Environmental Assessment of the Lower Cape Fear River System, 2021

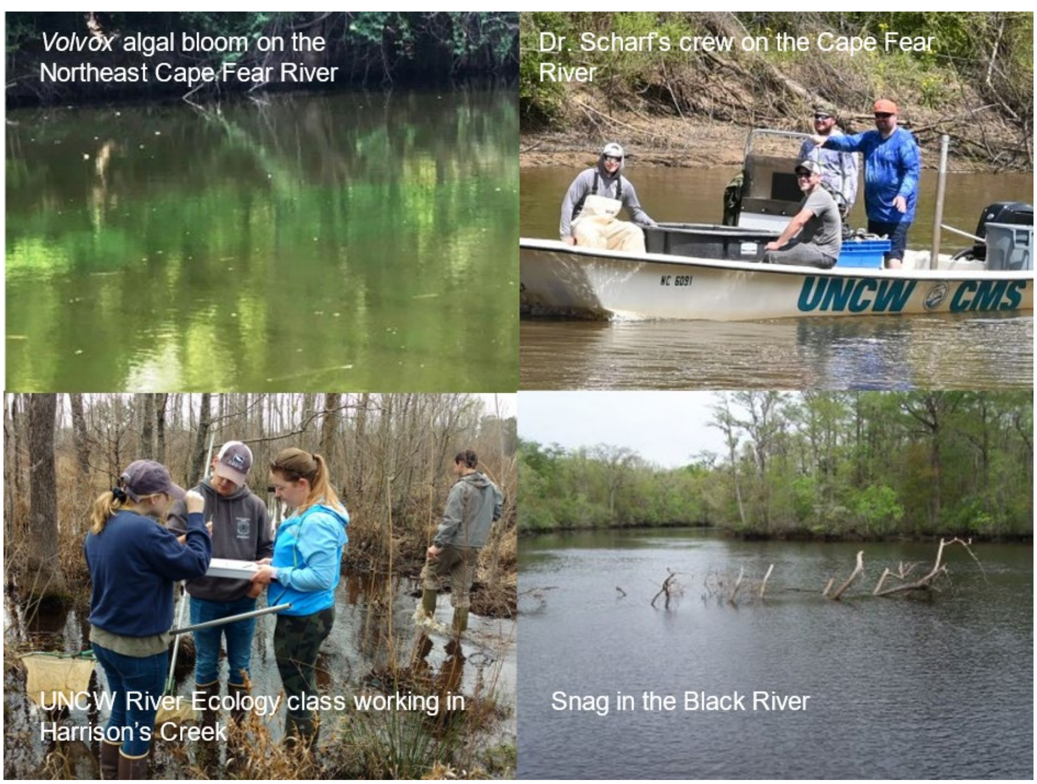
By

Michael A. Mallin, Matthew R. McIver, Colleen N. Brown and James F. Merritt

November 2022

CMS Report No. 22-02

Center for Marine Science
University of North Carolina Wilmington
Wilmington, N.C. 28409



Executive Summary

Background – Multi-parameter water quality sampling for the Lower Cape Fear River Program (LCFRP) http://www.uncw.edu/cms/aelab/LCFRP/index.htm, has been ongoing since June 1995. Scientists from the University of North Carolina Wilmington's (UNCW) Aquatic Ecology Laboratory perform the sampling effort. The LCFRP currently encompasses 32 water sampling stations throughout the lower Cape Fear, Black, and Northeast Cape Fear River watersheds (Table 1.1; Fig. 1.1). The LCFRP sampling program includes physical, chemical, and biological water quality measurements and analyses of the benthic and epibenthic macroinvertebrate communities, and has in the past included assessment of the fish communities. Principal conclusions of the UNCW researchers conducting these analyses are presented below, with emphasis on water quality of the period January - December 2021. The opinions expressed are those of UNCW scientists and do not necessarily reflect viewpoints of individual contributors to the Lower Cape Fear River Program.

The mainstem lower Cape Fear River is a 6^{th} order stream characterized by periodically turbid water containing moderate to high levels of inorganic nutrients. It is fed by two large 5^{th} order blackwater rivers (the Black and Northeast Cape Fear Rivers – Fig. 1.1) that have low levels of turbidity, but highly colored water with less inorganic nutrient content than the mainstem. While nutrients are reasonably high in the river channels, major algal blooms are normally rare because light is attenuated by water color or turbidity, and flushing in the estuary is usually high (Ensign et al. 2004). During periods of low flow algal biomass as chlorophyll *a* increases in the Cape Fear River because lower flow causes settling of more solids and improves light conditions for algal growth. Periodically major algal blooms are seen in the tributary stream stations, some of which are impacted by point source discharges. Below some point sources, nutrient loading can be high and fecal coliform contamination occurs. Other stream stations drain blackwater swamps or agricultural areas (traditional agriculture and/or industrialized animal production), and some sites periodically show elevated pollutant loads or effects (Mallin et al. 2015). This region has been hit by hurricanes several times in the past three decades and such storms have a marked impact on water quality and organisms.

GenX Issues - During the past four years there has been considerable controversy in the lower Cape Fear River watershed regarding a family of manufactured chemical compounds popularly known as GenX. To briefly summarize, DuPont constructed a facility known as Fayetteville Works near the river downstream of Fayetteville, where it manufactured fluoropolymers since 1971. DuPont manufactured a chemical called PFOA at Fayetteville Works beginning in 2001 and later stopped its manufacture due to health concerns surrounding this chemical. They then developed a substitute chemical called GenX, which they began manufacturing there, along with GenX's parent compound, called HFPO-DA fluoride. Both compounds hydrolize in water to a third compound called HFPO-DA, CAS; the toxicity of this group of chemicals is unclear. Subsequently, DuPont spun-off a company called Chemours, which assumed plant operations in 2015. In the past few years researchers from US EPA, North Carolina State University, and the University of North Carolina Wilmington have found HFPO-DA and related fluoroethers (which tend to be lumped under the blanket term GenX) in river water, river sediments, well water near the plant, in air samples, aquatic organism tissue, bird tissue, and in finished drinking water at the Wilmington water treatment facility, which obtains its water near Lock and Dam #1. Fayetteville Works says they have stopped the GenX discharge, and in 2019 built a thermal oxidizer to heat waste gases and reduce >99% of the chemicals from escaping; however these chemicals are still found in river water that enters the Cape Fear Public Utility Authority water treatment plant (which in 2022 had to increase its level of treatment in an effort to reduce these chemicals in Wilmington drinking water). Legal actions have been initiated against the company from a number of stakeholders to provide financial compensation for the pollution and for installation of pollution-reduction equipment. Sampling and analysis of GenX and related compounds is outside of the purview of the scientific staff of the Lower Cape Fear River Program and will not be discussed in this report.

Summary of water quality data results from 2021

Year after year there is a dissolved oxygen sag in the main river channel that begins at Station DP below a paper mill discharge and near the Black River input, and persists into the mesohaline portion of the estuary. Mean oxygen levels are highest at the upper river stations NC11 and ANC and in the low-to-middle estuary at stations M35 to M18 (Fig. 1.1). Lowest mainstem mean DO levels normally occur at the river and upper estuary stations NAV, HB, BRR and M61. The Northeast Cape Fear and Black Rivers are classified as blackwater systems because of their tea colored water. The Northeast Cape Fear and Black Rivers generally have lower DO levels than the mainstem Cape Fear River.

In 2021 GS (Goshen Swamp) was below standard 33% of occasions samples; SR 25% of the time, ANC (Angola Creek) and NCF6 (both on the Northeast Cape Fear River) were below standard on two sampling occasions. All of the other stream stations were below standard less than 10% of the time. Considering all sites sampled in 2021, we rated 3% as poor for dissolved oxygen, 16% as fair, and 81% as good.

Annual mean turbidity levels for 2021 were lower than the long-term average at all stations. Highest mean riverine turbidities (11-12 NTU) were at NC11-DP (Fig. 1.1) with turbidities generally low in the middle to lower estuary. The estuarine stations only exceeded standard in February 2021. Turbidity was considerably lower in the Northeast Cape Fear River and Black River than in the mainstem river. Turbidity levels were low in the freshwater streams, with all streams rated as good for 2021. Suspended solids were generally low except at NC11 and AC, the upper river sites.

Average chlorophyll *a* concentrations across most sites were low in 2021. The standard of 40 µg/L was not exceeded. There were several small blooms, mainly at GS and PB (Panther Branch). We note the highest chlorophyll *a* levels in the river and estuary typically occur late spring to late summer. Nuisance cyanobacterial blooms did not occur in the river and upper estuary in 2021. For the 2021 period UNCW rated 100% of the stations as good in terms of chlorophyll *a*.

Fecal bacteria counts in the estuary and at many of the stream stations were elevated in 2021. Sites with the highest counts in general were Goshen Swamp (GS), PB (Panther Branch), HAM (Hammond Creek), ROC (Rockfish Creek), NC403 (uppermost Northeast Cape Fear River site),LRC (Little Rockfish Creek, Angola Creek (ANC) and Sarecta (SAR). However, the main river and estuary sites were generally in good condition in 2021. For bacterial water quality overall, 16% of the sites rated as poor, 13% as fair, and 71% as good.

In addition, according to our experimentally-derived key concentrations, excessive nitrate and phosphorus concentrations were problematic at a number of stations. Sites with high nutrient concentrations included point-source locations NC403, PB and ROC and non-point locations 6RC (Six Runs Creek) and GCO (Great Coharie Creek).

A 20-year analysis of nutrient changes found that nitrate, total nitrogen and total phosphorus concentrations significantly increased in stream sites mainly in the Black and Northeast Cape Fear River basins; some sites had very high N and P concentrations as well. Note that the stations primarily drained watersheds that either had small or no sewage treatment plants, but contain numerous swine CAFOs, as well as a considerable number of poultry CAFOs. The mainstem Cape Fear River downstream of Lock and Dam#1 did not show such increases, and actually showed long-term decreases in orthophosphate. The pollutant showing the most widespread increases was fecal coliform bacteria, which increased in the blackwater areas but also in the main Cape Fear River stions from NC11 downstream to the upper estuary.

Table of Contents

1.0 Introduction

Michael A. Mallin
Aquatic Ecology Laboratory
Center for Marine Science
University of North Carolina Wilmington

The Lower Cape Fear River Program (LCFRP) is a unique science and education program that has a mission to develop an understanding of processes that control and influence the ecology of the Cape Fear River, and to provide a mechanism for information exchange and public education. This program provides a forum for dialogue among the various Cape Fear River user groups and encourages interaction among them. Overall policy is set by an Advisory Board consisting of representatives from citizen's groups, local government, industries, academia, the business community, and regulatory agencies. This report represents the scientific conclusions of the UNCW researchers participating in this program and does not necessarily reflect opinions of all other program participants. This report focuses on the period January through December 2021.

The scientific basis of the LCFRP consists of the implementation of an ongoing comprehensive physical, chemical, and biological monitoring program. Another part of the mission is to develop and maintain a data base on the Cape Fear basin and make use of this data to develop management plans. Presently the program has amassed a 27-year (1995-2021) data base that is available to the public, and is used as a teaching tool. Using this monitoring data as a framework the program goals also include focused scientific projects and investigation of pollution episodes. The scientific aspects of the program are carried out by investigators from the University of North Carolina Wilmington Center for Marine Science. The monitoring program was developed by the Lower Cape Fear River Program Technical Committee, which consists of representatives from UNCW, the North Carolina Division of Environmental Quality, The NC Division of Marine Fisheries, the US Army Corps of Engineers, technical representatives from streamside industries, the Cape Fear Public Utility Authority, Cape Fear Community College, Cape Fear River Watch, the North Carolina Cooperative Extension Service, the US Geological Survey, forestry and agriculture organizations, and others. This integrated and cooperative program was the first of its kind in North Carolina. The physical, chemical and biological data are state-certified and submitted to the US EPA.

Broad-scale monthly water quality sampling at 16 stations in the estuary and lower river system began in June 1995 (UNCW Aquatic Ecology Laboratory, directed by Dr. Michael Mallin). Sampling was increased to 34 stations in February of 1996, 35 stations in February 1998, and 36 stations in 2005, then lowered to 33 in 2011; currently it stands at 32 water quality stations. The Lower Cape Fear River Program added another component concerned with studying the benthic macrofauna of the system in 1996. This component is directed by Dr. Martin Posey and Mr. Troy Alphin of the

UNCW Biology Department and includes the benefit of additional data collected by the Benthic Ecology Laboratory under various grant-funded projects in the Cape Fear Estuary. These data are collected and analyzed depending upon the availability of funding. The third major biotic component (added in January 1996) was an extensive fisheries program directed by Dr. Mary Moser of the UNCW Center for Marine Science Research, with subsequent (1999) overseeing by Mr. Michael Williams and Dr. Thomas Lankford of UNCW-CMS. This program involved cooperative sampling with the North Carolina Division of Marine Fisheries and the North Carolina Wildlife Resources Commission. The fisheries program ended in December 1999, but was renewed with additional funds from the Z. Smith Reynolds Foundation from spring – winter 2000, then ceased.

1.1. Site Description

The mainstem of the Cape Fear River is formed by the merging of the Haw and the Deep Rivers in Chatham County in the North Carolina Piedmont. However, its drainage basin reaches as far upstream as the Greensboro area (Fig. 1.1). The mainstem of the river has been altered by the construction of several dams and water control structures. In the Coastal Plain, the river is joined by two major tributaries, the Black and the Northeast Cape Fear Rivers (Fig. 1.1). These 5th order blackwater streams drain extensive riverine swamp forests and add organic color to the mainstem. The watershed (about 9,164 square miles) is the most heavily industrialized in North Carolina with 203 permitted wastewater discharges with a permitted flow of approximately 429 million gallons per day, and (as of 2010) over 2.07 million people residing in the basin (NCDENR Basinwide Information Management System (BIMS) & 2010 Census). Approximately 23% of the land use in the watershed is devoted to agriculture and livestock production (2006 National Land Cover Dataset), with livestock production dominated by swine and poultry operations. Thus, the watershed receives considerable point and non-point source loading of pollutants. However, the estuary is a well-flushed system, with flushing time ranging from 1 to 22 days with a median flushing time of about seven days, much shorter than the other large N.C. estuaries to the north (Ensign et al. 2004).

Water quality is monitored by boat at eight stations in the Cape Fear Estuary (from Navassa to Southport) and one station in the Northeast Cape Fear Estuary (Table 1.1; Fig. 1.1). We note that after July 2011 sampling was discontinued at estuarine stations M42 and SPD, per agreement with the North Carolina Division of Water Quality; and in 2012 sampling was expanded at Smith Creek at the Castle Hayne Road bridge (Table 1.1) and initiated at a new site along the South River (SR-WC). Riverine stations sampled by boat include NC11, AC, DP, IC, and BBT (Table 1.1; Fig. 1.1). NC11 is located upstream of any major point source discharges in the lower river and estuary system, and is considered to be representative of water quality entering the lower system (we note that the City of Wilmington and portions of Brunswick County get their drinking water from the river just upstream of Lock and Dam #1). Station BBT is located on the Black River between Thoroughfare (a stream connecting the Cape Fear and Black Rivers) and the mainstem Cape Fear, and is influenced by both rivers. We consider B210 and NCF117 to represent water quality entering the lower Black and Northeast Cape Fear Rivers, respectively. Data has also been collected at stream and river stations throughout the Cape Fear, Northeast Cape Fear, and Black River watersheds (Table 1.1; Fig. 1.1; Mallin et al. 2001).

1.2. Report Organization

Section 1 of this report provides a summary and introduction, and Section 2 of this report presents a detailed overview of physical, chemical, and biological water quality data from the 32 individual stations, and provides tables of raw data as well as figures showing spatial or temporal trends. LCFRP data are freely available to the public. The LCFRP has a website that contains maps and an extensive amount of past water quality, benthos, and fisheries data gathered by the Program available at: www.uncw.edu/cms/aelab/LCFRP/. Additionally, there is an on-line data base. http://lcfrp.uncw.edu/riverdatabase/. Section 3 provides a long term analysis of concerning increases in nutrients, chlorophyll *a* and fecal coliform bacteria in the Black and Northeast Cape fear watersheds.

References Cited

Ensign, S.H., J.N. Halls and M.A. Mallin. 2004. Application of digital bathymetry data in an analysis of flushing times of two North Carolina estuaries. *Computers and Geosciences* 30:501-511.

Mallin, M.A., S.H. Ensign, M.R. McIver, G.C. Shank and P.K. Fowler. 2001. Demographic, landscape, and meteorological factors controlling the microbial pollution of coastal waters. *Hydrobiologia* 460:185-193.

Table 1.1 Description of sampling locations for the Lower Cape Fear River Program, 2021.

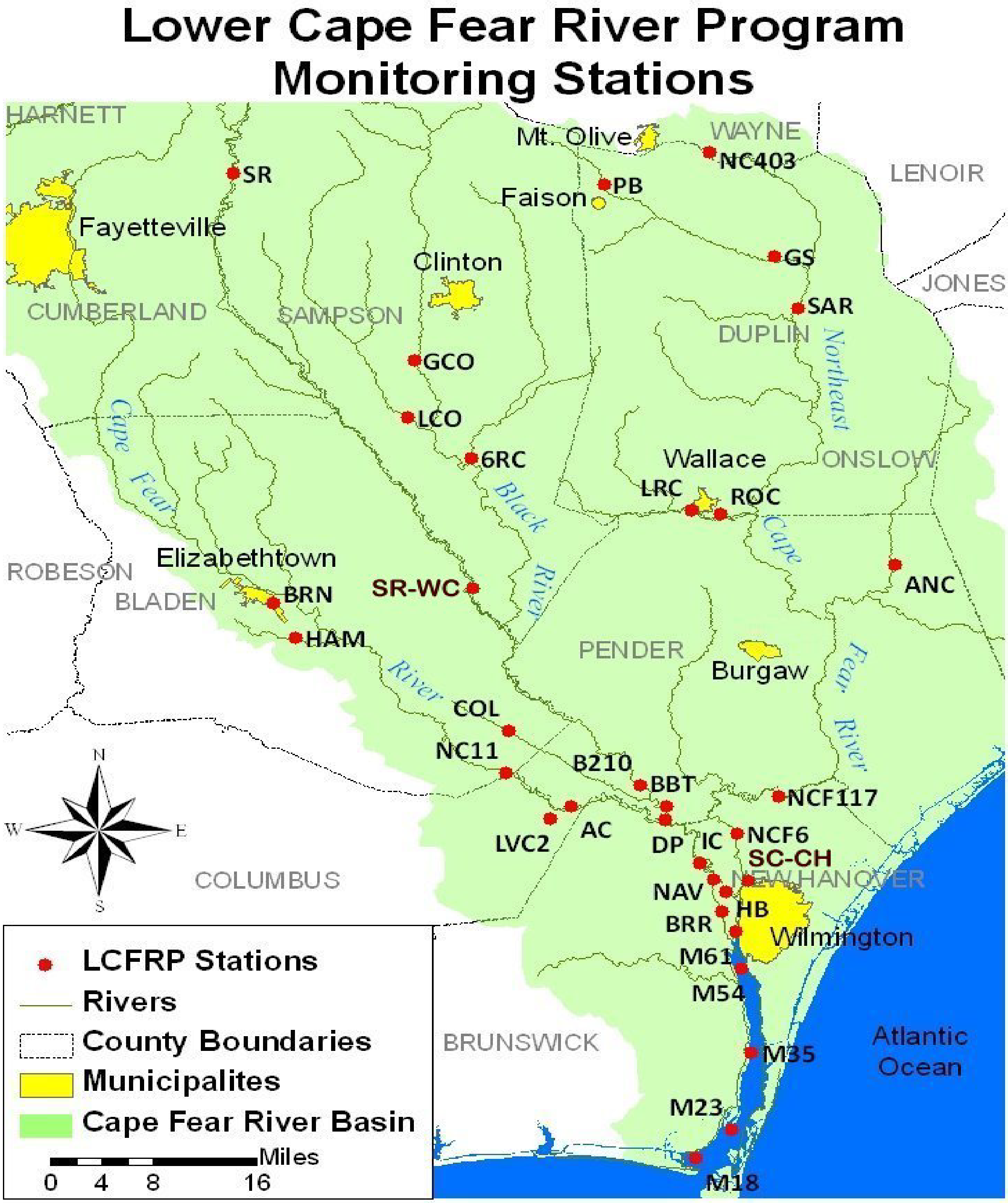
Collected by Boat

AEL Station	DWR Station #	Description	Comments	County	Lat	Lon	Stream Class.	HUC
NC11	B8360000	Cape Fear River at NC 11 nr East Arcadia	Below Lock and Dam 1, Represents water entering lower basin	Bladen	34.3969	-78.2675	WS-IV Sw	03030005
AC	B8450000	Cape Fear River at Neils Eddy Landing nr Acme	1 mile below IP, DWR ambient station	Columbus	34.3555	-78.1794	C Sw	03030005
DP	B8465000	Cape Fear River at Intake nr Hooper Hill	AT DAK intake, just above confluence with Black R.	Brunswick	34.3358	-78.0534	C Sw	03030005
BBT		Black River below Lyons Thorofare	UNCW AEL station	Pender	34.3513	-78.0490	C Sw ORW+	0303005
IC	B9030000	Cape Fear River ups Indian Creek nr Phoenix	Downstream of several point source discharges	Brunswick	34.3021	-78.0137	C Sw	0303005
NAV	B9050025	Cape Fear River dns of RR bridge at Navassa	Downstream of several point source discharges	Brunswick	34.2594	-77.9877	SC	0303005
HB	B9050100	Cape Fear River at S. end of Horseshoe Bend nr Wilmington	Upstream of confluence with NE Cape Fear River	Brunswick	34.2437	-77.9698	SC	0303005
BRR	B9790000	Brunswick River dns NC 17 at park nr Belville	Near Belville discharge	Brunswick	34.2214	-77.9787	SC	03030005
M61	B9800000	Cape Fear River at Channel Marker 61 at Wilmington	Downstream of several point source discharges	New Hanover	34.1938	-77.9573	SC	03030005
M54	B9795000	Cape Fear River at Channel Marker 54	Downstream of several point source discharges	New Hanover	34.1393	-77.946	SC	03030005
M35	B9850100	Cape Fear River at Channel Marker 35	Upstream of Carolina Beach discharge	Brunswick	34.0335	-77.937	SC	03030005
M23	B9910000	Cape Fear River at Channel Marker 23	Downstream of Carolina Beach discharge	Brunswick	33.9456	-77.9696	SA HQW	03030005
M18	B9921000	Cape Fear River at Channel Marker 18	Near mouth of Cape Fear River	Brunswick	33.913	-78.017	SC	03030005
NCF6	B9670000	NE Cape Fear nr Wrightsboro	Downstream of several point source discharges	New Hanover	34.3171	-77.9538	C Sw	0303007

Collected by Land

AEL Station	DWR Station #	Description	Comments	County	Lat	Lon	Stream Class.	HUC
6RC	B8740000	Six Runs Creek at SR 1003 nr Ingold	Upstream of Black River, CAFOs in watershed	Sampson	34.7933	-78.3113	C Sw ORW+	03030006
LCO	B8610001	Little Coharie Creek at SR 1207 nr Ingold	Upstream of Great Coharie, CAFOs in watershed	Sampson	34.8347	-78.3709	C Sw	03030006
GCO	B8604000	Great Coharie Creek at SR 1214 nr Butler Crossroads	Downstream of Clinton, CAFOs in watershed	Sampson	34.9186	-78.3887	C Sw	03030006
SR	B8470000	South River at US 13 nr Cooper	Downstream of Dunn	Sampson	35.156	-78.6401	C Sw	03030006
BRN	B8340050	Browns Creek at NC87 nr Elizabethtown	CAFOs in watershed	Bladen	34.6136	-78.5848	C	03030005
HAM	B8340200	Hammond Creek at SR 1704 nr Mt. Olive	CAFOs in watershed	Bladen	34.5685	-78.5515	C	03030005
COL	B8981000	Colly Creek at NC 53 at Colly	Pristine area	Bladen	34.4641	-78.2569	C Sw	03030006
B210	B9000000	Black River at NC 210 at Still Bluff	1st bridge upstream of Cape Fear River	Pender	34.4312	-78.1441	C Sw ORW+	03030006
NC403	B9090000	NE Cape Fear River at NC 403 nr Williams	Downstream of Mt. Olive Pickle, CAFOs in watershed	Duplin	35.1784	-77.9807	C Sw	0303007
PB	B9130000	Panther Branch (Creek) nr Faison	Downstream of Bay Valley Foods	Duplin	35.1345	-78.1363	C Sw	0303007
GS	B9191000	Goshen Swamp at NC 11 and NC 903 nr Kornegay	CAFOs in watershed	Duplin	35.0281	-77.8516	C Sw	0303007
SAR	B9191500	NE Cape Fear River SR 1700 nr Sarecta	Downstream of several point source discharges	Duplin	34.9801	-77.8622	C Sw	0303007
ROC	B9430000	Rockfish Creek at US 117 nr Wallace	Upstream of Wallace discharge	Duplin	34.7168	-77.9795	C Sw	0303007
LRC	B9460000	Little Rockfish Creek at NC 11 nr Wallace	DWR Benthic station	Duplin	34.7224	-77.9814	C Sw	0303007
ANC	B9490000	Angola Creek at NC 53 nr Maple Hill	DWR Benthic station	Pender	34.6562	-77.7351	C Sw	0303007
SR WC	B8920000	South River at SR 1007 (Wildcat/Ennis Bridge Road)	Upstream of Black River	Sampson	34.6402	-78.3116	C Sw ORW+	03030006
NCF117	B9580000	NE Cape Fear River at US 117 at Castle Hayne	DWR ambient station, Downstream of point source discharges	New Hanover	34.3637	-77.8965	B Sw	0303007
SC-CH	B9720000	Smith Creek at US 117 and NC 133 at Wilmington	Urban runoff, Downstream of Wilmington Northside WWTP	New Hanover	34.2586	-77.9391	C Sw	0303007

Figure 1.1. Map of the Lower Cape Fear River system and the LCFRP sampling stations.



2.0 Physical, Chemical, and Biological Characteristics of the Lower Cape Fear River and Estuary

2.1 - Introduction

This section of the report includes a discussion of the physical, chemical, and biological water quality parameters, concentrating on the January-December 2021 Lower Cape Fear River Program monitoring period. These parameters are interdependent and define the overall condition of the river. Physical parameters measured during this study included water temperature, dissolved oxygen, field turbidity and laboratory turbidity, total suspended solids (TSS), salinity, conductivity, pH and light attenuation. The chemical makeup of the Cape Fear River was investigated by measuring the magnitude and composition of nitrogen and phosphorus in the water, and metals as requested by NCDEQ. Selected biological parameters including fecal coliform bacteria (in freshwater) or *Enterococcus* bacteria (in the estuary) and chlorophyll *a* were examined.

2.2 - Materials and Methods

Samples and field parameters collected for the estuarine stations of the Cape Fear River (NAV down through M18) were gathered (when possible) on an ebb tide. This was done so that the data better represented the river water flowing downstream through the system rather than the tidal influx of coastal ocean water. Sample collection and analyses were conducted according to the procedures in the Lower Cape Fear River Program Quality Assurance/Quality Control (QA/QC) manual. Technical Representatives from the LCFRP Technical Committee and representatives from the NC Division of Environmental Quality inspect UNCW laboratory procedures and periodically accompany field teams to verify proper procedures are followed. By agreement with N.C. Division of Environmental Quality, changes have periodically occurred in the sampling regime. Station SC-CH (lower Smith Creek) was added October 2004; sampling was discontinued at Stations M42 and SPD (June 2011); sampling at Stations BCRR and BC117 was discontinued (December 2012); sampling was added at Station SR-WC on the South River (March 2013); and sampling was discontinued at Station LVC2 (July 2015). Special sampling for dissolved metals was initiated at selected stations by NCDEQ in 2015 and is ongoing.

<u>Physical Parameters</u>

Water Temperature, pH, Dissolved Oxygen, Turbidity, Light, Salinity, Conductivity

Field parameters other than light attenuation were measured at each site using a YSI EXO3 or YSI Pro D55. Each parameter is measured with individual probes on the sonde. At stations sampled by boat (see Table 1.1) physical parameters were measured at 0.1 m and at the bottom (up to 12 m); only surface data are reported within. Occasionally, high flow prohibited the sonde from reaching the actual bottom and measurements were taken as deep as possible. At the terrestrially sampled stations (i.e. from bridges or docks) the physical parameters were measured at a depth of 0.1 m. The Aquatic Ecology Laboratory at the UNCW CMS is State-certified by the N.C. Division of Environmental Quality to perform field parameter measurements. The light attenuation coefficient *k* was determined from data collected on-site using vertical profiles obtained by a Li-Cor LI-1000 integrator interfaced with a Li-Cor LI-193S spherical quantum sensor.

Chemical Parameters

Nutrients

A local State-certified analytical laboratory was contracted to conduct all chemical analyses except for orthophosphate, which is performed at CMS. The following methods detail the techniques used by CMS personnel for orthophosphate analysis.

Orthophosphate (PO_4^{-3})

Water samples were collected about 0.1 m below the surface in triplicate in amber 125 mL Nalgene plastic bottles and placed on ice. In the laboratory 50 mL (or 25 mL if turbid) of each triplicate was filtered through separate1.0 micron pre-combusted glass fiber filters, which were frozen and later analyzed for chlorophyll *a*. The triplicate filtrates were pooled in a glass flask, mixed thoroughly, and approximately 100 mL was poured into a 125 mL plastic bottle to be analyzed for orthophosphate. Samples were frozen until analysis.

Orthophosphate analyses were performed in duplicate using an approved US EPA method for the Bran-Lubbe AutoAnalyzer (Method 365.5). In this technique the orthophosphate in each sample reacts with ammonium molybdate and anitmony potassium tartrate in an acidic medium (sulfuric acid) to form an anitmony-phospho-molybdate complex. The complex is then reacted with ascorbic acid and forms a deep blue color. The intensity of the color is measured at a wavelength of 880 nm by a colorimeter and displayed on a chart recorder. Standards and spiked samples were analyzed for quality assurance.

Biological Parameters

Fecal Coliform Bacteria / Enterococcus

Fecal coliform bacteria were analyzed by a State-certified laboratory contracted by the LCFRP. Samples were collected approximately 0.1 m below the surface in sterile plastic bottles provided by the contract laboratory and placed on ice for no more than eight hours before analysis. After August 2011 the fecal coliform analysis was changed to *Enterococcus* bacteria in the estuarine stations downstream of NAV and HB (Stations BRR, M61, M35, M23 and M18).

Chlorophyll a

The analytical method used to measure chlorophyll *a* is described in Welschmeyer (1994) and US EPA (1997) and was performed by UNCW Aquatic Ecology Laboratory personnel. Chlorophyll *a* concentrations were determined utilizing the 1.0 micron filters used for filtering samples for orthophosphate analysis. All filters were wrapped individually in foil, placed in airtight containers and stored in the freezer. During analysis each filter was immersed in 10 mL of 90% acetone for 24 hours, which extracts the chlorophyll *a* into solution. Chlorophyll *a* concentration of each solution was measured on a Turner 10-AU fluorometer. The fluorometer uses an optimal combination of excitation and emission bandwidth filters which reduces the errors inherent in the acidification technique. The Aquatic Ecology Laboratory at the CMS is State-certified by the N.C. Division of Environmental Quality for the analysis of chlorophyll *a* (chlorophyll at three LCFRP stations are required by NCDEQ to be analyzed by state-certified methods); the rest of the large amount of chlorophyll a data presented here were not State-certified. The Aquatic Ecology Laboratory also participates in the chlorophyll *a* round robin laboratory comparisons when offered by NCDEQ.

Biochemical Oxygen Demand (BOD)

Five sites were originally chosen for BOD analysis. One site was located at NC11, upstream of International Paper, and a second site was at AC, about 3 miles downstream of International Paper (Fig.1.1). Two sites were located in blackwater rivers (NCF117 and B210) and one site (BBT) was situated in an area influenced by both the mainstem Cape Fear River and the Black River. For the sampling period May 2000-April 2004 additional BOD data were collected at stream stations 6RC, LCO, GCO, BRN, HAM and COL in the Cape Fear and Black River watersheds. In May 2004 those stations were dropped and sampling commenced at ANC, SAR, GS, N403, ROC and BC117 in the Northeast Cape Fear River watershed for several years. BOD analysis was stopped in August 2015 due to insufficient funding; previous BOD results are published (Mallin et al. 2006).

Parameter	***Method***	***NC DEQ Certified***
Water Temperature	SM 2550B-2000	Yes
Dissolved Oxygen	SM 4500O G-2001	Yes
pH	SM 4500 H+B-2011	Yes
Specific Conductivity	SM 2510 B-2011	Yes
Lab Turbidity	SM 2130 B-2001	Yes
Field Turbidity	SM 2130 B-2001	No
Chlorophyll *a*	EPA 445.0 Rev. 1.2	Yes
Biochemical Oxygen Demand	SM 5210 B-2001	No

Parameter	***Method***	***NC DEQ Certified***
Total Nitrogen	By addition	
Nitrate + Nitrite	EPA 353.2 Rev 2.0 1993	Yes
Total Kjeldahl Nitrogen	EPA 351.2 Rev 2.0 1993	Yes

Ammonia Nitrogen	EPA 350.1 Rev 2.0 1993	Yes
Total Phosphorus	SM 4500 PF-2012	Yes
Orthophosphate	EPA 365.5	No
Fecal Coliform	SM 9222 D-1997	Yes
Enterococcus	Enterolert IDEXX	Yes

2.3 - Results and Discussion

This section includes results from monitoring of the physical, biological, and chemical parameters at all stations for the time period January-December 2021. Discussion of the data focuses both on the river channel stations and stream stations, which sometimes reflect poorer water quality than the channel stations. The contributions of the two large blackwater tributaries, the Northeast Cape Fear River and the Black River, are represented by conditions at NCF117 and B210, respectively. The Cape Fear region was not impacted by hurricanes in 2021.

Physical Parameters

Water temperature

Water temperatures at all stations ranged from 5.8 to 29.9°C, and individual station annual averages ranged from 17.2 to 20.2°C (Table 2.1). Highest temperatures occurred during July and lowest temperatures during December. Stream stations were generally cooler than river stations, most likely because of shading and lower nighttime air temperatures affecting the shallower waters.

Salinity

Salinity at the estuarine stations (NAV through M18; also NCF6 in the Northeast Cape Fear River) ranged from 0.0 to 33.9 practical salinity units (psu) and station annual means ranged from 1.7 to 25.3 psu (Table 2.2). Lowest salinities occurred in spring and early summer of 2021 and highest in fall. The annual mean salinities for 2021 were similar to the twenty-six year average for 1995-2020 (Figure 2.1). Two stream stations, NC403 and PB, had occasional oligohaline conditions due to discharges from pickle production facilities. SC-CH is a blackwater tidal creek that enters the Northeast Cape Fear River just upstream of Wilmington and salinity there ranged from 0.0 to 7.0 psu.

Conductivity

Conductivity at the estuarine stations ranged from 0.08 to 51.53 mS/cm and from 0.05 to 4.37 mS/cm at the freshwater stations (Table 2.3). Temporal conductivity patterns followed those of salinity. Dissolved ionic compounds increase the conductance of water, therefore, conductance increases and decreases with salinity, often reflecting river flow conditions due to rainfall. Stations PB and NC403 are below industrial discharges, and often have elevated conductivity. Smith Creek (SC-CH) is an estuarine tidal creek and the conductivity values reflect this (Table 2.3).

pH

System pH values ranged from 3.7 to 8.0 and station annual means ranged from 4.2 (at COL) to 7.8 (Table 2.4). pH was typically lowest upstream due to acidic swamp water inputs and highest downstream as alkaline seawater mixes with the river water. Low pH values at COL predominate because of naturally acidic blackwater inputs in this wetland-rich rural watershed.

Dissolved Oxygen

Dissolved oxygen (DO) problems have long been a major water quality concern in the lower Cape Fear River and its estuary, and several of the tributary streams. There is an annual dissolved oxygen sag in the main river channel that begins at DP below a paper mill discharge and persists into the mesohaline portion of the estuary (Fig. 2.2). Working synergistically to lower oxygen levels are two factors: lower oxygen carrying capacity in warmer water and increased bacterial respiration (or biochemical oxygen demand, BOD), due to higher temperatures in summer. Unlike other large North Carolina estuaries (the Neuse, Pamlico and New River) the Cape Fear estuary rarely suffers from dissolved oxygen stratification. This is because, despite salinity stratification, the oxygen remains well mixed due to strong estuarine gravitational circulation and high freshwater inputs (Lin et al. 2006). Thus, hypoxia in the Cape Fear is present throughout the water column. Surface concentrations for all sites in 2021 ranged from 1.6 to 11.8 mg/L (both at GS) and station annual means ranged from 5.6 to 9.6 mg/L (Table 2.5). Overall, average dissolved oxygen levels for 2021 were similar to the long-term average (Fig. 2.2). River dissolved oxygen levels were low during the summer and early fall (Table 2.5), occasionally falling below the state standard of 5.0 mg/L at several river and upper estuary stations.

NAV, IC, HB, M61 and BRR were below 5.0 mg/L from 8-17% of occasions sampled. Based on number of occasions the river and estuary stations were below 5 mg/L dissolved oxygen UNCW rated NCF6 and and M61 as fair for 2021; the other estuary stations were rated as good. On a year-to-year basis, discharge of BOD waste from the paper/pulp mill just above the AC station, as well as inflow of blackwater from the Northeast Cape Fear and Black Rivers, helps to decrease oxygen in the lower river and upper estuary. Additionally, algal blooms periodically form behind Lock and Dam #1 (including the blue-green algal blooms from 2009-2012), and the chlorophyll *a* they produce is strongly correlated with BOD at Station NC11 (Mallin et al. 2006); thus algal blooms do contribute to lower DO in the river. As the water reaches the lower estuary higher algal productivity, mixing and ocean dilution help alleviate oxygen problems.

Most tributary stations were rated fair or good in 2021, except GS which was rated poor and ANC, SR and SC-CH which were rated fair (Table 2.5). Some hypoxia can be attributed to low summer water conditions and some potentially to CAFO runoff; however point-source discharges also possibly contribute to low dissolved oxygen levels at SR. Hypoxia is thus a continuing problem but improved with only 19% of stations impacted compared to 34% of the sites impacted in 2020.

Field Turbidity

Field turbidity levels ranged from 0 to 90 Nephelometric turbidity units (NTU) and station annual means ranged from 1 to 16 NTU (Table 2.6). The State standard for estuarine turbidity is 25 NTU, and for freshwater streams 50 NTU (for lakes and reservoirs it is 25 NTU). Highest mean turbidities were at the upper river sites NC11-DP (11-12 NTU), with turbidities generally low in the middle to lower estuary (Figure 2.3). The estuarine stations only exceeded standard in February 2021. For the stream stations ANC measured 82 NTU in May and LCO measured 90 in June. As in the previous year, mean turbidity levels for 2021 were well below the long-term average at all estuary sites (Fig. 2.3). Turbidity was considerably lower in the blackwater tributaries (Northeast Cape Fear River and Black River) than in the mainstem river. Average turbidity levels were low in the freshwater streams.

Note: In addition to the laboratory-analyzed turbidity that are required by NCDEQ for seven locations, the LCFRP uses nephelometers designed for field use, which allows us to acquire in situ turbidity from a natural situation. North Carolina regulatory agencies are required to use turbidity values from water samples removed from the natural system, put on ice until arrival at a State-certified laboratory, and analyzed using laboratory nephelometers. Standard Methods (APHA 1995) notes that transport of samples and temperature change alters true turbidity readings. Our analysis of samples using both methods shows that lab turbidity is nearly always lower than field turbidity; thus we do not discuss lab turbidity in this report.

Total Suspended Solids (TSS)

An altered monitoring plan was developed for the LCFRP in September 2011. These changes were suggested by the NC Division of Environmental Quality (then DWQ). NCDEQ suggested the LCFRP stop monitoring TSS at Stations ANC, GS, 6RC, LCO, SR, BRN, HAM, COL, SR-WC and monitor turbidity instead. DWQ believed turbidity would be more useful than TSS in evaluating water quality at these stations because there are water quality standards for turbidity. TSS is used by the NCDEQ NPDES Unit to evaluate discharges. No LCFRP subscribers discharge near these sites.

Total suspended solid (TSS) values system wide ranged from 1.3 to 52.2 mg/L with station annual means from 1.9 to 22.6 mg/L (Table 2.7). The overall highest river values were at NC11, DP and AC (especially in February and March), with higher values downstream through the estuary. In the stream stations TSS was generally considerably lower than the river and estuary. Although total suspended solids (TSS) and turbidity both quantify suspended material in the water column, they do not always go hand in hand. High TSS does not mean high turbidity and vice versa. This anomaly may be explained by the fact that fine clay particles are effective at dispersing light and causing high turbidity readings, while not resulting in high TSS. On the other hand, large organic or inorganic particles may be less effective at dispersing light, yet their greater mass results in high TSS levels. While there is no NC ambient standard for TSS, many years of data from the lower Cape Fear watershed indicates that 25 mg/L can be considered elevated (reached on several occasions in the river and estuary in 2021). The fine silt and clay in the upper to middle estuary sediments are most likely derived from the Piedmont and carried downstream to the estuary, while the sediments in the lowest portion of the estuary are marine-derived sands (Benedetti et al. 2006).

Light Attenuation

Due to instrumentation problems light attenuation values will not be reported for 2021.

<u>Chemical Parameters – Nutrients</u>

Total Nitrogen

Total nitrogen (TN) is calculated from TKN (see below) plus nitrate; it is not analyzed in the laboratory. TN ranged from 50 (detection limit) to 10,800 μg/L (at ROC) and station annual means ranged from 778 to 3,861 μg/L (at ROC; Table 2.8). Previous research (Mallin et al. 1999) has shown a positive correlation between river flow and TN in the Cape Fear system. In the main river total nitrogen concentrations were highest at NC11, then declining into the lower estuary, most likely reflecting uptake of nitrogen into the food chain through algal productivity and subsequent grazing by planktivores as well as through dilution and marsh denitrification. The highest median TN value at the stream stations was at ROC with 2,025 μg/L; other sites with elevated TN were NC403, ANC, 6RC, GS and LRC.

Nitrate+Nitrite

Nitrate+nitrite (henceforth referred to as nitrate) is the main species of inorganic nitrogen in the Lower Cape Fear River. Concentrations system wide ranged from 10 (detection limit) to 8,510 μg/L (at ROC) and station annual means ranged from 66 to 2,278 μg/L (at ROC; Table 2.9). The highest average riverine nitrate levels were at NC11 through DP (314-521 μg/L) indicating that much of this nutrient is imported from upstream. Moving downstream, nitrate levels decrease most likely as a result of uptake by primary producers, microbial denitrification in riparian marshes and tidal dilution. Despite this, the rapid flushing of the estuary (Ensign et al. 2004) permits sufficient nitrate to enter the coastal ocean in the plume and contribute to offshore productivity (Mallin et al. 2005). Nitrate can limit phytoplankton production in the lower estuary in summer (Mallin et al. 1999). The blackwater rivers carried lower concentrations of nitrate compared to the mainstem Cape Fear stations; i.e. the Northeast Cape Fear River (NCF117 mean = 78 μg/L) and the Black River (B210 = 277 μg/L). Lowest river nitrate occurred during August-September. In general, the 2021 nitrate concentrations were mixed compared with the long term average, with some sites higher and some sites lower (Fig. 2.4).

Several stream stations showed high levels of nitrate on occasion including NC403, ROC, 6RC, LCO and GCO. LCO, GCO and 6RC primarily receive non-point agricultural or animal waste drainage, while point sources a well as non-point contribute to ROC (1.5 MGD), NC403 (1.0 MGD) and PB (0.5 MGD). In general, the stream stations showed elevated nitrate in late winter and early spring. A considerable number of experiments have been carried out by UNCW researchers to assess the effects of nutrient additions to water collected from blackwater streams and rivers (i.e. the Black and Northeast Cape Fear Rivers, and Colly and Great Coharie Creeks). These experiments have collectively found that additions of nitrogen (as either nitrate, ammonium, or urea) significantly stimulate phytoplankton production and BOD increases. Critical levels of these dissolved nutrients were in the range of 200 to 500 µg-N/L (Mallin et al. 2004; Mallin and Cahoon 2020). Thus, we conservatively consider nitrate concentrations exceeding 500 µg-N/L in Cape Fear watershed streams to be potentially problematic to stream environmental health.

Ammonium/ammonia

Ammonium concentrations ranged from 10 (detection limit) to 1,400 µg/L (at ROC) and station annual means ranged from 33 to 260 µg/L (at ROC, Table 2.11). River areas with the highest mean ammonium levels this monitoring period included AC and DP, which are downstream of a pulp mill discharge, and M54, M23 and M18 in the mid-to-lower estuary. At the stream stations Colly Creek (COL) showed one occasion of excessive ammonium, 900 µg/L in May 2021 (Table 2.10). This station is in a wetland-rich watershed that has a low level of human development. Most previous years have showed generally low levels of ammonium; however, beginning in 2005 a few unusual peaks began to occur, which increased in magnitude and frequency after 2012, particularly in 2016, 2017 and 2018. We do not have a solid explanation for this increase in ammonium. We are aware that White Lake, located in the upper Colly Creek watershed has had problems with eutrophication (NC DEQ 2017), with nearby upper groundwater and surface runoff showing elevated nutrient concentrations (especially ammonium; potentially from failing local sewage infrastructure in the densely-developed area immediately surrounding the lake). General nutrient concentrations in the lake increased over time as well (NCDEQ 2017; Shank and Zamora 2019). Thus, possibly ammonium-rich drainage from this area has made its way down to the COL station. Additional areas with periodic elevated ammonium in 2021 included ROC and ANC (Table 2.11).

Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is a measure of the total concentration of organic nitrogen plus ammonium. TKN ranged from 50 (detection limit) to 3650 µg/L (at B210) and station annual means ranged from 650 to 1,591 µg/L (Table 2.11). TKN concentration decreases ocean-ward through the estuary, likely due to ocean dilution and food chain uptake of nitrogen. Stations with highest median concentrations included COL, ANC and ROC. As with ammonium, upper groundwater in the White Lake drainage contained high TKN (NC DEQ 2017), some of which may have gone downstream.

Total Phosphorus

Total phosphorus (TP) concentrations ranged from 10 (detection limit) to 1,520 μg/L (at ROC) and station annual means ranged from 102 to 717 μg/L (ROC; Table 2.12). For the mainstem and upper estuary, average TP for 2021 was considerably higher than the 1995-2020 average (Figure 2.5).

The experiments discussed above in the nitrate subsection also involved additions of phosphorus, either as inorganic orthophosphate or a combination of inorganic plus organic P. The experiments showed that additions of P exceeding 500 µg/L led to significant increases in bacterial counts, as well as significant increases in BOD over control. Thus, we consider concentrations of phosphorus above 500 μg/L to be potentially problematic to blackwater streams (Mallin et al. 2004; Mallin and Cahoon 2020). Streams frequently exceeding this critical concentration included GCO and ROC. NC403, PB, SR-WC, and BRN each yielded two values exceeding 500 μg/L. Stations NC403, PB and ROC are downstream of wastewater discharges, while ROC, GCO and BRN are in non-point agricultural areas (note that ROC also has a CAFO-rich watershed).

Orthophosphate

Orthophosphate ranged from 5 to 2,050 μg/L (at LRC) and station annual means ranged from 11 to 396 μg/L (Table 2.13). Much of the main river orthophosphate load is imported into the Lower Cape Fear system from upstream areas, as NC11 or AC typically have high levels; there are also inputs of orthophosphate from the paper mill above AC (Table 2.14. Orthophosphate can bind to suspended materials and is transported downstream via particle attachment; thus high levels of turbidity at the uppermost river stations may be an important factor in the high orthophosphate levels. Turbidity declines toward the lower estuary because of settling, and orthophosphate concentration also declines. In the estuary, primary productivity helps reduce orthophosphate concentrations by assimilation into biomass. Orthophosphate levels typically reach maximum concentrations during summertime, when anoxic sediment releases bound phosphorus. Also, in the Cape Fear Estuary, summer algal productivity is limited by nitrogen, thereby allowing the accumulation of orthophosphate (Mallin et al. 1999). In spring, productivity in the estuary is usually limited by phosphorus (Mallin et al. 1999).

ROC, LRC and GCO had the highest stream station orthophosphate concentrations. All of those sites are in mainly non-point source areas.

<u>Chemical Parameters - EPA Priority Pollutant Metals</u>

The LCFRP had previously sampled for water column metals (EPA Priority Pollutant Metals) on a bimonthly basis. However, as of 2007 this requirement was suspended by the NC Division of Water Quality and these data are no longer regularly collected by the LCFRP. Revised metals sampling (dissolved, not total metals) was re-initiated in late 2015 and has continued periodically upon request from NCDEQ. Results showed that for stations M35 and M23, concentrations of As, Cd, Cr, Cu, Pb, Ni and Zn were below detection limits on all sampling occasions. Iron (Fe) concentrations were measurable but not at harmful levels. M35 and M23 were previously on the 303(d) list being impaired for Copper Arsenic and Nickel. The DWR determined that these sites could be de-listed using the new dissolved metals criteria.

There were two metals samples collected in December 2018 at IC and NAV, with no unusual or adversely high concentrations. Samples were also collected at those two sites in June and December 2019. Most metals were below detection limits. Mercury at IC was 3.39 ng/L in June and 2.39 ng/L in December, and Hg at NAV was 2.79 in December 2019. Zinc was 0.012 µg/L at IC in December 2019. Metals were not collected in 2020. In May and September 2021 metals sampling was performed at IC and NAV. All metals were below the detection limit except for Hg, which ranged from 2.49 to 2.76 ng/L at IC, and from 0.624 to 2.39 mg/L at NAV.

<u>Biological Parameters</u>

Chlorophyll a

During this monitoring period, chlorophyll *a* was low in the river and estuary locations (Table 2.14). The state standard was not exceeded in the river or estuary samples in 2021, and the highest was 25 µg/L at M35 in July. We note that at the upper site NC11 it has been demonstrated that chlorophyll *a* biomass is significantly correlated with biochemical oxygen demand (BOD5 – Mallin et al. 2006). Multiple statistical approaches demonstrated that chlorophyll *a* near Lock and Dam #1 is strongly associated with nitrate generated upstream about 100 km, in an area of point source dischargers downstream of Fayetteville (Saul et al. 2019). System wide, chlorophyll *a* ranged from undetectable to 38 µg/L, and station annual means ranged from 1-12 µg/L. Production of chlorophyll *a* biomass is usually low to moderate in the rivers and estuary primarily because of light limitation by turbidity in the mainstem (Dubbs and Whalen 2008) and high organic color and low inorganic nutrients in the blackwater tributary rivers.

Spatially, along the river mainstem highest values are normally found in the mid-to-lower estuary stations because light becomes more available downstream of the estuarine turbidity maximum (Fig. 2.6). On average, flushing time of the Cape Fear estuary is rapid, ranging from 1-22 days with a median of 6.7 days (Ensign et al. 2004). This does not allow for much settling of suspended materials, leading to light limitation of phytoplankton production. However, under lower-than-average flows there is generally clearer water because of less suspended material and less blackwater swamp inputs. We note that there were a series of problematic cyanobacterial (blue-green algae) blooms of *Microcyctis aeruginosa* on the mainstem river in summers of 2009-2012 (Isaacs et al. 2014). Such blooms have not recurred in recent years.

Phytoplankton blooms occasionally occur at the stream stations, with a few minor blooms occurring at various months in 2021 (Table 2.14). These streams are generally shallow, so vertical mixing does not carry phytoplankton cells down below the critical depth where respiration exceeds photosynthesis. In areas where the forest canopy opens up large blooms can occur. When blooms occur in blackwater streams they can become sources of BOD upon death and decay, reducing further the low summer dissolved oxygen conditions common to these waters (Mallin et al. 2004; 2015; Mallin and Cahoon 2020). No stream station bloom exceeding the state standard of 40 µg/L were recorded, but lesser blooms occurred on occasion at GS, PB, and SR (Table 2.15).

Biochemical Oxygen Demand

Beginning in 2015 samples for BOD5 and BOD20 are no longer collected for the program due to insufficient funds.

Fecal Coliform Bacteria/ Enterococcus bacteria

Fecal coliform (FC) bacterial counts ranged from 5 to 7,500 CFU/100 mL and station annual geometric means ranged from 11 to 352 CFU/100 mL (Table 2.16). The state human contact standard (200 CFU/100 mL) was not exceeded in the mainstem river in 2021 (Table 2.16). During 2021 some stream stations showed elevated fecal coliform pollution levels. HAM and PB reached or exceeded 200 CFU/100 mL 50% of the time sampled, GS exceeded 42% of the time; NC403 and LRC 33% of the time, and SAR and ROC 25% of the time sampled. NC403 and PB are located below point source discharges and the other sites are primarily influenced by non-point source pollution. Beginning in 2015 but especially in 2017 COL had a number of unusually high fecal coliform counts; but counts had only one exceedence of the standard in 2021.

Enterococcus counts were initiated in the estuary in mid-2011, as this test is now the standard used by North Carolina regulators for swimming in salt waters. Sites covered by this test include BRR, M61, M54, M35, M23 and M18. The State has a single-sample level for Tier II swimming areas in which the enterococci level in a Tier II swimming area shall not exceed a single sample of 276 enterococci per 100 milliliters of water (15A NCAC 18A .3402); the LCFRP is using this standard for the Cape Fear estuary samples in our rating system. As such, in 2021 this standard was exceeded in the estuary samples once only, at M23. Geometric mean enterococci counts for 2021 were lower than those of the 2012-2020 period for the lower Cape Fear Estuary (Fig. 2.7). Overall, elevated fecal coliform and *Enterococcus* counts are problematic in this system, with 29% of the stations rated as fair or poor in 2021.

2.4 - References Cited

APHA. 1995. Standard Methods for the Examination of Water and Wastewater, 19th ed. American Public Health Association, Washington, D.C.

Benedetti, M.M., M.J. Raber, M.S. Smith and L.A. Leonard. 2006. Mineralogical indicators of alluvial sediment sources in the Cape Fear River basin, North Carolina. *Physical Geography* 27:258-281.

Dubbs, L. L. and S.C. Whalen. 2008. Light-nutrient influences on biomass, photosynthetic potential and composition of suspended algal assemblages in the middle Cape Fear River, USA. *International Review of Hydrobiology* 93:711-730.

Ensign, S.H., J.N. Halls and M.A. Mallin. 2004. Application of digital bathymetry data in an analysis of flushing times of two North Carolina estuaries. *Computers and Geosciences* 30:501-511.

Isaacs, J.D., W.K. Strangman, M.A. Mallin, M.R. McIver, and J.L.C. Wright. 2014. Microcystins and two new micropeptin cyanopeptides produced by unprecedented *Microcystis aeruginosa* blooms in North Carolina's Cape Fear River. *Harmful Algae* 31:82-86.

Lin, J. L. Xie, L.J. Pietrafesa, J. Shen, M.A. Mallin and M.J. Durako. 2006. Dissolved oxygen stratification in two microtidal partially-mixed estuaries. *Estuarine, Coastal and Shelf Science.* 70:423-437.

Mallin, M.A. and L.B. Cahoon. 2020. The hidden impacts of phosphorus pollution to streams and rivers. *BioScience.* 70:315-329.

Mallin, M.A., L.B. Cahoon, M.R. McIver, D.C. Parsons and G.C. Shank. 1999. Alternation of factors limiting phytoplankton production in the Cape Fear Estuary. *Estuaries* 22:985-996.

Mallin, M.A., M.R. McIver, S.H. Ensign and L.B. Cahoon. 2004. Photosynthetic and heterotrophic impacts of nutrient loading to blackwater streams. *Ecological Applications* 14:823-838.

Mallin, M.A., L.B. Cahoon and M.J. Durako. 2005. Contrasting food-web support bases for adjoining river-influenced and non-river influenced continental shelf ecosystems. *Estuarine, Coastal and Shelf Science* 62:55-62.

Mallin, M.A., V.L. Johnson, S.H. Ensign and T.A. MacPherson. 2006. Factors contributing to hypoxia in rivers, lakes and streams. *Limnology and Oceanography* 51:690-701.

Mallin, M.A., M.R. McIver, A.R. Robuck and A.K. Dickens. 2015. Industrial swine and poultry production causes chronic nutrient and fecal microbial stream pollution. *Water, Air and Soil Pollution* 226:407, DOI 10.1007/s11270-015-2669-y.

NCDEQ 2017. 2017 White Lake Water Quality Investigation, White Lake, Bladen County (Cape Fear Basin). North Carolina Department of Environmental Quality, Division of Water Resources.

Saul, B., M.G. Hudgens and M.A. Mallin. 2019. Upstream causes of downstream effects. *Journal of the American Statistical Association.* https://doi.org/10.1080/01621459.2019.1574226.

Shank, G.C. and P. Zamora. 2019. Influence of Groundwater Flows and Nutrient Inputs on White Lake Water Quality, Final Report.

U.S. EPA 1997. Methods for the Determination of Chemical Substances in Marine and Estuarine Environmental Matrices, 2nd Ed. EPA/600/R-97/072. National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Welschmeyer, N.A. 1994. Fluorometric analysis of chlorophyll *a* in the presence of chlorophyll *b* and phaeopigments. *Limnology and Oceanography* 39:1985-1993.

Table 2.1 Water temperature (^oC) 2021 at the Lower Cape Fear River Program stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	7.9	7.9	7.9	8.3	8.3	9.0	10.4	10.8
FEB	6.0	6.2	6.4	6.5	6.9	8.0	8.7	9.0
MAR	10.3	10.5	10.7	11.1	11.6	11.0	11.7	11.6
APR	19.8	19.8	19.7	19.8	19.3	18.8	18.8	18.9
MAY	23.1	23.2	23.1	23.2	23.1	23.3	23.1	23.1
JUN	27.3	28.0	27.4	27.0	27.0	27.3	27.2	27.1
JUL	28.9	28.6	29.0	29.4	29.5	29.9	29.3	29.6
AUG	26.1	26.3	26.4	27.2	27.3	27.0	27.4	27.1
SEP	27.9	28.1	28.7	28.0	28.1	28.0	27.8	27.9
OCT	23.5	23.5	23.5	24.3	23.9	24.1	25.3	24.0
NOV	19.7	19.8	20.3	19.7	20.1	19.9	19.8	19.8
DEC	12.5	12.8	13.0	13.3	13.6	12.9	13.2	13.5
mean	**19.4**	**19.6**	**19.7**	**19.8**	**19.9**	**19.9**	**20.2**	**20.2**
std dev	8.2	8.2	8.2	8.1	8.0	7.9	7.6	7.4
median	21.5	21.5	21.7	21.5	21.6	21.6	21.5	21.5
max	28.9	28.6	29.0	29.4	29.5	29.9	29.3	29.6
min	6.0	6.2	6.4	6.5	6.9	8.0	8.7	9.0

	NC11	AC	DP	BBT	IC	NCF6
JAN	7.8	7.9	8.0	8.0	8.3	8.3
FEB	5.8	6.0	6.2	6.2	6.2	
MAR	10.0	10.2	10.4	12.7	11.9	13.4
APR	19.7	19.8	20.1	19.7	19.8	21.1
MAY	22.8	23.1	22.9	23.3	22.9	23.4
JUN	27.5	27.8	27.9	27.3	28.2	27.5
JUL	28.8	28.8	28.0	26.9	27.4	28.3
AUG	28.1	27.8	28.3	26.4	28.7	26.6
SEP	23.3	23.4	23.8	24.2	24.5	24.1
OCT	24.2	24.5	24.0	23.9	24.7	25.8
NOV	15.5	15.6	15.5	15.4	15.8	
DEC	10.7	10.8	11.2	11.6	11.7	12.9
mean	**18.7**	**18.8**	**18.9**	**18.8**	**19.2**	**21.1**
std dev	8.4	8.3	8.2	7.7	8.1	7.1
median	21.3	21.5	21.5	21.5	21.4	23.8
max	28.8	28.8	28.3	27.3	28.7	28.3
min	5.8	6.0	6.2	6.2	6.2	8.3

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	7.8	7.9	8.6	8.9	8.7	9.6	8.8	11.1	11.3
FEB	13.1	13.2	15.1	13.3	13.0	13.1	12.7	8.7	9.5
MAR	15.7	16.9	18.2	16.9	18.0	20.5	17.4	14.8	14.8
APR	17.5	17.5	19.4	16.6	17.6	16.6	16.4	16.3	17.2
MAY	20.5	22.0	17.7	20.3	21.0	22.4	20.0	22.1	22.9
JUN	22.5	23.8	22.7	23.8	23.9	22.7	23.1	26.5	
JUL	23.7	24.3	25.1	26.3	26.1	25.1	24.3	27.1	
AUG	25.8	27.3	26.2	28.6	28.7	31.4	26.5	27.3	29.4
SEP	21.3	20.6	21.9	20.8	19.8	22.1	20.4	23.8	23.3
OCT	16.3	16.6	17.2	17.0	16.0	17.1	18.6	20.6	20.4
NOV	13.3	13.0	11.8	13.3	13.3	15.5	15.1	15.5	
DEC	9.4	7.8	8.0	9.0	7.7	8.7	9.7	12.1	
mean	**17.2**	**17.6**	**17.7**	**17.9**	**17.8**	**18.7**	**17.8**	**18.8**	**18.6**
std dev	5.7	6.3	6.0	6.3	6.5	6.6	5.6	6.6	6.7
median	16.9	17.2	18.0	17.0	17.8	18.8	18.0	18.5	18.8
max	25.8	27.3	26.2	28.6	28.7	31.4	26.5	27.3	29.4
min	7.8	7.8	8.0	8.9	7.7	8.7	8.8	8.7	9.5

	B210	COL	SRWC	6RC	LCO	GCO	SR	BRN	HAM
JAN	8.4	8.9	8.4	9.1	8.5	7.9	8.1	9.1	8.5
FEB	8.5	10.4	9.1	10.8	11.0	11.5	12.3	12.4	12.4
MAR	15.1	15.1	11.3	12.5	12.8	13.2	14.3	14.1	13.8
APR	21.1	20.6	19.6	20.7	20.8	22.0	21.6	19.5	18.9
MAY	25.7	22.9	23.4	23.1	22.9	24.3	27.3	22.9	20.8
JUN	25.2	23.7	25.7	25.7	25.8	26.5	26.6	22.9	21.2
JUL	26.6	26.9	24.5	24.5	24.5	25.3	25.6	25.8	25.1
AUG	25.9	26.1	25.7	25.9	26.3	26.5	27.5	27.0	26.9
SEP	21.3	19.9	26.4	26.4	26.6	27.7	26.8	20.5	20.0
OCT	22.5	21.5	16.3	16.3	16.0	16.2	15.9	21.3	20.6
NOV	12.8	11.3	7.6	7.2	7.2	7.2	7.8	11.0	10.5
DEC									
mean	**19.4**	**18.8**	**18.0**	**18.4**	**18.4**	**18.9**	**19.4**	**18.8**	**18.1**
std dev	7.0	6.4	7.7	7.4	7.5	7.9	7.9	6.1	6.0
median	21.3	20.6	19.6	20.7	20.8	22.0	21.6	20.5	20.0
max	26.6	26.9	26.4	26.4	26.6	27.7	27.5	27.0	26.9
min	8.4	8.9	7.6	7.2	7.2	7.2	7.8	9.1	8.5

Table 2.2 Salinity (psu) 2021 at the Lower Cape Fear River Program estuarine stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18	NCF6	SC-CH
JAN	0.0	0.0	0.0	1.0	1.4	4.5	15.8	19.8	0.1	0.1
FEB	0.0	0.0	0.0	0.1	0.6	4.4	19.6	23.4		0.0
MAR	0.0	0.0	0.0	0.0	0.7	2.7	9.0	9.4	0.0	0.9
APR	0.0	0.2	3.0	7.8	8.4	12.2	17.5	21.3	0.1	0.1
MAY	0.1	0.9	3.3	7.5	9.2	14.1	22.4	26.7	0.9	7.0
JUN	0.1	0.3	1.6	5.3	7.2	13.9	23.3	27.7	0.1	
JUL	0.1	0.1	0.1	2.5	5.8	12.1	27.0	31.7	0.1	
AUG	0.1	0.1	0.1	2.1	3.8	6.5	12.7	15.0	0.0	0.1
SEP	9.9	9.1	9.9	13.2	17.9	24.3	30.0	33.4	0.2	0.3
OCT	0.1	1.0	2.8	9.5	12.1	23.9	25.3	28.0	7.8	6.9
NOV	6.5	11.2	18.6	12.8	21.2	26.0	31.4	33.9		
DEC	7.9	10.8	18.2	13.7	21.8	28.1	32.3	33.7	8.0	
mean	**2.1**	**2.8**	**4.8**	**6.3**	**9.2**	**14.4**	**22.2**	**25.3**	**1.7**	**1.9**
std dev	3.7	4.6	6.9	5.2	7.6	9.1	7.5	7.8	3.3	3.1
median	0.1	0.3	2.2	6.4	7.8	13.1	22.9	27.2	0.1	0.2
max	9.9	11.2	18.6	13.7	21.8	28.1	32.3	33.9	8.0	7.0
min	0.0	0.0	0.0	0.0	0.6	2.7	9.0	9.4	0.0	0.0

Figure 2.1 Mean Salinity at the Lower Cape Fear River Program estuarine stations 1995-2020 versus 2021.

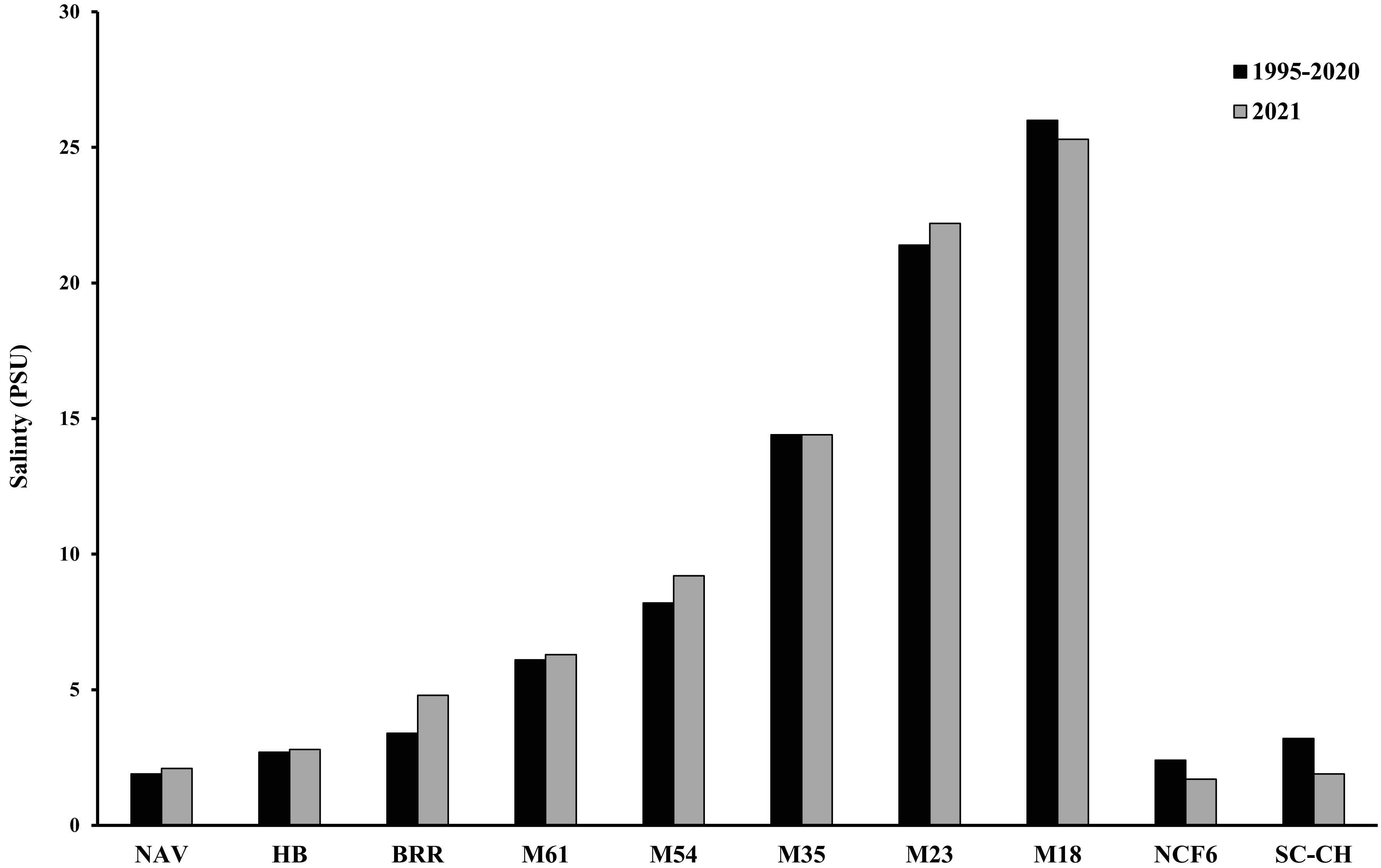


Table 2.3 Conductivity (mS/cm) 2021 at the Lower Cape Fear River Program stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	0.09	0.09	0.09	2.00	2.74	8.13	25.88	31.92
FEB	0.08	0.09	0.09	0.12	1.18	7.99	31.66	37.50
MAR	0.08	0.09	0.09	0.09	1.26	4.96	15.30	16.12
APR	0.14	0.37	5.45	13.25	14.48	20.29	28.36	33.84
MAY	0.16	1.70	6.03	13.04	15.78	23.23	35.40	41.67
JUN	0.26	0.59	3.08	9.57	12.62	23.01	36.84	43.13
JUL	0.12	0.16	0.27	4.69	10.40	20.38	42.63	48.81
AUG	0.11	0.13	0.12	4.00	7.65	11.36	21.27	24.60
SEP	16.94	15.64	16.88	22.02	29.10	38.37	46.35	51.05
OCT	0.17	1.46	5.14	16.25	20.18	27.97	39.61	43.60
NOV	11.38	19.18	29.96	21.20	33.79	40.57	48.03	51.53
DEC	13.25	18.26	29.39	22.62	34.66	43.63	49.48	51.24
mean	**3.57**	**4.81**	**8.05**	**10.74**	**15.32**	**22.49**	**35.07**	**39.58**
std dev	6.32	7.83	11.16	8.56	11.97	13.19	10.90	11.28
median	0.15	0.48	4.11	11.31	13.55	21.70	36.12	42.40
max	16.94	19.18	29.96	22.62	34.66	43.63	49.48	51.53
min	0.08	0.09	0.09	0.09	1.18	4.96	15.30	16.12

	NC11	AC	DP	BBT	IC	NCF6
JAN	0.07	0.09	0.09	0.07	0.08	0.10
FEB	0.08	0.08	0.08	0.08	0.10	
MAR	0.08	0.08	0.08	0.06	0.07	0.07
APR	0.10	0.19	0.14	0.10	0.12	0.13
MAY	0.10	0.22	0.16	0.11	0.13	1.86
JUN	0.12	0.12	0.12	0.10	0.12	0.13
JUL	0.11	0.20	0.16	0.08	0.11	0.13
AUG	0.09	0.09	0.12	0.07	0.10	0.08
SEP	0.09	0.12	0.15	0.12	0.14	0.48
OCT	0.08	0.22	0.14	0.14	0.31	13.61
NOV	0.17	0.22	0.20	0.20	0.67	
DEC	0.17	0.23	0.25	0.18	0.24	13.85
mean	**0.10**	**0.16**	**0.14**	**0.11**	**0.18**	**3.04**
std dev	0.03	0.06	0.05	0.04	0.17	5.66
median	0.10	0.16	0.14	0.10	0.12	0.13
max	0.17	0.23	0.25	0.20	0.67	13.85
min	0.07	0.08	0.08	0.06	0.07	0.07

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	0.07	0.11	0.10	0.28	0.56	0.09	0.09	0.08	0.16
FEB	0.07	0.11	0.10	0.39	0.66	0.08	0.09	0.06	0.07
MAR	0.07	0.12	0.11	0.39	0.94	0.11	0.13	0.12	1.78
APR	0.09	0.13	0.12	0.45	0.46	0.08	0.18	0.11	0.17
MAY	0.20	0.30	0.22	1.29	3.92	0.16	0.36	0.23	12.17
JUN	0.08	0.22	0.19	0.51	1.37	0.12	0.26	0.12	
JUL	0.08	0.12	0.11	0.54	0.64	0.10	0.11	0.12	
AUG	0.09	0.21	0.19	0.72	2.43	0.12	0.16	0.10	0.23
SEP	0.19	0.31	0.24	1.10	4.37	0.12	0.22	0.18	0.56
OCT	0.12	0.30	0.25	0.52	3.89	0.14	0.49	0.25	11.98
NOV	0.18	0.33	0.29	1.30	3.15	0.22	0.57	0.40	
DEC	0.15	0.27	0.28	0.52	0.79	0.15	0.31	0.40	
mean	**0.12**	**0.21**	**0.18**	**0.67**	**1.93**	**0.12**	**0.25**	**0.18**	**3.39**
std dev	0.05	0.09	0.07	0.36	1.52	0.04	0.16	0.12	5.39
median	0.09	0.22	0.19	0.52	1.16	0.12	0.20	0.12	0.40
max	0.20	0.33	0.29	1.30	4.37	0.22	0.57	0.40	12.17
min	0.07	0.11	0.10	0.28	0.46	0.08	0.09	0.06	0.07

	B210	COL	SRWC	6RC	LCO	GCO	SR	BRN	HAM
JAN	0.09	0.05	0.07	0.13	0.10	0.12	0.07	0.10	0.11
FEB	0.05	0.05	0.04	0.09	0.07	0.08	0.05	0.07	0.11
MAR	0.08	0.05	0.06	0.13	0.10	0.12	0.07	0.10	0.16
APR	0.09	0.06	0.07	0.14	0.10	0.16	0.10	0.11	0.10
MAY	0.12	0.05	0.08	0.15	0.12	0.26	0.09	0.13	0.25
JUN	0.09	0.06	0.07	0.14	0.08	0.14	0.08	0.12	0.17
JUL	0.07	0.06	0.05	0.09	0.07	0.08	0.05	0.12	0.20
AUG	0.07	0.06	0.05	0.09	0.08	0.09	0.07	0.11	0.15
SEP	0.10	0.07	0.07	0.16	0.11	0.20	0.09	0.13	0.20
OCT	0.14	0.06	0.09	0.17	0.12	0.39	0.11	0.15	0.23
NOV	0.15	0.06	0.09	0.21	0.13	0.27	0.11	0.15	0.26
DEC									
mean	**0.09**	**0.06**	**0.07**	**0.14**	**0.10**	**0.17**	**0.08**	**0.12**	**0.18**
std dev	0.03	0.01	0.02	0.04	0.02	0.10	0.02	0.02	0.06
median	0.09	0.06	0.07	0.14	0.10	0.14	0.08	0.12	0.17
max	0.15	0.07	0.09	0.21	0.13	0.39	0.11	0.15	0.26
min	0.05	0.05	0.04	0.09	0.07	0.08	0.05	0.07	0.10

Table 2.4 pH 2021 at the Lower Cape Fear River Program stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	6.5	6.6	6.6	6.6	6.8	7.2	7.9	8.0
FEB	6.7	6.8	7.2	7.0	7.5	7.4	8.0	8.0
MAR	6.7	6.7	7.1	6.7	7.0	7.0	7.4	7.3
APR	6.7	6.9	6.9	7.0	7.2	7.5	7.7	7.6
MAY	7.0	6.4	7.0	7.1	7.3	7.7	7.9	7.9
JUN	7.0	7.0	6.9	7.0	7.2	7.6	7.9	7.9
JUL	6.7	6.8	6.9	6.8	7.2	7.8	7.9	7.9
AUG	6.8	6.8	6.6	6.5	6.8	7.1	7.5	7.6
SEP	6.9	7.0	7.3	7.1	7.7	7.9	8.0	7.9
OCT	6.9	7.3	6.9	7.0	7.3	7.5	7.8	7.9
NOV	7.3	7.3	7.5	7.3	7.7	7.9	8.0	8.0
DEC	7.6	7.4	7.7	7.5	8.0	8.0	8.0	7.9
mean	**6.9**	**6.9**	**7.1**	**7.0**	**7.3**	**7.6**	**7.8**	**7.8**
std dev	0.3	0.3	0.3	0.3	0.4	0.3	0.2	0.2
median	6.9	6.9	7.0	7.0	7.3	7.6	7.9	7.9
max	7.6	7.4	7.7	7.5	8.0	8.0	8.0	8.0
min	6.5	6.4	6.6	6.5	6.8	7.0	7.4	7.3

	NC11	AC	DP	BBT	IC	NCF6
JAN	6.6	6.8	6.7	6.3	6.5	6.5
FEB	6.1	6.5	6.7	6.3	6.5	
MAR	6.3	6.5	6.6	6.1	6.3	5.9
APR	6.7	6.8	6.7	6.3	6.6	6.4
MAY	6.7	7.1	6.9	6.6	6.8	6.8
JUN	7.0	7.0	6.9	6.4	6.7	6.3
JUL	6.9	7.0	6.9	6.5	6.7	6.6
AUG	6.5	6.5	6.5	6.1	6.3	6.0
SEP	6.5	6.7	6.7	6.4	6.6	6.4
OCT	6.5	6.8	6.5	6.6	6.6	6.7
NOV	7.7	7.1	7.1	7.1	6.7	
DEC	7.6	7.6	7.9	7.6	7.7	6.7
mean	**6.8**	**6.9**	**6.8**	**6.5**	**6.7**	**6.4**
std dev	0.5	0.3	0.4	0.4	0.4	0.3
median	6.7	6.8	6.7	6.4	6.6	6.5
max	7.7	7.6	7.9	7.6	7.7	6.8
min	6.1	6.5	6.5	6.1	6.3	5.9

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	4.8	6.6	6.8	6.5	6.7	6.7	6.5	6.2	6.8
FEB	6.4	6.8	7.1	6.6	6.7	6.5	6.3	5.5	6.4
MAR	5.6	6.8	7.2	6.6	6.8	7.3	6.8	6.6	6.6
APR	6.1	7.0	7.1	6.6	6.7	6.6	6.9	6.2	6.5
MAY	6.9	7.2	6.9	6.9	6.8	7.8	7.5	7.2	7.4
JUN	5.7	7.2	7.0	7.0	6.9	7.4	7.0	6.3	
JUL	5.1	6.7	6.7	6.7	6.7	7.0	6.8	6.7	
AUG	4.7	6.9	6.7	6.9	7.0	7.4	6.7	6.1	6.8
SEP	7.0	7.4	7.3	7.1	6.8	7.4	7.2	6.8	6.9
OCT	6.6	7.0	6.6	6.8	6.8	7.6	7.5	6.9	6.9
NOV	6.9	7.2	6.7	7.2	6.8	7.6	7.4	7.3	
DEC	6.8	6.7	6.6	6.6	6.6	7.0	6.8	7.1	
mean	**6.1**	**7.0**	**6.9**	**6.8**	**6.8**	**7.2**	**7.0**	**6.6**	**6.8**
std dev	0.9	0.3	0.2	0.2	0.1	0.4	0.4	0.5	0.3
median	6.3	7.0	6.9	6.8	6.8	7.4	6.9	6.7	6.8
max	7.0	7.4	7.3	7.2	7.0	7.8	7.5	7.3	7.4
min	4.7	6.6	6.6	6.5	6.6	6.5	6.3	5.5	6.4

	B210	COL	SRWC	6RC	LCO	GCO	SR	BRN	HAM
JAN	6.0	3.7	5.1	5.9	6.0	6.2	6.3	6.2	6.3
FEB	5.9	4.0	5.7	6.4	6.4	6.7	6.6	6.3	6.7
MAR	6.1	4.1	6.3	6.4	6.5	6.5	6.7	6.4	6.9
APR	6.2	4.0	6.3	7.0	6.8	7.0	6.1	6.5	6.4
MAY	6.8	4.6	6.5	7.0	6.9	7.0	6.7	7.2	7.5
JUN	6.4	4.5	6.6	7.1	6.6	6.8	6.5	7.2	7.0
JUL	6.3	4.2	5.9	6.2	6.0	6.5	6.2	7.0	7.4
AUG	6.2	4.0	5.9	6.3	6.5	6.6	6.5	6.8	7.0
SEP	5.8	4.0	6.3	6.9	6.9	6.9	6.3	7.0	7.2
OCT	6.8	4.3	6.7	7.0	7.0	7.0	6.8	7.0	7.2
NOV	6.5	4.3	6.8	6.7	6.8	6.7	6.4	6.9	6.9
DEC									
mean	**6.3**	**4.2**	**6.2**	**6.6**	**6.6**	**6.7**	**6.5**	**6.8**	**7.0**
std dev	0.3	0.3	0.5	0.4	0.3	0.3	0.2	0.4	0.4
median	6.2	4.1	6.3	6.7	6.6	6.7	6.5	6.9	7.0
max	6.8	4.6	6.8	7.1	7.0	7.0	6.8	7.2	7.5
min	5.8	3.7	5.1	5.9	6.0	6.2	6.1	6.2	6.3

Table 2.5 Dissolved Oxygen (mg/l) 2021 at the Lower Cape Fear River Program stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	10.6	10.7	10.6	10.2	10.2	10.2	9.6	9.4
FEB	11.0	11.0	10.9	10.7	10.6	10.6	9.8	9.6
MAR	**10.3**	10.3	10.3	9.7	9.6	9.5	9.4	9.4
APR	6.9	6.9	6.9	6.8	7.4	7.9	8.2	8.0
MAY	6.1	6.2	6.1	6.3	6.8	7.3	7.4	7.1
JUN	5.6	6.0	5.3	5.3	5.6	6.5	6.7	6.7
JUL	5.4	5.5	5.8	5.6	6.3	7.7	6.3	6.5
AUG	5.1	5.0	4.8	4.4	4.7	5.4	5.5	5.9
SEP	4.2	4.6	5.7	4.8	6.4	7.3	6.9	6.4
OCT	5.9	6.0	5.4	5.4	5.3	5.8	6.3	6.5
NOV	5.7	5.9	6.2	5.9	6.8	7.1	7.2	7.1
DEC	8.2	8.3	8.2	8.4	9.0	8.6	8.5	8.4
mean	**7.1**	**7.2**	**7.2**	**7.0**	**7.4**	**7.8**	**7.7**	**7.6**
std dev	2.4	2.3	2.2	2.2	2.0	1.6	1.4	1.3
median	6.0	6.1	6.2	6.1	6.8	7.5	7.3	7.1
max	11.0	11.0	10.9	10.7	10.6	10.6	9.8	9.6
min	4.2	4.6	4.8	4.4	4.7	5.4	5.5	5.9

	NC11	AC	DP	BBT	IC	NCF6
JAN	11.0	10.8	10.7	10.1	10.1	9.3
FEB	11.7	11.5	11.4	10.5	10.8	
MAR	10.5	10.4	10.3	8.6	9.0	8.3
APR	8.0	7.7	7.4	5.5	6.5	5.8
MAY	7.6	7.3	6.9	5.2	6.2	6.3
JUN	6.7	6.4	6.1	4.4	5.4	3.6
JUL	6.3	5.9	5.5	4.8	5.1	4.4
AUG	6.4	6.0	5.5	4.5	5.0	3.9
SEP	6.0	6.1	6.0	4.9	5.6	4.5
OCT	6.0	5.0	4.8	4.8	4.9	4.8
NOV	8.7	8.3	7.5	7.4	7.4	
DEC	10.6	10.1	9.7	8.5	8.9	8.4
mean	**8.3**	**8.0**	**7.7**	**6.6**	**7.1**	**5.9**
std dev	2.1	2.2	2.3	2.3	2.1	2.1
median	7.8	7.5	7.2	5.4	6.4	5.3
max	11.7	11.5	11.4	10.5	10.8	9.3
min	6.0	5.0	4.8	4.4	4.9	3.6

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	8.4	10.2	11.1	10.2	10.0	10.7	9.4	7.5	8.1
FEB	9.7	9.7	11.8	10.1	9.9	10.2	8.8	9.5	9.8
MAR	7.0	8.1	11.1	9.5	8.7	10.2	8.3	8.2	8.5
APR	7.3	7.9	10.0	9.1	8.6	9.3	8.1	6.9	6.8
MAY	2.5	8.0	3.4	6.4	7.0	9.4	7.7	6.0	6.6
JUN	6.0	7.0	3.7	6.5	6.2	8.3	6.6	4.5	
JUL	4.9	6.2	4.6	5.8	4.9	7.0	5.8	4.3	
AUG	4.5	6.0	1.6	5.8	6.9	8.3	5.5	2.8	3.9
SEP	4.8	8.7	7.8	6.4	4.9	8.5	7.3	4.4	4.5
OCT	2.7	8.5	3.8	6.8	5.8	9.5	6.2	5.5	6.8
NOV	5.0	10.6	4.7	8.3	7.9	12.4	8.2	6.9	
DEC	4.6	9.0	7.6	8.4	8.4	10.9	8.0	7.9	
mean	**5.6**	**8.3**	**6.8**	**7.8**	**7.4**	**9.6**	**7.5**	**6.2**	**6.9**
std dev	2.2	1.5	3.6	1.7	1.8	1.4	1.2	2.0	2.0
median	5.0	8.3	6.2	7.6	7.5	9.5	7.9	6.5	6.8
max	9.7	10.6	11.8	10.2	10.0	12.4	9.4	9.5	9.8
min	2.5	6.0	1.6	5.8	4.9	7.0	5.5	2.8	3.9

	B210	COL	SRWC	6RC	LCO	GCO	SR	BRN	HAM
JAN	9.9	9.0	10.1	10.1	10.1	10.4	10.2	10.5	10.6
FEB	10.2	7.7	9.9	9.1	9.6	9.7	9.7	9.8	9.8
MAR	7.8	7.2	9.8	9.5	9.8	8.7	9.0	9.5	9.4
APR	5.6	5.9	7.5	7.6	7.5	6.7	4.1	8.3	7.4
MAY	6.0	4.7	6.5	6.9	7.6	6.4	6.1	8.5	6.7
JUN	5.3	6.0	6.7	6.6	6.5	6.2	4.7	7.9	5.6
JUL	5.2	5.7	6.1	5.2	5.6	5.8	4.6	7.4	6.5
AUG	5.3	4.9	5.6	4.6	5.6	5.2	3.9	7.1	6.7
SEP	6.0	6.4	6.1	6.2	6.5	6.2	1.9	8.1	7.4
OCT	5.0	6.2	7.9	8.4	8.5	8.2	3.3	7.9	6.3
NOV	8.1	7.1	10.9	11.6	11.3	10.6	6.8	10.0	7.7
DEC									
mean	**6.8**	**6.4**	**7.9**	**7.8**	**8.1**	**7.6**	**5.8**	**8.6**	**7.6**
std dev	1.9	1.3	1.9	2.2	1.9	1.9	2.8	1.1	1.6
median	6.0	6.2	7.5	7.6	7.6	6.7	4.7	8.3	7.4
max	10.2	9.0	10.9	11.6	11.3	10.6	10.2	10.5	10.6
min	5.0	4.7	5.6	4.6	5.6	5.2	1.9	7.1	5.6

Figure 2.2 Mean Dissolved Oxygen at the Lower Cape Fear River Program mainstem stations 1995-2020 versus 2021.

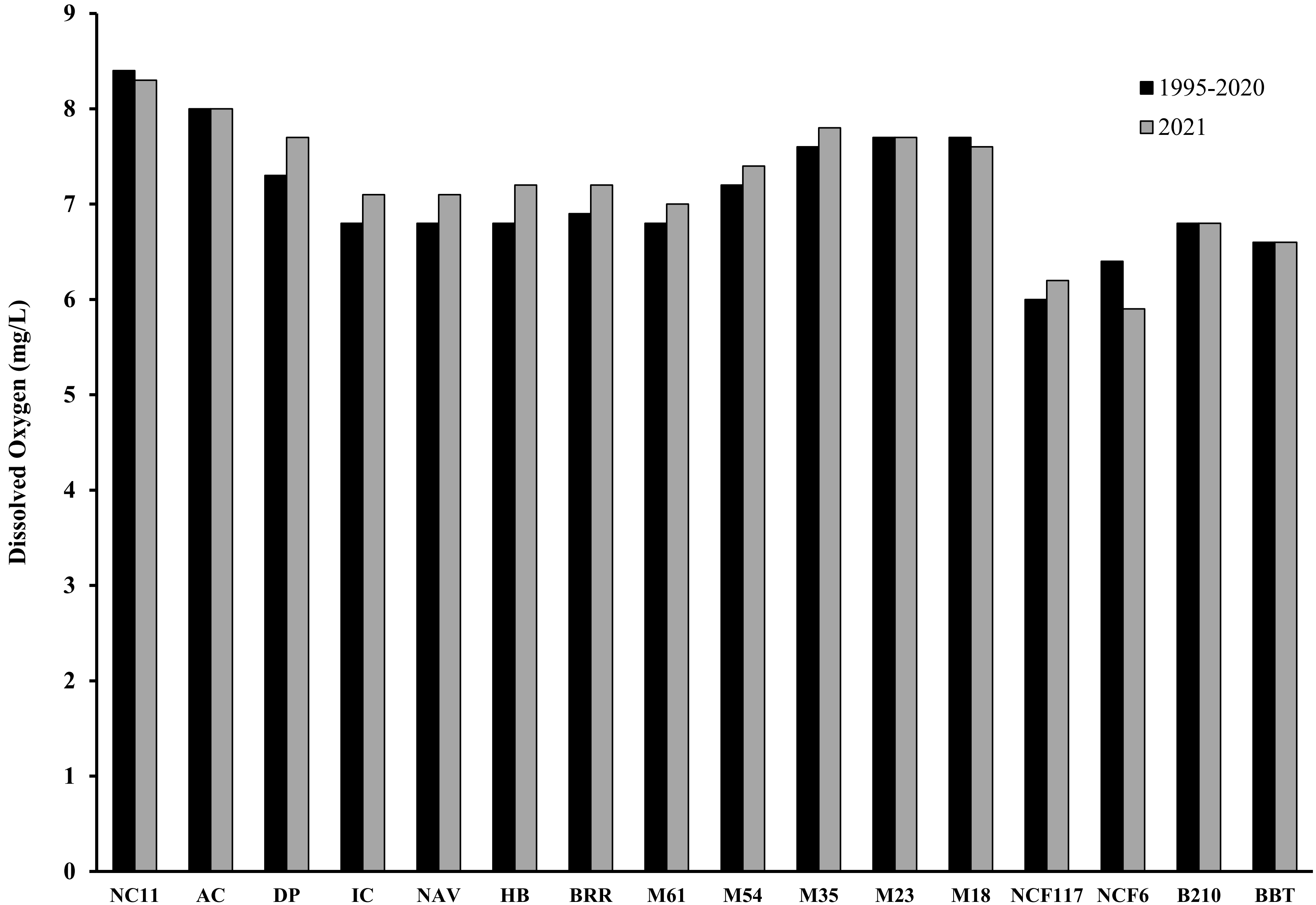


Table 2.6 Field Turbidity (NTU) 2021 at the Lower Cape Fear River Program stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	5	6	5	5	6	5	4	4
FEB	26	23	20	27	36	12	12	10
MAR	14	14	13	12	19	21	9	8
APR	6	7	5	3	3	4	4	4
MAY	8	7	7	6	6	6	6	6
JUN	14	13	8	5	6	6	4	4
JUL	8	9	10	8	6	4	2	4
AUG	9	9	6	3	2	2	1	1
SEP	7	6	4	3	6	2	1	2
OCT	7	8	7	6	5	5	4	4
NOV	11	9	8	7	5	4	6	8
DEC	11	8	11	4	5	9	6	7
mean	**10.5**	**9.9**	**8.7**	**7.4**	**8.8**	**6.7**	**4.9**	**5.2**
std dev	5.7	4.8	4.4	6.7	9.6	5.3	3.2	2.7
median	8.5	8.5	7.5	5.5	6.0	5.0	4.0	4.0
max	26.0	23.0	20.0	27.0	36.0	21.0	12.0	10.0
min	5.0	6.0	4.0	3.0	2.0	2.0	1.0	1.0

	NC11	AC	DP	BBT	IC	NCF6
JAN	11	12	13	5	7	4
FEB	37	36	27	11	17	
MAR	28	30	27	9	15	3
APR	5	7	8	5	6	3
MAY	3	6	7	5	5	5
JUN	8	8	8	3	4	2
JUL	5	8	11	4	7	10
AUG	5	4	4	1	3	2
SEP	14	11	6	1	2	5
OCT	12	12	8	8	6	5
NOV	3	4	5	5	13	
DEC	2	3	4	3	4	5
mean	**11.1**	**11.8**	**10.7**	**5.0**	**7.4**	**4.4**
std dev	10.9	10.5	8.1	3.0	4.9	2.3
median	6.5	8.0	8.0	5.0	6.0	4.5
max	37.0	36.0	27.0	11.0	17.0	10.0
min	2.0	3.0	4.0	1.0	2.0	2.0

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	5	4	4	6	10	5	5	7	6
FEB	3	3	1	3	9	7	4	6	7
MAR	10	4	0	4	7	3	2	3	13
APR	13	2	0	4	10	6	2	4	4
MAY	82	2	2	2	11	4	0	2	4
JUN	27	5	3	2	9	2	7	1	
JUL	16	3	1	3	17	8	10	1	
AUG	17	6	12	2	6	1	4	1	7
SEP	8	1	11	0	11	3	3	2	4
OCT	3	3	6	3	7	4	4	3	7
NOV	6	2	3	1	6	13	3	3	
DEC	6	6	2	5	7	9	6	3	
mean	**16.3**	**3.4**	**3.8**	**2.9**	**9.2**	**5.4**	**4.2**	**3.0**	**6.5**
std dev	21.8	1.6	4.0	1.7	3.1	3.4	2.6	1.9	3.0
median	9.0	3.0	2.5	3.0	9.0	4.5	4.0	3.0	6.5
max	82.0	6.0	12.0	6.0	17.0	13.0	10.0	7.0	13.0
min	3.0	1.0	0.0	0.0	6.0	1.0	0.0	1.0	4.0

	B210	COL	SRWC	6RC	LCO	GCO	SR	BRN	HAM
JAN	2	2	1	6	3	1	4	13	27
FEB	7	4	4	5	3	2	3	10	8
MAR	4	6	0	4	2	0	0	7	2
APR	5	4	1	2	4	3	7	8	12
MAY	2	3	0	1	1	3	1	2	3
JUN	2	3	2	6	90	3	4	2	42
JUL	2	1	3	5	5	0	6	4	3
AUG	2	0	0	2	1	1	5	7	4
SEP	3	1	1	3	1	4	2	2	2
OCT	3	4	2	4	2	3	2	4	3
NOV	3	2	2	2	1	1	1	1	4
DEC									
mean	**3.2**	**2.7**	**1.5**	**3.6**	**10.3**	**1.9**	**3.2**	**5.5**	**10.0**
std dev	1.6	1.7	1.3	1.7	26.5	1.4	2.2	3.9	12.9
median	3.0	3.0	1.0	4.0	2.0	2.0	3.0	4.0	4.0
max	7.0	6.0	4.0	6.0	90.0	4.0	7.0	13.0	42.0
min	2.0	0.0	0.0	1.0	1.0	0.0	0.0	1.0	2.0

Figure 2.3 Mean Field Turbidity at the Lower Cape Fear River Program mainstem stations, 1995-2020 versus 2021.

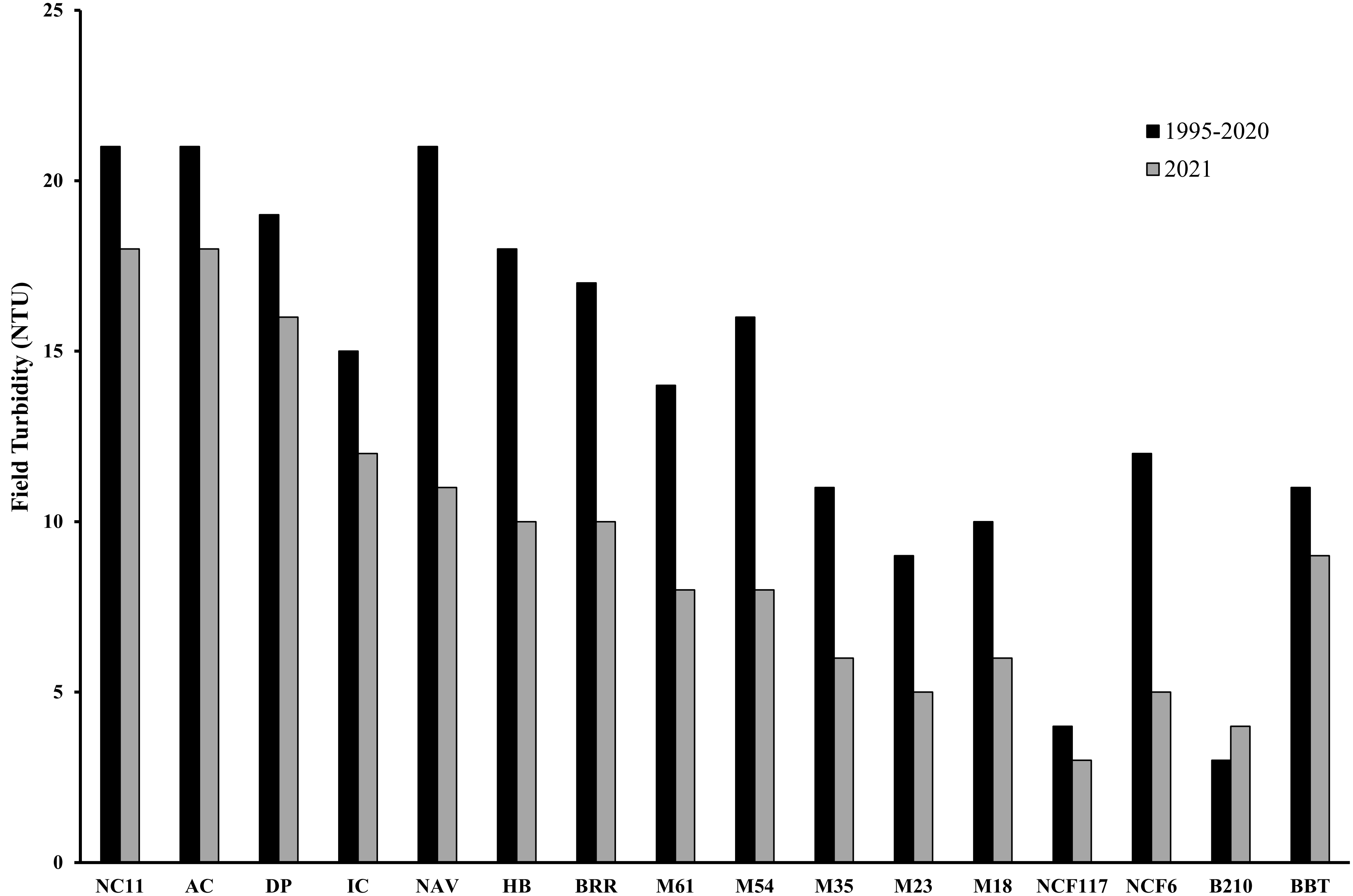


Table 2.7 Total Suspended Solids (mg/L) 2021 at the Lower Cape Fear River Program stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	4.4	5.0	4.5	6.6	8.3	8.9	17.8	18.3
FEB	24.2	16.7	11.8	35.4	52.2	17.0	30.0	32.4
MAR	8.4	13.6	9.6	10.0	22.5	32.7	16.2	12.2
APR	5.9	9.0	8.4	8.1	9.2	11.2	14.2	16.4
MAY	9.9	8.2	10.8	11.4	12.8	22.0	24.2	24.8
JUN	16.0	9.4	10.7	9.9	13.0	16.2	18.3	15.5
JUL	4.8	5.5	8.4	9.8	12.5	13.7	14.5	16.6
AUG	8.9	5.7	6.7	6.5	7.3	7.1	6.3	8.7
SEP	12.5	26.0	12.6	7.4	28.2	19.5	16.1	23.1
OCT	4.5	6.1	6.9	12.6	10.5	13.2	28.8	21.8
NOV	18.4	18.2	29.4	17.4	21.8	11.7	40.8	39.8
DEC	45.0	20.5	24.6	26.3	19.0	47.0	32.6	41.6
mean	**13.6**	**12.0**	**12.0**	**13.5**	**18.1**	**18.4**	**21.7**	**22.6**
std dev	11.7	6.9	7.4	8.9	12.6	11.3	9.7	10.5
median	9.4	9.2	10.2	10.0	12.9	15.0	18.1	20.1
max	45.0	26.0	29.4	35.4	52.2	47.0	40.8	41.6
min	4.4	5.0	4.5	6.5	7.3	7.1	6.3	8.7

	NC11	AC	DP	BBT	IC	NCF6
JAN	10.0	9.6	11.2		4.9	3.1
FEB	46.3	40.8	40.8		17.0	
MAR	27.9	23.7	23.8		11.2	2.5
APR	6.3	7.1	10.9		6.8	1.8
MAY	3.0	5.2	7.5		6.7	13.4
JUN	6.5	8.2	11.2		3.3	3.3
JUL	3.6	6.3	11.0	3.4	9.7	19.0
AUG	2.9	2.5	1.3	1.3	1.3	2.9
SEP	5.1	8.4	5.0	1.3	1.3	10.2
OCT	2.5	1.3	1.3	1.3	3.3	10.8
NOV	1.3	1.3	3.1	3.1	12.6	
DEC	1.3	3.0	3.7	3.9	4.1	10.9
mean	**9.7**	**9.8**	**10.9**	**2.4**	**6.9**	**6.9**
std dev	13.6	11.5	11.3	1.2	4.9	4.9
median	4.4	6.7	9.2	2.2	6.0	5.8
max	46.3	40.8	40.8	1.1	3.7	17.0
min	1.3	1.3	1.3	2.1	5.3	1.3

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN		1.3		7.0	5.0	3.6	2.5	3.7	5.1
FEB		2.5		4.1	7.0	5.5	3.2	3.4	4.2
MAR		5.2		5.1	6.2	2.5	2.7	2.7	19.6
APR		1.3		4.8	5.9	5.1	3.6	4.6	10.0
MAY		19.5		4.0	11.5	5.5	6.2	3.7	8.9
JUN		7.9		4.4	6.3	1.3	1.3	2.9	
JUL		4.6		5.1	10.0	7.9	11.0	1.3	
AUG		8.3		3.4	5.1	1.3	1.3	3.1	6.6
SEP		1.3		2.8	8.9	1.3	2.7	4.8	5.3
OCT		3.2		2.5	7.2	2.8	4.0	3.1	13.2
NOV		1.3		1.3	5.3	1.3	4.8	4.3	
DEC				4.4	6.6	10.6	5.2	4.0	
mean		**5.1**		**4.1**	**7.1**	**4.1**	**4.0**	**3.5**	**9.1**
std dev		5.4		1.5	2.0	3.0	2.6	1.0	5.2
median		3.2		4.3	6.5	3.2	3.4	3.6	7.8
max		19.5		7.0	11.5	10.6	11.0	4.8	19.6
min		1.3		1.3	5.0	1.3	1.3	1.3	4.2

	B210	COL	SRWC	6RC	LCO	GCO	SR	BRN	HAM
JAN	2.8					1.3			
FEB	3.5					1.3			
MAR	3.8					1.3			
APR	5.6					4.1			
MAY	1.3					1.3			
JUN	3.6					4.6			
JUL	2.9					1.3			
AUG	3.4					1.3			
SEP	2.6					1.3			
OCT	1.3					1.3			
NOV	1.3					1.3			
DEC									
mean	**2.9**					**1.9**			
std dev	1.3					1.2			
median	2.9					1.3			
max	5.6					4.6			
min	1.3					1.3			

Table 2.9 Total Nitrogen (µg/l) 2021 at the Lower Cape Fear River Program stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	1,960	2,050	1,730	2,160	1,780	1,660	1,240	1,110
FEB	1,330	1,290	1,160	1,320	1,150	1,230	560	370
MAR	2,490	1,440	1,120	1,700	1,290	740	580	1,100
APR	1,290	670	710	1,110	630	590	610	560
MAY	900	780	800	820	730	700	740	730
JUN	3,090	1,760	1,190	2,450	1,140	910	1,120	1,270
JUL	2,360	850	1,250	1,420	860	670	320	520
AUG	1,120	750	810	1,250	680	880	730	970
SEP	900	670	3,740	760	840	430	670	680
OCT	2,280	1,000	880	1,700	850	840	880	430
NOV	1,390	870	1,560	980	1,750	1,100	960	1,160
DEC	2,000	1,690	1,440	1,520	1,500	1,340	930	880
mean	**1,759**	**1,152**	**1,366**	**1,433**	**1,100**	**924**	**778**	**815**
std dev	705	479	812	513	405	351	259	308
median	1,675	935	1,175	1,370	1,000	860	735	805
max	3,090	2,050	3,740	2,450	1,780	1,660	1,240	1,270
min	900	670	710	760	630	430	320	370

	NC11	AC	DP	BBT	IC	NCF6
JAN	2,050	1,210	1,100		1,410	1,820
FEB	1,200	1,020	980		1,200	
MAR	670	730	800		830	1,230
APR	750	810	780		770	1,010
MAY	1,760	950	740		830	990
JUN	1,300	840	750		1,010	930
JUL	1,350	1,270	1,260	950	970	1,080
AUG	1,430	760	740	1,250	720	1,070
SEP	1,920	1,020	880	920	810	960
OCT	670	670	470	450	960	380
NOV	1,050	1,610	2,140	2,220	4,370	
DEC	1,940	1,780	1,600	1,120	1,480	1,040
mean	**1,341**	**1,056**	**1,020**	**1,152**	**1,280**	**1,051**
std dev	499	352	459	590	1,004	350
median	1,325	985	840	1,035	965	1,025
max	2,050	1,780	2,140	2,220	4,370	1,820
min	670	670	470	450	720	380

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	1,320	990	3,070	2,030	1,650	2,060	1,290	960	1,180
FEB	1,720	1,460	2,620	5,010	1,990	2,200	1,760	1,240	1,160
MAR	1,680	1,120	1,410	1,000	1,050	1,500	1,180	1,120	1,740
APR	1,930	1,160	1,890	1,510	1,050	1,490	1,320	1,410	1,770
MAY	2,320	1,240	1,100	1,170	1,310	1,530	2,910	1,160	1,420
JUN	2,500	1,670	1,450	1,390	2,290	1,370	2,290	1,470	
JUL	2,000	850	1,320	930	1,270	1,190	1,160	970	
AUG	1,940	750	1,160	740	700	1,460	1,570	880	880
SEP	1,270	1,780	1,000	1,950	1,100	1,890	5,730	1,100	1,530
OCT	490	2,440	1,280	2,470	950	1,040	6,980	270	810
NOV	1,120	1,730	850	4,730	750	820	10,800	960	
DEC	1,450	250	1,550	2,610	1,680	1,170	9,340	790	
mean	**1,645**	**1,287**	**1,558**	**2,128**	**1,316**	**1,477**	**3,861**	**1,028**	**1,311**
std dev	554	575	666	1,412	493	410	3,464	314	365
median	1,700	1,200	1,365	1,730	1,185	1,475	2,025	1,035	1,300
max	2,500	2,440	3,070	5,010	2,290	2,200	10,800	1,470	1,770
min	490	250	850	740	700	820	1,160	270	810

	B210	COL	SR-WC	6RC	LCO	GCO	SR	BRN	HAM
JAN	1,710	1,160	1,460	4,240	3,880	2,330	1,590	2,360	2,620
FEB	1,260	1,290	1,290	3,460	2,620	1,220	1,320	1,900	2,100
MAR	1,160	1,540	1,140	980	1,520	940	760	1,030	1,360
APR	1,050	1,700	1,150	2,300	1,490	1,010	1,500	1,300	1,460
MAY	1,060	3,680	1,510	2,060	1,970	1,620	1,710	1,550	1,050
JUN	3,650	2,060	910	910	1,200	1,120	1,490	1,280	1,170
JUL	620	1,280	1,320	1,190	1,140	680	910	800	530
AUG	1,040	1,400	1,130	1,960	1,100	660	970	1,140	1,540
SEP	1,480	1,270	880	910	680	1,920	850	1,190	880
OCT	250	360	340	1,290	390	4,410	380	640	110
NOV	2,170	1,510	1,030	2,430	920	790	580	760	50
DEC									
mean	**1,405**	**1,568**	**1,105**	**1,975**	**1,537**	**1,518**	**1,096**	**1,268**	**1,170**
std dev	902	814	325	1,095	987	1,096	446	512	782
median	1,160	1,400	1,140	1,960	1,200	1,120	970	1,190	1,170
max	3,650	3,680	1,510	4,240	3,880	4,410	1,710	2,360	2,620
min	250	360	340	910	390	660	380	640	50

Table 2.10 Nitrate/Nitrite (µg/l) 2021 at the Lower Cape Fear River stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	700	690	530	670	610	490	180	250
FEB	650	600	600	700	620	530	340	260
MAR	1,610	10	10	690	10	10	10	490
APR	560	10	10	470	10	10	10	80
MAY	10	10	10	10	10	10	120	10
JUN	1,110	110	90	800	40	10	20	40
JUL	460	10	10	630	10	10	10	10
AUG	230	10	10	340	10	10	10	340
SEP	300	70	170	270	180	10	10	10
OCT	1,160	90	50	650	10	10	10	220
NOV	530	130	400	110	220	200	10	60
DEC	770	670	430	550	330	160	60	40
mean	**674**	**201**	**193**	**491**	**172**	**122**	**66**	**151**
std dev	444	277	229	254	233	193	102	158
median	605	80	70	590	25	10	10	70
max	1,610	690	600	800	620	530	340	490
min	10	10	10	10	10	10	10	10

	NC11	AC	DP	BBT	IC	NCF6
JAN	670	590	450		660	820
FEB	660	520	540		590	
MAR	30	40	30		60	250
APR	10	10	10		10	10
MAY	800	10	10		10	10
JUN	450	10	10		10	10
JUL	540	500	330	140	240	190
AUG	650	10	10	10	10	10
SEP	580	200	40	200	180	40
OCT	670	670	470	450	470	380
NOV	120	420	1,090	1,060	3,160	
DEC	1,070	1,050	780	500	840	180
mean	**521**	**336**	**314**	**393**	**520**	**190**
std dev	321	342	362	376	881	256
median	615	310	185	325	210	110
max	1,070	1,050	1,090	1,060	3,160	820
min	10	10	10	10	10	10

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	270	120	2,020	1,110	610	1,270	380	160	520
FEB	250	440	1,700	3,870	740	1,070	290	130	740
MAR	190	30	670	90	50	460	10	10	800
APR	190	50	600	100	30	440	30	20	550
MAY	140	40	30	40	10	200	180	10	340
JUN	120	10	70	60	10	160	240	180	
JUL	430	10	20	10	10	130	10	10	
AUG	380	10	40	80	10	200	10	10	140
SEP	40	800	40	1,110	90	630	3,250	110	200
OCT	190	760	40	1,360	40	130	6,980	100	580
NOV	40	740	40	1,140	30	20	8,510	80	
DEC	30	250	270	1,400	560	490	7,450	120	
mean	**189**	**272**	**462**	**864**	**183**	**433**	**2,278**	**78**	**484**
std dev	129	324	695	1,113	278	392	3,374	64	239
median	190	85	55	605	35	320	265	90	535
max	430	800	2,020	3,870	740	1,270	8,510	180	800
min	30	10	20	10	10	20	10	10	140

	B210	COL	SR-WC	6RC	LCO	GCO	SR	BRN	HAM
JAN	1,040	90	730	3,330	2,960	1,680	790	1,200	1,070
FEB	250	60	540	2,260	1,970	490	560	850	1,140
MAR	190	50	330	230	590	80	20	220	610
APR	10	60	370	1,370	650	10	300	610	400
MAY	180	110	560	1,100	620	280	310	800	120
JUN	10	10	10	10	10	10	10	620	240
JUL	10	30	110	370	250	90	70	330	130
AUG	170	20	100	340	180	10	90	320	380
SEP	430	30	130	60	20	940	60	550	270
OCT	250	360	340	1,290	390	4,410	380	640	110
NOV	510	10	370	1,210	240	30	30	760	10
DEC									
mean	**277**	**75**	**326**	**1,052**	**716**	**730**	**238**	**627**	**407**
std dev	301	100	224	1,027	920	1,328	257	279	383
median	190	50	340	1,100	390	90	90	620	270
max	1,040	360	730	3,330	2,960	4,410	790	1,200	1,140
min	10	10	10	10	10	10	10	220	10

Figure 2.4 Mean Nitrate + Nitrite at the Lower Cape Fear River Program mainstem stations, 1995-2020 versus 2021.

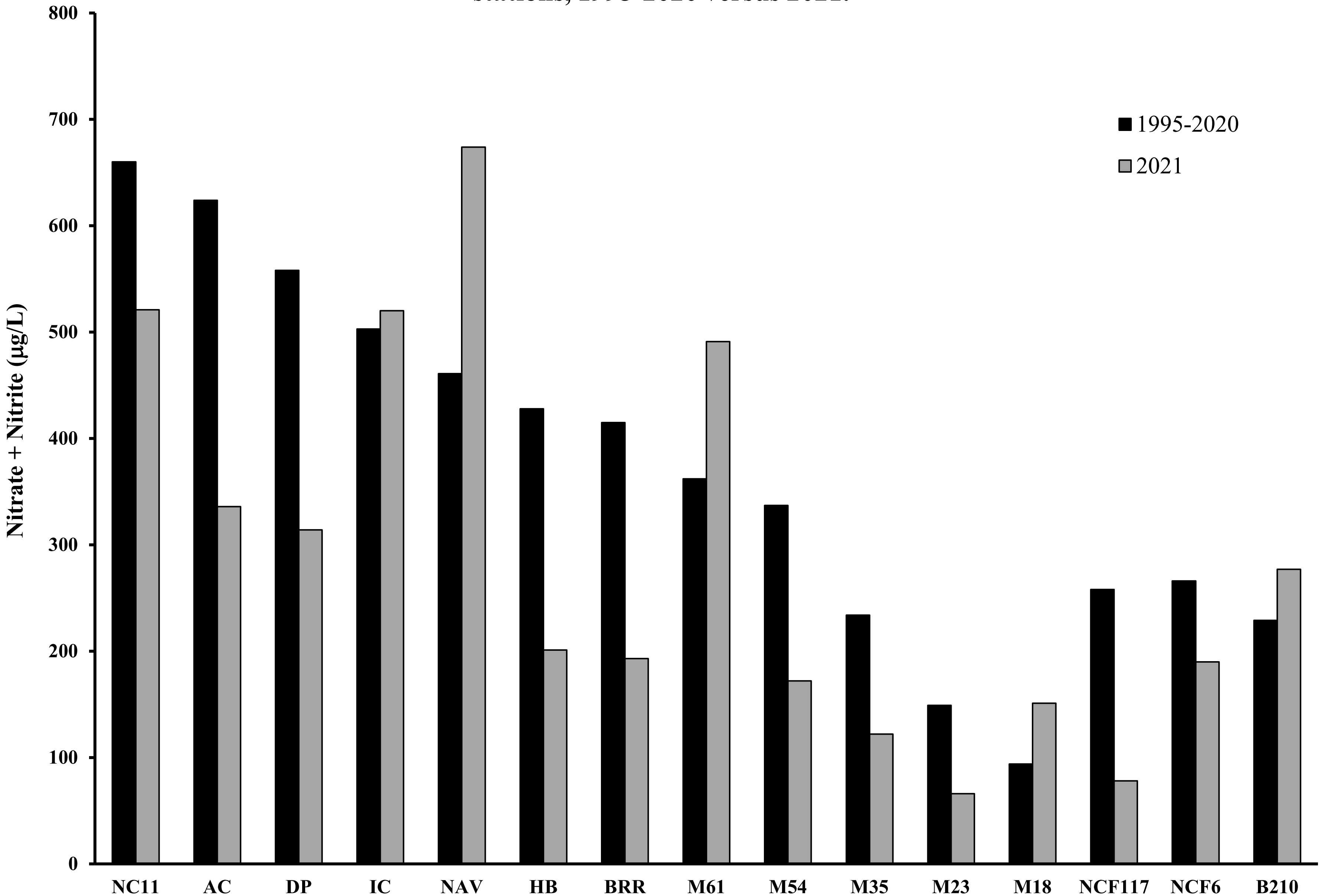


Table 2.11 Ammonia (µg/l) 2021 at the Lower Cape Fear River stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	60	50	90	100	110	70	10	10
FEB	100	70	110	70	110	80	10	10
MAR	50	40	70	30	170	80	70	100
APR	60	60	90	90	70	80	50	10
MAY	90	90	100	100	80	60	10	10
JUN	60	60	70	80	150	70	10	10
JUL	10	10	10	100	10	10	10	30
AUG	10	10	10	20	10	10	10	10
SEP	10	10	10	10	200	10	160	380
OCT	160	120	100	40	10	10	110	490
NOV	80	50	10	10	10	10	10	10
DEC	100	210	400	270	750	520	90	110
mean	**66**	**65**	**89**	**77**	**140**	**84**	**46**	**98**
std dev	44	56	106	71	203	141	51	163
median	60	55	80	75	95	65	10	10
max	160	210	400	270	750	520	160	490
min	10	10	10	10	10	10	10	10

	NC11	AC	DP	BBT	IC	NCF6
JAN	40	40	60		20	30
FEB	70	90	50		50	
MAR	100	100	90		70	50
APR	90	220	170		110	10
MAY	70	290	160		120	50
JUN	40	30	50		40	30
JUL	30	140	10	10	10	10
AUG	40	30	30	150	10	30
SEP	90	110	130	60	70	70
OCT	10	240	110	90	80	70
NOV	420	270	120	129	130	
DEC	70	50	60	10	90	140
mean	**89**	**134**	**87**	**75**	**67**	**49**
std dev	108	97	51	59	42	38
median	70	105	75	75	70	40
max	420	290	170	150	130	140
min	10	30	10	10	10	10

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	150	140	450	150	80	80	50	40	30
FEB	60	80	10	160	60	60	260	80	70
MAR	200	10	10	100	10	30	30	50	30
APR	90	10	10	160	50	50	20	110	10
MAY	150	30	10	70	50	70	40	10	40
JUN	460	30	120	50	60	80	260	150	
JUL	120	10	10	60	130	60	140	10	
AUG	120	10	190	10	40	60	50	10	10
SEP	30	20	20	30	90	100	770	30	80
OCT	10	90	80	100	100	200	1,400	20	10
NOV	60	60	60	60	30	50	90	60	
DEC	10	10	10	40	10	10	10	10	
mean	**122**	**42**	**82**	**83**	**59**	**71**	**260**	**48**	**35**
std dev	122	42	129	52	36	47	417	45	27
median	105	25	15	65	55	60	70	35	30
max	460	140	450	160	130	200	1,400	150	80
min	10	10	10	10	10	10	10	10	10

	B210	COL	SR-WC	6RC	LCO	GCO	SR	BRN	HAM
JAN	50	110	60	90	210	50	30	390	240
FEB	50	50	10	70	10	10	10	100	190
MAR	50	280	30	120	60	60	30	70	30
APR	10	60	140	40	50	60	100	20	50
MAY	50	900	30	10	20	40	80	10	30
JUN	10	260	30	80	60	30	10	30	60
JUL	10	170	10	10	10	10	10	10	10
AUG	10	50	10	10	10	10	10	10	20
SEP	10	40	90	100	60	60	80	70	30
OCT	70	190	10	10	10	30	10	50	40
NOV	110	30	10	110	10	30	10	10	10
DEC	70	190	10	10	10	30	10	50	40
mean	**42**	**194**	**37**	**55**	**43**	**35**	**33**	**68**	**63**
std dev	32	239	41	44	57	19	34	106	74
median	50	140	20	55	15	30	10	40	35
max	110	900	140	120	210	60	100	390	240
min	10	30	10	10	10	10	10	10	10

Table 2.12 Total Kjeldahl Nitrogen (µg/l) 2021 at the Lower Cape Fear River Program stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	1,260	1,360	1,200	1,490	1,170	1,170	1,060	860
FEB	680	690	560	620	530	700	220	110
MAR	880	1,440	1,120	1,010	1,290	740	580	610
APR	730	670	710	640	630	590	610	480
MAY	900	780	800	820	730	700	620	730
JUN	1,980	1,600	1,100	1,600	1,100	910	1,100	1,230
JUL	1,900	850	1,250	790	860	670	320	520
AUG	890	750	810	910	680	880	730	630
SEP	600	600	3,570	490	660	430	670	680
OCT	1,120	910	830	1,050	850	840	880	210
NOV	860	740	1,160	870	1,530	900	960	1,100
DEC	1,230	1,020	1,010	970	1,170	1,180	870	840
mean	**1,086**	**951**	**1,177**	**938**	**933**	**809**	**718**	**667**
std dev	448	334	784	329	312	220	273	324
median	895	815	1,055	890	855	790	700	655
max	1,980	1,600	3,570	1,600	1,530	1,180	1,100	1,230
min	600	600	560	490	530	430	220	110

	NC11	AC	DP	BBT	IC	NCF6
JAN	1,380	620	650		750	1,000
FEB	540	500	440		610	
MAR	640	690	770		770	980
APR	750	810	780		770	1,010
MAY	960	950	740		830	990
JUN	850	840	750		1,010	930
JUL	810	770	930	810	730	890
AUG	780	760	740	1,250	720	1,070
SEP	1,340	820	840	720	630	920
OCT	50	50	50	50	490	50
NOV	930	1,190	1,050	1,160	1,210	
DEC	870	730	820	620	640	860
mean	**825**	**728**	**713**	**768**	**763**	**870**
std dev	348	273	255	431	191	295
median	830	765	760	765	740	955
max	1,380	1,190	1,050	1,250	1,210	1,070
min	50	50	50	50	490	50

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	1,050	870	1,050	920	1,040	790	910	800	660
FEB	1,470	1,020	920	1,140	1,250	1,130	1,470	1,110	420
MAR	1,490	1,090	740	910	1,000	1,040	1,180	1,120	940
APR	1,740	1,110	1,290	1,410	1,020	1,050	1,290	1,390	1,220
MAY	2,180	1,200	1,070	1,130	1,310	1,330	2,730	1,160	1,080
JUN	2,080	1,670	1,380	1,330	2,290	1,210	2,050	1,290	
JUL	1,570	850	1,300	930	1,270	1,060	1,160	970	
AUG	1,560	750	1,120	660	700	1,260	1,570	880	740
SEP	1,230	980	960	840	1,010	1,260	2,480	990	1,330
OCT	300	1,680	1,240	1,110	910	910	50	170	230
NOV	1,080	990	810	3,590	720	800	2,310	880	
DEC	1,420	50	1,280	1,210	1,120	680	1,890	670	
mean	**1,431**	**1,022**	**1,097**	**1,265**	**1,137**	**1,043**	**1,591**	**953**	**828**
std dev	496	423	208	763	412	210	751	320	386
median	1,480	1,005	1,095	1,120	1,030	1,055	1,520	980	840
max	2,180	1,680	1,380	3,590	2,290	1,330	2,730	1,390	1,330
min	300	50	740	660	700	680	50	170	230

	B210	COL	SR-WC	6RC	LCO	GCO	SR	BRN	HAM
JAN	670	1,070	730	910	920	650	800	1,160	1,550
FEB	1,010	1,230	720	1,200	650	730	760	1,050	960
MAR	970	1,490	810	750	930	860	740	810	750
APR	1,050	1,640	780	930	840	1,010	1,200	690	1,060
MAY	880	3,570	950	960	1,350	1,340	1,400	750	930
JUN	3,650	2,060	910	910	1,200	1,120	1,490	660	930
JUL	620	1,250	1,210	820	890	590	840	470	400
AUG	870	1,380	1,030	1,620	920	660	880	820	1,160
SEP	1,050	1,240	750	850	660	980	790	640	610
OCT	50	50	50	50	50	50	50	50	50
NOV	1,660	1,510	660	1,220	680	760	550	50	50
DEC									
mean	**1,135**	**1,499**	**782**	**929**	**826**	**795**	**864**	**650**	**768**
std dev	919	844	291	382	336	336	399	352	462
median	970	1,380	780	910	890	760	800	690	930
max	3,650	3,570	1,210	1,620	1,350	1,340	1,490	1,160	1,550
min	50	50	50	50	50	50	50	50	50

Table 2.13 Total Phosphorus (µg/l) 2021 at the Lower Cape Fear River Program stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	100	360	1,390	90	80	120	340	160
FEB	160	160	130	150	200	280	140	110
MAR	290	290	270	140	180	160	130	180
APR	120	120	100	100	130	60	60	20
MAY	110	110	100	80	40	60	10	190
JUN	360	350	310	230	150	80	70	100
JUL	160	190	200	160	170	100	100	120
AUG	80	100	160	90	90	80	80	130
SEP	200	200	90	60	290	70	200	10
OCT	310	220	180	170	110	90	60	50
NOV	170	120	120	130	120	70	90	90
DEC	200	150	90	110	80	110	50	60
mean	**188**	**198**	**262**	**126**	**137**	**107**	**111**	**102**
std dev	85	87	347	45	64	59	84	56
median	165	175	145	120	125	85	85	105
max	360	360	1,390	230	290	280	340	190
min	80	100	90	60	40	60	10	10

	NC11	AC	DP	BBT	IC	NCF6
JAN	890	800	710		820	1,030
FEB	630	750	630		490	
MAR	200	250	160		380	300
APR	130	250	140		100	140
MAY	90	160	120		120	70
JUN	110	120	120		130	100
JUL	740	260	580	480	320	590
AUG	180	90	100	240	70	130
SEP	220	100	120	130	60	250
OCT	200	100	120	110	160	120
NOV	240	290	260	270	290	
DEC	210	210	230	120	210	100
mean	**320**	**282**	**274**	**225**	**263**	**283**
std dev	259	231	218	129	211	289
median	205	230	150	185	185	135
max	890	800	710	480	820	1,030
min	90	90	100	110	60	70

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	300	100	90	100	110	90	130	110	70
FEB	340	120	150	240	240	190	140	120	50
MAR	260	280	160	230	320	120	330	250	320
APR	250	80	110	110	300	100	330	180	130
MAY	180	120	50	90	170	130	1,340	90	100
JUN	330	190	180	180	440	110	850	130	
JUL	470	320	340	530	510	410	520	340	
AUG	420	610	840	720	730	180	560	150	90
SEP	360	340	140	280	220	190	730	100	130
OCT	390	250	190	190	180	100	1,000	140	140
NOV	130	230	80	300	140	100	1,520	140	
DEC	460	230	90	210	260	120	1,150	100	
mean	**324**	**239**	**202**	**265**	**302**	**153**	**717**	**154**	**129**
std dev	101	139	205	178	172	85	443	70	78
median	335	230	145	220	250	120	645	135	115
max	470	610	840	720	730	410	1,520	340	320
min	130	80	50	90	110	90	130	90	50

	B210	COL	SR-WC	6RC	LCO	GCO	SR	BRN	HAM
JAN	1,080	500	820	850	620	560	410	970	1,070
FEB	90	60	60	100	80	160	110	160	180
MAR	60	460	60	120	330	210	220	140	90
APR	290	410	610	470	210	370	130	620	280
MAY	150	360	20	50	40	960	30	30	100
JUN	430	250	70	150	190	350	90	110	310
JUL	90	100	70	150	70	260	60	50	230
AUG	200	50	150	140	170	160	60	270	170
SEP	570	170	390	610	360	790	110	60	160
OCT	270	150	140	160	70	1,170	80	90	310
NOV	540	240	40	270	50	580	40	90	150
DEC									
mean	**343**	**250**	**221**	**279**	**199**	**506**	**122**	**235**	**277**
std dev	288	154	256	243	170	326	104	281	261
median	270	240	70	150	170	370	90	110	180
max	1,080	500	820	850	620	1,170	410	970	1,070
min	60	50	20	50	40	160	30	30	90

Figure 2.5 Mean Total Phosphorus at the Lower Cape Fear River Program mainstem stations, 1995-2020 versus 2021.

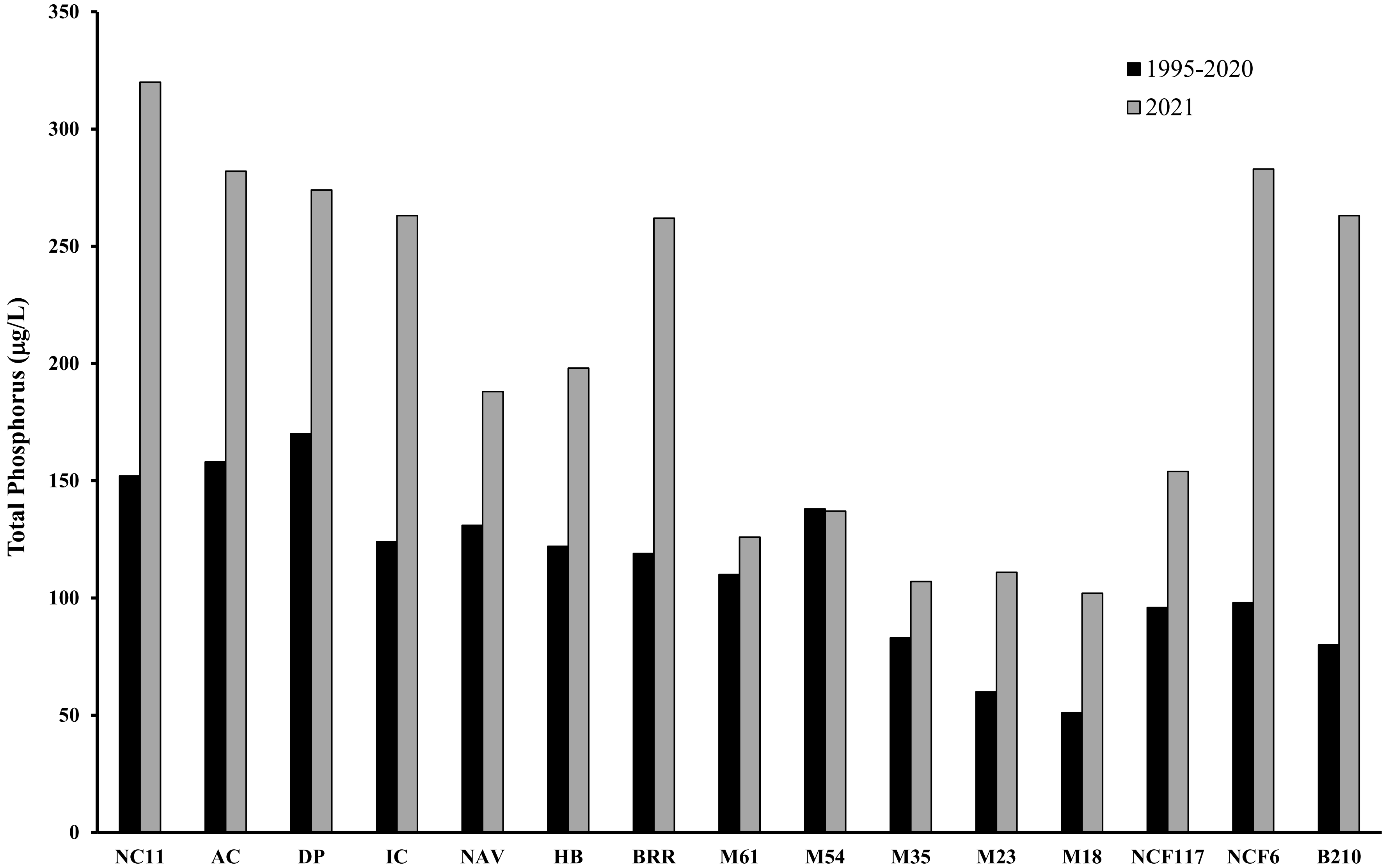


Table 2.14 Orthophosphate (µg/l) 2021 at the Lower Cape Fear River Program stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	20	30	20	30	30	20	20	10
FEB	20	20	30	30	30	20	10	10
MAR	20	20	20		30	20	20	20
APR	50	50	40	40	40	30	30	20
MAY	60	50	40	40	40	20	10	10
JUN	80	70	70	60	40	20	100	10
JUL	50	60	60	70	60	30	20	10
AUG	50	50	50	60	60	50	40	40
SEP	40	40	30	40	30	20	20	10
OCT	150	130	120	80	40	40	30	30
NOV	50	50	40	30	30	20	20	10
DEC	60	50	40	40	50	30	20	20
mean	**54**	**52**	**47**	**47**	**40**	**27**	**28**	**17**
std dev	35	29	27	17	11	10	24	10
median	50	50	40	40	40	20	20	10
max	150	130	120	80	60	50	100	40
min	20	20	20	30	30	20	10	10

	NC11	AC	DP	BBT	IC	NCF6
JAN	30	30	30		20	30
FEB	30	30	30	20	20	
MAR	30	30	30	20	20	30
APR	50	40	60	40	50	50
MAY	60	100	70	50	60	40
JUN	50	50	50	50	50	50
JUL	60	50	70	50	50	50
AUG	70	50	50	40	40	60
SEP	70	50	50	40	40	40
OCT	110	140	70	70	50	40
NOV	140	160	130	120	80	
DEC	100	130	120	70	110	30
mean	**67**	**72**	**63**	**52**	**49**	**42**
std dev	34	47	33	28	26	10
median	60	50	55	50	50	40
max	140	160	130	120	110	60
min	30	30	30	20	20	30

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	210	5	20	40	30	30	70	60	20
FEB	70	30	20	30	20	20	50	50	50
MAR	90	20	20	40	40	5	100	30	30
APR	140	40	30	30	80	5	180	50	20
MAY	70	60	20	70	40	50	350	90	20
JUN	80	60	40	60	70	30	420	70	
JUL	210	70	60	210	5	40	150	80	
AUG	330	80	50	180	90	2050	290	80	40
SEP	80	60	40	30	20	40	410	30	40
OCT	120	100	30	60	30	20	690	40	30
NOV	50	60	20	50	20	20	920	20	
DEC	90	80	20	70	50	50	1120	50	20
mean	**128**	**55**	**31**	**73**	**41**	**197**	**396**	**54**	**30**
std dev	82	27	14	59	26	584	346	22	11
median	90	60	25	55	35	30	320	50	30
max	330	100	60	210	90	2050	1120	90	50
min	50	5	20	30	5	5	50	20	20

	B210	COL	SR-WC	6RC	LCO	GCO	SR	BRN	HAM
JAN	10	50	5	30	5	40	5	10	60
FEB	20	10	5	30	5	20	10	20	20
MAR	20	180	10	20	10	40	5	20	20
APR	40	100	20	50	20	260	5	20	50
MAY	50	120	20	50	50	570	20	20	60
JUN	50	50	20	70	40	100	20	20	80
JUL	80	50	20	80	30	90	5	30	120
AUG	40	40	20	70	30	90	5	40	90
SEP	40	40	30	90	50	430	20	30	90
OCT	50	80	20	80	30	920	20	40	90
NOV	40	50	10	140	10	470	5	30	80
DEC									
mean	**40**	**70**	**16**	**65**	**25**	**275**	**11**	**25**	**69**
std dev	19	48	8	34	17	290	7	9	31
median	40	50	20	70	30	100	5	20	80
max	80	180	30	140	50	920	20	40	120
min	10	10	5	20	5	20	5	10	20

Table 2.15 Chlorophyll *a* (µg/l) 2021 at the Lower Cape Fear River Program stations.

	NAV	HB	BRR	M61	M54	M35	M23	M18
JAN	2	2	2	2	3	3	9	13
FEB	3	3	2	3	4	2	8	9
MAR	8	7	8	7	5	5	3	3
APR	1	1	2	6	5	6	5	7
MAY	1	3	6	6	7	13	11	5
JUN	4	8	6	4	8	9	6	6
JUL	1	2	4	6	16	25	5	8
AUG	1	1	1	1	2	4	2	3
SEP	8	11	16	12	18	16	9	6
OCT	1	1	1	2	3	3	3	3
NOV	3	4	4	5	4	2	5	5
DEC	2	3	3	3	4	4	5	5
mean	**3**	**4**	**5**	**5**	**7**	**8**	**6**	**6**
std dev	3	3	4	3	5	7	3	3
median	2	3	4	5	5	5	5	6
max	8	11	16	12	18	25	11	13
min	1	1	1	1	2	2	2	3

	NC11	AC	DP	BBT	IC	NCF6
JAN	2	2	2	1	2	4
FEB	4	3	3	2	2	
MAR	3	3	3	2	2	1
APR	1	1	1	1	1	3
MAY	1	1	1	1	1	4
JUN	1	2	1	1	1	2
JUL	2	1	1	1	1	2
AUG	2	2	3	1	1	1
SEP	1	2	2	1	2	2
OCT	1	1	0	0	6	2
NOV	1	1	1	0	2	
DEC	1	0	1	0	1	5
mean	**2**	**2**	**2**	**1**	**2**	**3**
std dev	1	1	1	1	1	1
median	1	2	1	1	2	2
max	4	3	3	2	6	5
min	1	0	0	0	1	1

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	2	8	12	2	2	2	2	5	6
FEB	3	2	6	2	1	1	1	1	2
MAR	6	2	2	5	4	3	1	1	3
APR	6	2	3	6	2	2	2	2	6
MAY	15	2	22	7	8	6	9	1	9
JUN	4	2	8	15	17	2	1	1	
JUL	4	3	3	12	13	10	5	3	
AUG	2	2	38	5	6	1	0	1	11
SEP	4	3	13	3	5	2	1	1	2
OCT	7	20	29	7	24	2	5	2	18
NOV	1	2	2	2	3	3	2	1	
DEC	1	5	5	8	38	1	2	1	
mean	**5**	**4**	**12**	**6**	**10**	**3**	**3**	**2**	**7**
std dev	4	5	12	4	11	3	3	1	5
median	4	2	7	6	6	2	2	1	6
max	15	20	38	15	38	10	9	5	18
min	1	2	2	2	1	1	0	1	2

	B210	COL	SR-WC	6RC	LCO	GCO	SR	BRN	HAM
JAN	2	3	2	6	11	8	15	7	8
FEB	1	2	1	1	5	2	4	1	1
MAR	1	5	1	2	1	1	4	4	5
APR	1	3	0	1	1	1	7	3	3
MAY	3	3	0	1	0	3	27	1	2
JUN	1	9	1	2	3	3	6	1	1
JUL	4	1	1	2	1	3	3	2	1
AUG	1	1	0	2	1	3	7	2	1
SEP	1	4	0	1	0	3	6	1	0
OCT	1	2	0	2	1	1	8	1	0
NOV	1	2	1	1	1	1	1	0	0
DEC									
mean	**2**	**3**	**1**	**2**	**2**	**3**	**8**	**2**	**2**
std dev	1	2	1	1	3	2	7	2	2
median	1	3	1	2	1	3	6	1	1
max	4	9	2	6	11	8	27	7	8
min	1	1	0	1	0	1	1	0	0

Figure 2.6 Mean Chlorophyll *a* at the Lower Cape Fear River Program mainstem stations, 1995-2020 versus 2021.

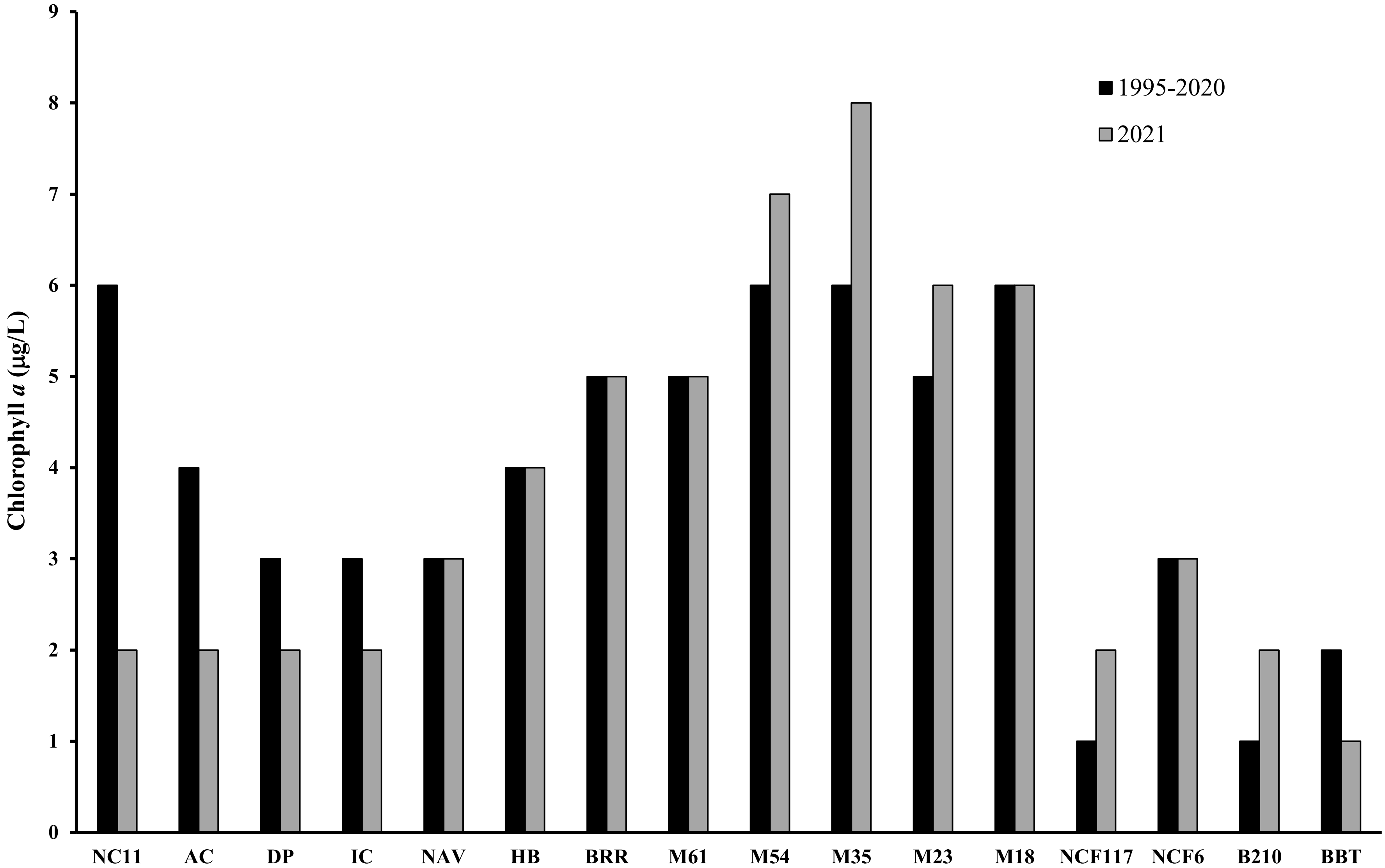


Table 2.16 Fecal Coliform (cfu/100 mL) and Enterococcus (MPN) 2021 at the Lower Cape Fear River Program stations.

	NC11	AC	DP	BBT	IC	NCF6	NAV	HB
JAN	23	15	10		5	5	28	10
FEB	105	91	110		23		68	82
MAR	28	19	10		14	28	15	41
APR	7	2	2		15	37	2	11
MAY	5	5	5		10	46	15	26
JUN	4	8	11		8	37	5	5
JUL	5	10	120	100	110	59	36	32
AUG	19	10	10	23	14	68	165	105
SEP	19	19	23	5	5	14	76	91
OCT	10	28	19	14	55	105	73	14
NOV	5	10	32	50	55		55	73
DEC	5	14	23	19	5	19	14	37
mean	**20**	**19**	**31**	**35**	**27**	**42**	**46**	**44**
std dev	27	23	38	32	30	28	44	33
max	105	91	120	100	110	105	165	105
min	4	2	2	5	5	5	2	5
Geomean	11	13	17	23	16	32	26	30

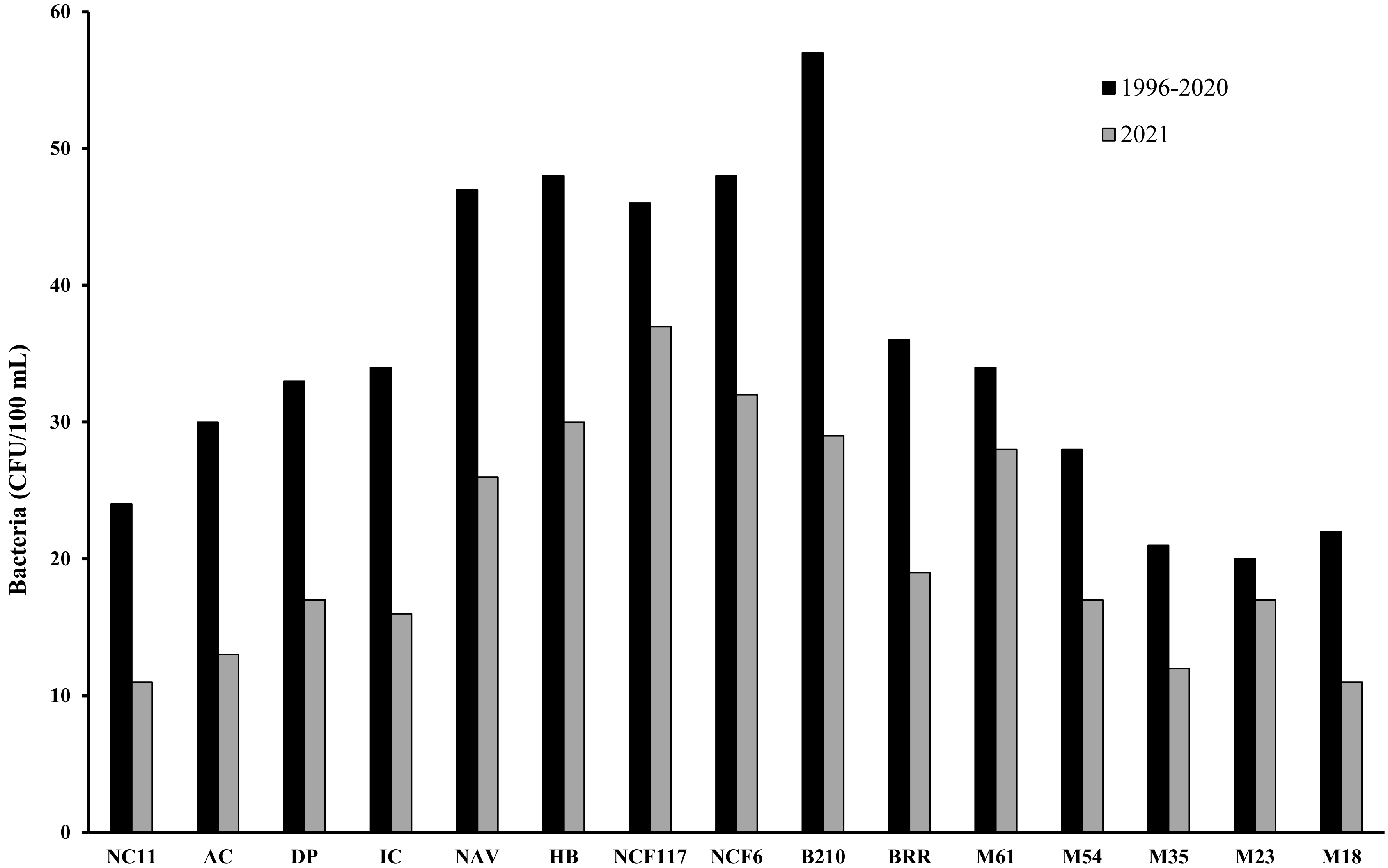
ENTEROCOCCUS

	BRR	M61	M54	M35	M23	M18
JAN	10	10	41	10	10	10
FEB	31	36	63	10	30	10
MAR	10	63	10	10	101	10
APR	10	10	10	10	10	10
MAY	134	75	41	10	10	10
JUN	10	10	10	10	20	10
JUL	20	41	10	10	1	1
AUG	31	84	75	84	20	10
SEP	31	10	10	10	366	210
OCT	31	31	10	10	10	10
NOV	10	52	10	10	10	10
DEC	10	20	10	10	10	10
mean	**28**	**37**	**25**	**16**	**50**	**26**
std dev	33	26	23	20	99	56
max	134	84	75	84	366	210
min	10	10	10	10	1	1
Geomean	19	28	17	12	17	11

	ANC	SAR	GS	NC403	PB	LRC	ROC	NCF117	SC-CH
JAN	19	73	5	37	14	19	50	59	32
FEB	14	91	5	32	14	10	41	32	23
MAR	44	146	17	28	31	38	20	29	84
APR	74	48	29	44	50	108	50	29	31
MAY	86	200	98	146	640	110	128	28	82
JUN	273	74	237	310	237	273	78	19	
JUL	955	546	500	410	637	7,500	1,410	158	
AUG	546	150	290	190	1,100	275	325	28	1,200
SEP	135	73	28	46	410	82	91	14	50
OCT	160	410	210	1050	200	64	135	28	82
NOV	5	82	19	55	28	91	110	59	
DEC	68	1,100	253	682	637	682	591	73	
mean	**198**	**249**	**141**	**253**	**333**	**771**	**252**	**46**	**198**
std dev	270	295	151	307	338	2,037	382	38	379
max	19	1,100	500	1,050	1,100	7,500	1,410	158	1,200
min	5	48	5	28	14	10	20	14	23
Geomean	81	152	57	120	138	126	118	37	73

	B210	COL	SRWC	6RC	LCO	GCO	SR	BRN	HAM
JAN	22	14	23	86	86	55	41	91	1,400
FEB	10	19	23	41	5	14	41	28	280
MAR	32	64	14	10	10	5	23	72	195
APR	5	46	10	24	28	6	24	170	546
MAY	42	141	35	17	8	33	28	62	65
JUN	28	108	37	130	819	64	110	90	600
JUL	32	155	130	135	95	145	91	280	155
AUG	73	68	64	500	50	100	160	200	165
SEP	29	225	130	77	82	68	86	165	500
OCT	165	110	113	210	125	120	32	190	500
NOV	28	130	50	23	32	10	32	82	1,000
DEC									
mean	**42**	**98**	**57**	**114**	**122**	**56**	**61**	**130**	**491**
std dev	42	61	44	136	224	46	43	72	385
max	165	225	130	500	819	145	160	280	1,400
min	5	14	10	10	5	5	23	28	65
Geomean	29	75	41	61	44	33	49	109	352

Figure 2.7 Geometric Mean Fecal Coliform (NC11-B210) and Enterococcus (BRR-M18) at the LCFRP mainstem stations, 1996-2020 (Entero 2012-2014) vs. 2021.



3.0. Nutrient Increases Across Multiple Coastal Plain Stream Stations

3.1. Introduction

The Lower Cape Fear River Program began sampling at selected sites in mid-1995. Since then the Program has built up a robust data set, with many stations sampled monthly since the beginning. Recently we decided to examine some of the data for long term trends, to see if human impacts, such as point source discharges or industrialized animal production (i.e. CAFOs, concentrated animal feeding operations) have affected the water quality. We were concerned that point source discharges may have increased due to increasing human populations in the upper Cape Fear River watershed. We were also concerned that poultry production has increased considerably in North Carolina, especially on the Coastal Plain (Patt 2017). Note that the large point source NPDES dischargers drain to the 6^{th} order Cape Fear River, and the vast majority of swine and poultry CAFOs drain into tributaries of the 5^{th} order Black River basin and the 5^{th} order Northeast Cape Fear River basin (Table 3.1).

3.2. Statistical Analysis

We chose to perform several trends analyses using a 20-year data set, running from 2000 to 2019. Although the LCFRP began in mid-1995, between 1996 and 1999 the Cape Fear region was hit by six major hurricanes: Bertha and Fran in 1996, Bonnie in 1998, and Dennis, Floyd and Irene in 1999. The hurricanes had extreme effects on water quality, thus we decided to begin our trend analyses after the direct influence of those storms passed. The LCFRP uses detection limits of 0.020 mg/L (20 ug/L) for nitrate, ammonium and total phosphorus, and 0.200 (200 ug/L) for TKN. For statistical purposes we used one-half of the detection limit in cases where analyses produced results less than the detection limit.

As nutrient parameters can be variable over a year’s time, we needed to account for extremes. We chose to analyze trends within the data set by three statistical procedures to account for the variability. The first was to determine the annual medians (i.e. the number in a list where 50% of the observations are above it and 50% of the observations are below it). The median can provide a measure of central tendency that is appropriate to use when the data are not a standard distribution or when there are extreme outliers (Gotelli and Ellison 2004). We used p values of < 0.05 to determine statistical significance. Additionally, graphing the medians and determining linear regressions provides a visually clear trendline when attempting to graph the changes occurring over 20 years (240 monthly data points on a graph is difficult to visualize).

Other statistical tests were also applied to the monthly water quality datasets from January 1999 to December 2019 to evaluate if there were any significant increasing or decreasing trends over time. Statistical analyses were computed using R Studio (2020). Linear regressions analyses are a common statistical method to quantify patterns of continuous data (i.e., time-series datasets). There are several assumptions of linear regression analyses that must first be checked before a linear regression model can be run. Linear regression analyses assume that the dataset being used in the model meets a certain set of criteria, one of which is the normality of residuals, or the difference between the observed values and predicted values. To test if the data were normally distributed, a Shapiro-Wilk Normality Test was computed. Non-normal data, including the fecal coliform and nutrient data (nitrate + nitrite, ammonium, orthophosphate, total nitrogen, and total phosphorus), were log-transformed to normalize it for the linear regression models. Single linear regression models assessed the change in concentration for each water quality parameter individually over the 20-year time period. The results of these linear regression models are *p*-values, which quantified the significance of the trendlines over time (considered significant if $p < 0.05$), and the regression coefficient values (R^2) that indicates the direction of the trend (positive for an increase, negative for a decrease) and strength of the relationship.

However, some data were still not normal after the log transformations, and thus non-parametric approaches were also applied as a third test to assess the trends in these timeseries datasets. The nonparametric approach, which does not assume normally distributed data, used in this study was the Mann-Kendall trend test (Kendall, 1938; Hirsch et al., 1982), a common approach to assess trends in long-term water quality monitoring datasets (Berryman et al., 1988; Meals et al., 2011; Mozejko, 2012). The trends assessed were the same as those for the linear regression, the change in water quality parameters over time. The correlation coefficient for the Mann-Kendall trend test is tau (t), which measures the strength of the correlation. For example, significant (*p*-value < 0.05) positive t values indicate an increasing trend over time, while negative values indicate decreasing trends over time.

3.3. Results and Discussion

When examining the resulting statistical data we decided to discuss trends if two of the three statistical methods provided evidence of a significant trend. Most of the discussion below concerns nutrients and fecal coliform bacteria; chlorophyll *a* is briefly discussed as well. Table 3.1 describes the sites analyzed, their general location and major influencing land use factors. Table 3.2 shows relevant statistical results for sampling stations and nutrient and fecal coliform counts. We only present data here for which 20 years are available. We found some trends among shorter data sets but those are not presented or discussed. We show four sets of linear trends for medians (Figure 3.1 for nitrate, Figure 3.2 for TN, Figure 3.3 for TP and Figure 3.4 for fecal coliforms) which present sites of particular interest.

<u>Nitrate</u>:
Nitrate significantly increased over the 20-year span at many stations (Fig. 3.1). with particularly sharp increases in Six Runs Creek (6RC), Great Coharie Creek (GCO) and Little Coharie Creek (LCO) in the Black River basin, as well as in the main 5th order collector Black River proper (B210). Those creeks showing particularly large increases all contained large numbers of CAFOs (Table 3.1). In contrast, Colly Creek (COL), which contain only four CAFOs, maintained low nitrate concentrations and showed no median increases (Fig. 3.1), although the other two tests detected slight increases.

Strong nitrate increases were also found at NC403, Angola Creek (ANC), Rockfish Creek (ROC) and Little Rockfish Creek (LRC) in the Northeast Cape Fear River basin, which also showed a significant nitrate increase at the 5th order collector site NCF117 near Castle Hayne. CAFOs are abundant in those watersheds as well, but some sites that showed increases (Rockfish Creek and NC403 also had small (0.5 – 1.5 MGD NPDES discharges upstream of the sampling sites. Additionally, there is a 5.4 MGD NPDES discharge located just downstream from the sampling site on ROC, and field crews have noted that during low flow periods discharges from this outfall can flow upstream to the sampling site. Note that NC403, ROC and 6RC all showed very high nitrate concentrations following about 2010 (Fig. 3.1).

Nitrate also significantly increased at Brown's Creek (BRN) and Hammond Creek (HAM) which drain into the mainstem Cape Fear River. The BRN watershed contains three CAFOs, traditional agriculture and drains stormwater from Elizabethtown. The HAM watershed contains13 swine CAFOs, 4 poultry CAFOs and traditional agriculture (Table 3.1). Notably, the main 6th order Cape Fear River proper did not show significant nitrate increases, nor did the estuary.

Ammonium:
Ammonium only increased at three locations, NC403, LRC and COL. COL is in a wetland-rich watershed that has a low level of human development. Most previous years have showed generally low levels of ammonium; however, beginning in 2005 a few unusual peaks began to occur, which increased in magnitude and frequency after 2012, particularly in 2016, 2017 and 2018. We do not have a solid explanation for this increase in ammonium. We are aware that The Town of White Lake, located in the upper Colly Creek watershed has had problems with old and compromised sewage infrastructure that leaks, and the lake itself has had recent bouts of eutrophication (NC DEQ 2017), with nearby upper groundwater and surface runoff showing elevated nutrient concentrations (Shank and Zamora 2019). We assume ammonium and other nutrients have escaped downstream from the aging infrastructure surrounding White Lake. Ammonium decreased at three sites, GS, SAR and GCO (Table 3.2).

Total nitrogen (TN):
TN significantly increased (Fig. 3.2) at several stations, although not as many as nitrate and often less strongly as nitrate. Key sites showing notable increases included 6RC, GCO and B210 in the Black River basin, NC403 and ROC in the Northeast Cape Fear basin, and BRN which drains directly into the mainstem Cape Fear River. The mainstem Cape Fear River and estuary did not show TN increases. Decreases in TN were not seen at any of the sites.

Orthophosphate:
Orthophosphate concentrations increased at a few locations, two in the Northeast Cape Fear River basin (ANC, LRC) and three in the Black River basin (B210, COL and GCO). What was very surprising is that orthophosphate significantly decreased at 10 locations stretching from the uppermost riverine site at NC11 downstream all the way to Channel

Marker 54 about mid-estuary (Table 3.2). Decreases were also seen at Sarecta (SAR) and South River (SR). While the reason for decreases at the latter two sides is not clear, the other ten sites are all impacted by major point source outfalls, either in the Piedmont, the upper Coastal Plain, or near Wilmington (Table 3.1).

Total phosphorus (TP):
There were significant TP increases (Fig. 3.3) at many stations (Table 3.2). Sharp increases were particularly seen at 6RC, GCO, LCO, COL and B210 are in the Black River watershed. COL has very few CAFOs but, as mentioned, is located well downstream from the town of White Lake. Panther Branch (PB), ANC, LRC, NCF117 and NCF6 are in the Northeast Cape Fear River basin. Note that PB is a small watershed with a 0.5 MGD wastewater discharge and little else. NCF6 is actually an upper estuary station a few miles upstream of the City of Wilmington.

M35, M23 and M18 are the lowest stations in the Cape Fear River estuary. They did show significant TP increases, but at very low TP concentrations; the reason for this is not evident.

Fecal coliform bacteria:
By far the pollutant showing the most widespread increases across the system was fecal coliform bacteria, with 19 sampling sites yielding significant increases as determined by two or three statistical tests (Table 3.2). Note that 12 sites showed increases by all three tests.

Along the mainstem Cape Fear River, increases were seen at NC11, DP, AC, IC and HB; note that while significant, these increases were slight, with all R^2 values < 0.08. The two tributaries downstream of Elizabethtown, BRN and HAM showed highly significant ($p < 0.001$) and stronger median increases, with R^2 at BRN = 0.25 and R^2 at HAM = 0.19. Note that the estuarine stations were not included in the 20-year trend analysis because the Program changed from collecting fecal coliform bacteria to *Entercoccus* bacteria in 2011.

In the Black River watershed 6RC, GCO, LCO, COL, SR and B210 all had significant increases, especially strong at 6RC, GCO and LCO. In the Northeast Cape Fear watershed nine sites showed significant increases, with the strongest increases seen at ROC, GS and NC403. Weaker increases were seen at SAR, LRC, NCF6 and NCF117.

Chlorophyll *a*
The primary response variable to nutrient inputs is chlorophyll *a*, a widely used representation of phytoplankton biomass. There were significant increases at several locations, and no significant decreases were seen. However, most of the sites that showed increases based on two or more statistical techniques actually had very low chlorophyll *a* concentrations. The only sites yielding notably higher concentrations of chlorophyll *a* were NC403 ($R^2 = 0.375$, $p = 0.004$ for medians) and SR ($R^2 = 0.555$, $p < 0.001$ for medians). Notably, significant decreases were not found for chlorophyll *a* in the data set.

3.4. Discussion and Conclusions

A clear theme that the data demonstrate is that sampling sites where nutrients showed large and significant increases were in the Black and Northeast Cape Fear River basins. Almost all of these sites has watersheds with abundant swine CAFOs, and, where data were available, abundant poultry CAOs as well (Table 3.1). Such sites included 6RC, GCO and LCO in the Black River basin, and ROC, ANC and ANC in the Northeast Cape Fear River basin. However, we note there were some locations that also had influence from small NPDES sources located upstream of the sampling sites, especially NC403 and ROC. Also, most nutrients did not show significant decreases in the mainstem Cape Fear River from NC11 downstream into the upper estuary (Table 3.2).

The principal response variable chlorophyll *a* showed several statistical increases as noted, but most of those were small. This is likely due to two reasons. First, the lower Cape Fear watershed has physical characteristics that work against long-term bloom formation in that the waters are darkly stained, which inhibits sunlight penetration. Second, in stream sites we know that algal blooms occur especially in summer, but appear to be washed out regularly by the intense thunderstorms that characterize the southeast in summer (see Mallin et al. 2015) for a fuller explanation.

The case of orthophosphate was particularly intriguing. There were a few increases in the Black and Northeast Cape Fear basins (ANC, 6RC, COL, B210) and a few deceases (SAR, NC403, SR, BRN). However, the mainstem stations from NC11 downstream through M54 all showed significant decreases (Table 3.2). The reason for this is unclear. This stretch of the lower system is most subject to large NPDES point sources discharges. The fact that orthophosphate trended lower, and the other nutrients showed no increases appears to demonstrate adherence to nutrient discharge limits.

In contrast to nutrients, fecal coliform bacteria showed, small, but statistically significant increases in the Cape Fear River sites from NC11 downstream to the upper estuary. The reason for the increases along the mainstem are not clear. Population may be the key; from 2000 to 2020 in the Cape Fear basin (excluding the Black and Northeast Cape Fear basins) human population increased by about 549,000, or a 36% increase (from data to be included in the upcoming NCDEQ Basinwide Plan). Previous research determined that exurban growth leads to fecal bacterial increases in nearby waterways (Alford et al 2016); thus such rapid growth may account for the mainstem bacteria increases. In the Black and Northeast Cape Fear basins, the previously mentioned factors likely accounted for the bacterial pollution as well as nutrient pollution.

3.5. References Cited

Alford, J.B., K.G. Debbage, M.A. Mallin and Z.-J. Liu. 2016. Surface water quality and landscape gradients in the North Carolina Cape Fear River basin: the key role of fecal coliform. *Southeastern Geographer*. 56:428-453.

Berryman, D., B. Bobée, D. Cluis and J. Haemmerli, 1988, Nonparametric Tests For Trend Detection In Water Quality Time Series. JAWRA Journal of the American Water Resources Association, 24: 545-556. https://doi.org/10.1111/j.1752-1688.1988.tb00904.x

Gotelli, N.J. and A.M. Ellison. 2004. A Primer of Ecological Statistics. Sinauer Associates, Inc. Publishers.

Hirsch, R. M., J.R. Slack & R.A. Smith. 1982. Techniques of trend analysis for monthly water quality data. Water Resources Research, 18(1), 107-121. https://doi.org/10.1029/WR018i001p00107

Kendall, M. G. 1938. A New Measure of Rank Correlation. Biometrika, 30(1/2), 81–93. https://doi.org/10.2307/2332226

Mallin, M.A., S.H. Ensign, M.R. McIver, G.C. Shank and P.K. Fowler. 2001. Demographic, landscape, and meteorological factors controlling the microbial pollution of coastal waters. *Hydrobiologia* 460:185-193.

Mallin, M.A., M.R. McIver, A.R. Robuck and A.K. Dickens. 2015. Industrial swine and poultry production causes chronic nutrient and fecal microbial stream pollution. *Water, Air and Soil Pollution* 226:407, DOI 10.1007/s11270-015-2669-y.

Meals, D.W., J. Spooner, S.A. Dressing and J.B. Harcum. 2011. Statistical analysis for monotonic trends, Tech Notes 6, November 2011. Developed for U.S. Environmental Protection Agency by Tetra Tech, Inc., Fairfax, VA, 23 p. Available online at https://www.epa. gov/polluted-runoff-nonpoint-source-pollution/nonpoint-source-monitoringtechnical-notes.

Mozejko, J. 2012. Detecting and Estimating Trends of Water Quality Parameters. In K. Voudouris, & D. Voutsa (Eds.), Water Quality Monitoring and Assessment. IntechOpen. https://doi.org/10.5772/33052

NCDEQ 2017. 2017 White Lake Water Quality Investigation, White Lake, Bladen County (Cape Fear Basin). North Carolina Department of Environmental Quality, Division of Water Resources.

Patt, H. 2017. A comparison of PAN and P_2O_5 produced from poultry, swine and cattle operations in North Carolina. North Carolina Division of Water Resources, Department of Environmental Quality, Raleigh.

Shank, G.C. and P. Zamora. 2019. Influence of Groundwater Flows and Nutrient Inputs on White Lake Water Quality, Final Report.

Table 3.1. Station descriptions including watershed information (see also Chapter 1, Figure 1.1 and Table 1.1. There is additional information from the Environmental Working Group and the Waterkeeper Alliance; also the NCDEQ website, also see Mallin et al. (2001).

Site	Description

Black River watershed sites: Note that there are no NPDES point source dischargers upstream of the LCFRP Black River sampling sites.

Station SR South River, 3rd order, upper watershed near Fayetteville, approximately 80 swine CAFOs in watershed (but 7 upstream of the sampling site), unknown number of poultry CAFOs, one NPDES discharger upstream of the sampling site, about 14% wetlands coverage.

Station COL Colly Creek, 3nd order, watershed approximately 55% wetland coverage; a tributary of the Black River; four swine CAFOs; note the Town of White Lake is in the headwater and has a failing sewage system.

Station 6RC Six Runs Creek, 3rd order tributary of the Black River, high influence of CAFOs (179 swine and 107 poultry CAFOs), about 8% wetlands coverage.

Station GCO   Great Coharie Creek, 3rd order, watershed contains 95 swine CAFOs and an unknown number of poultry CAFOs, about 11% wetlands coverage.

Station LCO Little Coharie Creek (LCO) –3rd order, 63 swine CAFOs in basin, unknown number of poultry CAFOs.

Station B210 is located in the lower 5th order Black River and is considered the main collector site for the Black River watershed.

Northeast Cape Fear River watershed sites

NC403 - Northeast Cape Fear River headwaters, 1st order, drains a watershed that hosts nine swine CAFOs, traditional agriculture; grazing cattle, and an NPDES point source wastewater discharge (1 MGD).

Station PB - Panther Branch, 1st order tributary of Northeast Cape Fear River, receives a NPDES point source wastewater discharge (0.5 MGD); one poultry CAFO in watershed.

Station SAR – Sarecta – located in the upper Northeast Cape Fear River proper.

Station AC - Angola Creek, 3rd order, contains 13 swine CAFOs, unknown number of poultry CAFOs, 27% wetlands coverage.

Station GS - Goshen Swamp, 3rd order, watershed contains 119 swine CAFOs and an unknown number of poultry CAFOs, 14% wetlands coverage.

Station ROC – Rockfish Creek, 4th order, Basin hosts about 74 swine CAFOs, an unknown number of poultry CAFOs and there is a 1.5 MGD point-source discharge (poultry rendering) upstream from our sampling site; note there is a 5.4 MGD municipal discharge into the creek about 10 m downstream of the sampling site, which during low flow backs upstream tour site. This watershed has about 16% wetlands coverage.

Station LRC – Little Rockfish Creek, formerly hosted an NPDES discharge but no longer does, mainly a non-point area, unknown number of swine and poultry CAFOs.

Station NCF17 is considered the main collector site for the 5th order Northeast Cape Fear River and is upstream of NCF6, fresh but tidal.

Station NCF6 is located in the upper estuary of the 5th order Northeast Cape Fear River about 6 miles upstream of Wilmington, generally oligohaline.

Main Cape Fear River: The Cape Fear watershed is 9,165 square miles, is the most heavily industrialized in NC with 218 NPDES wastewater discharges with a permitted flow of approximately 425 million gallons per day, and (as of 2020) and an estimated 2.3 million people residing in the basin (this is preliminary information from the Draft Cape Fear River Basin Plan – 11-18-22. The majority of NPDES point sources enter the Cape Fear River upstream of Lock and Dam #1, except for the Wilmington area.

Stations NC11, AC, DP and IC are located in the mainstem of the 6th order Cape Fear River, downstream of Lock and Dam #1 to above the Navassa Bridge, just upstream of the City of Wilmington.

Stations NAV, HB, BRR, M61, M54, M35, M23 and M18 are located along the Cape Fear Estuary moving downstream from the Navassa Bridge, past Wilmington and the State Port (M61) to the most oceanward station M18. Station M54 is the site closest to the Wilmington south Side wastewater treatment plant discharge along the shore (sampling station is mid-channel).

Station BRN - Browns Creek, 2nd order tributary of the Cape Fear River, presence of three swine CAFOs and traditional agriculture; drains stormwater from Elizabethtown (4,000 residents), about 13% wetland coverage.

Station HAM - Hammond Creek, 2nd order tributary of the Cape Fear River, 13 swine CAFOs and four poultry CAFOs, traditional agriculture, about 6% wetland coverage.

Table 3.2. Lower Cape Fear River Program sampling sites included in the 20-year trend analysis for nutrients, fecal coliform bacteria (FC) and chlorophyll *a*. + = significant increase, - = significant decrease. Only significant increases or decreases demonstrated by two or three statistical tests are presented. Note that the estuarine sites (BRR-M18) were not included in the fecal coliform analysis because fecal coliform sampling was ceased at those sites in 2011 and *Enterococcus* sampling was initiated.

	Ammonium	Nitrate	TN	OP	TP	FC
Cape Fear River mainstem sites						
NC11				-		+
AC				-		+
DP				-		+
IC				-		+
NAV				-		
HB				-		+
BRR				-		
M61				-		
M54				-		
M35					+	
M23					+	
M18					+	
BRN		+	+	-		+
HAM		+				+
Black River watershed sites						
SR		+		-		+
COL	+	+		+	+	+
6RC	+	+	+		+	+
GCO	-	+	+		+	+
LCO		+			+	+
B210		+	+	+	+	+
Northeast Cape Fear River watershed sites						
NC403	+	+	+	-		+
PB				+	+	
ANC		+		+	+	+
GS	-					
SAR	-			-		+
ROC		+	+			+
LRC		+	+	+	+	+
NCF117		+			+	+
NCF6				+	+	

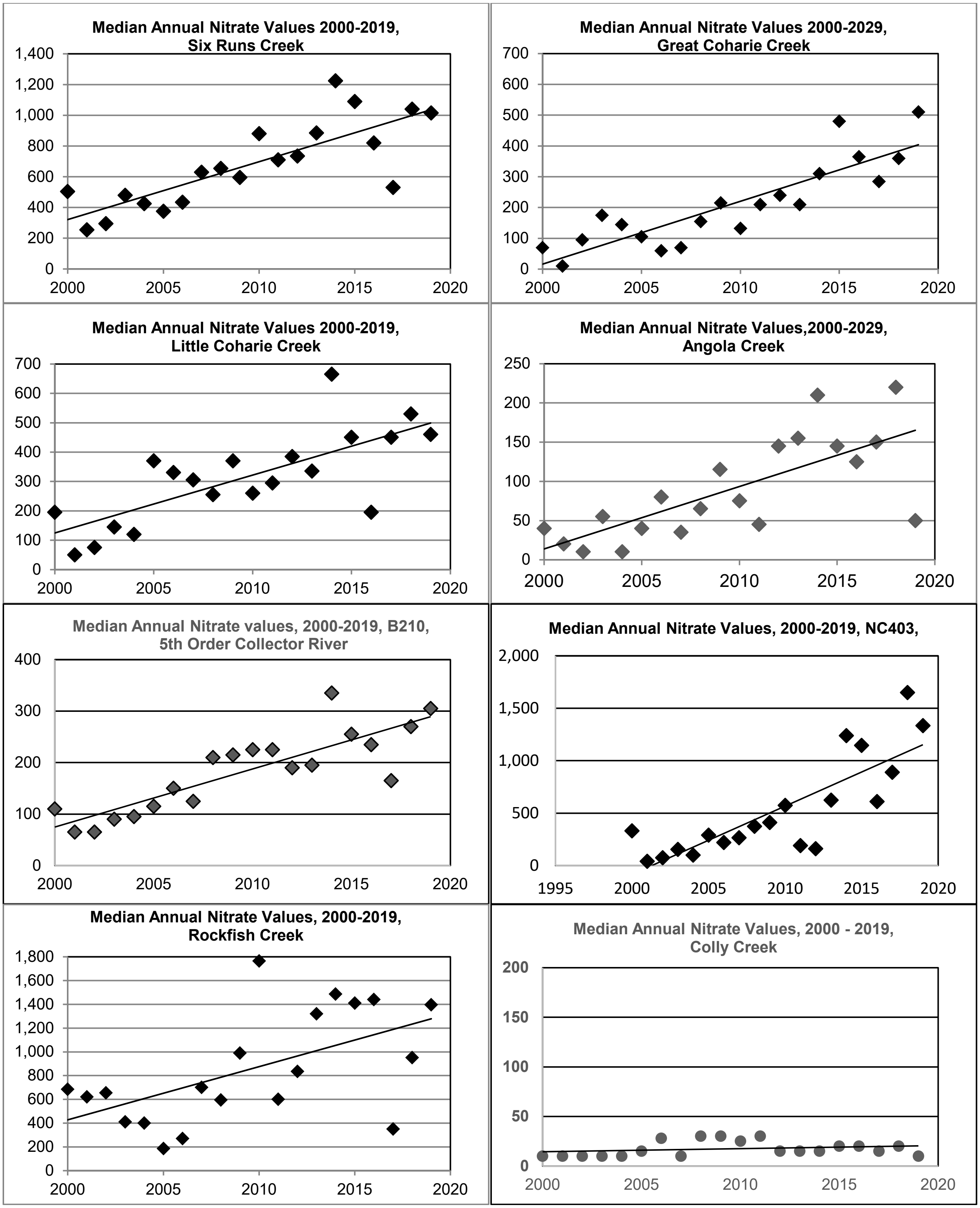


Figure 3.1. Long term nitrate trends for several key sampling sites in the lower Cape Fear River watershed, presented as annual medians, significant as $p < 0.05$ (Colly Creek non-significant).

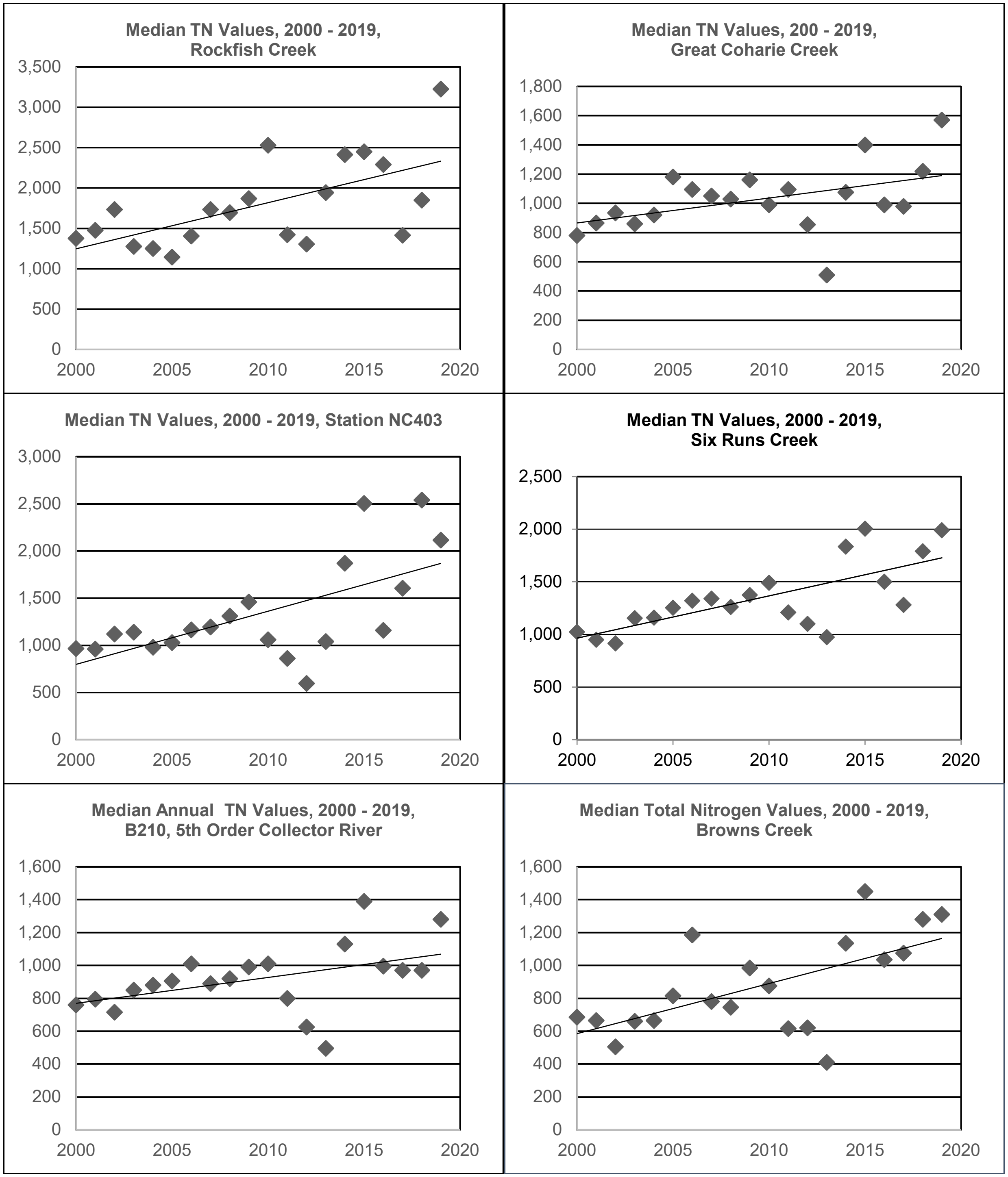


Figure 3.2. Long term total nitrogen (TN) trends for several key sampling sites in the lower Cape fear watershed, presented as annual medians, 2000 – 2019, significant at $p < 0.05$.

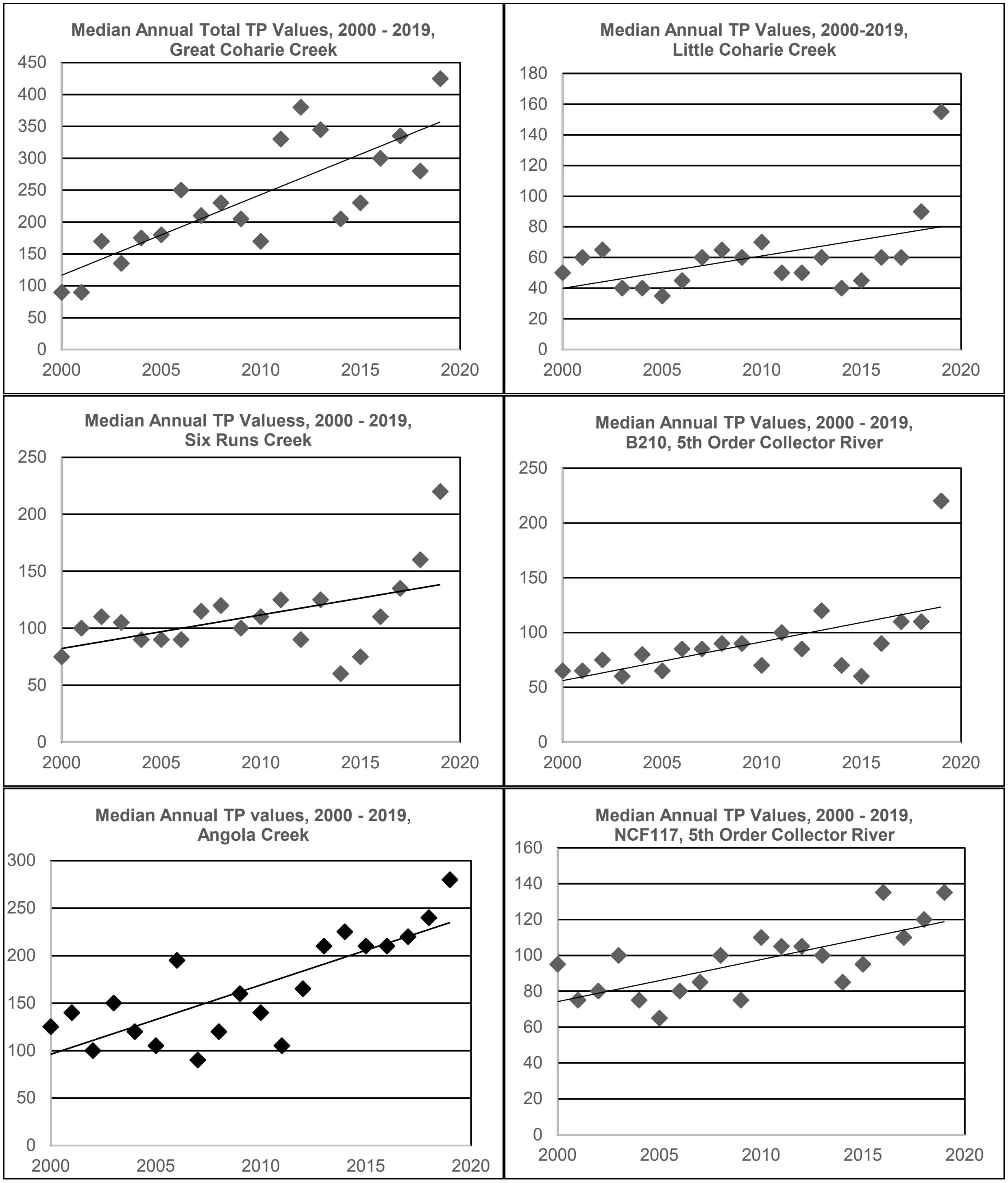


Figure 3.3. Long term total phosphorus (TP) trends for several key sampling sites in the lower Cape fear River basin, presented as annual medians, 2000-2019, significant at $p < 0.05$.

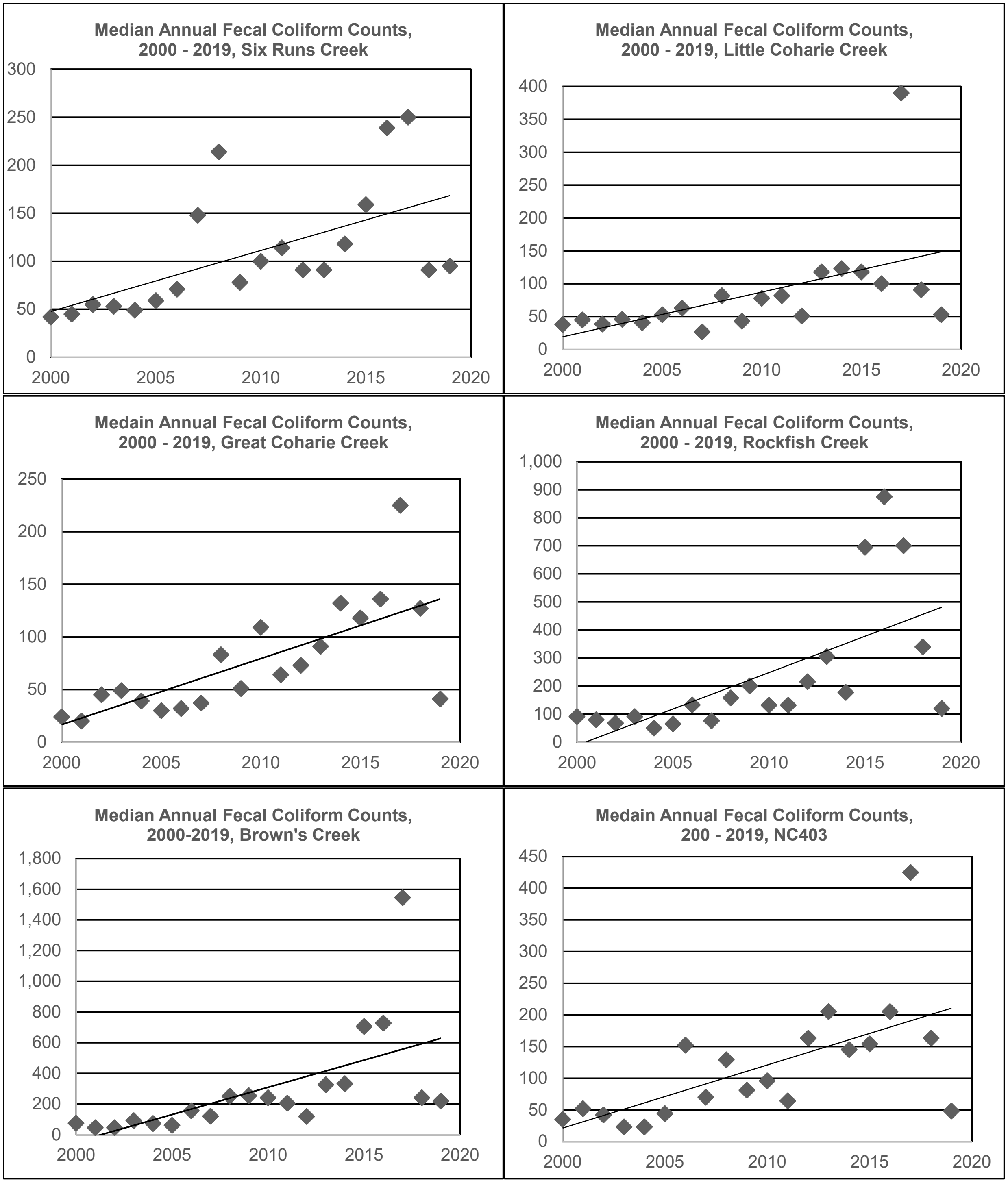


Figure 3.4. Long term fecal coliform bacteria count trends at key sampling sites in the lower Cape Fear River watershed, presented as annual medians, significant at $p < 0.05$.