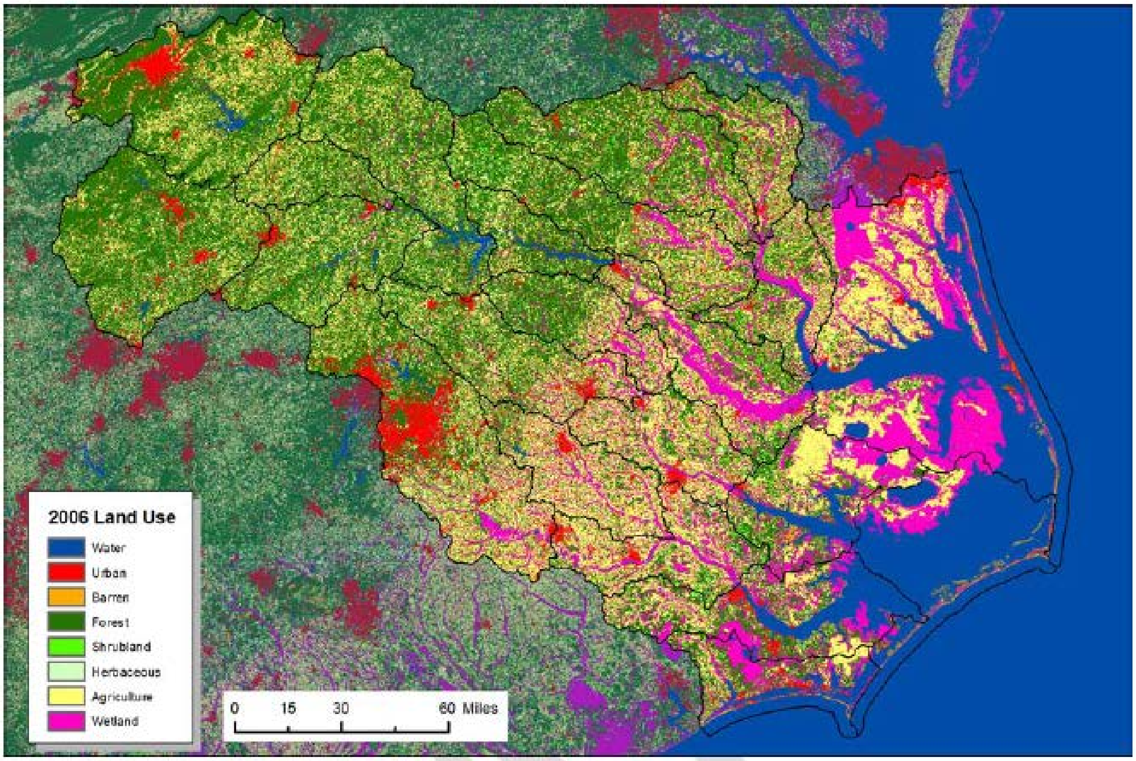


Figure 2. Location of land cover types within the Albemarle-Pamlico Region in 2006.

What Do the Data Show?

Ecosystem Extent, 2006

• For the entire Albemarle-Pamlico Region, the largest three land cover types were forests (40.1%), croplands (25.3%), and wetlands (15.8%) that collectively accounted for 81.2% of the total area (Table 1).

• Wetlands and croplands are more dominant in the Lower Coastal Plain. Forests are more dominant in the upper portion of the Albemarle-Pamlico Region (Figure 1).

Table 1. Area of land cover types for the Albemarle-Pamlico Basin in 2006.

Land Cover	*Acres*	*Percent*
Water	358,141	2.0
Urban	1,430,950	7.9
Barren	55,834	0.3
Forest	7,283,120	40.1
Shrubland	848,364	4.7
Herbaceous	719,795	4.0
Cropland	4,587,920	25.3
Wetland	2,861,580	15.8
Total*	18,145,704	100.0

*Percents sum to 100.1 due to rounding

• At the basin and sub-basin scales, land cover varies substantially (Table 2). White Oak and the Albemarle-Chowan had the highest proportion of wetlands. Roanoke had the highest proportion of forest and lowest proportion of wetlands. The proportion of croplands was generally consistent among all sub-basins with the exception of White Oak. The proportion of urban was also generally consistent with the exception of the Neuse which had the highest percent at 12.34% due to the high urbanization in the Upper Neuse sub-basin associated with Raleigh and Durham.

Land Cover Change, 1992-2001 and 2001-2006

• Of the selected land cover types, urban land cover had a net increase of 66,370 acres or 0.37% of the total Albemarle-Pamlico land area between 1992 and 2001, and increased by 39,154 acres (0.22% of the Albemarle-Pamlico Region) between 2001 and 2006 (Table 3).

• Forest had the largest net decrease of 299,536 acres (1.65% of Albemarle-Pamlico Region) followed by wetlands with a net decrease of 89,419 acres (0.49% of Albemarle-Pamlico Region) between 1992 and 2001. From 2001 and 2006 forest decreased an additional 198,036 acres (1.09% of the Albemarle-Pamlico region) and wetland loss amounted to 41,234 acres (0.23% of the Albemarle-Pamlico region) (Table 3).

• Cropland area was generally stable only experiencing a net loss of 4,387 acres (0.02% of Albemarle-Pamlico Region). From 2001 to 2006 a modest increase in cropland of 26,061 acres was seen within the Albemarle-Pamlico Region (0.14% of the Albemarle-Pamlico region) (Table 3).

• The source 1992-2001 NLCD Retrofit Data product is not error free. Specifically, there is a greater likelihood of classification confusion between the shrubland and herbaceous classes (not reported here) and the forest and wetland classes. As one example, a 30-meter pixel may be classified as forest in 1992 and erroneously as shrubland in 2001 resulting in error in the 1992-2001 change product. Similar inter-class confusion may exist for wetland and other classes (including confusion with forest). These caveats also exist for the 2001-2006 land cover classifications. Thus, these results should be interpreted with caution.

Change Analysis by Sub-Basin, 1992-2001:

• At the basin and sub-basin levels, land cover change varies substantially (Table 4). All basins and sub-basins experienced urban growth with the Neuse basin and Upper Neuse sub-basin being most prominent.

• The vast majority of wetland loss is accounted for by the Albemarle-Chowan basin and the Albemarle sub-basin more specifically (Table 4). Again, caution should be taken with these results for wetland change due to the potential of source product error.

Change Analysis by Sub-Basin, 2001-2006:

• At the basin and sub-basin levels, land cover change varies substantially (Table 5). All basins and sub-basins experienced urban growth with the Neuse basin and Upper Neuse sub-basin being most prominent.

• The largest amount of wetland loss is accounted for by the Albemarle-Chowan basin within which wetland loss is distributed fairly evenly across the sub-basins (Table 5). Again, caution should be taken with these results for wetland change due to the potential of source product error.

Table 2. 2006 land cover acres and percents for selected types at the basin and sub-basin levels.

Basins/Sub-basins	Total Acres	Urban		Cropland		Forest		Wetlands	
		acres	% of total	acres	% of total	Acres	% of total	Acres	% of total
Albemarle-Chowan	***4,856,193***	***294,958***	***6.07***	***1,256,835***	***25.88***	***1,616,805***	***33.29***	***1,200,527***	***24.72***
Albemarle	1,701,240	114,105	6.71	533,611	31.37	133,011	7.82	797,979	46.91
Blackwater	473,596	34,872	7.36	121,877	25.73	189,530	40.02	76,648	16.18
Chowan	547,537	32,157	5.87	156,547	28.59	176,268	32.19	113,405	20.71
Meherrin	1,031,410	57,230	5.55	239,960	23.27	507,800	49.23	103,686	10.05
Nottoway	1,102,410	56,594	5.13	204,840	18.58	610,196	55.35	108,809	9.87
Roanoke	***6,245,323***	***450,350***	***7.21***	***1,321,022***	***21.15***	***3,578,425***	***57.30***	***314,490***	***5.04***
Lower Roanoke	834,815	51,350	6.15	218,077	26.12	217,254	26.02	247,856	29.69
Roanoke Rapids	378,615	21,192	5.60	66,185	17.48	220,366	58.20	10,055	2.66
Middle Roanoke	1,112,130	47,415	4.26	234,920	21.12	664,970	59.79	29,222	2.63
Upper Roanoke	1,401,630	152,432	10.88	321,023	22.90	878,556	62.68	719	0.05
Banister	381,774	23,578	6.18	96,871	25.37	217,603	57.00	7,357	1.93
Lower Dan	821,399	52,782	6.43	163,336	19.89	486,575	59.24	14,740	1.79
Upper Dan	1,314,960	101,601	7.73	220,610	16.78	893,101	67.92	4,541	0.35
Pamlico	***3,040,826***	***201,832***	***6.64***	***890,987***	***29.30***	***940,836***	***30.94***	***599,816***	***19.73***
Pamlico Sound	280,227	9,933	3.54	51,573	18.40	17,747	6.33	139,570	49.81
Pamlico	739,623	30,713	4.15	226,644	30.64	155,319	21.00	212,968	28.79
Lower Tar	614,297	52,791	8.59	236,566	38.51	126,056	20.52	112,854	18.37
Upper Tar	834,737	78,243	9.37	229,849	27.54	370,941	44.44	64,983	7.78
Fishing	571,942	30,153	5.27	146,365	25.59	270,773	47.34	69,441	12.14
Neuse	***3,618,088***	***446,620***	***12.34***	***1,058,700***	***29.26***	***1,046,893***	***28.93***	***620,903***	***17.16***
Lower Neuse	752,149	48,021	6.38	146,430	19.47	217,089	28.86	230,227	30.61
Middle Neuse	681,419	59,921	8.79	233,315	34.24	136,297	20.00	147,821	21.69
Upper Neuse	1,539,320	282,739	18.37	393,493	25.56	560,892	36.44	133,333	8.66
Contentnea	645,200	55,939	8.67	285,462	44.24	132,615	20.55	109,522	16.97
White Oak	***385,256***	***37,186***	***9.65***	***60,371***	***15.67***	***100,159***	***26.00***	***125,851***	***32.67***
White Oak	385,256	37,186	9.65	60,371	15.67	100,159	26.00	125,851	32.67

Table 3. 1992-2001 and 2001-2006 land cover change for the Albemarle-Pamlico Estuary System, selected types

* Absolute value of acres gain/loss as a percentage of total APES land area.

	1992 - 2001		2001 - 2006	
Land cover class	Acres gain/loss (- indicates a net loss)	Percent of APES land area *	Acres gain/loss (- indicates a net loss)	Percent of APES land area *
Urban	66,370	0.37	39,154	0.22
Cropland	-4,387	0.02	26,061	0.14
Forest	-299,536	1.65	-198,036	1.09
Wetland	-89,419	0.49	-41,234	0.23

* Absolute value of acres gain/loss as a percentage of total APES land area.

Table 4. 1992-2001 land cover change at the basin and sub-basin levels, selected types.

Basins/Sub-basins	Total Acres	Urban		Croplands		Forest		Wetlands	
		acres	% of total	acres	% of total	Acres	% of total	Acres	% of total
Albemarle-Chowan	***4,856,193***	***7,521***	***0.15***	***17,952***	***0.37***	***-8,521***	***0.18***	***-84,013***	***1.73***
Albemarle	1,701,240	3,590	0.21	17,827	1.05	75,383	4.43	-107,754	6.33
Blackwater	473,596	587	0.12	-583	0.12	-16,195	3.42	14,087	2.97
Chowan	547,537	456	0.08	161	0.03	2,772	0.51	-7,096	1.30
Meherrin	1,031,410	1,516	0.15	1,651	0.16	-33,459	3.24	5,608	0.54
Nottoway	1,102,410	1,372	0.12	-1,104	0.10	-37,022	3.36	11,143	1.01
Roanoke	***6,245,323***	***22,109***	***0.35***	***15,239***	***0.24***	***-147,613***	***2.36***	***1,045***	***0.02***
Lower Roanoke	834,815	765	0.09	-11,284	1.35	-1,473	0.18	-1,234	0.15
Roanoke Rapids	378,615	1,009	0.27	-351	0.09	-15,407	4.07	471	0.12
Middle Roanoke	1,112,130	67	0.01	2,101	0.19	-34,479	3.10	762	0.07
Upper Roanoke	1,401,630	13,853	0.99	5,604	0.40	-24,193	1.73	47	0.00
Banister	381,774	764	0.20	2,811	0.74	-14,754	3.86	188	0.05
Lower Dan	821,399	1,493	0.18	2,435	0.30	-26,831	3.27	641	0.08
Upper Dan	1,314,960	4,157	0.32	13,922	1.06	-30,477	2.32	172	0.01
Pamlico	***3,040,826***	***5,912***	***0.19***	***-27,630***	***0.91***	***-51,799***	***1.70***	***-3,801***	***0.12***
Pamlico Sound	280,227	326	0.12	-5,229	1.87	1,584	0.57	-780	0.28
Pamlico	739,623	1,705	0.23	-14,711	1.99	-1,012	0.14	-2,076	0.28
Lower Tar	614,297	1,317	0.21	-6,314	1.03	-10,920	1.78	-3,147	0.51
Upper Tar	834,737	1,866	0.22	-193	0.02	-22,921	2.75	1,318	0.16
Fishing	571,942	698	0.12	-1,183	0.21	-18,530	3.24	885	0.15
Neuse	***3,618,088***	***29,552***	***0.82***	***-10,308***	***0.28***	***-87,344***	***2.41***	***1,249***	***0.03***
Lower Neuse	752,149	1,906	0.25	-4,663	0.62	-6,566	0.87	-2,704	0.36
Middle Neuse	681,419	1,623	0.24	-7,107	1.04	-8,282	1.22	207	0.03
Upper Neuse	1,539,320	25,249	1.64	676	0.04	-54,606	3.55	2,334	0.15
Contentnea	645,200	774	0.12	786	0.12	-17,889	2.77	1,412	0.22
White Oak	***385,256***	***1,277***	***0.33***	***360***	***0.09***	***-4,260***	***1.11***	***-3,900***	***1.01***
White Oak	385,256	1,277	0.33	360	0.09	-4,260	1.11	-3,900	1.01

Table 5. 2001-2006 land cover change at the basin and sub-basin levels, selected types.

Basins/Sub-basins	Total Acres	Urban		Croplands		Forest		Wetlands	
		acres	% of total	acres	% of total	Acres	% of total	Acres	% of total
Albemarle-Chowan	***4,856,193***	***3,976***	***0.08***	***23,708***	***0.49***	***-80,323***	***1.65***	***-19,861***	***0.41***
Albemarle	1,701,240	3,164	0.19	19,269	1.13	-27,667	1.63	-2,036	0.12
Blackwater	473,596	587	0.12	3,675	0.78	-3,800	0.80	-5,154	1.09
Chowan	547,537	11	0.00	-8,748	1.60	-13,790	2.52	-2,697	0.49
Meherrin	1,031,410	71	0.01	6,595	0.64	-25,667	2.49	-5,402	0.52
Nottoway	1,102,410	143	0.01	2,916	0.26	-9,399	0.85	-4,572	0.41
Roanoke	***6,245,323***	***3,414***	***0.05***	***6,276***	***0.10***	***-36,867***	***0.59***	***-4,767***	***0.08***
Lower Roanoke	834,815	448	0.05	9,872	1.18	-11,211	1.34	-4,479	0.54
Roanoke Rapids	378,615	36	0.01	2,295	0.61	-7,391	1.95	-124	0.03
Middle Roanoke	1,112,130	50	0.00	-6,506	0.58	-2,995	0.27	-314	0.03
Upper Roanoke	1,401,630	1,968	0.14	-3,738	0.27	-3,370	0.24	-9	0.00
Banister	381,774	50	0.01	-1,636	0.43	-257	0.07	-6	0.00
Lower Dan	821,399	232	0.03	-59	0.01	-8,448	1.03	-101	0.01
Upper Dan	1,314,960	630	0.05	-6,504	0.49	-3,195	0.24	266	0.02
Pamlico	***3,040,826***	***3,819***	***0.13***	***421***	***0.01***	***-23,577***	***0.77***	***-5,908***	***0.19***
Pamlico Sound	280,227	0	0.00	-1,255	0.45	72	0.03	1,077	0.38
Pamlico	739,623	119	0.02	5,788	0.78	-10,300	1.39	-174	0.02
Lower Tar	614,297	1,807	0.29	-1,041	0.17	-3,297	0.54	-4,082	0.66
Upper Tar	834,737	1,841	0.22	-3,255	0.39	-5,995	0.72	-866	0.10
Fishing	571,942	52	0.01	184	0.03	-4,057	0.71	-1,863	0.33
Neuse	***3,618,088***	***27,193***	***0.75***	***3,519***	***0.10***	***-49,791***	***1.38***	***-10,257***	***0.28***
Lower Neuse	752,149	975	0.13	9,323	1.24	-16,476	2.19	-68	0.01
Middle Neuse	681,419	2,276	0.33	-183	0.03	-12,233	1.79	-5,158	0.76
Upper Neuse	1,539,320	22,133	1.44	-4,450	0.29	-18,632	1.21	-2,158	0.14
Contentnea	645,200	1,809	0.28	-1,171	0.18	-2,460	0.38	-2,873	0.44
White Oak	***385,256***	***752***	***0.19***	***4,689***	***1.22***	***-7,478***	***1.94***	***-441***	***0.11***
White Oak	385,256	752	0.19	4,689	1.22	-7,478	1.94	-441	0.11

Why Can't This Entire Indicator Be Reported at This Time?

This indicator reports areas for land cover types in 2006 using the National Land Cover Database (NLCD 2011) produced by the Multi-Resolution Land Characteristics Consortium (MRLC). This data product is the most current product available the covers the entire Albemarle-Pamlico Region. The indicators report land cover change for 1992-2001 using the NLCD 1992/2001 Retrofit Land Cover Change data product also produced by the MRLC. Land cover change indicators for 2001-2006 were generated from a USGS data product provided to the authors that is similar in scope, methods, and intent to the NLCD 1992/2001 Retrofit Land Cover Change data product. At the time of report production this 2001-2006 data product was not yet publicly available on the MRLC website.

It would be desirable to report land cover patterns and change at a more detailed level using a temporally consistent time scheme with an end date that is more current than 2006. In spite of these limitations, indicators provide a relatively recent 2006 snapshot of land cover patterns and 1992-2001 and 2001-2006 patterns of land cover change that provide information on geographical and temporal trends of change.

Understanding the Data

Land cover type patterns in 2006 demonstrate the dominance of forest, cropland, and wetland in the Albemarle-Pamlico Region with an expected gradient of decreasing wetlands from the near estuary and lower coastal plain lands to the mountain uplands located in the northwest. A trend of land cover is observable where cropland abundance in the lower regions transitions to a greater mix of cropland and forest in the central Albemarle-Pamlico Region and then transitions to a greater dominance of forest in the upper Albemarle-Pamlico Region.

Land conversion patterns demonstrate that urban growth is occurring throughout the region, albeit unevenly. Urban growth is punctuated with high levels of increase in urban land cover being located in sub-basins associated with pre-existing large urban centers such as Raleigh/Durham (Upper Neuse sub-basin) and Roanoke (Upper Roanoke sub-basin). Many of the other sub-basins had low or moderate urban growth.

Cropland was generally stable during 1992-2001 and then showed a modest increase during 2001-2006 most concentrated in the Albemarle-Chowan basin. Wetland and forest both experienced declines in area during 1992-2001; however, caution should be taken for results, especially for these two land cover types, due to the potential for classification error and inter-class confusion in the source NLCD data product.

AMBIENT AIR TEMPERATURE

Darin Figurskey[6]

Why Is Air Temperature Important?

Climate variability and change can impact ecosystems, including the animals and plants within them, in many ways (NOAA, 2011). Warming of the ocean and atmosphere, for example, directly influences rates of growth, feeding, and respiration. Potential changes in the timing of seasonal transitions may affect food availability and newborn survival for animals whose reproductive cycles are synced to current seasonal patterns. The influence of climate on ecosystems can further extend to the base of marine and terrestrial food-webs.

Ecosystem processes, such as those that control growth and decomposition, have been affected by climate change. Already under multiple stresses, coastal and near-shore ecosystems are further stressed by climate changes, including temperature. Large-scale shifts have occurred in the ranges of species and the timing of the seasons and animal migration, and are very likely to continue. Fires, insect pests, disease pathogens, and invasive weed species have increased, and these trends are likely to continue. Some of the benefits ecosystems provide to society (ecosystem services) will be threatened by climate change; however, others will be enhanced (NOAA Climate Services, 2011).

What Does This Indicator Report?

This indicator includes three metrics reported from 1895 to 2009: annual average temperature, annual maximum temperature, and annual minimum temperature. Long-term trends in these temperature values demonstrate how the climate is likely to be changing.

What Do the Data Show?

Although there have been annual and decadal trends upward and downward, the long-term trend since 1895 has been for increasing values of annual average temperature, annual maximum temperature, and annual minimum temperature (Figure 1). Since 1895 the average annual maximum temperature has risen about 1.75°F, while the average annual minimum temperature has risen about 0.75°F. The annual average temperature has risen approximately 1.25°F.

[6] Supervisory Meteorologist, US National Weather Service, Raleigh, NC

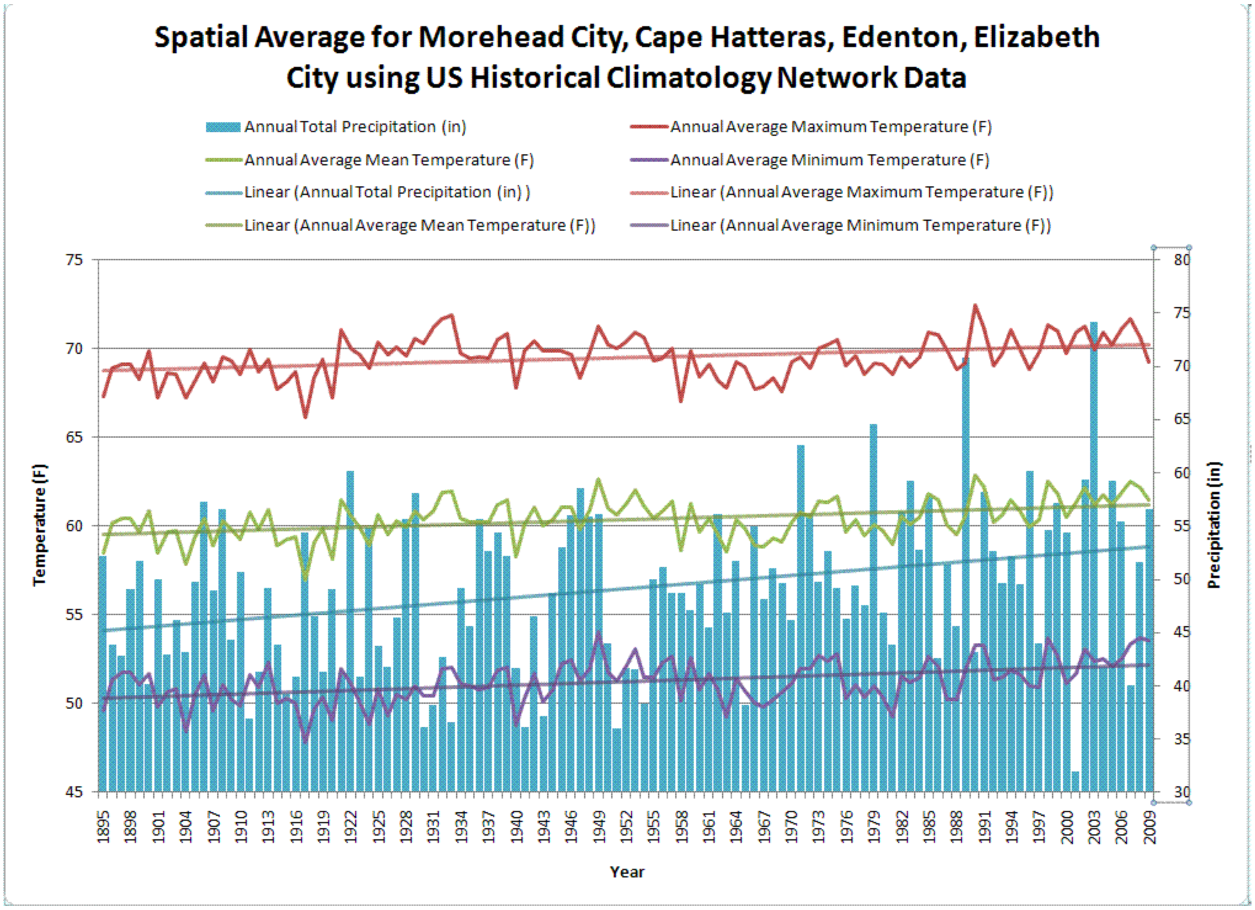


Figure 1. Spatial average annual average, annual average minimum, and annual average maximum temperature for Morehead City, Cape Hatteras, Edenton, and Elizabeth City, North Carolina. Data courtesy of the State Climate Office of North Carolina through the U.S. Historical Climate Network. Annual total precipitation is also included.

What Does This Indicator Not Report?

This indicator only accounts for surface-based temperatures. Temperatures at levels above the earth's surface are not included. Globally, measurements of the earth's temperature taken by weather balloons (also known as radiosondes) and satellites from the surface to 5-8 miles into the atmosphere, the layer called the troposphere, also reveal warming trends (USEPA, 2011). According to NOAA's National Climatic Data Center:

- Temperatures measured by weather balloons during the years 1958-2006 warmed at a rate of 0.22°F per decade near the surface and 0.27°F per decade in the mid-troposphere. The 2006 global mid-troposphere temperatures were 1.01°F above the 1971-2000 average, the third warmest on record.

- Since satellite measurements of troposphere temperatures began in 1979, various satellite data sets for the mid-troposphere showed similar rates of warming, ranging from 0.09°F per decade to 0.34°F per decade, depending on the method of analysis.

Weather balloons and satellites have also taken temperature readings in the stratosphere, which is the layer 9-14 miles above the earth's surface. This level of the atmosphere has cooled since the 1950s. The cooling is consistent with observed stratospheric ozone depletion since ozone is a greenhouse gas and has a warming effect when present. It's also likely that increased greenhouse gas concentrations in the troposphere are contributing to cooling in the stratosphere as predicted by radiative theory (Karl et al., 2006).

Understanding the Data

Over the past century, temperatures rose across the contiguous United States at an average rate of 0.11°F per decade (1.1°F per century) (NOAA-NCDC, 2011). Average temperatures from 1979 to 2005 rose at an increased rate of 0.56°F per decade. The most recent eight-, nine-, and ten-year periods were the warmest on record.

Warming occurred throughout most of the United States, with all but three of the eleven climate regions showing an increase of more than 1°F since 1901. The greatest temperature increase occurred in Alaska (3.3°F per century). The Southeast experienced a very slight cooling trend over the entire period (-0.04°F per century), but shows warming since 1979.

The degree of warming noted in the spatial average for Morehead City, Cape Hatteras, Edenton, and Elizabeth City is similar to the average temperature increase experienced across the rest of the United States. A warming trend in the long-term data is also evident since 1979. Unlike the rest of the Southeast, however, no long-term, slight cooling trend has been noted.

STORM FREQUENCY AND INTENSITY

Darin Figurskey[7]

Why Are Storm Frequency and Intensity Important?

While analysis of general temperature and precipitation patterns allows researchers to investigate broader climate changes, regional economies and communities are most sensitive to severe weather and climate events (State Climate Office of North Carolina). Indeed, the Albemarle-Pamlico region experiences almost every kind of severe weather pattern in existence. As a result, to provide a more comprehensive assessment of climate change and impacts to the regional ecosystem, one must include an analysis of severe events.

What Does This Indicator Report?

This indicator shows the number of severe events, including tornadoes, as well as tropical cyclones that have occurred since 1950. A severe event is defined as a wind gust of 58 mph (50 knots, 93 kmph), hail 3/4-inch (1.9 cm) or larger (changed to an inch (2.5 cm) or larger in 2010), and a tornado (NWS, 2010). Reports of significant wind damage to trees, utilities, or structures are used to represent severe weather events as well, and are events that would likely occur with thunderstorm winds of 58 mph or greater. The indicator also shows the number of tropical cyclones that have occurred within 150 miles (241 km) of Swan Quarter, North Carolina since 1950.

What Do the Data Show?

Since 1950, there have been several, long-track, strong tornadoes across the Albemarle-Pamlico region (Figure 1). Indeed, on April 16, 2011, the greatest tornado outbreak on record in North Carolina occurred. Approximately 40 tornadoes occurred in the entire Albemarle-Pamlico region, which unfortunately resulted in 24 human deaths and some tornado tracks that extended over 60 miles (Figure 1). That was the third deadliest outbreak on record for the state. Recent research (e.g., Frates, 2010; Allen, 2011) has shown that parts of central and eastern North Carolina are part of a relative maximum of tornadoes, known as a tornado "alley" (Figure 2), in the Southeast. Additionally, since 1950 every part of the Albemarle-Pamlico region has experienced large hail (Figure 3) and damaging thunderstorm wind gusts (Figure 4), with the greatest frequency of hail of an inch in diameter or less and wind gusts around the severe (58 mph) threshold.

In addition, since 1950 there have been 234 tropical cyclones within 150 miles of Swan Quarter (Figure 5), for an average of about four annually. Nine (4%) have been classified as major hurricanes, rated a category 3 or higher on the Saffir-Simpson scale. The total includes remnant tropical lows and extratropical storms, the latter being cyclones classified as losing true tropical characteristics.

[7] Supervisory Meteorologist, US National Weather Service, Raleigh, NC

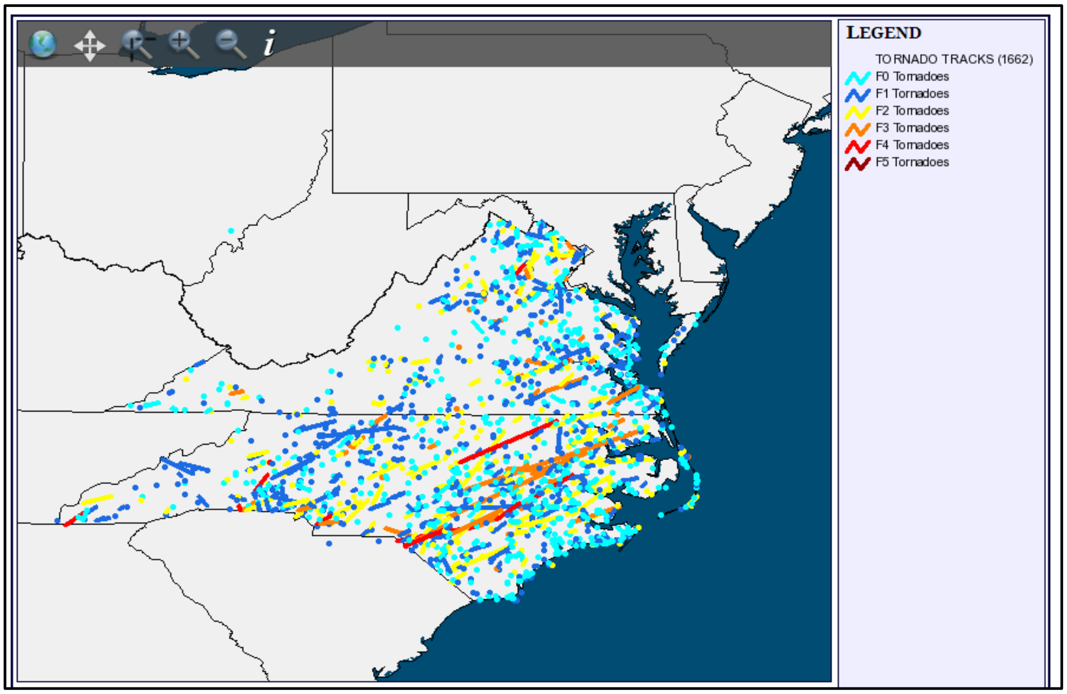


Figure 1. Tornado tracks 1950-2011. Data courtesy of the State Climate Office of North Carolina as taken from reports archived at the National Weather Service's Storm Prediction Center.

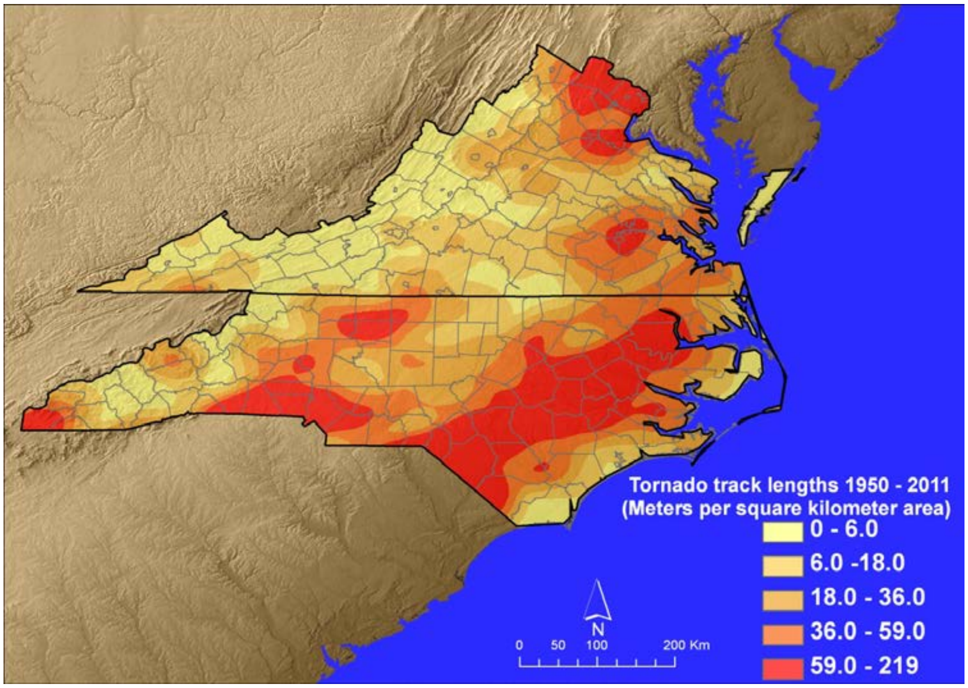


Figure 2. Tornado touchdown density in North Carolina and Virginia, in units of track distance for all years combined per area. Data courtesy of Thomas Allen, East Carolina University.

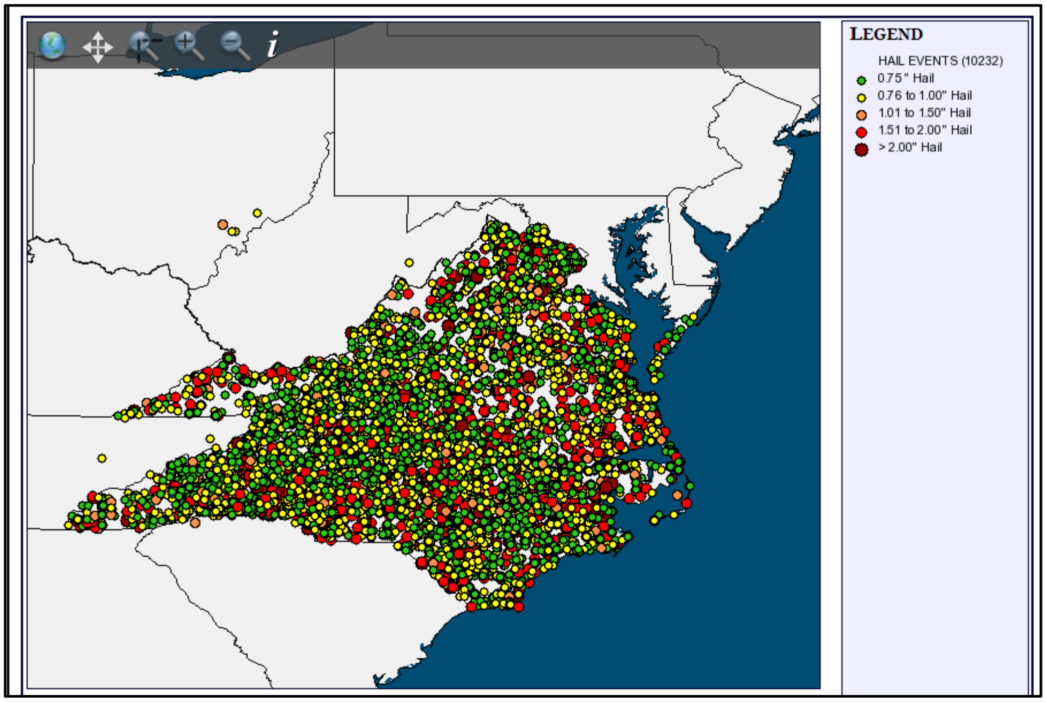


Figure 3. Large hail reports 1950-2011. Data courtesy of the State Climate Office of North Carolina as taken from reports archived at the National Weather Service's Storm Prediction Center.

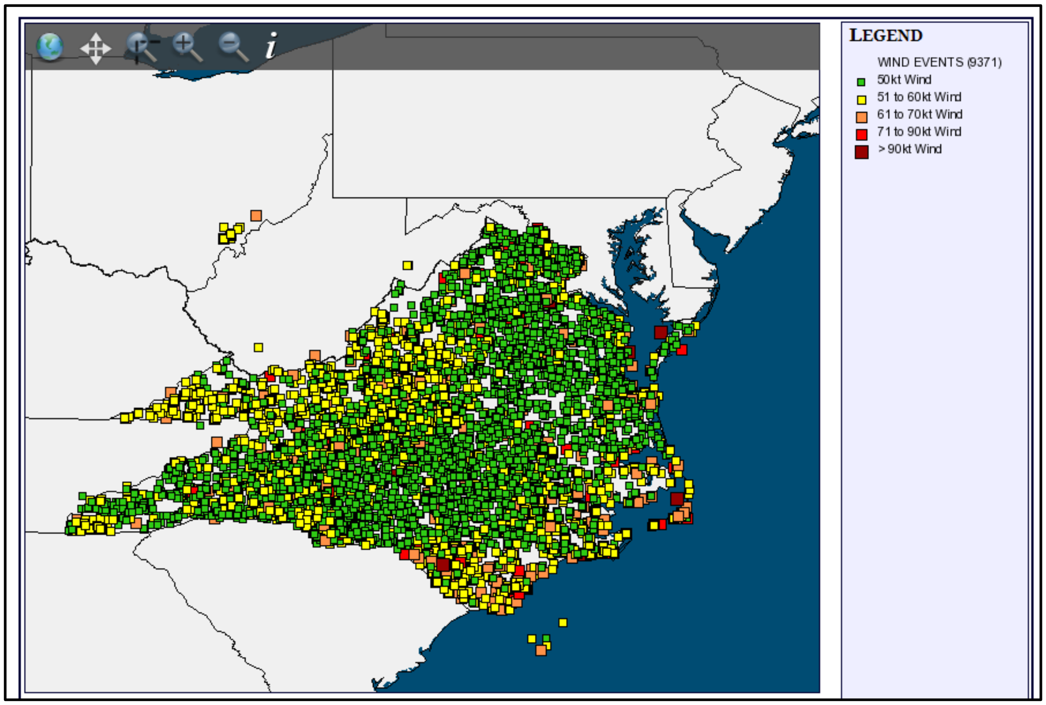
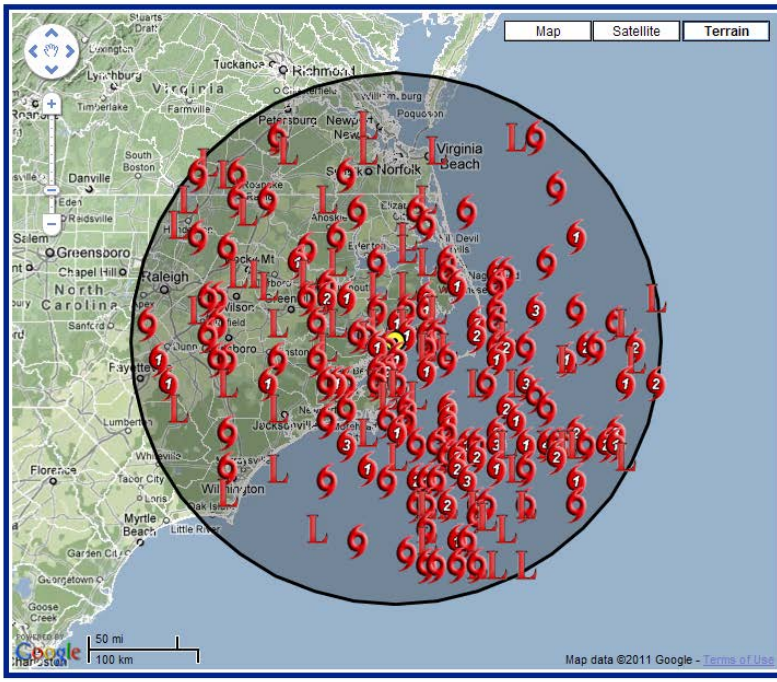


Figure 4. Severe wind reports 1950-2011. Data courtesy of the State Climate Office of North Carolina as taken from reports archived at the National Weather Service's Storm Prediction Center.



234 Storms Within 150 Miles

Cat	Name	Year	Wind (knots)	Distance (mi)
	Tropical Storm #3	1901	50	5.84
1	Hurricane Charley	1986	65	7.45
1	Hurricane Irene	2011	75	10.37
	Tropical Storm #4	1894	60	10.48
1	Hurricane #8	1861	70	10.48
	Tropical Storm Gabrielle	2007	45	10.48
1	Hurricane #6	1880	70	10.89
	Extratropical Storm #4	1925	60	12.26
L	Tropical Depression #2	2004	25	14.57
	Tropical Storm Bonnie	1998	60	16.30

Figure 5. Tropical cyclones within 150 miles of Swan Quarter, North Carolina since 1950. Location and strength are for the National Hurricane Center advisory point closest to Swan Quarter. Data courtesy of the State Climate Office of North Carolina.

What Is Not Shown by This Indicator?

Unfortunately, records of severe events are not as extensive as records and estimates of general precipitation and temperature patterns, both globally and locally (State Climate Office of North Carolina). For North Carolina, the best data on severe thunderstorms, high winds, hail, flooding, and tornadoes only go back to the 1950s. Since these severe events are highly localized, the data are highly sensitive to population density. Prior to modern weather radars, citizens were relied upon to report these events, so only data exist on reported severe events, not the numbers of actual events. However, good estimates of landfalling hurricanes in North Carolina exist back nearly 150 years. Still, the most accurate global information on hurricane activity and intensity is limited to only the past 30+ years, since this is the period when satellites have been able to accurately monitor the open oceans for such storms.

Understanding the Data

The available data on severe thunderstorms and tornadoes are limited and generally show no trend (State Climate Office of North Carolina). Since these kind of severe events are relatively rare in space and time there are relatively few samples and, therefore, techniques for analyzing trends and climate pattern shifts become more limited. Generally, there are insufficient data on these events to determine any climate pattern shift or trend. While some theory and models suggest we may see an increase in severe events like strong thunderstorms and floods, the data we have do not suggest any meaningful increase so far.

Since more extensive data on hurricane frequency and intensity exists, more detailed analysis is possible. Over the past 30+ years there has been an observed increase in tropical storm activity, especially since 1995. However, studies of global ocean circulation theory and observations suggest there is a natural oscillation in ocean heat content of approximately 25-30 years that is closely linked with tropical storm activity. Analysis of the more extensive record of landfalling hurricanes better identifies this oscillation, and in North Carolina, we certainly see the same pattern: the 1940s, 1950s, and early 1960s were generally a very active period for hurricanes to impact the state, while the 1970s, 1980s, and early 1990s were a very inactive period. Trend analysis of the landfalling hurricane record suggests that there is no meaningful increase over the entire 150+ year record.

The best global climate models suggest the tropical Atlantic Ocean will get warmer, and hurricane strength is directly linked to ocean temperatures, suggesting that in the future, the warm oscillations may produce more intense hurricanes. Unfortunately, the historical record doesn't provide the detail we need to validate this theory. Indeed, there are other factors in the atmosphere that also influence tropical storm development and intensity, and we certainly don’t yet have a sufficient understanding of tropical storm dynamics to be confident of whether future scenarios of our global climate will produce more frequent or intense hurricanes. The impact of global warming on hurricane frequency and intensity is very much an area of active research.

GROUND-LEVEL OZONE CONCENTRATION

Robin Dennis[8]

Why Is Ground-Level Ozone Concentration Important?

At elevated concentrations, ground-level ozone can cause respiratory problems for people and can harm vegetation, animals, and the built environment. These effects include those that damage or impair the intended use of the plant or ecosystem. Such effects are considered adverse to the public welfare and can include reduced growth and/or biomass production in sensitive plant species, including forest trees, reduced crop yields, visible foliar injury, reduced plant vigor (e.g., increased susceptibility to harsh weather, disease, insect pest infestation, and competition), species composition shift, and changes in ecosystems and associated ecosystem services. Ozone values much above naturally occurring levels can cause plant damage resulting in harvest loss greater than 10% and tree biomass loss greater than 2%, which is considered significant. Some of the common tree species in the Albemarle-Pamlico region that are sensitive to ozone are black cherry (*Prunus serotina*), tulip-poplar (*Liriodendron tulipifera)*, eastern white pine (*Pinus strobus*), white ash (*Fraxinus americana*), sycamore (*Platanus occidentalis*) and black walnut (*Juglans nigra*). Other common tree species, such as oak (*Quercus* spp.), except for white oak (*Quercus alba*), and hickory (*Carya* spp.), are not nearly as sensitive to ozone. High concentrations, besides harming people, trees, crops, and other plants, can harm wildlife, and pets, and can damage painted surfaces, plastics, and rubber materials.

What Does This Indicator Report?

- Ozone Cumulative Concentration-weighted Index, W126: Cumulative, biologically-relevant exposure to ozone concentrations that is associated with plant damage during the growing season. Units are parts per million-hours. The USEPA is considering a W126 secondary ozone standard of either 7 ppm-hr or 15 ppm-hr, providing two benchmarks for interpretation of index values. Lower values are more stringent or protective than higher values.

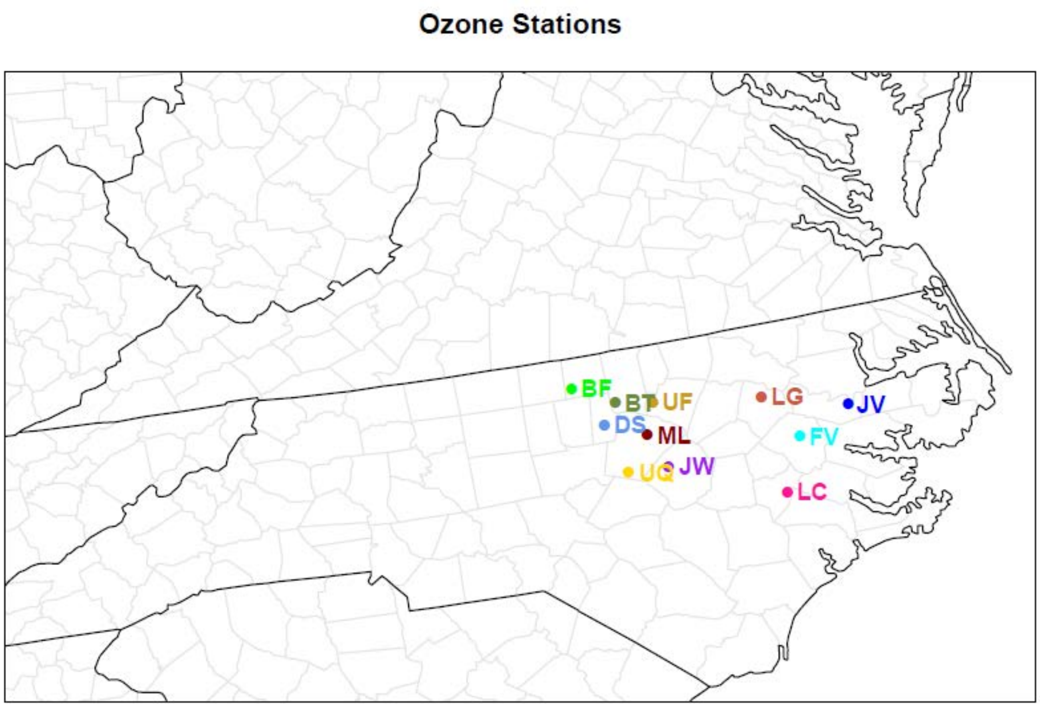
What Do the Data Show?

General

There are 11 ozone stations in North Carolina within the Albemarle-Pamlico region with sufficient data availability to be included in the assessment analysis. Seven are in the Piedmont (Person, Granville, Durham, Franklin, Wake (2), and Johnston Counties) and four are in the Coastal Plain (Edgecombe, Martin, Pitt, and Lenoir). Not all counties have monitoring stations. There are basically no ozone stations in Virginia within the Albemarle-Pamlico region.

[8] Senior Scientist, Office of Research & Development, US Environmental Protection Agency, Research Triangle Park, North Carolina

However, air quality model analysis shows that ozone exposure levels and temporal trends over the Virginia portion of the region are well represented by the North Carolina stations.
Figure 1. Location of ozone stations within the Albemarle-Pamlico Region with sufficient data availability.



Time Series
North Carolina ozone data is available from 1993 to 2010. The average of the W126 index for the 11 ozone stations across the Albemarle-Pamlico Region is shown as the thick black line in Figure 2. The average W126 index shows larger inter-annual variability due to the influence of meteorological variability on ozone values in the first half of the period. The mean W126 does not show any real trend for 1993 to 2002. The mean during this period is often above 20 ppm-hr. There does seem to be a modest downward trend from 2002 onward, in spite of the inter-annual variability. It is known, for example, that ozone production was suppressed in 2004 due to cool, wet weather. The general decline in the index after 2002 is believed to be in large part due to decreases in emissions of nitrogen oxides stemming from Clean Air Act regulations, particularly decreases in emissions from motor vehicles. Post 2001, the decreases in car fleet emissions have outpaced increases in vehicle miles traveled. The mean W126 in 2010 is approximately 9 ppm-hr. The data suggest that average ozone exposure during 1993-2002 was sufficient to cause some level of damage to vegetation. They also suggest that 2010 average ozone exposure has been reduced by more than a factor of two from the earlier period and at 9

ppm-hr compared to 7 ppm-hr is potentially causing only modest levels of ozone damage to vegetation.

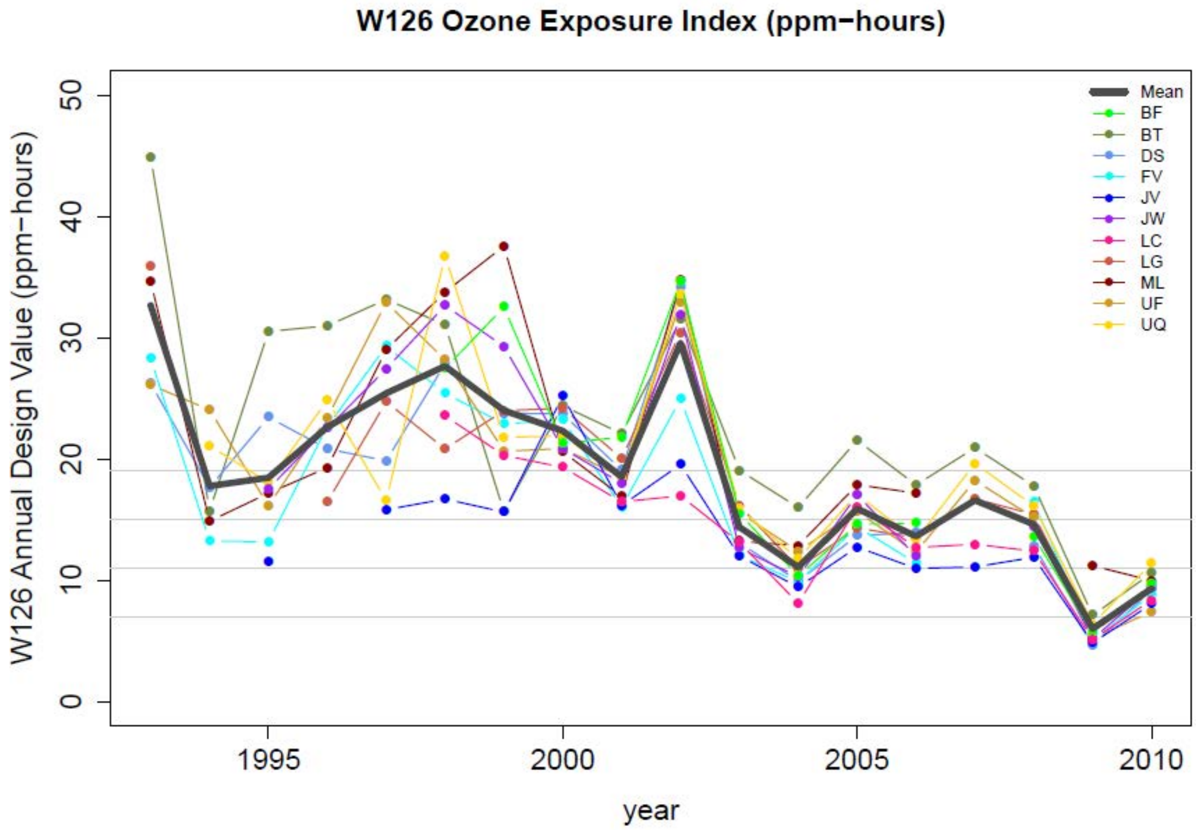


Figure 2. W126 ozone exposure index values (ppm-hr) at various stations with the Albemarle-Pamlico region from 1993 to 2010.

Spatial Pattern

The W126 index values averaged for the 1993 to 2010 indicate there has been a risk in North Carolina of modest crop or vegetation damage from ozone (Figure 3). The individual site values suggest that the risk has been in general higher in the Piedmont than in the Coastal Plain of the Albemarle-Pamlico region. Four of the Piedmont sites had average W126 values above 19 and three were in the range of 15-19. Three of the Coastal Plain sites had average W126 values in the range of 15-19 and one site was in the range of 11-15. The more recent index values for 2010 (not shown) suggest the risk still appears to remain highest in the Piedmont of the Albemarle-Pamlico region, particularly around the major metropolitan areas with index values between 7.4 and 11.4 (average = 9.7). The risk is somewhat smaller in the Coastal Plain, with index values between 8.0 and 9.6 (average = 8.7).

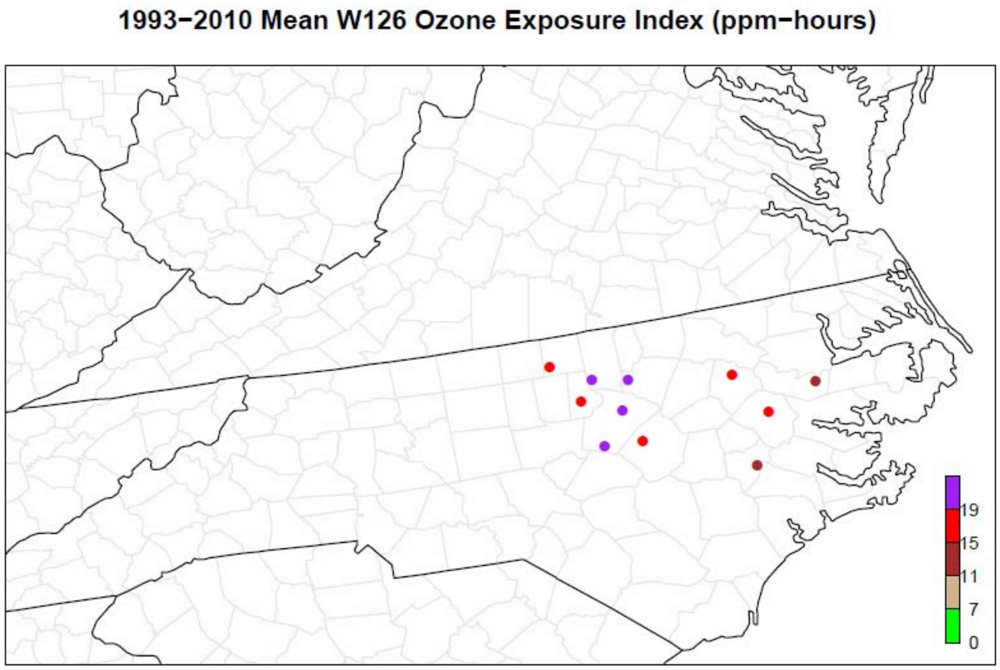


Figure 3. Mean W126 ozone exposure index values (ppm-hours) at various stations with the Albemarle-Pamlico Region from 1993 to 2010.

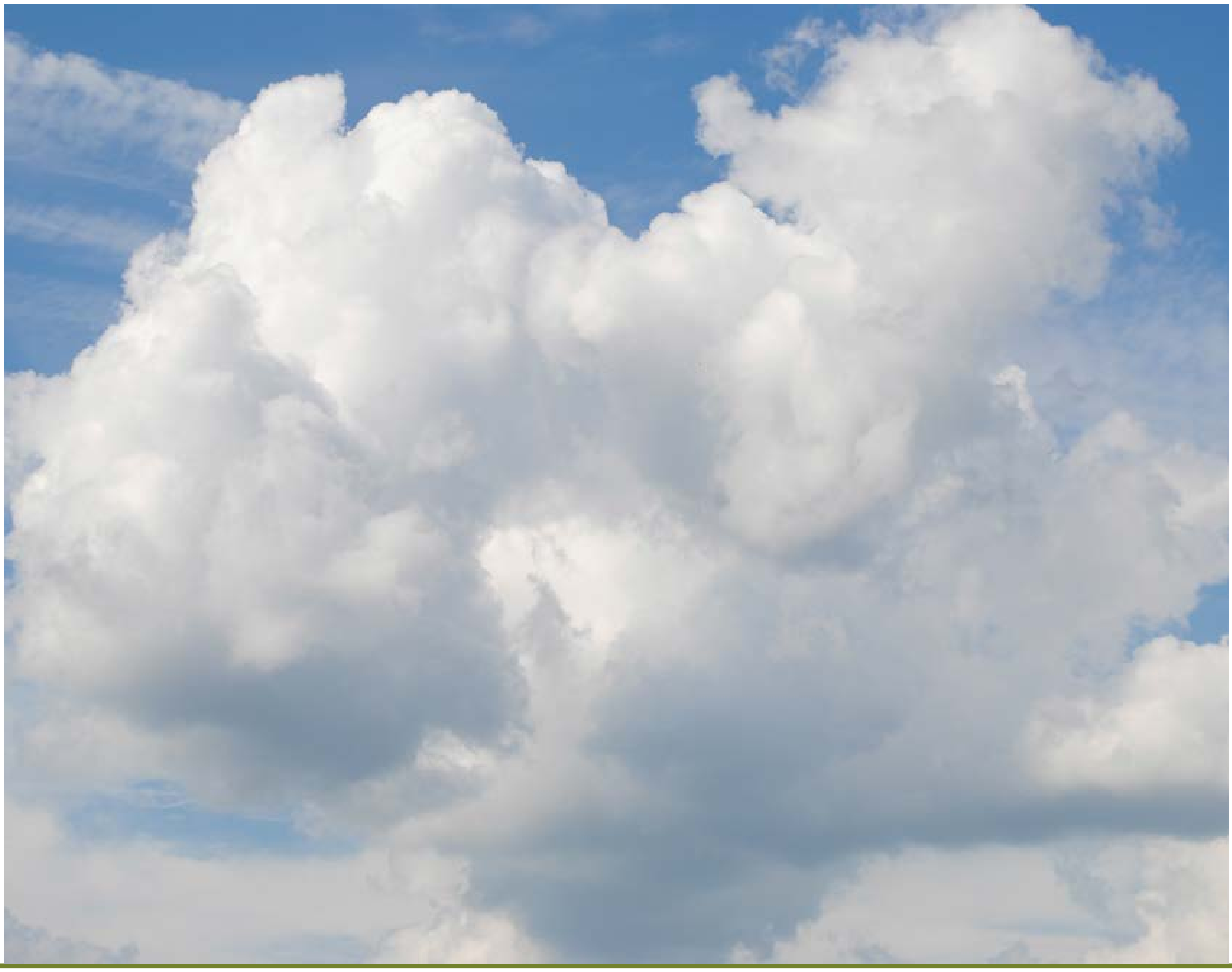
Why Can't This Entire Indicator Be Reported at This Time?

There are no issues with the reporting of the entire indicator since it is a single indicator. The entire indicator is able to be reported post 1993 given the availability of high quality base hourly ozone concentrations. Ozone data for the period earlier than 1993 are unavailable from the data repositories. Full spatial coverage is not possible because not all counties in North Carolina have ozone monitors located in them and there are no ozone stations in Virginia within the Albemarle-Pamlico region.

Understanding the Data

Human activities have increased the emissions of the two classes of ozone precursors, nitrogen oxides and volatile organic compounds. Volatile organics come from vehicles, paints, solvents, unburned fuel, and industrial sources. Nitrogen oxides come from combustion of fuels. In the atmosphere these compounds react with oxidizers and ultraviolet sunlight (bake) to produce ozone. In rural areas, where typically crops are grown and ozone damage is of concern, ozone production is limited by the availability of nitrogen oxides. Thus, trends in nitrogen oxide emissions should result in ozone concentration trends that are in the same direction. Ozone is able to travel long distances before being slowly cleansed from the atmosphere. Interannual fluctuations in ozone concentrations result from a combination of year-to-year variability in weather conditions and changes in emissions of ozone precursors, including trends in those precursor emissions. Ground-level ozone is the most important, plant-toxic air pollutant in the United States and the Albemarle-Pamlico region. High concentrations, besides harming people, can harm trees, crops, other plants, wildlife, and pets, and can damage painted surfaces, plastics, and rubber materials.

While data are gathered for estimating air concentration exposures of importance to ecosystems via the use of cumulative indexes, much of the actual damage from ozone stems from the dry deposition of ozone to the plant stomata through gas exchange. The empirical damage observed due to ozone exposure has implicitly assumed gas exchange or dry deposition, but that exchange was not directly associated with the plant damage. Dry deposition of ozone is difficult to measure directly and it is not routinely measured. Further work is needed to better understand the connection between ozone deposition and damage to plants.



TOTAL INORGANIC NITROGEN DEPOSITION

Robin Dennis[9]

Why Is Nitrogen Deposition Important?

Excess nitrogen (N) concentrations in estuaries are associated with increased algal growth and poor water quality. The algae sustain the growth of most other aquatic life forms. When overabundant, however, they can contribute to reductions in dissolved oxygen, cause fish kills, increase light attenuation, and cause shifts in the number and type of fish and other aquatic animals (also see indicator "Chlorophyll-a Concentration"). Either oxidized or reduced N compounds, deposited from the atmosphere to the watershed and the estuary, themselves can contribute to excess N loading, resulting in the aforementioned problems.

Atmospheric wet plus dry N deposition contributes a significant fraction of the nitrogen to the Albemarle-Pamlico system. Within the Neuse estuary, for example, it is estimated that at least one quarter of the nitrogen loading comes from atmospheric deposition (Paerl et al., 2002). Additionally, N compounds deposited from the atmosphere can (along with sulfate compounds) acidify soils and surface waters, especially in areas that are naturally sensitive to acidification. The delivery mechanism for atmospherically deposited N to the estuary as wet plus dry deposition differs from most N sources in that nitrogen can be directly deposited to the estuary, thereby bypassing biogeochemical changes that occur in the watershed/river. This can result in different ratios of reduced to oxidized nitrogen in atmospherically deposited N than what are delivered via the rivers. Changes in these ratios may result in community compositional changes, because different forms of N may be differentially used by phytoplankton and other microorganisms, possibly resulting in shifts towards less desirable species and translating into differential water quality impacts (e.g., harmful versus non-harmful algal blooms).

What Does This Indicator Report?

- Annual Wet N Deposition: The annual accumulated amount of inorganic N deposited via rain from the atmosphere at sites across the Albemarle-Pamlico region. Two forms of inorganic N are tracked: oxidized and reduced N. Oxidized N deposition stems from nitrogen oxide emissions (mostly from combustion processes) and reduced N deposition stems from ammonia emissions (mostly from agricultural operations). A three-year running average is used to filter out the change in values due to inter-annual meteorological variability.

- Annual Rainwater N Concentration: To reduce the impact of inter-annual variability of meteorology and account for any temporal trends in precipitation, wet concentration of oxidized and reduced N in the rainwater that is precipitation weighted is used as a co-

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indicator. This indicator provides a clearer picture of the underlying effect trends in emissions are having on the atmospheric deposition.

What Do the Data Show?

Atmospheric Wet Deposition of Oxidized, Reduced and Total Nitrogen

Temporal Trends
Five National Atmospheric Deposition Program (NADP) sites span the Albemarle-Pamlico region with three sites having a long-term record to provide a sense of long-term changes in the N deposition within the system (Figure 1). Because there is a modest trend in the precipitation amount from 1980 to 2010, increasing modestly up to 2000 and decreasing modestly after 2000, it is appropriate to also examine trends in rainwater concentrations.

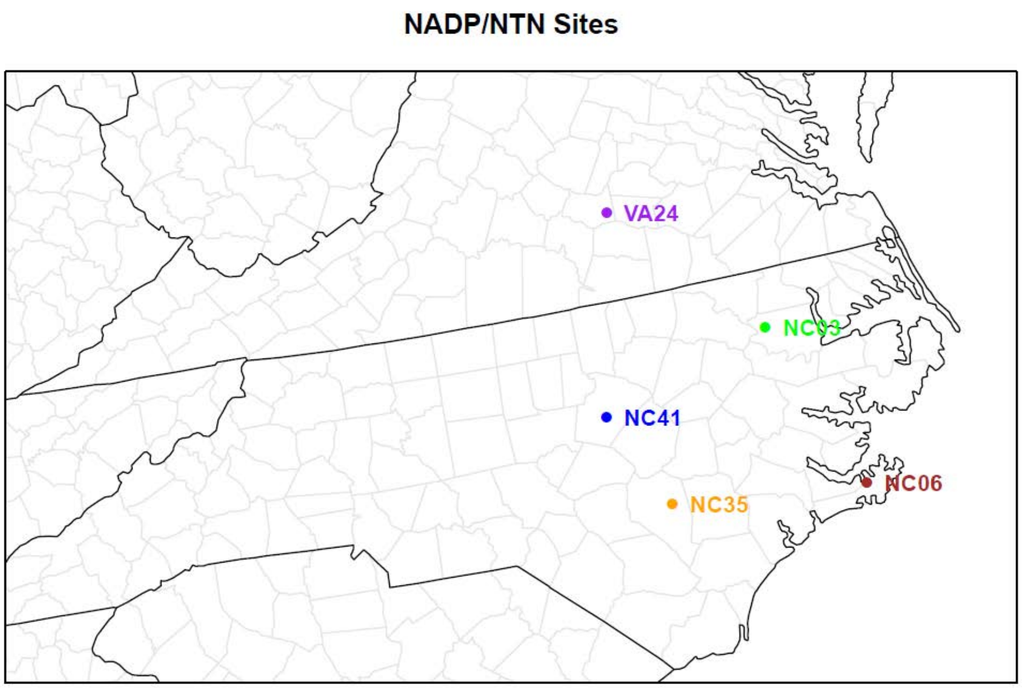

Figure 1. NADP/NTN sites within the Albemarle-Pamlico region.

Oxidized Nitrogen
The time series of annual oxidized N deposition (as nitrate, NO_3) for the three long-term sites and two short-term sites suggests a relatively constant deposition of oxidized N to the Albemarle-Pamlico region from 1980 to 2000, and then a modest, consistent annual decrease each year from 2000 to 2010 (Figure 2). The same trend is observed at each site, suggesting that regional, multi-state reductions in emissions are involved. The general decline after 2000 is believed to be in large part due to decreases in emissions of nitrogen oxides stemming from

Clean Air Act regulations that particularly targeted decreases in emissions from motor vehicles. Post 2001, the decreases in car fleet emissions have outpaced increases in vehicle miles traveled.

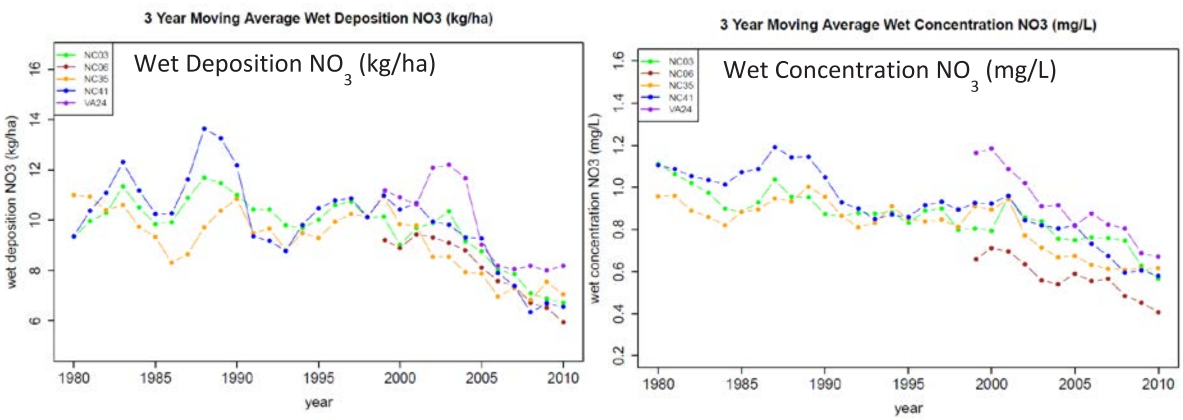

Figure 2. Time series of annual oxidized N deposition (as nitrate, NO_3) at sites in the Albemarle-Pamlico region from 1980 to 2010.

Reduced Nitrogen

The time series of annual reduced N (as ammonium, NH_4) for the three long-term sites and two short-term sites suggests a continual increase in deposition of reduced N to the Albemarle-Pamlico region from 1980 to 2010 (Figure 3). However, the increase varies by site. The site in Sampson County (NC35) has a noteworthy increase of almost a factor of three over this time period. This site represents the influence of confined animal operations on the southern Albemarle-Pamlico basins, such as the Neuse. The site in Bertie Country (NC03) has the smallest increase of the three. The short-term site in Virginia (VA24) does not show a trend.

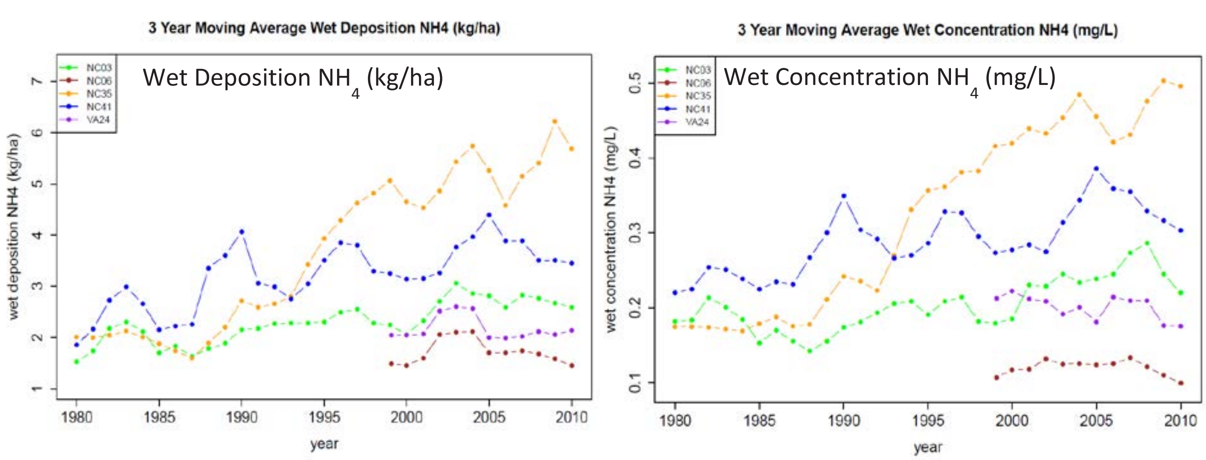

Figure 3. Time series of annual reduced N (as ammonium, NH_4) at sites in the Albemarle-Pamlico system from 1980 to 2010.

Total Nitrogen

The time series of annual total N (oxidized + reduced, normalized to units of nitrogen) for the three long-term sites suggests a slight increase in deposition of total N (NO_3-N + NH_4-N) to the Albemarle-Pamlico region from 1980 to 2010 at two of the sites and a significant increase at the Sampson County site (Figure 4). The long-term increase in total N deposition is most clearly shown by the bar chart that follows, which compares the 1980-87 average deposition to the 2002-2010 average deposition, all in units of N (Figure 5). The bar chart shows the components of total N as well as the total; the increase in reduced N (left set of bars) more than offsets the reductions in oxidized N (middle set of bars) to produce the total N deposition (right set of bars), which increases across this time period.

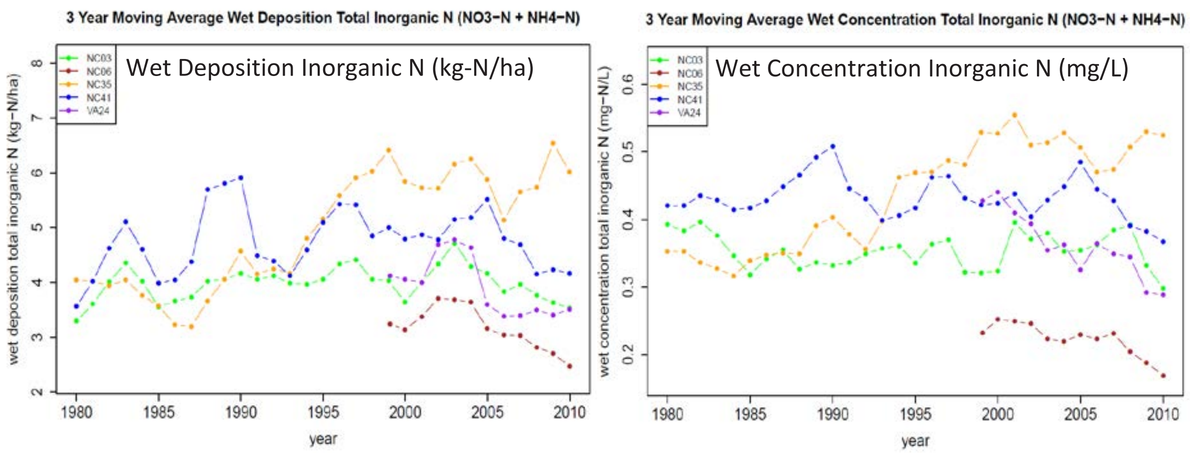

Figure 4. Time series of annual total N (oxidized + reduced, normalized to units of nitrogen) at sites in the Albemarle-Pamlico system from 1980 to 2010.

Average Wet Deposition Inorganic N (NO3−N + NH4−N) for 1980−1987 and 2003−2010

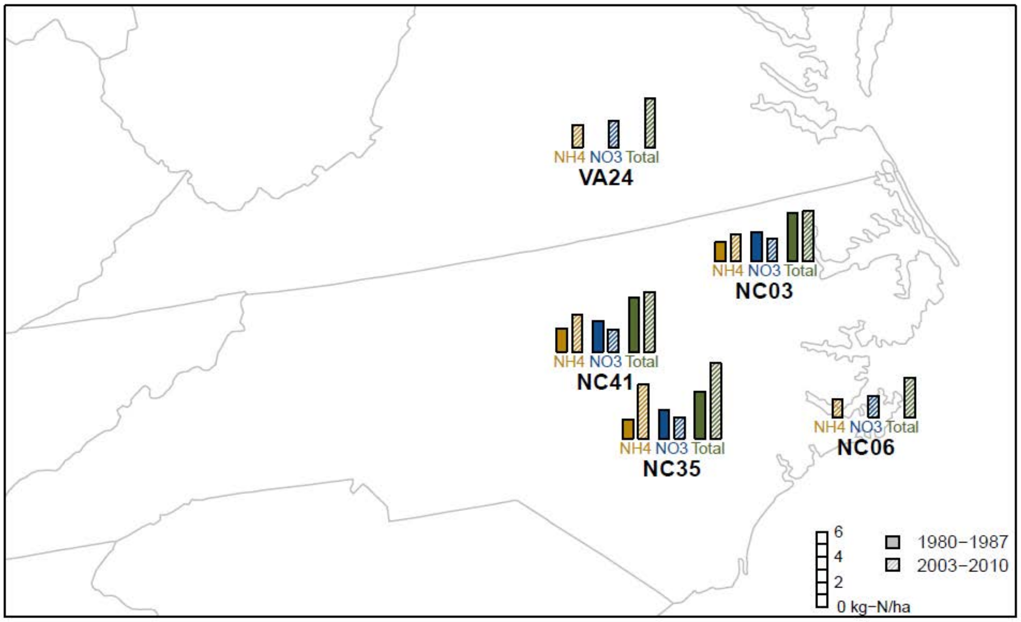

Figure 5. Average wet deposition of inorganic N (NO_3 and NH_4) from 1980 to 1987 and 2003 to 2010 at NADP/NTN sites within the Albemarle-Pamlico region.

Spatial Pattern

The magnitude of the oxidized N deposition and the decrease in oxidized N deposition is relatively uniform across the Albemarle-Pamlico region (Figure 5). This suggests broad regional sources from multiple states are contributing to oxidized N deposition. The increase in reduced N deposition shows a strong gradient across the Albemarle-Pamlico region, with the largest increase on the southern boundary of the region at Sampson County, and the smallest increase on the northern boundary in Bertie County (Figure 5). This suggests local sources of ammonia emissions within North Carolina are having an important influence on the reduced N deposition to the Albemarle-Pamlico region. Note that there are temporal and spatial changes in the relative contributions of oxidized and reduced N, with reduced N becoming responsible for a majority of N deposition at the three central sites, with the largest difference (reduced N becoming a major fraction) at the boundary with Sampson County (Figure 5).

Why Can't This Entire Indicator Be Reported at This Time?

Dry deposition is not directly measured, but can be inferred using meteorological and air concentration measurements with some error. An inferential approach is used by the Clean Air Status and Trends Network (CASTNet). There are no CASTNet sites for estimating dry deposition of atmospheric N across the watersheds of the Albemarle-Pamlico region, yet dry deposition can account for 20-80% of the total deposition. Data are also not gathered for organic N, wet or dry. There is one CASTNet site on the ocean side of Bogue Sound at Beaufort that could represent deposition to the Sound. However, several important species needed to estimate dry deposition with CASTNet, especially ammonia, are not measured, a deficiency that is being addressed for the future.

Understanding the Data

Many naturally occurring chemicals, such as N compounds, are essential nutrients for all organisms. Often, however, human activities cause concentrations of such chemicals to far exceed that of natural concentrations, leading to ecological and human health problems. N compounds from human activities are released into the atmosphere as gases from fossil fuel combustion, agricultural production, and other activities. Fossil fuel combustion emits oxidized N into the atmosphere and is responsible for most of the oxidized N that deposits. Agricultural activities emit reduced N or ammonia into the atmosphere and are responsible for most of the reduced nitrogen that deposits.

The emitted compounds react with oxidizers and other chemicals in the atmosphere and are influenced by the attraction to neutralize acidity, which is influenced by humidity and temperature, to form particles. The gases and particles can be carried short or long distances by the prevailing winds before being deposited as dry deposition, or being scavenged by rain, snow, and fog and deposited by wet deposition. Wet deposition reflects or is more indicative of the long-range transport of the pollutants because the scavenging occurs throughout the mixed and free tropospheric layers of the atmosphere. The chemicals deposited to watersheds (on soil surfaces and vegetation) are processed in the terrestrial system and a portion is transported to streams and lakes by surface runoff or groundwater flow. Excess nutrients in streams, rivers and estuaries can create conditions unsuitable for aquatic life.

DISSOLVED METAL CONCENTRATIONS

Lindsay Dubbs[10] and **Michael Piehler**[11]

Why are Dissolved Metal Concentrations Important?

Small amounts of many metals, such as copper (Cu), zinc (Zn), and nickel (Ni), are necessary for the nutrition of plants and animals, while others, such as mercury (Hg), lead (Pb), and cadmium (Cd), are nonessential. Metals are present in aquatic environments as dissolved metals or particle-associated metals that are sorbed or otherwise bound to particles. Dissolved metals are those that are biologically available, while particle-associated metals are not. The concentrations of the two forms together constitute the total metal concentration of the water.

Cu, Zn, Ni, Hg, Pb, Cd, silver (Ag), and chromium (Cr) are dissolved metals that are toxic to plants and animals when they exceed threshold concentrations, which are dependent upon water chemistry, water temperature, and the age and species of organism that are exposed to them. In addition, many of these metals can bioaccumulate and if eaten, affect human health. For these reasons, the concentrations of these metals in their dissolved form are an important component of water quality.

Dissolved metal standards are based upon the toxicity of, and bioaccumulation by, aquatic organisms after short-term, high concentration and long-term, low concentration exposure, or a combination of the two, to metals in fresh and salt water. These metal standards also depend upon water hardness, and thus, are not set values. A violation indicates that the highest acceptable concentration has been exceeded in a specific reach of a water body.

What Will This Indicator Report?

- Concentrations of dissolved metals (Cd, Cu, Ni, Zn, Pb, Cr, Ag, and Hg) in fresh and estuarine waters of the Albemarle Pamlico Estuarine System (APES).
- Extent of 303(d) dissolved metal violations in fresh and estuarine waters of the Albemarle-Pamlico region.

What do the Data Show?

Dissolved Cu, Ni, and Zn concentrations in the Virginia waters of the APES have remained relatively constant from 1997 through 2011 (Figures 1-3, respectively). The exceptions to the constant dissolved metals trends include a marked increase in measured concentrations of Cu (Figure 1) and Ni (Figure 2) in April through July 2006, and of Zn in May 2008 (Figure 3) in the Chowan Basin. Dissolved Hg concentrations have also remained constant at 0.2 µg/L during the

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years that they were measured in Virginia waters within the APES: 1997, 1998, and 2010 (not pictured). Dissolved lead concentrations similarly remained relatively constant in the Chowan River basin within Virginia (Figure 4), with several spikes in the concentrations in 1998, 2004-2005 and 2008-2009. Meanwhile, dissolved lead concentrations in the Virginia portion of the Roanoke River basin (Figure 4) and dissolved silver concentration in the Virginia portions of both river basins (Figure 5) remained constant from 1997 through 2009, and then decreased by over 50% in 2010. These concentrations remained relatively low through the spring of 2011. Chromium was the only dissolved metal that showed generally increasing trends in both the Virginia portions of the Chowan and Roanoke River basins from 1997 to 2011 (Figure 6).

With regard to water quality violations, the Drainage Ditch to Chesapeake/Albemarle Canal was initially listed as impaired for copper and zinc in 2004 and the feeder ditch to Dismal Swamp was initially listed for mercury in 2004. These waters have not yet been delisted.

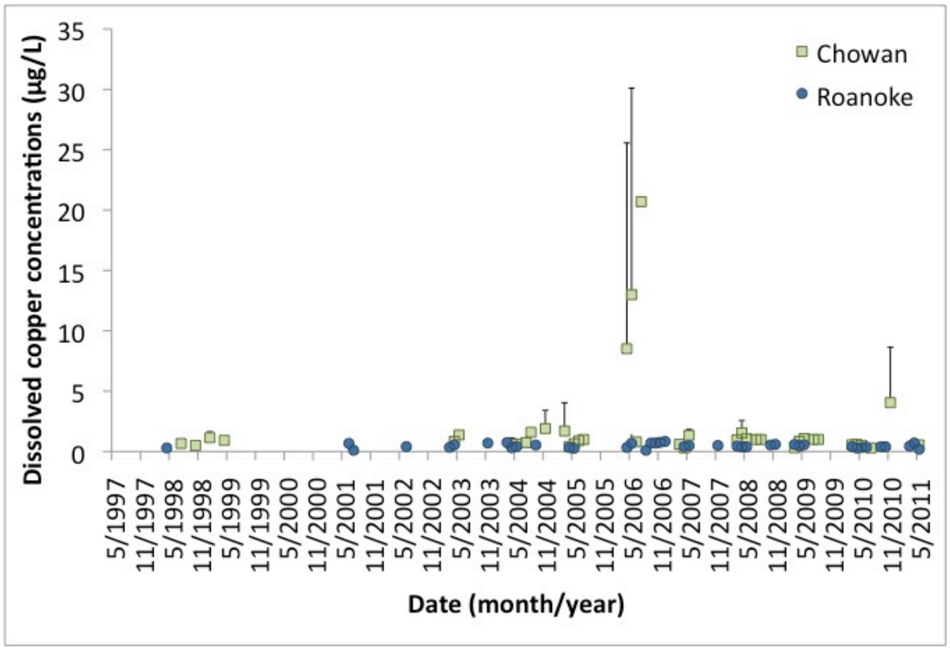

Figure 1. Monthly mean dissolved copper concentrations in Virginia fresh waters within the Roanoke and Chowan River basins. Error bars reflect one positive standard deviation from the mean.

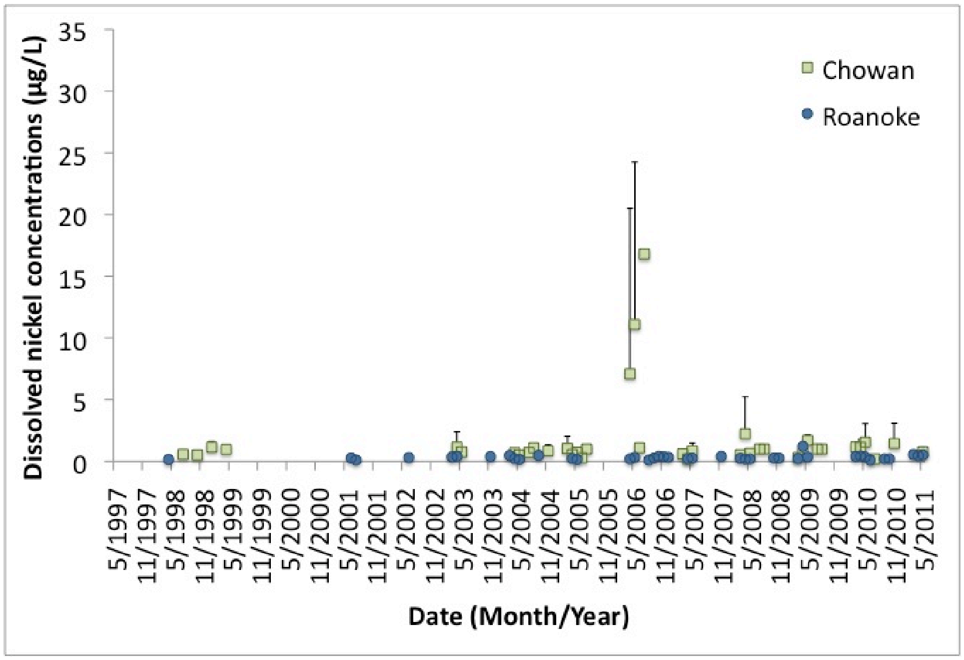

Figure 2. Monthly mean dissolved nickel concentrations in Virginia fresh waters within the Roanoke and Chowan River basins. Error bars reflect one positive standard deviation from the mean.

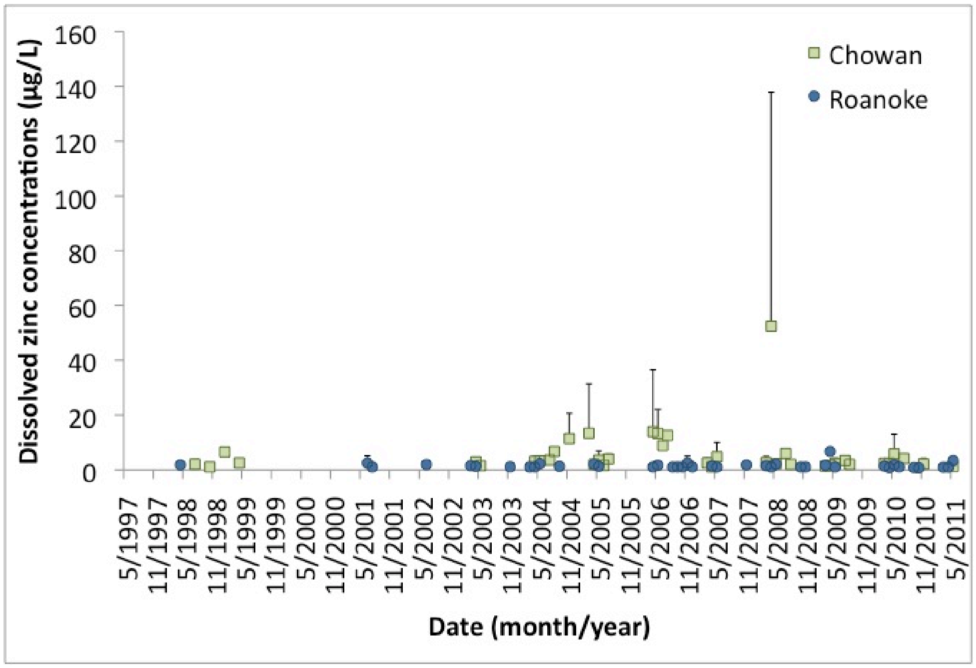

Figure 3. Monthly mean dissolved zinc concentrations in Virginia fresh waters within the Roanoke and Chowan River basins. Error bars reflect one positive standard deviation from the mean.

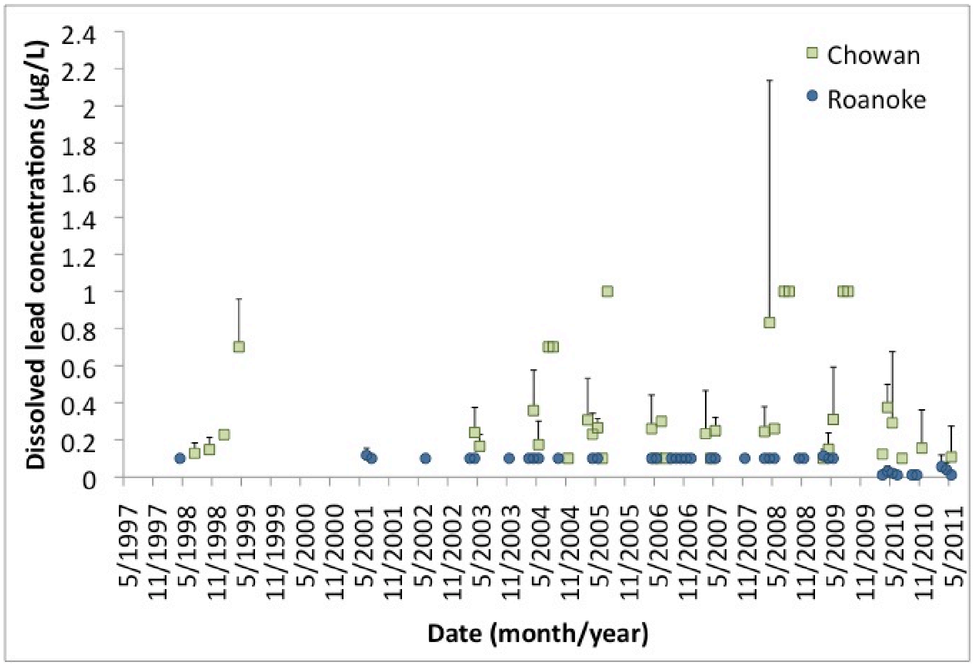

Figure 4. Monthly mean dissolved lead concentrations in Virginia fresh waters within the Roanoke and Chowan River basins. Error bars reflect one positive standard deviation from the mean.

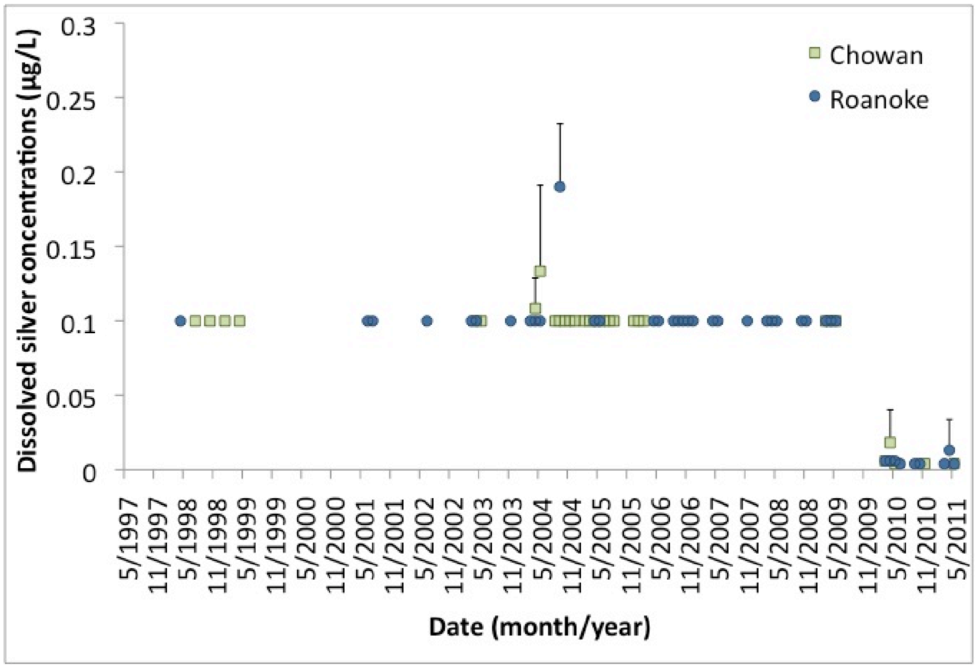

Figure 5. Monthly mean dissolved silver concentrations in Virginia fresh waters within the Roanoke and Chowan River basins. Error bars reflect one positive standard deviation from the mean.

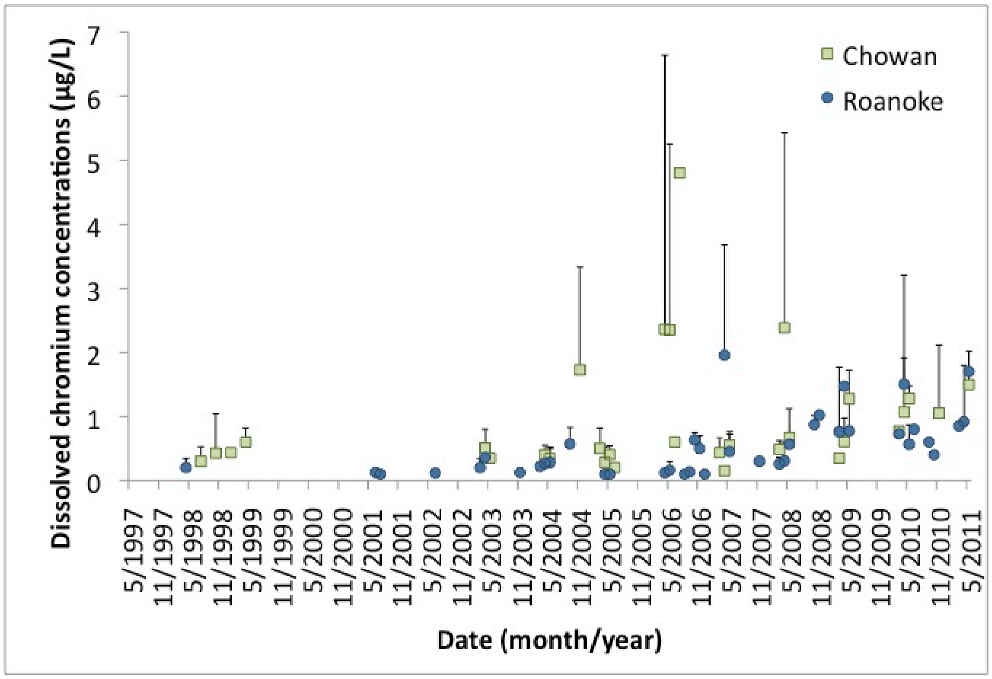

Figure 6. Monthly mean dissolved chromium concentrations in Virginia fresh waters within the Roanoke and Chowan River basins. Error bars reflect one positive standard deviation from the mean.

Why Can't This Indicator Be Reported at This Time?

Until recently, metal concentrations in North Carolina waters were measured as total rather than dissolved concentrations. Neither total nor dissolved metal concentrations have been measured at all in North Carolina since 2007. The North Carolina Division of Water Quality is currently developing dissolved metals standards for North Carolina waters (2008-2010 Triennial Review proposed amendments to 15A NCAC 02B.0206).

Dissolved Cu, Ni, Zn, Ag, Cr, Pb, and Hg, but not Cd, have been measured in Virginia waters since 1997. Therefore, only dissolved Cu, Ni, Zn, Ag, Cr, Pb, and Hg concentrations in the Virginia portions of the Roanoke and Chowan River basins are reported here.

Understanding the Data

Changes in the dissolved metal concentrations reflect increases or decreases in the supply of these metals to water bodies. Metals can be delivered to water bodies via atmospheric deposition, run-off, or discharge from point sources.

Recent calculations suggest that anthropogenic activities have become "a significant geomorphic agent in metal mobilization" (Rauch and Pacyna, 2009). The human impact on global metal cycles entails extraction of metals from the Earth's crust via mining, and the mobilization or emission of those metals when the mined products are combusted, processed, and/or applied to the land surface (Pacyna et al., 2006; Rauch and Pacyna, 2009). Metals are mobilized or emitted by way of the application of fungicides (contain Cu and Zn), pesticides (contain Cu and Zn), and fertilizers (Cd, Cu, and Zn) to agricultural fields; the combustion of fossil fuels (Cd and Hg); and industrial product cycles that release metals during mining, fabrication, and disposal phases.

Changes in metal concentrations, and thus, the extent of 303 (d) standard violations, reflects patterns in emissions of these substances and the extent to which they affect the water quality of the Albemarle-Pamlico region.

DISSOLVED OXYGEN CONCENTRATION VIOLATIONS

Lindsay Dubbs[12] and **Michael Piehler**[13]

Why is DO Concentration Important?

Dissolved oxygen (DO) concentrations are the amounts of miniscule oxygen bubbles in water. Aquatic organisms require dissolved oxygen to survive. Very low (< 3 mg/L) DO concentrations can stress fish and shellfish, and those below 2 mg/L may be lethal. DO concentration requirements are different for different species and different ages of those organisms. However, fewer types of organisms can survive in environments with low DO concentrations.

Low DO concentrations in flowing waters are often the result of the decomposition of large amounts of organic matter. High organic matter concentrations are a characteristic of some slow-moving blackwater streams and rivers in the Albemarle-Pamlico Estuarine System (APES), but high concentrations of organic matter and subsequently low DO concentrations are also consequences of anthropogenic pollution.

Therefore, to maintain water quality, a particular unit of a water body is in violation of USEPA DO water quality standards if its daily average DO concentration falls below 5 µg/L (or 6 µg/L in trout waters).

What Will This Indicator Report?

- DO concentrations in fresh and estuarine surface waters of the APES from 1980 to 2010.
- Listed 303 (d) DO violations in fresh and estuarine waters of the APES for 2010.

What Do the Data Show?

DO concentrations in the White Oak River (Figure 1) have significantly increased ($p = 0.08$), overall, from 1980 to 2010. Meanwhile, DO concentrations have shown overall significantly decreasing trends from 1980 to 2010 in the Chowan River (Figure 2b; $p=0.07$) and the Neuse River (Figure 3b; $p = 0.03$), which includes the Upper, Middle, and Lower Neuse River sub-basins (Figure 4). The DO concentrations in the Pamlico Sound, including four stations in the Pamlico River, Lower Neuse, and White Oak River sub-basins (Figure 4) similarly showed a decreasing trend from 1980 to 2010 (Figure 3c; $p = 0.00$). The trends in monthly mean DO concentrations showed no statistically significant trends in the Roanoke River (Figure 2a), Tar River (Figure 3a), or Albemarle Sound (Figure 2c). The large error bars for some monthly means reflect the spatial and temporal variability in chl *a* concentrations while the lack of error bars generally indicates that the monthly mean is comprised of only one sample (Figures 1-3).

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Several sections of the Middle and Lower Neuse, Upper Roanoke, and Chowan River and East Albemarle Sound sub-basins were listed as violating USEPA DO standards (Figure 4) in 2010.

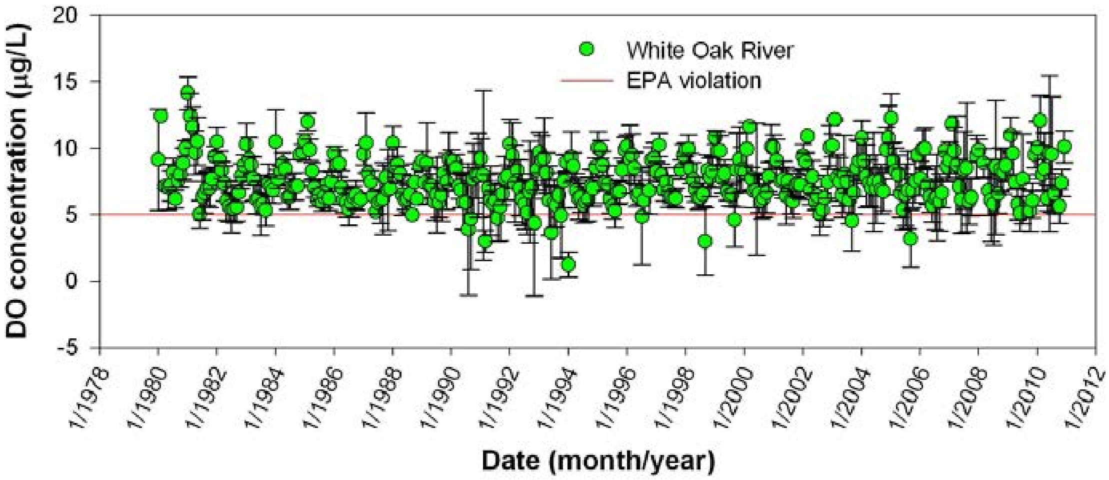

Figure 1. Monthly mean DO concentrations (mg/L) in surface waters of the White Oak River over time. Error bars represent one positive standard deviation from the mean of all samples measured each month. Note that the USEPA standard for North Carolina waters is minimum DO concentration of 5 mg/L (trout waters have a 6 mg/L minimum) in APES waters.

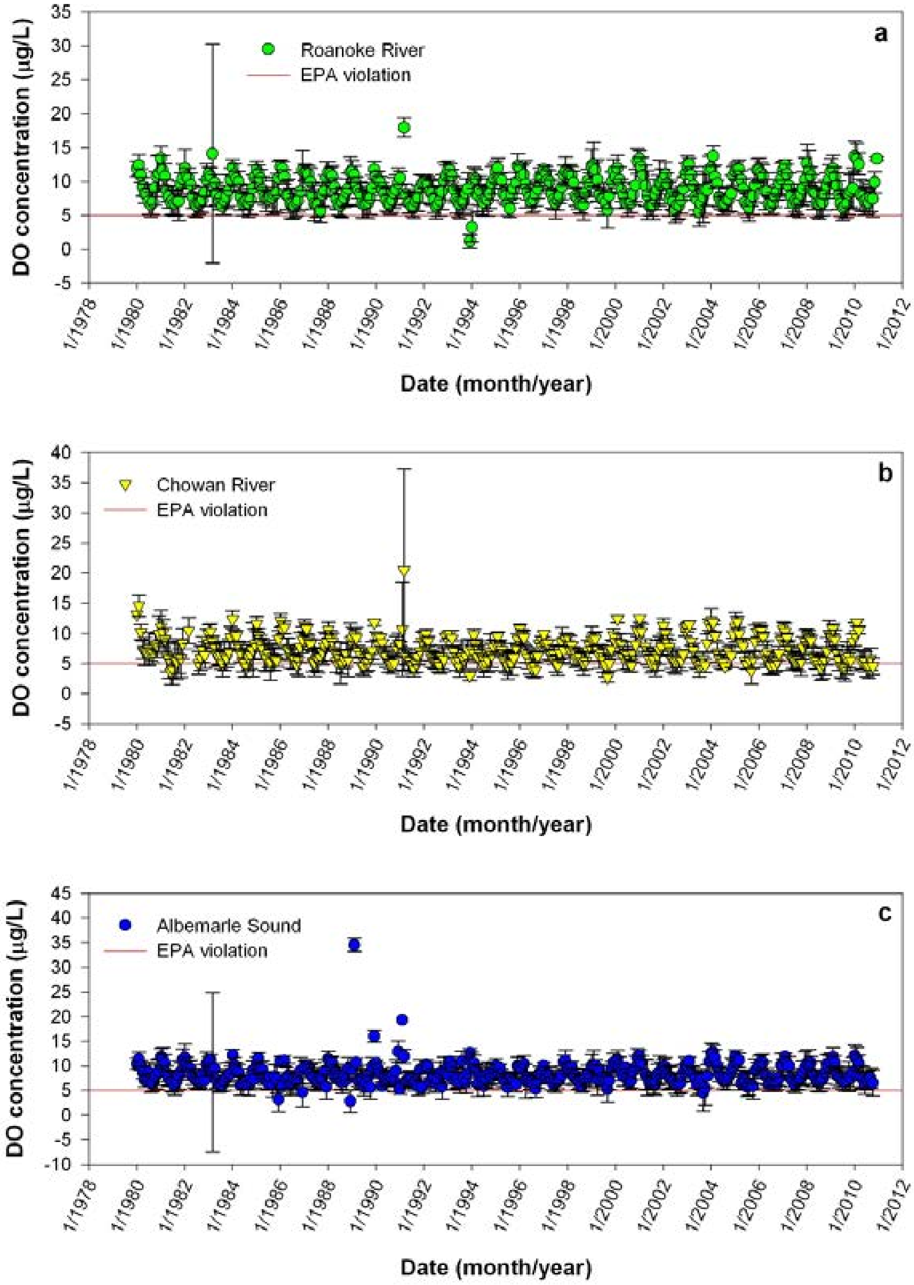

Figure 2. Monthly mean DO concentrations (mg/L) in surface waters of the Chowan (a) and Roanoke (b) Rivers and Albemarle Sound (c) over time. Error bars represent one positive standard deviation from the mean of all samples measured each month. Note that the USEPA standard for North Carolina waters is minimum DO concentration of 5 mg/L (trout waters have a 6 mg/L minimum) in APES waters.

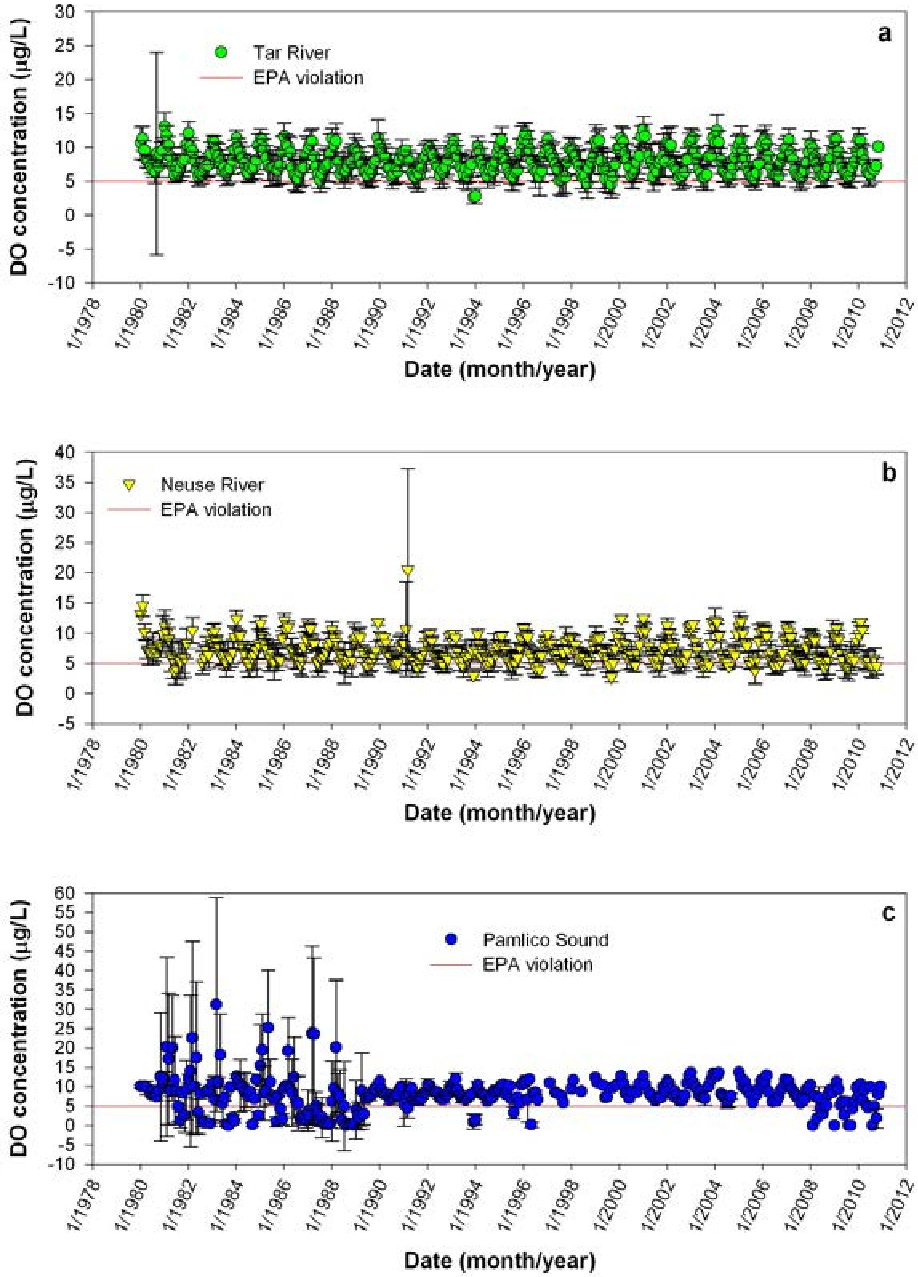

Figure 3. Monthly mean DO concentrations (mg/L) in surface waters of the Tar (a) and Neuse (b) Rivers and Pamlico Sound (c) over time. Error bars represent one positive standard deviation from the mean of all samples measured each month. Note that the USEPA standard for North Carolina waters is minimum DO concentration of 5 mg/L (trout waters have a 6 mg/L minimum) in APES waters.

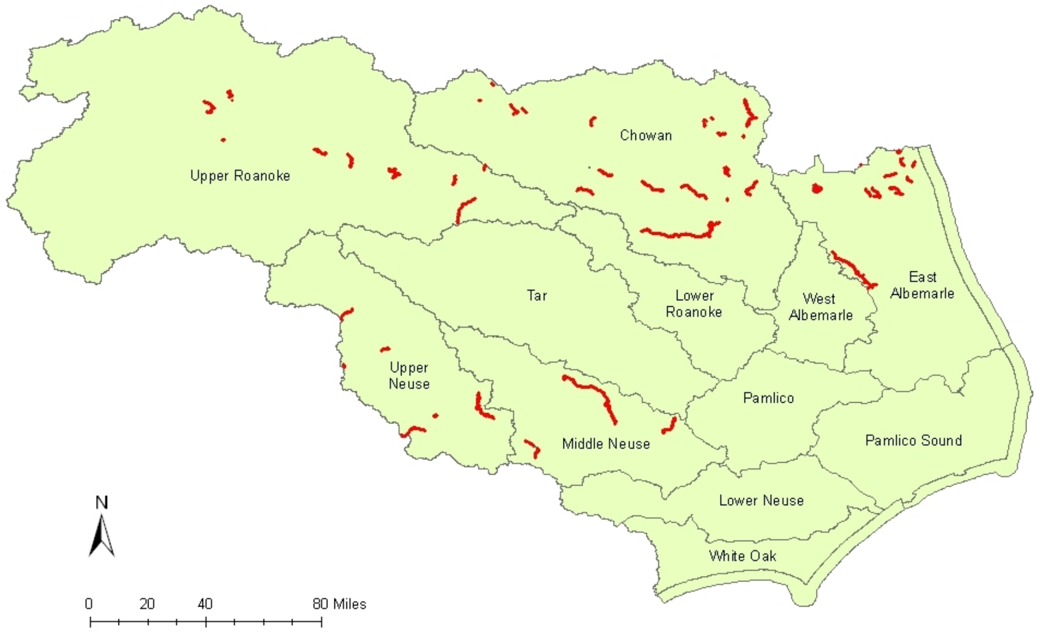

Figure 4. Sub-basins of the APES region and locations of DO violations (red) within the APES region listed on the 303(d) list in 2010.

Why Can't the Entire Indicator Be Reported at This Time?

The listed 303 (d) violations from before 2010 have not been reported here because the extents of hydrological units have changed over time. 2010 violations can be used as a point of comparison for future violations because their spatial extent is now tied to the measured values and violations.

Understanding the Data

Dissolved oxygen is added to water by diffusion from the atmosphere, aeration by wave action, and photosynthesis by phytoplankton and other aquatic plants. DO is removed from water by plant, bacterial, and animal respiration and by chemical processes such as sulfide oxidation and nitrification. DO concentrations in water are also dependent upon temperature, pressure, and the amounts of other dissolved substances in the water. Colder water with few dissolved substances (like salts or organic matter) can hold higher concentrations of DO than warmer water containing many other dissolved substances, and waters at high altitudes have higher DO concentrations than if those same waters were at low altitudes. Several of the factors that determine DO concentrations vary daily and seasonally, with changing light regimes and temperatures. The large error bars in Figure 1 represent the spatial and temporal variability in the conditions that influence DO concentrations.

Low DO concentrations can be the end result of nutrient pollution, which causes excessive growth of algae and the subsequent consumption of oxygen during the decomposition of plant biomass. Low oxygen concentrations can be harmful to aquatic organisms that are not well adapted for low oxygen conditions or that are not mobile. Conditions where there is low or no oxygen dissolved in the water are especially of concern when they persist, such as in the bottom of the water column of stratified waters (not well-mixed from the surface to the maximum depth). Low DO concentrations can also result from the natural conditions of source waters. For instance, groundwater, water draining from wetlands, and slow moving water generally contain relatively low concentrations of DO.

Some of the slow flowing surface waters of the APES have naturally low DO concentrations, but low DO can also be the result of anthropogenic nutrient pollution. However, the observed decrease in oxygen levels over the past thirty years (1980-2010) in most surface waters in the APES (Figures 1b and c and 2a, b, and c) may be the result of nutrient pollution, are of concern to the health of aquatic organisms in the APES, and indicate declining water quality.

Image courtesy of the N.C. Division of Water Quality

CHLOROPHYLL *a* CONCENTRATION VIOLATIONS

Lindsay Dubbs[14] and Michael Piehler[15]

Why is Chlorophyll *a* Concentration Important?

Chlorophyll is the pigment that allows plants to convert sunlight to biomass, and chlorophyll *a* (chl *a*) is the primary form of chlorophyll found in phytoplankton (algae). Chl *a* is frequently measured to provide an index of phytoplankton biomass, and because phytoplankton growth is determined by nutrient availability, chl *a* is also used as a proxy for nutrient concentrations.

The presence of chl *a* in water bodies indicates that there is a resident primary producing community, which significantly contributes to the base of the food chain in rivers, lakes, estuaries, and oceans. However, addition of excess nutrients to these water bodies can lead to excessive growth of phytoplankton, called blooms, that shade and kill rooted aquatic plants that otherwise provide habitat and an ecosystem of their own. Phytoplankton blooms can also add excess organic matter to the benthic (bottom) sediments and waters, which causes increased bacterial decomposition that consumes oxygen, eventually leading to hypoxic (low oxygen) or anoxic (void of oxygen) conditions that are unfavorable to other organisms and may even cause fish kills. Finally, some species of phytoplankton found in blooms can produce toxins that are harmful to humans and other organisms. Thus, there can be too much of the good thing, chl *a*.

The Clean Water Act requires that states monitor surface waters to ensure that they are meeting water quality standards set by the U.S. Environmental Protection Agency (USEPA). USEPA categorizes water bodies or sections thereof (from 1 to 5 with increasing impairment) based on the level to which they are attaining water quality standards. Waters that are impaired and require a total maximum daily load for the reduction of pollutants are identified as Category 5 and are placed on the 303(d) list.

To maintain water quality in sounds and estuaries, the state of North Carolina has established that chl *a* concentrations greater than 40 µg/L are in violation of state water quality standards (NCDENR 2007).

What Does This Indicator Report?

- Chl *a* concentrations in fresh and estuarine surface waters of the Albemarle Pamlico Estuarine System (APES) from 1980 to 2010.
- Listed 303 (d) chl *a* violations in fresh and estuarine waters of the APES region in 2010.

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What do the Data Show?

Chl *a* concentrations showed statistically significant decreasing trends from the 1980s to 2010 in the Roanoke River basin (p = 0.01; Figure 1a), which includes the Upper and Lower Roanoke sub-basins (Figure 2). Decreasing trends were also observed for the same period of time in the Chowan River basin (p = 0.00; Fig. 1b) and the Neuse River basin (p = 0.00; Figure 3b), which includes the Upper, Middle, and Lower Neuse River sub-basins (Figure 2). Meanwhile, a statistically significant increasing trend in chl *a* concentrations was observed from the 1980s to 2010 in the White Oak River basin (p = 0.01; Figure 4). There is not a statistically significant trend in chl *a* concentrations in the Tar-Pamlico River basin (Figure 3a) for the approximately 30-year record. However, there is a significantly increasing trend in the Tar-Pamlico River basin from 2003 through 2010 (p = 0.04; Figure 3a). The Albemarle Sound, including the East and West Albemarle Sound sub-basins (Figure 2), and the Pamlico Sound, including four stations in the Pamlico River, Lower Neuse, and White Oak River sub-basins (Figure 2) showed no statistically significant trends in chl *a* concentrations from the 1980s to 2010 (Figure 1c and 3c, respectively). The large error bars for some monthly means reflect the spatial and temporal variability in chl *a* concentrations while the lack of error bars generally indicates that the monthly mean is comprised of only one sample (Figures 1-3).

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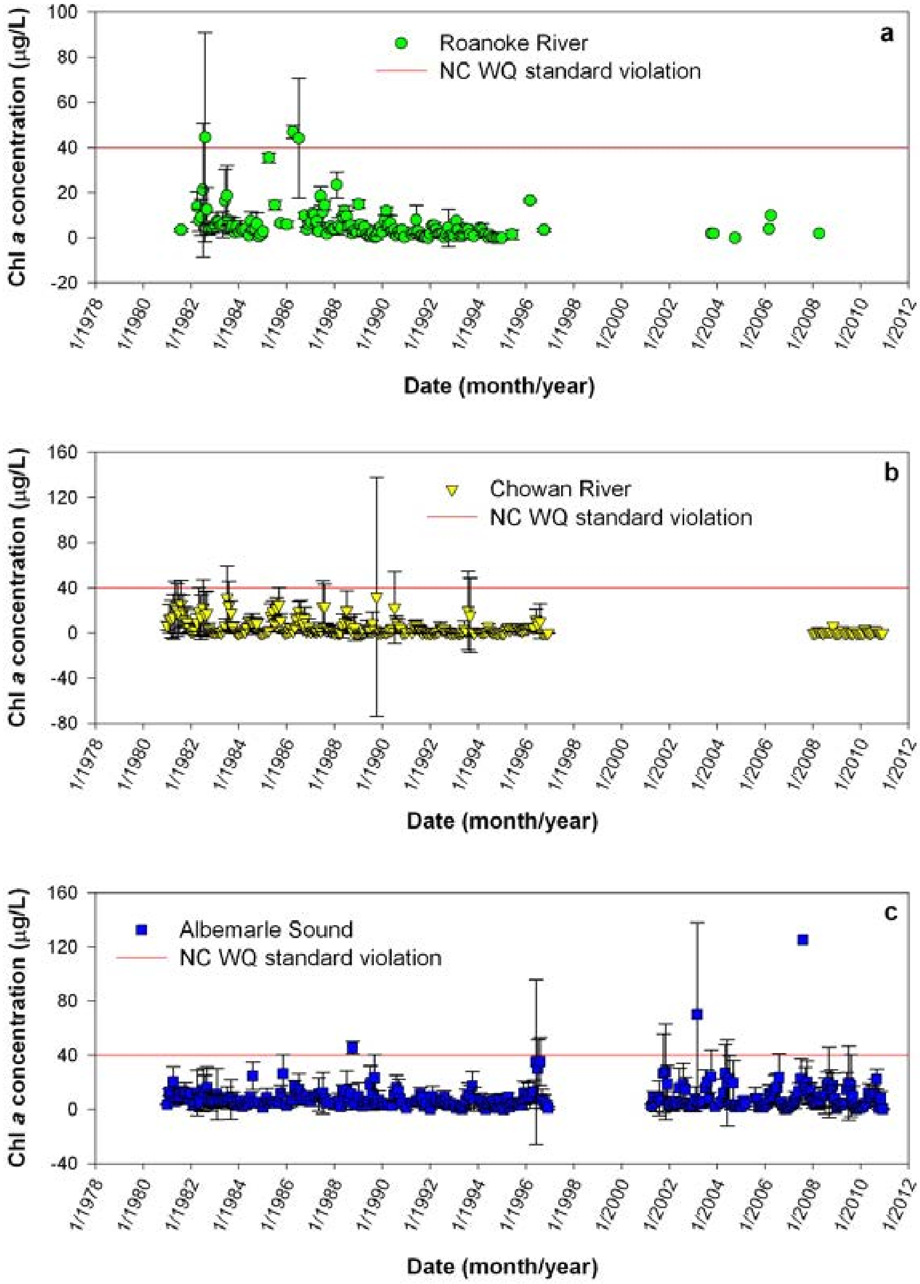

Figure 1. Monthly mean chl *a* concentrations (mg/L) in surface waters of the Chowan (a) and Roanoke (b) Rivers, and the Albemarle Sound (c) over time. Error bars represent one standard deviation from the mean of all samples for each month.

Figure 2. Sub-basins of the APES and locations of listed 303(d) chl *a* violations (green) within sub-basins in the APES in 2010.

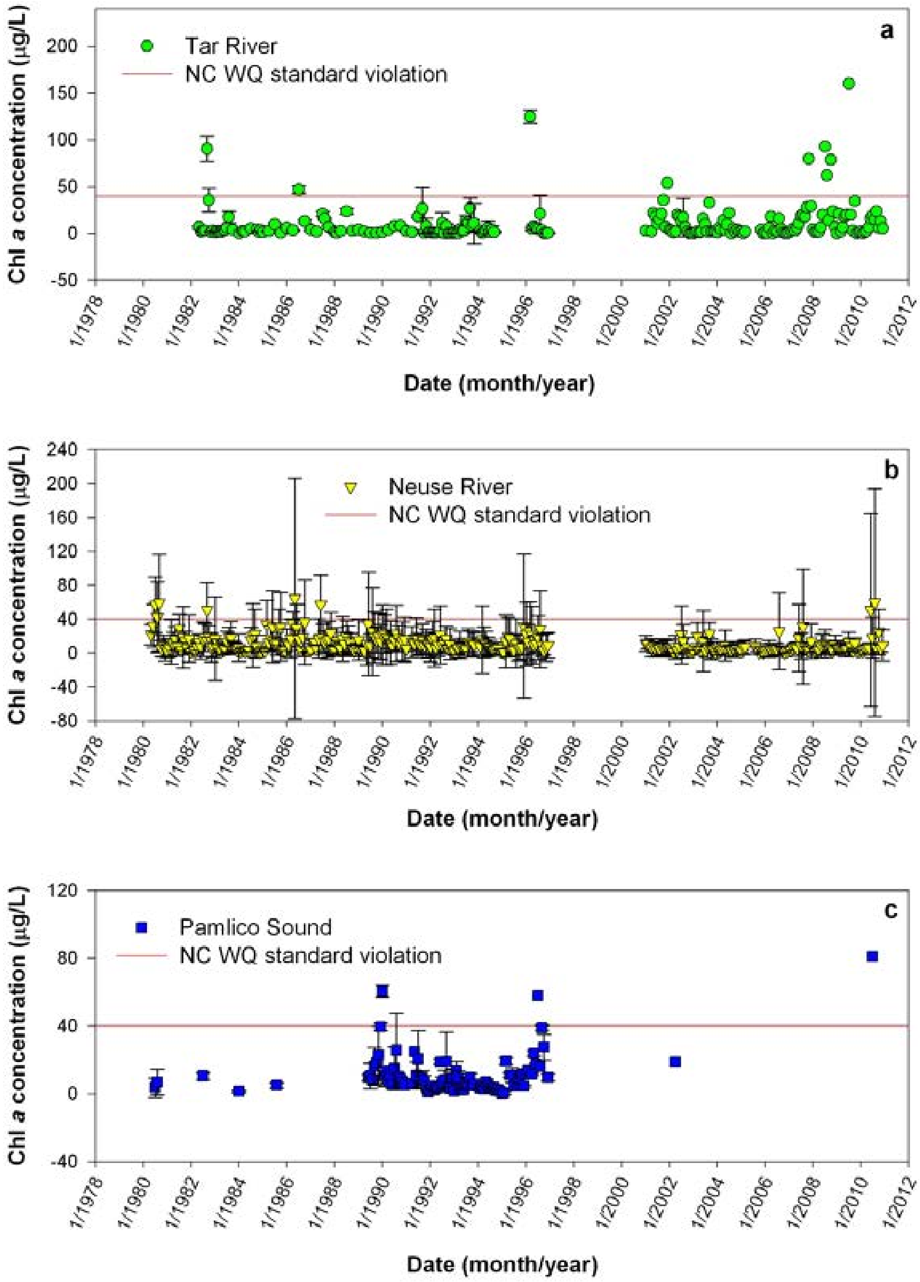

Figure 3. Monthly mean chl *a* concentrations (mg/L) in surface waters of the Tar-Pamlico (a) and Neuse (b) Rivers, and the Pamlico Sound (c) over time. Error bars represent one standard deviation from the mean of all samples for each month.

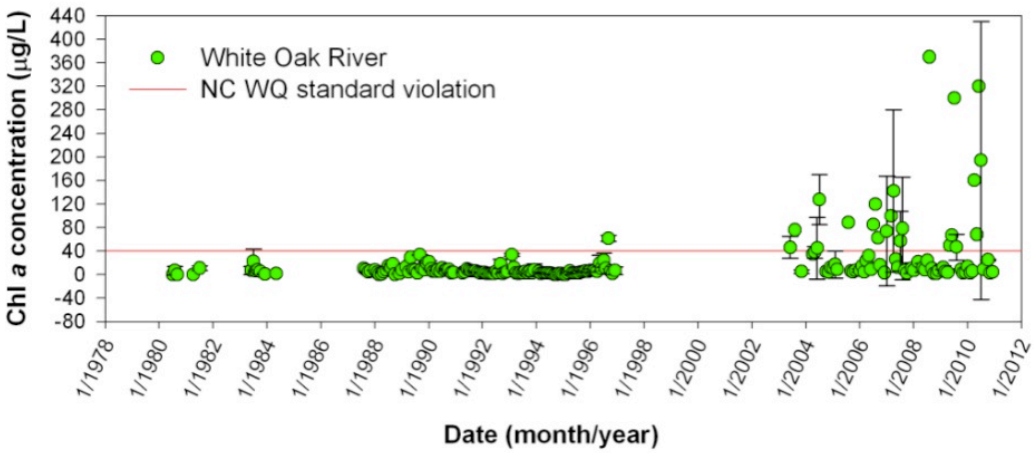

Figure 4. Monthly mean chl *a* concentrations (mg/L) in surface waters of the White Oak River over time. Error bars represent one standard deviation from the mean of all samples for each month.

Why Can't the Entire Indicator be Reported at This Time?

The listed 303 (d) violations from before 2010 have not been reported here because the extents of hydrological units have changed over time. 2010 violations can be used as a point of comparison for future violations because their spatial extent is now tied to the measured values and violations.

Understanding the Data

Chlorophyll concentrations vary over space and time, both seasonally and at longer time scales. This is in part because phytoplankton populations are dependent upon other environmental factors for their growth. These environmental factors include "bottom-up" influences, such as nutrient concentrations (Piehler et al., 2002; Piehler et al., 2004) and light availability (Whalen and Benson, 2007; Dubbs and Whalen 2008) and "top-down" influences such as populations of grazing and filter feeding organisms (Alpine and Cloern, 1992), which may in turn be influenced by larger food web dynamics (Carpenter et al., 2011). High nutrient concentrations and light availability will allow phytoplankton populations to proliferate (and thus, chl *a* concentrations to increase), while large populations of filter feeding organisms will reduce the number of phytoplankton. Multiple factors typically control phytoplankton abundance and determine the persistence of phytoplankton blooms (Paerl, 1988).

FISH POPULATIONS: RIVER HERRING ABUNDANCE

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Why Is the Status of River Herring Important?

Blueback herring (*Alosa aestivalis)* and alewife (*Alosa pseudoharengus)*, collectively known as river herring, are anadromous fish that spawn in various river systems along the Atlantic coast but spend the majority of their life cycle in the marine environment. They are selected as indicator species due to their historical significance from an ecological (prey species, vector of nutrient transfer), cultural (festivals, fishery heritage species) and economic (commercial and recreational fisheries) perspective. During the past, the Albemarle Pamlico ecosystem was the east coast epicenter for a highly significant commercial fishery for the species (NCDMF, 2007; NCDMF, 2011). Although the ranges of the two species overlap in the middle-Atlantic states, the alewife is a more northerly, cooler water species, with North Carolina at the southern edge of its range. In contrast, North Carolina is the heart of the distribution for blueback herring (McNaught et al., 2010:3).

Spawning occurs in the spring in fresh to nearly fresh waters of flooded backswamps, swamp margins, oxbows and tributary streams – often far upstream from coastal inlets. Alewife generally spawn earlier in the season and further downstream than blueback herring, which migrate further inland and later in the spring in warmer waters, including headwaters. The degree of spawning-site fidelity and river-basin fidelity of these species is unknown (McNaught et al., 2010:2). Sexual maturation occurs for a majority of males and females by ages 3 and 4 respectively (Grist 2005:34). Blueback herring from Albemarle Sound historically have reached age 10 (Kornegay, 1978 in Grist, 2005:15), but the maximum age at present is believed to be 7 (NCDMF, 2011). Annual spawning runs of blueback herring observed over three years in the Roanoke River were characterized by an overall duration of one month and a single principal peak (Hewitt 2003:24).

River herring are primarily zooplankton feeders while in the rivers and estuaries but during spawning migration, the diet of both species also includes insects. Their ocean diet consists of copepods, other plankton, pelagic shrimp, small fish (e.g., bay anchovy, *Anchoa mitcheli*) and fish fry (McNaught et al., 2010:4). A substantial amount of year-to-year variation in abundance is not unexpected given their short life span and variable recruitment (Hewitt, 2003:26).

Alewife and blueback herring in Albemarle Sound once supported large commercial fisheries for river herring (Grist, 2005:1) with Albemarle Sound and the Chowan River constituting the epicenter of the Atlantic coast river herring fishery (NCDMF, 2007). Herring historically have been harvested and processed in the Albemarle Sound/Chowan River region to yield salted

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herring, specialty products (i.e., canned herring), and roe. River herring are also highly valued as bait in the recreational striped bass fishery and in the commercial blue crab fishery (Hogarth et al. 1991:18). The widespread migration patterns of river herring make them susceptible to fishing operations both near-shore and off-shore (Lessard and Bryan, 2011:11). In addition to human consumption, seasonal spawning runs of river herring are ecologically important to facultative or obligate predatory fishes such as striped bass and water birds such as cormorants, ospreys, great blue herons, and American egrets, among others (McNaught et al., 2010:4). Young-of-year river herring are an important prey item for nearly all recreationally important fresh and salt water game fish within the Albemarle Sound estuary.

While dramatic population declines in river herring since the mid-1970s have reduced their commercial importance, they remain ecologically important as forage species (Rudershausen et al., 2005), and culturally important for local communities and institutions (i.e., the Cypress Grill in Jamesville, North Carolina, on the Roanoke River). Because of their combined ecological importance and federal designation as a species of concern (NMFS, 2009) there is momentum to enact a recovery plan for river herring species (Lessard and Bryan, 2011:10), and multiple states, including North Carolina, have imposed harvest moratoriums (Atlantic States Marine Fisheries Commission, in preparation).

Currently, both river herring species are undergoing a Status Review by the National Marine Fisheries Service, pursuant to the Endangered Species Act (NMFS, 2011). The Status Review was mandated by a determination that a petition filed by the Natural Resources Defense Council (NRDC, 2011) had merit. The NMFS determined that based on the information provided by the NRDC, there are ongoing multiple threats to both species as well as potential declines in both species throughout their ranges, and that the petition presents substantial scientific and commercial information indicating that the petitioned action concerning alewife and blueback herring may be warranted.

What Does This Indicator Report?

- Harvest Metric: Total Blueback Herring and Total Alewife Landings in Mass (Pounds) and Numbers for Chowan River, 1972 to 2004 (Grist 2005,:22, Figure 43)

The 2007 North Carolina Fishery Management Plan (hereafter FMP; NCDMF, 2007) established four stock recovery metrics for blueback herring, which serves as the current FMP indicator species. The metrics from the plan are:

- Abundance Metric: Blueback herring juvenile abundance from 11 core seine stations (NCDMF Program 100), June through October for years 1972-2010.

- Population Attribute Metric: Percent repeat spawners for Chowan River blueback herring, based on data from the commercial Chowan River pound net fishery (1972-2006), research set-aside fishery (2007) and Chowan River pound net survey (2008-2010).

- Population Attribute Metric: Chowan River blueback herring spawning stock biomass (SSB) by cohort for years 1972-2003.

- Abundance Metric: Chowan River blueback herring abundance at age (target age = 3) in numbers for years 1972-2003.

Images courtesy of the N.C. Division of Marine Fisheries

Table 1. Chowan River blueback herring and alewife landings and pound net landings, 1972-2004 (Grist, 2005:22).

Year	Total CR River Herring Landings (lb)	Percent of CR River Herring: Blueback Landings (%)	Total CR Blueback Landings (lb)	Percent of CR River Herring: Alewife Landings (%)	Total CR Alewife Landings (lb)	Percent of CR Landings: Pound Net Landings (%)	Total CR Pound Net Landings (lb)	Total CR Pound Net Blueback Landings (lb)	Total CR Pound Net Alewife Landings (lb)	Blueback Mean Weight Pounds (lb)	Total CR Catch Blueback Numbers (#)	Alewife Mean Weight Pounds (lb)	Total CR Catch Alewife Numbers (#)
1972	10,594,117	78%	8,263,411	22%	2,330,706	98%	10,338,274	8,063,853	2,274,421	0.404	20,443,867	0.551	4,229,956
1973	7,350,578	79%	5,806,957	21%	1,543,621	99%	7,308,578	5,773,776	1,534,802	0.417	13,918,880	0.513	3,009,594
1974	5,736,905	84%	4,819,000	16%	917,805	98%	5,637,262	4,735,300	901,962	0.397	12,141,597	0.513	1,789,442
1975	5,031,756	53%	2,666,831	47%	2,364,925	99%	4,968,795	2,633,461	2,335,334	0.366	7,286,423	0.513	4,610,889
1976	5,734,776	84%	4,817,212	16%	917,564	100%	5,704,034	4,791,388	912,646	0.397	12,121,822	0.513	1,788,972
1977	7,418,218	96%	7,121,489	4%	296,729	98%	7,292,770	7,001,059	291,711	0.423	16,831,692	0.513	578,532
1978	5,615,113	77%	4,323,637	23%	1,291,476	94%	5,260,737	4,050,767	1,209,970	0.443	9,762,107	0.513	2,517,988
1979	4,303,663	51%	2,194,868	49%	2,108,795	97%	4,154,720	2,118,907	2,035,813	0.446	4,921,229	0.513	4,111,513
1980	5,382,954	65%	3,498,920	35%	1,884,034	97%	5,213,820	3,388,983	1,824,837	0.459	7,617,940	0.523	3,602,359
1981	3,314,447	63%	2,088,102	37%	1,226,345	98%	3,240,189	2,041,319	1,198,870	0.479	4,360,204	0.533	2,302,563
1982	7,549,968	73%	5,511,477	27%	2,038,491	98%	7,380,980	5,388,115	1,992,865	0.435	12,658,422	0.494	4,130,681
1983	4,405,915	55%	2,423,253	45%	1,982,662	98%	4,327,749	2,380,261	1,947,488	0.407	5,955,402	0.506	3,919,854
1984	4,561,503	71%	3,238,667	29%	1,322,836	99%	4,501,994	3,196,416	1,305,578	0.359	9,023,870	0.565	2,341,717
1985	8,871,391	78%	6,919,685	22%	1,951,706	99%	8,776,370	6,845,568	1,930,802	0.377	18,364,344	0.449	4,343,881
1986	5,767,874	76%	4,383,584	24%	1,384,289	97%	5,584,579	4,244,280	1,340,299	0.399	10,997,451	0.411	3,368,919
1987	2,334,719	58%	1,354,137	42%	980,582	100%	2,333,795	1,353,601	980,194	0.370	3,664,782	0.468	2,093,918
1988	2,259,888	64%	1,446,328	36%	813,560	99%	2,234,554	1,430,114	804,440	0.348	4,162,095	0.418	1,947,247
1989	908,145	69%	626,620	31%	281,525	100%	907,569	626,222	281,347	0.354	1,772,115	0.398	706,816
1990	710,849	86%	611,330	14%	99,519	100%	710,386	610,931	99,455	0.379	1,612,157	0.513	194,032
1991	1,202,535	71%	853,799	29%	348,735	84%	1,014,392	720,218	294,174	0.335	2,545,614	0.533	654,655
1992	1,135,340	71%	806,091	29%	329,249	100%	1,135,340	806,091	329,249	0.353	2,281,605	0.469	701,425
1993	801,115	80%	640,892	20%	160,223	100%	800,115	640,092	160,023	0.364	1,763,114	0.513	312,386
1994	390,852	98%	383,035	2%	7,817	99%	385,437	377,728	7,709	0.277	1,380,804	0.427	18,311
1995	280,681	98%	275,067	2%	5,613	96%	268,534	263,163	5,371	0.338	814,048	0.427	13,148
1996	404,884	99%	400,835	1%	4,049	98%	398,476	394,491	3,985	0.384	1,043,026	0.427	9,485
1997	201,929	99%	199,909	1%	2,019	95%	191,991	190,071	1,920	0.426	468,830	0.427	4,729
1998	377,312	98%	369,766	2%	7,546	98%	368,658	361,285	7,373	0.334	1,105,760	0.427	17,676
1999	332,466	98%	325,815	2%	6,649	98%	324,995	318,495	6,500	0.343	948,791	0.320	20,804
2000	184,741	80%	146,126	20%	36,531	99%	182,658	146,126	36,532	0.335	436,067	0.401	91,168
2001	201,716	68%	137,167	32%	64,549	100%	201,468	136,998	64,470	0.378	363,260	0.443	145,676
2002	93,047	55%	51,138	45%	41,840	92%	85,883	47,235	38,648	0.383	133,659	0.458	91,394
2003	84,590	56%	47,371	44%	37,220	96%	80,940	45,326	35,614	0.331	143,201	0.395	94,204
2004	77,177	41%	31,642	59%	45,535	94%	72,184	29,595	42,589	0.309	102,534	0.441	103,277

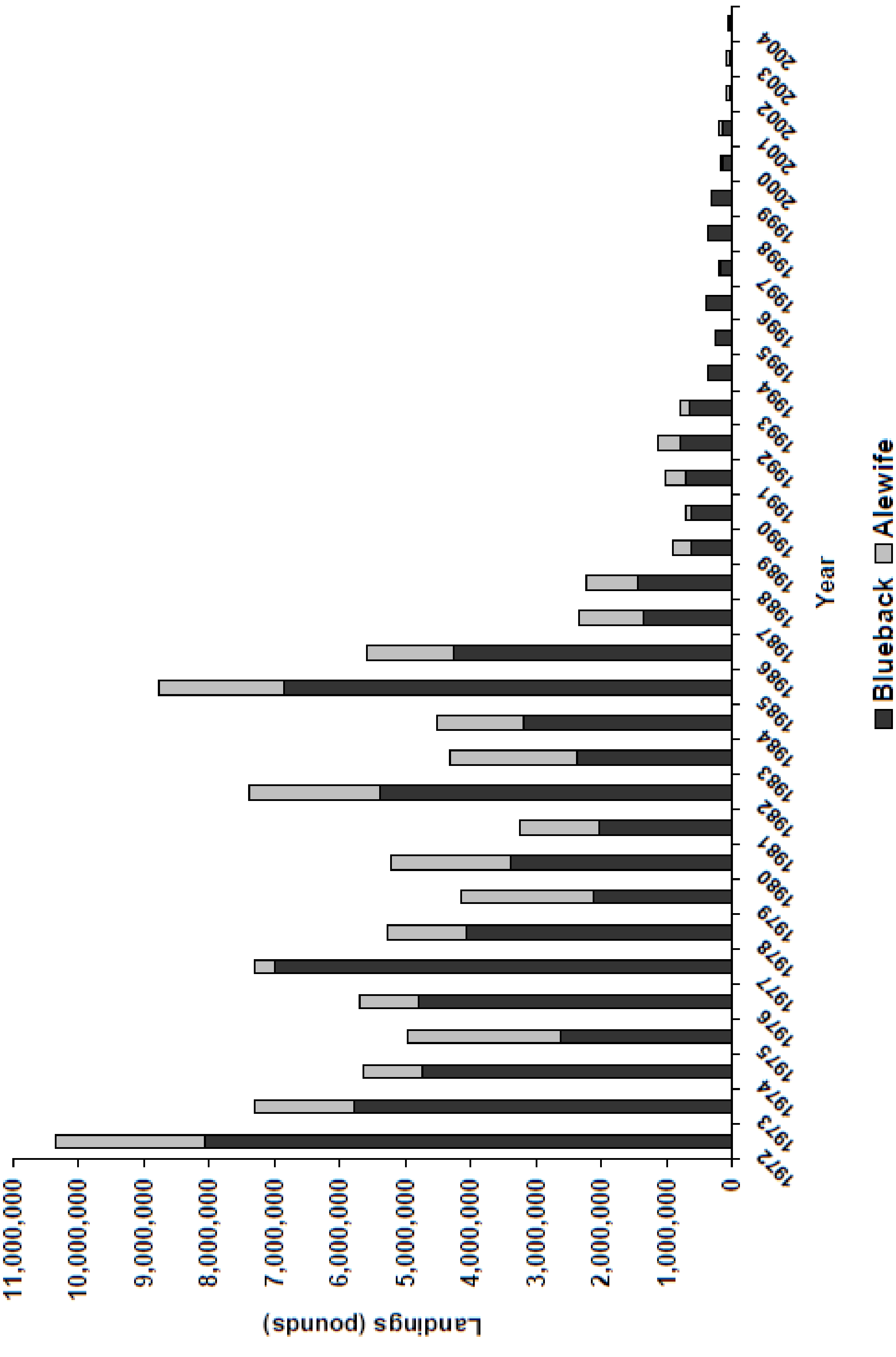

Figure 1. River landings from Chowan River pound nets, 1972-2004 (Grist, 2005:43).

What Do the Data Show?

North Carolina landings of river herring declined sharply during the 1970s as foreign fleets made large harvests in the ocean, exceeding previous domestic landings. Directed ocean landings essentially ended when foreign fishing was controlled by federal legislation in the late 1970s. Landings, however, remained depressed into the early 1980s and after some recovery mid-decade had continued to decline into 1990 (Hogarth et al., 1991:18). The bycatch of river herring in other mid-Atlantic and New England small-mesh fisheries has been cited as a potential factor precluding a rapid recovery of the stocks (Cieri et al., 2008; Cournane, 2010).

Blueback herring commercial landings from the Chowan River pound net fishery fluctuated substantially through the mid-1980's, and began a downward trend in 1986 that continued through 2004 (Table 1; Figure 1). From 1972 to 1985, landings averaged 1,996 metric tons (mt) (4.4 million lbs) and ranged between 990-3,600 mt (2.0-8.0 million lbs). Substantially lower landings between 1986 and 1994 resulted in an average for the period of only 540 mt (1.2 million lbs). Landings from 1995-1999 averaged 140 mt (305,501 lbs), with a range between 86-179 mt (190,071-394,491 lbs). The average harvest from 2000 to 2004 was 37 mt (81,056 lbs) (Grist, 2005:2).

Alewife commercial landings from the Chowan River pound net fishery followed the same trends as blueback herring landings and fluctuated through the mid-1980's and began a steady decline in 1986 (Table 1; Figure 1). Landings from 1972 to 1985 averaged 680 mt (1.5 million lbs) and ranged from 132-1,043 Mt (291,711 to 2.3 million lbs). Landings from 1986 to 1993 averaged only 243 mt (536,148 lbs) and ranged from 45-590 mt (99,455-1.3 million lbs). Landings reached historical lows in 1994 and averaged only 2.5 mt (5,476 lbs) from 1994 to 1999. Alewife landings increased slightly in 2000 but remained well below the historical level from 2000 to 2004, averaging 20 mt (43,571 lbs) (Grist, 2005:2).

Since 2000, the proportion of blueback herring in the total river herring landings has dropped steadily to only 41% in 2004, while the proportion of alewife has increased (Grist, 2005:1).

The juvenile abundance index for blueback herring show a clear downward trend, with fluctuations, from a high value in 1973 dropping to very low levels from 1994 to the present (Figure 2).

The percentage of repeat spawners (adult fish which survive to return to the sea and return to spawn again in subsequent years, Figure 3) depict a substantial decline in repeat spawning from the high value of nearly 25% of the 1980 population, to much lower and fluctuating values hovering near or below 5% of the 1983-2010 population. There appears to be some slight improvement near the end of the time series.

Blueback herring spawning stock biomass (SSB), and estimated number of recruits by cohort, at age 3, both show declines over time (Table 2, Figure 4, from Grist, 2005). The SSB high value was over 6575 mt (14.5 million lbs) in 1972, and varied between about 4536 and 1814 mt (10

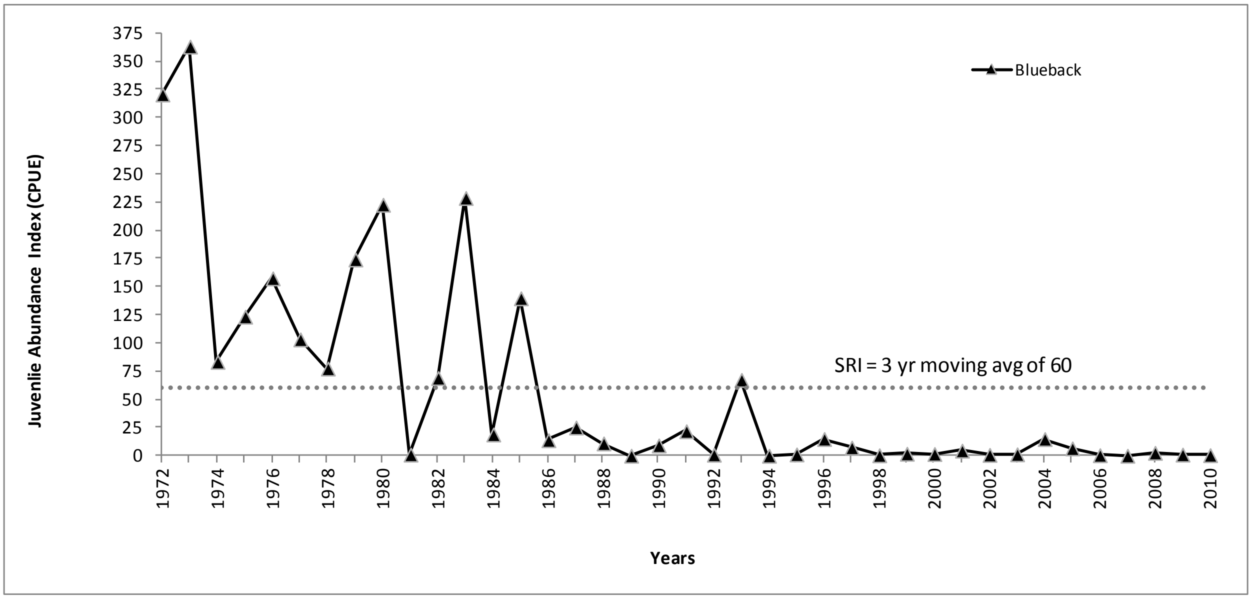

Figure 2. Blueback herring juvenile abundance from 11 core seine stations in the Albemarle Sound area, NC, 1972-2010.

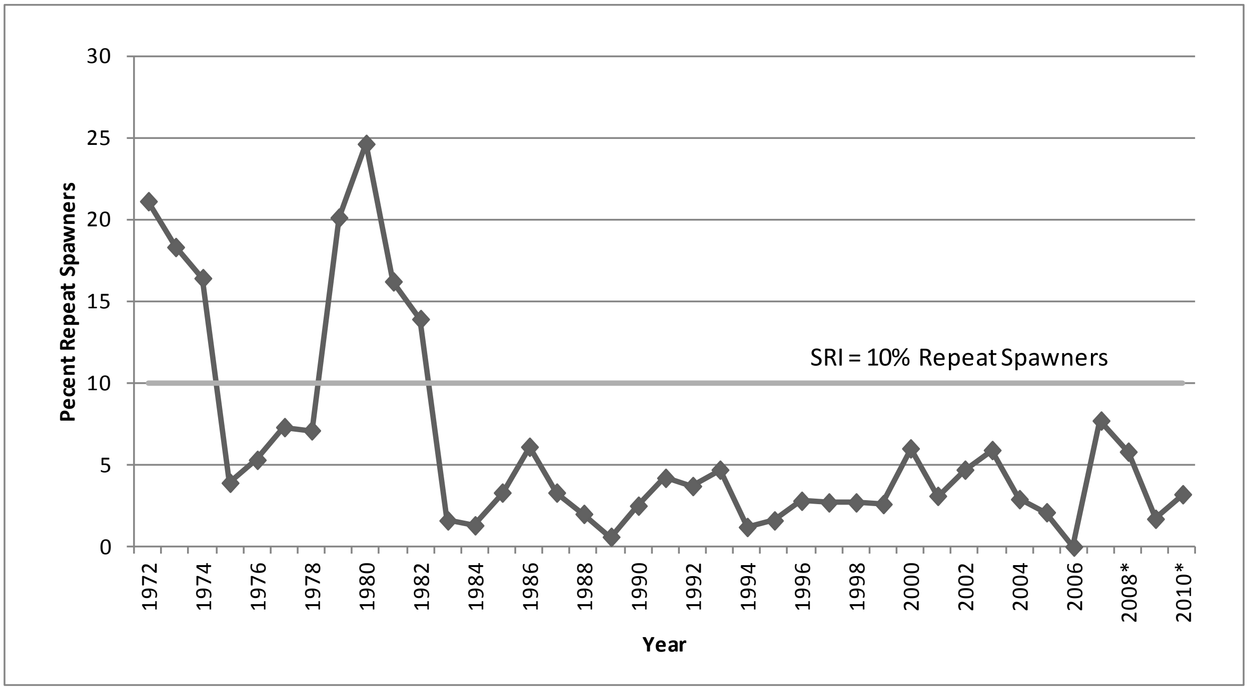

Figure 3. Blueback herring percent repeat spawners, sexes combined, from the Chowan River, North Carolina, 1972-2010.

and 4 million lbs) for the next decade and a half, until exhibiting a permanent downward trend from 1986 through 2003, when the lowest value in the time series was estimated. Blueback herring declines in recruitment through the 1990's dramatically reduced SSB to a record low of

41 mt (89,678 lbs) in 2003. Chowan River blueback herring recruitment averaged 28.9 million age-3 fish per year between 1972 and 1985. However, since 1986 it has only averaged around 3.6 million fish, and in the last five years of the time series, only 552,000 fish.

Table 2. Blueback herring stock biomass and recruitment by cohort based on catch at age analysis (Grist, 2005:39).

Year	SSB (lb)	Recruits by cohort (est. numbers at age-3)
1969		39,865,477
1970		23,506,889
1971		22,284,834
1972	14,522,222	51,118,274
1973	11,425,556	44,515,997
1974	8,548,280	21,013,218
1975	7,911,119	15,591,527
1976	9,911,718	16,829,710
1977	10,459,987	10,028,049
1978	8,022,784	38,857,247
1979	5,635,462	15,254,203
1980	4,417,303	38,099,778
1981	4,709,277	59,696,182
1982	6,008,350	7,987,989
1983	6,779,751	9,165,666
1984	8,723,894	8,969,447
1985	10,231,393	3,049,336
1986	7,313,002	5,103,808
1987	3,862,501	9,036,148
1988	2,559,345	7,797,123
1989	1,698,050	2,628,602
1990	1,497,323	4,380,587
1991	1,837,518	3,030,564
1992	1,822,752	1,864,735
1993	1,379,160	3,366,597
1994	1,072,525	2,476,938
1995	896,214	1,517,985
1996	838,699	1,055,377
1997	741,427	622,571
1998	815,045	343,726
1999	537,244	273,119
2000	283,041	467,359
2001	190,190	
2002	99,797	
2003	89,678	

Figure 4. Blueback herring annual estimates of spawning stock biomass, 1972-2003 (Grist, 2005:54)

Blueback herring catch-at-age has declined across all ages since the 1970's with the 2003 catch-at-age only 1.2% of the average catch-at-age observed during the 1970's (Table 3; Grist, 2005).

Recruitment is estimated at age-3 since virtually no fish younger than this appear in the blueback herring or alewife catch and there is no offshore survey data available to estimate the population of the sub-adults. Chowan River blueback herring recruitment averaged 28.9 million age-3 fish a year between 1972 and 1985, but since 1986 it has only averaged around 3.6 million fish (Figure 5) and in the last five-years, only 552,000 fish. Strong year classes of the late 1960s sustained the stock through the mid-1970s then poor 1975-1977 cohorts contributed to the decline in the late 1970s. Exceptional recruitment of the 1978 - 1981 cohorts, averaging 38.0 million fish, allowed the stock to rebuild in the early 1980s, but another series of poor cohorts from 1982 to 1986 combined with sustained high fishing mortality lead to a decline in overall stock abundance. Recruitment has been low over the last 10 years, only averaging 1.8 million fish a year. Moreover, any modest gains in blueback herring recruitment since the early 1980s supported catches over the short term and were quickly removed by high fishing mortality. For example, although the 1987 and 1988 year classes were the best in the last 10 years, these two blueback herring cohorts alone supported over 69% of the catch between 1991 and 1993. Similarly, the 1993 cohort supported nearly 10% of the 1996 catch, nearly 40% of the 1997 catch, and over 50% of the 1998 catch.

Although blueback herring from Albemarle Sound are reported to reach age-10 (Kornegay, 1978), in recent years the age structure is becoming increasingly truncated (Figure 6). Until the mid-1980s an occasional age-9 fish appeared in the catch and age-8 fish were fairly common, but since 1983 the oldest fish observed has been 7 years old, and in several years the maximum observed age was 6. This analysis suggests that the long-term decline in landings, overall and species specific, are related to a decline in population abundance and that current fishing mortality rates are not sustainable (Grist, 2005:15).

Table 3. Estimated blueback herring abundance at age in numbers, 1972-2003.

			AGE			
Year	3	4	5	6	7+	Sum (3-9)
1972	39,865,477	28,225,684	16,332,859	4,596,699	621,741	89,642,459
1973	23,506,889	23,640,276	11,438,335	3,895,696	1,244,697	63,725,893
1974	22,284,834	13,939,614	9,580,119	2,728,260	1,226,081	49,758,906
1975	51,118,274	13,214,933	5,648,968	2,285,040	943,185	73,210,400
1976	44,515,997	30,313,198	5,355,294	1,347,386	769,993	82,301,868
1977	21,013,218	26,398,040	12,284,291	1,277,339	505,035	61,477,923
1978	15,591,527	12,460,863	10,697,691	2,930,036	425,130	42,105,247
1979	16,829,710	9,245,795	5,049,710	2,551,602	800,271	34,477,088
1980	10,028,049	9,980,038	3,746,818	1,204,452	799,485	25,758,842
1981	38,857,247	5,946,645	4,044,367	893,687	477,977	50,219,923
1982	15,254,203	23,042,394	2,409,852	964,658	327,168	41,998,275
1983	38,099,778	9,045,761	9,337,830	574,795	308,125	57,366,289
1984	59,696,182	22,593,214	3,665,755	2,227,249	210,593	88,392,994
1985	7,987,989	35,399,908	9,155,801	874,352	581,472	53,999,523
1986	9,165,666	4,736,887	14,345,658	2,183,832	347,242	30,779,285
1987	8,969,447	5,435,251	1,919,603	3,421,711	603,709	20,349,721
1988	3,049,336	5,318,893	2,202,612	457,862	960,139	11,988,842
1989	5,103,808	1,808,260	2,155,458	525,365	338,220	9,931,111
1990	9,036,148	3,026,565	732,790	514,118	205,981	13,515,601
1991	7,797,123	5,358,447	1,226,502	174,784	171,757	14,728,613
1992	2,628,602	4,623,703	2,171,487	292,544	82,657	9,798,993
1993	4,380,587	1,558,764	1,873,736	517,941	89,492	8,420,520
1994	3,030,564	2,597,693	631,682	446,921	144,884	6,851,746
1995	1,864,735	1,797,128	1,052,704	150,668	141,157	5,006,392
1996	3,366,597	1,115,027	845,037	354,232	98,198	5,779,091
1997	2,476,938	1,994,012	442,309	191,834	102,708	5,207,801
1998	1,517,985	1,487,570	1,013,639	178,267	118,711	4,316,172
1999	1,055,377	898,507	583,264	223,995	65,627	2,826,769
2000	622,571	616,654	279,542	75,459	37,470	1,631,696
2001	343,726	367,029	225,051	52,326	21,138	1,009,270
2002	273,119	200,321	109,047	26,171	8,543	617,201
2003	467,359	161,699	78,877	24,334	7,746	740,016

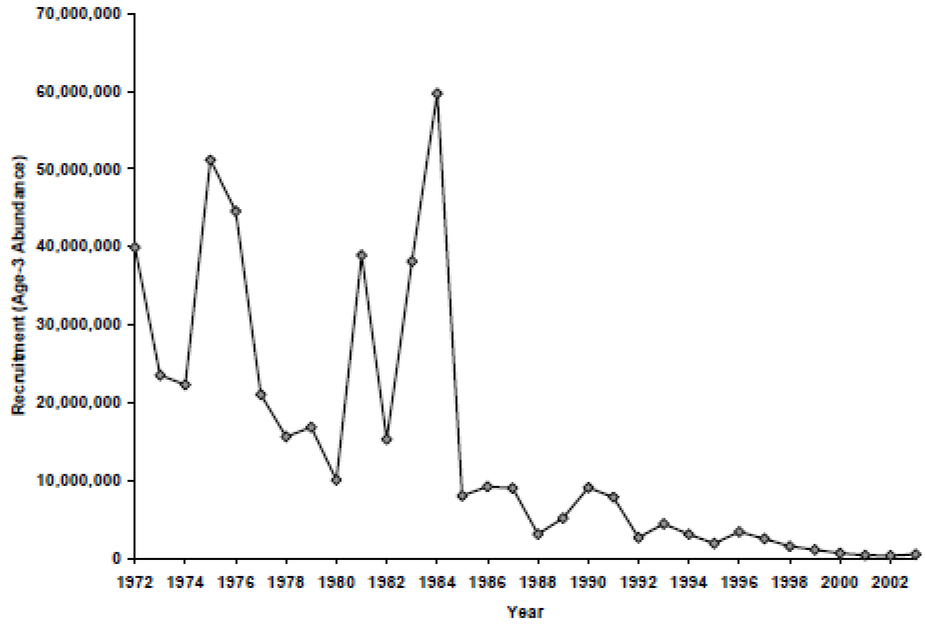

Figure 5. Blueback herring annual estimates of recruitment, 1972-2003 (Grist, 2005:53).

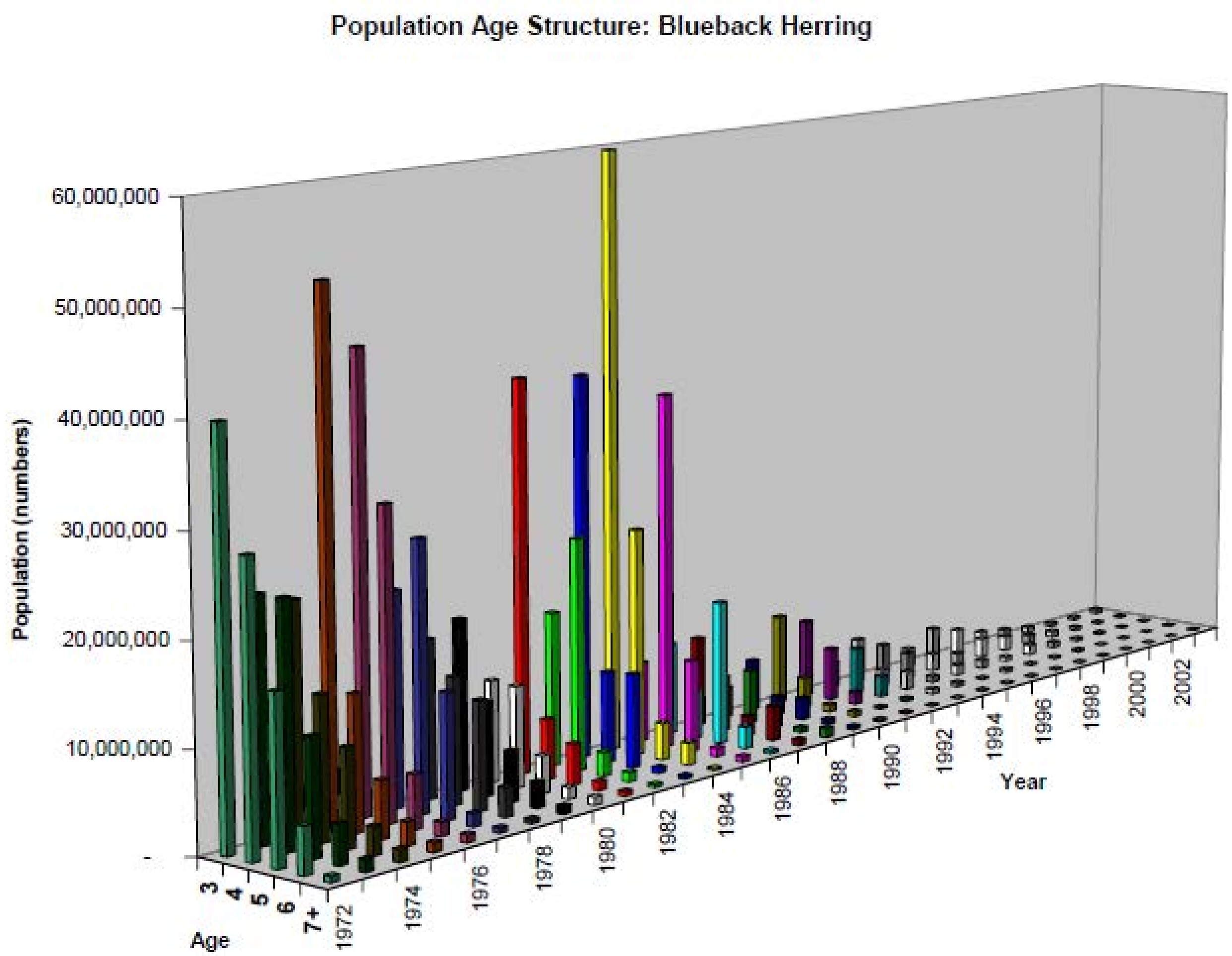

Figure 6. Blueback herring population age-structure for ages 3-7, 1972-2003 (Grist, 2005:62).

Why Can't This Entire Indicator Be Reported at This Time?

The harvest information used to construct the NCDMF population assessment (catches at age) includes only landings for alewife and blueback herring in the Chowan River pound net fishery (note the commercial fishery ended in 2006; however, other NCDMF sampling efforts have maintained the time series for the purpose of monitoring the stocks). Landings from other fisheries that harvest river herring from this stock, such as the gill net fishery in Albemarle Sound and the recreational fishery in inland waters, were not included (Grist, 2005:16).

Although the 2007 North Carolina River Herring Fishery Management Plan (FMP) was a statewide plan, river herring data from systems outside of the Albemarle Sound area are not available. The NCDMF has conducted spawning and nursery area surveys and some age composition work for most of the coastal streams outside the Albemarle Sound area, but this work ended 15-23 years ago (depending on area) as federal aid funds were decreased. Current data other than landings data simply do not exist for river herring outside the Albemarle Sound area.

Understanding the Data

High recruitment through much of the 1970s and early 1980s sustained the Chowan River stock of river herring in spite of very high fishing mortality. Much of the variability in landings, population abundance, and spawning stock biomass can be attributed to trends in recruitment. Historic spawning and nursery habitat loss and water quality degradation were also factors in the decline (S.E. Winslow, NCDMF, retired, personal communication). A succession of poor year-classes during the mid-1980s could not support the high fishing mortality at that time, and subsequently the stock declined to historic low levels. Spawning stock biomass and recruitment of blueback herring and alewife declined dramatically during the mid to late 1980s and has never recovered (Grist, 2005:14). Sustained high exploitation from 1980 to 2005 had reduced standing stock biomass (SSB) to the extent that 2005 levels were insufficient to produce even moderate recruitment for either blueback herring or alewife (Grist, 2005:15).

Concern over reductions in both landings and low numbers of juvenile herring found in surveys led to the imposition of seasonal harvest closures and reduced harvest quotas in the early 1990s and initiation of a North Carolina Marine Fisheries Commission (NCMFC) FMP to comprehensively manage the fishery. Seasonal restrictions were implemented in 1995 and 1997, and annual quotas, or total allowable catches (TACs) were established for 1996 (113 mt or 250,000 lbs), 1998 (181 mt or 400,000 lbs) and 1999 (204 mt or 450,000 lbs). Two management areas were established in the 2000 Albemarle Sound Area River Herring FMP: The Albemarle Sound River Herring Management Area (ASRHMA) and the Chowan River Herring Management Area (CRHMA). A TAC of 136 mt (300,000 lbs) was established in 2000 for the ASRHMA. Concurrently, a 25 fish per person per day (blueback herring and alewife combined) recreational creel limit was implemented (Grist, 2005:1-2). The NC Wildlife Resources Commission closed North Carolina's inland waters to river herring harvest in 2006, and the

NCMFC implemented a no-harvest provision for commercial and recreational fisheries in joint and coastal waters of the state in 2007 (NCDMF, 2011).

Should the species be listed by the National Marine Fisheries Service, all harvest would be prohibited coastwide and permits would be necessary for any agency sampling necessary to conduct stock monitoring.

Images courtesy of the
N.C. Division of Marine Fisheries

FISH POPULATIONS: AMERICAN SHAD ABUNDANCE

Dean Carpenter[19], Wilson Laney[20], Kathy Rawls[21]

Why Is the Status of American Shad Important?

The American shad (*Alosa sapidissima*) is the largest of the alosines occurring in the Albemarle-Pamlico ecosystem and has been significant in the system culturally, ecologically and economically both prehistorically and since Colonial times (Walburg and Nichols 1967; Winslow, 1994:72). Adult and juvenile shad serve as important prey for multiple predators (avian, fish, mammalian and reptilian) within the system (e.g., see Rudershausen et al., 2005; Tuomikoski et al., 2008). Adult American shad were the focus of historic commercial and more recent recreational fisheries, and serve as an important means of transferring marine nutrients into freshwater ecosystems (Limburg and Waldman, 2009:956). They provide multiple ecosystem services and are identified as a species of management importance by all federal and state fishery management agencies with jurisdiction in the Albemarle-Pamlico ecosystem.

During the early 1900s, American shad was the most commercially important fish species in North Carolina, and Stevenson (1899) stated that the North Carolina shad fishery was the most important on the Atlantic Coast (as reported in Mansueti and Kolb, 1953:44). For over a century and a half, North Carolina ranked in the top three states for commercial landings of American shad along the east coast (Walburg and Nichols, 1967). Annual landings of this anadromous species declined from over 3,600 metric tons (mt) (eight million pounds) then to the 450 mt (one million pound) range and below in the 1930s (Hogarth et al., 1991:20) to under 135 mt (300,000 pounds) this decade. The species was hugely important not only economically, but culturally (with nearly 7,000 employees in the North Carolina fishery; and significant recreational fisheries, see McPhee 2002) and certainly ecologically. Still today, remnant stocks of American shad ascend the Chowan, Roanoke, Tar, Neuse and Cape Fear rivers in North Carolina (Limburg et al., 2007b:128). American shad are usually among the latest anadromous species to begin their rather protracted seasonal spawning migration, from mid-April to mid-June (Hewitt, 2003:50).

To a limited degree, American shad are still harvested both commercially and recreationally, but agencies have little information about spawning run size and how that relates to harvest (Hewitt, 2003:7). Sadly, American shad has lost its place as a dominant species in East Coast estuaries and rivers, and has dropped out of commonplace memory in America. In the 21st Century, however, intensive management and restoration efforts could result in American shad becoming a bellwether of ecosystem health, managed not only for fisheries, but also as an indicator of the status of the connectivity and environmental quality of watersheds and coastal oceans (Limburg et al., 2007a:25).

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What Does This Indicator Report?

Indicators selected for American shad are those which are being employed by the NC Division of Marine Fisheries and NC Wildlife Resources Commission-Division of Inland Fisheries for monitoring and assessing stock status as approved by the Atlantic States Marine Fisheries Commission (see NCDMF and NCWRC, 2012). Because each major tributary to the Albemarle-Pamlico estuarine system has a distinct stock of American shad, status of each spawning run must be assessed using indicators for each river system.

<u>Albemarle Sound Sustainability Metrics</u>

- Female catch per unit effort (CPUE) [NCDMF independent gill net survey (IGNS)]: The female CPUE index based on the NCDMF IGNS was calculated as the number of fish per haul using data collected during January through May for the years 2000–2010.

- Female CPUE (NCWRC electrofishing survey): The female CPUE index based on the NCWRC electrofishing survey was calculated as the number of fish per minute for the years 2001–2010.

- Female Relative F (DMF IGNS): Female Relative F based on the NCDMF IGNS was calculated for the years 2000–2010 using commercial gill net landings of roes (females) in Albemarle Sound (February through April) and a female index derived from data collected in the 5.0, 5.5 and 6.0-inch mesh sizes of the IGNS (February through April). The February through April timeframe was used to reflect the period during which the commercial fishery is prosecuted. The mesh sizes selected most accurately reflect those used by the commercial fleet.

<u>Tar-Pamlico River Sustainability Metrics</u>

- Female CPUE (WRC electrofishing survey): The female CPUE index based on the NCWRC electrofishing survey was calculated as the number of fish per minute for the years 2000–2010.

- Female Relative F (NCWRC electrofishing survey): Female relative F based on the WRC electrofishing survey was calculated for years 2000–2010 using commercial landings of roes by all gear types from the Pamlico River and the female CPUE index from the Tar River electrofishing survey. Because the electrofishing survey primarily occurs during March through April, only commercial landings from those months were used in the calculations.

<u>Neuse River Sustainability Metrics</u>

- Female CPUE (NCWRC electrofishing survey): The female CPUE index based on the NCWRC electrofishing survey was calculated as the number of fish per minute for the years 2000–2010.

- Female Relative F (NCWRC electrofishing survey): Female relative F based on the NCWRC electrofishing survey was calculated for the years 2000–2010 using commercial landings of roes by all gear types from the Neuse River and the female CPUE index from the Neuse River electrofishing survey. Because the electrofishing survey primarily occurs during March through April, only commercial landings from those months were used in the calculations.

What Do the Data Show?

Coastwide harvests in recent years are on the order of 500-900 mt, nearly two orders of magnitude lower than in the late 19th Century (Figure 1). The stocks of American shad in their native range along the North American East Coast are currently at all-time lows (Limburg et al., 2007a:1). These low levels are likely due to a combination of overfishing, elimination of access to historical spawning habitats as a consequence of dam construction, and continued removals via bycatch in ocean fisheries.

North Carolina landings of American shad peaked in 1897 at 4,000 mt (8.8 million lbs) and decreased to 700 mt (1.5 million lbs) by 1918 (Figure 2). A second peak of just over 1,400 mt (3.1 million lbs) was reached in 1928. Landings declined and stabilized from 1930 to 1970 averaging 404 mt (891,000 lbs). Landings have declined since the early 1970s and have remained relatively stable with an average of 128 mt (282,000 lbs) from 1973 to 2005 (Limburg et al., 2007b:128). The following discussion evaluates data for the metrics selected for use in tracking American shad population trends (NCDMF and NCWRC, 2012) for the Albemarle Sound, Tar-Pamlico River, and Neuse River populations.

Albemarle Sound/Roanoke River: Mean statewide commercial harvest from Albemarle Sound since 1973 has been about 3% of the high reported in 1897 (Limburg et al., 2007b:129-130). It should be noted that effort (the number of participants in the fishery and amount of gear set) has dropped considerably and that many regulations were imposed on the fishery relative to season length, gear and allowable fishing areas. The 2007 Atlantic States Marine Fisheries Commission (ASMFC) stock assessment stated that American shad stocks in the Albemarle Sound and Roanoke River were low but stable and suggested a benchmark total mortality rate (Z_{30}) of 1.01 (Limburg et al., 2007b). Annual estimates of Z from the assessment indicate that values have fluctuated around the benchmark since 2000 (NCDMF and NCWRC, 2012).

Regarding recent monitoring in the Albemarle Sound, indices for recent female IGNS and electrofishing captures indicate an increase during the years 2007-2009, with a consequent decline in 2010 (Figures 3a and 3b). With fishery-independent catch data of females tracking the commercial landings data of females fairly closely (Figure 4a), their incorporation in relative fishing mortality (F) metric shows a variable pattern with no trend (Figure 4b). These data confirm the conclusions noted above and below that there has been no consistent directional trend in the Albemarle-Roanoke American shad stock during the last decade.

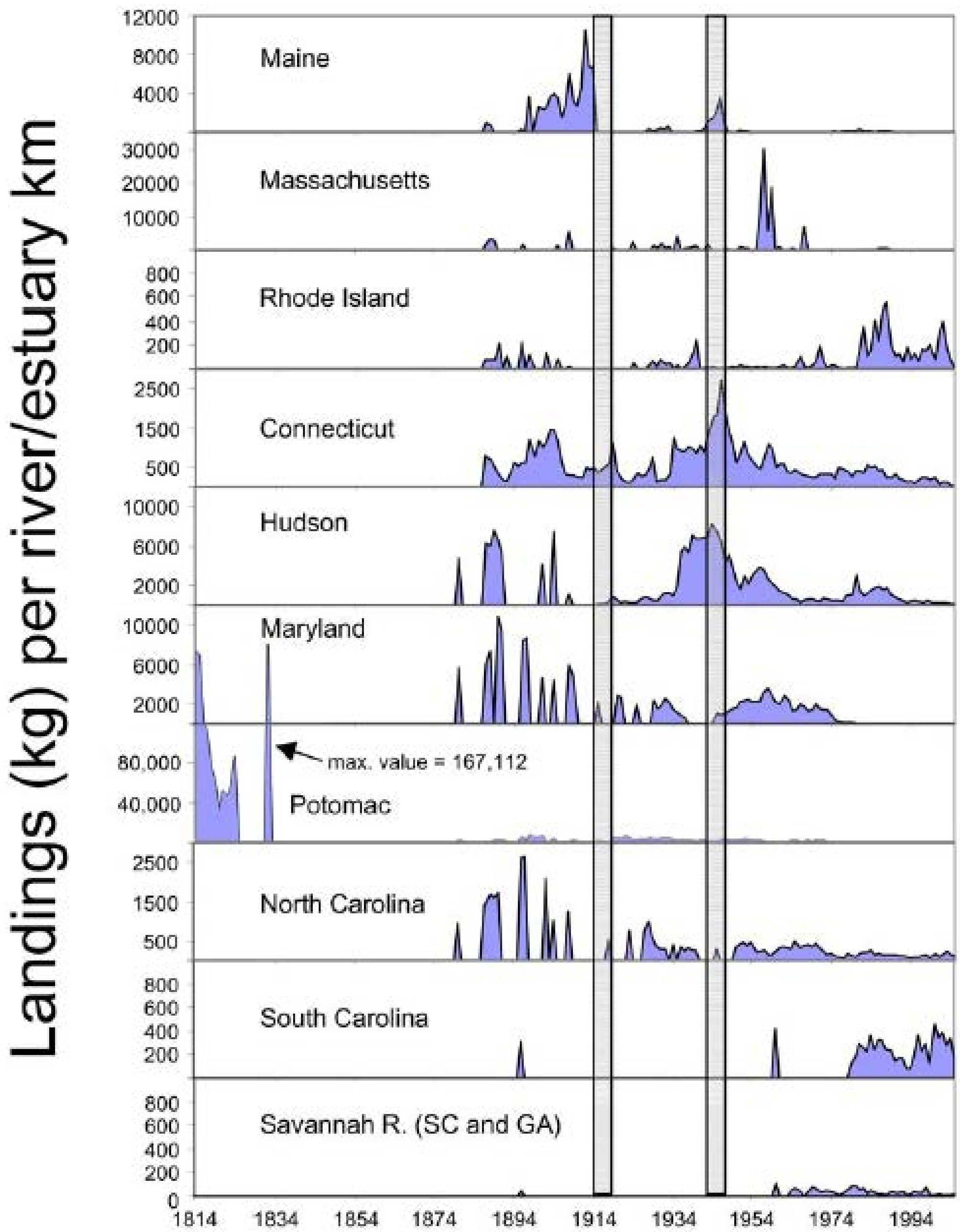


Figure 1. Time trend for American shad landings in North Carolina and other Atlantic states' rivers (1880s-2000s). Landings have been normalized by dividing the distance inland that a shad could migrate through estuaries and rivers from the sea. The two world wars are shown in light gray bars (Limburg et al., 2007a:26).

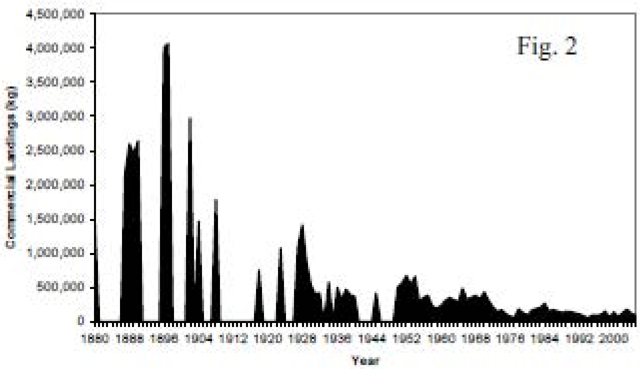


Figure 2. North Carolina commercial landings of American Shad, 1880-2007 (Limburg et al. 2007).

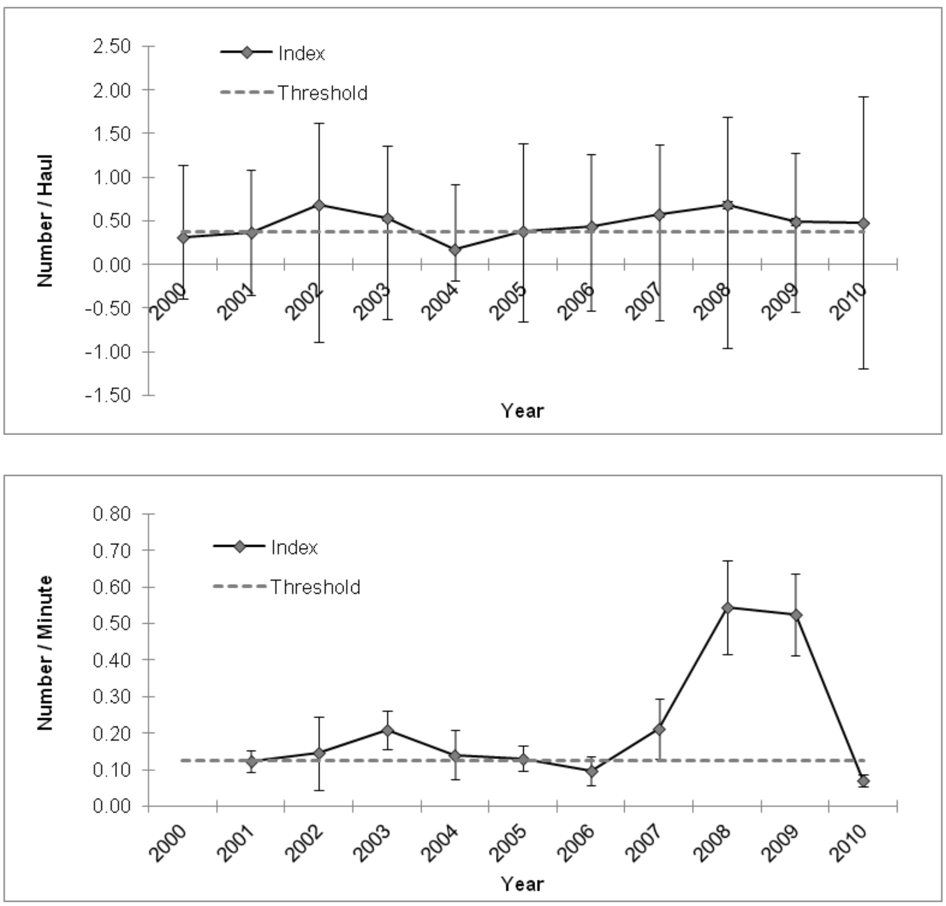


Figure 3. (a, top graph) Female index from IGNS (January–May) for Albemarle Sound, 2000–2010 and (b, bottom graph) female index from electrofishing survey (March–May). The error bars represent ±1 standard deviation. Threshold represents 25th percentile (where 75% of all values are greater).

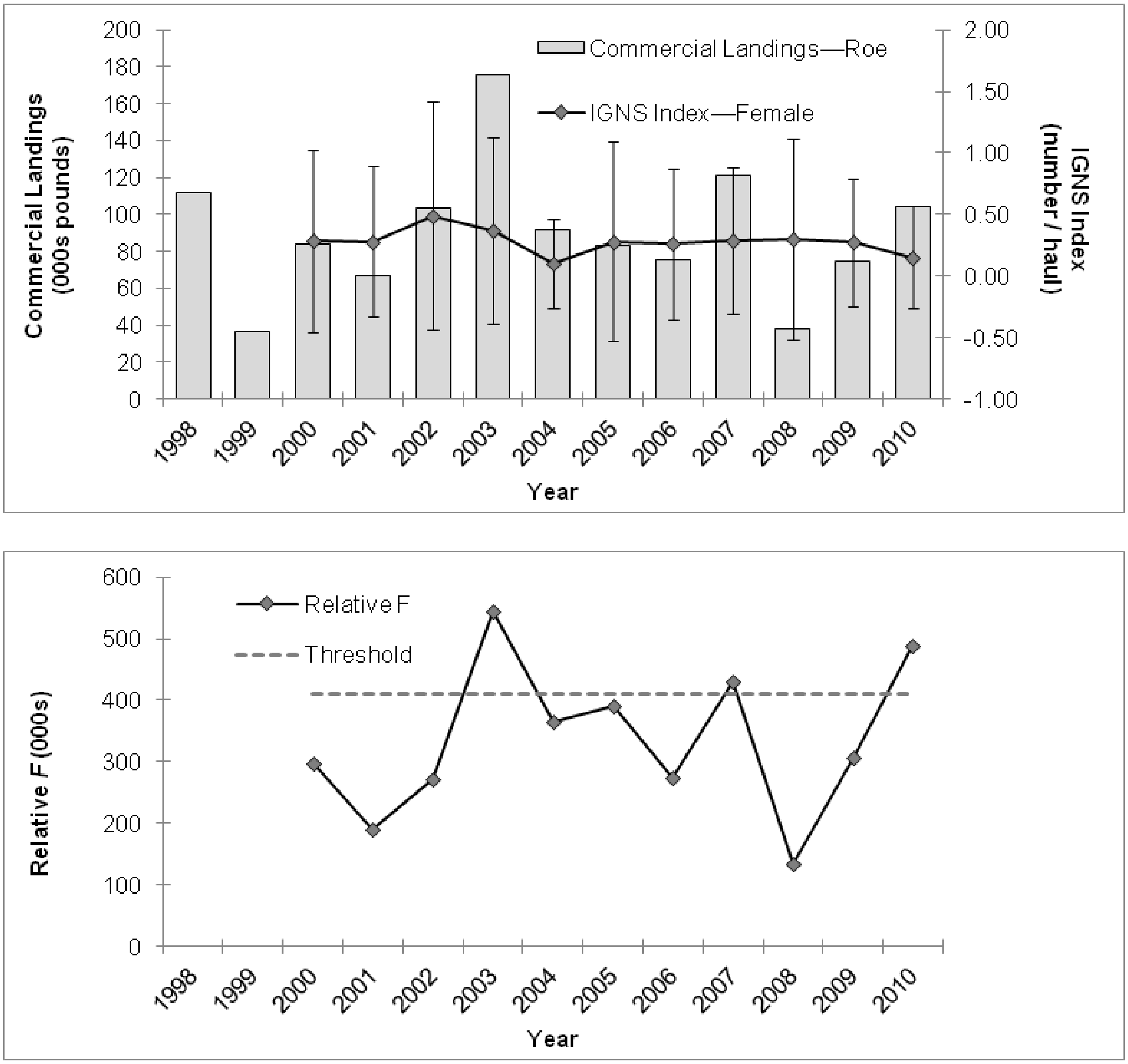


Figure 4. (a, top graph) Commercial gill net landings of roes (February–April) compared to the female IGNS index (5.0, 5.5 and 6.0-inch mesh sizes, February–April) and (b, bottom graph) annual estimates of Female Relative F based on these data for Albemarle Sound, 2000–2010. The error bars in the top graph represent ±1 standard deviation. The threshold represents the 75Th percentile (where 25% of all values are greater).

Tar-Pamlico River: Landings from the Pamlico River were much higher 20 years ago than in recent years. Current landings have been less than 10 mt (22,000 lbs) since the late 1980s. Estimates of total mortality have been relatively high since the mid-1970s. Gill-net CPUE and total effort have remained low and stable since 1994. Electrofishing CPUE on the spawning grounds, however, has been higher in the Tar than in other North Carolina rivers since 2000 (Limburg et al., 2007b:130). Stock status could not be determined for the Tar-Pamlico River based on the 2007 ASFMC stock assessment (Limburg et al., 2007b). There were no definitive trends in abundance, although it was noted that the electrofishing CPUE for the Tar River was higher than in other North Carolina rivers since 2000. A total mortality benchmark (Z_{30}) of 1.01 was suggested.

Regarding recent monitoring in the Tar-Pamlico River, both the electrofishing index (Figure 5) and the commercial gill net landings for females (Figure 6a) show a generally declining trend in abundance since 2003, with the notable exception of commercial gill net landings in 2007. Relative F has been below the selected threshold value for most of the time series except for the last three years when it has increased (Figure 6b). The observed increase is consistent with the observed pattern in commercial gill net landings (Figure 6a).

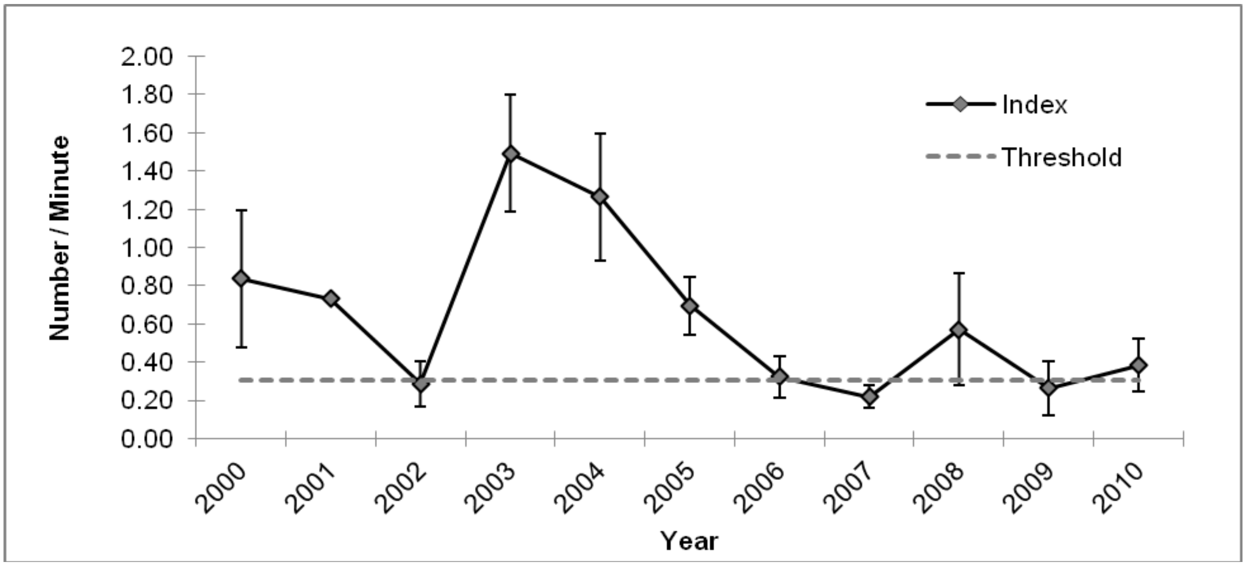
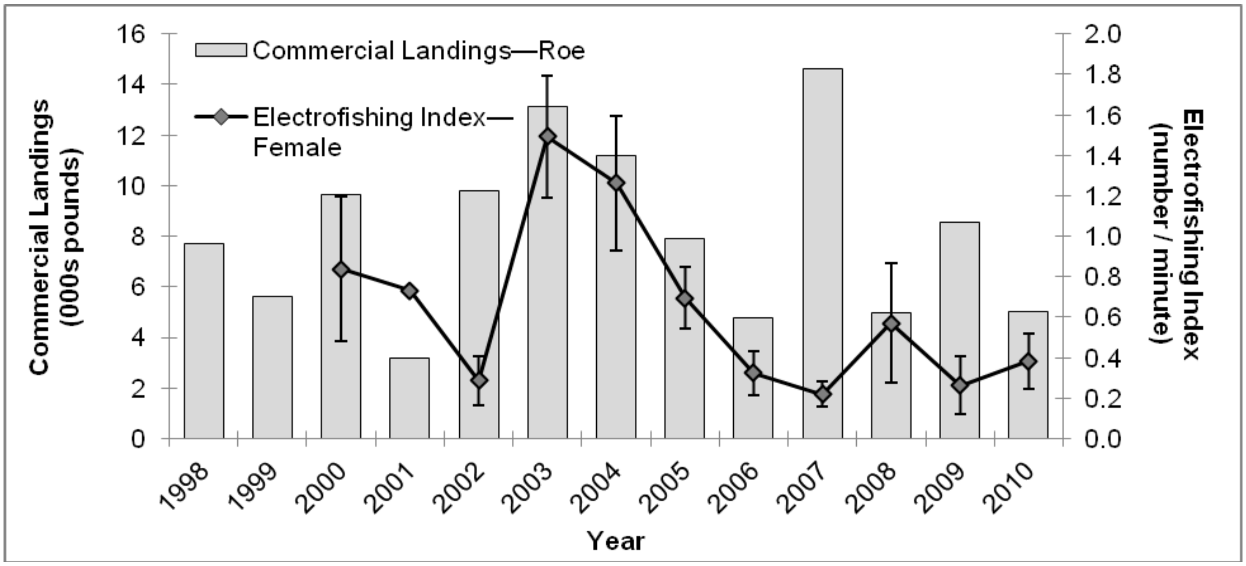


Figure 5. Female electrofishing index (March–May) for the Tar-Pamlico River, 2000–2010. The error bars represent ±1 standard deviation. The threshold represents the 25th percentile (where 75% of all values are greater).



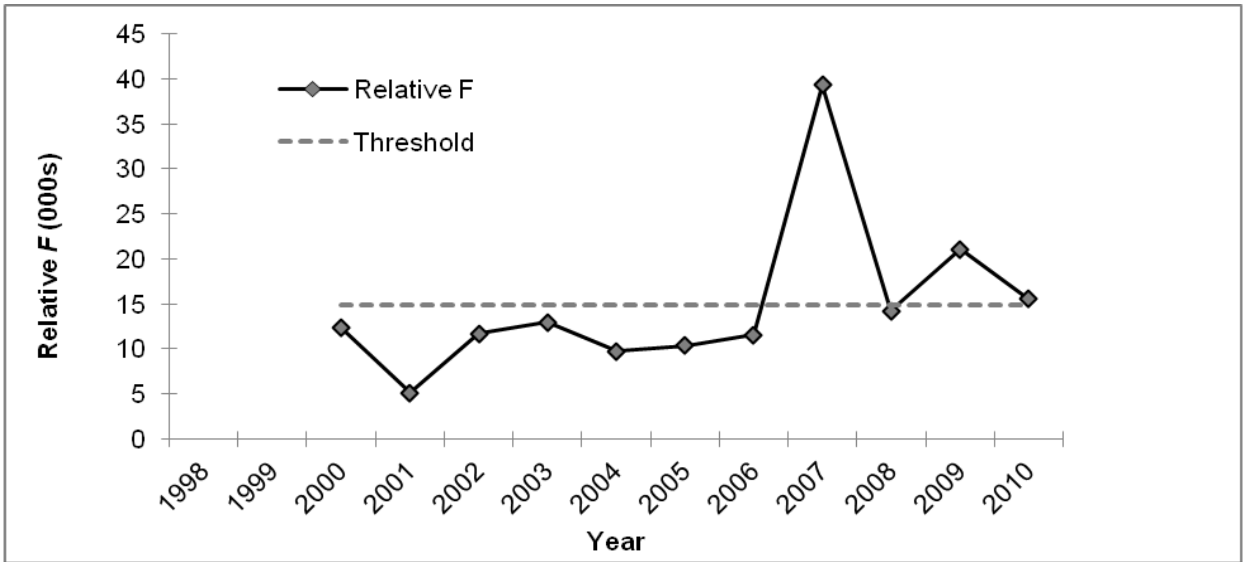


Figure 6. (a, top graph) Commercial landings of roes by all gear types (March–April) compared to the female electrofishing index (March–May) and (b, bottom graph) annual estimates of Female Relative F based on these data for the Tar-Pamlico River, 2000–2010. The error bars in the top graph represent ±1 standard deviation. The threshold represents the 75th percentile (where 25% of all values are greater).

Neuse River: Adequate historical harvest data specific to the Neuse River are not available to provide perspective to current landings. Landings displayed several peaks since 1972, but peaks were progressively lower (Limburg et al., 2007b:131). Stock status could not be determined for the Neuse River based on the 2007 ASFMC stock assessment (ASMFC, 2007b). There were no definitive trends in abundance over the most recent five to ten years of the assessment. A total mortality benchmark (Z_{30}) of 1.01 was suggested (ASMFC, 2007a).

Regarding recent monitoring in the Neuse River, electrofishing CPUE values have increased and decreased, with a decreasing trend the last three years (Figure 7), which corresponds to the commercial gill net catches which also trended down for the last three years of the series (Figure 8a). Relative F has been increasing for the last three years (Figure 8b).

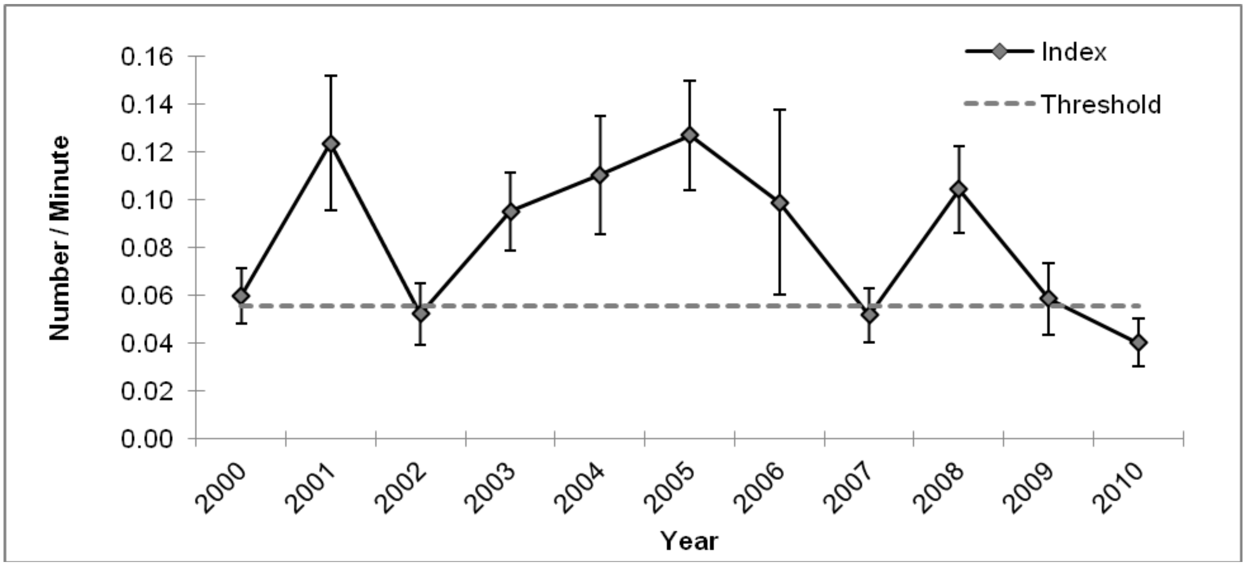
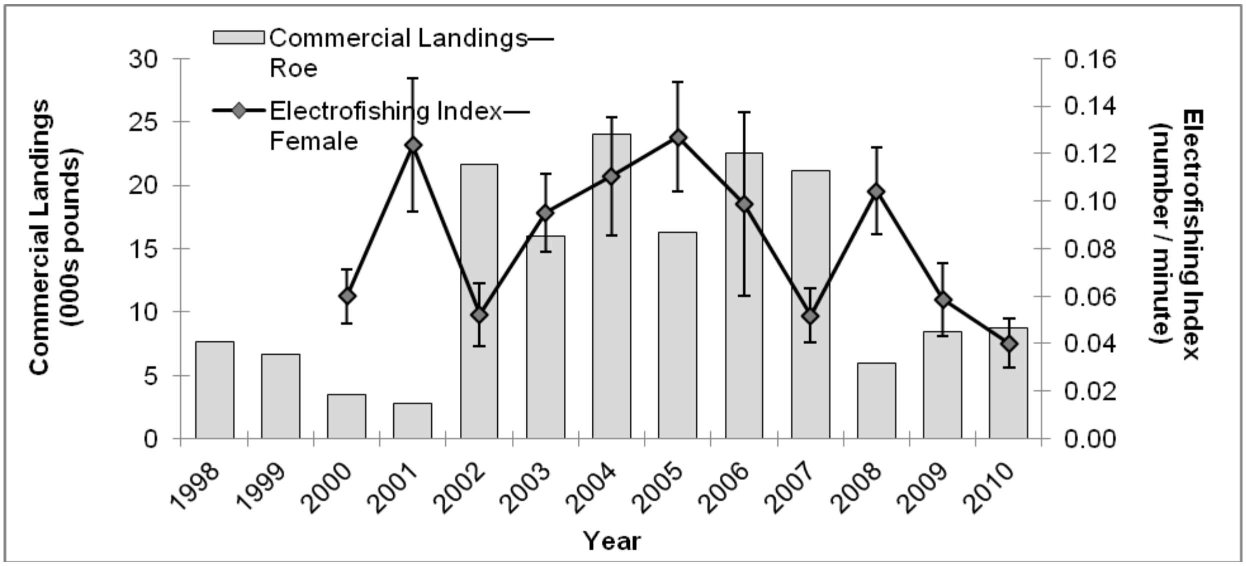


Figure 7. Female electrofishing index (March–May) for the Neuse River, 2000–2010. The error bars represent ±1 standard deviation. The threshold represents the 25th percentile (where 75% of all values are greater).



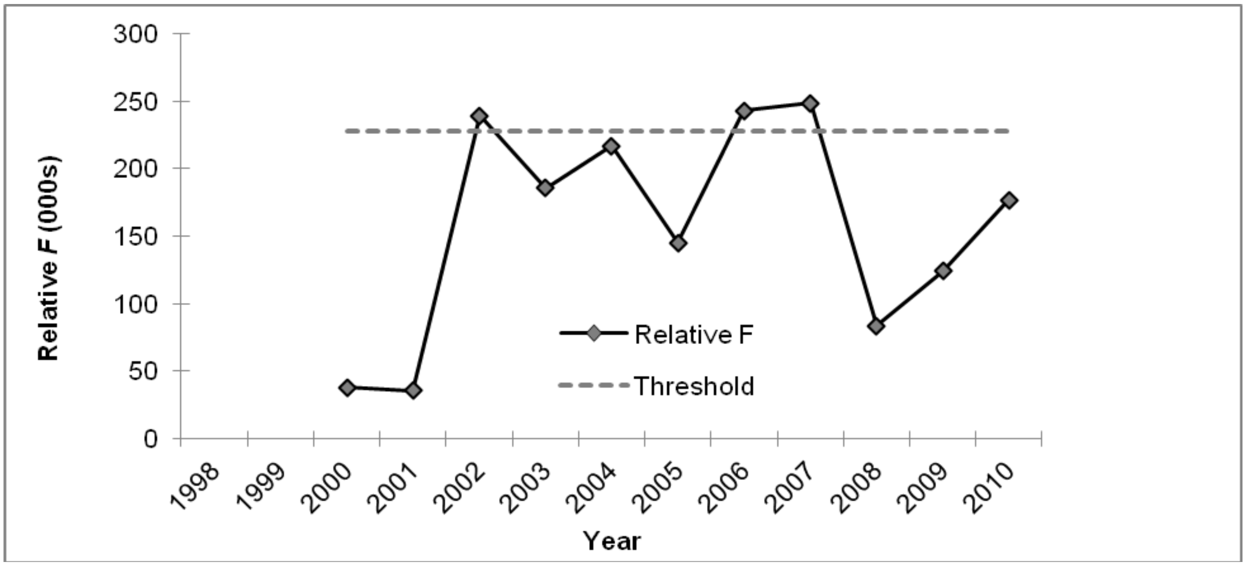


Figure 8. (a, top graph) Commercial landings of roes by all gear types (March–May) compared to the female electrofishing index (March–May;) and (b, bottom graph) annual estimates of female relative F based on these data for the Neuse River, 2000–2010. The error bars in the top graph represent ±1 standard deviation. The threshold represents the 75th percentile (where 25% of all values are greater).

Why Can't This Entire Indicator Be Reported at This Time?

Additional metrics for American shad may be added, pending further discussions with the NCDMF and NCWRC, should they be validated. It is desirable, for example to have some indicator of annual year class strength; however, the existing juvenile abundance indices are not felt by NCDMF and NCWRC to adequately reflect year class strength (M. Duval, NCDMF; S.E. Winslow, NCDMF retired, and B. Wynne, NCWRC, personal communication). Historical reconstructions (Hightower et al., 1996) may help to establish a baseline and benchmarks against which to measure recovery. The late 19th century harvests have been suggested as a baseline, but there is evidence that even these fisheries were conducted on depleted populations (Limburg et al., 2007a:25).

Understanding the Data

Shad spend most of their life at sea, emigrating from rivers and estuaries to the ocean in the fall as young-of-year, and returning to their natal river system only when sexually mature. By April, shad runs reach their peak in North Carolina. Adult shad spend summers in northwestern Atlantic waters as far north as the Gulf of Maine, the Bay of Fundy and off the coast of Nova Scotia. In the fall, they begin a southward migration to over-wintering areas off of Maryland, Virginia, and North Carolina. (Limburg et al., 2007b:3-7). American shad populations in North Carolina river systems south of Albemarle Sound occupy a region where stocks transition from the iteroparous (spawning more than once) stocks of the north to the semelparous (die after spawning once) stocks seen in the south. American shad are fully sexually mature at ages 7 or 8 in Albemarle Sound, while shad in other North Carolina systems reach full maturity at ages 6 or 7 (Limburg et al., 2007b:128).

Albemarle Sound/Roanoke River: While harvest levels in the late 1800s are useful as an indicator of stock size, they were likely not sustainable and should not be viewed as a goal for future harvest. Since landings from the Albemarle Sound fishery have made up a significant portion of statewide landings since the late 1980s, it is reasonable that current abundance in Albemarle Sound and its tributaries is well below the historic potential for these stocks. Current landings are much less than the maximum sustainable yield (MSY) of 1000-2000 mt (2.2- 4.4 million lbs) estimated for these stocks by Hightower and others (Limburg et al., 2007b:129-130).

Tar-Pamlico: Current status of American shad of the Tar-Pamlico River remains unknown. It is unknown whether the decline in landings is related to a decline in effort or to other factors. Historical data are needed to provide perspective on the potential harvest from this system. Electrofishing CPUE on the spawning grounds being higher in the Tar than in other North Carolina rivers since 2000 may be a function of stream size and physical configuration of the sampling sites, and not necessarily due to higher abundance. Apparently, mortality levels are high enough to keep the stock depressed, but not high enough to lead to stock collapse (Limburg et al., 2007b:130).

Neuse River: Effort data are not available for the entire time series making it difficult to determine whether declining stock size or effort caused the reduction. Years of increased effort generally corresponded to years of increased harvest with the exception of the last few years when effort remained high but catch and CPUE declined. The recent decline in CPUE also corresponded to relatively high estimates of total mortality and a decline in mean length (Limburg et al., 2007b:131).

Since the late 19th century, shad stocks declined along the Atlantic coast due to a combination of overfishing, pollution, and habitat loss due to dam construction (Hogarth et al., 1991:20, Limburg et al., 2007b:1). Although it may never be known definitively why American shad catches declined so precipitously in the early 20th century, there is ample evidence that raw sewage and other noxious pollution became severe and persistent in the period of the 1890s through the 1920s (Limburg et al., 2007:24).

From the 1920s to the late 1950s, fewer limits were placed on commercial fishing within the Albemarle-Pamlico system (e.g., there were some regulations relative to gear, areas and seasons, but no mesh size or yardage limits, shorter seasons, or closed areas). An area closure was instituted in 1988 for a portion of Albemarle Sound, along with gill net mesh restriction in other areas. Further rules were adopted in 1995 that made it unlawful to take American shad for commercial purposes by any method from April 15 through January 1. North Carolina’s ocean-intercept fishery was closed in 2005. Recreational fishermen in designated Joint and Coastal waters can harvest up to 10 shad per person per day by hook and line (Limburg et al., 2007b:128), but anglers in the inland waters of the Roanoke and Neuse rivers may only harvest one per day.

FISH POPULATIONS: STURGEON ABUNDANCE

Dean Carpenter[22] and Wilson Laney[23]

Why Is the Status of Sturgeon Important?

Two species of sturgeon historically occurred in the Albemarle-Pamlico Estuarine System (APES): the Atlantic sturgeon, *Acipenser oxyrinchus*, and the shortnose sturgeon, *Acipenser brevirostrum*. There are two subspecies of Atlantic sturgeon: *Acipenser oxyrinchus oxyrinchus*, which is distributed along the eastern coast of North America, and Gulf sturgeon, *Acipenser oxyrinchus desotoi,* which historically ranged from the Mississippi River to Tampa Bay (NMFS, 2010:61905).

Atlantic sturgeon is a long-lived, late maturing, estuarine-dependent, anadromous species. Atlantic sturgeon may live up to 60 years, reach lengths up to 4.3 m (14 ft), and weigh over 360 kg (800 lbs). (NMFS, 2010:61905). The age at maturity for Atlantic sturgeon in the Albemarle-Pamlico system is likely greater than for those in South Carolina (maturity at 5-19 years) (Smith *et al.,* 1982) but likely less than those of the Hudson River (maturity at 11-21 years) (NMFS, 2010:61906). The shortnose sturgeon is the smallest of the sturgeon species occurring in eastern North America, living 50–60 years, attaining maximum lengths of about 1.2 m (4 ft) and weights of 24 kg (49 lbs) (Dadswell et al., 1984 in Cope et al., 2011:1).

Although adult and sub-adult Atlantic sturgeon originating from different rivers mix in the marine environment (Stein et al., 2004a), the vast majority of Atlantic sturgeon return to their natal rivers to spawn (NMFS, 2010:61908). Atlantic sturgeon are not believed to spawn every year. Multiple studies have shown that spawning intervals range from 1-5 years for males (Smith, 1985; Collins et al*.,* 2000; Caron et al*.,* 2002 in NMFS, 2010:61906) and 2-5 years for females (Vladykov and Greeley, 1963; Van Eenennaam et al., 1996; Stevenson and Secor, 1999 in NMFS, 2010:61906). Recent spawning has been confirmed in the Roanoke and Tar-Pamlico Rivers based on incidents of hook-and-line capture of young-of-year fish, and the Neuse River has a possible, but unconfirmed, spawning population (NMFS, 2010:61906). Based on published spawning temperature ranges, shortnose sturgeon would be expected to spawn in the Roanoke River and other APES tributaries during March or early April whereas Atlantic sturgeon would be expected to spawn in April or early May (Hewitt, 2003:25). Recent (September 2010 and 2011) captures of running ripe males in the fall indicate a possible fall spawning run in the Roanoke River (J. Flowers, NCSU, personal communication).

Sturgeon are omnivorous benthic (bottom) feeders and filter large quantities of bottom sediments in search of their food. Adult sturgeon diets include mollusks, gastropods, amphipods, isopods, and fish. Juvenile sturgeon feed on aquatic insects and other invertebrates (ASSRT, 2007 in NMFS, 2010:61905).

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Shortnose sturgeon was listed by the United States government as an endangered species in 1967, and remains imperiled throughout its range (NMFS, 1998). Currently, 19 distinct population segments are known between Florida and Canada, and two of these segments occur in coastal North Carolina (NMFS, 1998; Armstrong, 1999 in Cope et al., 2011:1) Shortnose sturgeon was regarded as extirpated from the Roanoke River/Albemarle Sound region prior to the capture of a single adult in 1998 (Armstrong, 1999). The only other published record of the species in the Albemarle Sound region is a juvenile museum specimen collected in 1881 (Vladykov and Greeley, 1963 in Cope et al., 2011:1). The distinct "Carolina" population segment of Atlantic Sturgeon that includes those inhabiting the APES was included in a proposed endangered listing by the United States government in October 2010 (NMFS, 2010) and the NMFS published a Final Rule in February 2012 (NMFS, 2012).

Sturgeon were historically a significant ecological, cultural and economic component of the APES, and the intent of state and federal resource management agencies is that they will be so once again. Large Atlantic sturgeon have limited vulnerability to other predators, except humans. Both of the sturgeon species were historically a valuable source of food in the form of caviar (Donaldson and Cramer, 1971 in Hewitt, 2003:6) and smoked flesh. Oral tradition has sturgeon present in the Nottoway River (Chowan Basin), and documents from the Hand Site excavation in the 1960s recorded sturgeon bone or scales in Nottoway Indian fire pits (J. Turner, Blackwater Nottoway Riverkeeper Program, personal communication). Finally, sturgeon are of potential significance for ecotourism. In some parts of their range, because sturgeon often jump from the water, there is a growing human interest in viewing and recording this phenomenon. Because of their absolute dependence upon clean water and bottom sediments for successful spawning and feeding, sturgeon may be viewed as a key ecosystem health indicator species.

Ecosystem Service(s): Provisioning (Seafood); Cultural (Ecotourism, Recreational); Ecological (Nutrient transfer from marine to freshwater ecosystems).

What Does This Indicator Report?

- Abundance Metric: Catch per unit effort of sturgeon in NCDMF Albemarle Sound Fishery Independent Gill Net Survey (NCDMF Program 135)

- Abundance Metric: Catch per unit effort of sturgeon in NCDMF Fisheries Independent Assessment (NCDMF Program 915, Pamlico Sound, and Pamlico/Neuse Rivers components).

What Do the Data Show?

Historical records from the 1700s and 1800s document large numbers of sturgeon in many rivers along the Atlantic coast. The species persisted in many rivers, though at greatly reduced levels (1 to 5 percent of their earliest recorded numbers), and commercial fisheries were active in many rivers during all or some of the years 1962 to 1997. Historically, Atlantic sturgeon were abundant in most North Carolina coastal rivers and estuaries, with the largest fisheries occurring in the Roanoke River/Albemarle Sound system and in the Cape Fear River (Kahnle et al., 1998). Historical landings records from the late 1800s indicated that Atlantic sturgeon were very abundant within Albemarle Sound (approximately 61,500 kg [135,600 lbs] landed annually). Abundance estimates derived from these historical landings records indicated that between 7,200 and 10,500 adult females were present within North Carolina prior to 1890 (Armstrong and Hightower, 2002; Secor, 2002).

The North Carolina Division of Marine Fisheries (NCDMF) has conducted the Albemarle Sound Independent Gill Net Survey (IGNS), initially designed to target striped bass, since 1990 (Figure 1). During that time, 842 young-of-the-year (YOY) and sub-adult sturgeon have been captured. Incidental take of Atlantic sturgeon in the IGNS, as well as multiple observations of YOY from the Albemarle Sound and Roanoke River, provide evidence that spawning continues; catch records indicate that this population seemed to be increasing until 2000, when recruitment began to decline. Catch records and observations from other river systems in North Carolina exist (e.g., Hoff, 1980; Oakley, 2003, in the Tar and Neuse Rivers). (NMFS, 2010:61906)

Juvenile and sub adult abundance data for Atlantic Sturgeon are now available through 2009 (Table 1). There was a drop in abundance in 2002 and 2003; however from 2004 through 2009 there has been much improvement, with 2008 being one of the three highest abundance years in the time series (Figure 2, Table 1). (Daniel, 2010:5).

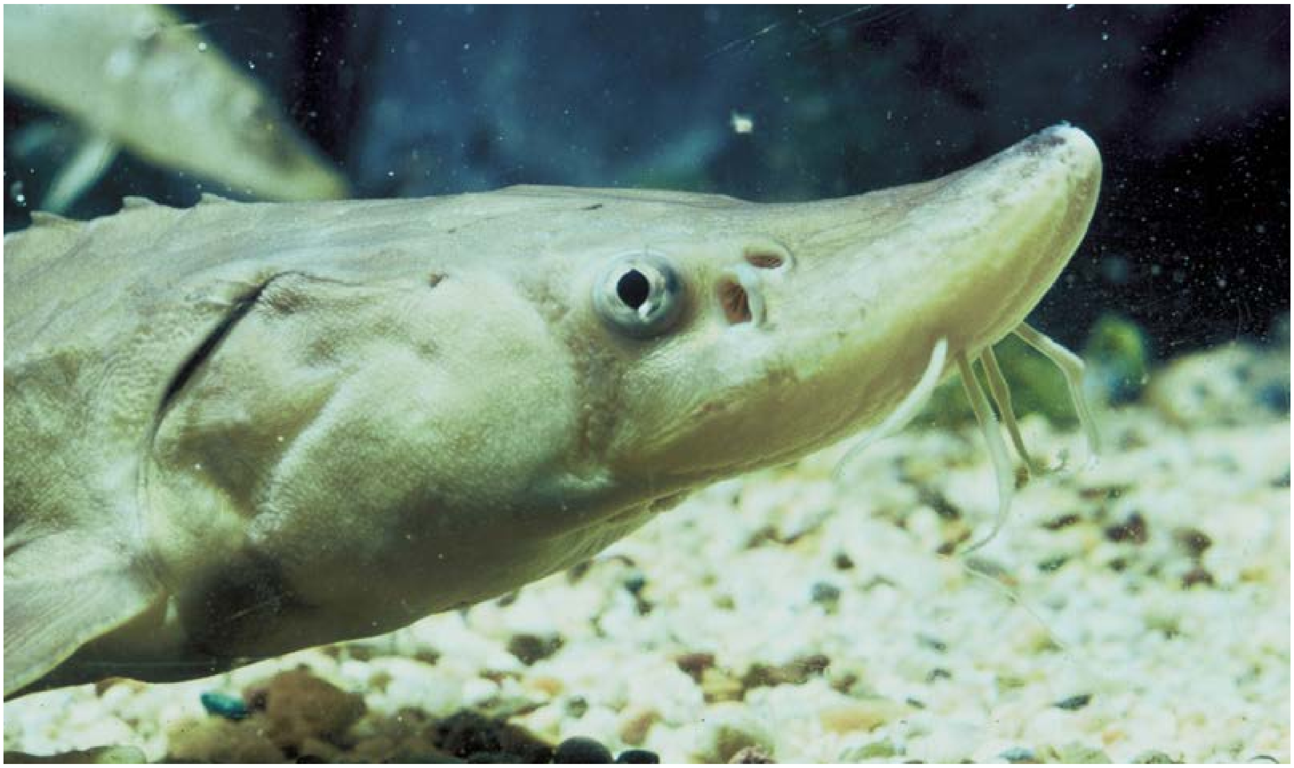

Image courtesy of the U.S. Fish and Wildlife Service

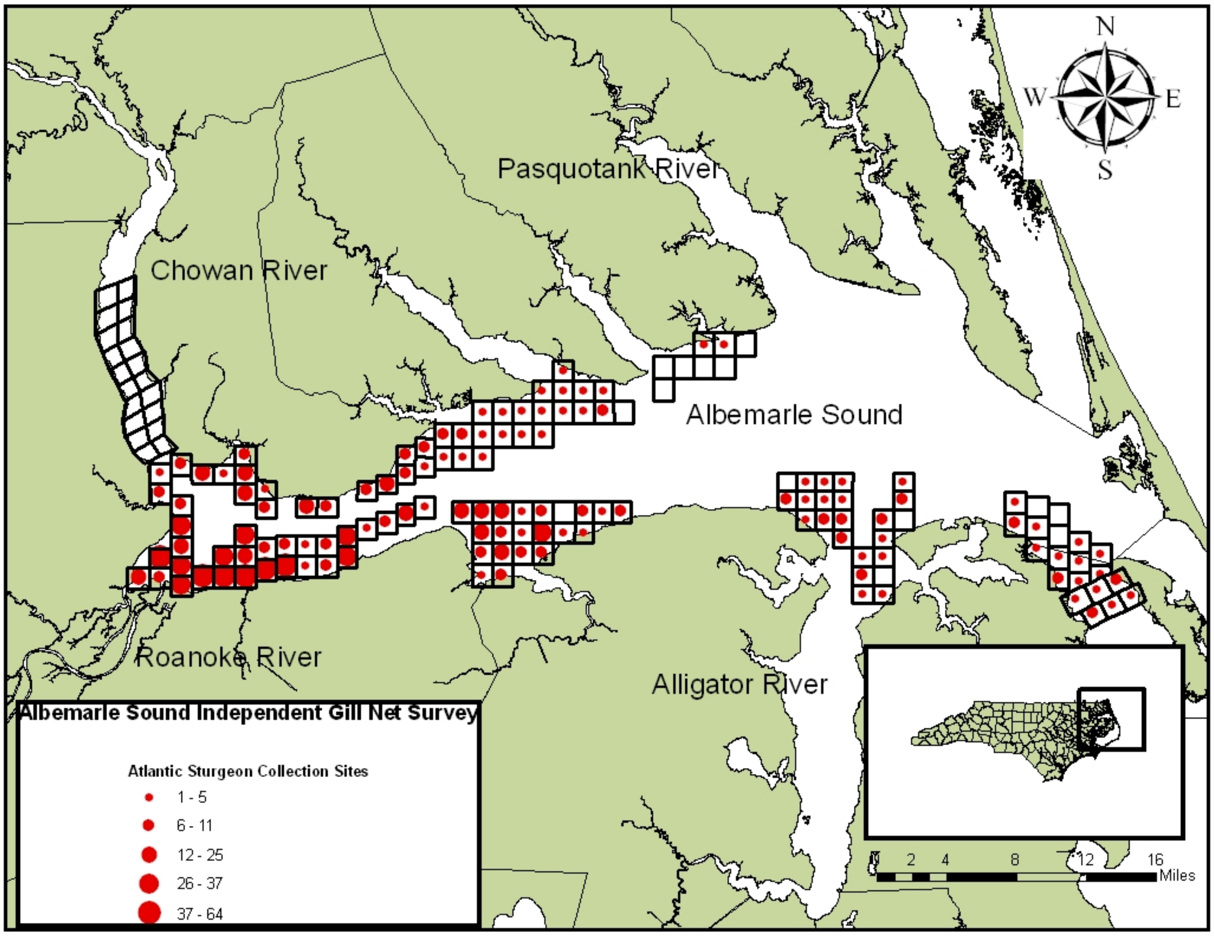

Figure 1. Albemarle Sound Independent Gill Net Survey sampling locations and collections of Atlantic sturgeon, NC, 1990-2011 (Daniel, 2010:21; Loeffler, 2012).

Table 1. Albemarle Sound Independent Gill Net Survey catch per unit effort (CPUE) and percent mortality of Atlantic sturgeon by year, NC, 1990-2011 (Daniel, 2010:15; Loeffler, 2012). The CPUE value for 1990 was based on only two months of sampling (October-November).

Year	Effort	# of Atl. Sturgeon	CPUE	# of Mortalities	% Mortality
1990	693	56	0.081	0	0
1991	5,155	60	0.012	0	0
1992	5,914	27	0.005	0	0
1993	5,237	31	0.006	0	0
1994	4,305	43	0.010	0	0
1995	4,264	21	0.005	0	0
1996	4,230	27	0.006	0	0
1997	4,256	61	0.014	0	0
1998	4,187	92	0.022	0	0
1999	4,332	55	0.013	1	2
2000	4,297	139	0.032	0	0
2001	4,151	132	0.032	0	0
2002	4,176	29	0.007	2	7
2003	4,464	21	0.005	4	19
2004	4,172	30	0.007	2	7
2005	4,094	48	0.012	2	4
2006	4,081	63	0.015	2	3
2007	4,143	71	0.017	3	4
2008	4,088	128	0.031	13	10
2009	3,817	56	0.015	5	9
2010	3,639	32	0.009	3	9
2011	3,728	47	0.013	2	4
Total	91,423	1,270	0.014	39	3

- 1 unit of effort is a 40 yard net fished for 24 hours
- Nets consist of 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 8.0, 10.0 ISM
- Fishing during June through October only occurred from 1991-1993
- Effort increases to 7 days a week March – May
- Effort for 1990 was only October – December

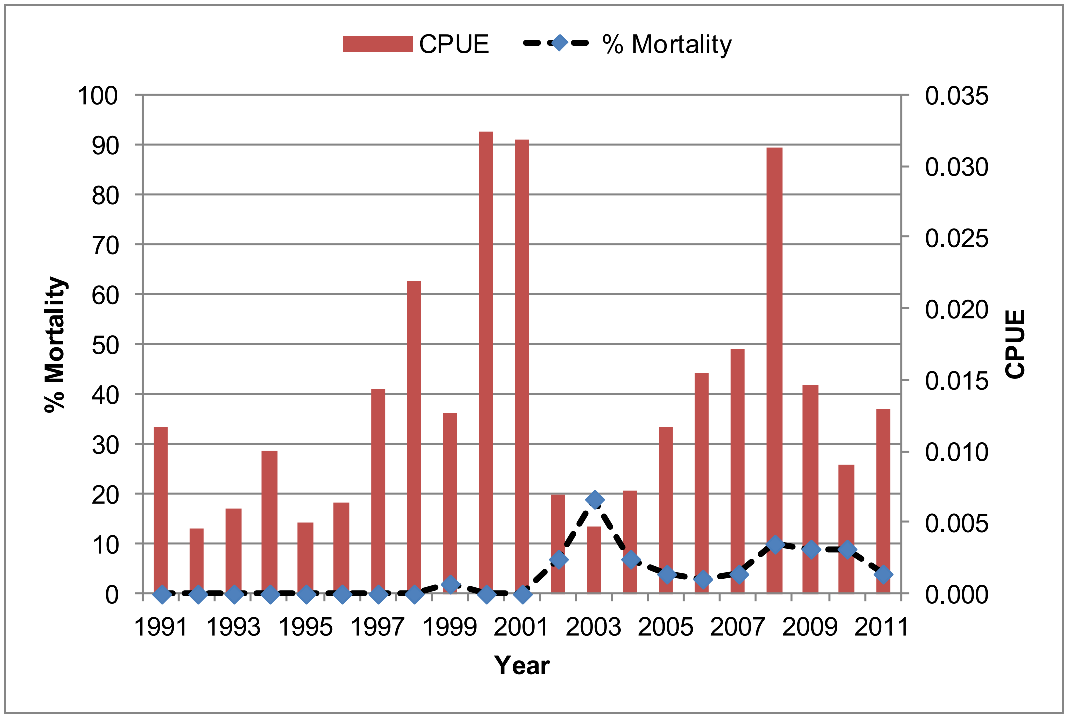

Figure 2. Albemarle Sound Independent Gill Net Survey percent mortality and catch per unit effort (CPUE) of Atlantic sturgeon by year, NC, 1991-2011 (Daniel, 2010:22; Loeffler, 2012).

- 1 unit of effort is a 40 yard net fished for 24 hours
- Nets consist of 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 8.0, 10.0 ISM
- Fishing during June through October only occurred from 1991-1993
- Effort increases to 7 days a week March – May
- Effort for 1990 was only October - December

Why Can't This Entire Indicator Be Reported at This Time?

The indicator does not estimate the total abundance of Atlantic sturgeon of all life stages and age classes within the system. The location of the spawning grounds remains undetermined. Current research being conducted by M. Loeffler, J.E. Hightower and J. Flowers (NCDMF, USGS and NCSU) may determine the location of the spawning grounds, and should reveal much about Atlantic sturgeon movement and migration within AP estuary and tributary rivers. Very small juvenile sturgeon are difficult to capture, so little is known about their distribution and habitat use within the system. There is also presently no indicator that tracks the abundance of adult Atlantic sturgeon in the system, either on the presumptive spawning grounds, or downstream in the estuary. The federal and state fishery management agencies (NCDMF, NCWRC, NMFS and USFWS) and other partners (Virginia Electric and Power Company, doing business as Dominion Virginia Power/North Carolina Power, NCSU, and USGS) collaborated to sample Atlantic sturgeon on potential spawning grounds in the Roanoke River in Fall 2010. Consideration is being given to continuing this sampling program.

The fishery independent gill net sampling programs conducted by NCDMF began in 1991, at the time of the last APES status report (Hogarth et al., 1991), but data on sturgeon were too sparse to make meaningful inferences. Historic commercial fishing records were truncated due to closure of the fishery for both species.

Understanding the Data

Atlantic sturgeon underwent significant range-wide declines relative to historical abundance levels due to overfishing in the late 1800s (NMFS, 2010:61906), including the international caviar craze of the 1890s (Secor and Waldman, 1999 in Limburg and Waldman, 2009:961). Sturgeon stocks were further impacted through environmental degradation, especially due to habitat access loss and reduced water quality from the construction of dams in the early to mid-1900s. (NMFS, 2010:61906). Despite regulatory protection, accidental bycatch in commercial fisheries threatens sturgeons at present (Stein et al., 2004, ASMFC, 2007; Limburg and Waldman, 2009:961).

The state of North Carolina recognized the importance of this species to the state and coastal ecosystem and was proactive before many other Atlantic coast states by implementing a state wide moratorium on Atlantic sturgeon harvest in 1991 (Daniel, 2010:1). State status for shortnose sturgeon concurs with the federal listing as endangered. A moratorium on Atlantic Sturgeon fishing in US waters was imposed in 1997 (Limburg and Waldman, 2009:963). The Atlantic States Marine Fisheries Commission (ASMFC) in 1998 completed Amendment 1 to the 1990 Atlantic Sturgeon Fishery Management Plan (FMP) that imposed a 20- to 40-year moratorium on all Atlantic sturgeon fisheries until the Atlantic Coast spawning stocks could be restored to a level where 20 subsequent year classes of adult females were protected (ASMFC, 1998; NMFS, 2010:61905).

Chapter 4 - Coasts, Sounds, and Near-Marine

Chapter 4: Coasts, Sounds, and Near-Marine

This chapter features eight assessments of the ecosystem type "Coasts, Sounds, and Near-Marine", including assessments of:

- two indicators of the major category "Extent and Pattern":
  - Submerged Aquatic Vegetation Extent,
  - *Phragmites australis* Extent;
- four indicators of the major category "Chemical and Physical Characteristics":
  - Relative Sea Level,
  - Ocean Shoreline Migration,
  - Estuarine Shoreline Migration,
  - Estuarine Salinity Concentration; and
- two indicators of the major category "Biological Components":
  - Shellfish Closures,
  - Unusual Fish Mortalities.

EXTENT OF SUBMERGED AQUATIC VEGETATION

Dean Carpenter[24], Jud Kenworthy[25], Don Field[26]

Why Is the Extent of Submerged Aquatic Vegetation Important?

Underwater vascular plants are key components of aquatic ecosystems that play multiple roles in keeping Albemarle-Pamlico Estuarine System (APES) waters healthy by providing habitat, food, and shelter for aquatic life, absorbing and recycling nutrients and filtering sediment, and acting as a barometer of water quality (Thayer et al., 1984). More commonly called "submerged aquatic vegetation" (SAV) these plants enrich shallow aquatic environments around the world, providing sanctuaries for crabs and finfish, and sustenance for waterfowl (Bergstrom et al., 2006:2). SAV includes marine, estuarine, and riverine vascular plants that are rooted in sediment (Deaton et al., 2010:223) and is one of five types of aquatic plants in APES waters, the others being floating aquatic vegetation, emergent aquatic vegetation, micro- and macroalgae, and blue-greens (cyanobacteria) (Bergstrom et al., 2006:2). Because SAV are rooted in anaerobic sediments, they need to produce a large amount of oxygen to aerate the roots, and therefore have the highest light requirements of all aquatic plants (Deaton et al., 2010:223). SAV can become stressed by eutrophication and other environmental conditions which impair water transparency and/or diminish the oxygen content of water and sediments. The plant's response to these factors enables them to be sensitive bio-indicators of environmental health (Biber et al., 2004).

While more than 500 species of SAV inhabit the world's rivers, lakes, estuaries, and oceans (Bergstrom et al., 2006:2), APES and its tidal tributaries are home to about 14 common species (Deaton et al., 2010:222). High salinity (18-30 ppt) species in APES include the temperate species, eelgrass (*Zostera marina*) and tropical species, shoal grass (*Halodule wrightii*). Brackish (5-18 ppt) species include widgeongrass (*Ruppia maritima*) and the co-occurrence of these three species is unique to North Carolina (Deaton et al., 2010:223). Low salinity (0-5 ppt) species are diverse and include wild celery (*Vallisneria americana*), Eurasian milfoil (*Myriophyllum spicatum*), busy pondweed (*Najas guadalupensis*), redhead grass (*Potamogeton perfoliatus*), and sago pondweed (*Potamogeton pectinatus*) (Deaton et al., 2010:223, 227-228). Beds of SAV occur here in subtidal water generally < 2m deep, and occasionally intertidal areas of sheltered estuarine and riverine waters where there is unconsolidated substrate (loose sediment), adequate light reaching the bottom, and moderate to negligible current velocities or wave turbulence (Thayer et al., 1984; Ferguson and Wood, 1994 in Deaton et al., 2010:224). SAV coverage ranges from small isolated patches less than a meter in diameter to continuous meadows covering many acres.

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Because SAV distribution, abundance, and density varies seasonally and annually in response to climatic variability coupled with its sensitivity to other stressors, large-scale SAV changes may occur. The major threats to SAV habitat include channel dredging and water quality degradation from excessive nutrient and sediment loading, plus the emerging threat of accelerated sea level rise, barrier island stability, and increasing water temperatures (Deaton et al., 2010:270). The high value of this resource through its multiple ecosystem services makes it essential that we have the ability to detect any onset of dramatic declines or of positive responses from APNEP protection and restoration activities via regular monitoring of this indicator.

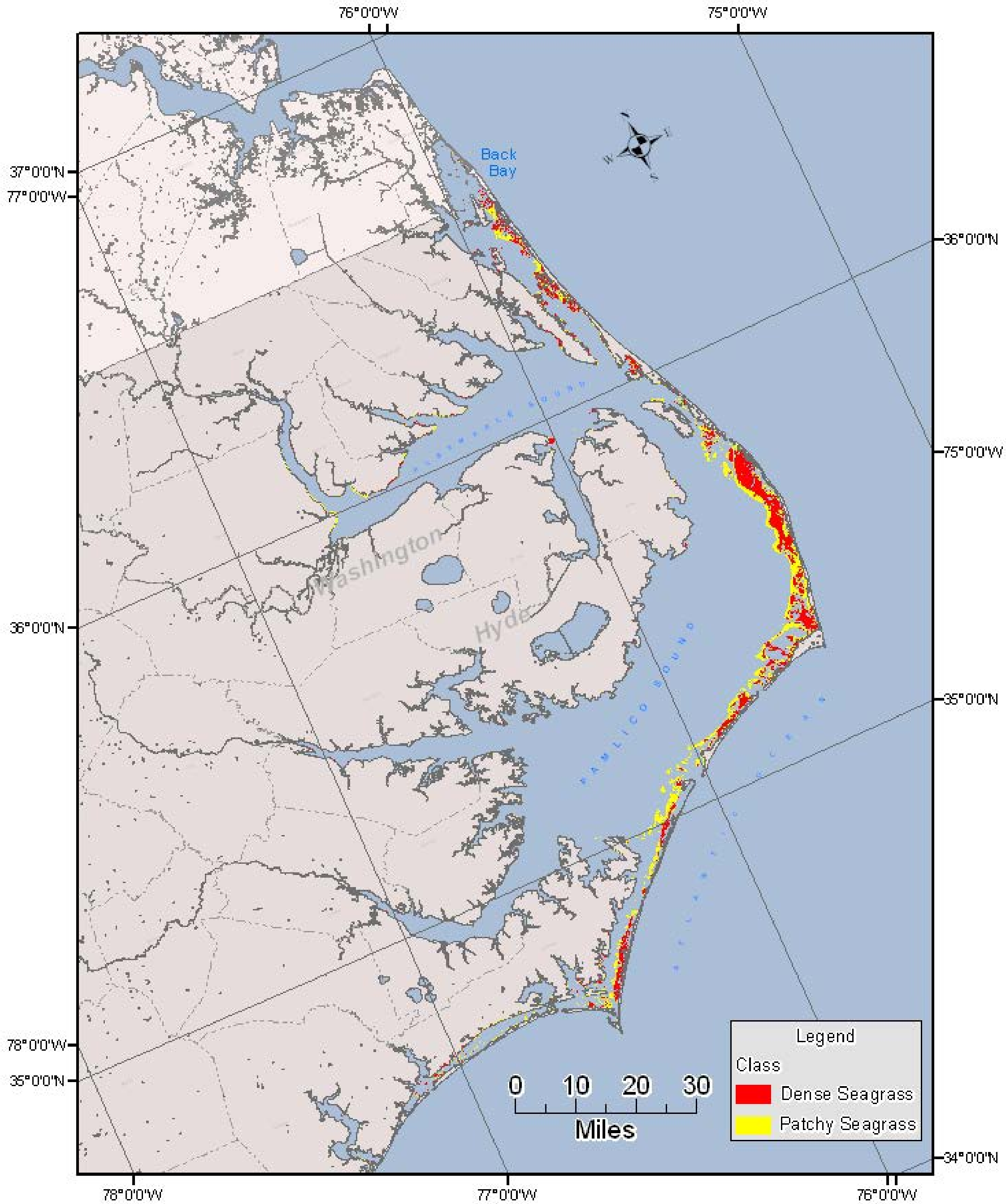

Figure 1. SAV location by density class in the APES, 2006-2008.

What Does This Indicator Report?

This indicator provides the extent and location of SAV by density class (dense, patchy, sparse to none) during the years 2006-2008.

What Do the Data Show?

The extent of visible SAV in the APES for the 2006-2008 sample period, excluding impounded beds, was 137,951 acres, or 99.6% of the total acreage visible SAV delineated from the APES coasts south to the South Carolina border (see Figure 1). The extent values by APES sub-region and density class is furnished in Table 1.

Table 1. Extent of visible SAV during 2006-2008 within APES reporting regions (acres).

	Chowan	Lower Neuse	Pamlico	White Oak	East Albemarle, Croatan Sound	Lower Roanoke	Pamlico Sound	South Coastal	West Albemarle	**TOTAL**
Dense	82	1,046	165	8,786	14,701	4	44,695	7	1,075	70,561
Patchy	598	1,909	52	10,572	9,789	92	42,511	53	1,814	67,390
TOTAL	680	2,955	217	19,358	24,490	97	87,206	60	2,890	137,951

Why Can't This Entire Indicator Be Reported at This Time?

Although aerial imagery enabled near-complete spatial coverage of the APES estuaries and lower tributaries within a relatively narrow time window (2006-2008), a substantial portion of SAV beds will remain invisible from remote sensing due to environmental factors above (e.g., haze), on (e.g., white-caps) and below (e.g., turbidity) the water's surface. The imagery also does not permit the discrimination of individual species coverage. To derive an extent estimate for this "invisible" portion, as well as species-specific information, will require monitoring from surface vessels using specialized equipment (e.g., underwater cameras, acoustics) or in situ with snorkel or SCUBA diving.

Understanding the Data

Based on interpretation and ground-truthing by NOAA of remotely-sensed imagery taken 1985-1990, the total area of visible SAV in APES was approximately 134,000 acres (Ferguson and Wood, 1994 in Street et al., 2005:259). Based on interpretation by NOAA of remotely-sensed imagery taken 1990-1992, the total area of SAV for seven of eight sub-regions in APES (all but Currituck) was approximately 115,000 acres (Ferguson and Wood, 1994:83-89). Surfaced-based mapping in western Pamlico Sound, Neuse River, and Tar/Pamlico River by North Carolina's Division of Marine Fisheries and Division of Water Quality have increased the total area of mapped SAV since to over 150,000 acres (Deaton et al., 2010:270).

It is not recommended that the data from 1985-1990 be compared directly to the 2006-2008 data in Table 1 because these two estimates were based on different technologies and protocols for data acquisition and interpretation. Furthermore there was a substantial fraction of SAV in North Carolina that was difficult to detect from aerial imagery: almost half (664 of 1,347 frames or 49.3 %) of the 2006-2008 imagery was located in the river systems on the western boundaries of the Albemarle –Pamlico systems. While some of the imagery in these areas was interpretable, some could only be partially interpreted or not interpreted at all. Data acquisition was limited by sea surface conditions and water quality. Some of the areas remotely sensed had either high surface reflectivity (poor sun angle and/or surface waves) or the water clarity was too poor for sufficient penetration to image the bottom features. These areas were located primarily along the western boundaries of Albemarle and Pamlico Sounds and in the riverine systems where it will be necessary to utilize ground based sampling to verify the presence of SAV and map their distribution. The eastern regions of Albemarle and Pamlico Sounds, Core Sound, Back Sound and Bogue Sound can all be reliably delineated and mapped using this remote sensing tool, but it will be necessary to verify species composition and deep edges of these seagrass beds with boat based survey protocols. The potential SAV habitat south of Bogue Sound has not been adequately sampled to verify the capability of the remotely sensed data to detect SAV and will require further investigation.

PHRAGMITES AUSTRALIS EXTENT

Dean Carpenter[27] **and Kirk Havens**[28]

Why Is the Extent of the Wetland Plant Species *Phragmites australis* Important?

Phragmites australis (Phragmites), or common reed, is a wetland grass that can grow up to 12 feet (4 meters) high in dense stands and is long-lived. *Phragmites* is capable of reproduction by seeds, but primarily does so asexually by means of underground reproductive structures called rhizomes. The species is widely distributed, ranging all over Europe, Asia, Africa, America and Australia. The origin of the species, however, is unclear. It likely was a minor component in North American wetlands for thousands of years (Havens et al., 2003, Krings in Smith, 2004). The status of the plant as native to North America or introduced had been in dispute until it was demonstrated that both native and introduced genotypes exist. A non-native strain of *Phragmites* is responsible for the spread of the nuisance aquatic plant since the 1960s (Saltonstall, 2002).

In just one growing season, introductions from wind-dispersed seeds or water-swept rhizome pieces can lead to dense growths of the non-native strain that consume available growing space and push out other plants including the native subspecies. It also alters wetland hydrology, increases the potential for fire, and reduces and degrades wetland wildlife habitat due in part to its very dense growth habit. Still, the perspective that the non-native strain provides no ecological benefits is unsupported (Weis and Weis, 2003; Hershner and Havens, 2008). There is currently limited evidence of hybridization between native and introduced forms occurring in the field (Meyerson et al., 2010; Paul et al., 2010; Kirk et al., 2011) and the extent of hybridization is under debate (Saltonstall, 2011). *Phragmites* is particularly aggressive in low-salinity marshes and in wetland areas where salinity levels are lowered by human-induced changes (Smith, 2004) but is capable of growing throughout mesohaline salinity (Chambers et al., 2003). Disturbances that expose mineral substrate, such as dredging and placing spoil, or natural disturbances such as wildfire and hurricanes, heighten rate of *Phragmites* colonization and spread (Pyke and Havens, 1999; Heffernan, 2010).

What Will This Indicator Report?

- Areal extent of *Phragmites australis* in the coastal plains of the Albemarle-Pamlico region.

What Do the Data Show?

The following areal extent estimates of *Phragmites* include results from a detailed survey in Back Bay National Wildlife Refuge (Table 1) and status reports submitted by select APNEP partners (Table 2).

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Table 1. (a) Status and (b) trends of Phragmites based on a 2009-2010 survey and census at Back Bay National Wildlife Refuge (Heffernan, 2010).

(a) Back Bay Status

Location	# Patches	Acreage	Mean (acres)	Largest Patch
Back Bay (2009-2010)	2411	7567	3.1	734

(b) Back Bay Trends

Year	Author	Acreage	% Cover
1964	Sincock et al.	0	0
1977	Silberhorn	85	0.9%
1990	Priest and Dewing	1000	10%
2010	Heffernan	5885	59%

Table 2. Recent status reports of *Phragmites* coverage in select conservation units in the Albemarle-Pamlico region.

System: Unit	Year	Acreage	Source
NC State Parks (Coastal): Fort Macon SP	2009	0.5	Lynch 2009
NC State Parks (Coastal): Goose Creek SP	2009	5	Lynch 2009
NC State Parks (Coastal): Jockey's Ridge SP	2009	1	Lynch 2009
NC State Parks (Coastal): Pettigrew SP	2009	5	Lynch 2009
NC State Parks (Coastal): Run Hill SNA	2009	10	Lynch 2009
US Fish & Wildlife Service: Back Bay NWR	2009-2010	7,567	Heffernan 2010
National Park System : Cape Hatteras NS	2009-2010	600-900	Swilling 2011
National Park System : Cape Lookout NS	2011	*	Rikard 2011
NC Coastal Reserve System : Buckridge	2011	34.5	Webster 2011
NC Coastal Reserve System : Kitty Hawk Woods	2011	*	Fear 2011
NC Coastal Reserve System : Buxton Woods	2011	*	Fear 2011
NC National Estuarine Research Reserve: Rachel Carson	2011	0.2	Fear 2011
NC National Estuarine Research Reserve: Currituck Banks	2011	*	Fear 2011

* = No quantitative estimates available.

Why Can't This Entire Indicator Be Reported at This Time?

Inventories in some limited areas have been completed but, except for Back Bay, long term trend analysis is lacking. Complete coverage of the APNEP region would require aerial surveys with a ground truth component. A survey protocol of particular promise is that from a US Fish

& Wildlife National Wetland Inventory (NWI)-funded pilot project underway at East Carolina University investigating the utility of hybrid satellite data, LIDAR-derived digital elevation, and advanced image classification techniques to map dynamic wetland species (Allen, 2011).

Discussion

Non-native *Phragmites* is an aggressive invasive grass that has been shown to crowd out native species and is particularly adept at colonizing disturbed areas. It does, however, provide some ecosystem services such as its capacity to stabilize disturbed sediments (Windham, 2001), uptake nutrients (Tanner, 1996; Chambers, 1999) and provide habitat (Meyerson et al., 2000). Due to its fecundity and colonization prowess, wholesale eradication of the species is improbable. Eradication and control at small scales may be feasible and warranted to protect sensitive habitats such as nature preserves, refuges, or areas with high diversity or rare, threatened, or endangered species. Monitoring of such locations would require periodic surveys to determine if *Phragmites* was encroaching or had become established on site.

RELATIVE SEA LEVEL

Chris Zervas[29] and Lindsay Dubbs[30]

Why is Relative Sea Level Important?

While global sea level provides a measure of the volume of the Earth's oceans, relative sea level (RSL) is a local measure of sea level. The Albemarle-Pamlico region has extensive ocean and estuarine coastlines, and approximately 5836 km^2 (3626 mi^2) and 968.5 km^2 (602 mi^2) of the North Carolina and Virginia coasts are < 1.5 m (4.9 ft) above sea level, respectively (Figure 1; Titus, 2001). Low-lying areas are subject to erosion and inundation with the rising sea level. Sea level rise exceeding the threshold height of the elevation of coastal lands will eliminate or displace ecosystems, human communities, and structures. A relative sea level indicator was not featured in the previous Albemarle-Pamlico Status and Trends Report (1991) because RSL was not a concern two decades ago.

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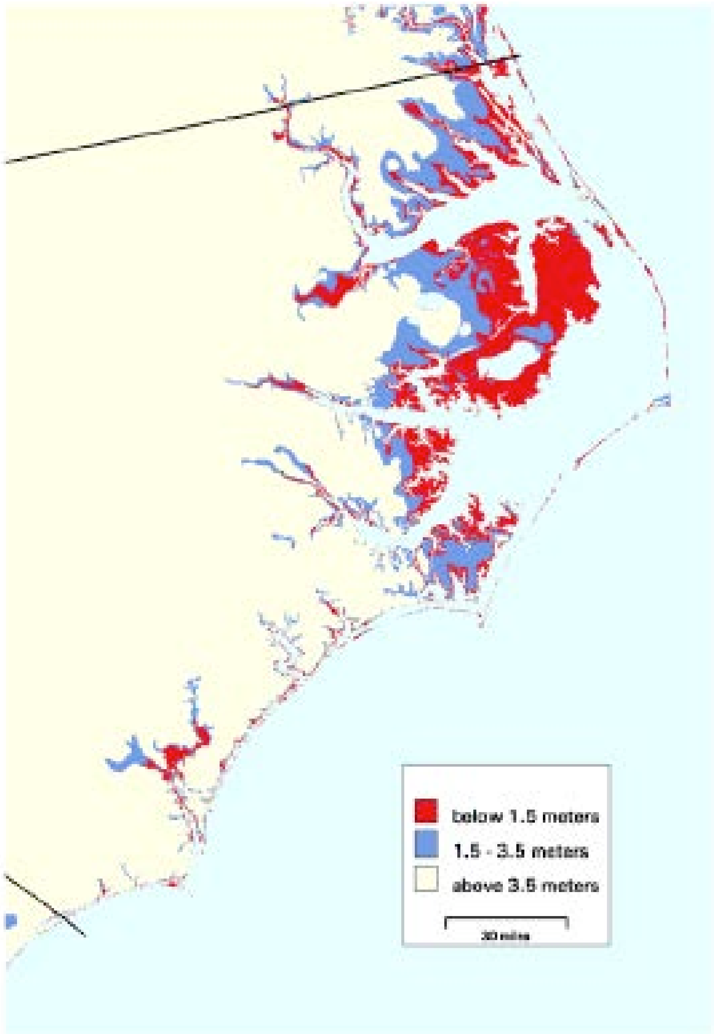

Figure 1. A map published by Titus (2001) illustrating areas of the Virginia and North Carolina coasts that are at elevations at risk of being affected by rising sea level.

What Does This Indicator Report?

- This indicator reports the trend in RSL for four locations along the coast of the Albemarle-Pamlico region.

What Do the Data Show?

The mean RSL trends for all tide gauge stations in the Albemarle-Pamlico region (Figure 2) showed increases of between 2.55 ± 2.37 cm (1.00 ± 0.93 inches)/decade to 4.27 ± 1.45 cm (1.68 ± 0.57 inches)/decade when data collected through 2002 were considered (Table 1). Subsequent trends (data through 2006), based on at least 30 years of data (only the Beaufort and Oregon Inlet Marina tide gauge stations), are similar and indicate RSL trend increases of 2.57 ± 0.44 cm (1.01 ± 0.17 inches)/decade to 2.82 ± 1.76 cm (1.11 ± 0.69 inches)/decade, respectively (Table 1). The most recent calculations of RSL, including data collected through 2010, reflect trends ranging from 2.61 ± 0.41 cm (1.03 ± 0.16 inches)/decade to 4.64 ± 1 cm (1.83 ± 0.4 inches)/decade (Table 1), with lower rates in the southern portion of the Albemarle-Pamlico region. The greatest rate is at Duck, which is similar to the trends measured in Virginia.

The trends in RSL increased from those reported in 2004 and 2009 to the most recent calculations, which are based on larger data sets, for both the Duck and Oregon Inlet Marina tide gauge stations. The reported trends in RSL at the Beaufort tide gauge station decreased from 2004 to 2009 and then increased slightly when four additional years of data, through 2010, were included. The variations of a station's calculated trend as more data are collected are not statistically significant since the trend's confidence intervals overlap. The most important point to note is that more data results in the narrowing of the confidence intervals around the station's true long-term trend.

What is Not Shown by This Indicator?

Tide gauges are located at four discrete locations along the North Carolina coast, while RSL varies locally. Therefore, RSL can be extrapolated for the entire Albemarle-Pamlico region but is only measured at several discrete points along its marine coast. There are currently no long-term measurements of RSL from locations within the estuarine waters of the Albemarle-Pamlico region. Estuarine RSL may be highly spatially and temporally variable because of the variable influences of ocean and wind tides on specific locations.

Table 1. Sea level trends with 95% confidence intervals at tide gauge stations in the APES region for three time periods: through 2002, through 2006, and through 2010.

Station Number	Station Name	Mean RSL Trend (cm/decade)	Mean RSL Trend (inches/ decade)	Period of Data	Source
8651370	Duck	4.64 ± 0.10	1.83 ± 0.40	1978-2010	Zervas, unpublished
8652587	Oregon Inlet Marina	3.31 ± 1.65	1.30 ± 0.65	1977-1980, 1994-2010	Zervas, unpublished
8656483	Beaufort	2.61 ± 0.41	1.03 ± 0.16	1953-2010	Zervas, unpublished
8652587	Oregon Inlet Marina	2.82 ± 1.76	1.11 ± 0.69	1977-1980, 1994-2006	Zervas, 2009
8656483	Beaufort	2.57 ± 0.44	1.01 ± 0.17	1953-2006	Zervas, 2009
8651370	Duck	4.27 ± 1.45	1.68 ± 0.57	1978-2002	Zervas, 2004
8652587	Oregon Inlet Marina	2.55 ± 2.37	1.00 ± 0.93	1977-1980, 1994-2002	Zervas, 2004
8654400	Cape Hatteras	3.46 ± 1.47	1.36 ± 0.58	1978-2002	Zervas, 2004
8656483	Beaufort	3.20 ± 1.06	1.26 ± 0.42	1973-2002	Zervas, 2004

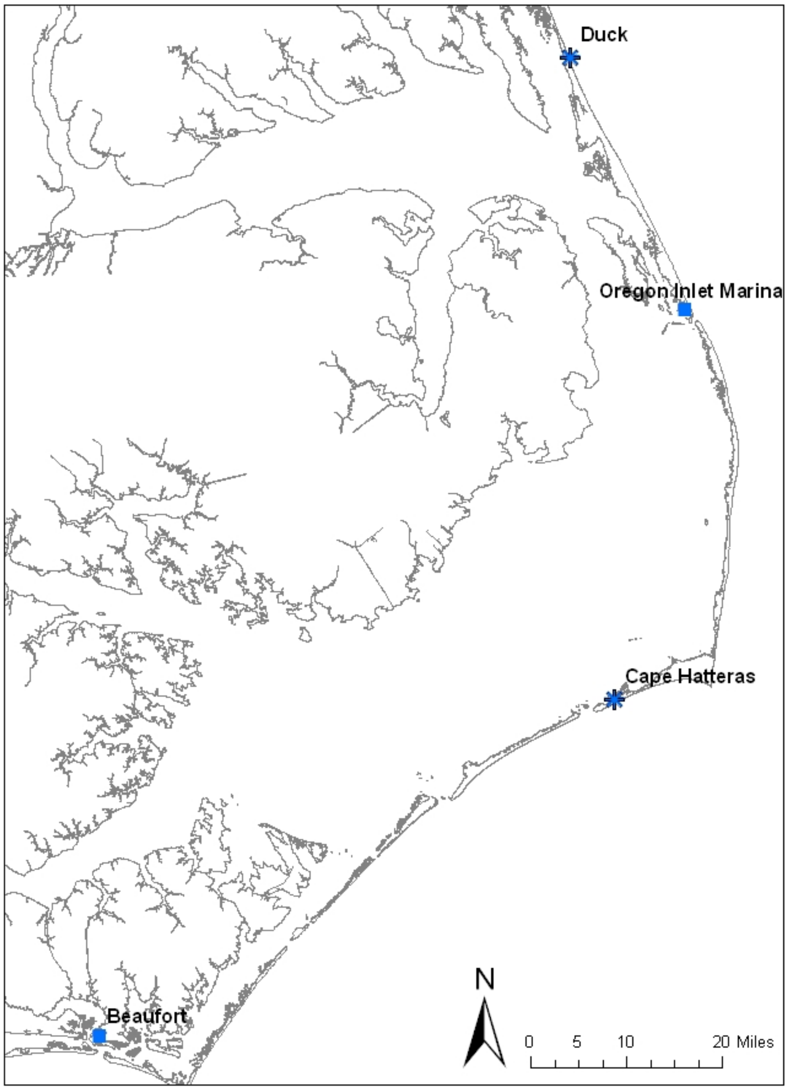

Figure 2. Locations of tide gauges within the Albemarle-Pamlico region from which RSLs are calculated. Gauges with 30 or more years of data (as of 2006) are identified by squares, and those with less than 30 years of data (as of 2006) are identified by asterisks. The figure is adapted from Figure 1 in Zervas (2009).

Understanding the Data

The volume of Earth's oceans has increased over the recent past, which is evident from satellite-based measurements of global mean sea level rise of 2.8 ± 0.4 cm (1.0 ± 0.2 inches) /decade from 1992 to present (NOAA Laboratory for Satellite Altimetry). Global mean sea level is predicted to continue to rise because of increasing global temperatures (IPCC, 2007) and subsequent thermal expansion of ocean water and the melting of glaciers. However, there are also factors that influence the height of seawater relative to specific points on land on a regional or local level, called relative sea level. The vertical movement of coastal land can be different from one place to the next and can change because of tectonic activity, subsidence resulting from compaction of the land surface or drainage of the water table (or other fluids, e.g., oil), or the rising of areas once covered by ice and sinking of adjacent areas of land. The variations in the heights of coastal land, along with regional variations in the height of water due to temperature and salinity variations, global currents and wind, mean that the increase in the volume of the Earth's oceans will not result in equal rises in relative sea levels everywhere. While global sea level provides information about the change in the volume of the world's oceans, relative sea level is important for coastal management and planning because it is specific to particular locations along the coast. Sea level is rising at all locations at which it is being measured in the Albemarle-Pamlico region. The length of the tidal gauge record is a primary influence on the size of the confidence intervals for the RSL trend. Longer data sets result in smaller confidence intervals.

OCEAN SHORELINE MIGRATION

Helena Mitasova[31], Margery Overton[32], Ross Oliver[33], Eric Hardin[34]

Why is Ocean Shoreline Migration Important?

Ocean shoreline migration reflects sand redistribution due to wave action and sea level rise, as well as coastal management interventions. Landward shoreline migration (erosion) poses threat to buildings and infrastructure, diminishes beach-dune habitat, and increases potential for over-wash or barrier island breach. In the extreme cases it can lead to a new inlet formation and major changes in estuary ecosystems due to influx of saltwater and higher tides. Seaward movement of the shoreline (accretion) may be due to natural processes or human interventions like beach nourishment or sand disposal.

What Does This Indicator Report?

Ocean shoreline migration is reported here using two independent measures: (a) long-term *shoreline erosion/accretion rate* in meters per year [m/yr] based on the 1933-52 and 2009 shorelines, and (b) short-term *range of shoreline position* for the years 1996-2009 in meters [m]. For the long-term erosion/accretion rates, negative values indicate shoreline erosion (associated with loss of land to ocean), positive values indicate shoreline accretion (associated with land mass gain). Short-term range of shoreline position is the distance between the most ocean-ward (maximum) and most landward (minimum) locations of the shoreline within the years 1996-2009. The shoreline could have migrated in one direction only (e.g. landward in case of systematic erosion or ocean-ward in case of systematic accretion) or back and forth (e.g. erosion due to hurricane followed by recovery, or due to erosion-nourishment-erosion cycle).

What Do the Data Show?

The area covered by this report spans 300 km (186 mi) of shoreline from the Virginia border to the White Oak River (Figure 1). The long-term data show that over 70% of the shoreline experienced erosion with the mean erosion rate of -1.14 m (3.74 ft)/yr, exceeding the mean accretion rate of +0.76 m (2.49 ft)/yr observed for 30% of the shoreline (Table 1). The long-term erosion rates based on the composite 1933-52 shoreline and 2009 shoreline are larger in spatial extent and magnitude when compared to the rates estimated for the shorter time period ending more than a decade ago (1980 – 1997, Morton and Miller, 2005).

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Table 1. Long-term and past short term shoreline erosion/accretion rates.

time period	# of transects: shoreline length [km]	mean erosion rate [m/yr]	% shoreline length eroding	mean accretion rate [m/yr]	% shoreline length accreting	mean shoreline change rate[m/yr]
1933/52-2009*	6141: 307	-1.14	70.6%	+0.76	29.4%	-0.59
1980 – 1997**	6302: 315	-0.94	57.3%	+0.93	42.7%	+0.25

* Derived at NCSU from USGS and NOAA shorelines
**Unites States Geological Survey (Morton and Miller 2005)

Mean long-term shoreline erosion/accretion rates, reported by segments (Table 2) show that all segments are eroding over more than 65% of their length, except for a small section between Cape Hatteras and Hatteras Inlet and the southernmost White Oak River sections. The highest erosion rates are observed at small sections around Cape Lookout and along the section north of Cape Hatteras (Table 2, Figure 1).

Table 2. Long-term mean shoreline erosion/accretion rates derived from the 1933-52 and 2009 shorelines for barrier island segments shown in Figure 1.

Segment name, transect #	Segment length [km]	Shoreline erosion/accretion rate [m/yr]	% length erosion	% length accretion
Oregon Inlet #6794-8404	80.5	-0.37	69.6%	30.4%
Cape Hatteras #8405-9661	62.8	-1.07	77.9%	22.1%
Hatteras Inlet #298-730	21.6	+0.78	50.6%	49.4%
Ocracoke Inlet #731-1221	24.5	-0.90	72.9%	27.1%
Drum Inlet #1222-1902	34.0	-0.88	86.7%	13.3%
Cape Lookout #1903-2603	35.0	-1.21	89.9%	10.1%
Lookout Bight #2604-2712	5.4	-1.55	78.8%	21.3%
Beaufort Inlet #2713-2945	11.6	-0.67	81.3%	18.7%
White Oak River #2946-3731	30.2	+0.14	36.3%	63.7%

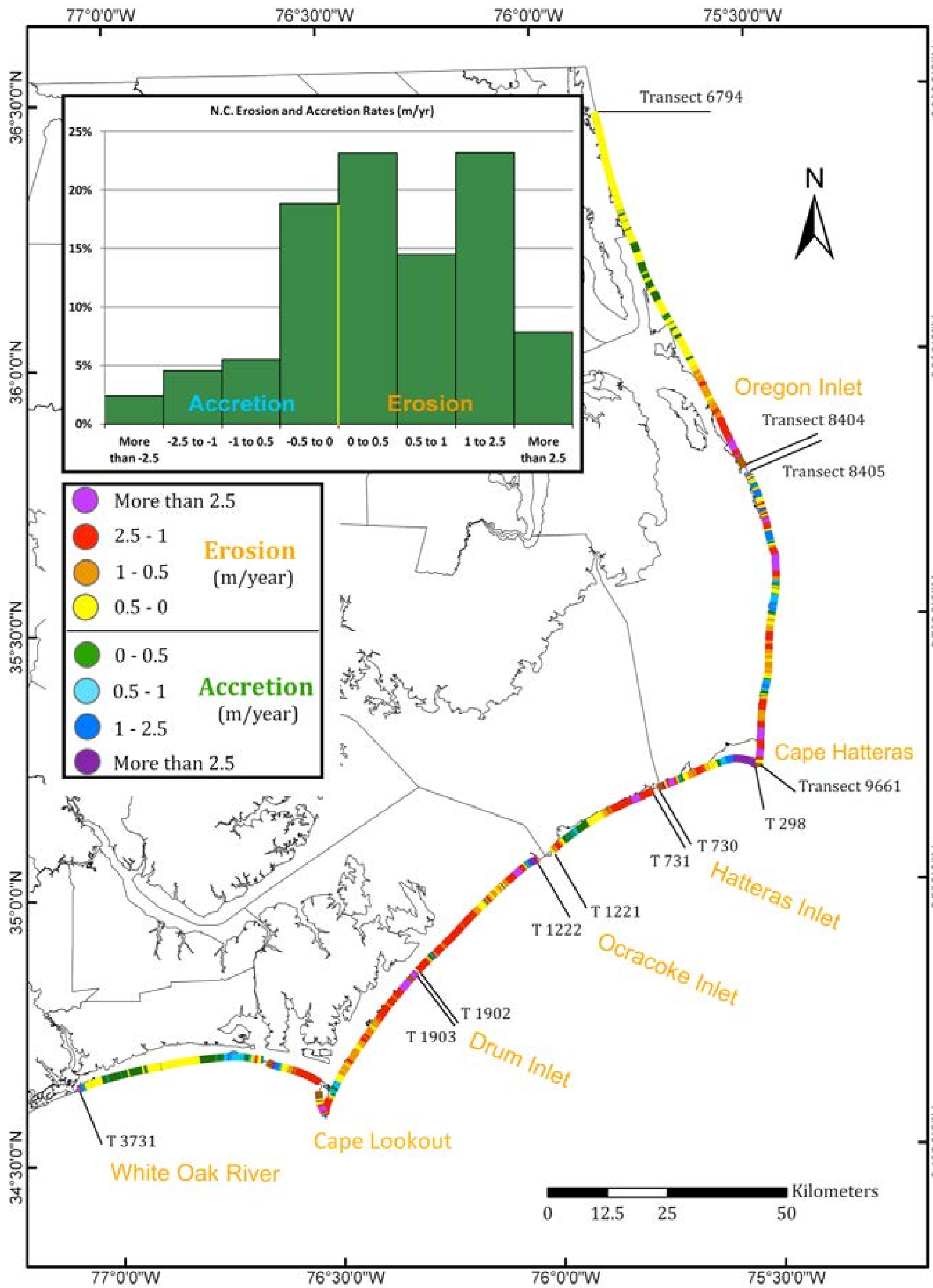

Figure 1. Long-term shoreline erosion/accretion rates and a histogram that shows percentage of shoreline length experiencing erosion/accretion rates in each category. The map also shows segments with associated transect numbers for which the mean rates are reported in Table 2.

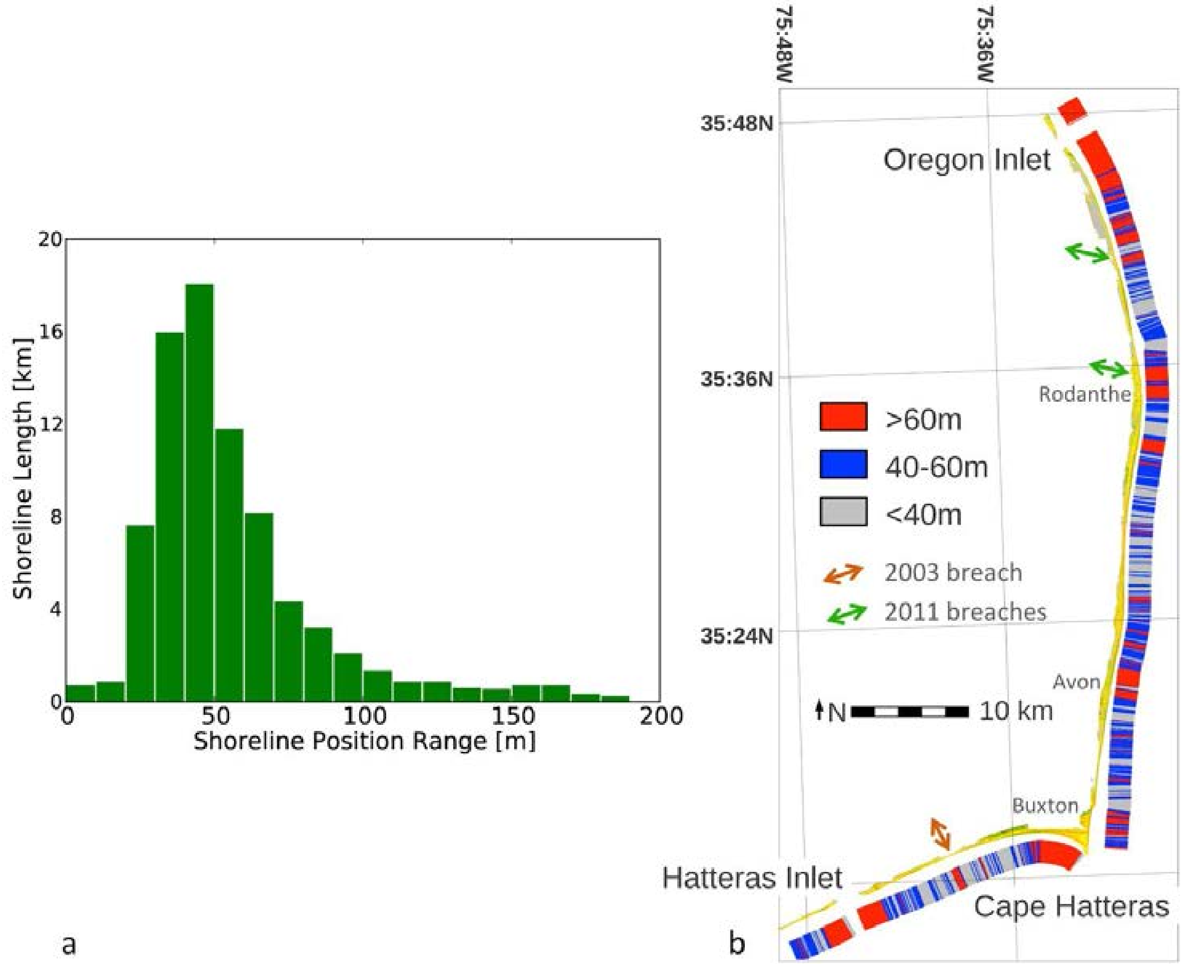

Figure 2. Short-term range of shoreline position for a region between Oregon and Hatteras Inlets during the time period 1996-2009: (a) length of shoreline for different ranges of shoreline position; (b) spatial pattern of shoreline position range (shoreline along red areas moved more than 60 m) and locations of recent barrier island breaches.

The short-term range of shoreline position for the years 1996-2009 has the mean value of 63 m (207 ft) and median 49 m (161 ft). Most of the shoreline (66% of total 95 km (59 mi) length) changed it's the position 30-70 m (98 -230 ft) over this time period. The largest range of shoreline position was observed near Oregon and Hatteras Inlets, and Cape Hatteras (Figure 2). The smallest ranges are located at the undeveloped areas north of Rodanthe, north of Avon and along the village of Buxton.

The study area shorelines can be substantially reconfigured by storms. High waves and water levels can breach or overwash the barrier islands and cause sudden and substantial changes in the shoreline configuration. During Hurricane Isabel in 2003, a location between the towns of Frisco and Hatteras on Hatteras Island was breached (Figure 2), causing an opening that remained in place for several weeks before being filled by the US Army Corps of Engineers. Hurricane Irene in 2011 caused breaching in two areas on Hatteras Island. The most significant of these was a location at the Pea Island north of Rodanthe that remains open as of July 2012. Access to areas south along North Carolina Highway 12 has been restored via a temporary bridge with plans for a permanent structure. The reconfiguration by Irene is not reflected in the indicators presented due to data availability.

Why Can't This Entire Indicator Be Reported at This Time?

The ocean-side long-term shoreline erosion/accretion indicator computed by the end-point method is relatively complete, but it does not represent annual, seasonal or post-storm changes and is estimated only from two shoreline positions (1933-52 and 2009). The short-term range of shoreline position takes into account position of all 13 shorelines measured over the time period 1996-2009. Due to the gaps in LIDAR data coverage the short-term range of shoreline position was computed only for the section between the Oregon and Hatteras Inlets. The latest LIDAR data acquired in the years 2010 and 2011 were not included in the analysis because they became available only recently, therefore, the impact of Hurricane Irene of 2011 that has caused several island breaches is not included in the results. To fully capture the barrier islands shoreline dynamics, including seasonal variations, a consistent LIDAR mapping semiannually, with complete island coverage would be needed.

Understanding the Data

Shoreline position can be mapped using a variety of 2D and 3D approaches. Historically, shorelines have either been mapped using ground survey technologies (e.g., the National Ocean Service (NOS) Topographic Sheets [T-sheets]) or by using photo-identifiable shoreline position surrogates (e.g., the wet/dry line). The US Army Corps of Engineers (USACE) routinely maps the beach, dune, and nearshore using cross-shore profiles and relevant tidal datum such as mean high water (MHW) to determine shoreline position. LIDAR surveys provide elevation data that are used to extract contour or datum defined shorelines from digital elevation models (DEMs).

The long-term rates presented in this assessment are based on the 1933-52 shoreline digitized from the MHW on NOS T-sheets and the 2009 shoreline digitized from aerial orthophotography using the wet/dry line surrogate for shoreline. The 1933-52 shoreline is a composite shoreline representing the 'early date' shoreline for the endpoint rate calculation. NOS T-sheets are used to build the composite shoreline. Multiple dates are required since no single NOS T-sheet covers the entire study area.

The short-term range of shoreline position is based on 13 shorelines derived as elevation contours equal to MHW, from 0.5 m resolution DEMs. The MHW is approximated from the nearest tidal recording station. The elevation data used to derive these shorelines were acquired on October 16, 1996; October 2, 1997; September 7, 1998; September 9 and 18, 1999 (pre-hurricanes Dennis and Floyd respectively); February 2001, September 16 and 21, 2003 (pre and post-Isabel); September 25, 2004; November 26, 2005; March 27, 2008 and December 1, 2009.

What is Not Shown by This Indicator?

Shoreline-based metrics such as erosion/accretion rate and position range do not measure volume of sediment moved or the location of the displaced volume. For example, while many storm events erode the beach, the sediment is carried into the nearshore and beach recovery can occur after the storm as the waves build the beach. On the other hand, during a wash over event, both sediment from the beach and the dune may be carried landward and taken out of the beach and dune system. The long-term shoreline erosion/accretion rate indicates the mean trend of shoreline migration but does not capture the variation in position or reversals in trend. Short-term range of shoreline position quantifies the variability of shoreline position, but does not provide long-term trend information. For example, the 2009 shoreline was at the shoreline position minimum (most landward position observed between 1996-2009) only along 19% (18 km) of the analyzed 95 km barrier island section.

Image courtesy of the WCU Program for the Study of Developed Shorelines

ESTUARINE SHORELINE MIGRATION

D. Reide Corbett[35], **J. P. Walsh**[36], **Devon Eulie**

Why Is Estuarine Shoreline Migration Important?

Coastlines are constantly changing due to both natural and anthropogenic forces, and climate change and associated sea level rise will continue to reshape coasts in the future. Erosion is not only apparent along oceanfront areas; shoreline dynamics in sheltered water bodies, like those along the Albemarle-Pamlico Estuarine System (APES) have also recently gained greater attention. These sheltered shorelines are impacted by a variety of factors, including high energy events, such as storm tides and wind waves. As a result of sea-level rise (see indicator "Relative Sea Level") and potentially enhanced storm activity (see indicator "Storm Frequency and Intensity"), many coastal areas will experience increased frequency and levels of flooding, accelerated erosion, and loss of wetlands, among other impacts. Due to the significance of estuaries as fish nurseries and waste, pollution, and excess nutrient filters, and with a higher density of people residing in coastal counties, considerable interest surrounds the dynamics of the estuarine shoreline.

What Does This Indicator Report?

This indicator focuses on shoreline change rates (SCRs), a distance per time at which the shoreline is retreating or prograding.

What Do the Data Show?

Three studies provide the bulk of the data on shoreline change rate in the APES. These studies use time-series aerial imagery to quantify shoreline change over different spatial and temporal scales. Riggs and Ames (2003) focused on 21 sites throughout the APES (Figure 1), utilizing the 1998 Digital Orthophoto Quarter Quadrangles (DOQQ) to determine the "modern" shoreline and compared that to aerial images of the past (images typically prior to 1975). Cowart et al. (2011) focused on the entire shoreline of the Neuse River Estuary (Figure 1), measuring the change in shoreline position between 1958 and 1998. Finally, Walsh and Corbett (unpublished data), through funding received from APNEP, selected five wetland sites throughout the APES (Figure 1) to evaluate shoreline dynamics on a telescoping temporal scale (months to decades). This study also uses aerial photography similar to the two previous data sets, but also incorporates field-based mapping via RTK-GPS to evaluate short-term (months) change.

Riggs and Ames (2003) Summary
Most estuarine shorelines in APES are eroding in response to the interaction of storms and sea-level rise. However, previous studies indicate that shoreline erosion is extremely variable from

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site to site with significant ranges in erosion rates evident over short distances (Riggs, 2001; Riggs and Ames, 2003). The site with the highest average rate (measured between 1969 and 1998) of recession in the Riggs and Ames (2003) study was the platform marsh at Point Peter Road (Pamlico Sound; Figure 1) with an average recession rate of -2.3 m (-7.5 ft) per year (range of -2.2 and -2.5 m (-7.1 and -8.3 ft) per year) in contrast to the lowest average recession rate (measured between 1970 and 1998) of less than -0.3 m (-1 ft) per year along the bluff shoreline at Bay Hills (head of Pamlico River; Figure 1). Shoreline change rates varied from 0 m per year during periods of low storm activity to a high of -7.9 m (-26 ft) per year (erosion) along the sand bluffs at the north end of Roanoke Island during periods of high storm activity. Riggs and Ames (2003) determined that the average annual estuarine shoreline change rates for specific shoreline types ranged between +0.2 m (+0.6 ft) per year (accretion) for back-barrier beaches to -1.0 m (-3.3 ft) per year (erosion) for the mainland marshes.

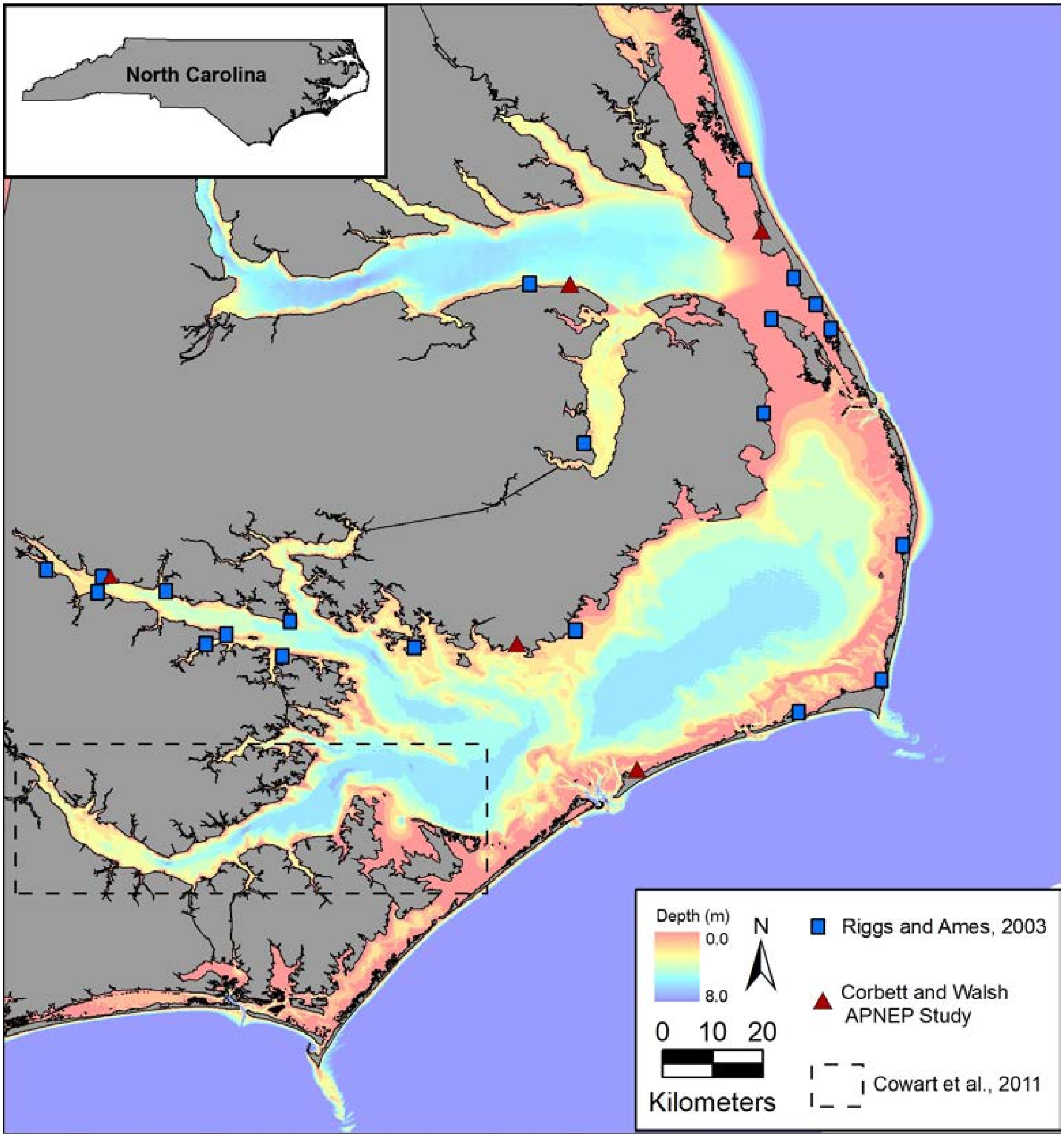

Figure 1. Sites in the Albemarle-Pamlico that have been the focus of shoreline change analysis.

Neuse River Estuary (Cowart et al., 2011)

Over 40 years (1958-1998), the vast majority (93%) of the Neuse River Estuary shoreline eroded (the shoreline moved landward). Only a small fraction (6.6%) of the shoreline accreted (the shoreline moved seaward), and less than 1% did not change (Figure 2). The rate of shoreline change varied widely from -3.5 m (-11.5 ft) per year (erosion) to +2.9 m (+9.5 ft) per year (accretion). The average shoreline change rate for the entire study area, including the protected tributaries, over the 40 year period was approximately -0.3 m (-1 ft) per year (erosion).

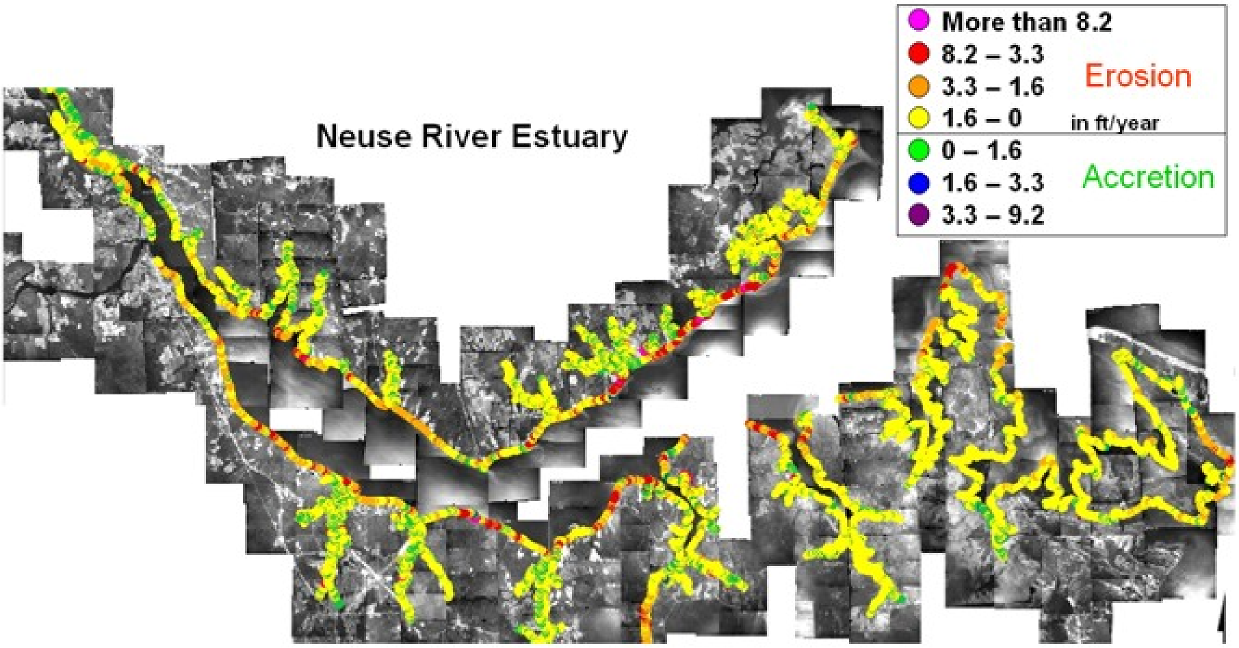

Figure 2. Map of shoreline change rate between 1958 and 1998 (40 years) along the Neuse River Estuary. Areas with higher erosion rates are denoted by yellow to pink, while areas that have accreted are represented by green to purple.

APNEP Study (Walsh and Corbett, unpublished data)
Rates of shoreline erosion for the sites were found to be similar to previous work. However, it is important to note the range in shoreline change rates between sites and within a site (Figure 3). All sites portray erosion over time; however, the rate of erosion varies over time. RTK-GPS survey following a single storm event, Hurricane Earl, which passed within 100 miles of the study area, had similar rates of shoreline erosion. Accretion was locally measured at several of the study sites during bi-monthly surveys, but generally, net erosion is dominating the change and slow steady erosion from regular wave action appears to be controlling change based on this preliminary dataset.

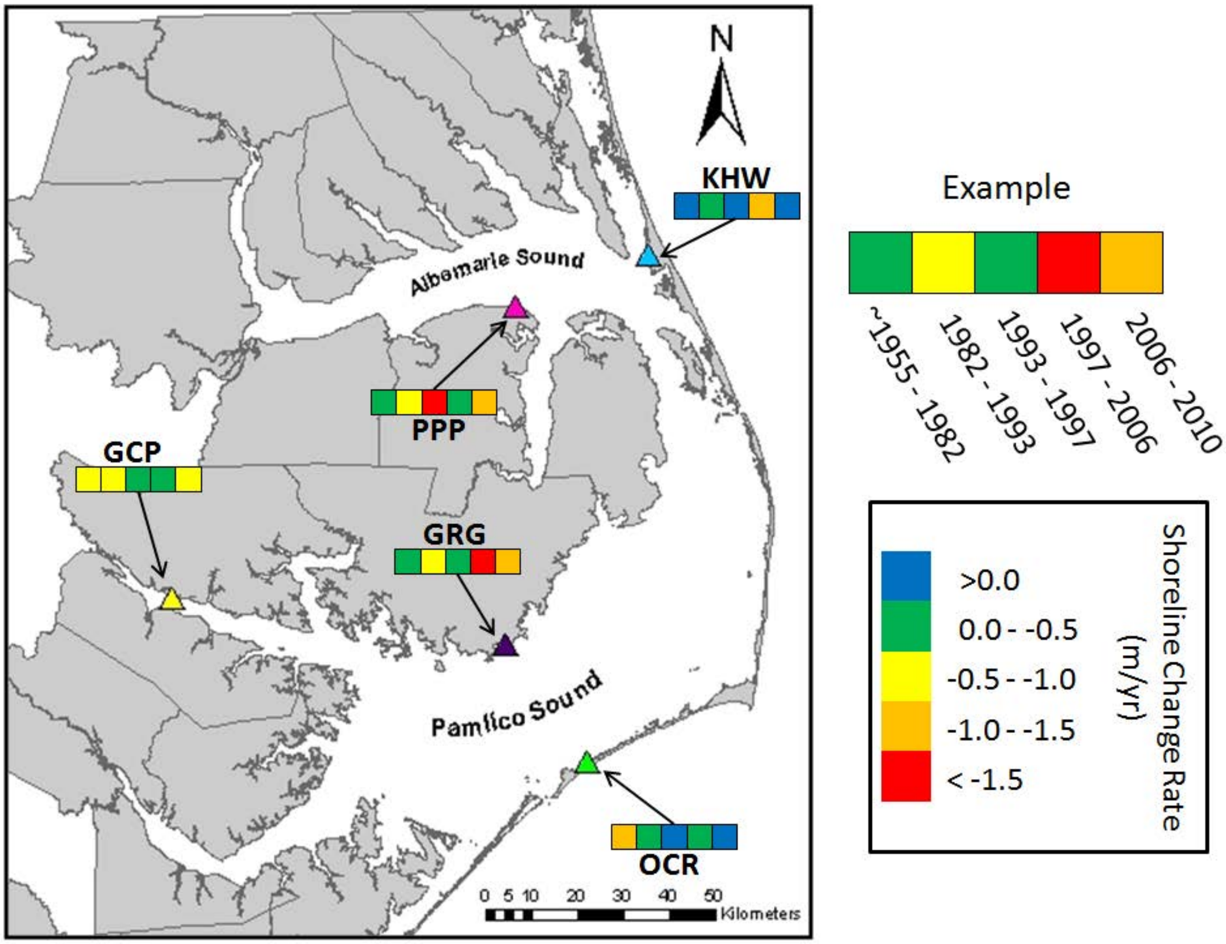

Figure 3. A recent study funded by APNEP used time series aerial photography to evaluate the shoreline change variability over time. Note the inter– and intra-site variability.

Why Can't This Entire Indicator Be Reported at This Time?

Calculating shoreline change rates using the methods applied herein is extremely time consuming, requiring hours of digitizing shorelines from at least two different time periods. To date, there have been only a handful of studies that have focused on shoreline change in the APES. These studies have focused on different regions of the system, typically analyzing change on km-scale sections of the shoreline in different areas throughout the APES. These studies (see previous section) provide some idea of spatial variation and changes in shoreline change rates over different time scales (measured over decades to months). However, the rate of change varies on small spatial scales (hundreds of meters; Cowart et al., 2010, 2011) and should therefore be done in as many areas as possible. In addition, the rate of change may vary through time due to natural (e.g., storms, inundation) and anthropogenic (e.g., hardened structures) influences. As such, it is necessary to monitor the rate of change over varying timescales in order to understand the temporal changes that are likely to occur.

Understanding the Data

Riggs and Ames (2003) Summary
From the Riggs and Ames (2003) data, several important patterns concerning average annual shoreline erosion rates for major shoreline types and estuarine regions are obvious. Mainland marsh and low sediment bank have the overall highest average rates of estuarine shoreline recession (-1.0 m [-3.3 ft] per year). They are also the most abundant shoreline types, constituting about 85% of the coastal system in northeastern North Carolina. Bluffs and high sediment banks, with their available sand, debris and vegetation, are less abundant (about 8%) and generally erode more slowly (-0.8 m [-2.6 ft] per year) compared to low sediment banks. Swamp forest shorelines are the least abundant (about 7%) and erode the slowest (-0.7 m [-2.3 ft] per year) due to their lack of elevation and low offshore gradients together with the role of trees in abating wave energy. Based upon this and other studies, several physical variables have been identified that act to shape/modify the shoreline as sea-level rises, producing alongshore variability in erosion rates (Table 1).

Table 1. Physical variables shaping estuarine shorelines (modified from Riggs and Ames, 2003).

Shoreline Variables	Definition	Potential for Erosion Low	Potential for Erosion High
Fetch	Average distance of open water in front of shoreline	Short Fetch (< 305 m, 1000 ft)	Long Fetch (> 305 m, 1000 ft)
Offshore bottom character	Water depth and bottom slope in the nearshore area	Shallow, gradual slope (< 0.9m, 3 ft)	Deep, steep slope (> 0.9 m, 3 ft)
Geometry of shoreline	Shape and regularity of shoreline (sinuosity)	Highly irregular or in a cove	Straight or on a headland
Height of sediment bank	Bank height at shoreline or immediately behind sand beach	High (> 1.8 m, 6 ft)	Low (< 1.8 m, 6 ft)
Composition of sediment bank	Composition and degree of cementation of bank sediments	Rock, tight clay	Uncemented sand, peat
Fringing vegetation	Type and abundance of vegetation (aquatic plants, marsh grasses, shrubs, trees, etc.) occurring in front of sediment bank	Very abundant, dense	Absent
Boat wakes	Proximity of property to, frequency and type of boat channel use	Absence of boats	Marinas, intracoastal waterway
Storms	Storms are the single most important factor determining specific erosional events	Depends on type, intensity, duration and frequency of storms	

Neuse River Estuary (Cowart et al., 2011)
The rate of shoreline retreat is influenced by many factors, including but not limited to, wave energy and duration, fetch of water that generates these waves, and boat wakes (Table 1). The influence of fetch, and therefore the resultant wave energy, can easily be seen in the erosion rates observed in the Neuse River Estuary. For example, some of the lowest erosion rates are found in the small tributaries and in head water portions of the estuary (symbols are mostly yellows and greens, Figure 2). In contrast, those areas along the main trunk of the estuary exposed to a fetch that included Pamlico Sound, had the greatest rates of erosion (Figure 2). This higher erosion rate along much of the Neuse River trunk is associated with the relentless wave attack during windy days and strong storms (e.g., hurricanes and nor'easters). With rising sea level and possible enhanced storm activity, it is highly probable that estuarine shoreline recession will become more severe in the near future.

APNEP Study (Walsh and Corbett, unpublished data)
In this study, five wetland sites were chosen across the APES to represent a range of wetland shorelines and locations/orientations. The goal was to focus on shoreline change rates over telescoping temporal scales. On the decadal scale (similar to the above two studies), sites were digitized using the most recent set of North Carolina State aerial photography, as well as several older images from different time periods obtained directly from the counties of interest. In order to evaluate shoreline changes over shorter time periods (weeks to months) and associated with individual storm events, each site was initially surveyed during early summer 2010 using an RTK-GPS. Sites were then reoccupied on a bi-monthly basis from August 2010 to February 2011 and following storm events. A Balloon Aerial Photography System was also employed to image the shoreline. Shoreline change was analyzed for each time-step and methodology (RTK, Balloon System, and on-screen digitizing).

ESTUARINE SALINITY CONCENTRATION

Lindsay Dubbs[37]

Why are Estuarine Salinity Concentrations Important?

Salinity can be highly spatially and temporally variable within estuarine systems because of riverine freshwater (0 ppt) and ocean saltwater (~35 ppt) influences. Bacteria, plants, and animals are adapted to specific ranges of salinity. Salinity across an estuarine system dictates the distribution of organisms, affects productivity, and influences the cycling of nutrients, metals, and toxins.

Changes in precipitation patterns and water table levels associated with climate change, and the demand for and use of freshwater, influence river flows and thus influence estuarine salinity. Sea level rise and changes in the number and locations of inlets can also cause changes in the salinity regime. Thus, climate change and an increasing human population within the Albemarle-Pamlico Region are expected to cause changes in the spatial and temporal patterns of salinity.

What Does This Indicator Report?

- Monthly mean salinity concentrations in the estuarine waters of Albemarle-Pamlico sub-regions (Figure 1) from 1980 to 2009.

What Do the Data Show?

The annual mean salinity concentrations in the Lower Chowan, Roanoke, and Tar and Middle Neuse sub-basins were less than 1 ppt over the 30-year record. Monthly mean salinity concentrations in the Lower Chowan (Fig. 2a), Lower Roanoke (Fig. 2b), Lower Tar (Fig. 2c) and Middle Neuse (Fig. 3a) sub-basins spanned slightly wider ranges (0-3 ppt, 0-4 ppt, 0-8 ppt, and 0-10 ppt, respectively). However, the monthly means remained relatively constant and increased slightly over the 30-year period. The increases were statistically significant ($\alpha = 0.10$) at all six Lower Chowan River stations, all three Lower Roanoke River stations, and one of three Middle Neuse stations. The trend was not statistically significant ($\alpha = 0.10$) for the single Tar River station.

From 1980 to 2009 the mean annual salinity concentrations in the East Albemarle (including the Pasquotank River basin) and West Albemarle sub-basins remained lower than 5 ppt. However, monthly mean salinity concentrations in the East (Fig. 3b) and West (Fig. 3c) Albemarle sub-basins fluctuated more than an order of magnitude (0-11 ppt and 0-20 ppt, respectively). The patterns of fluctuation were not seasonal. Over the 30-year period from 1980-2009, the monthly mean salinity concentrations in these Albemarle Sound sub-basins also followed

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slightly increasing trends (Fig. 3b and 3c, respectively) that were statistically significant (α = 0.10) in half of the stations (one of the two East Albemarle stations and three of the five West Albemarle stations.

The 30-year mean salinity concentration in the Pamlico Sound (Fig. 4a) was slightly higher (~7 ppt) than in the Albemarle Sound and northern river mouths and Middle Neuse. Monthly means ranged from 0 to 17 ppt and showed no statistically significant (α = 0.10) trends over the 30-year records from eight stations.

Meanwhile, the White Oak River basin, followed by the Lower Neuse sub-basin had the highest 30-year mean salinities (18 and 8 ppt, respectively) and largest ranges of monthly mean salinity concentrations (0 to 37 ppt and 0 to 21 ppt, respectively). The monthly mean salinities showed no statistically significant (α = 0.10) trends in the Lower Neuse and slightly increasing trends at five of the eight stations within the White Oak River basin from 1980 to 2009.

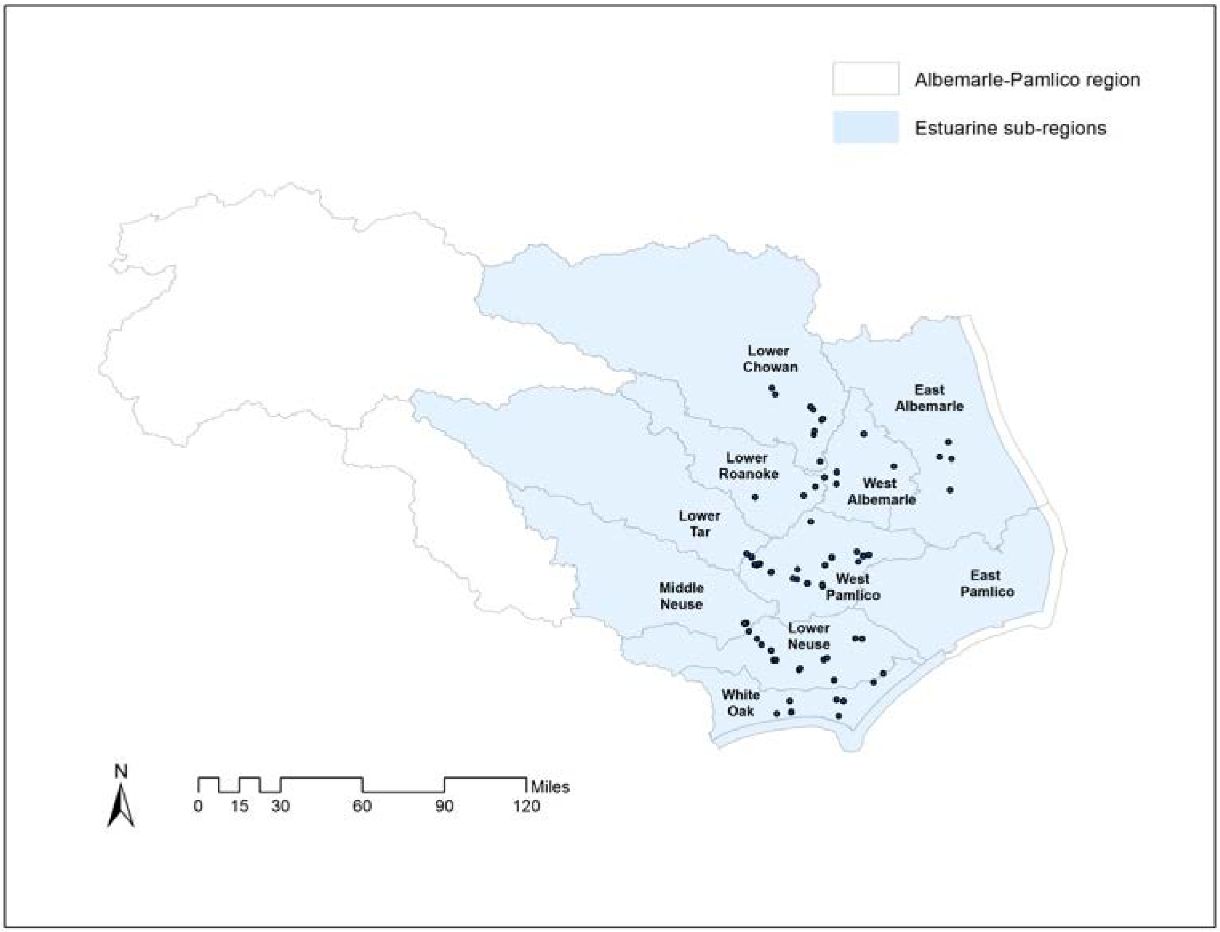

Figure 1. Estuarine sub-regions of the APES and the larger Albemarle-Pamlico region. North Carolina Division of Water Quality (DENR) sampling stations at which there was a 21-year or greater record of salinity data available are depicted as blue circles.

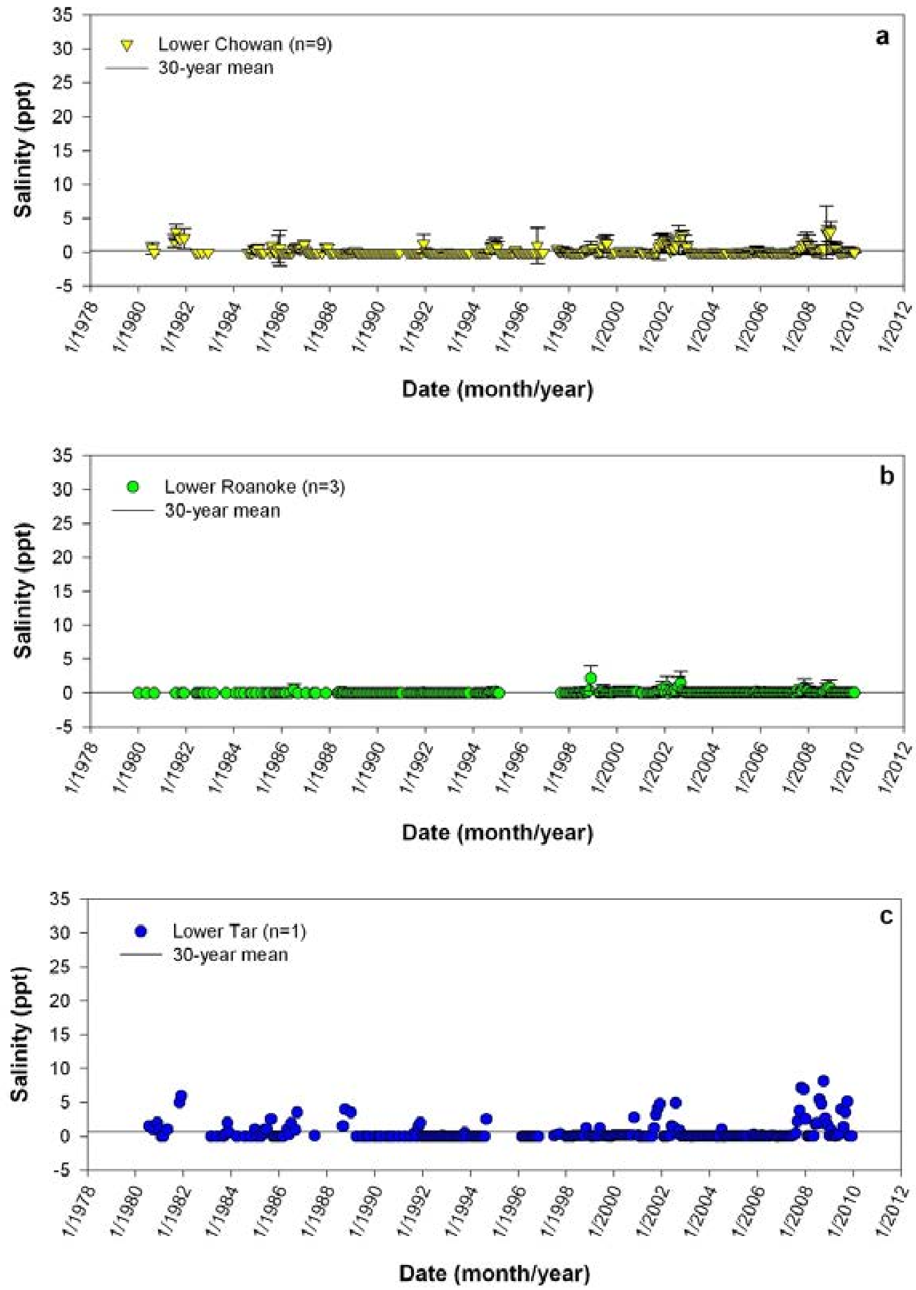

Figure 2. Monthly mean salinity concentrations (n= number of sampling stations in the sub-region) and the thirty year average salinity concentrations for the Lower Chowan (a), Lower Roanoke (b), and Lower Tar (c) River sub-basins.

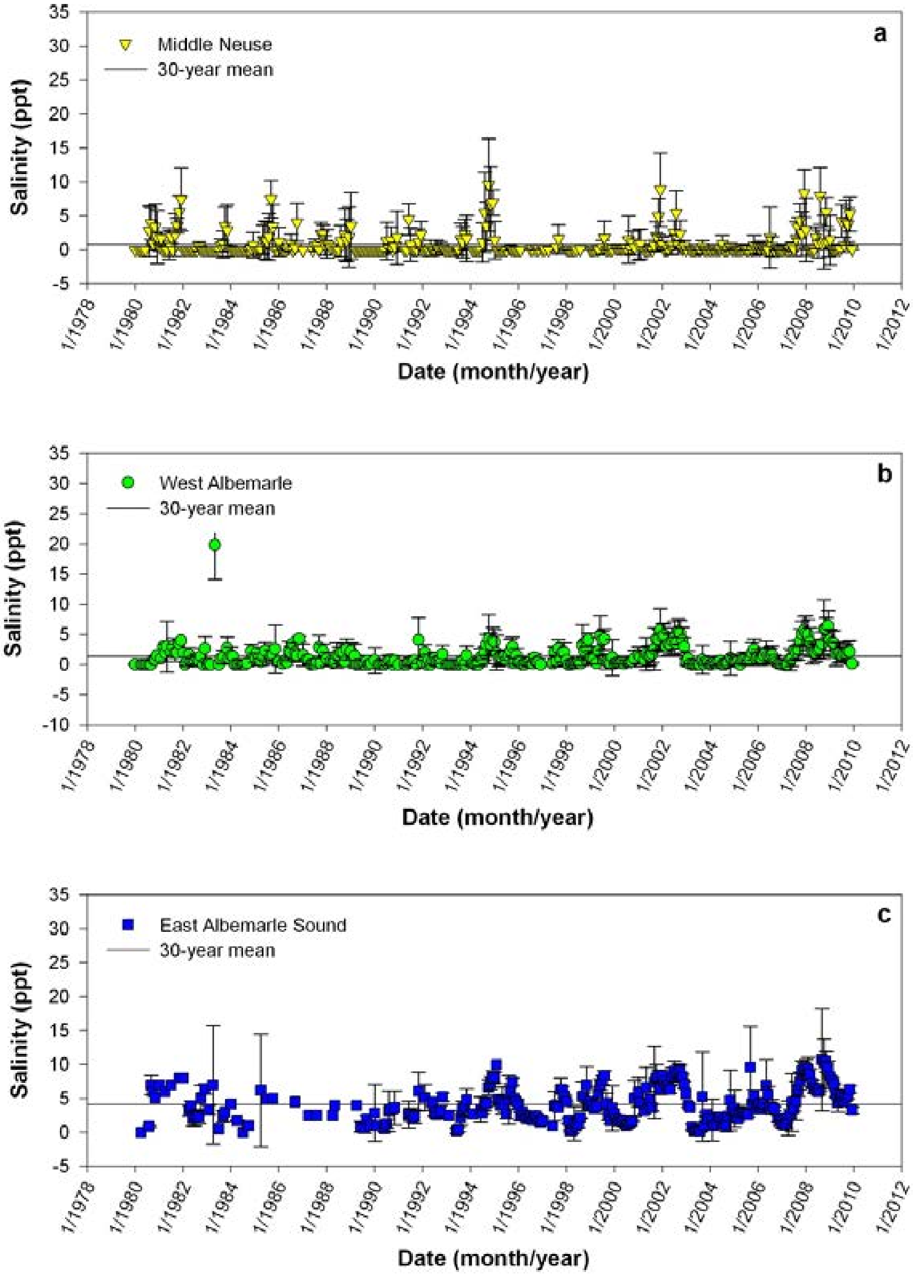

Figure 3. Monthly mean salinity concentrations (n= number of sampling stations in the sub-region) and the thirty year average salinity concentrations for the Lower Neuse River (a) and West (b) and East Albemarle (c) Sound sub-basins.

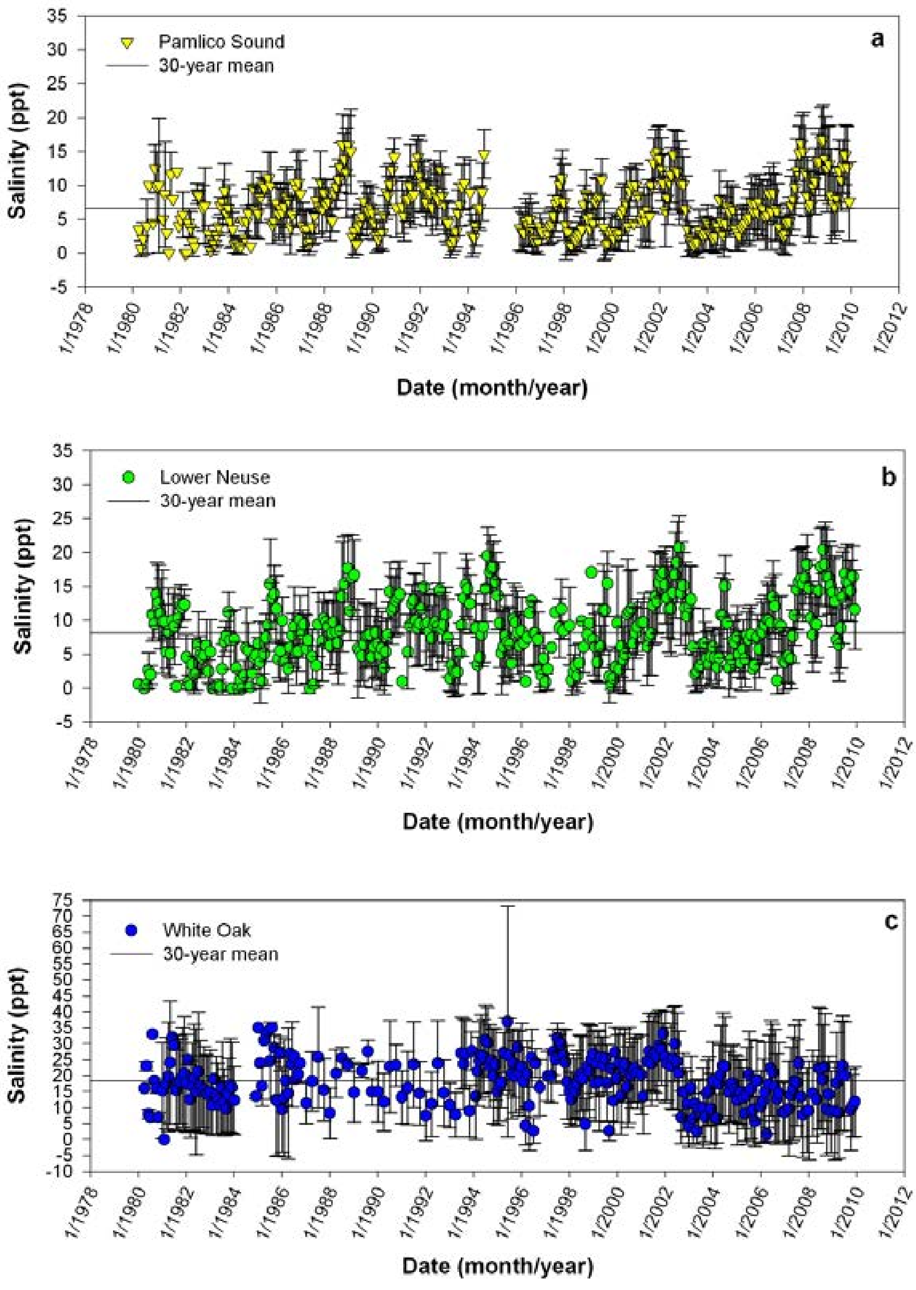

Figure 4. Monthly mean salinity concentrations (n= number of sampling stations in the sub-region) and the thirty year average salinity concentrations for the West Pamlico Sound (a), Middle Neuse River (b), and White Oak River (c) sub-basins.

What Is Not Shown by This Indicator?

There was not sufficient salinity data available to analyze trends in salinity concentrations for the East Pamlico Region from 1980 to 2009.

Understanding the Data

Salinity within an estuarine system is determined by freshwater inputs from river flow and precipitation, saltwater input from the ocean, evaporation, and the mixing of fresh and salt water. Salinity varies across an estuary based on a location's relative supply of fresh and salt water, which in the APES is foremost dependent upon its proximity to river mouths and inlets. The relationship between proximity to sources of fresh and salt water and salinity is indicated by the high degree of spatial variability across the estuarine waters of the APES. It also explains the consistently low salinity concentrations in the Lower Chowan, Lower Roanoke, Lower Tar and Middle Neuse regions (Figs. 2 and 3a), which are within river mouths and furthest from ocean influence, and the consistently higher salinity in the White Oak and Lower Neuse regions, which are closest to ocean inlets (Figs. 3b and 3c).

Salinity can also vary over time at particular locations, especially those that are in close proximity to ocean inlets and river mouths and within the direct flow path of ocean and river waters. Accordingly, temporal variation was observed in the APES, especially at sites closest to inlets (Figs. 3b and 3c).

Over the 30-year period from 1980 to 2009, salinity concentrations generally showed a slight statistically significant increase at one or more stations of all APES sub-basins except for the Lower Neuse River and Pamlico Sound, indicting a gradual increase in the supply of saline ocean water to the region or a decrease in the flow of freshwater from rivers.

SHELLFISH CLOSURES

Lindsay Dubbs[38] and Michael Piehler[39]

Why are Shellfish Closures Important?

Oysters, clams, bay scallops, and mussels are among the shellfish that grow in the Albemarle Pamlico Estuarine System (APES), and all but bay scallops (whose fishery was closed in 2006 because of a depleted population) are harvested for human consumption. Shellfish are filter feeders, filtering food particles from the water and also consuming and concentrating bacteria, viruses, and other pathogens. When people consume raw or undercooked shellfish, the pathogens contained within them have the potential to cause illness. For this reason, shellfish beds are closely monitored and closed when there is the potential for consumption of the shellfish within them to threaten human health. Shellfish closures provide information about bacterial contamination in aquatic systems.

Closure management of shellfish beds began because of observed increases in bacterial levels. Now, shellfish beds are characterized by potential sources of pollution nearby and then monitored for fecal coliform bacteria. While fecal coliform bacteria do not themselves generally threaten human health, they can serve as an indicator of bacterial contamination because they are present when water is contaminated by human or other animal waste.

What Does This Indicator Report?

- The percentage (%) of the area of shellfish beds in the APES permanently closed to fishing from 1980 to 2010.

What do the Data Show?

The total designated shellfishing area comprised 740,019 ha (1,829,576 ac) of APES waters from 1980 through 2006. Then, due to reassessments, it increased slightly to 773,985 ha (1,911,742 ac) in 2007. When the GIS method was employed instead of the hand tally method in 2007, the acreage increased slightly again and fluctuated between values ranging from 846,738 ha (2,091,443 ac) to 852,611 ha (2,105,948 ac) from 2007 to 2010.

The permanently closed portion of the total shellfish area decreased by 5% from 1980 to 1981. This is the largest change in the % of closed shellfish area over the entire 30-year record. After 1981, the % of closed shellfish acreage remained relatively constant through 1990. From 1990 to 1991, the % of shellfish bed area that was closed increased by 1%, and since then has remained relatively constant through 2007 (blue bars, Figure 1). The percentage of shellfish

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area that was closed as determined by the GIS method increased by 1% from 2007 to 2008 and then remained relatively constant from 2008 to 2010 (red bars, Figure 1).

In 2007 the method for measuring shellfish bed area changed from hand tally to GIS. Both methods were used in 2007 and can be used for comparison of methods (Figure 1, 2007, red and blue bars). When all data are considered together, the % of the shellfish acreage within the APES closed due to fecal coliform contamination markedly decreased in 1980 and then gradually increased over the next 10 years of the 30-year period from 1980 to 2010. The % of the shellfish area that is closed to fishing has remained relatively constant from the early 1990s to 2010.

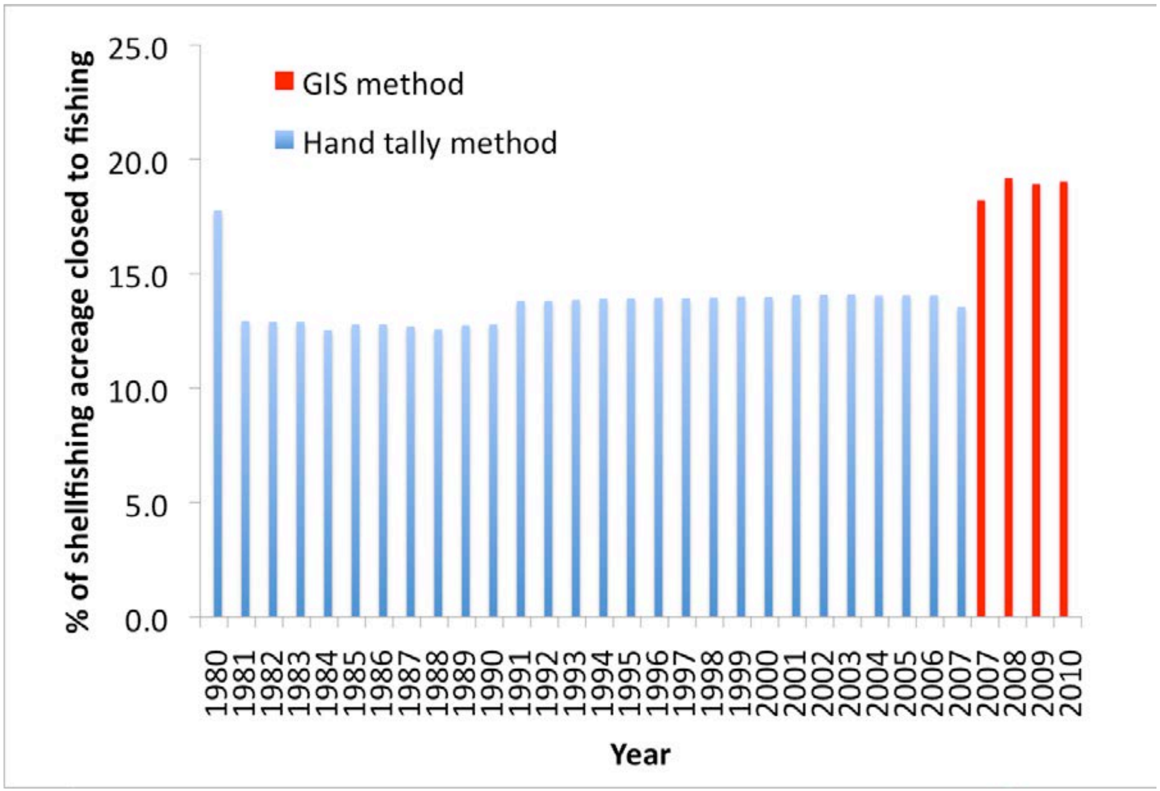

Figure 1. The % of shellfish acreage within the APES that was closed to shellfishing from 1980 to 2010, as determined by using a hand tally method (blue bars; 1980-2007) and a GIS-based method (red bars; 2007-2010).

Understanding the Data

Shellfish beds in North Carolina waters surrounding marinas with greater than ten boat slips are automatically closed to shellfishing (an exclusion to this rule exists for marinas with less than 30 boats without heads and cabins of a size of 24 feet or less) because of the potential for discharge of sanitary wastes, contaminated with bacteria, from boats docked there (NCDEH, 1989). Likewise, shellfish beds nearby to some point sources, including wastewater treatment plant outfalls, are automatically closed to fishing. To prevent closure of shellfish beds in other waters, the median and geometric mean fecal coliform most probable number (MPN) must not exceed 14 per 100 ml and not more than 10% of the samples can exceed a fecal coliform MPN of 43 per 100 ml (NCDEH, 1989). Thus, shellfish closures can either be associated with specific point sources along the coast or measured bacterial contamination.

In either case, increased bacterial contamination of estuarine waters, which leads to shellfish bed closures, has been related to development. Increased fecal coliform levels in estuarine waters have been associated with many types of estuarine shoreline development (White et al., 1999; Kirby-Smith and White, 2005) and increasing percentages of developed land within a watershed (Mallin et al., 2000). Likewise, increased export of fecal coliform, and other pollutants, has been observed with increasing development within a watershed (Line et al., 2008) and changes to hydrology that increase water flow rates (White et al., 1999). Increasing development within the APES likely contributed to bacterial contamination and thereby, increased closures of shellfish beds from 1981 to 1991. Limited increases in the % of shellfish areas closed to fishing since that time may be the result of limited additional changes to watershed hydrology along with the implementation of storm water mitigation measures within watersheds.

The large decrease in the % of shellfish acreage closed to shellfishing from 1980 to 1981 is the result of a reassessment of closures completed in 1980 that led to the opening of several shellfish areas for which there was previously not sufficient data available to allow for their evaluation and classification (S. Jenkins, personal communication).

UNUSUAL FISH MORTALITIES AND DISEASE EVENTS

Wilson Laney[40] **and Lindsay Dubbs**[41]

Why Are Unusual Fish Mortalities and Disease Events Important?

As noted in the Heinz Center report on the state of the nation's ecosystems, events in which aquatic organisms "…die unexpectedly in high numbers or under unusual circumstances may threaten sensitive…populations and may indicate that stresses such as toxins, pollution, or changing weather patterns are affecting…ecosystems (The Heinz Center, 2008:82)."

The 1991 assessment of the Albemarle-Pamlico Estuarine Study provided the rationale for tracking the incidence of kills (mortality) and disease in populations of important aquatic organisms (primarily fish, blue crabs and oysters; Steel, 1991:Fisheries:48; Hogarth et al., 1991). The potential impact of diseases upon the amount of biomass of any affected stock is great. Disease is also important from the perspective of aesthetics, with visibly diseased fish or shellfish being unsalable when sold whole (Hogarth et al., 1991:48). Unhealthy aquatic organisms could potentially be related to human health, with fish, crabs, oysters or shrimp exposed to contaminants developing carcinomas and other organ dysfunctions serving as an indication of potential human health issues. Toxin-producing phytoplankton can accumulate in the edible tissues of fish and/or bivalves, posing potential risks to humans. Some pathogens causing disease in fish also can be pathogenic to humans. Finally, fish and aquatic organism health may be an indicator of general ecosystem health (Sindermann, 1983; Hogarth et al., 1991:48).

Portions of the Albemarle-Pamlico ecosystem were impacted by fish kills and diseases in the past as noted in the 1991 assessment (Steel, 1991). That assessment reported increased numbers of fish kills from the Pamlico River (Steel, 1991:Introduction:16), which were attributed to oxygen depletion as a probable consequence of eutrophication, increased organic oxygen demand and stratification. Outbreaks of ulcerative mycosis were reported in commercially important species such as Atlantic menhaden (*Brevoortia tyrannus*, up to 100% affected) and other species as well (flounder, *Paralichthys* spp, and weakfish, *Cynoscion regalis*) in the Pamlico River estuary. The occurrence of MSX and dermocystidius (diseases fatal to oysters) were first reported as a widespread problem in 1988. Blue crabs from the Pamlico River estuary were reported having wounds in their shells, which were thought to be the result of microbial invasion, possibly facilitated by water quality degradation (Steel, 1991: Introduction:16).

The present assessment seeks to document the incidence of fish kills, and diseases of aquatic organisms (including blue crabs and oysters), occurring within the Albemarle-Pamlico system in

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the interval since the 1991 assessment. To the extent that they produce significant health issues, parasites are also documented, especially those which are exotics.

What Will This Indicator Report?

Potential metrics for this indicator could include the following:

- Fish kills: number of fish kills by county, and/or by individual watersheds. There are several data sources which may be used to generate this metric; the North Carolina Division of Water Quality (NCDWQ), Basinwide Water Quality Planning Section documents fish kills by watershed in their five-year basinwide assessments; the NCDWQ Environmental Sciences Section has provided annual reports of fish kills from 1997 to the present, including kill location, type and number of fish, and suspected cause. Some summarization of these data has been provided in the North Carolina Coastal Habitat Protection Plans (Street et al., 2005; Deaton et al., 2010).

- Hurricane-related fish kills: number, location and composition of fish kills caused as a direct result of hurricane-related flooding and consequent flushing of anoxic water from floodplain forested wetlands. These events are tracked to some extent by North Carolina Wildlife Resources Commission (NCWRC), Division of Inland Fisheries, and NCDWQ.

- Occurrence and prevalence of newly-documented diseases within the Albemarle-Pamlico Estuarine System. New diseases are derived from fish disease surveys conducted in the interval since the 1991 assessment by the United States Fish & Wildlife Service (USFWS) as part of the National Wild Fish Health Survey in cooperation with North Carolina (NCWRC, Division of Inland Fisheries). This survey is still active and ongoing (Personal communication, Norm Heil, Director, Warm Springs Fish Health Center, USFWS, Warm Springs, Georgia).

- Reports derived from ongoing survey of the literature by APNEP collaborators; and/or derived from consultation with the NCSU College of Veterinary Medicine.

What Do the Data Show?

Fish Kills: The fish kill data compiled by NCDWQ indicate that fish kills remain a serious issue within the Albemarle-Pamlico ecosystem (Table 1). Of the total kills reported by water basin from 1996 through 2010 within the state (n = 659), 63.4% were recorded from basins within the Albemarle-Pamlico ecosystem. The leading basins were the Neuse (n = 215; 32.6% of the total for the entire time series), and the Tar-Pamlico (n = 114; 17.3% of the total). The dominance of the major Albemarle-Pamlico river-estuaries as fish kill locations is reflected when the numbers are graphically portrayed (Figure 1).

Table 1. Fish kills by basin within the Albemarle-Pamlico ecosystem, 1996-2010 (NCDWQ, 2012:5).

Year	Chowan	Neuse	Pasquotank	Roanoke	Tar/Pamlico	White	Annual Totals
1996	2	14	10	2	3	3	**34**
1997	2	12	2	None	6	3	**25**
1998	1	8	8	1	5	1	**24**
1999	1	16	2	None	11	3	**33**
2000	None	23	None	None	14	3	**40**
2001	1	37	1	None	23	3	**65**
2002	2	9	6	None	8	3	**28**
2003	2	21	2	2	6	None	**33**
2004	1	8	None	1	2	None	**12**
2005	1	9	2	1	1	1	**15**
2006	None	10	None	2	2	None	**14**
2007	1	10	1	1	5	None	**18**
2008	2	21	4	None	16	None	**43**
2009	2	15	None	None	11	None	**28**
2010	1	2	1	None	1	1	**6**
Total	**19**	**215**	**39**	**10**	**114**	**21**	**418**

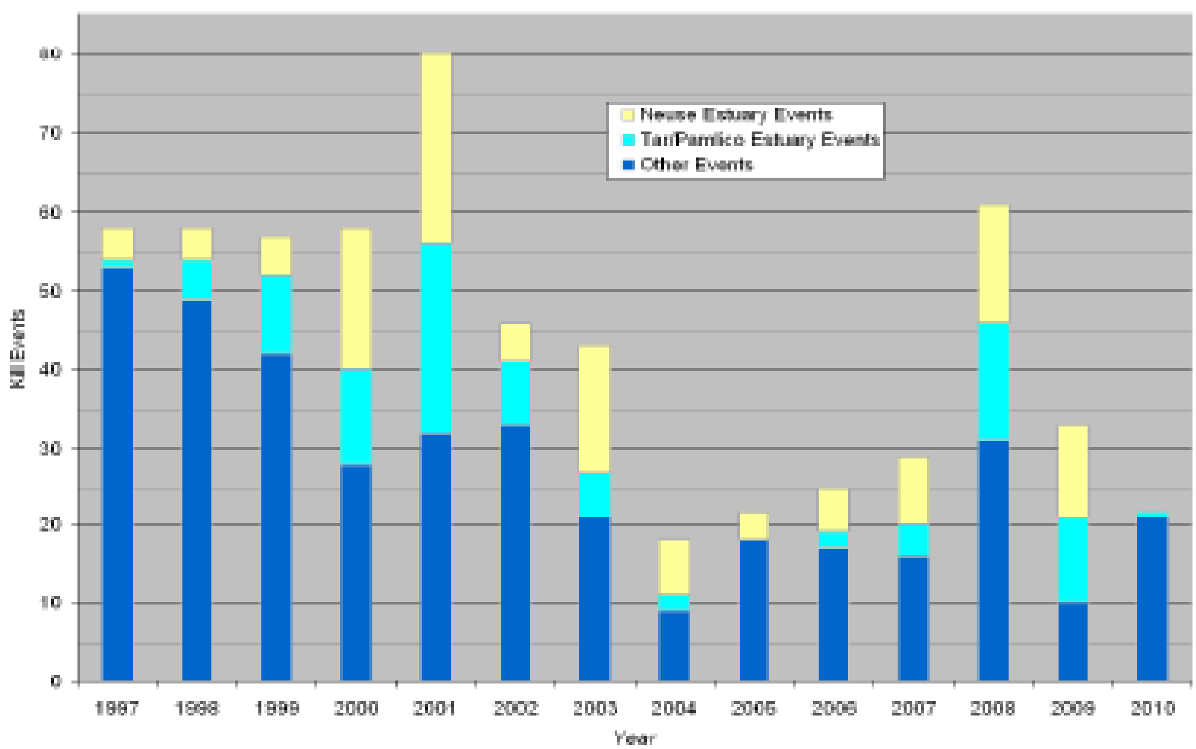


Figure 1. Reported annual fish kill events, 1997-2010 (NCDWQ, 2010:6).

Fish kills occurring in association with tropical storms have been documented on multiple occasions since the 1991 assessment (Maiolo et al., 2001; Luczkovich et al., 2001; Burkholder et al. 2004; Homan, 2012; McCargo, 2012). The Albemarle-Pamlico ecosystem has been, and will continue to be, affected often by tropical storms. Since the 1991 assessment there have been 85 hurricanes or tropical storms (Barnes, 1995; Wikipedia, 2012) which affected North Carolina, many of them producing effects within the Albemarle-Pamlico basins. A number of these produced significant fish kills (see further discussion below).

A search of the National Wild Fish Health Survey database (USFWS, National Fish Health Centers, <>), generated 224 case reports of examinations for fish disease in North Carolina for the period 1996 - present. Of these, 50 (22.3%) were from counties and water bodies of the Albemarle-Pamlico region. Twenty percent of the case files are "pending" with regard to the diagnosis field (see explanation below under Data Quality/Caveats); of the remaining 80% (n = 40), 15 were positive for the largemouth bass virus (LMBV; see below). Locations positive included Contentnea Creek, Neuse River in several locales, Falls Reservoir, Chowan River, North Flat River, Belews Reservoir, Michie Reservoir, and Lake Phelps.

***Diseases**:* Multiple additional diseases, and/or fish parasites producing disease, have appeared in the Albemarle-Pamlico ecosystem subsequent to the 1991 assessment, and additional research has increased understanding of those documented then.

Blue Crab Shell Disease: Noga et al., (1994, 2000) and other investigators (Weinstein et al., 1992) continued their investigations of shell disease in blue crabs. Levels of aluminum, arsenic, cobalt, manganese, nickel, titanium, vanadium and zinc were significantly higher in both gill and hepatopancreas in blue crabs from a contaminated area (Weinstein et al., 1992).

Dermocystidius: Research on "dermo" has continued, funded in part by North Carolina Sea Grant. Oysters from some areas within the Albemarle-Pamlico estuarine system are resistant to the causative organism (*Perkinsus marinus*) (Brown et al., 2005) A review of the literature failed to document any ongoing monitoring program to track the prevalence of dermo in oysters within the Albemarle-Pamlico estuarine system.

MSX (Haplosporidium nelsoni): Studies of MSX have also continued since the 1991 Albemarle-Pamlico assessment. A summary of what was known about MSX was published in 1993 (Ewart and Ford (1993). Although monitoring is occurring within established oyster sanctuaries in North Carolina in the Albemarle-Pamlico estuarine system, monitoring of MSX incidence is apparently not included in the protocols used (Black, 2011).

Lymphocystis virus: Lymphocystis has been reported in striped bass (Smith and Pasnik, 2010), although the incidence appears to be infrequent (Krantz, 1970). This viral disease does not cause severe pathology or death, but it produces small, raised, nodular lesions on the skin and fins. Fish heal after sloughing infected cells, but the virus released from these cells serves as infectious material that can transmit the disease to other fish. It is commonly observed in pre-spawning striped bass and is associated with stress (J.M. Law, College of Veterinary Medicine, North Carolina State University, Raleigh, personal communication).

Pfiesteria piscida: Additional work was conducted on the toxic dinoflagellate *Pfiesteria piscida*. Post-1991 studies documented production of ecotoxins which could be absorbed from water or fine aerosols (Burkholder et al., 1992, 1993, 1995; Glasgow et al., 1995). High concentrations of the flagellated form induced formation of open ulcerative sores, hemorrhaging, and death of finfish and shellfish. Human exposure to aerosols from cell cultures was associated with narcosis, respiratory distress with asthma-like symptoms, severe stomach cramping, nausea, vomiting and eye irritation accompanied by reddening and blurred vision (lasting hours to days), and other significant adverse symptoms. *Pfiesteria piscida* was determined to be euryhaline and eurythermal. Concerns regarding the potential for adverse impacts to human health led to the development of dinoflagellate monitoring strategies (Oldach et al., 1998) as well as surveillance methodologies for determining human impacts (Backer et al., 2001; Moe et al., 2001). While *Pfiesteria* was likely a significant factor in Albemarle-Pamlico fish mortality events during the 1990's, in association with poor water quality (low dissolved oxygen, possibility salinity stress) and high water temperatures, it does not seem to have been as significant a factor in the last decade, and the mechanism of its impact on aquatic organisms remains uncertain (J.M. Law, College of Veterinary Medicine, North Carolina State University, personal communication).

Ulcerative mycosis: Ulcerative mycosis investigations continued in the 1990's (Noga et al., 1991; Noga et al., 1993; Noga et al., 1998; Noga, 2000). Lesions similar to ulcerative mycosis were documented in multiple other species in the Tar-Pamlico Estuary (southern flounder, *Paralichthys lethostigma*; hickory shad, *Alosa mediocris*; striped bass; bluefish, *Pomatomus saltatrix*; Atlantic croaker, *Micropogonius undulatus*; weakfish, *Cynoscion regalis*; spot, *Leiostomus xanthurus*; silver perch, *Bairdiella chrysura*; pinfish, *Lagodon rhomboides*; and hogchoker, *Trinectes maculatus*). Other associated diseases were noted and that poor environmental quality in the Tar-Pamlico Estuary was hypothesized as a contributing factor. Striped bass exposed to an acute (two hour) confinement stress caused skin ulceration on the fins, but not on the body (Noga et al,. 1998). Lesions had varying degrees of epithelial erosion and ulceration. Direct contact with toxins, such as those produced by *Pfiesteria*, may contribute to ulcer formation (Noga, 2000). However, multifactorial pathways that operate at both the ecological and the organismal levels, as well as the nonspecific response of the skin to insults make it very challenging to link epidemic skin ulcers to any single cause in natural aquatic populations (Noga, 2000:807).

Newly (since 1991) Documented Disease, *Anguillicola crassus* parasite: After the 1995 discovery of a single parasitized American eel in Winyah Bay, South Carolina (Barse and Secor, 1999), Moser et al. (2001), sampled eels from multiple watersheds in North Carolina to determine the frequency of infestation. Of the eels captured and examined (n = 1,111), overall 52% were infected (prevalence ranged from 26 – 100% among the rivers sampled). The number of parasites within individual eels ranged from 1 to 53. At the time, infestation rates in North Carolina were higher than those measured in Chesapeake Bay or the Hudson River

Estuary. Subsequent investigations within the Roanoke River in association with hydropower licensing studies have shown lower rates of infestation.

Newly (since 1991) Documented Disease, Bluefish nematode: Bluefish (*Pomatomus saltatrix*) from the Outer Banks were found to be infested with dracunculoid nematodes (*Philometra saltatrix*). Percent prevalence reached a peak of 88% in July 2003 and decreased after the peak of the spawning season (Clarke et al., 2006). Bluefish contained up to 100 parasites per fish. Infection was associated with a range of disorders, including hemorrhage, inflammation, edema, prenecrotic and necrotic changes, and follicular atresia, that may prevent proper development of the oocytes and probably affect bluefish fecundity. The historical occurrences, life cycle, and geographical distribution of the nematode remain largely unknown, but it may play an important role in the recruitment processes of bluefish (Clarke et al., 2006).

Newly (since 1991) Documented Diseases, Largemouth Bass Virus (LMBV): LMBV is a relatively recent arrival to Albemarle-Pamlico rivers and upstream reservoirs (Michaelson, 2010). The following information is from a Virginia Department of Game and Inland Fisheries (VDGIF) news release: "Largemouth bass virus (LMBV) is a disease that impacts several fish species but only appears to cause death in some largemouth bass. First discovered in Florida in 1991, LMBV spread throughout the southern United States and was responsible for a number of largemouth bass deaths in the late 1990's. However, in some reservoirs LMBV only led to a decrease in survival and growth rates. When those declines occur, anglers catch fewer quality-size (greater than three pounds) largemouth bass. The good news is that impacts from the virus outbreak are normally short lived and largemouth bass fisheries recover in about three years. The VDGIF and the North Carolina Wildlife Resources Commission (NCWRC) tested several reservoirs between 2000 and 2003 with most either having no occurrence of LMBV or very slight infection rates. However, in a few reservoirs in North Carolina almost 40% of the largemouth bass tested were positive for LMBV. One of those systems was Shearon Harris Reservoir, which continues to support one of the best largemouth bass fisheries in the state. Recent virus testing coordinated by VDGIF this past August [2010] revealed that LMBV was present in about 40% of the bass tested at John H. Kerr Reservoir/Buggs Island Lake and is responsible for the decline in the bass fishery. Largemouth bass from Briery Creek Lake and Sandy River Reservoir (Prince Edward County) were also tested and the virus was detected and confirmed. A small largemouth bass mortality event which occurred at Briery Creek Lake in late June 2010 was most likely the result of LMBV in the population. Due to the popularity of the largemouth bass fishery at Kerr Reservoir/Buggs Island Lake, anglers have expressed concerns about the LMBV spreading to other area reservoirs. However, some of the area reservoirs already contain LMBV and fish have likely built-up an immunity to the virus. For example, largemouth bass in Lake Gaston tested positive for LMBV in 2000. However, recent surveys at Lake Gaston indicate that the largemouth bass population is doing well (Michaelson, 2010).

Newly (since 1991) Documented Diseases, Mycobacteriosis in striped bass: Mycobacteriosis has been identified as present in striped bass (*Morone saxatilis*) in Chesapeake Bay and is the cause of an ongoing epizootic. Prevalence of the disease is high in pre-migratory striped bass from the Bay; however, prevalence within a sample (n = 249) of striped bass caught during the 2005-

2006 winter fishery in coastal North Carolina was low (6.8% of all fish examined) (Matsche et al., 2010). Monitoring and additional experimentation is ongoing, and the Atlantic States Marine Fisheries Commission's Striped Bass Technical Committee is working with a number of researchers to determine the effect of the disease on the migratory population.

Newly (since 1991) Documented Diseases, *Spring viremia of carp virus (SVCV)*: SVCV was first detected in the United States in 2002. (Center for Food Security and Public Health, 2007; Miller, 2007; Miller et al., 2007; Becker, 2010). Unfortunately, there is evidence that koi had been distributed from this hatchery to most of the 48 contiguous states before being confirmed with SVCV. The disease is caused by a virus (*Rhabdovirus carpio*) which enters fish through the gills or can enter through parasites such as the carp louse or leeches. SVC usually occurs in the spring where water temperatures are less than 18°C. Infected fish shed this virus through feces and possibly through urine and gill mucus. Experimental infections have been reported in several species which occur in the Albemarle-Pamlico system, golden shiners (Notemigonus crysoleucas) and pumpkinseed (Lepomis gibbosus).

Newly (since 1991) Documented Diseases, Trichodinosis: An epidemic of trichodinosis occurred in adult largemouth bass from the Chowan River drainage (Huh et al., 2005). In late winter to early spring 2002, anglers reported fish with a "jelly-like slime coat" on the skin. Electrofishing sampled documented that about 10% of sampled largemouth bass had a very thick, bluish-white "mucoid layer" on the body and fins. Moderate to heavy infestations of the ciliate *Trichodina* were detected. Fish with the epidermal infection also had significant gill infestations. The environmental cause of the epidemic is uncertain but the lesions suggest that some chronic stressor was involved (Huh et al., 2005).

Why Can't This Entire Indicator Be Reported at This Time?

NCDWQ data are available and can be further analyzed to provide additional information on the number of kills, and numbers of species of fish in each kill as well as the total killed. With regard to diseases (and parasites), while the National Wildlife Fish Health Survey is continuing (Norm Heil, Warm Springs Fish Health Center, USFWS, personal communication), it does not constitute a systematic survey of fish health or fish diseases within the Albemarle-Pamlico ecosystem. It does provide data which can be further analyzed to provide more information regarding diseases within the Albemarle-Pamlico ecosystem. While there have been periodically-funded projects to assess the health of individual species (i.e., Atlantic menhaden; see Johnson et al., 2007), North Carolina does not currently conduct a systematic survey of fish health or disease (J.M. Law, College of Veterinary Medicine, NCSU, personal communication). Comprehensive data on the health and presence of disease in fish and other aquatic organisms within the Albemarle-Pamlico ecosystem are lacking.

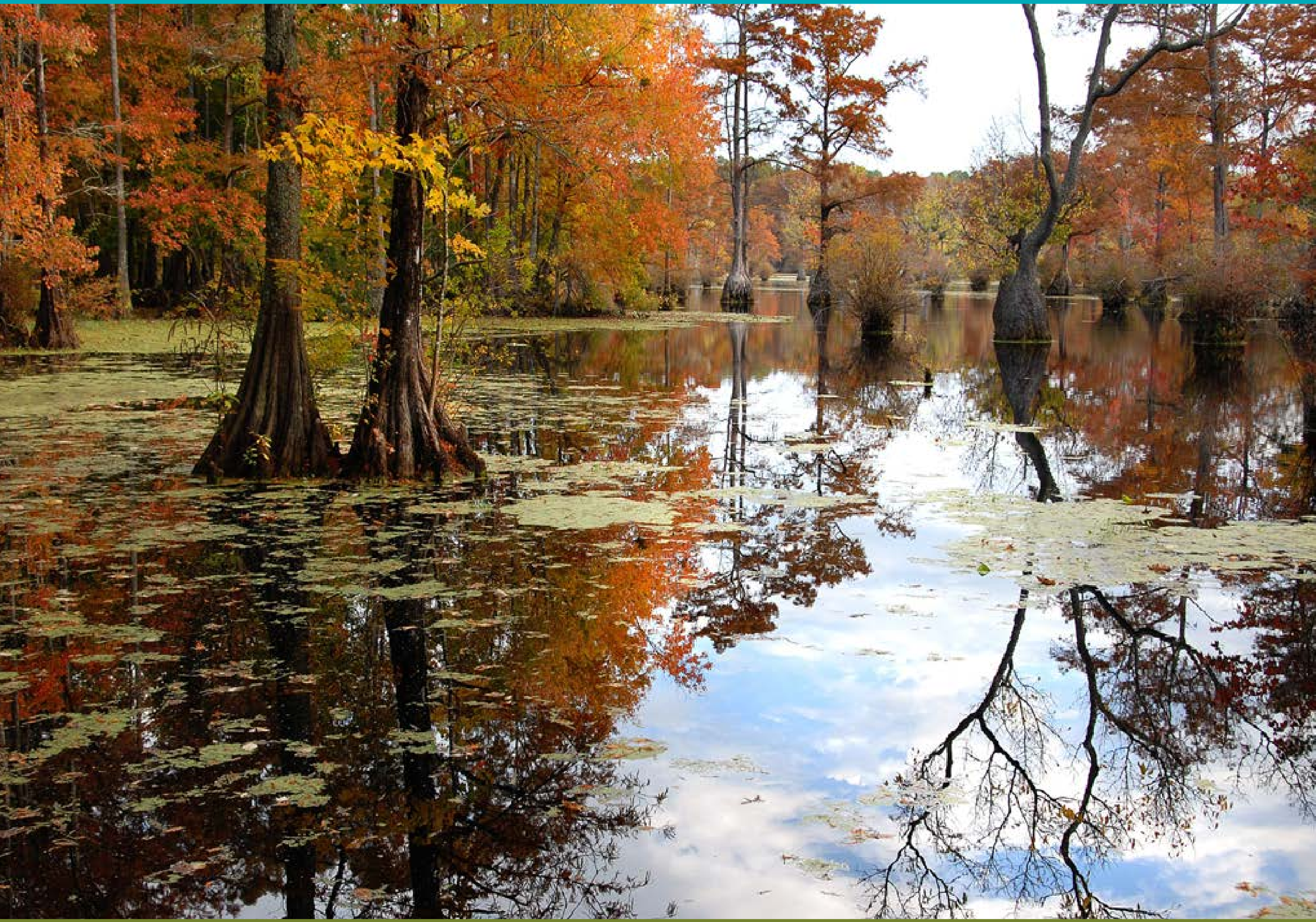
Understanding the Data

High volumes of rainfall produced by Hurricane Allison (June 6, 1995) indirectly led to a massive fish kill on the Roanoke River when the U.S. Army Corps of Engineers abruptly terminated flood discharges from John H. Kerr Reservoir (Kornegay, 1995). Precipitation from Allison was a major contributing factor to the prolonged Roanoke River flooding of June and July 1995. On top of the prolonged flooding, there were the record high air temperatures. Agency knowledge in 1995 of how the Corps dealt with flood flows was poor. Up until then everyone had focused on spawning season flows only. The fish kill of 1995 was a pivotal event that led the resource agencies to an examination of year-round flow management in the Roanoke (J. W. Kornegay, NCWRC-Division of Inland Fisheries, Camden, retired personal communication).

Hurricane Fran (1996) produced massive fish kills in association with severe dissolved oxygen deficits and high contaminant loadings (total nitrogen, total phosphorus, suspended solids, and fecal bacteria; Burkholder et al., 2004). Hurricanes Dennis, Floyd and Irene (all 1999) produced significant flooding, but delivered more dilute contaminant loads and no major fish kills were reported (Burkholder et al., 2004). Hurricane Isabel (2003) produced widespread kills in the northeastern and central North Carolina Coastal Plain rivers and streams as a consequence of reduced dissolved oxygen (McCargo, 2012). Extensive fish kills occurred within a 75-km reach of the Roanoke River. Kills occurred also in the upper Chowan River, and within upper tributaries of the Perquimans, Little, Pasquotank and Scuppernong Rivers. Air-breathing species such as bowfin (*Amia calva*) and longnose gar (*Lepisosteous longirostris*) were not observed in the kills. Hurricane Irene (2011) also caused extensive hypoxia and anoxia within much of the Coastal Plain, with additional associated fish kills (Homan, 2012).

It is clear from surveying the peer-reviewed literature that the Albemarle-Pamlico ecosystem harbors multiple fish diseases; however it does not appear from our review thus far that there is any systematic effort to monitor or quantify disease prevalence, with the possible exception of LMBV. The National Wild Fish Health Survey has sampled numerous sites within the Albemarle-Pamlico ecosystem for LMBV, and has documented it present in multiple locations. Given the significant economic importance of the recreational fishery for largemouth bass, monitoring for LMBV and other diseases which affect the species would seem to be a priority need.

Chapter 5 - Fresh Waters



Chapter 5: Fresh Waters

This chapter features four assessments of the ecosystem type "Fresh Waters", including assessments of:

- four indicators of the major category "Chemical and Physical Characteristics":
  - Streamflow,
  - Point Source Discharges,
  - Riverine Transport of Phosphorus and Nitrogen, and
  - Suspended Sediment.

Indicators of the major categories "Extent and Pattern" and "Biological Components" will be included in future editions.

STREAMFLOW

Timothy Spruill[42]

Why Is Streamflow Important?

Streams, lakes, and estuaries are all reliant upon water that drains off the land surface in order to function. The functions include support of aquatic and terrestrial organisms, removal of waste and debris from the land to the oceans, and support of human populations (really a subset of support of terrestrial organisms). On the Coastal Plain, approximately 38 cm (15 in) (of the annual average of 127 cm (50 in) of precipitation runs off as streamflow, with about 13 cm (5 in) moving over the land surface as surface runoff and 25 cm (10 in) moving through shallow aquifers as groundwater runoff or baseflow. A little more than this typically runs off as stream flow in the Piedmont portion of the Albemarle-Pamlico Basin. Most of the remaining precipitation [86 cm (34 in)] returns to the atmosphere as evaporation, with only about 3 cm (1 in) that moves to deeper confined aquifers (Wilder et al., 1978).

The amount of water carried by a stream and how it changes over time determines the types of plants and animals that inhabit a stream, as well as the quantities of organisms that can live there. Less water moving in a stream translates to less viable habitat for aquatic organisms because of less channel area needed to transport the volume of water. Stream flow volume can also affect chemistry of the receiving lakes and estuaries by diluting chemical properties during high flow periods and concentrating them during low flow periods. These issues, as timing of flows relate to primary productivity in the Albemarle-Pamlico estuaries were discussed in the first APNEP status and trends assessment (Steele, 1991). High streamflows that occur during wet years, or even seasonal hurricanes, can result in extremely dilute water in the Albemarle-Pamlico sounds and estuaries. Conversely, extended low flows that occur during droughts can cause chemically concentrated water in the sounds and estuaries and can actually allow upstream movement of salt water. These chemical changes can directly affect organisms that are present and usability of the water for various human water-supply needs. Long-term changes in the average volume of streamflow, as might occur during a climatic shift to wetter or drier conditions, have direct implications for the ecology of ecosystems and human communities in the Albemarle-Pamlico Basin.

Surface water is a primary pathway within the hydrologic cycle, as well as the geologic cycle. In order for the ecosystem to function normally, the quantity of water that flows in channels over the land to the oceans must occur in quantities that organisms have evolved to survive and thrive in. That amount is usually the average flow for the region. A little more or a little less river and stream flow in some years would not normally be cataclysmic, but persistent long term changes, as might occur due to climate change or abnormal diversion and removal of

[42] US Geological Survey (Retired)

water from a system, could influence and ultimately alter the ecology and economy of an area in the sense that characteristic organisms and habitats and water supplies could change dramatically.

What Does This Indicator Report?

- Mean annual flow and 95% confidence intervals for six selected stations in the Neuse River Basin
- Results of test for trends in mean annual flow at six selected stations in Neuse River Basin for the period 1997-2008
- Mean annual flow and results of tests for trend for Contentnea Creek at Hookerton, North Carolina, Roanoke River near Roanoke Rapids, North Carolina and Blackwater River near Franklin, Virginia

What Do the Data Show?

Trend assessments for selected streams in the Neuse Watershed are shown in Table 1. No significant trends ($\alpha = 0.05$) for mean annual flow were detected at four of the six stations included in this assessment. Decreasing flows were detected at Little River at Orange Factory and Eno River at Hillsborough, both relatively small streams located in the Piedmont of North Carolina in the Neuse River Watershed. Both of these streams drain into Falls Lake and exhibited significantly decreasing flows for the period 1997 through 2008, with lowest flows occurring between 2004 and 2008. During this time period, the years 1998 and 2003 were the wettest for the two Piedmont streams. The rest of the streams, located in the Coastal Plain, had very wet years in 1999, 2003, and 2006, with 1999 being the largest streamflows at stations located near the coast, due primarily to Hurricane Floyd.

Long-term flow records were analyzed for Contentnea Creek at Hookerton in Neuse River Watershed (1930-2008), Roanoke River at Roanoke Rapids (1964-2008), and Blackwater River near Franklin, Virginia (1945-2010) (Figures 1-3). Summarized data for these three streams are shown in Table 2. No significant long-term trends ($p > 0.05$) were detected for any of the three mean annual flows for the periods analyzed, suggesting that no major changes in water use/water management or rainfall or rainfall/runoff relationships have occurred in these large rivers since the beginning of the record. However, some shorter periods may exhibit trends, although no attempt was made to analyze these.

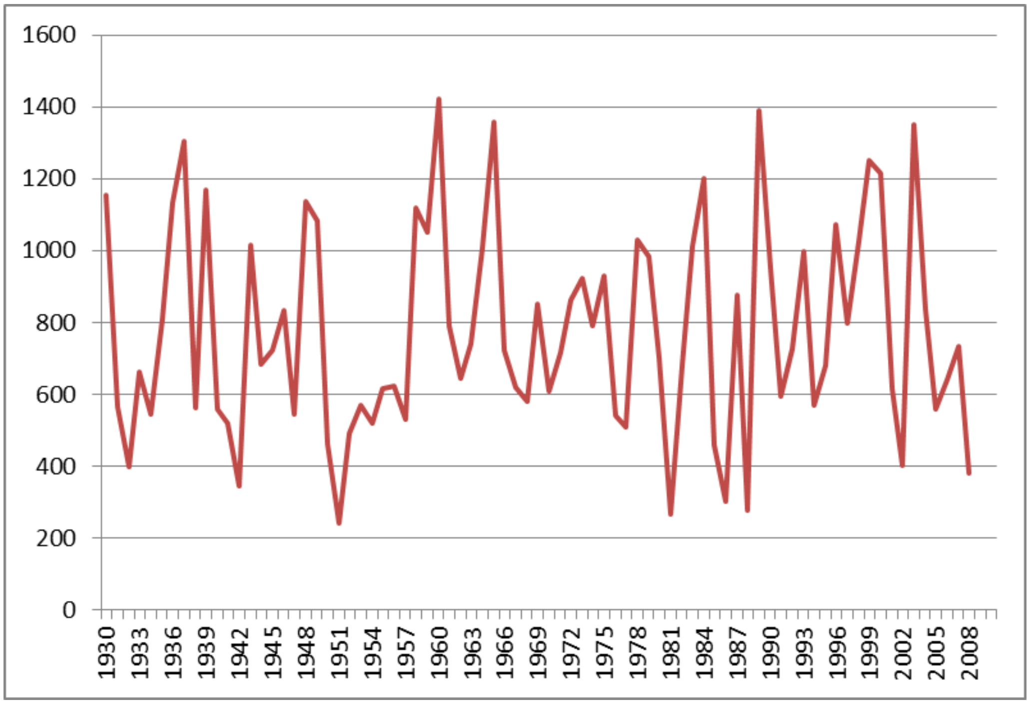


Figure 1. Mean annual flow (cubic feet per second) for Contentnea Creek at Hookerton, NC, 1930-2008 (Data from USGS, 2011).

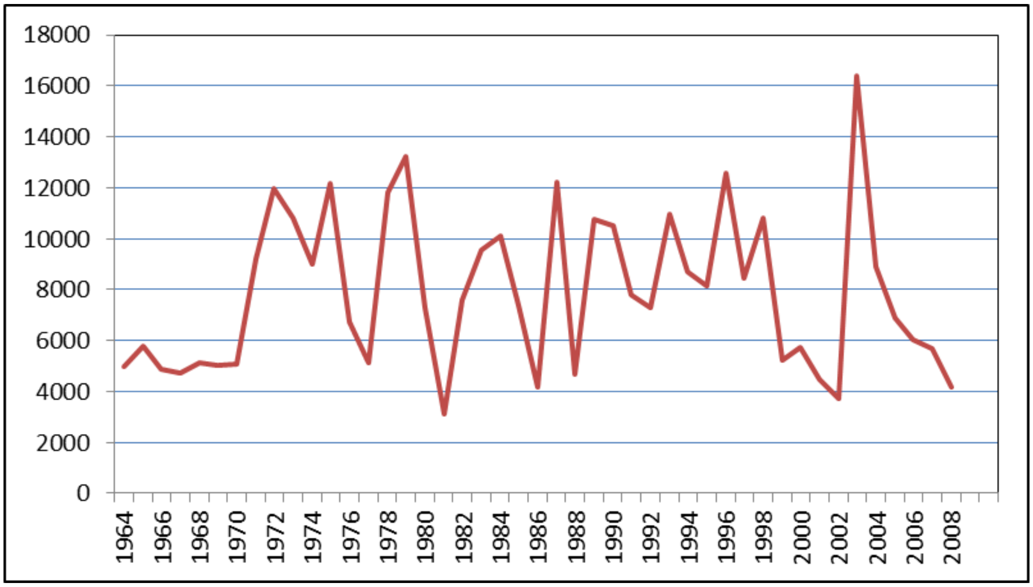


Figure 2. Mean annual flow (cubic feet per second) for Roanoke River near Roanoke Rapids, NC, 1964-2008 (Data from USGS, 2011).

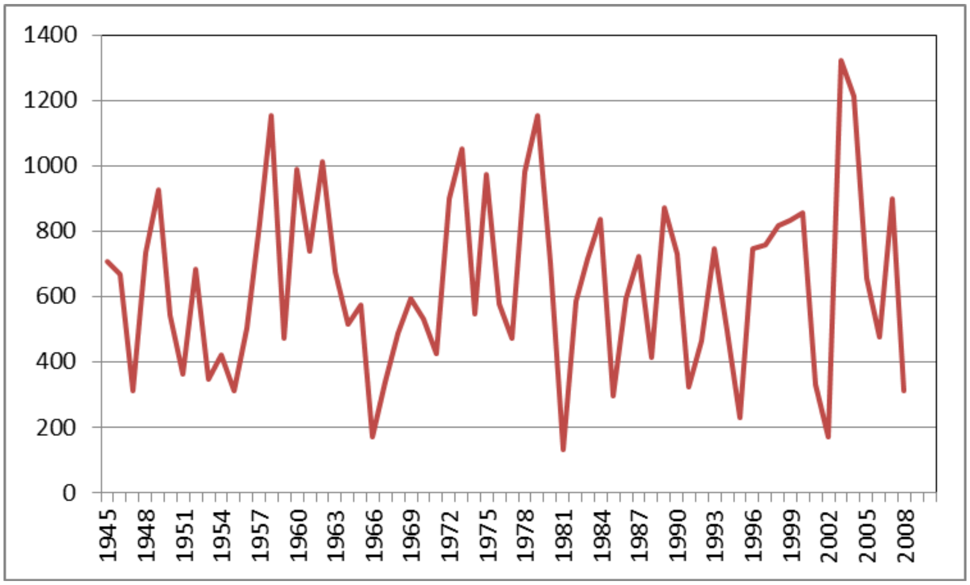


Figure 3. Mean annual flow (cubic feet per second) for Blackwater River near Franklin, VA, 1945-2008 (Data from USGS, 2011).

Table 2. Mean annual flow with 95% confidence interval, and trend evaluation using the Pearson Correlation test for three selected streams in the Albemarle-Pamlico region.

Station	Period of Record	Basin	Mean and 95% C.I. m^3/s (cfs)	Trend? (α = 0.05)
Contentnea Creek near Hookerton, NC	1930-2008	Neuse	22, 20-24 (774, 708-840)	No
Roanoke River near Roanoke Rapids, NC	1964-2008	Roanoke	223, 201-250 (7888, 6957-8819)	No
Blackwater River near Franklin, VA	1945-2008	Chowan	18, 16-20 (640, 573-708)	No

Why Can't This Indicator be Fully Reported at This Time?

The Albemarle-Pamlico Basin covers approximately 78,000 km^2 (30,000 mi^2). Only streams (some only tributary streams) from three of the five major drainages were used to evaluate streamflow data, thus representing only a little more than 30% of the entire Albemarle-Pamlico Basin. Streams were selected based on readily available information. Data from about 20-30 streams representing a larger portion of the A-P Basin should be included in future reports.

What is Not Shown by This Indicator?

Mean annual streamflow is only one measure of change in a hydrologic regime of the Albemarle-Pamlico Basin. Other important features of the streamflow, or surface runoff, include changes in average low and high seasonal flows, occurrence of extreme high and extreme low flows, flow variability, and flood-flow frequency (the occurrence of flows that exceed bank full volumes). All of these features of streamflow have important implications for ecological and human wellbeing (Richter and Postel, 2003). None of these additional metrics were evaluated for this assessment, but are planned for future assessments.

Understanding the Data

Understanding changes in streamflow over time is very important because of implications indicated in the introductory paragraph above, but difficult, because of large variability of streamflows and the multiplicity of factors than can cause such variability. The variability of streamflow and the difficulties that it presents for managing and forecasting water availability were noted in an early publication by Leopold and Langbein (1960). Average annual streamflow of rivers can vary greatly from year to year, using river flows shown in Figures 1 to 3 within the Albemarle-Pamlico Basin as examples: these annual average flows range from 2 to 8 fold over the course of only a few years. Nevertheless, these flows usually cluster, in a long-term sense (over the course of several decades), around some mean value. Mean flows measured over shorter periods (5-20 years), can be statistically lower or higher than other similar periods—these streamflows can vary according to periodic climatic phenomena (McCabe et al., 2004; Mitchell et al., 1979; Perry, 2006) and with anthropogenic phenomena such as artificial drainage, diversion and dams for water supply, or pumpage of an aquifer that supplies groundwater (baseflow) to a stream. Because more than one of these phenomena can occur simultaneously, it is important to consider several possibilities when interpreting streamflow trend data.

Image courtesy of the N.C. Division of Water Resources

POINT SOURCE DISCHARGES

Timothy Spruill[43]

Why Are Numbers And Types Of Point Source Dischargers Important?

Sources of pollution are classified as either nonpoint (diffuse discharge across the land surface) or point (concentrated discharge from a pipe, ditch or other well defined point). Material (rocks, plant, and animal) is naturally corroded and/or eroded and transported to rivers and ultimately to the oceans. Before the development of human societies, all "pollution" (defined here as the addition of chemicals to water moving through the hydrologic cycle) was, of course, nonpoint and consisted entirely of geologic processes (rock dissolution and mechanical erosion through wind, water and tectonic action) and biological processes (primarily decomposition, metabolism, and excretion). Communities in the United States and Europe, having a need to rid their living environment of wastes generated from manufacturing and domestic sources, have used pipes engineered to carry water and wastes (either directly or indirectly) into streams over the last 100-150 years. Although pipes to convey untreated wastes were used as early as 3000 BCE (Schladweiler, 2002) and continued even well into the 20th century in some small towns and rural areas (i.e., the practice of "straight piping"), by the late 1800s it was increasingly realized by large municipalities that some treatment was required to prevent odor and disease problems. Still, the practice of allowing streams to "purify" (dilute) the stream downstream of where it was discharged was not uncommon until the middle of the 20th century in rural areas and small communities. As noted below, untreated wastes were discharged by half the dischargers in the Albemarle-Pamlico Basin as late as 1960.

Untreated municipal wastes contain large amounts of solids and organic materials, and can potentially contain toxins (particularly from industrial operations), bacteria and viruses (including pathogens), nutrients, pharmaceuticals, and various other chemical products and compounds. Wastewater treatment has improved tremendously through the years, beginning in earnest in the United States during the 1950s with the removal of solids (primary treatment, which removes about 10% of the nitrogen (N) (Stanley, 1992:47)) before discharging to a stream. Biological (secondary) treatment processes remove organic material (removing between 25-45% of the contained N) and chemical (tertiary) treatment remove toxic compounds and nutrients, as well as disinfection before discharging to a receiving body of water, were added in subsequent years.

Before 1950 no significant N removal from discharged wastes occurred (Stanley, 1992). The number of point source dischargers increased from around 200 in 1960 in the North Carolina portion of the Albemarle-Pamlico drainage (with only about half of these facilities with primary treatment or better) to around 400 in 1990, with all required to provide secondary treatment or better (Steel 1991). The Neuse River Basin, which was selected for this assessment, has

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ranged between about 140-170 individual permits, with about 30 discharging 1 million gallons per day (MGD) or more since 1990 (Table 1). Point source discharges can contribute pollutants of various kinds to streams depending on the level of treatment. Most of the major dischargers in the Neuse River Basin are municipalities. All discharges are required to be permitted by the states under the National Pollutant Discharge Elimination System (NPDES) through the U.S. Environmental Protection Agency, the Virginia Department of Environmental Quality (VDEQ) and the North Carolina Department of Environment and Natural Resources (NCDENR).

The numbers and types of waste dischargers can potentially have a major effect on water quality. However, the quantity and quality of waste discharged into streams ultimately determines the impact on the receiving stream lake or estuary and water quality impacts are not necessarily related to the number of dischargers. The amounts of different types of wastes allowed to be discharged are defined in the effluent limits on each NPDES Permit. Point sources can contain many different contaminants which can be detrimental to the environment, which include toxic, dissolved oxygen depleting wastes, and nutrients. Because nutrients in point-source wastes are very important in impacting eutrophication concerns in the Albemarle-Pamlico basin, one of these contaminants, N, in the Neuse River Basin is the focus of this assessment.

What Does This Indicator Report?

- Numbers of major and minor wastewater dischargers in the Neuse River Basin between 1960 and 2008.
- Total N loads discharged by point sources to the Neuse River Basin between 1960 and 2008.
- The percentage of N discharged from point sources compared to N transported from all sources in the Neuse River at Fort Barnwell between 1960 and 2008.

What Do the Data Show?

Although population in the Neuse River Basin more than doubled from 645,000 in 1960 (Stanley, 1992) to 1.4 million in 2008 (NCDWR, 2008), point source discharges of total N decreased significantly ($\rho = -0.89$, $p < 0.05$) through the period from more than 1,200 tons annually before 1995 to less than 700 tons annually for selected years after 2000 (Table 1). This decrease is primarily attributed to improved wastewater treatment technology since the mid-1990s (NCDWQ, 2009). From data shown in Table 1, the number of major dischargers (discharging more than 1 MGD) has remained relatively constant, at least since 1990, and ranged from 27 to 34 dischargers. The North Carolina Division of Water Quality states that 95% of N originates from these major dischargers (NCDWQ, 2009). Although the amount of wastes discharged is not significantly correlated to N transported by the Neuse River at New Bern ($\rho = -0.27$, $p > 0.05$), the percentage contribution to the total N stream load is significantly correlated ($\rho = 0.89$, $p < 0.05$) to the diminished point-source N load (see the last paragraph in the "Understanding the Data" section below for an explanation of the significance of these two relationships).

Table 1. Number of major (≥ 1 MGD) and minor (< 1 MGD) wastewater dischargers, estimated annual N load and percent of total N Load transported in the Neuse River at New Bern, for selected years between 1960 and 2008 (nd = no data).

Individual Permits	Major >= 1 MGD	Minor < 1 MGD	Method	Year	Reference	Point Total N [mt (T)]	Total N at New Bern [mt, (T)]	Point Sources: %N at New Bern
			PopTfactor	1960	Stanley, 1992	1138 (1254)	nd	nd
			PopTfactor	1973	Stanley, 1992	1317 (1452)	8704 (9594)	15
			PopTfactor	1980	Stanley, 1992	1467 (1617)	4130 (4552)	36
			PopTfactor	1986	Stanley, 1992	1746 (1925)	2409 (2656)	72
169	30	139	ConXFlow	1990	Dodd et al., 1992	1226 (1351)	4473 (4931)	27
	30		ConXFlow	1993	NCDWQ, 1993	1320 (1455)	5277 (5817)	25
168			ConXFlow	1995	NCDWQ, 2009	1088 (1199)	6769 (7462)	16
157	27	130	ConXFlow	2001	NCDWQ, 2002	620 (683)	2575 (2839)	24
157	34		ConXFlow	2003	NCDWQ, 2009	589 (649)	6247 (6886)	9
162	30	132	ConXFlow	2006	NCDWQ, 2009	386 (425)	4267 (4704)	9
136	25	111	ConXFlow	2008	NCDWQ, 2009	269 (297)	2990 (3296)	9

Why Can't This Entire Indicator Be Reported at This Time?

There are many contaminants in wastewater that can be toxic, oxygen depleting, carcinogenic, or which contain nutrients which can overly stimulate phytoplankton growth. Because of a shortage of time and funding required to prepare a comprehensive assessment of all possibly significant contaminants in all of the major river basins of the Albemarle-Pamlico basin, only the Neuse River Basin was assessed here and only N because of its importance in influencing eutrophication processes. Although phosphorus is important in eutrophication of water bodies, most published data has been focused on N in the Neuse River basin, particularly after 1995. An assessment for each river basin in the Albemarle-Pamlico Region which addresses other significant contaminants should be included in future Albemarle-Pamlico Basin assessments.

Understanding the Data

Between 1880 and 1987 N produced from all point and nonpoint sources in the entire Albemarle-Pamlico Basin increased from 30,000 to 55,000 metric tons (mt) (33,000 to 61,000 tons [T]), with most (80%) of the increase occurring after 1959 (Stanley 1992) due primarily to increased use of fertilizer on crops. The pattern of increase is similar for the Neuse River Basin, increasing from about 9,000 to 36,000 mt (10,000 to 39,700 T) from 1880 to 1987 (Stanley, 1992; Figure 3 in Stow et al., 2001), again with most (76% or 20,500 mt) of the increase occurring after 1959.

By 1998 total N inputs in the Neuse Basin had increased to approximately 59,000 mt (65,000 tons), with most of the increase through the 1990s due to increased animal waste production (Stow et al., 2001). Waste production from point sources between 1960 and 1998 increased from 1,000 mt (1,100 T) to 2,000 mt (2,200 T). Although the point source discharges of N increased in the Neuse watershed, point source contribution to all N sources in the Neuse Basin decreased from approximately 7% in 1960 to 3.4% in 1998 (Stow et al., 2001). Point sources averaged about 2.6% of all N sources in eight selected basins with the Albemarle-Pamlico Region by 1990 (about 4% in the Neuse River at Kinston, NC), indicating that point sources were 3-4% percent of all sources until nearly 2000 (Harned et al., 1995).

Even though point sources comprised a little more than 3% of *all* sources of N produced in the basin by 1998, point sources comprise a much larger percentage of the N transported in the river—from approximately 70% in a very dry (low-flow) year like 1986, to less than 10% during 2003 (a very wet (high-flow) year), 2006 and 2008 (Table 1). Currently (2012), the percentage contribution is approximately 10% for years having average flow. The higher percentage point-source contribution to in-stream N load relative to all in-stream N sources is because the amount of point-source N reported is entirely discharged to the river at each discharge point (pipe), whereas only a fraction of the N reported from all other sources (about 12% in the Neuse River at Kinston (Harned et al., 1995, Table 12); estimated to be less than 10% for both N and phosphorus (Stow et al., 2001)) enters and is directly transported in the river. The reason that nonpoint N sources at their point of origin on the land are less than the amount delivered to the receiving stream or water body is that N from fertilizer or other non-point sources is chemically reduced or retained by soils and vegetation as the water moves over or through the soils to the stream or is removed from a watershed (i.e., crops harvested).

Thus, although the reduction of point source N in the Neuse (and probably other watersheds of the Albemarle-Pamlico Basin) through better treatment technology did not appear to significantly reduce the N load of the Neuse River (as indicated by the insignificant correlation between point-source and total N load transported by the Neuse River—indicating other factors such as flow or nonpoint sources may be more important in influencing total N transported by the river), the reductions did result in lower percentage N contributions by point sources transported by the river, and possibly the decreased annual N *concentrations* observed after 1995 (see the APNEP Indicator “Riverine Transport of Nitrogen and Phosphorus”). These lower percentages are particularly important during low flow years when impacts from point sources on load and concentration are greatest. Thus, improved waste water technology in the Neuse River Basin has resulted in observable improvements in water quality by significantly reducing N loading from point sources and reducing the overall percentage contribution.

RIVERINE TRANSPORT OF NITROGEN AND PHOSPHORUS

Timothy Spruill[44]

Why Is the Movement of Nitrogen and Phosphorus to Coastal Waters Important?

Nitrogen (N) and phosphorus (P) are essential for plant life. However, nutrients supplied in excess of the amount needed by plants can result in rapid and excessive growth, known as eutrophication. Rivers, streams, lakes, and estuaries become eutrophic when nutrients occur in excess of the amount needed to maintain a stable aquatic vegetative community. Increased loads of nutrients (N and P species) in rivers and streams over the last several decades are thought to have been a major factor in declining water quality in streams, rivers, and estuaries worldwide. Excessive algal and vegetative growth results in choking or blockage of surface water bodies and massive die-offs that deplete dissolved oxygen by microbial metabolism associated with the decay process, killing many normally resident species and resulting in biological rebound with more undesirable pollution tolerant species, including toxic dinoflagellates (Vitousek et al., 1997), many of which are harmful to people and fish (Burkholder and Glasgow, 2001). The response variable to nutrient enrichment that is often measured is chlorophyll a, where more nutrient availability results in higher concentrations and persistence of chlorophyll *a* in the aquatic environment (see "Chlorophyll *a*" indicator for more detailed description). Thus, for the Albemarle-Pamlico Basin, as well as for the rest of the nation, use and disposal of nutrients must be limited in the environment to preserve or improve water quality to meet national or state minimum standards. Currently, North Carolina water quality is considered impaired if chlorophyll *a* concentrations in a water body exceeds 40 ug/L (NCDWQ, 2004).

Sources of Nutrients and their role in eutrophication

Typically, the major sources of excessive P or N in the environment are animal and human wastes and fertilizer. For N, an additional significant source is combustion from power plants and automobiles that release nitrogen oxides (NOx) to the atmosphere that is later returned to land and water through rainfall. Combustion products resulting in nitrogen oxides in the atmosphere also account for a significant proportion of stream N loads: atmospheric inputs of N are a major source of N to rivers draining the Atlantic and Gulf coasts of the United States (10-35%, Alexander et al., 2000; ~7-50%, Castro et al., 2000) and have been estimated to be the primary N source in many streams of the southeastern United States, including North Carolina (Hoos and McMahon, 2009).

Because increased nutrients in the environment are a result of human activities and because they increase the rate of eutrophication, the process is known as cultural eutrophication. P often is the primary cause of freshwater blooms and eutrophication because N is relatively more abundant and P occurs at very low concentrations under conditions not impacted by

[44] US Geological Survey (Retired)

humans—it is typically the limiting nutrient for growth in freshwater systems and is required by most plants in far lower concentrations than most other nutrients to maintain physiological health. N is not normally limiting in freshwater streams because of its pervasive occurrence in terrestrial environments, and particularly since the introduction of the Haber process during the early 20th century, which extracts atmospheric N to produce ammonia—it is a major component of many agricultural products, primarily fertilizer. N is often the limiting nutrient in estuarine environments, particularly in the most downstream portions of estuaries (Paerl et.al. 2004). The increased number and extent of dead zones in estuaries worldwide has resulted primarily from increasing nutrient loads over the last several decades (Diaz and Rosenberg, 2009), indicating increasing cultural eutrophication and deteriorating water quality worldwide.

Poor water quality of streams, lakes and estuaries in Albemarle-Pamlico Basin in the 1970s, 1980s, and early 1990s was documented and investigated by several researchers (Paerl, 1982; Paerl, 1983; Harned, 1982; Alling, 1990; Steel, 1991; Harned et al., 1995; Burkholder and Glasgow, 2001). In response to these findings, new requirements for nutrient reduction were established by the North Carolina Department of Environment and Natural Resources during the mid-1990s to improve water quality. As a result, several monitoring efforts and studies were implemented since that time in order to evaluate possible changes in water quality. The purpose of this assessment is to independently evaluate new, as well as older, information and data to determine if water quality improvements have occurred in a selected area of the Albemarle-Pamlico Basin, the Neuse River Basin. Harned et al. (2009) included results on nutrient concentrations from the Neuse, as well as other basins of the Albemarle-Pamlico drainage, and these will be referenced. For more detailed information, see Harned et al. (2009).

What does this indicator report?

- Total annual loads by mass, and yields by mass per unit area, of total N and total P transported annually between 1997 and 2008 in six selected streams located in the Neuse River Basin, a major watershed draining the Albemarle-Pamlico area (Table 1, Figure 1).

- Trend information about total N and total P concentration trends in the Neuse and selected basins of the Albemarle-Pamlico Basin

- Total annual flow, load and concentration of total N from the 1979 to 2008 for the Neuse River (Figures 2-4).

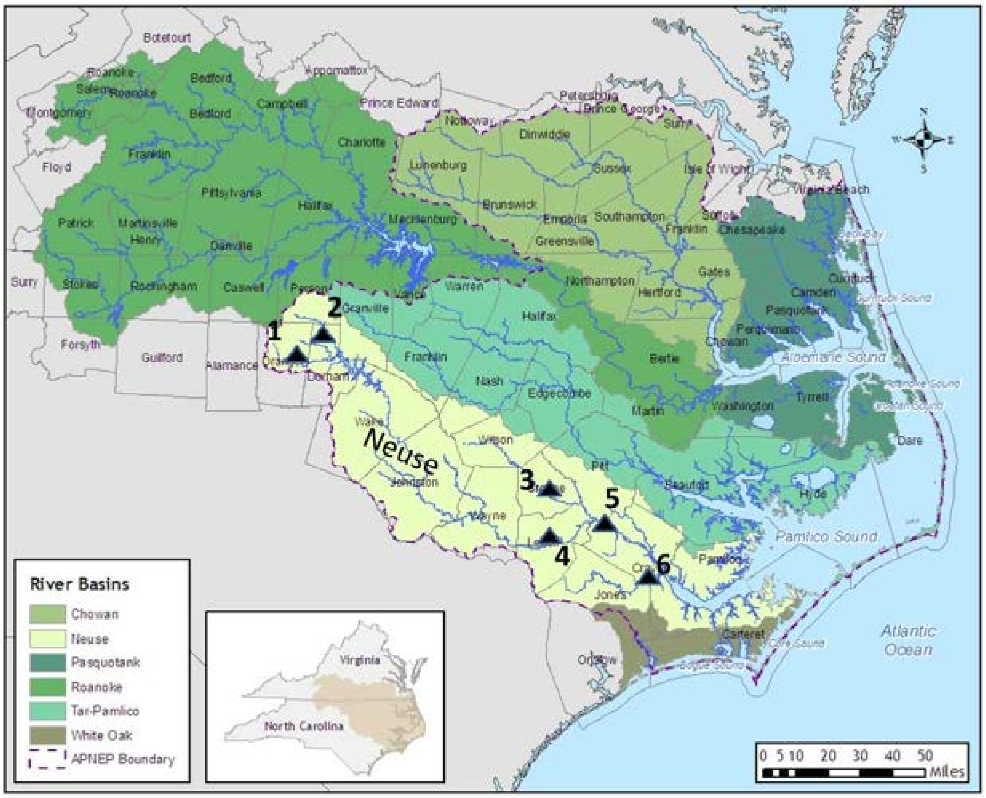

Figure1. Location of the Neuse River Basin and sampling stations in the Albemarle-Pamlico Basin: 1-Eno River near Hillsborough, 2-Little River near Orange Factory 3-Contentnea Creek near Hookerton, 4-Bear Creek near Mays Store, 5-Neuse River at Fort Barnwell, 6-Trent River near Trenton.

What Do the Data Show?

Significant decreases in concentrations of both N and P occurred in the Neuse River Basin, as well as the Roanoke Basin, between the 1970s and 2005 (Harned et al., 2009), indicating a general improvement in water quality of the Neuse River and Roanoke River. In general, N and P loads decreased or remained essentially unchanged in the Neuse Watershed between 1997 and 2008 (Table 1), although N concentrations in the Neuse River Basin continued to decrease after 1993 (Harned et al., 2009). N annual loads ranged from 45-3600 metric tons (mt) (50-4000 tons [T]) and yields ranged from 0.27-1.4 mt/km^2 (0.77-4 T/mi^2); total P annual loads ranged from 5-390 mt (6-430 T) and yields ranged from 0.04-0.14 mt/km^2 (0.11-0.41 T/mi^2) (Table 1). The highest yields occurred in Bear Creek near Mays Store (Table 1), signaling some of the poorest water quality (as measured by chemical nutrient yields) observed-these yields have not changed significantly since at least 1997 (Table1). N concentrations significantly increased at one station (Trent River at Trenton), while P decreased. Total N loads decreased in the two smallest drainage basins, although discharge decreased at one of the stations (Little River at Orange Factory) as well. Total P concentration decreased at Contentnea Creek at Hookerton, NC between 1997 and 2008, with no decrease in flow detected (Table 1), indicating a decrease to a factor other than flow. Long-term data (1979-2008) from the Neuse River at Fort Barnwell, NC, including data from 1979-2000 published in NCDENR (2001) and combined with data for this study (1997-2008) indicates that N loads have been decreasing since 1989 (significant at 5% level), when flow and loads peaked (Figs. 2 and 3), but are currently returning to levels transported during the mid to late 1980s. Discharge also decreased (significant at 5%). Because of the resemblance of long-term behavior of flow and N load shown in Figs. 2 and 3, the following paragraph explains the need for caution when trying to explain causes of long-term load patterns.

In general, nutrient loads and concentrations remained unchanging or exhibited decreasing concentrations for streams shown in this analysis, although it is important to understand the relationship between flow and load. Decreases in total N load were detected in the Eno and Little River, although decreasing flow was also detected. Flow is highly correlated to load and decreased loads may be simply due to decreased flow. Very significant increases in total N concentrations were detected at Trent River at Trenton during the period. No trend in discharge was detected at this station, implying that the increase was not due simply to an increase in flow. Because mass transport by rivers is so strongly correlated to flow, determining trends due to factors other than flow may be difficult, as explained in the next section. For this reason, trends in annual concentrations (concentration = total annual load/ total annual flow), which decreases or eliminates the impact of flow volume, are shown for 1997-2008. An increase in total N concentration at Trent River near Trenton and a decrease in total P concentration at Contentnea Creek near Hookerton (which had no trend in flow) and Trent River near Trenton were detected, suggesting that these loads were related to some factor other than flow.

Table 1. Total nitrogen, phosphorus, and flow trends in the Albemarle-Pamlico region, 1997-2008. Three numbers in columns (x, y-z) are as follows: x is the mean (12 years) followed by range (y-z) of the 95% confidence interval. Trends tested with Spearman rho: N = no trend, I = increasing, D = decreasing, α = 0.05 (* = significant at 5%, ** = significant at < 1%).

Location		Total Nitrogen			Total Phosphorus			Row		Concentration	
Station	**Basin**	**TN Trend**	**TN Load [mt (T)]**	**TN Yield [mt/km^2 (T/mi^2)]**	**TP Trend**	**TP Load [mt (T)]**	**TN Yield [mt/km^2 (T/mi^2)]**	**Row Trend**	**Row [m^3/s (cfs)]**	**TN Trend**	**TP Trend**
Eno River Hillsborough	Neuse	D*	45, 25-65 (50, 28-72)	0.27, 0.15-3.85 (0.77, 0.43-11)	N	5.8, 2.3-9.3 (6.4, 2.5-10.3)	0.04, 0.01-0.07 (0.10, 0.04-0.19)	D*	0.99, 0.88-2.12 (35, 31-75)	N	N
Little River Orange Factory	Neuse	D*	63, 34-91 (69, 38-100)	0.30, 0.17-0.44 (0.86, 0.48-1.26)	N	7.42, 3.94-10.90 (8.18, 4.34-12.02)	0.04, 0.02-0.05 (0.10, 0.05-0.15)	D*	1.91, 1.26-2.56 (67.4, 44.5-90.3)	N	N
Contentnea Creek Hookerton	Neuse	N	811, 604-1014 (894, 666-1118)	0.43, 0.32-0.53 (1.22, 0.91-1.52)	D*	100, 60.5-140.1 (110, 66.7-154.4)	0.05, 0.03-0.07 (0.15, 0.09-0.21)	N	22.6, 15.2-30.0 (798, 537-1059)	N	D*
Neuse River at Fort Barnwell	Neuse	N	3576, 2779-4373 (3942, 3063-4820)	0.35, 0.27-0.43 (1.01, 0.78-1.23)	N	390, 293-487 (430, 323-537)	0.04, 0.03-0.05 (0.11, 0.08-0.14)	N	109.8, 80.6-139.1 (3879, 2845-4912)	N	N
Bear Creek Mays Store	Neuse	N	210, 133-288 (232, 147-317)	1.38, 0.88-1.88 (3.94, 2.50-5.38)	N	21.96, 1.01-42.94 (24.21, 1.11-47.33)	0.14, 0.01-0.28 (0.41, 0.02-0.80)	N	2.3, 1.4-3.1 (79.9, 50.7-109)	N	N
Trent River near Trenton	Neuse	N	187, 118-259 (208, 130-286)	0.44, 0.27-0.60 (1.25, 0.78-1.72)	N	19.9, 10.9-28.8 (21.9, 12.0-31.8)	0.05, 0.02-0.07 (0.13, 0.07-0.19)	N	5.41, 3.43-7.39 (191, 121-261)	I**	D*

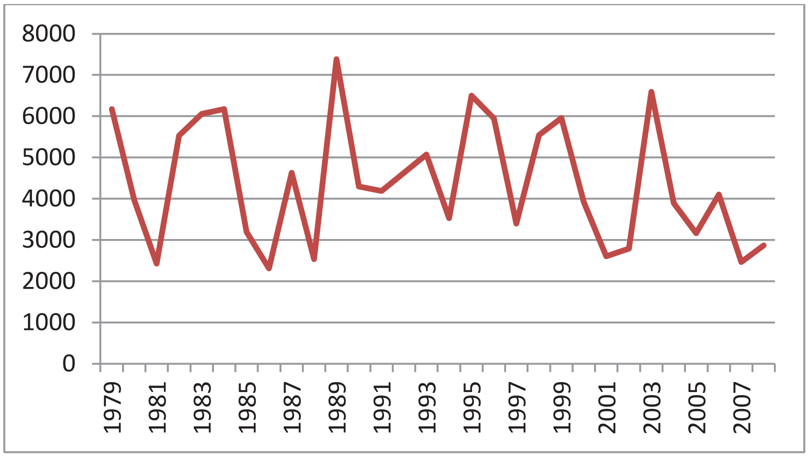

Figure 2. Neuse River at Fort Barnwell-Total nitrogen load, in tons transported, 1979-2008.

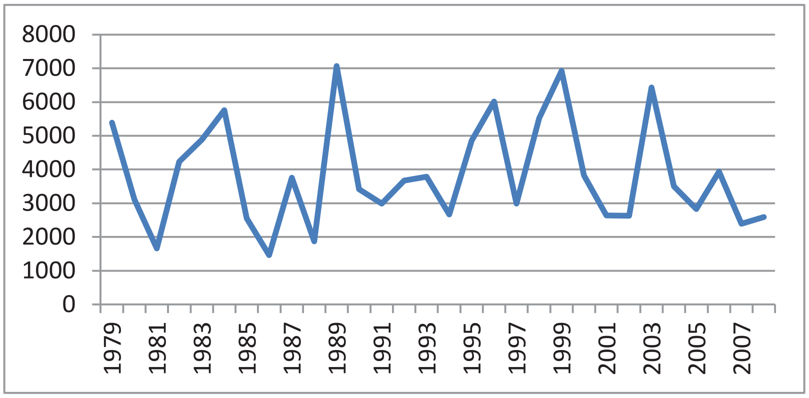

Figure 3. Neuse River at Fort Barnwell, Mean annual flow in cubic feet per second, 1979-2008.

Why Can't this Entire Indicator be Reported at this Time?

The Albemarle-Pamlico Basin covers approximately 78,000 km^2 (30,000 mi^2). Only streams and river segments from the Neuse River Basin were used to compute annual loads for this report, leaving out loading estimates for the other Basins that represent the other 90% of the region, including the Tar-Pamlico, Roanoke, Chowan, and Pasquotank. Data sets from both USGS and NCDENR for approximately 30 other streams are being processed by USGS, but were not available for this reporting period.

Although thousands of daily samples were processed for each of the streams, only annual total loads, yields, and concentrations are shown. Therefore, the data for this report are only adequate for analyzing annual phenomena.

Understanding the Data and Implications for Management

Stream and river loads of nutrients are determined by the nutrient concentration and the flow or discharge: Load = Discharge X Concentration. Because load is primarily affected by flow, the trends in flow will directly affect trends in load and can mask relatively smaller changes in concentration. This phenomenon can be seen in the flow record and stream load transported in the Neuse River at Fort Barnwell, where the flow and total N load are highly correlated (ρ[Spearman correlation coefficient] = 0.92 significant at less than 1%). Annual concentration, however, significantly decreased after 1994 from about 1.4 to around 1 mg/L (Fig. 4), indicating a general improvement in water quality (where improvement is equated to a decrease in concentration or load) and yet had little effect on load transported (ρ = -0.21, not significant at 5%). Thus, loads can reflect not only changes in chemical inputs from human activities, but also changes in climatic patterns that affect precipitation and runoff---it is very important to be able to distinguish which when used to determine the effectiveness of management actions on water quality. Where a chemical parameter exhibits a significant trend without a corresponding significant trend in discharge, it is an indication that the cause may not be related to discharge. A designation of no trend simply means that the load or concentration has remained essentially unchanged through the period. Additional research and data from other stream and river stations in the Albemarle-Pamlico should be included in future analyses and assessments to better discern differences between changes in land use and nutrient loading and the effects of climatic variables on stream loads and concentrations.

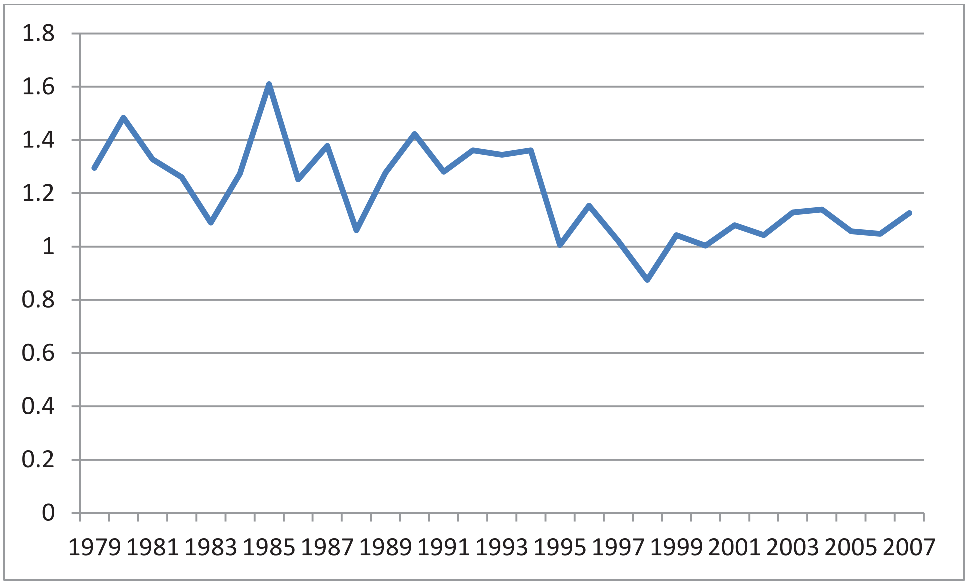

Figure 4. Annual total nitrogen concentration (mg/L), in collected from the Neuse at Fort Barnwell, 1979-2008.

Comparison of worldwide and Atlantic coastal trends in nutrient stream loads and yields in the last 40 years with loads and yields in the Albemarle Pamlico Drainage Basin in the 1990s

The use of fertilizer to enhance crop production began around 1920, and then dramatically increased after 1950 (Smil, 1991; Schlesinger, 1997) with a resultant increase in N and P transported by streams worldwide: the P load, as measured by the dissolved inorganic phosphorus (DIP) to the world's oceans, has increased from 26 X 10^6 kilomoles (kmol)/year (~860,000 T) in 1970 (reported by Meybeck, 1982) to 74 X 10^6 kmol /yr (~2.5 X 10^6 T) in the 1990s according to Smith et al. (2003); according to these same authors, the load of dissolved inorganic N (DIN) increased from 480 x 10^6 kmol/yr (7.4 X 10^6 T) in 1970 to 1350 X 10^6 kmol/yr (20.8 X 10^6 T) in the 1990s. Both the DIP and DIN load increased worldwide about 2.8 times according to Smith et al. (2003) during this period. Yields of 0.7 mt/km^2 (2 tpsm) for the southeastern United States and almost 1.1 mt/km^2 (3 tpsm) for the Northeastern US of DIN after the 1990s were reported by Howarth et. al. (1996) and Castro et al. (2000). Areas along the developed portions of Europe and the United States shown in Smith et al. (2003) yielded about 17 kmol/km^2 (0.7 tpsm) of DIN during the 1990s. For DIP, yields of about 1 kmol/km^2 (0.08 tpsm) were reported by Smith et al. (2003) in these same areas. Based on information presented in Smith et al., 2003, converting from DIN (~30% of total N) and DIP (~40% of total P), 1990s yields of total N are estimated to be 0.7 mt/km^2 (2.1 tpsm) and 0.07 mt/km^2 (0.2 tpsm) for total P. With a three-fold increase in yields between the 1970s and 1990s, yields during the 1970s along the Atlantic coast would have been approximately 33% of yields in the 1990's-about 0.2 mt/km^2 (0.7 tpsm) for DIN and about 0.02 mt/km^2 (0.07 tpsm) for DIP.

Compared to global averages, and even other areas along the Atlantic Coast (Castro et al., 2000; Howarth, 1996; Smith et al., 2003), streams draining the Albemarle-Pamlico Basin appear to have somewhat lower P and N loads than those estimated for the 1990s. Average total P yields, of which DIP comprises about 40% (Meybeck, 1982) and the organic P fraction comprising the rest, between 1982 and 1992 for eight streams in the Albemarle-Pamlico Basin ranged from 0.01-0.06 mt/km^2 (0.03-0.21 tpsm) (Harned et.al., 1995 table 16, p. 117). Average total N loads, of which DIN comprises only 33% and the organic N comprising the remainder (Meybeck, 1982), in the Albemarle-Pamlico Basin during the same period ranged from 0.19-0.56 mt/km^2 (0.53-1.6 tpsm) (Harned et. al., 1995, table 16, p. 117). The Neuse River and its tributary streams (n = 14) included in a study by Spruill et al. (2005) all had estimated annual yields of dissolved total N ranging from 0.12-1.2 mt/km^2 (0.33-3.4 tpsm), with a mean of 0.40 mt/km^2 (1.15 tpsm) in 2000 and 2001. The P load reported in Spruill et al. (2005) for these same streams ranged from 0.007-0.10 mt/km^2 (0.02 to 0.29 tpsm), with a mean of 0.03 mt/km^2 (0.09 tpsm). These yields are similar to those reported by Harned et al. (1995).

SUSPENDED SEDIMENT

Timothy Spruill[45]

Why is Suspended Sediment Important?

Suspended sediment is the fine rock and organic material in the water column that was mechanically eroded and moved by rain or wind from the land surface. Generally, the steeper the land slope and the less the vegetative cover, the more erosion and therefore the more sediment that is transported. Where vegetation is sparse, particularly in arid or semi-arid regions, suspended sediment concentrations are usually highest (Milliman and Meade, 1983) and erosion rates are generally higher where vegetation has been removed for agriculture (Schlesinger, 1997). Because streams draining urban and agricultural watersheds have the highest sediment yields, they also have in general the greatest potential to affect the stream environment by producing stream water with a high turbidity and a high potential to deposit excessive sediment on the stream bed.

High concentrations of suspended sediment can limit the types of animals and plants that inhabit such streams. It is easy for even the most casual observer to literally see that urban streams are severe environments largely devoid of benthic invertebrates except for the most pollution tolerant, such as scuds and midge larvae. Often, the stream bottoms are coated with fine sediment. The suspended sediment blocks gill structures of larval insects and prevents oxygen uptake and, after it settles, smothers any eggs, which require oxygen for development. Sediment-coated rocks, concrete blocks, and sand make for a very inhospitable environment for eggs of most invertebrates. Unfortunately, where there are no insects and invertebrates, there are also few, if any, frogs, turtles, or fish, because they have no prey. In addition to the physical problems to organismal physiology caused by sediment, sediment derived from an urban environment often has trace metals adsorbed onto the particle surface. These sediment particles are often toxic or are derived directly from broken down and eroded pavement, which contains a variety of toxins and carcinogens. Bacteria, some of which are unhealthy (pathogenic) to both animals and humans, also coat sediment particles. Excessive sediment and erosion in urban environments basically creates an aquatic environment practically devoid of both animals and plants.

Streams that drain agricultural watersheds also have elevated suspended sediment, although often to a lesser degree compared to urban watersheds. Yet such streams also can significantly affect stream biota by generally decreasing biological diversity, decreasing primary productivity, and decreasing environmental niches through filling of pore spaces and crevices in the stream bed. In agricultural watersheds, increased sediment loads and sedimentation are thought primarily to degrade habitat (Allan, 2004).

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[45] US Geological Survey (Retired)

What Does This Indicator Show?

- Suspended sediment load (mass) and yield (mass per land area).
- Turbidity (percent > 50 NTU)

Suspended solids and suspended sediment are slightly different technically, although these terms are used interchangeably for this assessment. Both are included in the term "suspended and bedded sediments" (USEPA, 2003). Although stream suspended solids/sediment yields are very useful in conveying information about mass transport from land because it represents the mass per unit area, stream load and concentration (mass/ unit volume of water) are the more commonly reported metrics for water quality. All of these can be used as indicators for change in mass transport of material--in this case, suspended solids/sediment. Because the most commonly used metric for trend analysis is concentration, this is the metric used for this assessment. Another metric that can be used as a surrogate for suspended solids/sediment is turbidity (NTU). Future assessments of the Albemarle-Pamlico Basin should include yields as well. Suspended sediment and turbidity are primarily indicators of change in land use through time.

What Do the Data Show?

In general, suspended solids/sediment concentrations either decreased or exhibited no change between 1980 and 1995 in the Albemarle-Pamlico Basin. During the 1980s and 1990s suspended sediment/solids ranged from 2.5-70 metric tons (mt) per square kilometer (km^2) (7-200 tons per square mile [tpsm]) (Table 1), with most yielding 14 mt/km^2 (40 tpsm) or less. The only suspended solids data collected post-1995 and reported for this assessment were analyzed for two stations: Neuse River and Contentnea Creek (Harned et al., 2010). Although total suspended solids/sediment data have been collected by both the United States Geological Survey (USGS) and North Carolina Division of Water Quality (NCDWQ), the most recently published interpretive information on suspended sediment concentration trends in North Carolina were reported in 1995 and 2010 (Table 2).

Significant long-term (1973-2005) decreasing trends in suspended sediment were detected in the Neuse River and Contentnea Creek (Harned et al., 2010). No trends were detected at these stations between 1993 and 2005 (Harned et al., 2010), however, so most of the change occurred before 1993. Decreases in suspended sediment at eight stations in the Albemarle-Pamlico Basin were detected between 1980 and 1989 (Table 2). Decreases were also reported between 1980 and 1989 for the Blackwater River in Virginia, the Roanoke River in Virginia and North Carolina, the Dan River in Virginia, Contentnea Creek the Neuse River, the Tar-Pamlico and the Chowan in North Carolina (Harned and Davenport, 1990). Only one site (the Neuse River at Smithfield, NC) showed an increase in suspended solids concentration between 1980 and 1989 (Harned and Davenport, 1990).

Table 1. Suspended sediment/solids load and yields (1980-1992) and trends for selected stations within the Albemarle-Pamlico region for selected time periods (data from (A) Harned et al., 1995 and (B) Harned et al., 2010. Seasonal Kendall Tau applied as test for trend (na = not analyzed, D = decreasing trend, N = no trend).

				Trends During Period of Analysis		
Station	**Basin**	**Load [mt (T)]**	**Yield (A) [mt/km^2 (T/mi^2)]**	**1973-2005 (B)**	**1980-1989**	**1993-2005 (B)**
Contentnea Creek at Hookerton, NC	Neuse	22,599 (24,911)	11.8 (33.8)	D	D	N
Dan River at Paces, VA	Roanoke	478,765 (527,748)	71.4 (204)	na	N	na
Neuse River at Kinston, NC	Neuse	89,062 (98,174)	32.8 (36.2)	na	D	na
Tar River at Tarboro, NC	Tar-Pamlico	64,706 (71,326)	11.2 (32.1)	na	D	na
Blackwater River at Franklin, VA	Chowan	4,322 (4,764)	2.73 (7.81)	na	N	na
Meherrin River at Emporia, VA	Chowan	22,303 (24,585)	12 (33)	na	na	na
Nottoway River near Sebrell, VA	Chowan	18,040 (19,886)	12.5 (13.8)	na	na	na
Roanoke River near Roanoke Rapids, NC	Roanoke	75,875 (83,638)	8.05 (8.87)	D	D	N

Table 2. Trend evaluation using Seasonal Kendal Tau on suspended solids data from 48 streams in major watersheds of the Albemarle-Pamlico Basin, 1980-1989 (data from Harned et al., 1995).

Watershed	Increasing	Decreasing	No Trend	No Data
Roanoke	0	3	8	1
Dan River	0	1	5	1
Chowan	0	0	3	3
Tar-Pamlico	0	1	6	1
Neuse	1	3	7	4
Total	**1**	**8**	**29**	**10**

Turbidity, another metric, can be used to predict sediment concentration because of the typically strong correlation between the two parameters (typically > 0.90 [Ellison et al., 2010; Franklin et al., 2001]). As such, turbidity data offer additional information on trends in suspended sediment through time. Although there have been few reports that evaluated total suspended sediment yields through time, NCDWQ has presented turbidity data that can be used to estimate long-term trends of TSS through time (<http://portal.ncdenr.org/c/document_library/get_file?uuid=19f2cf5a-8f29-4eb4-b63e-d6b1ccab6aaa&groupId=38364>).

The trends in turbidity > 50 NTU are shown for the Mountains, Piedmont and Coastal Plain in Figure 1.

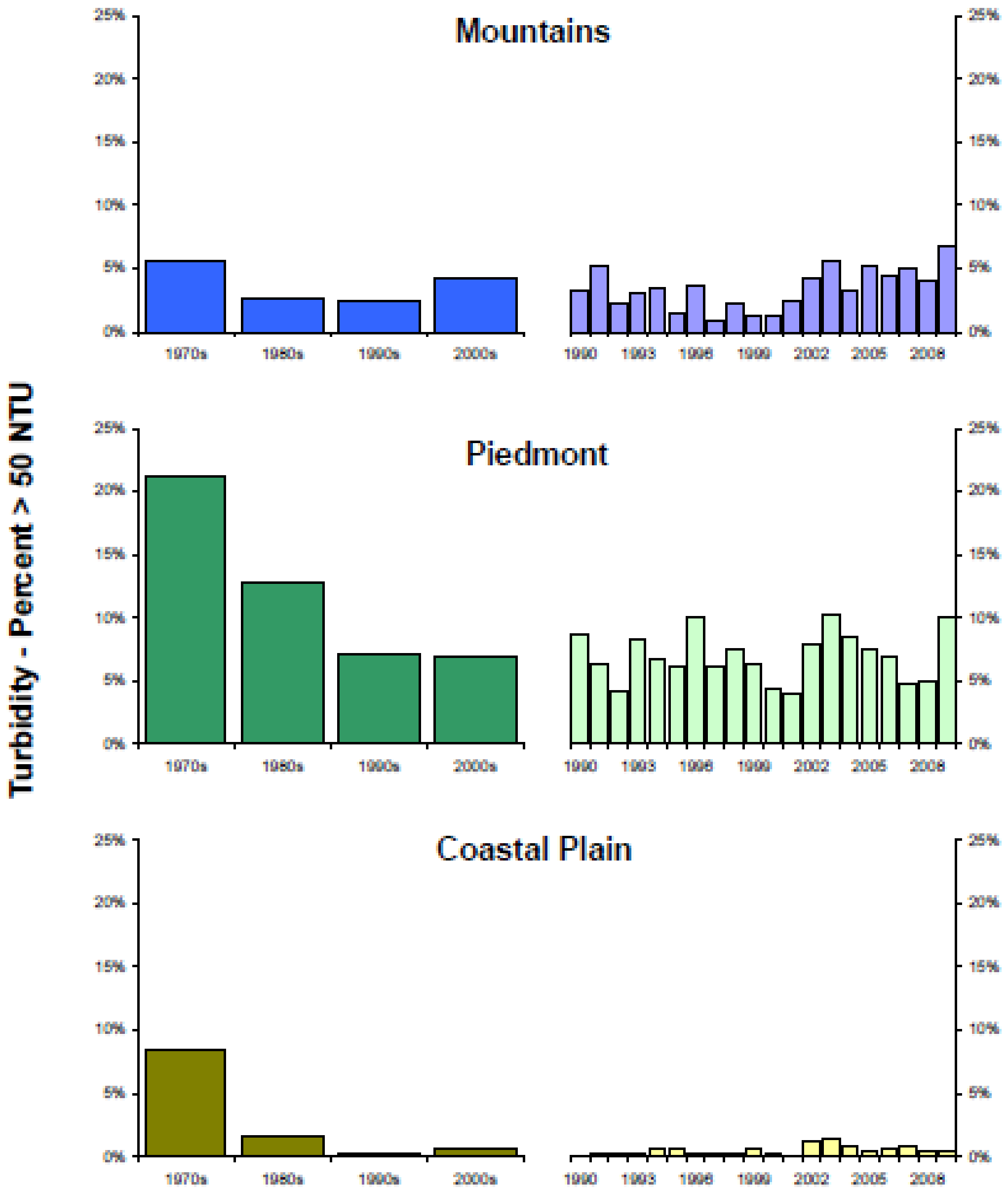

Figure 1. Turbidity data from streams draining three physiographic regions of North Carolina used as a surrogate indicator for suspended sediment (Data from North Carolina Department of Environment and Natural Resources). Bars on left show decadal change 1970s-2000s. Bars on right show annual change 1990-2009.

Between the 1970s and 2000s, turbidity (and by the demonstrated relationship to total suspended sediments [TSS]), shows no clear trend in the Mountains, although dramatic decreases are observable in both the Piedmont and Coastal Plain. TSS has remained very low in the Coastal Plain since the 1990s, much lower than either the Mountains or Piedmont. Between 1990 and 2008, turbidity appeared to slightly increase in the Mountains and Coastal Plain, without any noticeable temporal trend in the Piedmont, although no statistical evaluation was performed on these data.

What is Not Shown by This Indicator?

Only data that have been already published in the scientific literature were included in this assessment. These data largely focused on changes that occurred during the 1980s. Although it appears from the few sites where data were presented that no dramatic trends in suspended solids/sediment were occurring in the 1990s and 2000s, too few sites were included to draw a definitive conclusion. The turbidity data published by NCDWQ suggest that some increases in suspended sediment/solids were occurring in the Mountains and Coastal Plain during this latter period, however. Data are available from both the North Carolina Department of Environment and Natural Resources (NCDENR) and United States Geological Survey (USGS), but insufficient time and personnel were available to analyze the datasets for this report. Future reports should include data from at least 20-30 streams throughout the Albemarle-Pamlico Basin to conduct a more thorough assessment.

Discussion

Average annual sediment yields In North America during the 1980s and early 1990s were about 98 mt/km^2 (280 tpsm) (Milliman and Meade, 1983). Data from eight streams In the Albemarle-Pamlico Basin during the 1980s and early 1990s indicated the highest sediment yields for the Dan River at Paces (about 71 mt/km^2 [204 tpsm]), with the remaining streams ranging between approximately 2.5-14 mt/km^2 (7 -40 tpsm) (Harned et al., 1995). Stream yields in the highly agricultural Midwest US during the late 1990s, such as those in the Illinois River Basin, ranged from 24-245 mt/km2 (69-700 tpsm) (Terrio, 2006). In contrast, streams draining more forested areas such as those in the Southeastern United States typically yield about 7 mt/km^2 (20 tpsm) (Smith et al., 1993).

Land uses where vegetation is removed affects erosion rates and transport of suspended sediment, with urban (particularly from construction) and agricultural land uses resulting in the highest rates of erosion (Pimentel, 1995). The Piedmont of North Carolina exhibited the highest sediment yields from an urban stream and the lowest yields from a forested stream (Lenat and Crawford, 1994). This general pattern has also been reported in the United States using the USGS SPARROW model and data from more than 1800 stream sites sampled between 1975 and 2007: annually, around 46 mt/km^2 (130 tpsm) for urban, 18 mt/km^2 (50 tpsm) for agricultural, and 0.7 mt/km^2 (2 tpsm) for forested land uses (Schwarz, 2008). Although sediment is known to impair habitat, it is usually not the sole reason for declines in water quality and biota in agricultural areas. Nevertheless, keeping sediment yields relatively low (< 11 mt/km^2 [30 tpsm]) or reducing them where they are high (> 18 mt/km^2 [50 tpsm]), will be desirable to maintain or improve water quality.

Chapter 6 - Next Steps

Chapter 6: Next Steps

Active Assessment Function

Now and into the foreseeable future, human impacts to the Albemarle-Pamlico Ecosystem are expected to increase. These impacts hail from environmental stressors originating both on the landscape, like population growth and land use change, and on the waterscape, like aquatic habitat damage. These stressors will be coupled with others that originate largely outside of the region, including atmospheric deposition and a changing climate. These accumulating environmental challenges will incur financial and societal costs to mitigate or eliminate their respective impacts. To approach these challenges effectively, decision-makers will rely upon ecosystem assessments based on scientific information of the highest quality. APNEP, through promulgation of its new strategic plan (CCMP), has accepted the challenge of integrating or extending today's operational systems for monitoring and assessment of environmental and social conditions. Into the future, these efforts will provide more useful guidance for environmental managers and policymakers as they navigate a transition toward sustainability (Kates et al., 2001).

As suggested in the introduction (Chapter 1), the critical role of assessment to the application of ecosystem-based management requires the consistent development and refinement of assessment products. While this document is a significant milestone for the program in its own right, the utility of this assessment product goes beyond what is featured in Chapters 3 through 5. The publication of this assessment has also illuminated areas where a lack of information precludes a thorough assessment of the state of the ecosystem. The following sections offer insight from APNEP on how this current assessment's limitations might be overcome in future versions of this document.

Improved Condition Baseline

Before discussing the assessment of other indicators to gain a more comprehensive description of ecosystem condition (see "Additional Indicators" below), we begin by reflecting on how the assessment of our current baseline of featured indicators can be improved.

Magnitude: Pending the incorporation of targets into APNEP's management plan, future assessments should reference management targets in the text and provide figures to show whether the actions of APNEP and its partners are influencing indicator values as intended. Example targets can be either absolute, such as contaminant concentrations (criteria), or relative, such as percentage change of an indicator's value within a fixed period of time.

Extent: Many of the indicators are limited in spatial scale, both in extent and resolution (Table 2-1). Many indicators were not assessed region-wide, either because the data did not exist for particular areas, were not readily available, or the author team did not have adequate resources to complete a broader assessment. Circumstances where data is nonexistent or has an insufficient density should be addressed by the upcoming APNEP Integrated Monitoring Strategy.

Trend: Many of the indicators are limited in temporal scale as well, both in extent and resolution (Table 2-1). Many of the data sets expressed temporal ranges of a decade or less, some with ranges of a single year or two. These limited time ranges occurred because historical data did not exist for particular time periods, were not readily available, or the author team did not have the resources to complete a broader assessment. Yet to evaluate restoration success, APNEP must have a reliable pre-restoration baseline for ecosystem condition. To address situations where no historical data exist, holistic ecosystem models like mass-balance and agent-based frameworks can hindcast by providing approximate quantitative snapshots of historical ecosystems (Pitcher and Lam, 2010). Anticipating time and resource challenges for this project, authors were tasked at a minimum to target for analysis the period between the original CCMP (mid-1990s) and the present. Circumstances where present-day data does not exist or have an insufficient frequency should be addressed by the upcoming APNEP Integrated Monitoring Strategy.

Additional Indicators and Chapters

This interim assessment of the Albemarle-Pamlico ecosystem reports on the status and trends of ecosystem indicators representing three of five ecosystem categories. The featured indicators in the categories “system-wide” (Chapter 3), “coasts, estuaries, and near-marine” (Chapter 4), and “fresh waters” (Chapter 5) are a starting point and by no means reflect a robust suite of indicators for their respective categories. With the judicious incorporation of additional indicators in the three categories, one can expect future condition assessments to be more robust.

Furthermore, the remaining two categories to be incorporated in the next version of this assessment are “Forests, Farmlands, and Grasslands” and “Urban and Suburban”. With the inclusion of indicators to reflect these upland categories in subsequent assessments, a comprehensive survey of regional ecosystem condition will be initiated.

Beyond Condition

Diagnosis: As components of the ecosystem improve or decline, managers try to determine the cause of these changes by facilitating a diagnosis of the phenomena. The diagnosis involves two phases. First, the primary ecological factors causing the component’s dynamics should be investigated. Once the factors are identified, the inquiry shifts to the second phase of diagnosis: determining the primary influences responsible for dictating factor trends. This is especially pertinent when human activities are responsible for factor dynamics. Such diagnostics help validate the ecosystem model on which forecasts are based.

Forecasting: Forecasting is the most challenging phase of assessment, yet it is also potentially the most beneficial. In forecasting, analysis shifts from evaluating past ecosystem behavior (retrospective) to modeling future ecosystem behavior (prospective). Projections are useful exercises to help plan for future uncertainty in a dynamic system (Pandolfi et al., 2011:421). The complexity of ecosystem behavior, like that of the global economic system, dictates that ecosystem models rather than simple linear extrapolation are often the most prudent course. Furthermore, because of ecosystem momentum operating at regional scales, traditional experimental protocols are often infeasible. Varied treatments and multiple replicates necessary for these approaches would require huge area and time commitments, which as a practical matter excludes them from consideration. Environmental managers should strive to have a decision support system whereby the influence of various human activities can be effectively modeled. In return, the decision support system would provide increasingly accurate estimates of the ecosystem services and economic value gained and lost in the region. Ultimately, this ability to forecast future events based on current management decisions seeks to provide optimal solutions that reduce societal vulnerability to ecosystem degradation at an efficient cost.

Beyond Ecosystem Outcomes

The sections above have suggested improvements to this type of environmental assessment. APNEP must also produce other types of assessments, including assessments of management actions in the region and assessments of stakeholder understanding of the ecosystem's dynamics. Management assessments are essential to resolve whether undesirable ecosystem trends are due to inadequate implementation of management actions or an inadequate understanding of the ecosystem itself.

In conclusion, APNEP staff and volunteer authors have invested substantial time and resources to generate this interim assessment. This partnership is hopeful that information provided in the preceding chapters will spark partner investment in higher quality and more diverse decision support products as discussed above. If successful, this region's citizens, managers, and policymakers will benefit greatly by more fully understanding the ramifications of their current and future actions. Because the culture and economy of the region are so intimately intertwined with the Albemarle-Pamlico ecosystem, APNEP aspires for its work in this area to substantially improve the well-being of the citizens of the region.

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Appendix - Technical Methodologies of Indicator Assessments

Appendix: Technical Notes

Human Population (T. Crawford)

Extent of Land Cover Types (T. Crawford, S. Terziotti)

Ambient Air Temperature (D. Figurskey)

Storm Frequency and Intensity (D. Figurskey)

Ground-Level Ozone Concentration (R. Dennis)

Total Inorganic Nitrogen Deposition (R. Dennis)

Dissolved Metal Concentrations (L. Dubbs, M. Piehler)

Dissolved Oxygen Concentration Violations (L. Dubbs, M. Piehler)

Chlorophyll-a Concentration Violations (L. Dubbs, M. Piehler)

River Herring Abundance (D. Carpenter, W. Laney)

Shad Abundance (D. Carpenter, W. Laney)

Sturgeon Abundance (D. Carpenter, W. Laney, K. Rawls)

Extent of Submerged Aquatic Vegetation (D. Carpenter, J. Kenworthy, D. Field)

Phragmites australis Extent (D. Carpenter, K. Havens)

Relative Sea Level (C. Zervas, L. Dubbs)

Ocean Shoreline Migration (H. Mitasova, M. Overton, R. Oliver, E. Hardin)

Estuarine Shoreline Migration (R. Corbett, J. Walsh, D. Eulie)

Estuarine Salinity Concentration (L. Dubbs)

Shellfish Closures (L. Dubbs, M. Piehler)

Unusual Fish Mortalities and Disease Events (W. Laney, L. Dubbs)

Streamflow (T. Spruill)

Point Source Discharges (T. Spruill)

Riverine Transport of Nitrogen and Phosphorus (T. Spruill)

Suspended Sediment (T. Spruill)

TECHNICAL NOTES: HUMAN POPULATION

The Indicator

- Total human population and human population change for the Albemarle-Pamlico region, basins, and sub-basins from 1990-2010.

The Data

Data Description: US Census block data originate from decennial census tabular data products that are joined to census TIGER files that represent the census geographical units as census block boundaries and their associated centroid point locations. Census blocks are the finest resolution census data containing total population amounts.

US watersheds are delineated by the USGS into hydrologic units that sub-divide in a nested hierarchical fashion. The USGS uses hydrologic unit codes (HUCs) to identify each hydrologic unit. The finest watershed level used for this indicator is the sub-basin, which in USGS terminology is at the 8-digit HUC level. Sub-basins nest to form basins (Figure 2). For example, the Lower Neuse, Middle Neuse, Upper Neuse, and Contentnea sub-basins make up the Neuse basin.

Data Manipulation: Census block centroid points were assigned identification codes that identify their respective sub-basins and basins via a GIS "point-in-polygon" overlay. In other words, centroid points and their associated human populations were assigned to the sub-basin and basin in which they were located. Standard tabular data operations were used to aggregate total human population for sub-basins and basins and to calculate change amounts for 1990-2000, 2000-2010, and 1990-2000.

Percent change in human population was calculated with the following formula, with percent change 1990-2010 used as the example:

% Change 1990-2010 = [(2010 Population – 1990 Population) / 1990 Population] x 100

Thus, an identical amount of raw population growth by decade will result in different values for percent change for successive decades. For example, a basin with 1990 population of 100,000 that has growth of 10,000 during 1990-2000 and growth of 10,000 during 2000-2010 will have the follow results for percent change:

% Change 1990-2000 = [(110,000 - 100,000) / 100,000] x 100 = 10.0%
% Change 2000-2010 = [(120,000 - 110,000) / 110,000] x 100 = 9.1%
% Change 1990-2010 = [(120,000 - 100,000) / 100,000] x 100 = 20.0%

Data Quality/Caveats: Census blocks data are the highest quality and finest resolution available data to use to estimate total human population amounts. A minor level of estimate error is introduced by using block centroid points to spatially represent the location of block populations. It is possible for some of a block's population to be located in a sub-basin adjacent to the sub-basin in which the block centroid point is located. These rare situations can occur only for blocks with areal footprints spanning more than one sub-basin.

Basin and sub-basin data are the highest quality available data for representation of hydrologic units and are produced by the USGS.

Data Availability: *Census Data:*

1990: GIS census blocks and tabular population data downloaded from the National Historical Geographic Information System, <http://www.nhgis.org/>.

2000: GIS census blocks and tabular population data from the ESRI® Data & Maps 2005 DVD distributed by the Environmental Systems Research Institute (ESRI) in Redlands, CA.

2010: GIS census blocks from TIGER/Line® Shapefiles downloaded from US Census, <http://www.census.gov/geo/www/tiger/tgrshp2010/tgrshp2010.html>. Tabular population data from Summary File 1 downloaded from US Census, <http://www2.census.gov/census_2010/04-Summary_File_1/>.

Basin and Sub-basin Data:

Basin and sub-basin GIS boundaries and attributes from the USGS Digital Watershed Boundary Dataset produced downloaded from the USDA Spatial Data Gateway, <http://datagateway.nrcs.usda.gov/>.

TECHNICAL NOTES: EXTENT OF LAND COVER TYPES

The Indicator

- Land Cover Patterns: Area and percentages of land cover types summarized by basin and sub-basin for the year 2006.

- Land Cover Change: Total acres and percentages of change for selected land cover types summarized by basin and sub-basin for change occurring during 1992-2001 and 2001-2006. Changes within the entire basin for 2001-2006.

The Data

Data Description: US watersheds are delineated by the USGS into hydrologic units that sub-divide in a nested hierarchical fashion. The USGS uses hydrologic unit codes (HUCs) to identify each hydrologic unit. The finest watershed level used for this indicator is the sub-basin, which in USGS terminology is at the 8-digit HUC level. Sub-basins nest to form basins. For example, the Lower Neuse, Middle Neuse, Upper Neuse, and Contentnea sub-basins make up the Neuse basin.

Land cover data are represented using 30-meter pixels where each pixel is coded according to its land cover (e.g., urban, forest, wetland) resulting in a land cover classification data product. With more than one date, it is possible to create a land cover change product. These land cover and change classification products are created via image processing techniques applied to remotely sensed satellite data. This report relied on 1992-2001 land cover classification products produced by the Multi-Resolution Land Characteristics Consortium (MRLC), which is comprised of 11 partners including well known agencies such as the USGS, EPA, NOAA, USFS and others. Personnel associated with these agencies produced the data products used for analysis. The report also relied on 2001-2006 land cover classification products provided by the USGS. Technical documentation related to these products, including discussion of classification error, is available in the cited sources below:

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Fry, J.A., M.J. Coan, C.G. Homer, D.K. Meyer, and J.D. Wickham. 2009. *Completion of the National Land Cover Database (NLCD) 1992–2001 Land Cover Change Retrofit product.* Open-File Report 2008–1379, U.S. Geological Survey. 18 pp.

Data Manipulation: GIS processing was performed to calculate 2006 land cover areas/percentages and 1992-2001 and 2001-2006 land cover change areas/percentages. Large open water bodies that can be viewed as receiving waters from terrestrial areas were excluded in calculations. This means that large estuary bodies and ocean areas technically located inside

8-digit HUC sub-basins were excluded. This was done to focus results on terrestrial land cover patterns. Including these large water bodies would inappropriately skew results for near estuary and ocean sub-basins. For example, a large percentage of the Albemarle and Pamlico Sound sub-basins would be classified as water without the process taken here of excluding their respective open water areas. Figure 3 shows the land area used for processing.

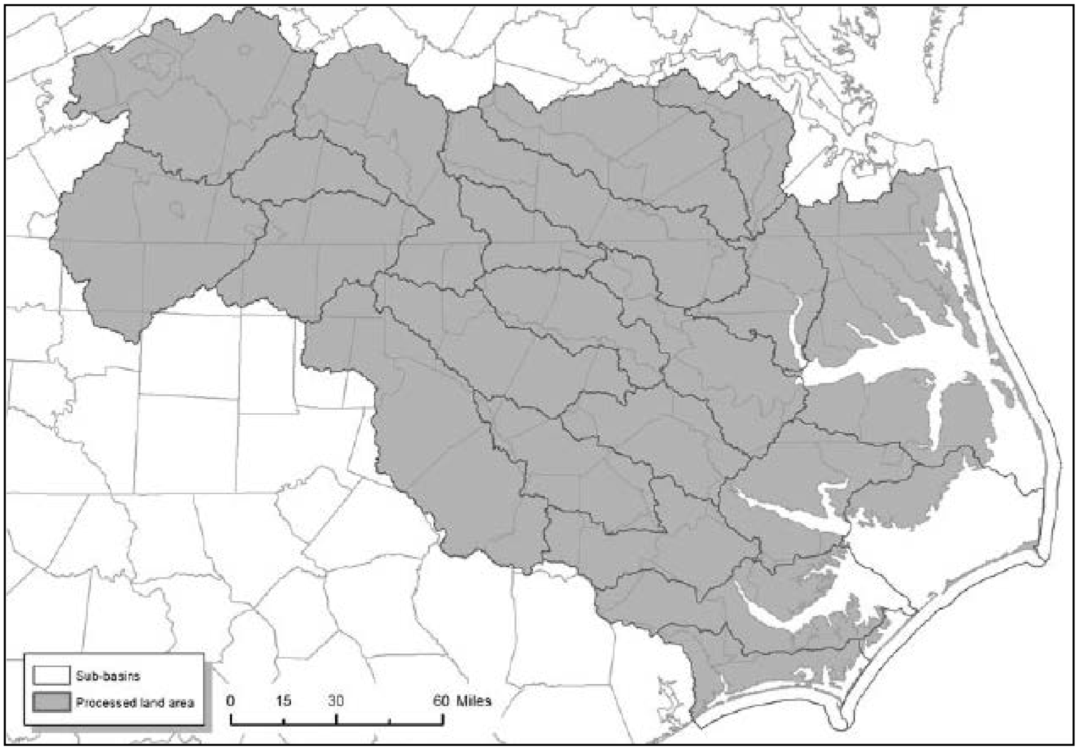

Figure 3: Land area used for data processing

Data Quality/Caveats: Basin and sub-basin data are the highest quality available data for representation of hydrologic units and are produced by the USGS. The 2006 and 1992-2002 NLCD and 2001-2006 land products are the most current best available data sources that cover the entire Albemarle-Pamlico region and are amenable to GIS processing for indicator generation. Processing of the 2001-2006 data product included some small unpopulated islands typically located on the backside of barrier islands or proximal to estuarine peninsulas that are predominantly wetlands. Processing of the 1992-2001 data product did not include these islands so that direct comparison of wetland amounts across these two periods particularly for ocean proximal sub-basins is not advised. Readers are also directed to caveats related to classification error that are more fully described in the references cited above and in online content cited below.

Data Availability: *Data Sources:*
Basin and Sub-basin Data:
Basin and sub-basin GIS boundaries and attributes from the USGS Digital Watershed Boundary Dataset downloaded from the USDA Spatial Data Gateway, <http://datagateway.nrcs.usda.gov/>.

Land Cover Data:
National Land Cover Database 2006 (NLCD 2006) from the Multi-Resolution Land Characteristics Consortium (MRLC), <http://www.mrlc.gov/nlcd06_data.php>.
National Land Cover Database 1992-2001 Retrofit Land Cover Change (NLCD 1992/2001) from the Multi-Resolution Land Characteristics Consortium (MRLC), <http://www.mrlc.gov/nlcdrlc_data.php>.

TECHNICAL NOTES: AMBIENT AIR TEMPERATURE

The Indicator

- Annual average, maximum, and minimum temperature for four sites within the Albemarle-Pamlico region from 1895 to 2009.

The Data

Data Description: The data were calculated using a combination of the high temperatures, low temperatures, and average temperatures for four sites: Morehead City, Cape Hatteras, Edenton, and Elizabeth City. These locations are part of the United States Historical Climate Network (USHCN). USHCN is a high-quality moderate sized data set of monthly averaged maximum, minimum, and mean temperature and total monthly precipitation developed to assist in the detection of regional climate change.

Data Quality/Caveats: USHCN is comprised of 1,221 high-quality stations from the United States Cooperative Observing Network within the 48 contiguous United States. The period of record varies for each station but generally includes the period 1900-1995. The stations were chosen using a number of criteria including length of period of record, percent missing data, number of station moves and other station changes that may affect the data homogeneity, and spatial coverage. Included with the official data set are metadata files that contain station history information about station moves, instrumentation, observing times, and elevation.

Data Availability: USHCN was developed by and is maintained at the National Climatic Data Center (NCDC) and the Carbon Dioxide Information and Analysis Center (CDIAC) of Oak Ridge National Laboratory through a cooperative agreement between the NCDC and the US Department of Energy.

References

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TECHNICAL NOTES: STORM FREQUENCY AND INTENSITY

The Indicator

- Number and locations of severe weather events, including tornado tracks and touch-downs, storms with large hail and or/ severe winds, and tropical cyclones in the Albemarle-Pamlico region since 1950.

The Data

Data Description: The data includes instances and locations of tornado tracks and touchdowns, instances and locations of reported hail and high wind events, and instances and locations of tropical cyclones striking within 241 km (150 mi) of Swan Quarter, NC since 1950.

Data Quality/Caveats: Gaps in reporting of hail and severe wind gusts, shown in Figures 3 and 4 respectively, are likely due to lack of available reports because of low human population densities.

Data Availability: Tornado track, hail report, and severe wind report data were gathered by the State Climate Office of North Carolina from the National Weather Service Storm Prediction Center. Tropical data is courtesy of the State Climate Office of North Carolina.

References

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U.S. Department of Commerce, NOAA, National Weather Service, Silver Spring, MD.

TECHNICAL NOTES: GROUND-LEVEL OZONE CONCENTRATION

The Indicator

- W126 is an ozone exposure metric that counts the hours plants are exposed to potentially damaging ozone levels during the day within the May-September growing season, taking into account the level of exposure. The units are parts per million-hours or PPM-Hours. The hours that are summed are weighted by the ozone concentrations with zero weight for concentrations that are considered not harmful, a weight of one for concentrations that are clearly harmful and a transition between these two extremes. The EPA is considering a W126 secondary ozone standard of either 7 PPM-Hrs or 15 PPM-Hrs, providing two benchmarks for interpretation of index values. Lower values are more stringent or protective than higher values.

The Data

Data Description: The first figure reports on ozone trends using a calculated index (W126) for the cumulative value of ozone concentrations during the growing season. The W126 index is the cumulative exposure to ozone during 12 hours of daylight over three consecutive months of summer that emphasizes higher ozone values and deemphasizes low, near background ozone values.

Annual W126 indices (PPM-Hours/Year) were calculated for each ozone monitor in the Albemarle –Pamlico region from North Carolina's ozone monitoring data base for 1993 to 2010. Data from prior to 1993 are unavailable from either North Carolina or from EPA's Air Quality System (AQS) data base. There were no monitors from Virginia within the Albemarle-Pamlico region. Data from monitors with more than 75% of hourly measurements in a given year were included. For monitors with less than 100% of the relevant values, annual W126 calculations were adjusted. No monitors were excluded for the analysis. To constrain the influence of individual monitors for the time trends the average annual W126 value for all monitors was constructed and shown along with the individual monitors. For the spatial map, annual values of W126 at each monitoring site are mapped to the location of the monitor. No attempt was made to interpolate the ozone exposure across space because that information is too uncertain.

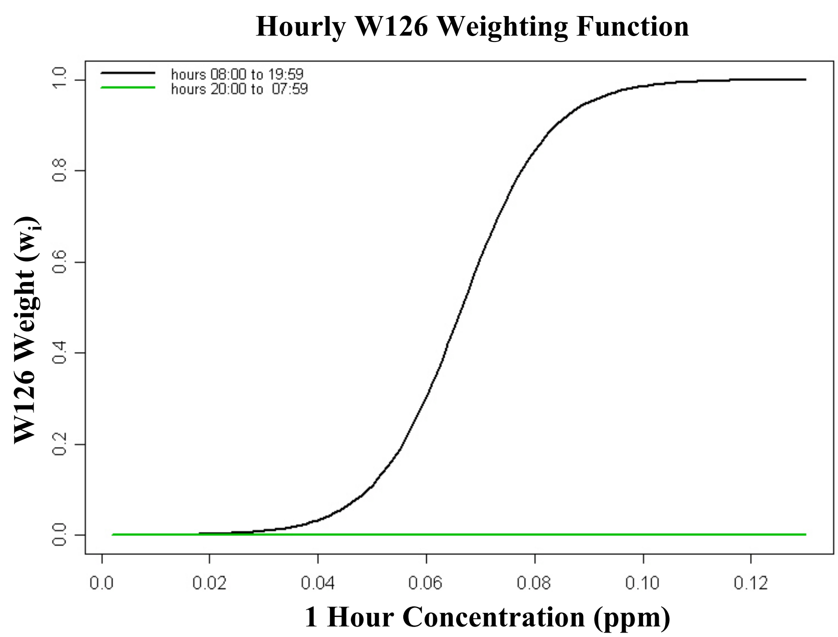
Data Manipulation: The W126 index reports on trends in atmospheric concentrations of ozone that are relevant to causing biological damage. The index is biologically relevant and expresses our empirical understanding of vegetation yield loss (harvest loss) as a function of ozone concentration based on National Crop Loss Assessment Network experiments. W126 is a seasonal metric derived from the sum of weighted hourly ozone values measured during the 12-hour daylight period during the ozone season (May through September) with the higher hourly concentrations being weighted more heavily than lower concentrations. The application of the W126 index is designed to characterize high concentrations over a seasonal three-month exposure period.

Hourly Weighting, $w_i = 1/[1 + 4403 \exp(-126c_i)]$

Where

w_i = weighting value for hourly concentration i, and

c_i = hourly ozone concentration i in ppm.



Then

Where n = number of hours with valid ozone concentrations,

Ozone concentrations are in units of PPM, and

The exposure unit is PPM-Hours.

First the monthly W126 index is calculated based on daylight hours (8 am to 8 pm) only for the months of May through September for the year of interest. Then the highest of the rolling 3-month sums for a consecutive 3-month period is the W126 value for the site for that year.

For reference, a W126 index value of 21 PPM-Hrs is associated with a level of crop protection of approximately no more than 10% yield loss in 50% of crop cases studied in the National Crop Loss Assessment Network (NCLAN) experiments. A W126 index value of 13 PPM-Hrs is associated with a level of crop protection of approximately no more than 10% yield loss in 75% of NCLAN cases.

Data Quality/Caveats: The ozone data are from the regulatory network run by the State of North Carolina and therefore are of known data quality because of the quality checks required by the US EPA. The W126 index is intended to capture ozone exposure conditions when a majority of plant species across the US are engaged in gas exchange and is not optimized for ozone effects on sensitive plant species or those that exhibit night-time gas exchange.

Data Availability: Ozone data are available from North Carolina's Department of Environment and Natural Resources, Division of Air Quality's Statistical Services. W126 calculations are also available from Division of Air quality Statistical Services. Raw ozone data are also available through EPA's Air Quality System (AQS), < http://www.epa.gov/ttn/airs/airsaqs/>. Ozone data and W126 calculations for North Carolina were obtained from the Division of Air Quality Statistical Services through Wayne Cornelius and analyzed and graphed/mapped by personnel from US EPA's Office of Research and Development/National Exposure Research Laboratory/Atmospheric Modeling and Analysis Division.

TECHNICAL NOTES: TOTAL INORGANIC NITROGEN DEPOSITION

The Indicator

- Annual Wet N Deposition: The annual accumulated amount of inorganic N deposited via rain from the atmosphere at sites across the Albemarle-Pamlico region. Two forms of inorganic N are tracked: oxidized and reduced N. Oxidized N deposition stems from N oxide emissions (mostly from combustion processes) and reduced N deposition stems from ammonia emissions (mostly from agricultural operations). A three-year running average is used to filter out the change in values due to inter-annual meteorological variability.

- Annual Rainwater N Concentration: To reduce the impact of inter-annual variability of meteorology and account for any temporal trends in precipitation, wet concentration of oxidized and reduced N in the rainwater that is precipitation weighted is used as a co-indicator. This indicator provides a clearer picture of the underlying effect trends in emissions are having on the atmospheric deposition.

The Data

Data Description: Data on annual atmospheric deposition of wet inorganic N (nitrate or oxidized-N and ammonium or reduced-N) were gathered by the National Atmospheric Deposition Program (NADP) through a national system of monitors. Five monitors that spanned the Albemarle-Pamlico region were selected for analysis. Three of the sites reported for the entire period from 1980 to 2010 while two of the sites reported only for recent time periods. Wet deposition of inorganic N is measured through chemical analysis of rainwater samples that are accumulated over a week and collected on a routine weekly schedule. For each year, data from monitors with less than 75% of valid samples, less than 90% of precipitation amounts available, less than 75% of total measured precipitation associated with samples or less than 75% collection efficiency (sum of sample bucket depths divided by the sum of rain gage amounts) were excluded from analysis. The data for each year at each North Carolina and Virginia site met these criteria, and thus, no years had to be excluded.

Data Quality/Caveats: To fully characterize atmospheric N deposition, both wet and dry deposition would be reported. On a broad regional basis (total Albemarle-Pamlico region), dry deposition constitutes more than half of the total oxidized N deposition and less than half of the reduced N deposition. However, for reduced N near confined animal operations, dry deposition of reduced N can be up to 10 times larger than wet deposition. On a broad regional basis, dry deposition constitutes roughly half of the total inorganic nitrogen deposition. But the NADP network currently measures wet deposition only. Organic N, which has been estimated to constitute as much as 30% of the total N in wet deposition, is not included in NADP measurements.

The NADP network shows a continual downward trend in sulfate wet deposition, suggesting that over time there is less sulfate in the atmosphere to be neutralized by ammonia, thereby leaving more ammonia to dry deposit downwind of the confined animal operations in North Carolina. This hypothesized increase in dry deposition of ammonia, with no change in emissions, cannot be verified given the lack of data. There is inadequate spatial coverage of wet deposition to address gradients across the watersheds of the two inorganic forms measured (oxidized and reduced N). Organic N is estimated to constitute about 30% of the total wet N deposition.

Data Availability: Tabular and mapped data are available (NADP 2012). The data were graphed, mapped and analyzed by personnel from US EPA's Office of Research and Development/National Exposure Research Laboratory/Atmospheric Modeling and Analysis Division.

Data Gaps: Currently, dry N deposition cannot be directly measured due to technical constraints, i.e., lack of capable measurement methods. The Clean Air Status and Trends Network (CASTNet) estimates dry deposition flux based on combining weekly average particle and gas measurements with hourly meteorological measurements and land surface features, termed the inferential method (CASTNet 2012). However, CASTNet does not measure the key species, ammonia, nor does it measure important oxidized nitrogen species beyond nitric acid and particle nitrate. Also, there are no CASTNet sites in the Albemarle-Pamlico region representative of deposition to the watersheds. There is one CASTNet site at Beaufort that could represent deposition to the Pamlico Sound that includes recent experimental measurements of ammonia, which might be useful in the future.

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TECHNICAL NOTES: DISSOLVED METAL CONCENTRATIONS

The Indicator

- Concentrations of dissolved metals, including Cd, Cu, Ni, Zn, Pb, Cr, Ag, and Hg in North Carolina and Virginia waters within the Pasquotank, Chowan, Roanoke, Tar-Pamlico, Neuse, and White Oak River basins.

- Extent (length and area) of reported dissolved metal 303 (d) violations in North Carolina and Virginia waters within the Albemarle-Pamlico region.

The Data

Data Description: Concentrations were measured by the North Carolina Division of Water Quality (NCDWQ), the Virginia Department of Environmental Quality (VDEQ), and other government and nonprofit agencies. Violations were determined by standards developed by the US Environmental Protection Agency and state agencies.

The concentrations are presented as monthly concentrations in the freshwater and saltwater portions of individual river basins and the entire Albemarle-Pamlico region. In addition, the extent (miles and acres) of violations for each type of metal are summed for each, and then all river basins in the Albemarle-Pamlico region.

Data Manipulation: All dissolved Cd, Cu, Ni, Zn, Pb, Cr, Ag, and Hg concentrations measured at sites within the Virginia portions of the Chowan and Roanoke River Basins were averaged by month for each respective river basin.

Data Quality Caveats: Metal violations for North Carolina reflect action on total metals concentrations, not dissolved metals concentrations.

Data Gap: Total metal concentrations were measured as a part of the NCDWQ Ambient Monitoring Program until 2007. The NCDWQ is presently collecting dissolved metal concentration data from discrete locations to determine standards so that dissolved metal concentrations can be incorporated into the NCDWQ Ambient Monitoring Program and provide biologically relevant water quality information.

Data Availability: Dissolved metal concentrations have been measured as part of the VDEQ water quality monitoring program since 1997 and are available upon request. 303(d) violation information for North Carolina and Virginia are available online through the EPA WATERS website, <http://www.epa.gov/waters/index.html>.

References

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Acknowledgements

The authors are grateful to Roger E. Stewart II, Virginia Department of Environmental Quality, Division of Water Quality for supplying clean metals data for VA waters within the Albemarle-Pamlico region.

TECHNICAL NOTES: DISSOLVED OXYGEN CONCENTRATION VIOLATIONS

The Indicator

- Mean monthly dissolved oxygen (DO) concentrations ($\pm$ 1 standard deviation from the mean) of surface waters [defined as ≤ 0.15 m (0.5 ft)] from 1980 to 2010 for all sampling stations reporting surface water DO concentrations within the Albemarle-Pamlico region.
- Listed DO 303 (d) violations in North Carolina and Virginia waters within the Albemarle-Pamlico region in 2010.

The Data

Data Description: DO concentration data from sampling stations within the Pasquotank/Chowan, Roanoke, Tar-Pamlico, Neuse, and White Oak River basins and Albemarle and Pamlico Sounds were averaged for each month from 1980 to 2010. Concentrations and violations are based on measurements made by the NC Division of Water Quality (NCDWQ); the Virginia Department of Environmental Quality (VDEQ), Division of Water Quality; and other government and nonprofit agencies.

Data Manipulation: Monthly mean DO concentrations were calculated for all sampling stations within each of the following basins of the Albemarle-Pamlico region as classified by the EPA STORET database: Chowan, Roanoke, Tar-Pamlico, Neuse, and White Oak River basins and Albemarle and Pamlico Sounds were averaged for each month from 1980 to 2010. The numbers of samples that contributed to the monthly means for these drainage basins spanned varied ranges: Chowan River basin (n=1 to 130), Neuse River basin (n=1 to 187), White Oak River basin (n=2 to 85), Roanoke River basin (n=1 to 62), Tar Pamlico River basin (n=2 to 85), Albemarle Sound (n=1 to 63), and Pamlico Sound (n=1 to 36).

Trend analysis was conducted on monthly averages that were grouped into four seasons (December-February; March-May; June-August; and September-November) using a Seasonal Kendall test (Helsel et al., 2006).

Data Quality/Caveats: In waters that are not well-mixed (stratified), surface DO concentrations (as reported here) will not reflect low oxygen (hypoxic) and no oxygen (anoxic) conditions in bottom waters where oxygen sources are limited despite biological and chemical removal of oxygen from the water column. Such conditions can be detrimental or lethal to bottom-dwelling organisms and to all organisms when the water is mixed, and hypoxic and anoxic zones are distributed. For this reason, measurements from bottom waters would serve as a better indicator of water quality. However, maximum depths of water at sampling stations were not provided, and thus, data from bottom waters were not identifiable.

Data Availability: The measured DO concentrations of waters within the Pasquotank, Chowan, Roanoke, Tar-Pamlico, Neuse, and White Oak River basins and the Albemarle and

Pamlico Sounds from 1980 to 2010 were obtained from the EPA STORET Data Warehouse <http://www.epa.gov/storet/dbtop.html>.

All EPA 303(d) violations data and GIS files were obtained from the EPA WATERS (Watershed Assessment, Tracking & Environmental Results) database <http://www.epa.gov/waters/>.

References

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TECHNICAL NOTES: CHLOROPHYLL a CONCENTRATION VIOLATIONS

The Indicator

- Mean monthly chl *a* concentrations (± 1 standard deviation from the mean) of surface waters [defined as ≤ 0.15 m (0.5 ft)] from 1980 to 2010 for all sampling stations reporting surface water chl *a* concentrations within the Albemarle-Pamlico region.

- Listed chl *a* 303 (d) violations in North Carolina and Virginia waters within the Albemarle-Pamlico region in 2010.

The Data

Data Description: Concentrations are based on measurements made by the NC Division of Water Quality (NCDWQ); the Virginia Department of Environmental Quality (VDEQ), Division of Water Quality; and other government and nonprofit agencies. A fluorometric method was used to measure chl *a* concentrations before 2002, and EPA method 445 was used to determine chl *a* concentrations from 2002 to 2010.

Data Manipulation: Monthly mean chl *a* concentrations from 1980 to 2010 were calculated for all sampling stations within each of the following basins of the Albemarle-Pamlico region as classified by the EPA STORET database: the Chowan, Roanoke, Tar-Pamlico, Neuse, and White Oak River basins and Albemarle and Pamlico Sounds. The numbers of samples that contributed to the monthly means for these drainage basins spanned varied ranges: Chowan River basin (n=1 to 92), Neuse River basin (n=2 to 78), White Oak River basin (n=1 to 42), Roanoke River basin (n=1 to 8), Tar Pamlico River basin (n=1 to 4), Albemarle Sound (n=1 to 62), and Pamlico Sound (n=1 to 6).

Trend analysis was conducted on monthly averages that were grouped into four seasons (December-February; March-May; June-August; and September-November) using a Seasonal Kendall test (Helsel et al., 2006).

Data Availability: The measured chl *a* concentrations of waters within the Chowan, Roanoke, Tar-Pamlico, Neuse, and White Oak River basins and the Albemarle and Pamlico Sounds from 1980 to 2010 were obtained from the EPA STORET Data Warehouse <http://www.epa.gov/storet/dbtop.html>.

All EPA 303(d) violations data and GIS files were obtained from the EPA WATERS (Watershed Assessment, Tracking & Environmental Result) database <http://www.epa.gov/waters/>.

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TECHNICAL NOTES: RIVER HERRING ABUNDANCE

The Indicator

- Harvest Metric: Total Blueback Herring and Total Alewife Landings in Mass (Pounds) and Numbers for Chowan River, 1972 to 2004 (Grist, 2005:22, Figure 43).
- Abundance Metric: Blueback herring juvenile abundance from 11 core seine stations (NCDMF Program 100), June through October for years 1972-2010.
- Population Attribute Metric: Percent repeat spawners for Chowan River blueback herring, based on data from the commercial Chowan River pound net fishery (1972-2006), research set-aside fishery (2007) and Chowan River pound net survey (2008-2010).
- Population Attribute Metric: Chowan River blueback herring spawning stock biomass (SSB) by cohort for years 1972-2003.
- Abundance Metric: Chowan River blueback herring abundance at age (target age = 3) in numbers for years 1972-2003.

The Data

Data Description: Data used for assessing the status and trends of alewife and blueback herring in the Albemarle-Pamlico Estuarine System (APES) consist of indices derived from fishery-independent juvenile and adult survey and monitoring programs, as well as statistics derived from past commercial fishery data within the Chowan River pound net fishery.

Data Manipulation: Raw data are converted into indices of abundance (JAI), percentages (for repeat spawners), or other forms for analysis. Unlike data in the 2000 North Carolina Division of Marine Fisheries (NCDMF) assessment, data in the 2005 NCDMF assessment included species-specific population status estimates for both blueback herring and alewife (Grist, 2005:1).

Data Quality/Caveats: There are currently only data for river herring from the Albemarle Sound/Chowan River portion of the system; some of the historic commercial fisheries data are restricted due to confidentiality requirements.

Data Availability: NCDMF

Data Gaps: As noted in the text, there are at present insufficient data for analysis of other river herring stocks within APES. One of the key research recommendations in the 2007 FMP (NCDMF, 2007) was to expand data collection programs to other river systems in the state. Currently, no expansion of those data collection programs has occurred.

Pending further discussion with NCDMF and NCWRC and an evaluation of results from the benchmark assessment released by the Atlantic States Marine Fisheries Commission (ASMFC, 2012; Winslow et al., 2012), APNEP may elect to incorporate one or more of the following metrics as well:

- Harvest Metric: Blueback Herring Weight-At-Age (Pounds) and Catch-At-Age (Numbers) landed in the Chowan River pound net fishery: 1972-2003 (Grist, 2005:24,26, Figure:50)
- Harvest Metric: Alewife Weight-At-Age (Pounds) and Catch-At-Age (Numbers) landed in the Chowan River pound net fishery: 1972-2003 (Grist, 2005:27,29, Figure:50)
- Harvest Metric: Blueback Herring and Alewife pound net effort in Chowan River, 1972 to 2004 (Grist, 2005:30, Figure:45)
- Abundance Metric: Blueback Herring and Alewife Juvenile Abundance Index (fish per seine) in Albemarle Sound Area, 1972 to 2004 (Grist, 2005:31, Figure:46)
- Abundance Metric: Blueback Herring and Alewife Juvenile Abundance Index (Hassler trawl survey CPUE) in western Albemarle Sound Area, 1972 to 2004 (Grist, 2005:32)
- Abundance Metric: Blueback Herring and Alewife ASRHMA independent gill net survey for 2.5-inch stretch mesh, 1991-2003 (Grist, 2005:33, Figure:44)
- Abundance Metric: Blueback Herring and Alewife ASRHMA independent gill net survey for 3.0-inch stretch mesh, 1991-2003 (Grist, 2005:33)
- Abundance Metric: Blueback Herring and Alewife abundance at age in numbers, 1972 to 2003 (Grist, 2005:35-36; Figure:53, 62-63)
- Abundance Metric: Blueback Herring and Alewife Juvenile Abundance Index for Albemarle Sound, 1955 to the present. This is a fishery-independent measure of recruitment.

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TECHNICAL NOTES: AMERICAN SHAD ABUNDANCE

The Indicator

Two abundance metrics are featured for selected major tributaries (Tar-Pamlico and Neuse) within the Albemarle-Pamlico Estuarine System (APES) during 2000-2010:

- Catch per unit effort (CPUE) of female American shad in the North Carolina Wildlife Resources Commission (NCWRC) annual electrofishing surveys,
- "Female Relative F" for female American shad based on data collected in the NCWRC annual electrofishing surveys.

Three abundance metrics are reported for the Roanoke River-Albemarle Sound system:

- Catch per unit effort (CPUE) of female American shad in the North Carolina Wildlife Resources Commission (NCWRC) annual electrofishing surveys;
- CPUE of female American shad in the NCDMF Albemarle Sound Fishery Independent Gill Net Survey (IGNS) (NCDMF Program 135); and
- "Female Relative F" for female American shad based on data collected in the IGNS.

These metrics are pending final approval by the Atlantic States Marine Fisheries Commission (ASMFC) Shad and River Herring Management Board, having just been approved by the NC Marine Fisheries Commission in November 2012 (NCDMF and NCWRC 2012).

The Data

Data Description: Data used for assessing the status and trends of American shad in the APES tributaries consist of CPUE statistics derived from NCDMF gill net sampling in the sounds, and NCWRC electrofishing sampling on the spawning grounds of each major tributary.

Data Quality/Caveats: The time series for the NCDMF gill net data is longer than for the NCWRC electrofishing data. Although the NCDMF IGNS has been conducted since 1991, use of the 2000–2010 time series will allow for more consistent comparison with the female CPUE index from the Roanoke River electrofishing survey, which has been conducted annually since 2000. Data from the 2000 NCWRC electrofishing survey were unavailable for analysis due to database construction but will be included when parameters are updated for the annual compliance report. Electrofishing sampling is significantly influenced by river discharge, in that high flows may greatly reduce CPUE. The development of additional indicators is desirable in order to assess year class production.

Data Availability: NCDMF and NCWRC-Division of Inland Fisheries.

Data Gaps: There are currently no juvenile abundance data for any of the systems, other than Albemarle Sound.

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TECHNICAL NOTES: STURGEON ABUNDANCE

The Indicator

- Abundance metric: Catch per unit effort (CPUE) of sturgeon in North Carolina Division of Marine Fisheries (NCDMF) Albemarle Sound Fishery Independent Gill Net Survey (NCDMF Program 135)

- Abundance metric: CPUE of sturgeon in NCDMF Fisheries Independent Assessment (NCDMF Program 915, Pamlico Sound, and Pamlico/Neuse Rivers components).

The Data

Data Description: Data used for assessing the status and trends of Atlantic sturgeon in the APES consist of CPUE statistics derived from NCDMF fishery-independent gill net sampling in Albemarle Sound, Pamlico Sound, and near the mouth of the Pamlico and Neuse rivers.

Data Manipulation: None

Data Quality/Caveats: The time series for some of these data sets is relatively short, and the gear used captures only juvenile and sub-adult sturgeon.

Data Availability: NCDMF

Data Gaps: There are currently no data on the abundance of adult sturgeon in the APES, although data are presently being collected via a National Marine Fishery Service (NMFS) Section 6 grant project which may provide some information on adults.

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TECHNICAL NOTES: EXTENT OF SUBMERGED AQUATIC VEGETATION

The Indicator

- Extent and location of submerged aquatic vegetation (SAV) by density class (dense, patchy, sparse to none) during 2006-2008.

The Data

Data Description: All imagery was collected with Intergraph's Z/I Digital Mapping Camera (DMC). The mainland and outer banks of Bogue Sound and Back Sound, and the mainland side of Core Sound north to Atlantic, North Carolina was collected on May 31 and June 1, 2006. Aircraft height was 3,048 m for a final imagery product with 0.3 m pixel size. All other areas in the state were collected on October 12, 14, and 15, 2007 and May 27, 2008 with an aircraft height of 6,096 m for a final imagery product with 1.0 m pixel size.

Data Manipulation: The imagery was loaded into ArcGIS for manual on-screen digitizing using procedures described in Rohman and Monaco (2005). Digitizing scale was typically set to 1:1,500 except when larger homogonous areas required zooming out to a greater extent that was usually accomplished at approximately 1:6,000. Habitat boundaries were delineated around benthic habitat features (e.g. areas with visually discernable differences in color and texture patterns). The scanned images were occasionally manipulated in terms of brightness, contrast and color balance to enhance interpretability of subtle features and boundaries. This was extremely helpful, especially in deeper water where subtle boundaries or problems caused by turbidity can made features difficult to detect. The classification scheme consisted of three thematic classes: dense seagrass, patchy seagrass and unvegetated. Dense seagrass was defined as areas covering 70% or greater of the substrate that may contain unvegetated or sparsely vegetated areas that are smaller than the minimum mapping unit (MMU – 0.2 ha in this study). Patchy seagrass was defined as discontinuous communities covering more than 10% but less than 70% of the substrate. These areas were diffuse and irregular consisting of isolated patches that are below the MMU. Areas with less than 10% seagrass are considered beyond the level of detection of the imagery used and thus fell in the unvegetated category.

Approximately 1,000 field points were visited in 2007. All of these points were used as training data to guide digitization of seagrass habitats. The points were randomly generated in GIS, based on areas where seagrasses were previously mapped or in water down to a depth of 2 m. Points were located in small craft with the aid of Differential Global Positioning Systems (DGPS) or Wide Area Augmentation System (WASS) GPS accurate to approximately 5 m. Areas were identified visually from the boat (or wading in shallow waters) or with the aid of rakes where the bottom could not be visualized.

Data Quality/Caveats: MMU is generally defined as the smallest feature (e.g., an individual seagrass bed) or aggregate of features (e.g., seagrass patches) that is delineated using a given source of imagery (Rohmann and Monaco, 2005). For this study the MMU was approximately 0.2 ha, or in general patches that are at least 15 m across on their longest axis.

It was hoped that up to one half of the 1,000 field points could be held out, not used at all by interpreters, and used in an accuracy assessment. Unfortunately, due to less than ideal imagery quality in some locations and interpreters who did not have the opportunity to go out in the field, it was decided to forgo the accuracy assessment and use all the field points to aid interpretation.

Data Availability: Data and mapped SAV data are available from APNEP. <http://portal.ncdenr.org/web/apnep/sav-resources#map>.

Data Gap: While the compilation of 2006-2008 aerial images covered all potential SAV coastal areas and hence there are no spatial coverage gaps, there are spatial interpretative gaps due to limitations described in the "Understanding the Data" section of the assessment.

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TECHNICAL NOTES: PHRAGMITES AUSTRALIS EXTENT

The Indicator

- Areal extent of *Phragmites australis* in the coastal plains of the Albemarle-Pamlico region.

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TECHNICAL NOTES: RELATIVE SEA LEVEL

The Indicator

- Long-term trends of relative sea level (RSL) at four locations in the Albemarle-Pamlico region.

The Data

Data Description: Water level has been measured for various lengths of time (Table 1) at NOAA tide gauge stations in North Carolina: Duck, the Oregon Inlet Marina, Cape Hatteras, and Beaufort. Tide gauge stations in the Oregon Inlet Marina and Beaufort have operated for 30 years or more while those in Duck and Cape Hatteras have operated for less than 30 years.

The uncertainties for trends reported by Zervas (2006 and unpublished) are the 95% confidence intervals, which are 1.96 times the standard deviations. The trends presented by Zervas (2004) were given as ± one standard deviation but are here converted to the 95% confidence intervals.

The Cape Hatteras station was destroyed by Hurricane Isabel in 2003 and was not reinstalled due to the lack of a suitable pier. A new station was installed nearby last year, but is located inside the Pamlico Sound, so its tidal characteristics are very different and incomparable to the Cape Hatteras station measurements.

Data Manipulation: The trend in and confidence limits for mean RSL were calculated from monthly water levels using a linear regression with an autoregressive coefficient and a seasonal cycle. Detailed methods are described by Zervas (2001).

Data Quality/Caveats: With regard to Figure 1, Titus (2001) requested that the following stipulation be stated: "This map is based on modeled elevations, not actual surveys or the precise data necessary to estimate elevations at specific locations. The map is a fair graphical representation of the total amount of land below the 1.5- and 3.5-meter contours; but the elevations indicated at particular locations may be wrong. Those interested in the elevations of specific locations should consult a topographic map. Although the map illustrates elevations, it does not necessarily show the location of future shorelines. Coastal protection efforts may prevent some low-lying areas from being flooded as sea level rises; and shoreline erosion and the accretion of sediment may cause the actual shoreline to differ from what one would expect based solely on the inundation of low land. This map illustrates the land within 1.5 and 3.5 meters of the National Geodetic Vertical Datum of 1929, a benchmark that was roughly mean sea level in the year 1929 but approximately 20 cm [or fill in local estimate] below today's sea level."

Data Availability: Updated sea level trends reported by NOAA can be accessed online <http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml>. Summary reports of sea level trends and further explanation of those trends can be accessed through individual NOAA publications, accessible online <http://tidesandcurrents.noaa.gov/pub.html>.

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TECHNICAL NOTES: OCEAN SHORELINE MIGRATION

The Indicator

- Long-term *shoreline erosion/accretion rate* in meters per year [m/yr] based on the 1933-52 and 2009 shorelines.

- Short-term *range of shoreline position* in meters [m] for the years 1996-2009.

The Data

Data Manipulation: The shoreline position is measured from a reference line and shoreline erosion/accretion rate is computed as a difference (distance) between the shoreline positions at the beginning and at the end of the given time period divided by number of years (this approach is referred to as the end point method). The shoreline displacement is measured at discrete locations using a series of equidistant spaced (in this study 50 m), cross-shore transects. The methods are described by Dolan et al. (1978, 1980), Overton and Fisher (1996), and others, with similar methods used in Morton and Miller (2005). Derivation of the shoreline evolution band used to compute the range of shoreline position is described by Mitasova et al. (2010) and Hardin et al. (2011).

Data Description: Detailed description of the data can be found on the respective websites and in metadata files provided with the data sets. Shorelines used for the long-term erosion/accretion rate were downloaded from the North Carolina Division of Coastal Management (NCDCM) website <http://dcm2.enr.state.nc.us/Maps/chdownload.htm>, transects were downloaded from the USGS website <http://pubs.usgs.gov/of/2005/1326/gis-data.html>. Lidar point data used to compute the digital elevation models (DEMs) were downloaded from the NOAA Digital Coast web site, <http://www.csc.noaa.gov/digitalcoast/data/coastallidar/index.html>.
All data were georeferenced to NC State Plane coordinate system NAD83, with vertical datum NAVD88.

Data Quality/Caveats: The composite 1933-52 shoreline was digitized from NOS T-Sheets with maximum shoreline position error between 10.8 and 5.1 m (Morton and Miller, 2005). The 2009 shoreline, digitized as wet/dry line from aerial orthophoto has published accuracy of 1.7 m (5.5 ft) and an uncertainty of 4.0 m (13.1 ft). Accuracy of shoreline positions derived from lidar data published in literature is 1.4 m (no accuracy assessment was done specifically for this study but similar accuracy can be expected). Finally, it is important to note that shoreline erosion/accretion can be measured using different methods and different sets of data. This can lead to different rates estimated for specific locations and specific time periods.

Data Availability: Shorelines, imagery, and lidar data are available from NOAA Digital Coast web site:
<http://www.csc.noaa.gov/digitalcoast/data/index.html>

<http://shoreline.noaa.gov/>
<http://www.csc.noaa.gov/digitalcoast/data/coastallidar/index.html>
<http://www.csc.noaa.gov/digitalcoast/data/highresortho/download.html>

Additional long term shoreline erosion rates are available from the NC DCM website <http://dcm2.enr.state.nc.us/Maps/mapsdata.htm> and a USGS report <http://pubs.usgs.gov/of/2005/1401/>.

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TECHNICAL NOTES: ESTUARINE SHORELINE MIGRATION

The Indicator

Shoreline change can be calculated through the time-series comparison of various data sets that include ground surveys, aerial photography, satellite imagery, synthetic aperture radar, light detecting and ranging (LIDAR), and global positioning systems. Although new satellite and other remotely sensed approaches are becoming feasible (e.g., LIDAR surveys, see Li et al., 2001), aerial photography analysis remains the most commonly used method to calculate shoreline change (Boak and Turner, 2005).

The Data

Data Description: Riggs and Ames (2003) provide a detailed summary of former shoreline change studies conducted in coastal North Carolina. These earlier works were based on old aerial photography and without the benefit of computer technology and associate software. The data presented herein use an array of aerial photography through time, detailed field descriptions, and new computer technology.

Data Quality/Caveats: Spatial and temporal errors exist when using aerial photography to calculate shoreline change. Spatial distortion includes tilt, radial distortion, and relief displacement. However, these distortions are generally corrected when the image is rectified. Rectification gives the image a spatial reference and is necessary before shoreline demarcation. Since aerial photographs are a snapshot in time of a dynamic system, it is important to consider the events occurring just prior to the capture of the image (e.g., storms, flood). Regardless, it is essential to document and understand both the storm-dominated shoreline processes and the chronic change over decadal timescales that reflect net long-term variability.

It is important to understand that shoreline change data provides an average rate of change over timescales in which the measurements were made. For instance, the research conducted in the Neuse River Estuary (Figure 2) provides a 40-year average in the rate of shoreline change. Recent work in the Albemarle-Pamlico Estuarine System (APES) demonstrates the possible variation in these rates likely associated with storm activity and timing of image collection (Figure 3). However, these rates can help for planning purposes and provide a baseline on which to understand changes in the landscape. It is essential to understand the rates of change over a telescoping range of time (months, years, decades) for a more accurate understanding of future shoreline position. Most research has demonstrated fetch and wave energy as important parameters driving change along the shoreline.

Data Availability: Please see references. Data is available upon request.

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TECHNICAL NOTES: ESTUARINE SALINITY CONCENTRATION

The Indicator

- Salinity concentrations across estuarine sub-basins of the Albemarle-Pamlico Estuarine System (APES) from 1980 to 2009.

The Data

Data Description: Salinity concentration data is from estuarine North Carolina Division of Water Quality (NCDWQ) sampling stations in the APES. Data from stations that reported for the 1980s, 1990s, and 2000s were used for further calculations. If a station did not have data available from one or more of the three decades, the data from that station was not used.

Data Manipulation: Monthly mean salinity concentrations were calculated for all sampling stations within the Lower Chowan, Lower Roanoke, Lower Tar, Lower and Middle Neuse, and White Oak River basins and the East Albemarle (including the Pasquotank River basin), West Albemarle, and West Pamlico Sounds from 1980 to 2009.

Trend analysis was conducted for individual stations on monthly averages that were grouped into four seasons (Dec-February; March-May; June-August; and September-November) using a Seasonal Kendall test (Helsel et al., 2006).

Data Quality/Caveats: The two DWQ stations in the Eastern Pamlico region did not have sufficient datasets available to calculate decadal trends for that region.

Data Availability: Salinity concentration data for estuarine waters within the APES from 1980 to 2010 were obtained from the EPA STORET Data Warehouse, <http://www.epa.gov/storet/dbtop.html>.

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TECHNICAL NOTES: SHELLFISH CLOSURES

The Indicator

- Percentage of shellfish acreage within counties of the Albemarle-Pamlico region permanently closed to fishing. This indicator provides information about bacterial contamination.

The Data

Data Description: Percentages of areas that were closed to shellfishing are based on total shellfish acreage and closed acreage of shellfish beds within Beaufort, Bertie, Camden, Carteret, Chowan, Craven, Currituck, Dare, Gates, Halifax, Hertford, Hyde, Jones, Martin, Northampton, Pamlico, Pasquotank, Perquimans, Tyrell, and Washington counties. Acreage data from 2007 onward has been calculated using the North Carolina Department of Environmental Health, Shellfish Sanitation and Recreational Water Quality Section (NCDEH-SSRWQS) GIS layer. Acreage figures from 2007 and earlier were hand tallied using a planimeter on National Oceanic and Atmospheric Administration (NOAA) Charts.

Data Availability: The data used in this study were made available by NCDEH-SSRWQS staff. Permanent shellfish closures and pollution proclamations can be accessed online <http://portal.ncdenr.org/web/mf/proclamations-polluted-areas>.

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TECHNICAL NOTES: UNUSUAL FISH MORTALITIES AND DISEASE EVENTS

The Indicator

Potential metrics for this indicator could include the following:

- Fish kills: number of fish kills by county, and/or by individual watersheds.
- Hurricane-related fish kills: number, location and composition of fish kills caused as a direct result of hurricane-related flooding and consequent flushing of anoxic water from floodplain forested wetlands.
- Occurrence and prevalence of newly-documented diseases within the Albemarle-Pamlico Estuarine System.
- Reports derived from ongoing survey of the literature by APNEP collaborators; and/or derived from consultation with the NCSU College of Veterinary Medicine.

The Data

Data Description: The reporting of fish kill activity across North Carolina is based on protocols established by the North Carolina Division of Water Quality in 1996 (NCDWQ, 2010). The protocols were developed with assistance from NCDWQ Regional Office staff, North Carolina Wildlife Resources Commission (NCWRC) biologists, and NC Division of Marine Fisheries (NCDMF) biologists as a means to improve the tracking and reporting of fish kill events throughout the year. Fish kill and fish health investigation data are recorded on a standardized form and sent to the NCDWQ Environmental Sciences Section where the data are reviewed and compiled.

Data Manipulation: Fish kill investigation forms, laboratory test results and supplemental information sent to the NCDWQ Environmental Sciences Section are entered into a central database where the information is managed, queried and reported. Fish kill information for the current year is posted weekly from June to November on the NCDWQ-ESS website <http://portal.ncdenr.org/web/wq/ess/fishkillsmain>. Kill report locations for the current year are also available on the website as a Google Earth coverage.

Data provided to the U.S. Fish & Wildlife Service (USFWS) for the National Wild Fish Health Survey are entered into a national database, <http://www.fws.gov/wildfishsurvey/database/page/intro>. The database is searchable by state, species, pathogen, water body, and partnering organizations. Individual case reports are associated with each entry and provide additional information.

Data Quality/Caveats: Fish kills are only reported and investigated if they are observed. There are undoubtedly kills which occur in little-traveled areas which go unobserved by people or are removed by predators shortly after they occur.

In the absence of a systematic survey for fish health and fish diseases, the only data generated result from opportunistic collaboration between NCDWQ, NCWRC and USFWS. While the National Wild Fish Health Survey is ongoing, it is also opportunistic in that only cases discovered during the course of agency operations for other purposes, or those reported by the public, are investigated and results reported. Some of the National Wild Fish Health Survey case reports are at present of limited utility, because they lack any information about the final diagnosis of the samples examined. This is due to moving all the records into a new database, which failed to correctly enter the data. Staff at the USFWS Warm Springs Fish Health Center are in the process of re-entering the data (Norm Heil, Director, Warm Springs Fish Health Center, USFWS, Warm Springs, GA, personal communication).

Data Availability: NCDWQ; USFWS, Warm Springs Fish Health Center; North Carolina State University, College of Veterinary Medicine, individual researchers; NCWRC, Division of Inland Fisheries, Raleigh.

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TECHNICAL NOTES: STREAMFLOW

The Indicator

- Mean annual flow and 95% confidence intervals for six selected stations in the Neuse River Basin during the period 1997-2008

- Mean annual flow for Contentnea Creek at Hookerton, NC, Roanoke River near Roanoke Rapids, NC and Blackwater River near Franklin, VA

The Data

Data Description: A brief description of how streamflow data are monitored and computed is presented under the technical note for "Riverine Transport of Nitrogen & Phosphorus." All streamflow data used in this report were collected and reported by the US Geological Survey (USGS) and are available for the stations shown below at <http://waterdata.usgs.gov/nc/nwis/sw>. Station Numbers are as follows:

Site 02085000- Eno River at Hillsborough, NC
Site 208521324 Little River Orange Factory, NC
Site 2091500 Contentnea Creek at Hookerton NC
Site 2091814 Neuse River at Fort Barnwell, NC
Site 0208925200 Bear Creek Mays Store
Site 02092500 - Trent River near Trenton, NC

Data Manipulation: Mean annual streamflow is computed by summing all of the daily flows and dividing by 365 (days). Mean annual flow data published by the USGS is the average of all daily flows measured for the entire water year (October to September) or calendar year (January to December). Calendar year was the period used in this assessment.

Trends are evaluated using a Spearman rho correlation (Conover 1980) analysis for sample pairs (rank of flow and rank of year) less than 30 and a Pearson Correlation (Klugh 1970) for sample pairs (flow and year) greater than 30. This assessment of trends can include one or two periods: first, where available, for the entire period of record available to 2008 from USGS and second, the period from 1997-2008, essentially the time since the release of the first CCMP. Only stations that were analyzed for nutrient load trends for this assessment are included. Trends were considered to be statistically significant at the 95% confidence level (0.05 significance level).

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TECHNICAL NOTES: POINT SOURCE DISCHARGES

The Indicator

- Numbers of major and minor wastewater dischargers in the Neuse River Basin between 1960 and 2008.
- Total nitrogen (N) loads discharged by point sources to the Neuse River Basin between 1960 and 2008.
- Percentage of N discharged from point sources compared to N transported from all sources in the Neuse River at Fort Barnwell between 1960 and 2008.

The Data

Data Manipulation: Two methods were used for determining how much N was discharged into the river. In the case of the population-and-treatment-factor method (tagged “PopTfactor” in Table 1), the N discharge to the river is based on the size of the sewered population and the efficiency of the treatment process (Stow et al., 2001). The method used most commonly after 1990 (“ConXFlow” in Table 1) is direct calculation from chemical concentration and physical flow data collected from all dischargers in the basin. Stanley (1992) reported good agreement between both methods applied to selected data sets in the Neuse, Chowan and Tar-Pamlico river basins.

The Spearman Correlation Test (Conover 1980) was used to test trend for data shown in this report. The Spearman test is suitable for small data sets and for data whose parent distribution is unknown. The Spearman test was applied to point source loads and total stream load through time which tests the (two-sided) hypothesis that ranked values of loads either increase or decrease though time. Trends were considered significant at the 0.05 significance level. For the ten point N load values shown (1960 was left out) in Table 1, a ρ (rho, the Spearman correlation coefficient) of +-0.648 or larger (smaller) would be required to be significant at 5% significance. As shown in the explanation above, ρ= -0.89, a significant (at 0.05) decrease in the point N load though time.

The health of the Neuse River Estuary has been the focus of management since the late 1990s. Because the Neuse River at New Bern is the point in the Basin where the estuary begins, the N load at New Bern is used as point where the N baseline was established—the baseline N load, which was to be reduced by 30%, was 4.38 million kg (9.65 million lbs) (NCDWQ, 2002) or 4,780 mt (4,825 T) at New Bern, with 1.51 million kg (3.32 million lbs) or 1,506 mt (1,660 T) the baseline for point source N. The baseline N loads were established to measure progress toward N reductions established as part of a TMDL (Total Maximum Daily Load) to improve water quality of the Neuse River (NCDWQ, 2002).

Because no station exists at New Bern, the N load must be estimated from the upstream station and tributary stations that discharge near New Bern. To obtain a total N load at New Bern, the load in the mainstem river (a station was established at Fort Barnwell in 1996 for collection of both flow and water quality) and sum of two tributaries, Little River and Trent River, constitute the entire N load into the estuary. Total N loads after 1996 were estimated using the USGS LOADEST program (Runkel et al., 2004).

Long-term water quality data have been collected at two stations (Neuse River at Kinston and Contentnea Creek at Hookerton, a major tributary to the Neuse) on the Neuse River since at least the 1970s and were used by Stow and Borsuk (2003) to estimate stream loads between 1979 and 1996 at Fort Barnwell. Since 1997 data have been collected by NCDENR and the USGS at Fort Barnwell, the most downstream station before the Neuse becomes tidally influenced.

To estimate the total N load at New Bern for this assessment, loads estimated from Stow and Borsuk (2003) for the period 1979-1996 were combined with loads directly computed from flow and concentration data at Fort Barnwell collected between 1997 and 2008 and then multiplied by 1.15 to account for the additional load from Swift Creek and Trent River. The 15% additional load was derived from information published in Spruill et al. (2005), where the total load at New Bern [4,361 mt (4,807 T)] in 2000 was obtained by adding the annual load at the two tributaries [188 and 370 mt (207 and 408 T)) to the annual load at Fort Barnwell [3,803 mt (4192 T)].

Data Quality Caveats: Chemical and flow data are collected by individual dischargers, as required by their permit. Specific requirements for flow and nutrient analysis for wastewaters is defined for North Carolina under General States Chapter 143-215.1. For most domestic wastewater dischargers of greater than 194,000 L/day (50,000 gal/day) in the Piedmont and eastern part of the State, N and P samples are required quarterly to monthly. Although these analyses are required to be performed by State-certified laboratories, the hourly and daily variability and event-specific variability are unknown so that it is unknown how representative monthly or quarterly samples are of point-source discharges. Actual discharge estimates can vary depending upon the technique used and the error associated with using one or two samples per month (or less) to calculate annual or seasonal discharges. Quality assurance information for USGS laboratory and streamflow measurements is available through their Techniques of Water Resources Investigations publications. Quality assurance information for the water quality data collected by NCDWQ are available at <http://portal.ncdenr.org/web/wq/ess/eco/ams>.

The Data Gap: Generally, N and P data should be available for all permitted dischargers. However, information on P in point source discharges has not been published as widely as information on N, particularly since focusing on N effects in the Albemarle-Pamlico Estuarine System since the early 1990s.

Data Availability: The data on point-source discharges after 1990 were obtained from NCDWQ's Basinwide Water Quality Management Plans for the Neuse River published between

1993 and 2009. For data collected before 1990, estimates of point source discharges were obtained from Stanley (1992). The nutrient concentration data and point source discharge data were collected by individual dischargers, who are listed in the publications listed below. Streamflow data were obtained from USGS. Chemical quality data were obtained from NCDWQ and EPAs STORET database and the USGS National Water Inventory System (NWIS).

Information on numbers and types of point source dischargers and point source discharges of N in the Albemarle-Pamlico region were obtained from sources identified in Table 1. All of the NCDENR publications are available online at <http://ncdenr.gov/web/wq/ps/bpu> and were accessed last on December 15, 2011.

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TECHNICAL NOTES: RIVERINE TRANSPORT OF NITROGEN AND PHOSPHORUS

The Indicator

- Total annual loads in mass, and yields in mass per unit area, of total nitrogen (N), and total phosphorus (P) transported annually between 1997 and 2008 in six selected streams located in the Neuse River Basin (Table 1, Figure 1).

- Total annual flow, load and concentration of total N for the Neuse River from 1979 to 2008 (Figures 2-4).

The Data

Data Manipulation: *Data and methods used to calculate nutrient stream loads*
Nutrient stream loads are the masses of N and P compounds that are eroded or dissolved from the land and moved into stream channels that transport water and nutrients to estuaries and the ocean. In order to estimate the amounts being transported, loads are estimated by the following simple formula showing each component and its measurement units:
Instantaneous load or L (mass per unit time) = Concentration or C (mass/unit volume) X streamflow or Q (volume/unit time) (Equation 1)

The above representation of load is referred to as an instantaneous load. However, accurately estimating stream load is anything but simple because flow and concentration can vary by the minute, hour, and day and the actual load estimated to be transported during some practical time unit (i.e., a day or year) can only be estimated by summing a discrete number of instantaneous loads calculated with multiple flow and chemical measurements made at several times. The load (total load) for a discrete time period is calculated summing the instantaneous loads:
Total load [for a given time period (i.e., hour, day, year)] =Sum (individual instantaneous loads) (Equation 2)

Largely because of expense and logistical complexity, chemical samples are typically collected only once or twice monthly through the year. These samples are collected over a range of flows. Streamflow (or stream discharge) is calculated by multiplying cross sectional stream area (stream width X stream depth or stage) by measured stream velocity:
Streamflow (or Q in volume per unit time) = Cross sectional stream area (A) X Stream velocity (or V, in distance per unit time) (Equation 3)

Streamflow measurements are also made several times during the year by water scientists (hydrologists) and these measurements are related to stream stage (distance or height above the stream bed (or bottom) which is measured continuously by stream gages installed at selected gaging station locations) through regression procedures. The fact that stream stage can be measured simply and continuously using a float or sensing device coupled to a digital recorder is the primary reason why stream flow is so useful and can be used to generate stream load estimates for any time period. A regression equation, using least squares (Draper and

Smith 1998) is developed from the measured stage and flows, by plotting stage on the x-axis and flow on the y axis so that flow can be predicted from the stage information:
Streamflow (predicted) = b +m (stage) (equation 4)
where m = slope of the resulting regression line and b is the y-intercept-the y intercept being the lowest value of stream flow when the stage is at zero.

Where stream gages are in place, stream flow data are available for a variety of time intervals as small as 15 minutes. Unit stream flow, recorded every 15 minutes, is estimated from this stage-discharge relationship—when the stage is at a particular height above the stream bed and is related to a particular discharge determined by the regression and recorded as the flow for that 15 minute interval. Unit flows are transmitted by satellite to a digital data base, checked, processed, and recorded. Daily flows are compiled from the unit values into daily values. Various flow statistics are available for gaged river stations included in the U.S. Geological Survey's (USGS') National Water Inventory System and are available for North Carolina <http://nc.water.usgs.gov/> and for Virginia <http://va.water.usgs.gov/>.
The average flow for an entire year can be derived from taking the average of the daily flows to establish an average annual flow:
Average annual flow = sum (average daily flows) / 365 days (equation 5)

The annual average streamflow used to calculate trends presented in this assessment were derived this way.
Streamflow data are available every day, but concentration data are not and therefore daily loads cannot be calculated directly. Similar to the way missing flow data are predicted, so daily load data are calculated using regression. Daily loads for this APNEP assessment were estimated using procedures implemented in the USGS computer program LOADEST. The details of the procedure to estimate stream loads using LOADEST are presented in Runkel et al. (2004). Although 365 daily flows are available, chemical nutrient samples are only collected on relatively few days every year. The laboratory analytical methods used for both P and N species determination are available at the NCDENR website <http://portal.ncdenr.org/web/wq/lab/staffinfo/techassist#Practical_Quantitation_Limits>. In some cases, total N and total P samples were collected by USGS and combined with data from NCDWQ. Because there are typically 12-24 or so concentration measurements annually from each stream in the North Carolina portion of the Albemarle-Pamlico region and 365 daily stream flows, loads can be explicitly calculated for only 12-24 of the 365 days without some method of estimating loads for the remaining 341 days (assuming 24 nutrient samples are available). Mathematical regression is used to relate load to stream flow to predict load on days when no concentration data are available to calculate instantaneous loads. Within LOADEST, instantaneous loads are regressed on up to nine flow or time variables to predict loads for days when concentration data were not collected. Although ordinary least squares regression can be used, in general most of the loads for this assessment were estimated using the Adjusted Maximum Likelihood Estimate (AMLE) method, which yields nearly unbiased estimates of loads for data that have concentrations reported below detection limits. Samples collected for N and P from many stations in the Albemarle-Pamlico region have values that were reported below detection limits (0.01 mg/L for total P; 0.01 for nitrate and ammonium, and 0.2 mg/L for total

Kjeldahl N). Annual loads for this assessment were calculated by estimating the average of 365 daily loads (or fluxes) for total N and total P and then summing the daily average for each year to obtain total annual loads. Details about AMLE and other procedures used to calculate loads are described in Runkel et al. (2004) and in Cohn et al. (1992).

Method used to evaluate trends through time

After computing loads, to evaluate whether a monotonic trend is detectable and if so, whether it is increasing or decreasing, requires the application of statistical correlation methods. Correlation tests the hypothesis that increasing values of one variable are positively or negatively related to values of another variable or not related at all (i.e., no correlation). In the case of loads or concentrations, time trends are evaluated by looking at the relationship between time (year) and load or concentration. The relationship is tested using a rank correlation technique suited to small sample sizes: the Spearman rho correlation coefficient (Conover 1980). A perfect positive correlation (successively increasing rank values of time with increasing rank values of loads or concentrations) would be 1 (i.e., the resulting line defined by the time and load/concentration values would have a slope of 1); a perfect negative correlation would be successively decreasing rank values of load or concentration with successively increasing rank values of time would be -1 (the line would have a slope of -1). A less than perfect positive or negative relation between the time and load or concentration values, but with slopes greater or lesser than 0, would be a decimal fraction between 0 and 1 for a positive correlation or a decimal fraction between 0 and -1 for a negative correlation. A perfect lack of correlation would be 0: either the points would have no linear relation and appear scattered between the time and load/concentration axis or the load/concentration data would be constant through time (i.e., no trend) with the line having a slope of 0.

Whether a correlation is significant or not is determined statistically by the relative slope of the line and the number of sample pairs. Often a significance level of 5%, or conversely a 95% confidence level, is considered the minimum level to be used to determine whether a correlation is significant or not. The slope magnitude necessary to be considered significant at 5% for the particular number of sample pairs can be found in significance tables for the Spearman correlation coefficient in texts such as Conover (1980). For this assessment, a slope of at least 0.59 or -0.59, for 12 sample pairs is required to be significant at the 5% level.

Although daily or monthly data require consideration of seasonal or cyclic variability and appropriate adjustments for what is referred to as serial correlation (Helsel and Hirsch, 1993), no such adjustments are needed for annual load and streamflow data shown for this assessment. Except for trends reported by Harned et al. (2009), who did use methods to correct for seasonality, only annual flow, load or concentration was used in the analysis presented for new data in this assessment. This approach yields information on annual load and concentration, represented by a single load or concentration value. The annual load used in this assessment is the sum of the daily loads estimated using LOADEST. Confidence intervals for these estimates are possible using the daily load information from the LOADEST program, but are not shown. The annual concentration is simply computed by dividing the total annual load by the total annual volume of water.

Data Quality Caveats: Although much seasonal information is lost using this approach and is certainly important, annual information yields simple understandable information on major annual trends without requiring additional statistical seasonal adjustment procedures.

The Data Gap: Only streams and river segments from the Neuse River basin were used to compute annual loads for this report, leaving out loading estimates for the other basins that represent the other 90% of the region, including the Tar-Pamlico, Roanoke, Chowan, and Pasquotank. Data sets from both USGS and NCDWQ for approximately 30 other streams are being processed by USGS, but were unavailable for this reporting period. Although thousands of daily samples were processed for each of the streams, only annual total loads, yields, and concentrations are shown. Therefore, the data for this report are only adequate for analyzing annual phenomena.

Data Availability: Stream loads for this assessment are based on chemical data collected and analyzed by NCDWQ or USGS. Most of the nutrient samples collected for watersheds draining the North Carolina portion of Albemarle-Pamlico region are included in the State's Ambient Monitoring System <http://portal.ncdenr.org/web/wq/ess/eco/ams> and stream flow data collected by USGS (websites cited above for North Carolina and Virginia).

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TECHNICAL NOTES: SUSPENDED SEDIMENT

The Indicator

- Suspended sediment load (mass) and yield (mass per land area).
- Turbidity (percent > 50 NTU)

The Data

Data Manipulation: Where significant trends were reported as detected, these trends are significant at the 5% significance level.

Data Quality Caveats: Method differences between total suspended solids and suspended sediment concentration can account for differences observed between data precision and accuracy associated with each parameter. Making comparisons and assessments with mixed data must be done with care on a river by river basis.

The Data Gap: Total suspended solids data are collected at North Carolina Division of Water Quality's (NCDWQ's) Ambient Monitoring System stations in most areas of the Albemarle-Pamlico region.

Data Availability: All data or information presented for this assessment were collected and analyzed by either US Geological Survey (USGS) or NCDWQ. Data collected for suspended sediment by USGS are available from the USGS NWIS data base <http://waterdata.usgs.gov/nc/nwis/>. Data for both flow and water quality can be retrieved from this site. Data collected by NCDWQ for suspended solids (considered equivalent to suspended sediment for this assessment) are available from EPA's STORET data base <http://www.epa.gov/storet/>. Details about specific stations and methods of data collection for NCDWQ's Ambient Monitoring System can be obtained at <http://portal.ncdenr.org/web/wq/ess/eco/ams>.
All methods for data collected and analyzed by USGS are presented in Harned et al. (1995) and Harned et al. (2010). Information on turbidity presented by NCDWQ is available at <http://portal.ncdenr.org/c/document_library/get_file?uuid=5ffb1b6b-2c54-46f4-ae78-882d1ced281a&groupId=38364>.

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