ENVIRONMENTAL QUALITY OF WILMINGTON AND NEW HANOVER COUNTY WATERSHEDS 2006-2007

by

Michael A. Mallin, Matthew R. McIver, Mary I.H. Spivey, Mary E. Tavares, Troy D. Alphin and Martin H. Posey,

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

This report represents combined results of Year 13 of the New Hanover County Tidal Creeks Project and Year 9 of the Wilmington Watersheds Project. Water quality data are presented from a watershed perspective, regardless of political boundaries. The combined programs involved 11 watersheds and 57 sampling stations. In this summary we first present brief water quality overviews for each watershed from data collected between August 2006 – September 2007.

Barnards Creek – Barnards Creek drains into the Cape Fear River Estuary. It drains a 2,944 acre watershed that consists of is about 17% impervious surface coverage, and a population of 12,547. There was one station sampled in this watershed during 2007, lower Barnard's Creek at River Road. This site had good water quality in terms of algal blooms, BOD, turbidity, and fecal bacteria. It had some issues with low dissolved oxygen, but no extreme problems.

Bradley Creek – Bradley Creek drains the largest tidal creek watershed in the area (6,016 acres), including much of the UNCW campus, into the Atlantic Intracoastal Waterway (ICW). The watershed contains about 23% impervious surface coverage. Seven sites were sampled, all from shore. In 2007 there were no problems with excessive turbidity, but there were a few algal blooms in the upper branches. Dissolved oxygen was good to fair at all sites except the branch at College Acres (BC-CA) and the north branch (BC-NB) at Wrightsville Avenue, where the water was rated as poor quality from low dissolved oxygen. Fecal coliform bacteria samples were collected at one station in 2006-2007 (BC-CA) which showed very high fecal bacteria counts. There was one sewage spill in the creek near Wrightsville Avenue in July 2007.

Burnt Mill Creek – Burnt Mill Creek drains a 4,288 acre watershed which is extensively urbanized (36% impervious surface coverage) into Smith Creek. Six locations were sampled in 2007. This creek has very poor water quality, with large algal blooms, extensive substandard dissolved oxygen, and major issues with high fecal coliform counts, with all six sites exceeding the human contact standard > 25% of occasions sampled. Restoration efforts are continuing in a joint effort by the City, NCSU, and UNCW funded through the US EPA. Sediment metals concentrations were below harmful levels except for lead at the Princess Place site. However, sediment polychlorinated aromatic hydrocarbon (PAH) concentrations exceeded levels known as harmful to aquatic biota at five of the six sampling sites.

The effectiveness of Ann McCrary wet detention pond and the Kerr Avenue wetland as pollution control devices was poor during 2007. Several water quality parameters indicated a subsequent worsening of the creek from where it exited the detention pond to the downstream Wallace Park and Princess Place sampling stations.

Futch Creek – Futch Creek is situated on the New Hanover-Pender County line and drains a 3,106 acre watershed into the ICW. Six locations were sampled by boat. Futch Creek maintained good microbiological water quality in the lower stations and Foy Creek, as it has since channel dredging at the mouth occurred in 1995 and 1996. there were some minor algal bloom and low dissolved oxygen problems in 2006-2007.

However, this creek continues to display good water quality relative to other creeks in the New Hanover County tidal creek system, due to generally low development and impervious surface coverage in its watershed.

Greenfield Lake – This lake drains a watershed of 2,560 acres, covered by about 36% impervious surface area. This urban lake was sampled at three tributary sites and three in-lake sites. The three tributaries of Greenfield Lake (near Lake Branch Drive, Jumping Run Branch, and Lakeshore Commons Apartments) all suffered from severe low dissolved oxygen problems. All three of the tributaries also had frequent high fecal coliform counts, and maintained geometric mean counts well in excess of the state standard for human contact waters.

Algal blooms are periodically problematic in Greenfield Lake, and have occurred during all seasons, but are primarily a problem in spring and summer. Fortunately the number of blooms in 2007 dropped considerably from 2006, either a result of the remedial action by the City or less stormwater runoff and lower nutrient inputs as a result of the drought. Low dissolved oxygen was found only at the uppermost lake station GL-2340. High biochemical oxygen demand (BOD5 > 3.0 mg/l) continues to occur at the in-lake stations. Despite the drought, high fecal coliform counts continue to impact the lake.

In spring of 2005 and 2006 several steps were taken by the City of Wilmington to restore viability to the lake. Sterile grass carp were introduced to the lake to control (by grazing) the overabundant aquatic macrophytes and four SolarBee water circulation systems were installed in the lake to improve circulation and force dissolved oxygen from the surface downward toward the bottom. Also, on several occasions a contract firm applied the herbicide Sonar to further reduce the amount of aquatic macrophytes. These actions led to a major reduction in aquatic macrophytes lake wide. In 2007 there was good dissolved oxygen at two of the stations (especially nearest the SolarBees), but low dissolved oxygen concentrations were measured at GL-2340, near the upper lake. In 2006 and 2007 there was a highly statistically significant relationship within the lake between chlorophyll *a* and BOD5, meaning that the algal blooms are an important cause of low dissolved oxygen in this lake. Thus, a challenge for Greenfield Lake is to continue to reduce the frequency and magnitude of the algal blooms, which will lead to continuing dissolved oxygen improvements.

Hewletts Creek – Hewletts Creek drains a large (5,952 acre) watershed into the Intracoastal Waterway. This watershed has about 19% impervious surface coverage. In recent years this system has been plagued by a number of sewage spills. In 2006-2007 the creek was sampled at five tidal sites and five non-tidal freshwater sites. There were several incidents of low dissolved oxygen seen in our sampling; three at NB-GLR (the north branch at Greenville Loop Rd.) and three at SB-PGR (the south branch at Pine Grove Rd.), although none were severe (below 3.5 mg/L). One large algal bloom and two minor blooms occurred at NB-GLR and one major and one minor bloom occurred at SB-PGR.

Sewage spills continued to be problematic in this creek in late 2006 when approximately 655,000 gallons leaked from the Northeast Interceptor in the period up to and on November 19 and an additional 72,000 on November 25. These incidents caused severe fecal pollution in the creek with fecal coliform bacteria counts in the upper middle branch at MB-PGR ranging from 21,000 to 226,000 CFU/100 mL during this period. Peak counts at the other upper creek stations were 48,000 CFU/100 mL at SB-PGR and 13,000 CFU/100 mL at NB-GLR, and at the lower creek stations 36,000 CFU/100 mL occurred at HC-3 and 13,000 CFU/100 mL at HC-2.

From January 2004 to September 2007 five non-tidal sites were sampled in the Hewletts Creek watershed. One site is PVGC-9, draining Pine Valley Country Club. This stream had some low dissolved oxygen problems but particularly high fecal coliform bacteria pollution problems, with counts exceeding the State standard on 100% of the occasions sampled in 2007. Generally high nitrate from fertilizer runoff characterizes this stream. The other sites were being sampled to gain pre and post construction information on the water quality of streams entering (DB-1, DB-2, DB-3) and exiting (DB-4) a newly constructed wetland/future park area known as the Dobo site, draining into the headwaters of Hewletts Creek. Dissolved oxygen was low, particularly so at DB-4. Fecal coliform bacteria counts were high at all sites, particularly DB-1 and DB-4 (these sites are essentially drainage ditches). With the completion of the wetland wet weather inflow and outflow studies are being planned to assess the performance of the wetland.

Howe Creek – Howe Creek drains a 3,264 acre watershed into the ICW. This watershed hosts a population of 4,224 with about 19% impervious surface coverage. Five stations were sampled in Howe Creek in 2006-2007. The drought had a positive effect on water quality in this creek, with lower nutrient and fecal bacteria inputs from less stormwater runoff. Algal blooms and turbidity showed no problems, and only the uppermost station sampled was rated poor for fecal coliform bacteria (the others were rated good for 2006-2007). Dissolved oxygen concentrations were generally good in lower Howe Creek and fair in upper Howe Creek. Since wetland enhancement was performed in 1998 above Graham Pond the creek below the pond at Station HW-GP has had fewer and smaller algal blooms than before the enhancement.

Motts Creek – Motts Creek drains into the Cape Fear River Estuary. This creek was sampled at one station, at River Road. Dissolved oxygen concentrations were below the state standard of 5.0 mg/L on four of seven occasions in 2007 (minimum 2.4 mg/L) for a poor rating. Neither turbidity nor suspended solids were problematic in 2007, and there was one minor algal bloom. However, fecal coliform bacteria contamination was a problem in Motts Creek, with the State standard of 200 CFU/100 mL exceeded on four of seven occasions (an improvement over the previous year, however). BOD5 samples yielded a mean value of 1.5 mg/L and a median value of 1.6 mg/L, generally higher than the previous year. Thus, this creek showed mixed water quality, with no algal bloom or turbidity problems, but poor dissolved oxygen and fecal coliform conditions.

Pages Creek – Pages Creek drains a 3,039 acre watershed into the ICW. This creek was sampled at nine stations, two of which receive drainage from developed areas near Bayshore Drive (PC-BDUS and PC-BDDS). There were no algal blooms or turbidity problems in 2006-2007. Fecal bacteria water quality was good in the lower creek but had some incidences of elevated counts in the upper stations. One incident resulted from a sewage line spill near PC-H that our sampling detected in June 2007; the County subsequently repaired the problem. Dissolved oxygen levels were generally fair throughout the creek but poor at the uppermost station PC-H. Because of the relatively low watershed development and low amount of impervious surface coverage in the watershed, this is one of the least-polluted creeks in New Hanover County. However, we note that both dissolved oxygen and fecal coliform bacteria concentrations have deteriorated since 2000-2001, the last time all nine stations were sampled.

Smith Creek – Smith Creek drains into the lower Northeast Cape Fear River just upstream of where it merges with the Cape Fear River. It has a watershed of 2,880 acres that has about 28% impervious surface coverage, with a population of 25,904. Two estuarine sites on Smith Creek proper, SC-23 and SC-CH were sampled in 2007. Overall the water quality can be described as poor. Dissolved oxygen concentrations were poor at both stations, as were fecal bacteria counts. Turbidity was rated as fair at both sites, and algal blooms appeared to have increased in this creek over recent years.

Whiskey Creek – Whiskey Creek is the southernmost large tidal creek in New Hanover County that drains into the ICW. It has a watershed of 1,344 acres, a population of 7,107, and is covered by approximately 17% impervious surface area. Four stations were sampled from shore along this creek in 2006-2007. Whiskey Creek had low to moderate nutrient loading and only one algal bloom. This creek had good water quality in terms of dissolved oxygen and turbidity in 2006-2007. Fecal coliform bacteria were not sampled in 2006-2007 in Whiskey Creek.

Water Quality Station Ratings – The UNC Wilmington Aquatic Ecology Laboratory utilizes a quantitative system with four parameters (dissolved oxygen, chlorophyll *a*, turbidity, and fecal coliform bacteria) to rate water quality at our sampling sites. If a site exceeds the North Carolina water quality standard for a parameter less that 10% of the time sampled, it is rated Good; if it exceeds the standard 10-25% of the time it is rated Fair, and if it exceeds the standard > 25% of the time it is rated Poor for that parameter. We applied these numerical standards to the water bodies described in this report, based on 2006-2007 data, and have designated each station as good, fair, and poor accordingly (Appendix B).

Fecal coliform bacterial conditions for the entire Wilmington City and New Hanover County Watersheds system (42 sites sampled for fecal coliforms) showed 38% to be in good condition, 10% in fair condition, and 52% in poor condition. Dissolved oxygen conditions system-wide (57 sites) showed 32% of the sites were in good condition, 35% were in fair condition, and 33% were in poor condition. For chlorophyll *a*, 82% of the stations were rated as good, 12% as fair and 5% as poor.

The drought reduced the inputs of nutrients into the creeks and there were fewer algal blooms in the creeks entering the ICW and Greenfield Lake. However, Burnt Mill and Smith Creeks continued to have algal blooms problems despite the drought. In some systems the reduced runoff from the drought led to lower fecal bacteria inputs, but some water bodies continued to have major fecal bacteria problems regardless (Burnt Mill Creek, upper Bradley Creek, Smith Creek, Greenfield Lake). It is important to note that the three water bodies with the worst water quality in the system also have the most developed watersheds with the highest impervious surface coverage (Burnt Mill Creek –

36% impervious coverage; Greenfield Lake – 36% impervious coverage; Smith Creek – 28% impervious coverage).

Optical Brighteners, Fecal Bacteria, and Detecting Sewage Leaks in Tidal Creeks – Optical brighteners (OBs) are commonly used in laundry detergents to prevent color fading in clothes. With used wash water they are flushed into the sewer or septic systems where they can persist until they become degraded by chlorination or UV radiation from sunlight. If found in surface waters their presence may indicate sewage or septic system leaks or spills. We sampled OBs along with fecal coliform bacteria in Bradley, Futch, and Hewletts Creeks on three occasions in fall 2007. OBs were in low concentration in Futch Creek and unrelated to fecal coliform counts. However, OB concentrations and fecal coliform concentrations were strongly correlated in Bradley Creek and Hewletts Creek (especially the middle branch), indicating they may have come from the same sources. Both of these creeks suffered from sewage spills in the past two years. The correlation betweens OBs and coliforms may indicate that there are ongoing sewage leaks or faulty septic systems in Bradley and Hewletts Creeks.

Oyster Reef condition in Three Tidal Creeks - Oyster reef work as performed by the UNCW benthic Ecology Laboratory is continuing on the tidal creeks, with emphasis on Howe, Hewletts and Pages creeks. There seems to be a good supply of larval oysters into the creeks that settle on all available areas of shell. In 2006 live oyster density was greatest in Howe Creek, but older shell material apparently is rapidly covered by sediments coming in from upstream construction activities. Pages Creek had the highest percent coverage of both live and dead shell material. There were no consistent differences among the three creeks with respect to oyster reef complexity (called rugosity) and condition of the individual oysters. Individual oyster condition was elevated in 2006, but in summer 2005 and 2007 it was comparable to oyster conditions found in some highly impacted systems in Chesapeake Bay. The majority of the oyster population in the tidal creeks appears to be in the sub-legal size range (45-55mm). We expected to see a shift in the size distribution toward a greater percentage of larger (>75mm) oysters since none of the areas sampled are subject to harvest pressure. This does not appear to be the case. The UNCW Benthic Ecology Lab continues to evaluate potential causes of the for the loss of larger size class of oyster. Based on finding reported in 2006 this loss does not appear to be the result of DERMO infections that although highly prevalent, were not intense.

Table of Contents

1.0 Introduction

In 1993 scientists at the UNC Wilmington Center for Marine Science Research began studying five tidal creeks in New Hanover County. This project, funded by New Hanover County, the Northeast New Hanover Conservancy, and UNCW, yielded a comprehensive report detailing important findings from 1993-1997, and produced a set of management recommendations for improving creek water quality (Mallin et al. 1998a). Data from that report were later published in the peer-reviewed literature (Mallin et al. 2000a; Mallin et al. 2001) and were used in 2006 by the N.C. General Assembly (Senate Bill 1566) as the scientific basis to redefine low density coastal areas as 12% impervious surface coverage instead of the previously used 25% impervious cover. In 1999-2000 Whiskey Creek was added to the matrix of tidal creek watersheds analyzed in our program.

In October 1997 the Center for Marine Science began a project (funded by the City of Wilmington Engineering Department) with the goal of assessing water quality in Wilmington City watersheds under base flow conditions. Also, certain sites were analyzed for sediment heavy metals concentrations (EPA Priority Pollutants). In the past six years we have produced combined Tidal Creeks – Wilmington City Watersheds reports (Mallin et al. 1998b; 1999; 2000b; 2002a; 2003; 2004; 2006a; 2007). In the present report we present results of continuing studies from August 2006 - July 2007 in the tidal creek complex and January - September 2007 in the City of Wilmington watersheds. The UNCW Aquatic Ecology Laboratory is also involved with a project headed up by North Carolina State University (NCSU) and funded through the EPA 319 Grant program that is designed to provide stream restoration to Burnt Mill Creek. Thus, three stations have been added to the Burnt Mill creek sampling matrix under this program.

The water quality data within are presented from a watershed perspective. Some of the watersheds cross political boundaries (i.e. parts of the same watershed may lie in the County but not the City). Bradley and Hewletts Creeks are examples. Water quality parameters analyzed in the tidal creeks include water temperature, pH, dissolved oxygen, salinity/conductivity, turbidity, nitrate, ammonium, orthophosphate, chlorophyll *a*, and in selected creeks fecal coliform bacteria. Similar analyses were carried out in the City watersheds with the addition of total Kjeldahl nitrogen (TKN), total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS) and biochemical oxygen demand (BOD) at selected sites.

1.1 Water Quality Methods

Field parameters were measured at each site using a YSI 6920 Multiparameter Water Quality Probe (sonde) linked to a YSI 650 MDS display unit. Individual probes within the instruments measured water temperature, pH, dissolved oxygen, turbidity, salinity, and conductivity. YSI Model 85 and 55 dissolved oxygen meters were also used on occasion. The instruments were calibrated prior to each sampling trip to ensure accurate measurements. The UNCW Aquatic Ecology laboratory is State-Certified for field measurements (temperature, conductivity, dissolved oxygen and pH) and for laboratory chlorophyll *a* measurements. The light attenuation coefficient $\underline{k}$ was determined (at locations where depth permitted), 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.

For the six tidal creeks, water samples were collected monthly, at or near high tide. For nitrate+nitrite (hereafter referred to as nitrate) and orthophosphate assessment, three replicate acid-washed 125 mL bottles were placed ca. 10 cm below the surface, filled, capped, and stored on ice until processing. In the laboratory the triplicate samples were filtered simultaneously through 25 mm Millipore AP40 glass fiber filters (nominal pore size 1.0 micrometer) using a manifold with three funnels. The pooled filtrate was stored frozen until analysis. Nitrate+nitrite and orthophosphate were analyzed using a Bran-Luebbe AutoAnalyzer following EPA protocols. Samples for ammonium were collected in duplicate, field-preserved with phenol, stored on ice, and analyzed in the laboratory according to the methods of Parsons et al. (1984). Fecal coliform samples were collected by filling pre-autoclaved containers ca. 10 cm below the surface, facing into the stream. Samples were stored on ice until processing (< 6 hr). Fecal coliform concentrations were determined using a membrane filtration (mFC) method (APHA 1995). North Carolina water quality standards are listed in Appendix A.

The analytical method used to measure chlorophyll *a* is described in Welschmeyer (1994) and US EPA (1997). Chlorophyll *a* concentrations were determined from the 1.0 micrometer glass fiber filters used for filtering samples for nitrate+nitrite and orthophosphate analyses. All filters were wrapped individually in aluminum foil, placed in an airtight container and stored in a freezer. During the analytical process, the glass filters were separately immersed in 10 ml of a 90% acetone solution. The acetone was allowed to extract the chlorophyll from the material for 18-24 hours. The solution containing the extracted chlorophyll was then analyzed for chlorophyll *a* concentration using a Turner AU-10 fluorometer. This method uses an optimal combination of excitation and emission bandwidths that reduces errors in the acidification technique.

Samples were collected on six occasions within the Wilmington City watersheds from January through September 2006. Field measurements were taken as indicated above. Nutrients (nitrate, ammonium, total Kjeldahl nitrogen, total nitrogen, orthophosphate, and total phosphorus) and total suspended solids (TSS) were analyzed by a state-certified contract laboratory using EPA and APHA techniques. We also computed inorganic nitrogen to phosphorus molar ratios for relevant sites (N/P). Chlorophyll *a* was run at UNCW-CMS as described above, except filters were ground using a Teflon grinder prior to extraction.

For a large wet detention pond (Ann McCrary Pond on Burnt Mill Creek) and for a constructed wetland on Kerr Avenue (at the headwaters area of Burnt Mill Creek) we collected data from input (control) and outfall stations. We used these data to test for statistically significant differences in pollutant concentrations between pond input and output stations. The data were first tested for normality using the Shapiro-Wilk test. Normally distributed data parameters were tested using the paired-difference t-test, and non-normally distributed data parameters were tested using the Wilcoxon Signed Rank test. Statistical analyses were conducted using SAS (Schlotzhauer and Littell 1987).

2.0 Barnards Creek

Snapshot
Watershed area: 2,944 acres (1,191 ha) Impervious surface coverage: 17%
Watershed population: 12,547
Overall water quality: Good
Problematic pollutants: Low dissolved oxygen

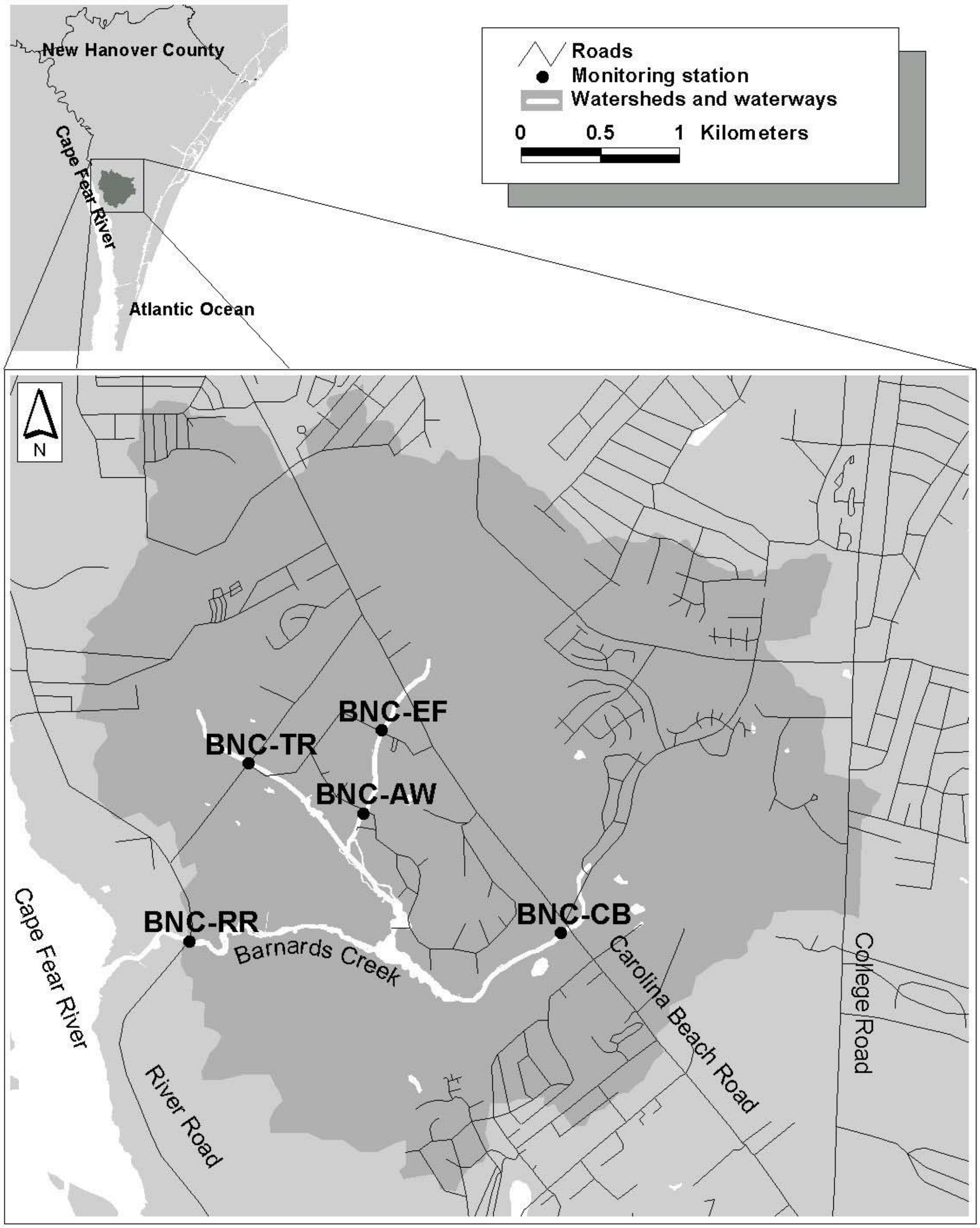
The water quality of lower Barnard's Creek is an important issue as single family and multifamily housing construction has occurred upstream of Carolina Beach Rd. in the St. Andrews Dr. area. Another major housing development is breaking ground for the area east of River Road and between Barnards and Motts Creeks. In 2007 we collected data at a station located on Barnards Creek at River Road (BNC-RR) that drains part of this area (Fig. 2.1).

BNC-RR had an average salinity of 14.9 ppt with a range of 3.8-25.4 ppt, higher than the previous year. This station had dissolved oxygen levels ranging from 3.4-5.1 from May through September, with two of those months having DO less than 3.6 mg/L. Concentrations of nitrate and orthophosphate were among the highest in the Wilmington area, but concentrations of the other nutrient species were unremarkable (Table 2.1). Turbidity on average was moderate (13 NTU), and did not exceed the state standard for estuarine waters of 25 NTU. Average total suspended solids concentrations were among the highest among area creeks, but there was only one minor algal bloom of 20 µg/L chlorophyll *a* in August 2007 (Table 2.1). BOD5 was sampled seven times at BNC-RR yielding a median of 1.3 mg/L and a mean of 1.5 mg/L, which was similar to the BOD5 concentrations found the past two years (Mallin et al. 2006a; 2007). Fecal coliform counts did not exceed the state standard on any sampling occasions, slightly better than the previous year. Thus, in 2007 this station was impaired by low dissolved oxygen, with no other parameters exhibiting problems.

Table 2.1. Mean and standard deviation of water quality parameters in Barnards Creek watershed, January - September 2007. Fecal coliforms as geometric mean; N/P ratio as median (n = 7 for all parameters).

Parameter BNC-RR	mean (st. deviation)	range
Salinity (ppt)	14.9 (9.0)	3.8-25.4
DO (mg/L)	5.7 (2.5)	3.4-9.7
Turbidity (NTU)	13 (5)	7-23
TSS (mg/L)	19 (10)	10-41
Nitrate (mg/L)	0.229 (0.147)	0.080-0.490
Ammonium (mg/L)	0.114 (0.083)	0.020-0.220
TN (mg/L)	0.874 (0.376)	0.370-1.390
Phosphate (mg/L)	0.047 (0.008)	0.040-0.060
TP (mg/L)	0.096 (0.018)	0.070-0.120
N/P molar ratio	13.0	
Chlorophyll *a* (μg/L)	9.8 (6.0)	2.4-20.0
BOD5	1.4 (0.4)	0.7-2.0
Fecal coliform bacteria (/100 mL)	55	3-140

Figure 2.1 Barnards Creek watershed



3.0 Bradley Creek

Snapshot
Watershed area: 6,016 acres (2,435 ha) Impervious surface coverage: 23%
Watershed population: 16,719
Overall water quality: poor
Problematic pollutants: fecal bacteria, low dissolved oxygen, occasional algal blooms

The Bradley Creek watershed has been a principal location for Clean Water Trust Fund mitigation activities, including the purchase and renovation of Airlie Gardens by the County. The development of the former Duck Haven property bordering Eastwood Road is of great concern in terms of its potential water quality impacts to the creek. This creek is one of the most polluted in New Hanover County, particularly by fecal coliform bacteria (Mallin et al. 2000a). Seven stations were sampled in the past year, both fresh and brackish (Fig. 3.1).

As with last year, turbidity was not a major problem during 2006-2007 (Table 3.1). The standard of 25 NTU was exceeded only once during our sampling. There were some problems with low dissolved oxygen (hypoxia), with BC-NB having DO < 5.0 mg/L on four occasions and BC-CA having substandard dissolved oxygen conditions on four of seven sampling occasions (Appendix B).

Fecal coliform bacteria counts were not run on the tidal stations in 2006-2007. However, samples at the freshwater station BC-CA exceeded the standard on all seven of seven collections for a 100% exceedence rate, with a geometric mean of 3,677, 15X the state standard (Table 3.1).

Nitrate concentrations were highest at stations BC-CR, BC-CA, BC-SBU and BC-NBU. Nitrate concentrations were lower than the previous year (Mallin et al. 2007) likely a reflection of the drought and lower runoff. Ammonium was elevated at BC-CA, but low at other locations. The highest orthophosphate levels were found at BC-CA and BC-CR, with relatively low orthophosphate levels at the rest of the stations (Table 3.2). Bradley Creek did not host excessive algal blooms in 2006-2007 except at BC-SB, which had a bloom of 52 μg/L as chlorophyll *a* in May and BC-NB, which had a bloom of 37 μg/L in March (Table 3.2).

Table 3.1 Water quality parameter concentrations at Bradley Creek sampling stations, August 2006-July 2007. Data as mean (SD) / range, fecal coliform bacteria as geometric mean / range (for BC-CA, n = 7 months).

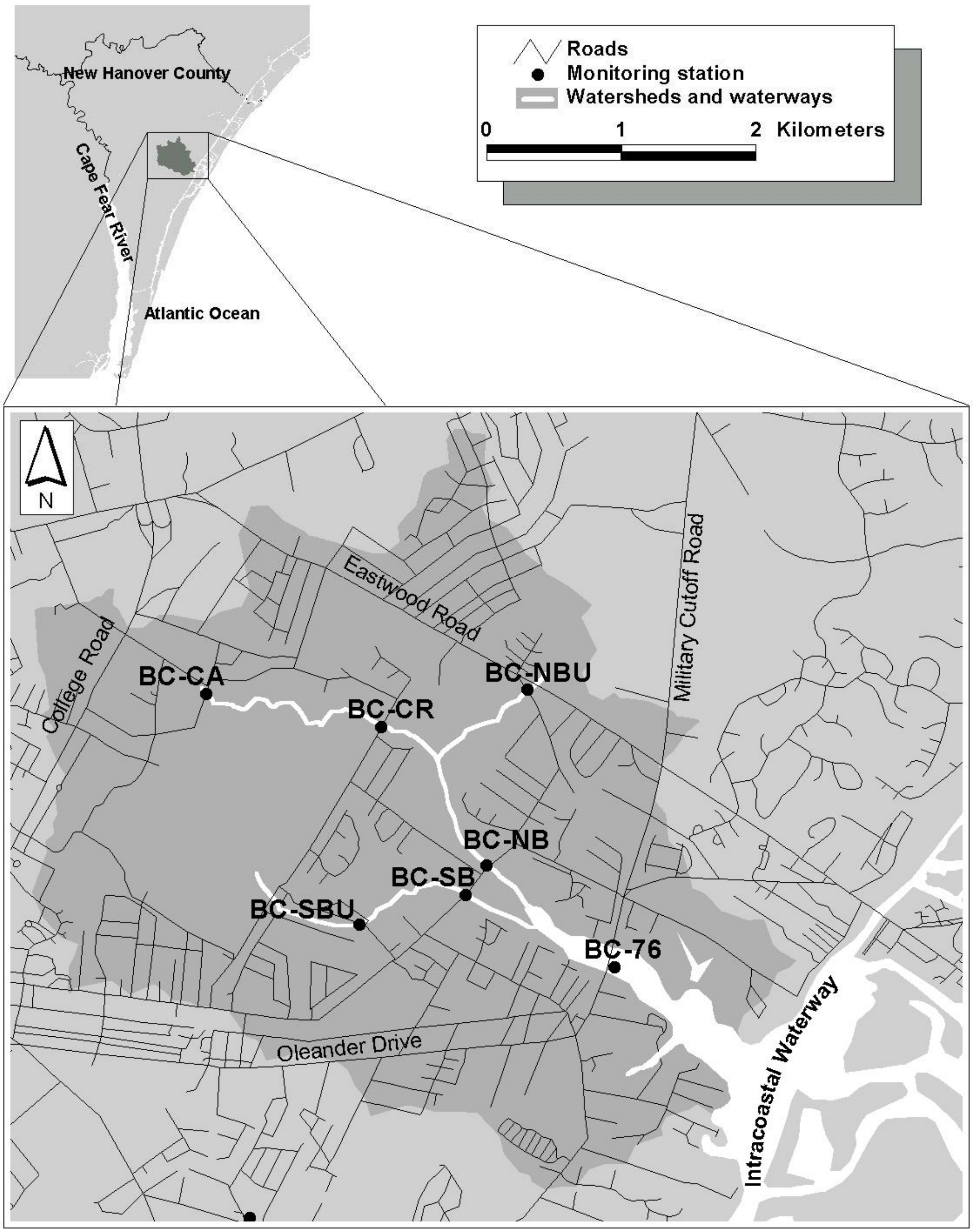
Station	Salinity (ppt)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Fecal coliforms (CFU/100 mL)
BC-76	31.5 (2.7) 25.9-34.6	5 (3) 0-12	6.9 (1.8) 4.1-9.5	
BC-SB	9.2 (10.1) 0.1-27.6	7 (6) 2-20	7.3 (1.8) 3.7-9.8	
BC-SBU	0.1 (0.0) 0.1-0.1	3 (3) 0-9	6.9 (1.1) 5.4-8.8	
BC-NB	24.2 (8.8) 5.7-32.6	9 (10) 0-36	7.1 (2.8) 2.9-12.6	
BC-NBU	2.0 (6.6) 0.1-23.0	9 (4) 4-18	7.3(1.2) 4.2-9.0	
BC-CR	0.2 (0.2) 0.0-0.8	2 (2) 0-8	7.8 (0.6) 7.1-8.9	
BC-CA	0.1 (0.0) 0.0-0.1	6 (3) 3-11	5.3 (2.5) 2.5-9.6	3677 364-60,000

Table 3.2. Nutrient and chlorophyll *a* data at Bradley Creek sampling stations, August 2006-July 2007. Data as mean (SD) / range, nutrients in mg/L, chlorophyll *a* as µg/L.

Station	Nitrate	Ammonium	Orthophosphate	Chlorophyll *a*
BC-76	0.011 (0.008) 0.003-0.029	0.016 (0.011) 0.001-0.031	0.010 (0.005) 0.004-0.022	2.7 (2.7) 0.2-10.3
BC-SB	0.019 (0.023) 0.004-0.077	0.023 (0.023) 0.001-0.060	0.020 (0.023) 0.003-0.077	8.3 (14.9) 0.5-52.3
BC-SBU	0.035 (0.042) 0.004-0.131	NA	0.030 (0.027) 0.001-0.072	2.2 (3.1) 0.1-9.8
BC-NB	0.021 (0.031) 0.005-0.107	0.028 (0.021) 0.002-0.066	0.018 (0.019) 0.004-0.065	5.8 (10.5) 0.3-36.9
BC-NBU	0.023 (0.023) 0.001-0.072	NA	0.041 (0.068) 0.001-0.219	0.8 (0.6) 0.2-1.9
BC-CR	0.082 (0.102) 0.001-0.301	NA	0.171 (0.223) 0.001-0.621	2.2 (3.4) 0.2-10.2
BC-CA	0.091 (0.099) 0.010-0.300	0.111 (0.060) 0.020-0.290	0.061 (0.05 0.010-0.150	11.0 (7.7) 4.5-24.6

NA = not analyzed

Figure 3.1. Bradley Creek watershed and sampling sites.



4.0 Burnt Mill Creek

Snapshot
Watershed area: 4,288 acres (1,735 ha) Impervious surface coverage: 36%
Watershed population: 26,511
Overall water quality: poor
Problematic pollutants: Fecal bacteria, algal blooms, low dissolved oxygen, high sediment PAH concentrations

In 1997 the City of Wilmington contracted with the Aquatic Ecology Laboratory at the UNC Wilmington Center for Marine Sciences to begin citywide water quality sampling. Since then the Burnt Mill Creek watershed (Fig. 4.1) has been sampled just upstream of Ann McCrary Pond on Randall Parkway (BMC-AP1), and about 40 m downstream of the pond outfall (BMC-AP3). Ann McCrary Pond is a large (28.8 acres) regional wet detention pond draining 1,785 acres, with an apartment complex at the upper end near BMC-AP1. The pond itself periodically hosts a thick growth of submersed aquatic vegetation, with *Hydrilla verticillata, Egeria densa, Alternanthera philoxeroides, Ceratophyllum demersum* and *Valliseneria americana* having been common at times. There have been efforts to control this growth, including addition of triploid grass carp as grazers. The ability of this detention pond to reduce suspended sediments and fecal coliform bacteria, and its failure to reduce nutrient concentrations, was detailed in a scientific journal article (Mallin et al. 2002b). Numerous waterfowl utilize this pond as well.

In 2005 sampling began on the inflow (BMC-KA1) and outflow (BMC-KA3) channels of the Kerr Avenue constructed wetland (Fig. 4.1). This sampling began as a part of a larger project (through North Carolina State University funded by the EPA 319 Program) to provide stream restoration to Burnt Mill Creek. Construction of the 0.7 acre Kerr Avenue Wetland was funded by the N.C. Wetlands Restoration Program, now known as the Ecosystem Enhancement Program. Wetland construction was completed in November 2000 and the first aquatic macrophyte planting (sponsored by Cape Fear River Watch) occurred later that month (various rushes, sedge, pickerelweed, lizard's tail, water tupelo, wax myrtle, black gum, pond pine, bald cypress, etc.). Since then there have been many supplemental plantings as well as tree donations. The vegetation coverage is presently so dense that macrophytes from this site have been transplanted into other wetland restoration sites. The wetland has a forebay to collect sediment, and the system is designed to retain and treat the first 0.5 inches of a rainfall event before an overflow channel is utilized. This Best Management Practice (BMP) lies in the headwaters of Burnt Mill Creek, which is on the State 303(d) list for poor biological condition. Another station is located along the main stem of the creek in the Wallace Park area (BMC-WP) and an older station is also on the creek at the bridge at Princess Place (BMC-PP - Fig. 4.1). Recent water quality results of these continuing studies have been published previously (Mallin et al. 2006a; Mallin et al. 2007).

Results from 2007

Kerr Avenue Wetland: This represents the third year of statistically comparative data useful for assessing the efficacy of this wetland as a pollutant removal device. Results of the seven sampling trips showed that turbidity and suspended solids both appeared to have higher concentrations leaving the wetland compared with entering it, with the turbidity difference being statistically significant (Table 4.1). There were no differences in nutrient concentrations entering or leaving the wetland; however, inorganic nutrients were low entering the wetland, probably due to the drought and less runoff. There was no significant difference in BOD5 entering or leaving the wetland. Fecal coliform bacteria were high both entering and exiting the wetland, with no statistical difference entering or leaving the pond. The presence of a number of dumpsters surrounding the site, and consequent small mammals foraging and defecating, may be a localized source of fecal coliform bacteria, BOD and organic nutrients. City staff indicates that the size of the constructed wetland is too small to effectively treat runoff from the watershed.

Ann McCrary Pond: Turbidity and suspended solids concentrations entering and leaving this large regional pond were low to moderate, with incoming nutrients low due to the drought and less runoff (Table 4.1). Fecal coliform concentrations entering Ann McCrary Pond at BMC-AP1 were very high, however (Table 4.1), possibly a result of pet waste runoff from the apartment complex and runoff from urban upstream areas. Five of seven samples collected in 2007 at BMC-AP1 had counts exceeding 200 CFU/100 mL; and four of seven samples from BMC-AP3 exceeded the standard. The high variability among counts prevented the apparent reduction through the pond from being statistically significant. There was a major algal bloom at BMC-AP1 in August (chlorophyll *a* 287 µg/L) and a minor bloom in September (24 µg/L). At BMC AP-3 there were major algal blooms June through September (chlorophyll *a* $\geq$ 30 µg/L) and a minor bloom of 25 µg/L in April 2007. The pond hosted more algal blooms than usual during 2007. The efficiency of Ann McCrary Pond as a pollutant removal device was poor in 2007, with no pollutant significantly reduced during passage through the pond. As in previous years, it is likely that inputs of nutrients have entered the pond from a suburban drainage stream midway down the pond across from our former BMC-AP2 site (Fig. 4.1), short circuiting the ability of the pond to remove nutrients. Also, intensive waterfowl use of the pond, particularly at a tributary near the outfall, may have contributed to phosphorus loading in the pond and along its shoreline. However, as mentioned the concentrations of nutrients entering the pond were not high to begin with. There was no significant decrease in conductivity through the pond. Dissolved oxygen significantly increased through the pond, probably because of in-pond photosynthesis and aeration by passage over the final dam at the outfall. There was a significant increase in pH, probably due to utilization of CO_2 during photosynthesis in the pond.

Lower Burnt Mill Creek: Both the Wallace Park (BMC-WP) and the Princess Place location (BMC-PP) experienced several water quality problems during the sampling period. Dissolved oxygen was substandard (between 2.0 and 5.0 mg/L) three of seven times at BMC-WP and four of seven times at BMC-PP. No problems were seen with turbidity or suspended solids. Nutrients were unremarkable at either site. One major algal bloom (chlorophyll *a* of 452 µg/L) occurred at Wallace Park in May with two minor blooms of 28 and 25 µg/L occurring in June and September, respectively. Two excessively high algal blooms of 588 and 140 µg/L as chlorophyll *a* occurred at Princess Place in May and June. BOD5 increased from the previous year, likely a response to the algal blooms. Conductivity was much higher than the previous year, probably due to the prolonged drought and lack of runoff.

An important issue, from a public health perspective, was the excessive fecal coliform counts, which maintained geometric means (1820 CFU/100 mL at BMC-WP and 1890 CFU/100 mL at BMC-PP) well in excess of the State standard for human contact waters (200 CFU/100 mL). Fecal coliform counts were greater than 200 CFU/100 mL in six of seven months at Wallace Park and seven of seven months at Princess Place, a deterioration from the previous year. We note that these high fecal bacterial counts occurred during a drought year with limited stormwater runoff. It is notable that fecal coliform bacteria increased along the passage from BMC-AP3 to the Wallace Park location, while dissolved oxygen decreased (Table 4.1). BOD5 analyses were performed at Wallace Park, with median concentrations (2.2 mg/L) higher than rural streams but typical of urban streams in the Wilmington area (Mallin et al. 2006b).

Table 4.1. Mean and (standard deviation) of water quality parameters in upper Burnt Mill Creek, Jan. – Sep. 2007. Fecal coliforms as geometric mean; N/P as median.

Parameter	KA-1	KA-3	BMC-AP1	BMC-AP3
DO (mg/L)	6.5 (2.2)	5.5 (2.5)	6.4 (2.1)	9.5 (1.3)**
Cond. (µS/cm)	254 (175)	296 (116)	237 (78)	231 (44)
pH	7.4 (0.4)	7.3 (0.3)	7.3 (0.2)	8.1 (0.4)**
Turbidity (NTU)	8 (7)	22 (12)*	14(10)	10 (3)
TSS (mg/L)	9 (6)	33 (30)	44 (41)	10 (5)
Nitrate (mg/L)	0.129 (0.130)	0.047 (0.094)	0.044 (0.055)	0.037 (0.035)
Ammonium (mg/L)	0.044 (0.049)	0.022 (0.027)	0.030 (0.016)	0.032 (0.036)
TN (mg/L)	0.923 (0.494)	0.651 (0.510)	1.010 (0.486)	0.774 (0.364)
OrthoPhos. (mg/L)	0.016 (0.010)	0.031 (0.048)	0.010 (0.000)	0.010 (0.000)
TP (mg/L)	0.079 (0.073)	0.237 (0.241)	0.157 (0.114)	0.059 (0.015)
N/P molar ratio	22	4	11	11
Chlor. *a* (µg/L)	22.7 (43.7)	11.4 (8.9)	51.8 (103.7)	35.3 (31.3)
Fec. col. (/100 mL)	2626	2727	1159	422
BOD5	1.6 (0.8)	2.2 (1.3)	NA	NA

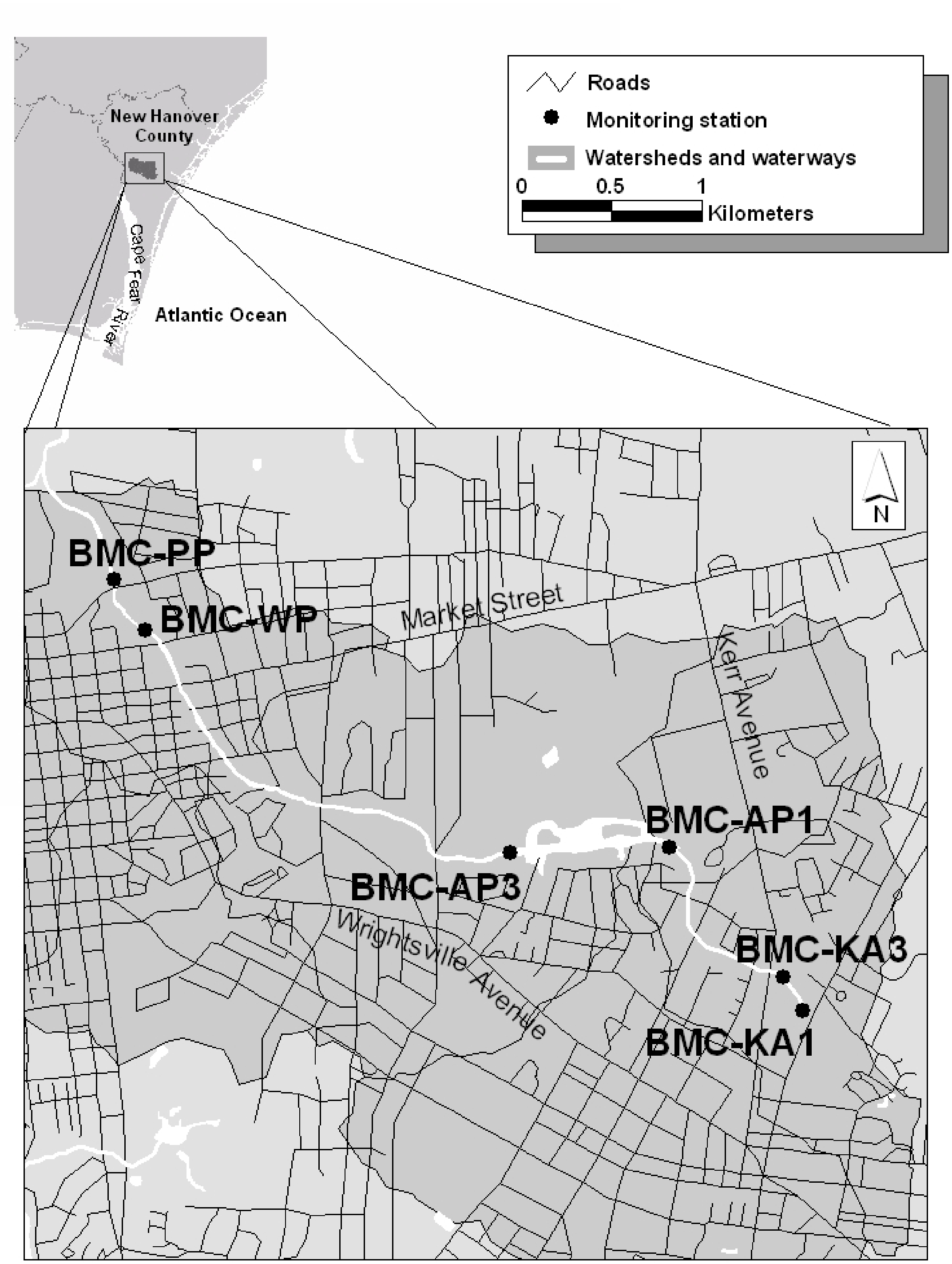
** Indicates statistically significant difference between inflow and outflow at $p<0.01$.
NA = not analyzed.

Table 4.2. Mean and (standard deviation) of water quality parameters in lower Burnt Mill Creek, Jan. – Sep. 2007. Fecal coliforms as geometric mean; N/P as median.

Parameter	BMC-WP	BMC-PP
DO (mg/L)	6.0 (2.5)	5.1 (2.4)
Cond. (μS/cm)	2779 (3296)	4128 (4495)
pH	7.4 (0.1)	7.3 (0.1)
Turbidity (NTU)	8 (3)	9 (5)
TSS (mg/L)	12 (9)	7 (3)
Nitrate (mg/L)	0.114 (0.078)	0.130 (0.170)
Ammonium (mg/L)	0.071 (0.051)	0.083 (0.071)
TN (mg/L)	1.721 (1.379)	0.936 (0.379)
OrthoPhos. (mg/L)	0.023 (0.026)	0.027 (0.023)
TP (mg/L)	0.174 (0.133)	0.111 (0.156)
N/P molar ratio	19	18
Chlor. *a* (μg/L)	113.3 (214.6)	81.2 (163.6)
Fec. col. (/100 mL)	1820	1890
BOD5	3.1 (2.5)	NA

NA = not analyzed

Figure 4.1. Burnt Mill Creek watershed and sampling sites.



Sediment Metals and PAH Concentrations

As part of the stream restoration effort funded through NCSU and the EPA 319 program, we collected sediment samples on one occasion throughout Burnt Mill Creek for analysis of sediment metals and polycyclic aromatic hydrocarbons (PAHs). The State of North Carolina has no official guidelines for sediment concentrations of metals and organic pollutants in reference to protection of invertebrates, fish and wildlife. However, academic researchers (Long et al. 1995) have produced guidelines (Appendix D) based on extensive field and laboratory testing that are used by the US Environmental Protection Agency in their National Coastal Condition Report II (US EPA 2004).

Table 4.3. Guideline values for sediment metals and organic pollutant concentrations (ppm, or μg/g, dry wt.) potentially harmful to aquatic life (Long et al. 1995; U.S. EPA 2004). ERL = (Effects range low). Concentrations below the ERL are those in which harmful effects on aquatic communities are rarely observed. ERM = (Effects range median). Concentrations above the ERM are those in which harmful effects would frequently occur. Concentrations between the ERL and ERM are those in which harmful effects occasionally occur.

Metal	ERL	ERM
Arsenic (As)	8.2	70.0
Cadmium (Cd)	1.2	9.6
Chromium (Cr)	81.0	370.0
Copper (Cu)	34.0	270.0
Lead (Pb)	46.7	218.0
Mercury (Hg)	0.15	0.71
Nickel (Ni)	20.9	51.6
Silver (Ag)	1.0	3.7
Zinc (Zn)	150.0	410.0
Total PCBs	0.0227	0.1800
Total PAHs	4.02	44.80
Total DDT	0.0016	0.0461

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds with a fused ring structure. PAHs with two to five rings are of considerable environmental concern. They are compounds of crude and refined petroleum products and coal and are also produced by incomplete combustion of organic materials (US EPA 2000). They are characteristic of urban runoff as they derive from tire wear, automobile oil and exhaust particles, and leaching of asphalt roads. Other sources include domestic and industrial waste discharge, atmospheric deposition, and spilled fossil fuels. They are carcinogenic to humans, and bioconcentrate in aquatic animals. In these organisms they form carcinogenic and mutagenic intermediaries and cause tumors in fish (US EPA 2000).

Most of the stations had sediment metals concentrations that were well below levels considered potentially toxic to benthic organisms. One exception was lead, which exceeded the ERL (Table 4.3) at the Princess Place station (BMC-PP) and approached harmful levels at the Wallace Park station BMC-WP (Table 4.4). Otherwise, sediment metals concentrations were lower than during 2006, and similar to levels in 2005. All of the PAH sediment samples exceeded the ERM except for Station AP3, below Ann McCrary Pond, where PAHs were below the detection limit (Table 4.4). This sediment PAH concentration distribution in general was similar to those of 2005 and 2006 (Mallin et al. 2006a; Mallin et al. 2007). Compared with sediment samples taken in 1999 at BC-PP, there was a decrease in copper, chromium, lead, and zinc in 2005-2007 (Mallin et al. 1999). This may have been a result of burial of contaminated sediments by further sedimentation, or flushing from subsequent storm-induced flooding.

Table 4.4. Concentrations of sediment metals and polycyclic aromatic hydrocarbons (PAHs) in Burnt Mill Creek, 2007 (as mg/kg = ppm). Concentrations in bold type exceed the level at which harmful effects to benthic organisms may occur, and italicized concentrations are near potentially harmful levels (see Table 4.3 for more detail).

Parameter	KA1	KA3	AP1	AP3	WP	PP
Antimony	0.105	<0.032	0.093	<0.031	<0.034	0.084
Arsenic	<0.097	<0.101	<0.114	<0.099	<0.109	<0.113
Beryllium	0.055	0.021	<0.054	0.028	0.152	0.065
Cadmium	0.190	0.048	0.114	0.129	0.464	0.329
Chromium	3.140	0.828	2.530	1.650	6.600	3.430
Copper	3.26	1.03	12.00	0.75	5.29	6.36
Lead	0.95	1.52	3.46	<0.06	*34.20*	**60.00**
Mercury	<0.002	<0.002	<0.003	<0.002	0.023	0.004
Nickel	1.840	0.379	0.701	0.926	3.240	1.360
Selenium	0.085	<0.063	<0.070	0.091	<0.070	<0.070
Silver	<0.060	<0.063	<0.070	<0.060	<0.070	<0.080
Thallium	<0.012	<0.013	<0.014	<0.012	<0.014	<0.014
Zinc	41.70	9.67	32.70	28.30	45.90	60.50
Total PAH	**5,026**	**9,978**	**13,334**	BDL	**1,141**	**13,582**
TN	25	76	609	121	328	528
TP	763	119	43	57	413	187
TOC	19.6	14.4	30.9	11.9	47.5	40.9

BDL = below detection limit

5.0 Futch Creek

Snapshot
Watershed area: 3,136 aces (1,269 ha) Impervious surface coverage: >11%
Watershed population: 1,720 (New Hanover County only)
Overall water Quality: Good
Problematic pollutants: some low dissolved oxygen (DO 3.0-5.0 ppm in summer); some algal blooms, potential fecal bacteria increase in recent years at upstream site

Six stations have been sampled in Futch Creek since 1993. During 1995 and 1996 two channels were dredged in the mouth of Futch Creek (Fig. 5.1) to improve circulation from the ICW and hopefully reduce fecal coliform bacterial concentrations. The result was a statistically significant increase in salinity in the creek in the months following dredging, significantly lower fecal coliform counts, and the lower creek was reopened to shellfishing (Mallin et al. 2000c). Salinities were considerably higher in 2006-7 than during the previous year. This was possibly a result of the drought conditions and low amounts of stormwater runoff entering the creek. During 2006-2007, there were only two incidences of creek stations having turbidity levels exceeding the state standard of 25 NTU, both of them at FC-17. Low dissolved oxygen was a moderate problem particularly in the upper creek stations FC-13 and FC-17 (Table 5.1; Appendix B).

Table 5.1. Physical parameters at Futch Creek sampling stations, August 2006 - July 2007. Data given as mean (SD) / range.

Station	Salinity (ppt)	Turbidity (NTU)	Light attenuation (k/m)	Dissolved oxygen (mg/L)
FC-4	34.2 (1.9)	4 (4)	1.0 (0.8)	7.1 (1.8)
	30.5-36.6	0-12	0.4-2.1	4.2-10.2
FC-6	33.6 (2.1)	5 (5)	1.0 (0.6)	6.8 (2.2)
	29.1-36.4	0-13	0.5-1.7	3.1-10.9
FC-8	32.9 (1.9)	6 (9)	0.7 (0.3)	7.0 (2.3)
	29.6-35.7	0-22	0.5-1.1	3.7-10.9
FC-13	29.8 (2.6)	7 (8)	0.5 (0.1)	6.3 (2.4)
	26.2-33.5	0-24	0.5-0.6	2.2-9.8
FC-17	22.9 (7.1)	8 (9)	0.9 (0.1)	6.4 (2.2)
	10.4-33.3	0-27	0.8-0.9	3.4-9.5
FOY	29.7 (3.1)	7 (9)	0.7 (0.1)	6.7 (2.3)
	24.9-34.1	0-30	0.6-0.7	3.2-10.9

Nutrient concentrations in Futch Creek remained generally low, with a decrease in nitrate over the previous year at all stations (Table 5.2). One source of nitrate has been identified as groundwater inputs entering the marsh in springs existing in the area stretching from upstream of FC-17 downstream to FC-13 (Mallin et al. 1998b). Overland runoff during and following rain events is another nitrate source to this creek, and the lack of rain and consequent stormwater inputs undoubtedly led to the lower nitrate inputs. Orthophosphate showed an average increase over the previous year, particularly at the upper stations. Ammonium increased in the creek from the previous year, particularly at FC-17.

One major algal bloom occurred at Station FC-8 in June (49 µg/L as chlorophyll *a*); a minor bloom (24 µg/L) occurred at FC-13 that same month, and two minor blooms of 18 µg/L occurred in June and July at FC-17.

Table 5.2. Nutrient and chlorophyll *a* data from Futch Creek, August 2006-July 2007. Data as mean (SD) / range, nutrients in mg/L, chlorophyll *a* as µg/L.

Station	Nitrate	Ammonium	Orthophosphate	Chlorophyll *a*
FC-4	0.019 (0.025) 0.002-0.100	0.025 (0.015) 0.001-0.050	0.015 (0.013) 0.003-0.044	2.0 (1.4) 0.2-4.3
FC-6	0.015 (0.013) 0.003-0.044	NA	0.009 (0.004) 0.004-0.018	2.2 (1.7) 0.5-5.3
FC-8	0.014 (0.012) 0.005-0.038	NA	0.014 (0.012) 0.005-0.038	7.0 (14.9) 0.4-49.0
FC-13	0.018 (0.019) 0.005-0.058	NA	0.018 (0.019) 0.005-0.058	5.6 (7.4) 0.5-24.1
FC-17	0.043 (0.003) 0.024-0.193	0.045 (0.042) 0.010-0.165	0.038 (0.030) 0.006-0.090	6.3 (6.5) 0.7-18.3
FOY	0.027 (0.006) 0.006-0.084	0.037 (0.029) 0.002-0.107	0.022 (0.016) 0.007-0.044	3.8 (3.5) 0.7-9.9

NA = not analyzed

As reportedly previously (Mallin et al. 2000c) the dredging experiment proved to be successful and the lower portion of the creek was reopened to shellfishing. During 2006-2007 there was a decrease in microbiological water quality at Station FC-6, with geometric mean coliform counts increasing from 12 in 2005-2006 to 27 in 2006-2007, and the percent of samples exceeding 43 CFU/100 mL increasing from 9% in 2005-2006 to 40% in 2006-2007 (Table 5.3). The uppermost stations continued to have fecal coliform bacterial concentrations below those of the pre-dredging period, although 2004, 2006 and 2007 showed troubling increasing trends at FC-17 (Fig. 5.2). This was despite the fact that 2007 was a drought with less stormwater runoff into the creek and its tributaries. All stations had geometric mean fecal coliform counts that were within safe limits for human contact waters (Appendix B). In summary, Futch Creek still maintains good water quality in general (Appendix B).

Table 5.3. Futch Creek fecal coliform bacteria data, including percent of samples exceeding 43 CFU per 100 mL, August 2006 - July 2007.

Station	FC-4	FC-6	FC-8	FC-13	FC-17	FOY
Geomean (CFU/100 mL)	4	27	9	24	74	18
% > 43 /100ml	0	40	9	36	75	18

Figure 5.1. Futch Creek watershed and sampling sites.

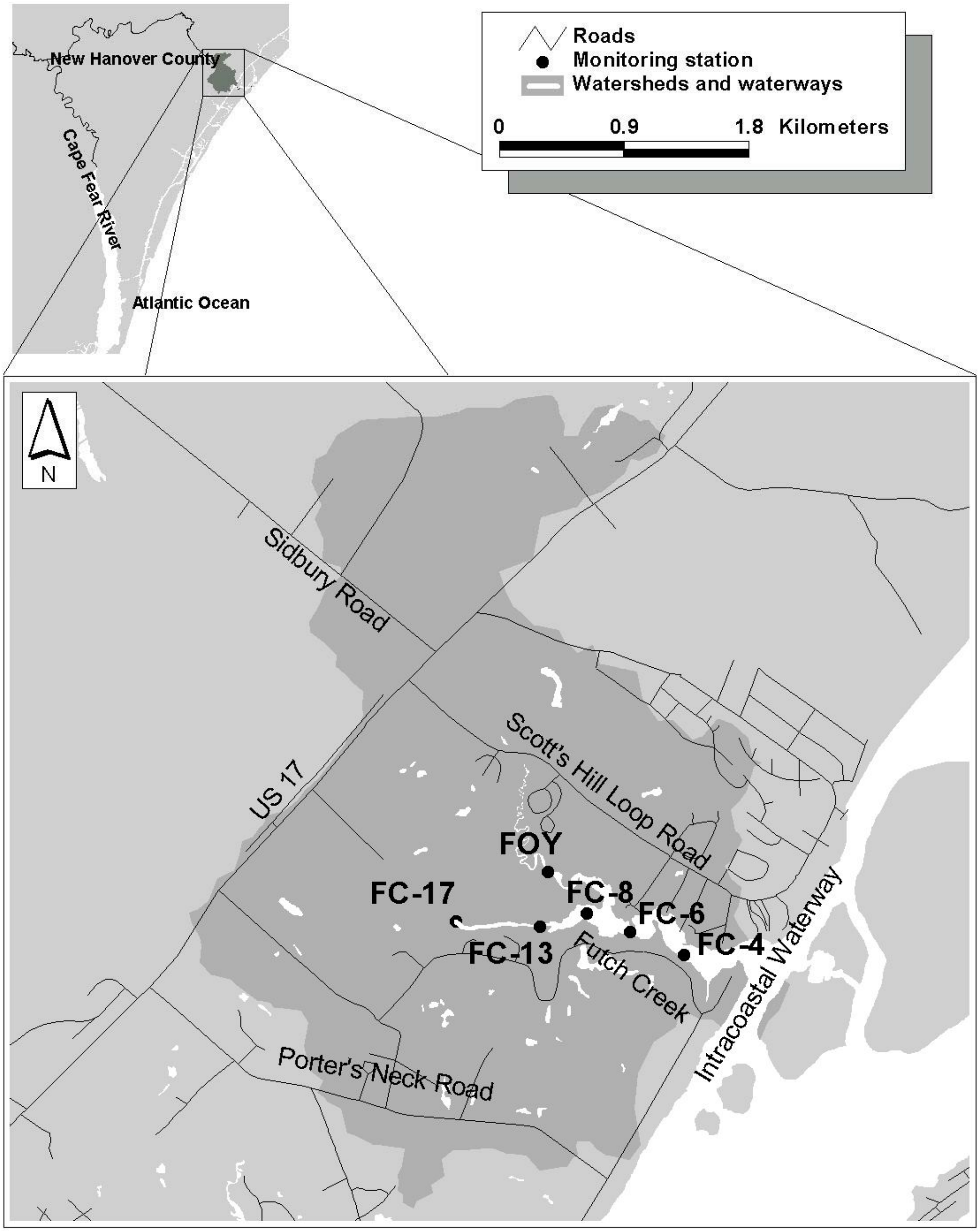
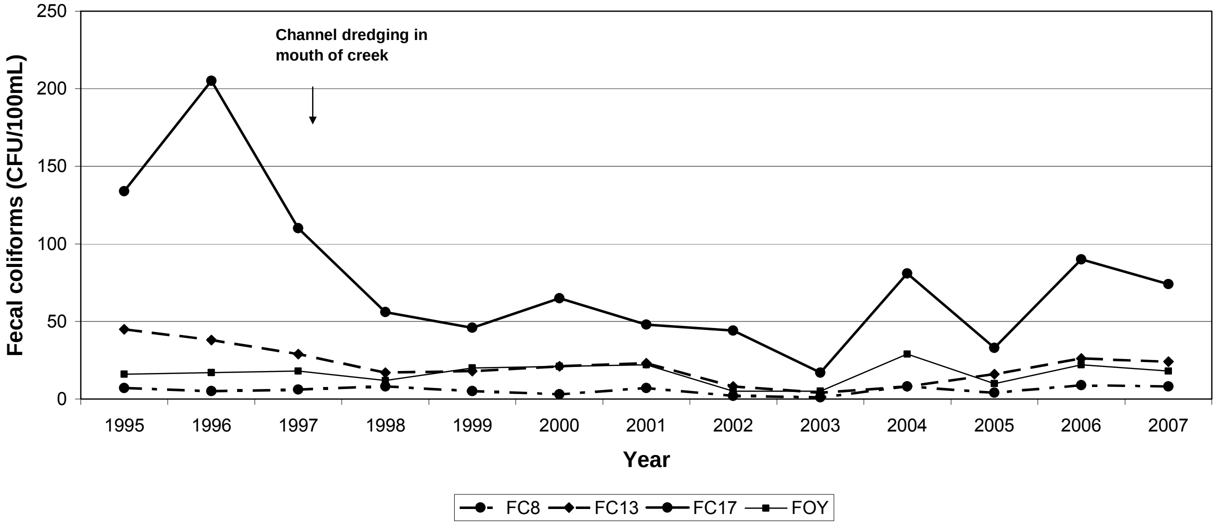


Figure 5.2 Fecal coliform bacteria counts over time at selected Futch Creek stations, 1994-2007



6.0 Greenfield Lake Water Quality

Snapshot

Watershed area: 2,560 acres (1,036 ha) Impervious surface coverage: 36%
Watershed population: 12,270 Overall water quality: Poor, improving
Problematic pollutants: Fecal bacteria, low dissolved oxygen in tributaries, algal blooms

Three tributaries of Greenfield Lake were sampled for physical, chemical, and biological parameters (Table 6.1, Fig. 6.1). All three tributaries suffered from hypoxia, with GL-JRB (Jumping Run Branch), GL-LB (creek at Lake Branch Drive) and GL-LC (creek beside Lakeshore Commons) all showing average concentrations below the state standard (DO < 5.0 mg/L). Dissolved oxygen levels were 2.0 mg/L or less on five occasions at GL-LB and twice each at the other two stations (Table 6.1; Appendix B). Turbidity and suspended solids were generally low in the tributary stations except for high turbidity at GL-LB and GL-LC in August 2007 (Table 6.1). Total nitrogen and nitrate concentrations were highest at GL-LC (Table 6.1). Ammonium was highest at GL-LB, followed by GL-LC. Total phosphorus concentrations were similar at these three sites. All three of these input streams maintained fecal coliform levels indicative of poor water quality, with fecal coliform counts exceeding the state standard for human contact waters (200 CFU/100 mL) five of seven times at GL-LB and GL-JRB, and seven of seven times at GL-LC. Geometric mean fecal coliform bacteria concentrations exceeded the state standard at all three sites, but these were lower than the previous year's counts. There were two major algal blooms in 2007 at GL-LC, with chlorophyll *a* levels of 102 µg/L in July and 142 µg/L in August. A minor bloom of 25 µg/L occurred at GL-JRB, and GL-LC had one major bloom of 42 µg/L in April 2007. BOD5 was highest at GL-LC, with a maximum of 11.4 mg/L in July concurrent with the bloom.

Table 6.1. Mean and (standard deviation) of water quality parameters in tributary stations of Greenfield Lake, January - September 2007. Fecal coliforms as geometric mean; N/P ratio as median; n = 7 samples for all parameters.

Parameter	GL-JRB	GL-LB	GL-LC
DO (mg/L)	3.8 (2.8)	3.3 (3.7)	2.8 (1.3)
Turbidity (NTU)	3(1)	12 (19)	21 (31)
TSS (mg/L)	3 (1)	6 (5)	8 (8)
Nitrate (mg/L)	0.120 (0.140)	0.184 (0.276)	0.443 (0.192)
Ammonium (mg/L)	0.047 (0.031)	0.189 (0.151)	0.140 (0.104)
TN (mg/L)	0.563 (0.210)	0.970 (0.599)	1.157 (0.251)
Orthophosphate (mg/L)	0.044 (0.021)	0.044 (0.024)	0.016 (0.010)
TP (mg/L)	0.084 (0.030)	0.116 (0.069)	0.181 (0.353)
N/P molar ratio	8	15	93
Fec. col. (/100 mL)	283	264	776
Chlor. *a* (µg/L)	9.4 (7.7)	13.0 (14.3)	38.9 (58.1)
BOD5	1.6 (0.6)	1.8 (0.8)	3.4 (3.8)

Three in-lake stations were sampled (Table 6.2). Station GL-2340 represents an area receiving a considerable influx of urban/suburban runoff, GL-YD is downstream and receives some outside impacts, and GL-P is at Greenfield Lake Park, away from inflowing streams but in a high-use waterfowl area (Fig. 6.1). Low dissolved oxygen was only a problem at GL-2340, with concentrations below the state standard of 5.0 mg/L on five of seven occasions (see Section 6.1). Turbidity and suspended solids were low to moderate at these three sites, except for high TSS (151 mg/L) in September at GL-2340. Fecal coliform concentrations were problematic at all three sites in the lake, exceeding the State standard three of seven times at each location in 2007 (Appendix B).

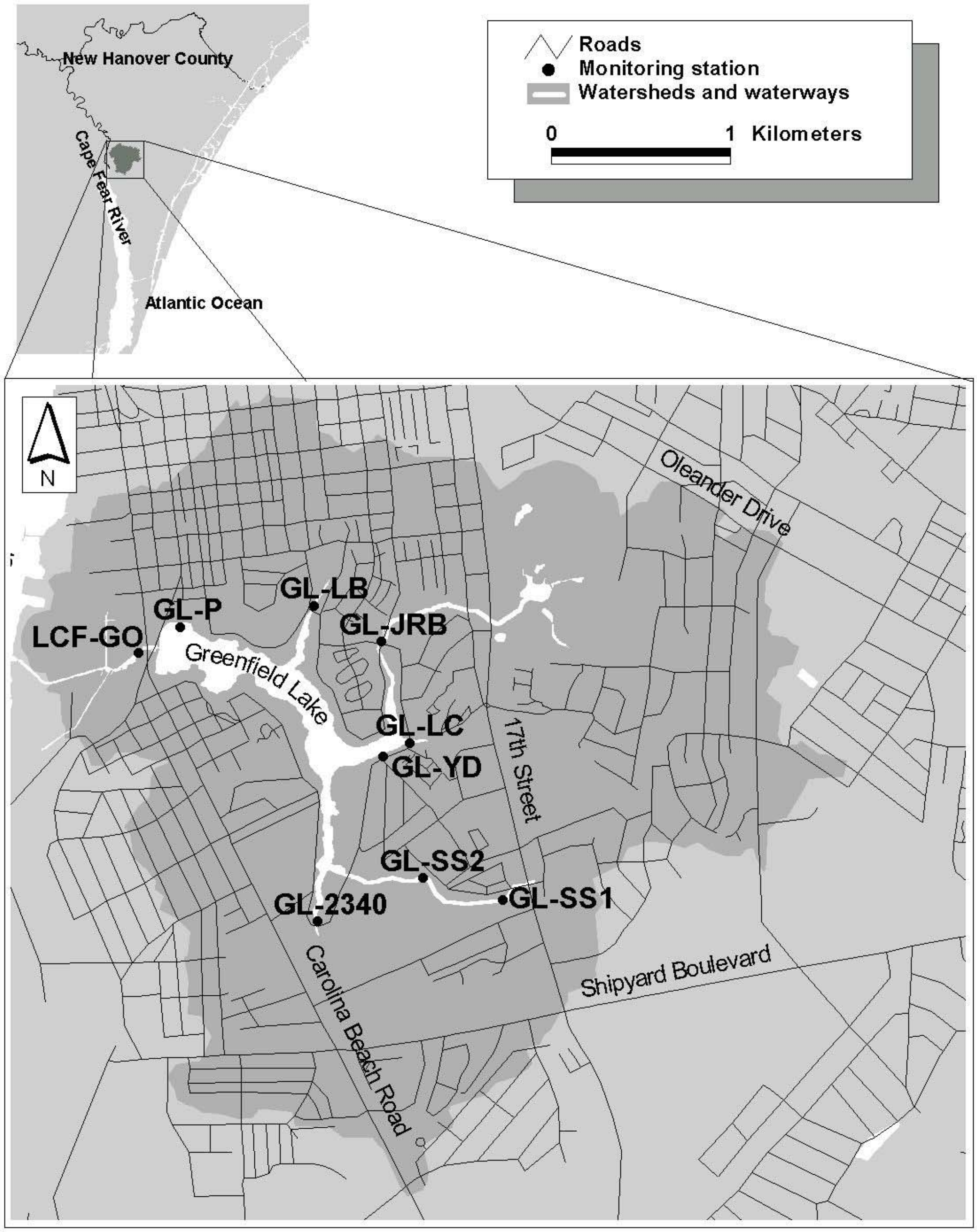
Nitrogen concentrations were generally highest at GL-P, followed by GL-2340; total nitrogen was lower in 2007 than 2006, possibly reflecting the drought and less runoff inputs. Total phosphorus concentrations were highest at GL-YD, and none of the phosphorus values were remarkable (Table 6.2). Inorganic N/P molar ratios can be computed from ammonium, nitrate, and orthophosphate data and can help determine what the potential limiting nutrient can be in a water body. Ratios well below 16 (the Redfield ratio) can indicate potential nitrogen limitation, and ratios well above 16 can indicate potential phosphorus limitation (Hecky and Kilham 1988). Based on the median N/P ratios (Table 6.2), phytoplankton growth in Greenfield Lake was limited by nitrogen. Our previous bioassay experiments indicated that nitrogen was usually the limiting nutrient in this lake (Mallin et al. 1999).

Phytoplankton blooms are periodically problematic in Greenfield Lake, and usually consist of green or blue-green algal species, or both together. These blooms have occurred during all seasons, but are primarily a problem in spring and summer. Three blooms exceeding 34 µg/L of chlorophyll *a* occurred at GL-YD and two blooms of 32 µg/L of chlorophyll *a* occurred at GL-2340, with no blooms at GL-P in 2007. However, there was only one in-lake bloom exceeding the state standard of 40 µg/L in 2007, a big improvement over 2006 when eight in-lake blooms exceeded the standard. Thus, during 2007 Greenfield Lake was impaired by moderate algal blooms, high fecal coliform counts and low dissolved oxygen concentrations, although the latter parameter continues to be better than the 2003-2004 pre-restoration period (see Section 6.1A). The tributary stations were also impaired by high fecal coliform counts and low dissolved oxygen. These same problems have occurred in the lake for several years (Mallin et al. 1999; 2000; 2002; 2003; 2004; 2005; 2006; 2007).

Table 6.2. Mean and (standard deviation) of water quality parameters in Greenfield Lake sampling stations, January - September 2007. Fecal coliforms given as geometric mean, N/P ratio as median; n = 7 samples collected.

Parameter	GL-2340	GL-YD	GL-P
DO (mg/L)	3.1 (1.7)	6.8 (2.2)	10.4 (2.3)
Turbidity (NTU)	3 (2)	5 (6)	5 (4)
TSS (mg/L)	24 (56)	4 (1)	3 (1)
Nitrate (mg/L)	0.103 (0.108)	0.056 (0.083)	0.041 (0.067)
Ammonium (mg/L)	0.041 (0.032)	0.021 (0.020)	0.037 (0.068)
TN (mg/L)	1.160 (0.988)	0.641 (0.170)	0.857 (0.432)
OrthopPhosphate (mg/L)	0.024 (0.020)	0.020 (0.013)	0.034 (0.032)
TP (mg/L)	0.067 (0.021)	0.079 (0.009)	0.066 (0.019)
N/P molar ratio	9	4	4
Fec. col. (/100 mL)	176	196	217
Chlor. *a* (μg/L)	14.6 (14.1)	22.7 (18.9)	6.6 (4.6)
BOD5	2.6 (1.0)	2.5 (1.0)	2.2 (1.0)

Figure 6.1 Greenfield Lake watershed



6.1 A Continuing Assessment of the Efficacy of the 2005-2006 Greenfield Lake Restoration Measures

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

Introduction

Greenfield Lake is a 37 ha blackwater system located in the City of Wilmington, North Carolina. It was first dammed and filled as a millpond in 1750, and purchased for a city park in 1925. It has an average depth of 1.2-1.5 m, it is about 8,530 m around the shoreline, and its watershed drains approximately 1,036 ha (2,560 acres). The lake has one outfall, but is fed by six perennial inflowing streams (as well as intermittent ditches). The lake is surrounded by a watershed that is comprised mainly of residential, office, institutional and commercial areas, with an overall watershed impervious surface coverage of 36%.

In recent decades a number of water quality problems have become chronic within the lake, including high fecal coliform bacterial counts, low dissolved oxygen problems, nuisance aquatic macrophyte growths, algal blooms and fish kills. Some of these problems are typically related to eutrophication, a process driven by loading of excessive nutrients to a body of water. The State of North Carolina Division of Water Quality considers the lake to have a problem with aquatic weeds (NCDENR 2005). Periodic phytoplankton blooms have occurred in spring, summer and fall. Some of the most frequent bloom forming taxa are the cyanobacterium *Anabaena cylindrica* and the chlorophytes *Spirogyra* and *Mougeotia* spp. The free-floating macrophyte *Lemna* sp. (duckweed) is frequently observed on the surface, and below a massive *Lemna* bloom in summer 2004 dissolved oxygen concentrations at the park station were nearly anoxic. In-situ monitoring instruments have demonstrated that dissolved oxygen concentrations can decrease by as much as 45% at night compared with daytime DO measurements.

In 2005 several steps were taken by the City of Wilmington to restore viability to the lake (David Mayes, City of Wilmington Stormwater Services, personal communication). During February one thousand sterile grass carp were introduced to the lake to control (by grazing) the overabundant aquatic macrophytes. During that same month four SolarBee water circulation systems were installed in the lake to improve circulation and force dissolved oxygen from the surface downward toward the bottom. Finally, from April through June 2005 a contract firm applied the herbicide Sonar to further reduce the amount of aquatic macrophytes. On March 29-31 2006 City crews applied 35 gallons of K-Tea algaecide and on July 18 applied 0.63 gallons of habitat aquatic herbicide. A contract firm stocked the lake with 500 additional grass carp on April 4, 2006 and applied 40 gallons of Nautique aquatic herbicide on April 25.

Since 1998 the University of North Carolina Wilmington's Aquatic Ecology Laboratory, located at the Center for Marine Science, has been performing water quality sampling and associated experiments on Greenfield Lake. The City of Wilmington Engineering Department has funded this effort. Monitoring of various physical, chemical, and biological parameters has occurred monthly. These data allow us to perform a assessment of the effectiveness of the City's lake restoration efforts by comparing summer data from 2003 and 2004 (before restoration efforts) with data from the summers of 2005 through 2007 (after restoration efforts have been ongoing).

Results

To assess the results so far we have chosen several parameters to examine over time. One parameter that is not quantified is surface coverage by nuisance macrophyte vegetation. In the summers of 2003 and 2004 extensive mats of duckweed (*Lemna* sp.), mixed with algae and other vegetation covered large areas of the lake's surface, with visible estimates for some coves exceeding 95% coverage. In summer of 2005 surface coverage was minimal; with most lake areas 95% clear of surface mats. Some coverage returned in 2006 and minimal coverage was seen in 2007.

<u>Dissolved oxygen (DO)</u>: During 2003 and 2004 hypoxia (DO < 4.0 mg/L) was common in surface waters. Areas beneath thick *Lemna* mats were anoxic (DO of zero) or nearly so, especially at GL-P, the main Park area (Fig. 6.1). Following the onset of herbicide addition in April 2005, the May DO (mean of the three in-lake stations) showed a distinct decrease; however, it subsequently rose in June and remained at or above the State standard of 5 mg/L through the rest of the summer of 2005 (Fig. 6.2). In summer of 2006 the average lake DO levels decreased compared with 2005, but were still higher than in 2003 and 2004 (Fig. 6.2). This was because Station GL-2340 experienced low DO levels from 1.2 to 3.8 mg/L from July through September, although the other two in-lake stations (GL-P and GL-YD) maintained good DO levels. In 2007 GL-2340 continued to have poor dissolved oxygen problems but the other two in-lake stations had generally good dissolved oxygen (Table 6.2).

<u>Turbidity</u>: Turbidity was not excessive in the lake during the two years prior to restoration efforts (Mallin et al. 2006). It has remained low following these efforts throughout 2007 (Table 6.2).

<u>Ammonium</u>: Ammonia, or ammonium is a common degradation product of organic material, and is an excretory product of fish and other organisms. The addition of grass carp and the herbicide usage has not raised ammonium concentrations in the lake (Fig. 6.3). Potentially some of the ammonium produced may have been utilized by phytoplankton.

<u>Nitrate</u>: Nitrate is an inorganic form of nitrogen that is known to enter the lake during rainfall and runoff periods (Mallin et al. 2002). The concentration of nitrate in the lake does not appear to have been influenced by the restoration efforts (Table 6.2). Nitrate concentrations are generally impacted by stormwater runoff, and the low rainfall in 2007 likely provided minimal nutrient inputs to the lake.

Total nitrogen: Total nitrogen (TN) is a combination of all inorganic and organic forms of nitrogen. Mean concentrations and concentrations at individual stations appeared to be unaffected by the restoration efforts (Table 6.2; Fig. 6.4).

Orthophosphate: Orthophosphate is the most common inorganic form of phosphorus, and is utilized as a key nutrient by aquatic macrophytes and phytoplankton. Orthophosphate was not found at excessive concentrations in the water column either before (Mallin et al. 2006a) or after the restoration effort (Table 6.2).

Total phosphorus: Total phosphorus (TP) is a combination of all organic and inorganic forms of phosphorus in the water. Although pulses of TP occurred in summer 2005 and spring 2006, they were similar in magnitude to pulses of TP seen in 2003 and 2004 (Fig. 6.5). Pulses in 2007 were smaller than the previous years (Figure 6.5).

Chlorophyll *a*: Chlorophyll *a* is the principal measure used to estimate phytoplankton biomass (algal bloom strength) in water bodies. As mentioned above, algal blooms have been a common occurrence in this lake. They are generally patchy in space, usually occurring at one or two stations at a time. However, in summer 2005 extensive phytoplankton blooms occurred at all three in-lake stations, with levels well exceeding the State standard of 40 μg/L (Fig. 6.6). Blooms continued throughout 2006 as well (Table 6.2; Fig. 6.6). A positive signal is that blooms within the lake in 2007 were fewer than in previous years (Fig. 6.6), either because of continuing restoration efforts or lower stormwater driven inputs of nitrate to feed the blooms. Algal blooms are the result of nutrient inputs, either from outside the lake or from release from decaying material. Algal blooms, when they die, cause a BOD (biochemical oxygen demand) load (Mallin et al. 2006b). This is organic material that natural lake bacteria feed on and multiply, using up dissolved oxygen in the lake as they do so. We compared our 2007 chlorophyll *a* concentrations with the corresponding BOD concentrations for the three in-lake stations. The results (Fig. 6.7) show a statistically significant relationship between the chlorophyll *a* levels and BOD. Statistically speaking, the regression equation on Fig. 6.7 means that approximately 40% of the variability in Greenfield Lake BOD is caused by algal blooms. These blooms thus can lead to low dissolved oxygen in the lake.

Fecal coliform bacteria: Fecal coliform bacteria are commonly used to provide an estimate of the human or animal derived microbial pollution in a water body. Greenfield Lake is chronically polluted by high fecal coliform counts, well exceeding the state standard of 200 CFU/100 mL during several months (Table 6.2; Fig. 6.8). In summer 2005 there were particularly large fecal coliform counts at each in-lake station, though the individual stations did not have pulses during the same months. Excessive fecal coliform counts occurred to a lesser degree in 2006 in the lake, mainly at GL-2340 (Table 6.2). In 2007 high fecal coliform counts occurred within the lake on about 43% of the occasions sampled (Fig. 6.8). These counts are not expected to be influenced by the type of restoration efforts ongoing in the lake.

Discussion

A risk that is taken when applying herbicides to lakes is the creation of biochemical oxygen demand (BOD) from decomposing organic matter that is a product of dead or dying plant material. As mentioned above, this would serve to drive the lake DO concentrations downward. DO levels in summer 2005 were nearly twice what they were during summers of 2003 and 2004, and DO levels in 2006 were also higher than 2003 and 2004. It is very likely that the use of the SolarBee circulation systems maintained elevated DO even when there was an obvious BOD source. The in-lake station with lowest DO levels in 2006 was GL-2340, which is located quite a distance from the SolarBees. This pattern continued into 2007.

Water column nutrient concentrations did not appear to change notably after the introduction of grass carp or use of herbicide. Certainly ammonium, an excretory and decomposition product would be expected to rise following the consumption and death of large quantities of plant material. Likewise phosphorus did not increase, although it is a common excretory product. However, ammonium (like orthophosphate) is readily used as a primary nutrient by phytoplankton. Nutrient addition bioassay experiments have demonstrated that phytoplankton in this lake is limited by nitrogen (Mallin et al. 1999). It is likely that ammonium produced by fish excretion or dying plant material was utilized by phytoplankton to produce the excessive algal blooms that characterized the lake in 2005 and 2006. The phytoplankton blooms were dominated by blue green algae (cyanobacteria) including species containing heterocysts. These species have the added ability to fix atmospheric nitrogen when phosphorus is replete. Thus, while large amounts of macrophyte material disappeared from the lake, some of the resultant nutrients were utilized by phytoplankton to produce the blooms. As mentioned, a problem with algal blooms is that when they die, they become labile forms of organic material, or BOD (Fig. 6.7). Published research has previously demonstrated that chlorophyll *a* in this lake is strongly correlated with BOD (Mallin et al. 2006b). However, the positive news from 2007 is that algal blooms were fewer than in previous years. This may be due to the restoration efforts, less stormwater runoff during the drought, or some combination of the two.

The continuing problems with fecal coliform bacteria does not appear to be related to any of the restoration activities. Fecal coliform bacteria enter the environment from the feces of warm blooded animals, so it is possible that increases in waterfowl or dogs brought to the lake by their owners, or feral cats could lead to increased fecal coliform bacteria counts, but we have no data to support this speculation either way.

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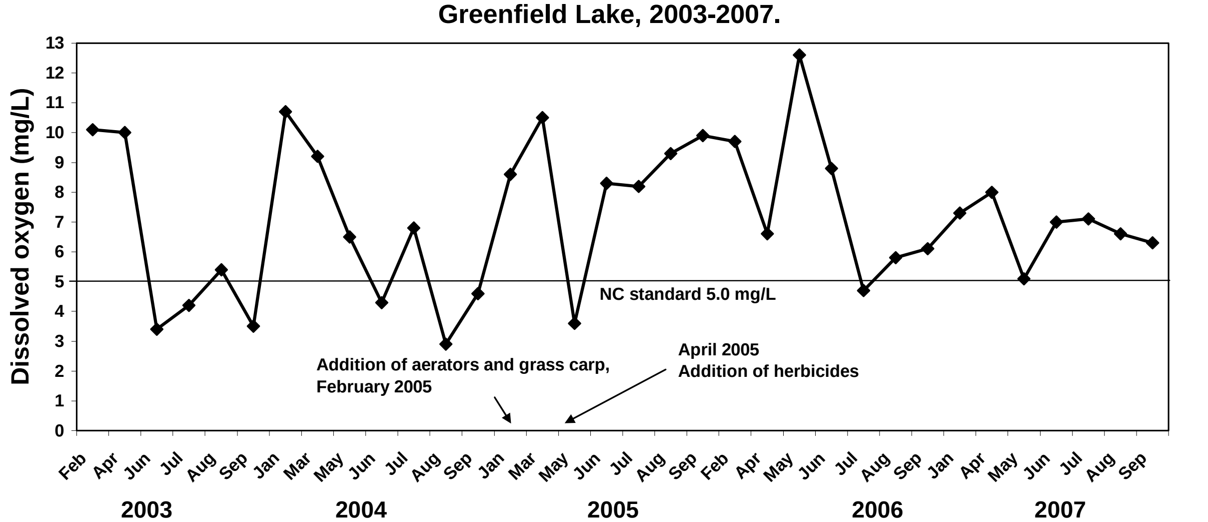
Figure 6.2. Average dissolved oxygen concentrations in Greenfield Lake, 2003-2007.



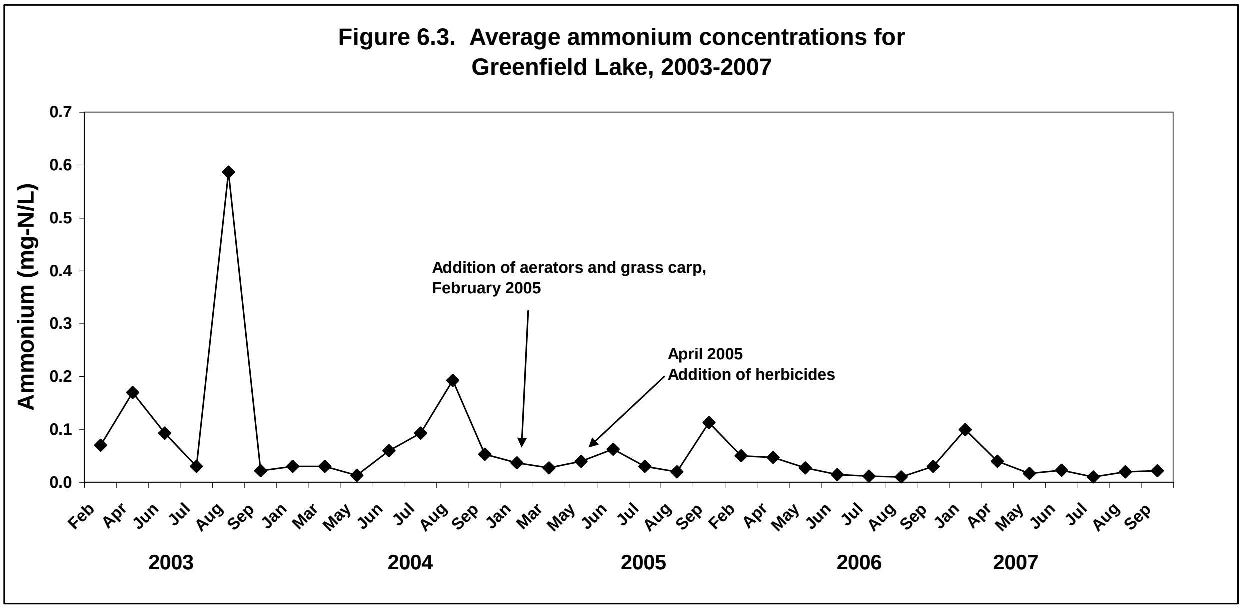


Figure 6.3. Average ammonium concentrations for Greenfield Lake, 2003-2007
Ammonium (mg-N/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Addition of aerators and grass carp, February 2005
April 2005 Addition of herbicides
Feb Apr Jun Jul Aug Sep Jan Mar May Jun Jul Aug Sep Jan Mar May Jun Jul Aug Sep Feb Apr May Jun Jul Aug Sep Jan Apr May Jun Jul Aug Sep
2003
2004
2005
2006
2007

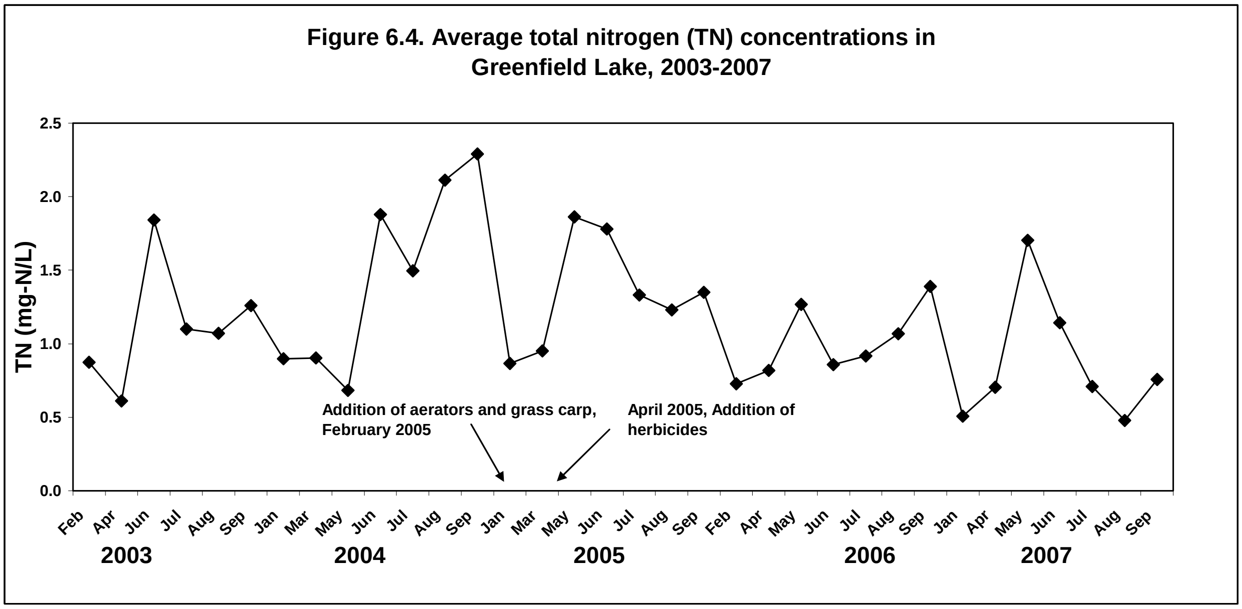


Figure 6.4. Average total nitrogen (TN) concentrations in Greenfield Lake, 2003-2007
TN (mg-N/L)
2.5
2.0
1.5
1.0
0.5
0.0
Addition of aerators and grass carp, February 2005
April 2005, Addition of herbicides
Feb Apr Jun Jul Aug Sep Jan Mar May Jun Jul Aug Sep Jan Mar May Jun Jul Aug Sep Feb Apr May Jun Jul Aug Sep Jan Apr May Jun Jul Aug Sep
2003
2004
2005
2006
2007

Figure 6.5. Average total phosphorus (TP) concentrations for Greenfield Lake, 2003-2007

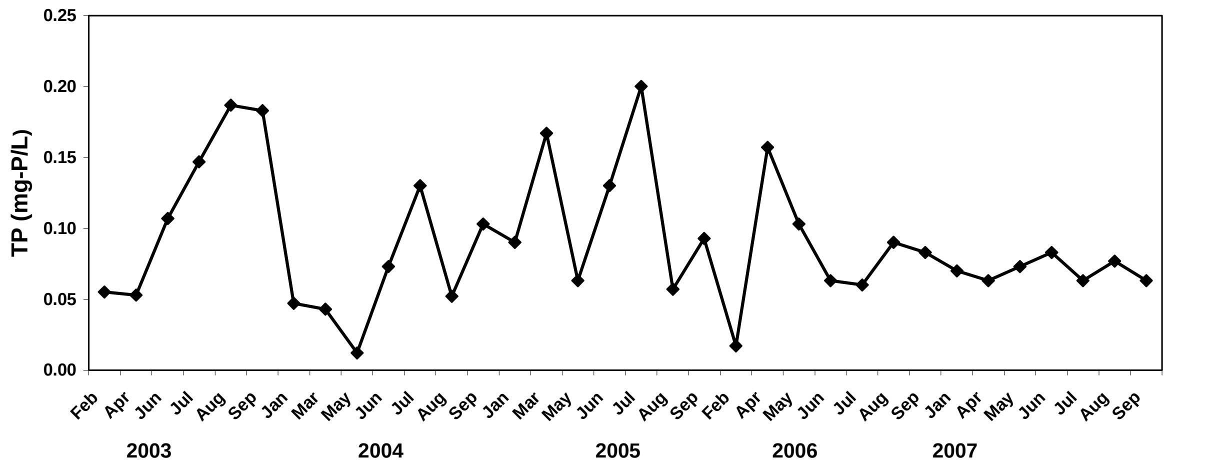


Figure 6.6. Average chlorophyll *a* values in Greenfield Lake, 2003-2007

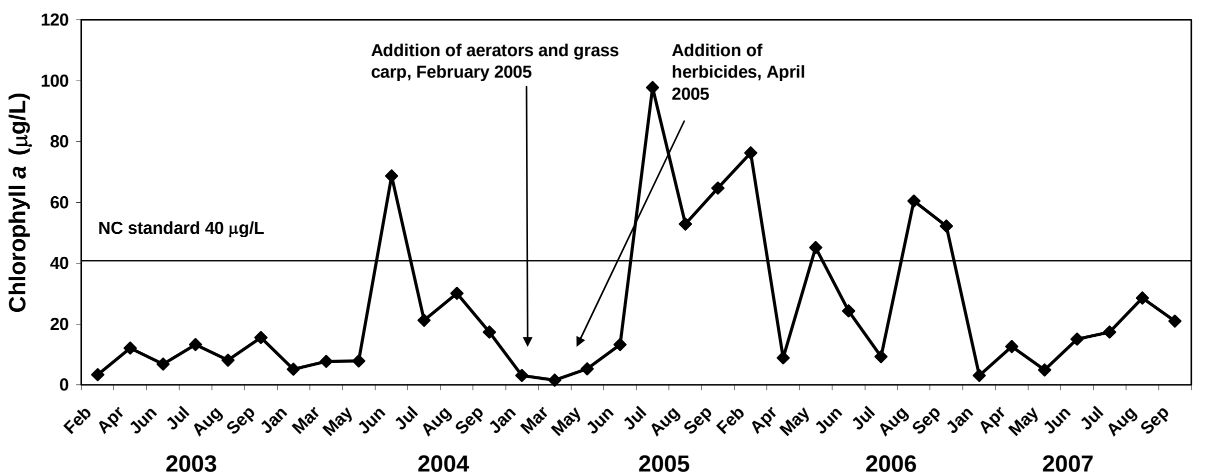


Figure 6.7. BOD5 as a function of chlorophyll *a* in Greenfield Lake, 2007 (data from all three in-lake stations combined).

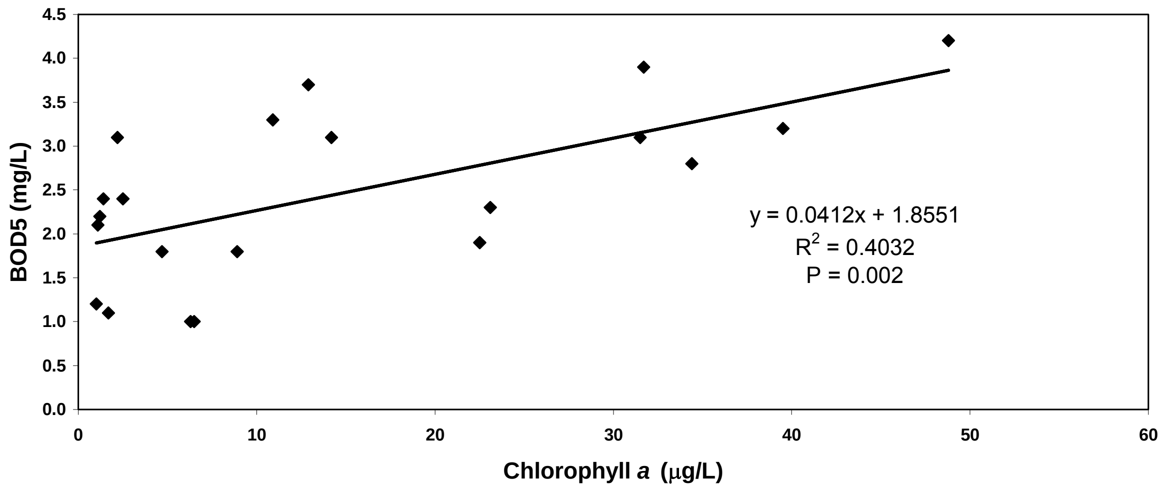
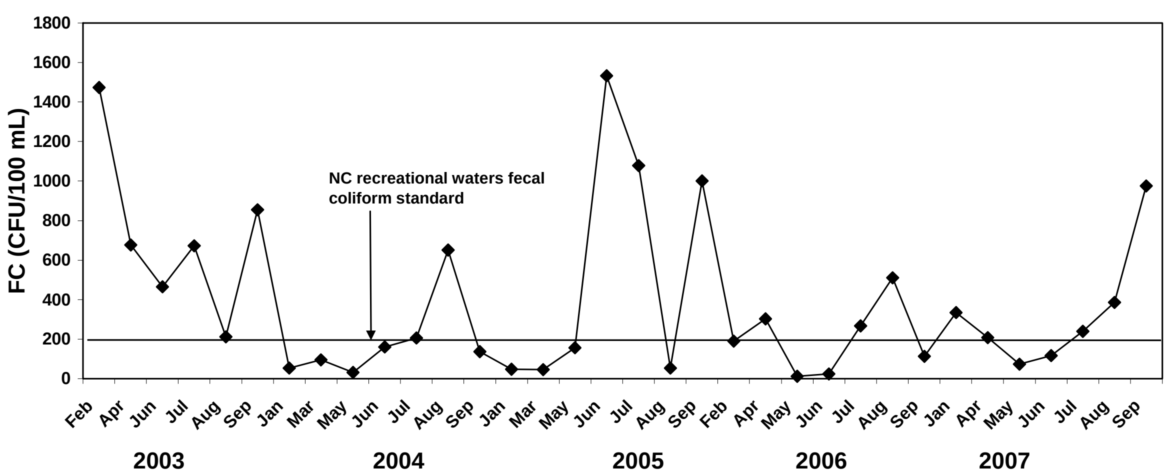


Figure 6.8. Average fecal coliform bacteria counts (FC) for Greenfield Lake, 2003-2007



7.0 Hewletts Creek

Snapshot
Watershed area: 5,952 acres (2,409 ha) Impervious surface coverage: 19%
Watershed population: 21,335
Overall water quality: Fair
Problematic pollutants: Algal blooms, fecal bacteria, minor dissolved oxygen issues

Hewletts Creek was sampled at seven tidally-influenced areas (HC-M, HC-2, HC-3, NWB, NB-GLR, MB-PGR and SB-PGR) and a freshwater stream station draining Pine Valley Country Club (PVGC-9 - Fig. 7.1). Four freshwater stations in the headwaters of the south branch were added in 2004 at the "Dobo" site, where a created wetland for runoff treatment was planned (Fig. 7.2). At the tidal stations the physical data indicated that turbidity was well within State standards during this sampling period except for an incident of 30 NTU in May 2007 at NB-GLR, and an incident of 29 NTU in January 2007 at MB-PGR (Tables 7.1 and 7.2). There were several incidents of hypoxia seen in our regular monthly 2006-2007 sampling; three at NB-GLR and three at SB-PGR, although none were below 3.9 mg/L. Nitrate concentrations were somewhat higher in the middle branch (MB-PGR), which drains both Pine Valley and the Wilmington Municipal Golf Courses (Fig. 7.1; Mallin and Wheeler 2000), than at the other stations. Nitrate concentrations were lower than 2005-2006, likely a result of drought and less runoff. Phosphate concentrations increased considerably from the previous year. The monthly chlorophyll *a* data (Table 7.1) showed that Hewletts Creek hosted a major algal bloom at NB-GLR in August 2006 of 46 µg/L of chlorophyll *a* and two minor algal blooms at that site in March and April 2007 (27 and 35 µg/L of chlorophyll *a* respectively). A major bloom of 48 µg/L of chlorophyll *a* was seen at SB-PGR in March 2007, as well as a lesser bloom of 31 µg/L at that station in August 2006. Algal blooms have been common in upper Hewletts Creek in the past (Mallin et al. 1998a; 1999; 2002a; 2004; 2005; 2006).

Nitrate concentrations were elevated leaving the golf course at PVGC-9 relative to the other stations (Tables 7.1 and 7.2). Fecal coliform bacteria counts exceeded State standards all seven out of seven times in 2007 at PVGC-9. An earlier assessment (Mallin and Wheeler 2000) noted higher fecal coliform counts entering the course from suburban neighborhoods upstream than counts at PVGC-9 leaving the course.

Table 7.1. Selected water quality parameters at lower and middle creek stations in Hewletts Creek watershed as mean (standard deviation) / range, August 2006-July 2007. Fecal coliform bacteria presented as geometric mean / range.

Parameter	HC-2	HC-3
Salinity (ppt)	33.6 (1.4) 31.6-36.3	31.8 (2.5) 27.9-36.2
Turbidity (NTU)	5 (3) 2-12	6 (4) 2-14
DO (mg/L)	7.1 (1.4) 4.4-9.2	6.9 (1.6) 4.2-9.1
Nitrate (mg/L)	0.007 (0.002) 0.003-0.010	0.017 (0.021) 0.003-0.074
Ammonium (mg/L)	0.015 (0.008) 0.001-0.026	NA
Orthophosphate (mg/L)	0.016 (0.014) 0.006-0.041	0.013 (0.010) 0.001-0.037
Mean N/P Median	5.1 5.0	NA
Light attenuation (K/m)	1.0 (0.4) 0.6-1.5	NA
Chlorophyll *a* (µg/L)	2.0 (1.3) 0.6-5.8	2.7 (2.6) 0.5-10.5
Fecal col. CFU/100 mL	NA	NA

NA = not analyzed

Table 7.2. Selected water quality parameters at upstream stations in Hewletts Creek watershed, as mean (standard deviation) / range, fecal coliforms as geometric mean / range, August 2006-July 2007; for PVGC-9, n = 6 months.

Parameter	NB-GLR	SB-PGR	MB-PGR	PVGC-9
Salinity (ppt)	13.9 (10.5) 0.6-32.6	20.8 (8.0) 6.2-34.2	0.2 (0.2) 0.1-0.9	0.1 (0.0) 0.1-0.1
Turbidity (NTU)	13 (8) 3-30	12 (16) 3-21	7 (8) 2-29	14 (10) 3-28
DO (mg/L)	7.1 (2.2) 4.0-10.7	6.5 (2.0) 3.9-9.6	7.3 (1.0) 6.0-9.4	5.9 (1.9) 3.5-9.1
Nitrate (mg/L)	0.056 (0.073) 0.005-0.237	0.028 (0.032) 0.003-0.106	0.047 (0.046) 0.008-0.135	0.440 (0.247) 0.140-0.780
Ammonium (mg/L)	0.049 (0.052) 0.001-0.206	0.045 (0.037) 0.010-0.114	0.152 (0.386) 0.016-1.376	0.030 (0.013) 0.010-0.050
Orthophosphate (mg/L)	0.063 (0.079) 0.002-0.240	0.041 (0.067) 0.006-0.227	0.124 (0.119) 0.009-0.301	0.011 (0.004) 0.010-0.020
Mean N/P ratio Median	12.8 5.4	7.6 6.3	9.0 14.7	99 113
Light attenuation (K/m)	NA	NA	NA	NA
Chlor *a* (µg/L)	12.7 (15.3) 0.5-46.4	12.1 (14.1) 0.5-48.1	1.6 (1.7) 0.2-6.0	5.2 (3.7) 1.1-10.2
Fecal coliforms CFU/100 mL	NA	NA	NA	764 235-2700

NA = not analyzed

Sewage Spill Investigations: Monthly fecal coliform bacteria samples were not collected in the tidal areas of the creek in 2006-2007. However, there were two sewage spills that occurred in November 2006 in upper middle Hewletts Creek. The first was a 655,000 gallon spill on November 19th, and the second was a 72,000 gallon spill on November 25th, occurring from the Northeast Interceptor. The UNCW Aquatic Ecology laboratory entered into a collaboration with the City of Wilmington to sample the creek. UNCW collected field samples on eight occasions from November 20 – December 1, and ran fecal coliform counts on November 20 and December 1. The City of Wilmington ran fecal coliform counts in their laboratory on the other six occasions. The results showed significant contamination from November 20 through November 25, with particularly high fecal counts in the middle branch at MB-PGR and the south branch at SB-PGR, as well as in the upper main creek body at HC-3 (Table 7.3). Contamination lingered at least until December 1. Elevated counts also occurred at times in the north branch at NB-GLR and as far downstream as HC-2 (Table 7.3).

Table 7.3. Fecal coliform bacteria counts in Hewletts Creek following the November 19 and November 25 sewage spills, data as colony-forming units (CFU)/100 mL). The N.C. human contact standard for fecal coliform bacteria is 200 CFU/100 mL; the U.S. shellfishing water standard is 14 CFU/100 mL.

Station	11/20	11/21	11/22	11/24	11/25	11/27	11/29	12/1
HC-2		13,143	868	8	9	7	1	121
HC-3	24,000	36,000	4,750	96	13	2	5	240
NB-GLR	6,950	4,700	4,000	12,857	5,250	310	300	315
MB-PGR	226,000	85,455	21,000	62,000	39,000	248	226	255
SB-PGR	22,150	48,000	10,000	3,500	1,322	66	86	730

Dobo Property: The New Hanover County Tidal Creeks Advisory Board, using funds from the North Carolina Clean Water Management Trust Fund, purchased a former industrial area owned by the Dobo family in August 2002. This property was bought to be used as a passive treatment facility for the improvement of non-point source runoff drainage water before it enters Hewletts Creek. As such, the City of Wilmington is contracted with outside consultants to create a wetland on the property for this purpose. Baseline data were needed to assess water quality conditions before and after the planned improvements. In January 2004 the UNCW Aquatic Ecology Laboratory began sampling three inflowing creeks and the single outflowing creek (Fig. 7.2). DB-1 is a creek entering the southern side of the property adjacent to Brookview Road. DB-2 is a small stream entering the property along Bethel Road. DB-3 is a deeply-incised stream running along the northern edge of the property. DB-4 is the outflowing stream, sampled at Aster Court. Construction of the wetland was ongoing during the spring and summer sampling in 2007, so some sites were unreachable at times. Hence, DB-1 was only sampled on three occasions, and DB-2 on only two occasions in 2007.

In 2007 the nitrogen species were as high or higher exiting the site than entering, while phosphorus was reduced exiting the site (Table 7.4). Dissolved oxygen was particularly low only at DB-4, a considerable drop from the previous year (Mallin et al. 2007). Very likely the construction activities accounted for this decrease. Turbidity was relatively high entering the site at DB-1 and DB-3, but particularly high leaving the site at DB-4 (a poor rating – Appendix B). Again, the high turbidity leaving the site was probably a result of construction of the wetland. Suspended solids concentrations were also periodically elevated at all of the sites. Fecal coliform bacteria counts were high at all sites, particularly DB-1 and DB-4 (Table 7.4). It will likely take over a year post-construction for reductions in parameter concentrations to become significant as growth of the wetland vegetation occurs.

Table 7.4. Selected water quality parameters at non-tidal Dobo site stations in Hewletts Creek watershed, as mean (standard deviation) / range, fecal coliforms as geometric mean / range, January - September 2007. n = 7 for DB-3 and DB-4, 3 for DB-1, and 4 for DB-2.

Parameter	DB-1	DB-2	DB-3	DB-4
Turbidity (NTU)	23 (32) 0-60	9 (9) 0-5	22 (16) 0-50	41 (35) 12-109
TSS mg/L	35 (38) 7-78	16 (15) 2-37	14 (10) 4-32	17 (10) 5-35
DO (mg/L)	4.6 (2.6) 3.0-7.6	7.5 (1.6) 5.5-9.4	4.7 (2.3) 1.0-8.2	3.7 (2.7) 1.5-8.3
Nitrate (mg/L)	0.070 (0.060) 0.010-0.130	0.028 (0.035) 0.010-0.060	0.030 (0.031) 0.010-0.080	0.027 (0.029) 0.010-0.070
Ammonium (mg/L)	1.117 (1.321) 0.100-2.610	0.173 (0.128) 0.030-0.300	0.347 (0.450) 0.080-1.360	0.359 (0.295) 0.070-0.850
TN (mg/L)	3.030 (3.118) 0.870-6.610	0.903 (0.480) 0.380-1.310	1.273 (1.475) 0.570-4.610	1.284 (0.596) 0.710-2.010
Orthophosphate (mg/L)	0.043 (0.015) 0.030-0.060	0.010 (0.000) 0.010-0.010	0.020 (0.014) 0.010-0.040	0.017 (0.013) 0.010-0.040
TP (mg/L)	0.227 (0.229) 0.080-0.490	0.060 (0.035) 0.030-0.110	0.060 (0.016) 0.040-0.080	0.049 (0.030) 0.010-0.080
Chlor *a* (µg/L)	4.5 (3.2) 1.1-7.5	40.5 (61.2) 0.6-130.8	3.8 (2.9) 1.2-8.2	5.4 (3.9) 1.6-13.1
Fecal coliforms CFU/100 mL	977 388-2200	266 41-1550	292 37-20,000	855 270-2700

Figure 7.1 Hewletts Creek watershed

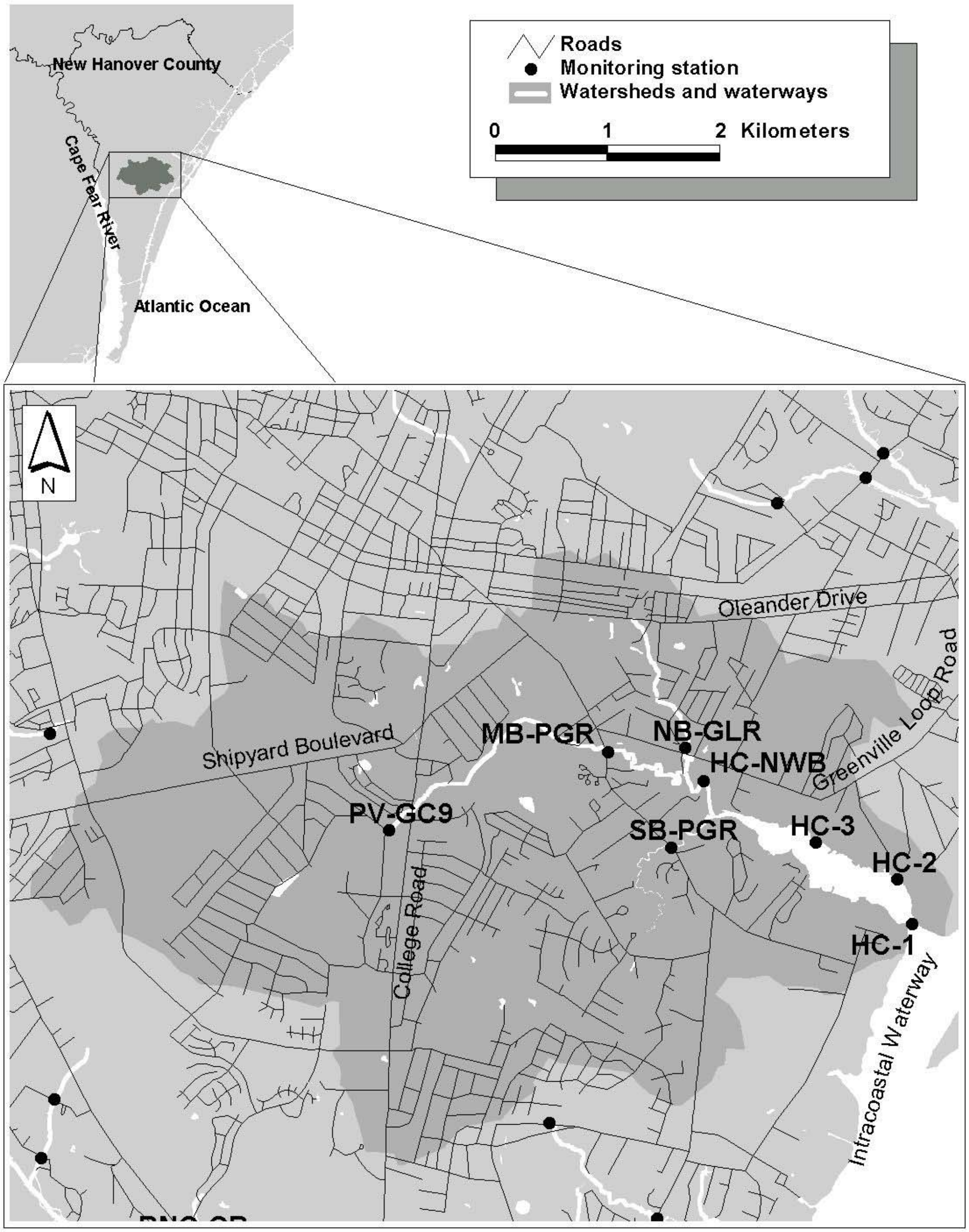
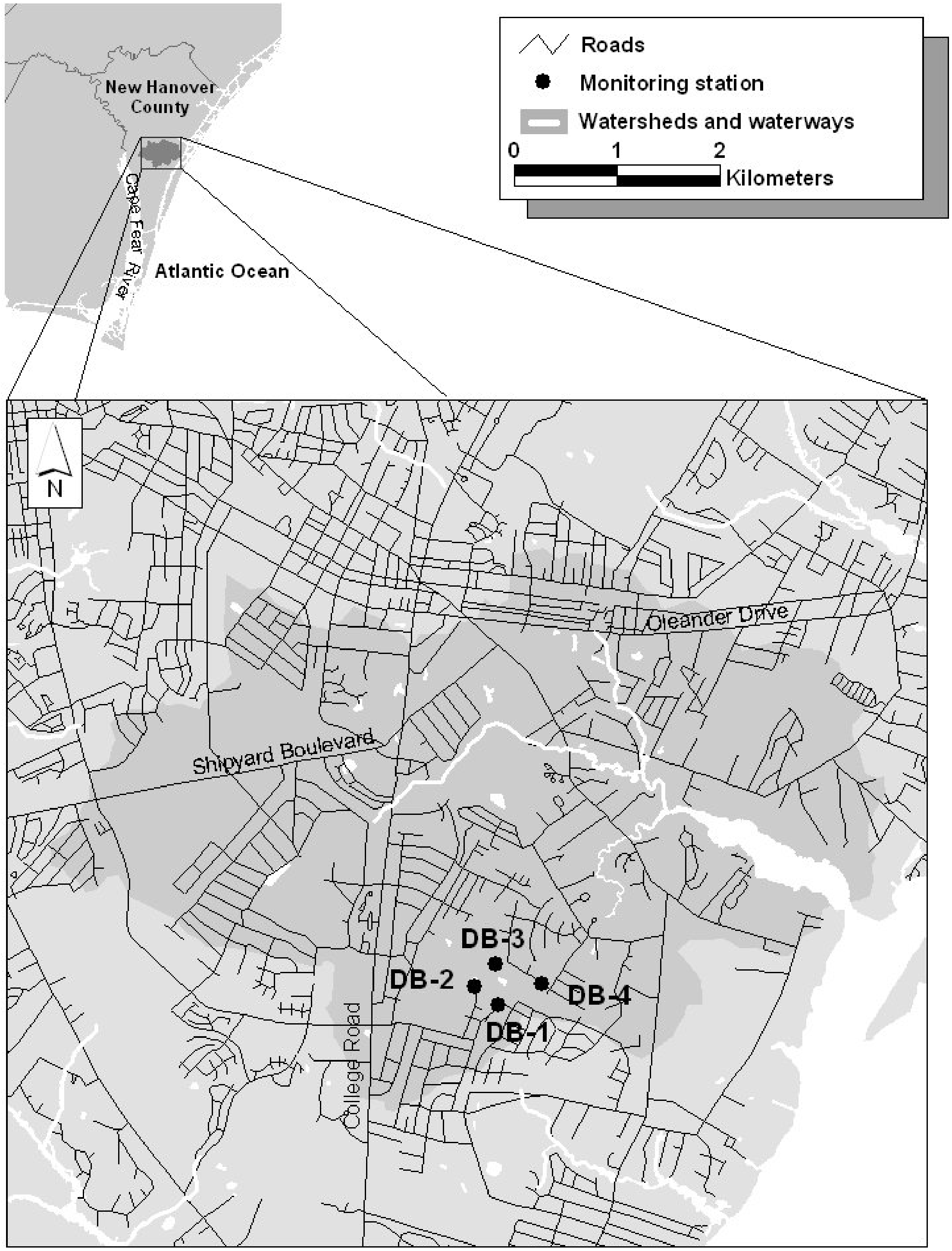


Figure 7.2 Dobo Sites within Hewletts Creek watershed



8.0 Howe Creek Water Quality

Snapshot
Watershed area: 3,264 acres (1,321 ha)   Impervious surface coverage: 19%
Watershed population: 4,224
Overall water quality: Fair
Problematic pollutants: Fecal coliform bacteria, some low dissolved oxygen

Howe Creek was sampled for physical parameters, nutrients, chlorophyll *a*, and fecal coliform bacteria at five locations during 2006-2007 (HW-M, HW-FP, HW-GC, HW-GP and HW-DT- Fig. 8.1). Turbidity was generally low and did not exceed the North Carolina water quality standard of 25 NTU at any site (Table 8.1; Appendix B). Dissolved oxygen concentrations were good to fair in Howe Creek, with HW-GP and HW-DT each below the standard of 5.0 mg/L on three occasions (Appendix B). Nitrate concentrations were low at the lower stations but increased upstream (Table 8.2). Median inorganic molar N/P ratios were low, reflecting low nitrate levels, and indicating that nitrogen was probably the principal nutrient limiting phytoplankton growth at all stations. There was one major algal bloom of 37 µg/L as chlorophyll *a* at HW-DT. Since wetland enhancement was performed in 1998 above Graham Pond the creek below the pond at HW-GP has had fewer and smaller algal blooms than before the enhancement (Fig. 8.2). Light attenuation showed generally clear water except for elevated readings of 2.5-3.0/m at the upper stations in spring 2007 (Table 8.1).

Table 8.1. Water quality summary statistics for Howe Creek, August 2006-July 2007, as mean (st. dev.) / range. Fecal coliform bacteria as geometric mean / range.

	Salinity (ppt)	Diss. oxygen (mg/L)	Turbidity (NTU)	Light (K/m)	Chlor *a* (µg/L)	Fecal coliforms (CFU/100 mL)
HW-M	34.2 (1.8)	7.4 (1.4)	3 (3)	0.7 (0.1)	2.2 (1.2)	3
	31.0-36.3	5.7-9.2	0-8	0.6-0.8	0.8-3.8	1-10
HW-FP	34.5 (1.8)	7.3 (1.5)	3 (3)	0.8 (0.1)	2.7 (2.9)	3
	31.3-36.4	5.6-9.1	0-7	0.6-0.9	0.7-10.9	1-36
HW-GC	32.8 (3.6)	7.1 (1.8)	4 (3)	0.9 (0.4)	2.3 (2.0)	9
	25.4-36.4	4.2-9.0	1-10	0.6-1.3	0.5-7.2	1-53
HW-GP	21.9 (11.2)	6.8 (2.0)	6 (6)	1.9 (0.5)	4.1 (4.1)	115
	0.2-35.0	4.0-9.4	0-21	1.5-2.5	0.8-15.4	31-191
HW-DT	8.6 (9.4)	7.3 (2.1)	9 (6)	2.8 (0.3)	9.1 (10.5)	339
	0.1-26.3	3.9-9.4	2-22	2.5-3.0	1.0-37.2	125-870

Figure 8.1. Howe Creek watershed and sampling sites.

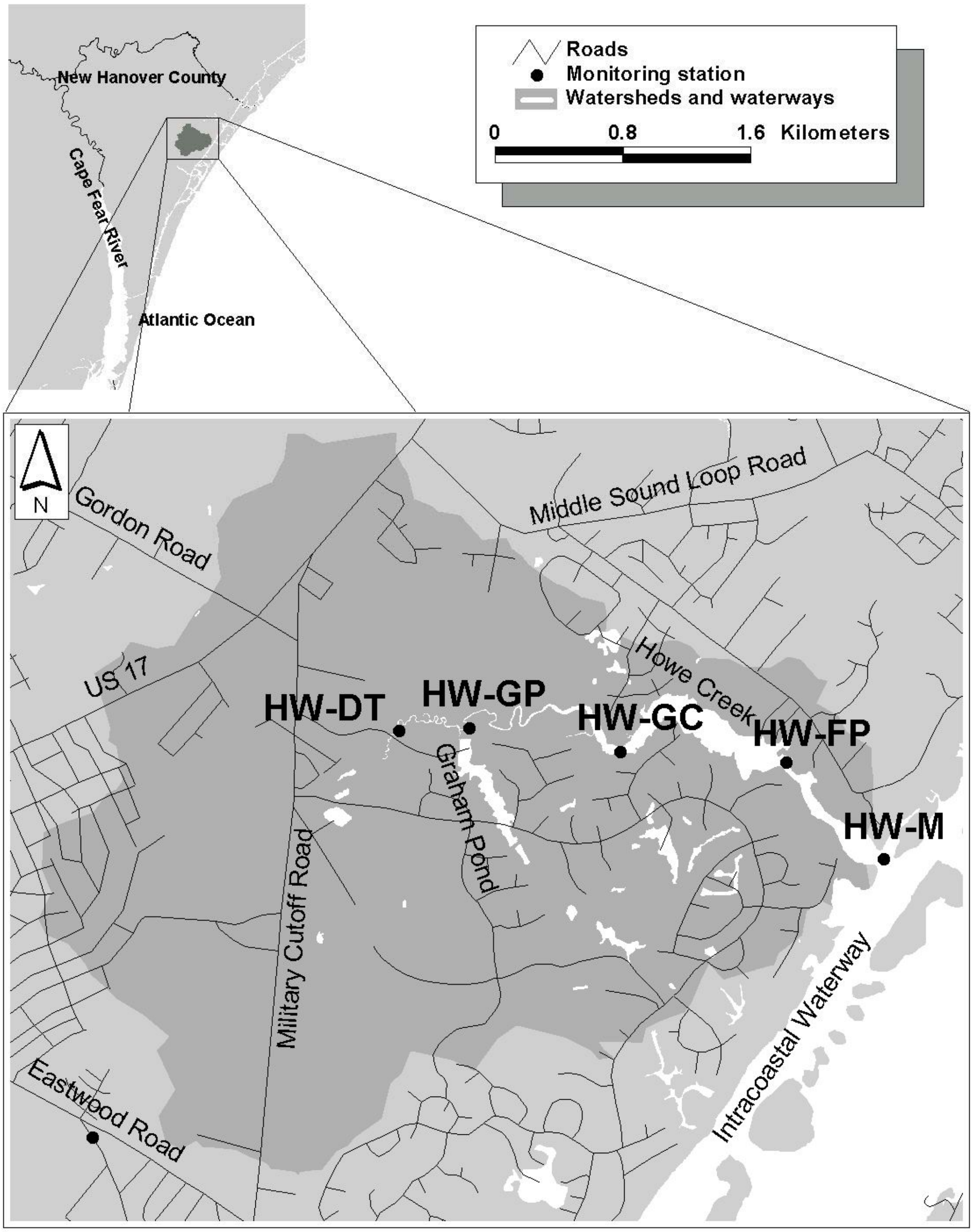


Figure 8.2. Chlorophyll *a* concentrations (algal blooms) in Howe Creek below Graham Pond before and after 1998 wetland enhancement in upper Graham Pond.

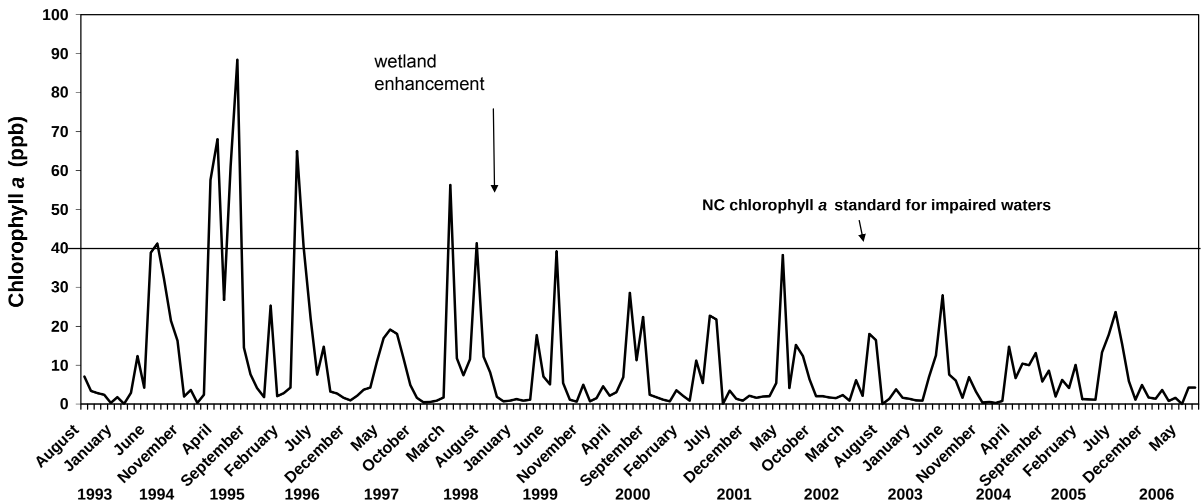


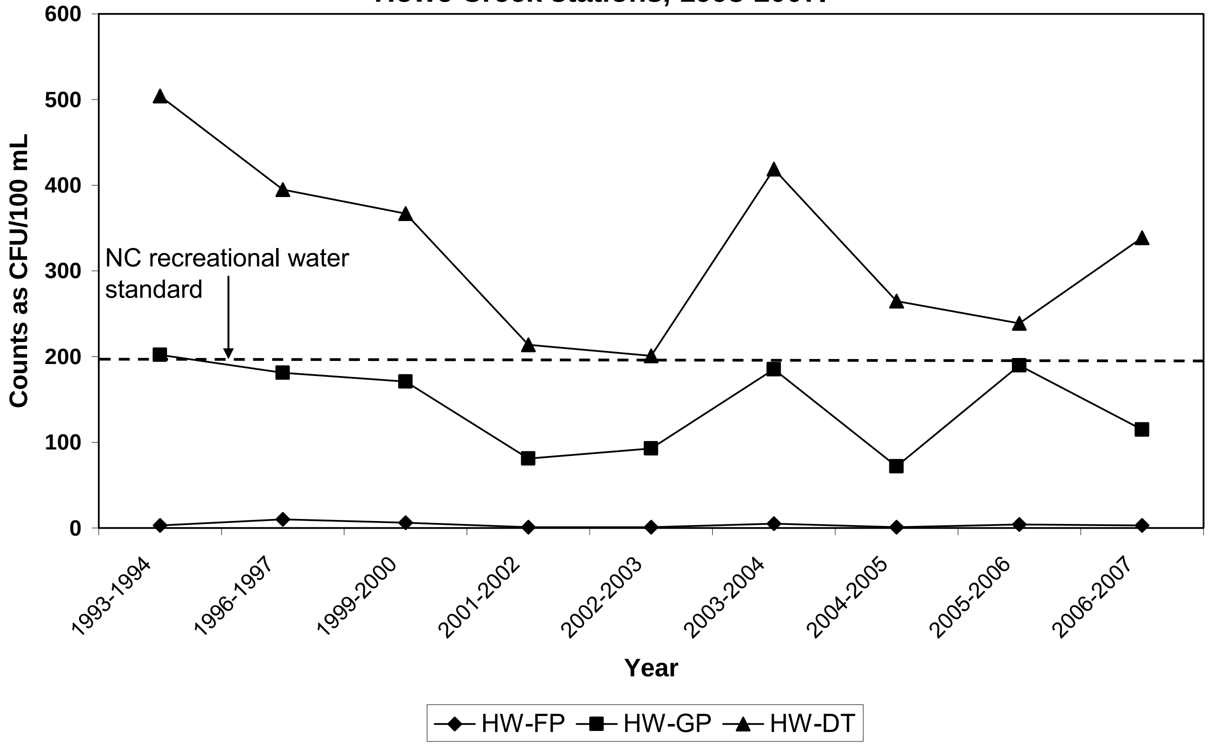
Table 8.2. Nutrient concentration summary statistics for Howe Creek, August 2006-July 2007, as mean (standard deviation) / range, N/P ratio as mean / median.

	Nitrate (mg/L)	Ammonium (mg/L)	Orthophosphate (mg/L)	Molar N/P ratio
HW-M	0.005 (0.003) 0.002-0.011	0.009 (0.010) 0.001-0.039	0.008 (0.004) 0.002-0.014	6.6 4.4
HW-FP	0.009 (0.012) 0.003-0.042	0.009 (0.008) 0.001-0.026	0.007 (0.004) 0.001-0.015	9.2 4.8
HW-GC	0.006 (0.003) 0.001-0.010	NA	0.009 (0.003) 0.005-0.014	NA
HW-GP	0.011 (0.009) 0.004-0.034	0.026 (0.024) 0.001-0.079	0.018 (0.024) 0.001-0.081	10.0 4.9
HW-DT	0.028 (0.041) 0.003-0.114	0.020 (0.015) 0.001-0.047	0.027 (0.031) 0.005-0.093	6.1 4.6

NA = not analyzed

Fecal coliform bacterial abundances were low near the Intracoastal Waterway, moderate in mid-creek, and high at the uppermost station (Table 8.1; Fig. 8.3). The lower and middle sites did not exceed the North Carolina human contact standard on any occasion, but counts at HW-DT exceeded the standard on seven of 12 occasions (Appendix B). With the exception of HW-DT the 2006-2007 data showed improved fecal coliform counts compared with 2005-2006 Howe Creek (Fig. 8.3).

Figure 8.3. Fecal coliform counts over time for three Howe Creek stations, 1993-2007.



9.0 Motts Creek

Snapshot
Watershed area: 2,389 acres (967 ha)   Impervious surface coverage: 14%
Watershed population: 4,800
Overall water quality: poor
Problematic pollutants: fecal coliform bacteria, low dissolved oxygen

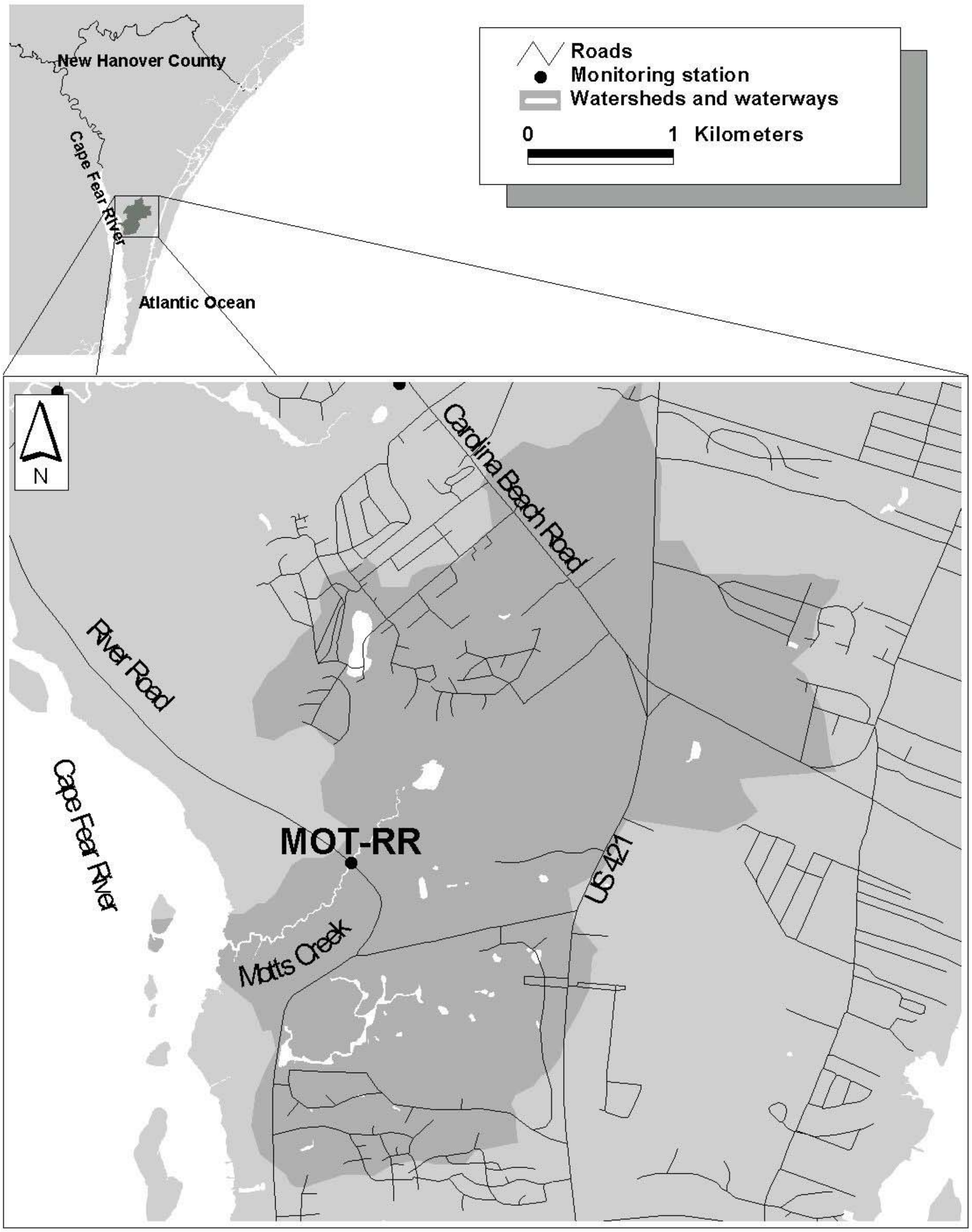
Motts Creek drains into the Cape Fear River Estuary (Fig. 9.1), and the creek area near River Road has been classified by the State of North Carolina as a Natural Heritage Site because of the area's biological attributes. These include the pure stand wetland communities, including a well-developed sawgrass community and unusually large flats dominated by *Lilaeopsis chinensis* and spider lily, with large cypress in the swamp forest. Thus, it is important that these attributes should be protected from land and water-disturbing activities. UNCW scientists sampled Motts Creek at the River Road bridge (Fig. 9.1). A large residential development is under construction upstream of the sampling site between Motts and Barnards Creeks. In recent years extensive commercial development occurred along Carolina Beach Road near its junction with Highway 421.

Dissolved oxygen concentrations were below 5.0 mg/L on four of seven samplings (range 2.4-4.7 mg/L) similar to previous years (Mallin et al. 2003; 2004; 2006). Neither turbidity nor suspended solids were problematic in 2007, likely a result of low rainfall. Fecal coliform contamination was a problem in Motts Creek, with the geometric mean of 220 CFU/100 mL slightly above the State standard of 200 CFU/100 mL, but lower than the previous year's geometric mean of 660 CFU/100 mL (Appendix B). Total nitrogen, ammonium, and total phosphorus levels were similar to the previous year's study, and chlorophyll *a* concentrations were not a problem, with only one minor algal bloom of 24 µg/L detected in June 2007 (Table 9.1). BOD5 was sampled on seven occasions in 2007, yielding a mean value of 1.5 mg/L and a median value of 1.6 mg/L, generally similar to previous years (Mallin et al. 2003; 2004; 2005; 2006; 2007). Thus, this creek showed mixed water quality, with algal blooms and BOD not problematic but low dissolved oxygen and elevated fecal coliform counts a continuing problem.

Table 9.1. Selected water quality parameters at a station (MOT-RR) draining Motts Creek watershed before entering the Cape Fear Estuary, as mean (standard deviation) and range, January-September 2007. Fecal coliforms as geometric mean / range.

Parameter	MOT-RR	
	Mean (SD)	Range
Salinity (ppt)	10.5 (9.4)	0.5-22.8
TSS (mg/L)	12 (4.0)	7-19
Turbidity (NTU)	11 (3)	7-16
DO (mg/L)	5.5 (2.5)	2.4-8.7
Nitrate (mg/L)	0.133 (0.159)	0.010-0.480
Ammonium (mg/L)	0.058 (0.052)	0.005-0.160
Total nitrogen (mg/L)	1.766 (2.477)	0.430-7.340
Orthophosphate (mg/L)	0.019 (0.011)	0.010-0.030
Total phosphorus (mg/L)	0.070 (0.015)	0.050-0.090
Mean N/P ratio	33	
Median	14	
Chlor *a* (µg/L)	10.6 (7.1)	3.5-24.0
BOD5 (mg/L)	1.5 (0.5)	0.8-2.6
Fecal coliforms (CFU/100 mL)	220	30-2850

Figure 9.1 Motts Creeks watershed



10.0 Pages Creek

Snapshot
Watershed area: 3,546 acres (1,435 ha) Impervious surface coverage: >13%
Watershed population: 4,600
Overall Water Quality: Fair
Problematic pollutants: Fecal coliform bacteria; low dissolved oxygen

Pages Creek was sampled at nine stations, two of which receive drainage from developed areas near Bayshore Drive (PC-BDUS and PC-BDDS - Fig. 10.1). During the past sample year turbidity was low with no incidents of turbidity exceeding the state standard of 25 NTU (Table 10.1). However, there were several incidents of hypoxia during summers of 2006 and 2007, with the upper stations affected more severely than the main branch and creek mouth stations (Table 10.1; Appendix B). Fecal coliform bacteria abundances were low in the creek mouth and lower main creek stations (Table 10.1). However, elevated fecal coliform counts occurred three times each at Stations PC-BDDS and PC-H (in the upper creek), and twice at PC-BDUS. One pulse at PC-H (June 2007) was attributable to a sewage leak from a county pump station. Nitrate and orthophosphate concentrations were generally low, and phytoplankton biomass as chlorophyll *a* was low with no significant algal blooms seen (Table 10.1). Median inorganic nitrogen-to-phosphorus molar ratios were at or below 16, indicating that phytoplankton growth in this creek is probably nitrogen limited. Because of the relatively low watershed development and low amount of impervious surface coverage in the watershed (Mallin et al. 1998a; 2000b), this is one of the least-polluted creeks in New Hanover County. However, the problems with fecal coliform bacteria contamination and low dissolved oxygen were greater in 2006-2007 than the last time all nine stations were sampled, which was 2000-2001 (Mallin et al. 2002).

Table 10.1. Selected water quality parameters in Pages Creek as mean (standard deviation) / range, August 2006-July 2007. Fecal coliforms as geomean/range.

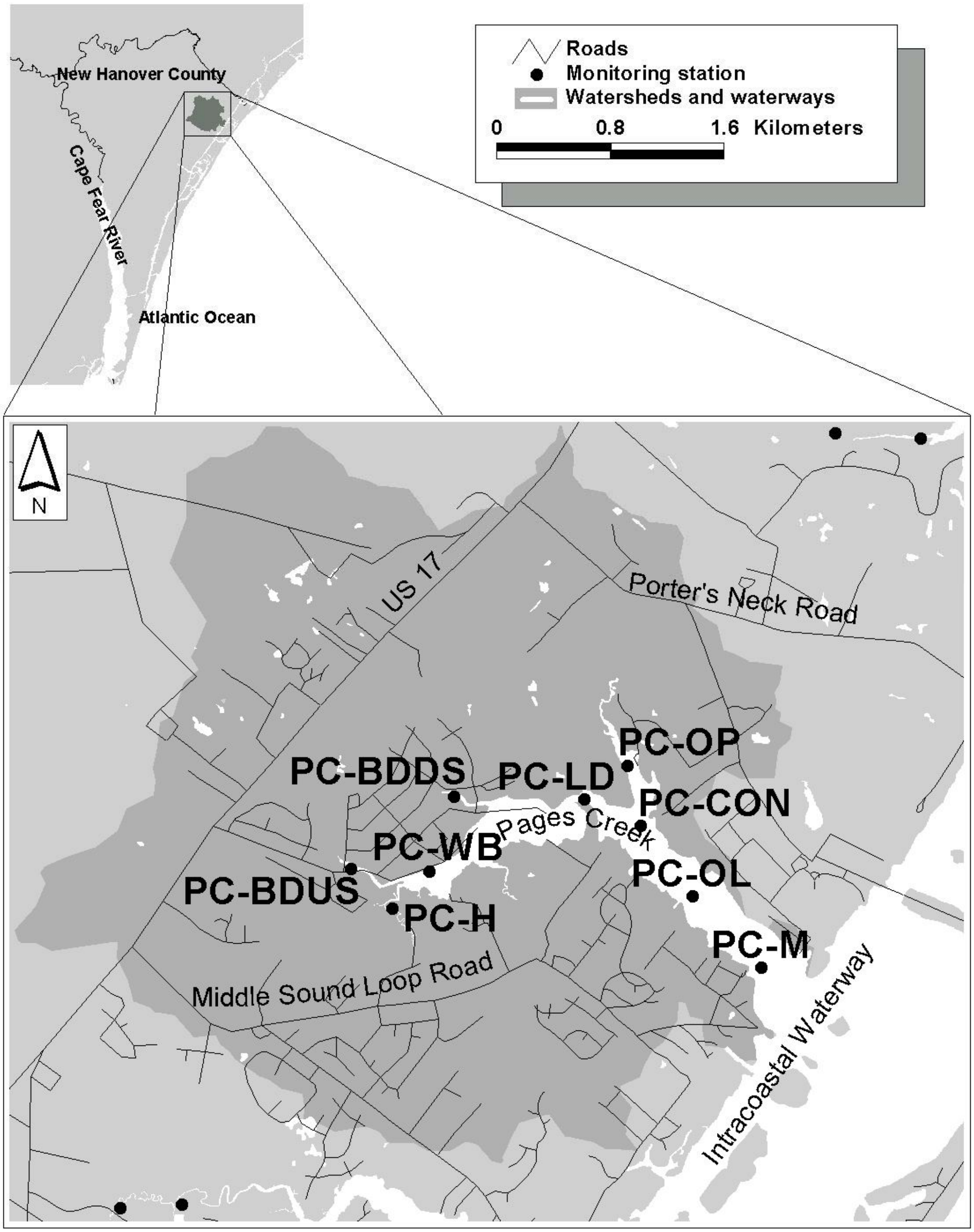
Parameter	Salinity	Dissolved oxygen	Turbidity	Light Atten.	Fecal colif.
PC-M	34.3+2.0	7.1+1.9	5+4	1.1+0.7	3
	30.6-36.8	4.2-9.4	0-11	0.6-2.4	1-22
PC-OL	34.5+1.8	6.9+1.9	4+4	0.8+0.3	3
	30.6-36.7	3.8-9.4	0-12	0.4-1.1	1-12
PC-CON	34.4+1.9	7.0+1.8	5+4	0.8+0.2	2
	30.7-37.0	4.5-9.5	0-11	0.6-1.2	1-12
PC-OP	33.2+2.5	6.8+2.1	6+5	1.3+0.6	8
	29.3-36.6	3.2-9.7	0-14	0.6-2.0	2-19
PC-LD	34.2+2.0	7.0+1.8	5+4	0.9+0.2	6
	30.5-36.8	4.1-9.4	0-12	0.6-1.1	6-19
PC-BDDS	31.8+4.2	6.6+2.1	6+5	1.4+0.3	131
	22.7-36.3	3.3-9.4	0-14	1.0-1.7	29-1040
PC-WB	31.5+2.9	6.5+2.0	7+5	NA	37
	28.0-36.0	3.3-9.5	1-14		5-360
PC-BDUS	26.7+8.1	5.9+2.2	9+7	NA	98
	11.0-36.0	2.4-8.9	1-25		21-1536
PC-H	30.7+3.8	6.2+2.4	7+6	NA	94
	24.9-36.5	2.2-9.8	1-17		21-909

Table 10.2. Selected water quality parameters in Pages Creek as mean (standard deviation) / range, August 2006-July 2007. Inorganic N/P as mean/median.

Parameter	Nitrate	Ammonium	Phosphate	N/P	Chlorophyll *a*
PC-M	16.4+31.9 1.5-106.9	17.4+10.1 4.7-34.6	19.2+39.0 1.0-129.6	3.4 1.7	2.6+1.9 0.4-5.7
PC-OL	5.0+2.8 1.0-9.3	NA	6.1+3.9 0.4-11.4		2.5+2.4 0.3-7.7
PC-CON	6.6+6.5 1.0-22.4	NA	12.3+10.3 5.5-38.9		2.0+1.6 0.2-5.5
PC-OP	7.1+3.4 1.9-11.9	NA	11.0=10.1 1.0-33.8		2.5+2.3 0.2-7.5
PC-LD	9.1+4.4 0.2-15.0	NA	12.3+8.7 3.3-32.9		2.4+2.0 0.2-6.0
PC-BDDS	13.7+16.3 3.9-59.2	29.9+18.9 2.3-59.1	11.8+4.5 6.0-21.8	8.8 7.8	5.0+5.3 0.3-17.9
PC-WB	8.8+6.6 1.8-24.6	NA	9.4+7.3 0.5-20.3		3.5+3.2 0.4-9.0
PC-BDUS	15.4+11.4 3.3-37.3	79.1+31.4 24.6-138.7	15.5+9.2 3.1-32.1	17.4 14.7	3.2-2.7 0.5-8.5
PC-H	11.1+9.8 3.1-36.2	43.7+43.5 1.0-157.3	12.7+6.7 1.0-22.0		4.6+4.7 0.5-11.3

NA = not analyzed

Figure 10.1. Pages Creek watershed and sampling sites.



11.0 Smith Creek

Snapshot
Watershed area: 2,880 acres (1,166 ha) Impervious surface coverage: 28%
Watershed population: 25,904
Overall water quality: Poor
Problematic pollutants: Fecal coliform bacteria, low dissolved oxygen, algal blooms

Smith Creek drains into the lower Northeast Cape Fear River just before it joins with the mainstem Cape Fear River at Wilmington (Fig. 11.1). Two estuarine sites on Smith Creek, SC-23 and SC-CH (Fig. 11.1) were sampled in 2007. Dissolved oxygen concentrations were below 5.0 mg/L on three occasions at SC-23 and four occasions at SC-CH between June and September 2007, with the lowest value was 3.2 mg/L. The North Carolina turbidity standard for estuarine waters (25 NTU) was only exceeded once at both sites during the 2007 sampling, in July. Suspended solids concentrations in Smith Creek were comparatively moderate in the Wilmington watersheds system.

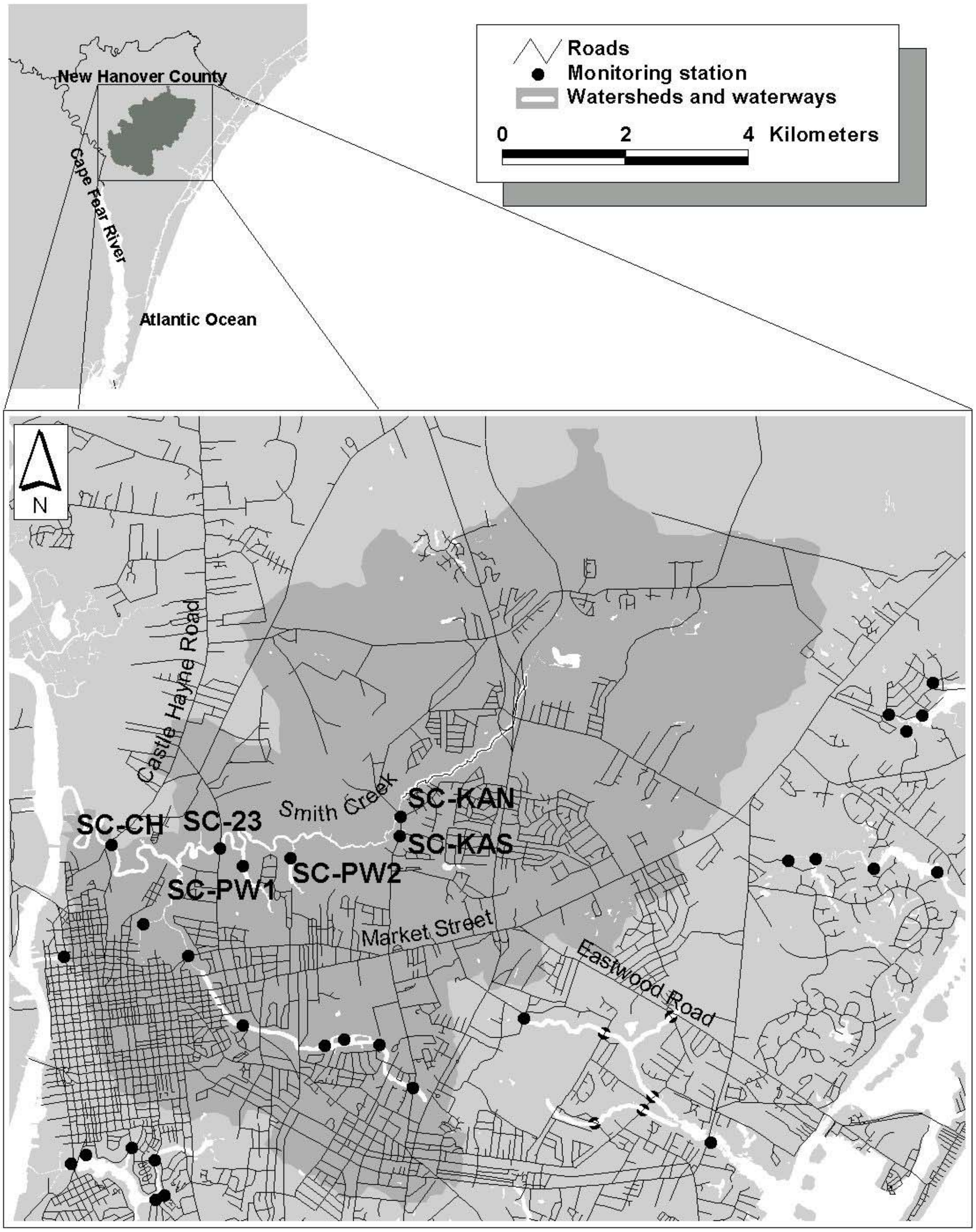
Nutrient concentrations remained similar to last year's levels (Table 11.1). A massive algal bloom well exceeding the State standard was found in 2007, a value of 187 µg/L chlorophyll *a* at SC-23 in June. Lesser algal blooms of 36 and 39 µg/L of chlorophyll *a* occurred at SC-23 in May and August, and blooms of 36 and 28 µg/L occurred in May and June at SC-CH. Fecal coliform bacteria concentrations were above 200 CFU/100 mL on two occasions at SC-CH, but on five occasions at SC-23, a deterioration from the last two years (Mallin et al. 2006; 2007) and all months tested well above the shellfishing standard (14 CFU/100 mL) in the estuarine portion of the creek (Table 11.1). BOD5 was sampled on seven occasions in 2007 at SC-CH, with a mean value of 1.2 mg/L and a median value of 0.8 mg/L, similar to last year.

Table 11.1. Selected water quality parameters in Smith Creek watershed as mean (standard deviation) / range. January - September 2007.

Parameter	SC-23		SC-CH	
	Mean (SD)	Range	Mean (SD)	Range
Salinity (ppt)	5.7 (5.2)	0.1-13.3	10.1 (8.6)	0.2-21.6
Dissolved oxygen (mg/L)	6.2 (2.4)	3.2-9.7	5.7 (2.3)	3.6-9.4
Turbidity (NTU)	13 (6)	9-26	14 (7)	8-29
TSS (mg/L)	14 (6)	10-27	14 (6)	4-24
Nitrate (mg/L)	0.139 (0.132)	0.010-0.380	0.313 (0.159)	0.010-0.480
Ammonium (mg/L)	0.039 (0.039)	0.005-0.110	0.033 (0.028)	0.010-0.090
Total nitrogen (mg/L)	0.817 (0.126)	0.580-0.960	0.989 (0.261)	0.750-1.470
Orthophosphate (mg/L)	0.021 (0.012)	0.010-0.040	0.033 (0.017)	0.010-0.050
Total phosphorus (mg/L)	0.150 (0.196)	0.050-0.590	0.111 (0.047)	0.070-0.210
Mean N/P ratio	22		27	
Median	18		18	
Chlor. *a* (μg/L)	45.6 (63.8)	1.8-187.4	13.4 (13.5)	1.2-36.2
Fecal col. /100 mL (geomean / range)	408	84-2200	118	45-410
BOD5 (mg/L)	NA	NA	1.2 (1.0)	0.3-2.8

NA = not analyzed

Figure 11.1 Smith Creek watershed



12.0 Whiskey Creek

Snapshot
Watershed area: 1,344 acres (544 ha)   Impervious surface coverage: 19%
Watershed population: 7,107
Overall water Quality: Good
Problematic pollutants: Fecal bacteria in headwater stations

Whiskey Creek drains into the ICW. Sampling of this creek began in August 1999, at five stations. One station was dropped due to access issues in 2005; thus four stations were sampled in 2006-2007; WC-M (at the marina near the creek mouth), WC-MLR (from the bridge at Masonboro Loop Road), WC-SB (in fresh to oligohaline water along the south branch at Hedgerow Lane), and WC-NB (in fresh to oligohaline water along the north branch at Navajo Trail – Fig. 12.1). Dissolved oxygen concentrations were below the State standard on two of 12 occasions at WC-MB, with below standard readings on only one occasion each at WC-MLR and WC-SB (Table 12.1). Turbidity was within state standards for tidal waters on all sampling occasions (Table 12.1; Appendix B). Algal blooms are rare in this creek; there was one bloom of 33 μg/L at WC-MLR in August 2006 (Table 12.1). Nitrate concentrations were highest upstream at WC-NB, with little difference among the other sites (Table 12.2) and concentrations in general were lower than in to previous years – likely a result of drought and low runoff. Ammonium levels were highest at WC-NB and WC-SB, and these levels were among the highest of all the tidal creek stations sampled. Phosphate concentrations were highest at WC-NB, followed by WC-SB; phosphate in general increased from the previous year of sampling. The N/P ratios were lower than previous years, again owing to drought, low runoff and nitrate, and somewhat elevated phosphate. Phosphate, ammonium and nitrate at WC-MB were highest among all creek mouth stations in the tidal creek system (there is a marina at the creek mouth which may have contributed). Fecal coliform bacteria were not sampled in 2006-2007. Whiskey Creek is presently closed to shellfishing by the N.C. Division of Marine Fisheries

Table 12.1. Water quality summary statistics for Whiskey Creek, August 2006-July 2007, presented as mean (standard deviation) / range.

	Salinity (ppt)	Dissolved oxygen (mg/L)	Turbidity (NTU)	Chlor *a* (μg/L)	Light attenuation (*k*/m)
WC-MB	31.8 (2.4) 28.4-35.7	7.0 (1.6) 4.0-9.2	6 (3) 2-12	2.1 (1.4) 0.1-4.7	1.1 (0.4) 0.8-1.3
WC-MLR	26.1 (4.4) 18.5-34.1	7.0 (2.0) 2.4-9.3	8 (3) 4-14	6.4 (8.8) 0.4-32.5	NA NA
WC-SB	0.1 (0.0) 0.1-1.2	7.5 (1.3) 4.6-9.2	6 (4) 1-15	2.9 (4.3) 0.1-12.8	NA NA
WC-NB	0.2 (0.1) 0.1-0.2	7.0 (1.6) 5.0-9.6	6 (4) 1-15	0.6 (0.8) 0.1-2.9	NA NA

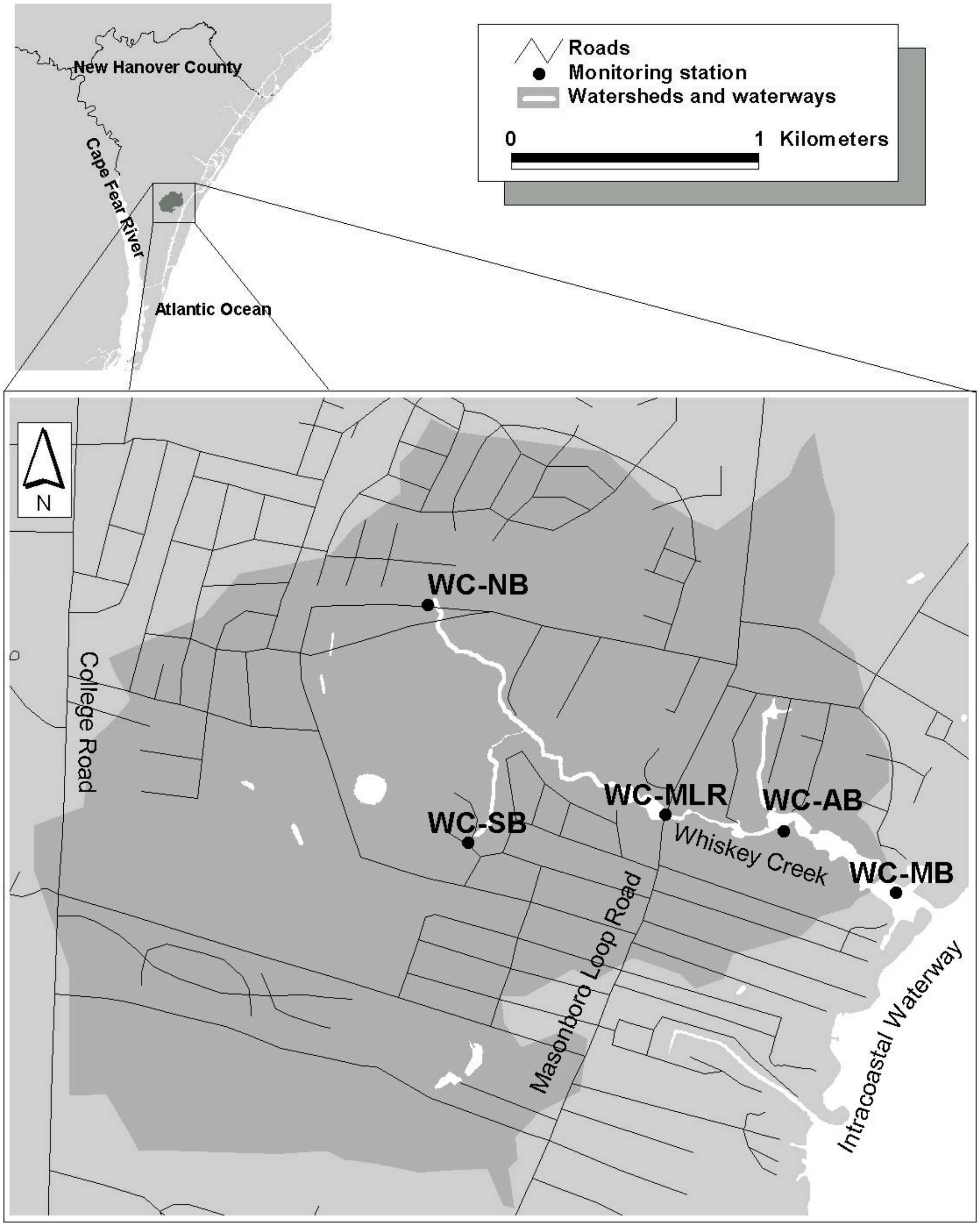
NA = not analyzed

Table 12.2. Nutrient concentration summary statistics for Whiskey Creek, August 2006-July 2007, as mean (standard deviation) / range, N/P ratio as mean / median.

	Nitrate (mg/L)	Ammonium (mg/L)	Phosphate (mg/L)	Molar N/P ratio
WC-MB	0.015 (0.004) 0.009-0.020	0.029 (0.016) 0.001-0.057	0.016 (0.016) 0.005-0.054	9.1 7.4
WC-MLR	0.019 (0.009) 0.007-0.031	0.037 (0.028) 0.006-0.096	0.014 (0.010) 0.003-0.032	10.6 9.7
WC-SB	0.018 (0.025) 0.001-0.061	0.132 (0.057) 0.073-0.260	0.028 (0.024) 0.001-0.069	838.7 11.3
WC-NB	0.044 (0.066) 0.001-0.158	0.169 (0.074) 0.061-0.295	0.073 (0.069) 0.001-0.189	110.1 4.8

NA = not analyzed

Figure 12.1. Whiskey Creek. Watershed and sampling sites.



13.0 Testing Optical Brighteners and Fecal Coliforms to Detect Sewage Leaks in Tidal Creeks

Mary Tavares[1], Mary I.H. Spivey[2], Matthew R. McIver[2] and Michael A. Mallin[2]

[1]Department of Environmental Studies

and

[2]Center for Marine Sciences

University of North Carolina at Wilmington

Abstract

Three New Hanover County, North Carolina, tidal creeks were sampled for the presence of optical brighteners and fecal coliform bacteria. Optical brighteners, compounds added to nearly all modern laundry detergents, adhere to fabric and absorb and emit light, countering the yellowing appearance of whites and making other colors appear brighter. The presence of optical brighteners in water bodies may indicate pollution from septic and/or sewer line leaks. When coupled with fecal bacteria sampling, testing for optical brighteners may strengthen identification of human fecal contamination. Samples were collected from Futch, Hewlett's and Bradley Creeks for three months in the fall of 2007. Optical brighteners were analyzed using a fluorometer that was calibrated to filter out background fluorescence from organic matter. Fecal bacteria were analyzed using a membrane filtration (mFC) method. Statistical analyses found a significant relationship between the abundance of fecal coliform bacteria and the mean optical brightener readings at Hewletts Creek and Bradley Creek, but not at Futch Creek. These results suggest that fecal coliform bacterial contamination in Hewletts and Bradley Creeks in fall 2007 was at least in part derived from human sewage or septic system leakage. Hewletts Creek suffered from several sewage spills in 2005 and 2006, and Bradley Creek had a sewage spill in 2007. The lack of a significant statistical relationship between fecal bacteria and optical brighteners in Futch Creek suggests that human sewage is not significantly contaminating the creek. Futch Creek is on septic systems and previous testing found the local septic systems functioning properly. Thus, simultaneous testing for fecal bacteria and optical brighteners can be a viable procedure for use in detecting human-sourced fecal bacteria in water bodies.

Introduction

Tidal creek ecosystems are abundant along the Atlantic Seaboard of the United States from New Jersey to Florida, as well as along the Gulf Coast. The four southernmost coastal counties in North Carolina (Onslow, Pender, New Hanover, and Brunswick) contain at least 73 tidal creeks that are second-order or larger (Mallin and Lewitus 2004). Many tidal creeks in southeastern North Carolina are currently or rapidly becoming urbanized by housing, marinas, shopping malls, and golf courses. This urbanization is due to both an increase in population (Mallin et al. 2000a) and the increase in tourism (USEPA 1992) that have occurred in North Carolina in recent years. Unfortunately, development along tidal creeks often leads to degraded water quality along with increased human health risk. While human development has been on the rise in New Hanover County, shellfishing areas have progressively been closed to harvest due to elevated fecal coliform bacterial counts (Mallin et al. 1998). Pathogenic enteric bacteria may be sourced from the excrement of humans or animals (Dadswell 1993) and contaminated water can cause human illness or death by means of direct contact or consumption of shellfish (USFDA 1995). One indicator for estimating fecal pathogenic bacteria presence is the abundance of fecal coliform bacteria (Dadswell 1993, Ford and Colwell 1996, Rees et al. 1998). The North Carolina Water Quality standard for fecal coliform counts is 200 CFU/100mL (human contact waters) and 14 CFU/100 mL (shell fishing waters), with no more than 10% of the samples exceeding 43 CFU/100mL (USFDA 1995; NCDEHNR 1996). Two potential pathways by which fecal coliform bacteria can enter a tidal creek are via runoff and sewer or septic system leaks.

In regards to runoff, an analysis of demographic and land use factors indicated a strong relationship between the percentage of impervious surface in a watershed and the mean estuarine fecal coliform abundance of the estuarine waters (Mallin et al. 2000b). The same study indicated that degraded water occurs when a watershed contains >20% impervious surface. Likewise, impaired microbiological water quality occurs in areas >10% impervious surface, while acceptable microbiological water quality occurs at <10% It is possible to decrease water quality degradation and human health risks through changes in development practices and land use planning, however, these environmentally sound land use practices have yet to be used on a large scale basis.

Leaks from septic systems or sewer lines represent another pollution source that can negatively affect microbiological water quality in local tidal creeks. Both Bradley Creek and Hewlett's Creeks have suffered several significant sewage spills since 2005. Failing septic systems may also present a pollution source within watersheds as some 1215 New Hanover County residents still use septic systems as opposed to sewer (personal correspondence, Catherine Timpy, New Hanover County Health Department). Pollution from a point source such as a sewer line or septic system is easier to both trace and eliminate, while non-point sources caused by development and poor land use planning are more challenging. As development continues, additional measures for detecting fecal coliform bacteria in these waterways must be added in an effort to protect public health. Testing for optical brighteners may prove to be a relatively inexpensive and effective way to locate and address sites of sewer line and septic systems leaks.

Optical brighteners, compounds added to laundry detergents, adsorb to clothing and form a light reflective layer creating the appearance of whiter whites and brighter colors. These compounds are excited by light in the near UV range (360-365nm) and emit light in the blue range (400-440nm). After light absorbtion, fluorescence is given off during the second excited state and can be measured by a fluorometer. In the United States, 97% of all laundry detergents contain one or both of two types of fluorescent whitening agents; FWA-1 also called DAS1 or FB-28, or FWA-2 referred to as DSBP or Tinopal CBS-X. Both compounds have been determined as safe for primary consumers. Aside from laundry detergents, optical brighteners are also added to textiles, plastics, synthetic fibers, and many kinds of paper. Other uses include medical, chemical, and petroleum applications (Hagedorn et al. 2005a).

Since household plumbing systems combine wastewater from toilets and washing machines, the presence of optical brighteners and fecal coliform bacteria in a waterway may indicate an input of human origin. Detection of both fecal coliform bacteria and optical brightener contamination suggests one of four scenarios (Table 1).

Fecal bacteria	Optical brightener	Probable cause
High	High	Sewer pipe leak or failing septic system
High	Low	Other warm-blooded mammal source or human waste from another source or outhouse
Low	High	Gray water in storm water system
Low	Low	Background fluorescence of insignificant contamination

Table 1. Probable cause for combined fecal coliform and optical brightener contamination. Any fecal coliform number that exceeds the state standard of 200 CFU/mL is considered high (modified from, Hartel et al. 2007a).

Outflow from wastewater treatment plants should neither contain optical brighteners nor fecal coliform bacteria; both are destroyed at the plant by decontamination procedures such as chlorination or UV light. Although it is generally known that optical brighteners biodegrade at a relatively slow rate, studies conflict on their photo-decay rates. One study indicated that optical brighteners photo-decay and biodegrade at relatively slow rates allowing them to be present in a waterway long enough to be detected (URS Co. 2004). Alternatively, optical brighteners have displayed photo-decay in a matter of hours when exposed to UV light (Kramer et al. 1996). Although laundry facilities are not present in every location that uses a sanitary sewer or septic system, detection of optical brighteners is still possible due to their presence in many soaps and almost all brands of toilet paper.

There are currently several methods for detecting optical brighteners in waterways. The first method involves placing cotton pads in waterways (typically smaller streams or creeks), and allowing them to adsorb optical brighteners over a period of time. After collection, the pads are dried and then exposed to UV light. The pad will fluoresce if optical brighteners are present. This method is both inexpensive and simple, yet yields low sensitivity (Sargent and Castonguay, 1998). The next approach is high performance liquid chromatography; a method which offers an instrument of high sensitivity, yet is expensive and requires a trained technician (Shu and Ding, 2005). The final approach is to use a fluorometer, an instrument that offers ease of use, moderate expense, and high sensitivity (Hagedorn et al. 2005b). Due to its formerly stated benefits, the fluormeter was the instrument of choice for our research.

Methods

The methodology for detecting optical brighteners in New Hanover County tidal creeks was based on Hartel et al, (2007a), and Hartel et al, (2007b). Optical brightener samples were collected monthly at or near high tide. Bradley and Hewletts Creek were sampled from shore, while Futch samples were taken by boat. Sampling at Futch Creek during the month of November was performed by Coastal Planning and Engineering of North Carolina, Inc. Optical brightener samples were collected by filling Nalgene 125mL opaque collection bottles 10 cm below the surface facing into the stream. Collection bottles were acid washed and triple rinsed before sampling. Samples were refrigerated in the dark at 8º C and read within 8 days. Fecal coliform samples were collected by filling pre-autoclaved containers ca. 10 cm below the surface, facing into the stream. Samples were stored on ice and processed within six hours. Fecal coliform concentrations were determined using a membrane filtration (mFC) method (APHA 1995). At each site, data were collected for temperature, salinity, dissolved oxygen, conductivity, pH, and turbidity using a YSI 6920 (YSI, Incorporated, Cincinnati, OH).

Fluorometry was performed with a laboratory fluorometer (Model 10-AU-000, Turner Designs, Sunnyvale, California). A kit was added to the fluorometer that included a lamp (10-049) emitting near UV light at 310-390 nm, an excitiation filter (10-069R) for the 300-400nm light range, and a 436 nm emission filter was added to decrease background fluorescence from dissolved organic compounds (Hartel 2007a). A standard curve was created using serial dilutions from 100 mg of Tide (Procter and Gamble, Cincinnati, Ohio) in one liter of deionized water. Tide is a commonly used laundry detergent known to contain optical brighteners. When the fluorometer was adjusted to an 80% sensitivity scale, the fluorometric value of 100 was equal to 100mg of Tide in 1 L of deionized water. The standard curve demonstrated that there was a linear relationship between the fluorometric response and detergent-sourced optical brighteners up to a reading of 100. Following field collections, each field sample was read on the fluorometer in triplicate at room temperature after 10 seconds to minimize degradation of optical brighteners by UV light (Hartel 2007b).

After all data sets were recorded, exploratory data analyses including regression and correlation, were performed and scatter plots were constructed to determine if significant relationships existed between optical brightener readings and fecal coliform bacteria counts. Data were analyzed as a whole as well as by individual creek. Data were normalized by log-transformation before statistical analyses. If a significant relationship was found between fecal bacteria counts and optical brightener presence it is likely that both were derived from the same human source(s) (Table 1).

Site Descriptions

Bradley Creek, Hewletts Creek, and Futch Creek are three tidal creeks which have been monitored since 1993 by researchers at UNC Wilmington's Aquatic Ecology Laboratory. Each of the three creeks has a salinity gradient between 35 ppt, where they meet the ICW, to fresh water 3-5 km upstream. Past data have indicated a strong inverse relationship between fecal coliform counts and salinity in area tidal creeks. This relationship is thought to be due to decreased coliform survival in higher salinity waters, increased flushing near the ICW and headwaters being closer to pollution sources (Mallin et al. 2000a). Primary marsh vegetation is black needlerush (*Juncus roemerianus*) in the oligohaline areas, and marsh cordgrass (*Spartina alterniflora*) in the mesohaline to polyhaline areas. The three creeks were chosen due to their watershed population and land use factors. Out of five tidal creeks in New Hanover County, the Bradley and Hewletts Creek watersheds are ranked first and second for population density, developed land and percentage of impervious cover, while Futch Creek is ranked fifth. Again, the amount of developed land in a watershed, namely the percentage of impervious surface in a watershed, has a strong negative influence on the receiving waterways bacteriological water quality.

a. Bradley Creek

The Bradley Creek watershed is the largest in the area and drains into the Atlantic Intracoastal Waterway (ICW). This watershed includes a large section of the UNC Wilmington campus. Several areas of development along Bradley Creek present considerable concern to water quality; one of these being the former Duck Haven property on Eastwood Road. In the past, the Bradley Creek watershed has been a location for Clean Water Management Trust Fund mitigation activities, including New Hanover County's purchase and restoration of Airlie Gardens. In terms of fecal bacteria, Bradley Creek is considered one of the most polluted creeks in the county. It was first closed to shellfishing in 1947, and among the county's five tidal creeks, it contains the highest population (13,657), percentage of developed land (77.8), and percentage of impervious cover (21.9) (Mallin et al. 2000a). Seven stations, including both fresh and brackish sites were sampled from shore for fecal coliform bacteria during the 2005-2006 report year, with five of the seven stations impacted by significant fecal bacteria pollution. At stations BC-SB, BC-SBU, BC-NB and BC-CR fecal coliform counts exceeded the state standard of 200 CFU/100mL for human contact waters on 33% of the sampling occasions. At Station BC-CA fecal coliform counts exceeded the state standard at an 86% exceedence rate (Mallin et al. 2007a). A recent study also performed at the UNCW's Aquatic Ecology Lab indicated human sourced fecal bacteria in water samples taken at station BC-NBU in both July and August 2006, and at station BC-SB in June 2006 (Spivey et al. unpublished).

b. Hewletts Creek

Hewletts Creek drains into the ICW and consists of both tidal and freshwater sites. During the 2005-2006 year, fecal coliform samples were only taken at the five non-tidal freshwater sites. Fecal coliform bacteria counts tested high at each freshwater site, particularly at PVGC-9, a site draining Pine Valley Country Club. Counts at this site exceeded the State standard 71% of the time and had a geometric mean of 530 CFU/100ml. A special sampling was ordered for the tidal portions of Hewletts Creek after a substantial sewage leak occurred on or around February 27, 2006. On the official day of the spill, fecal coliform counts were 20,000 CFU/100mL at MB-PGR. Samples taken on March 2 reported counts of 4,000, 2,580 and 2,200 at NB-GLR, MB-PGR and SB-PGR, respectively, along with counts of 41 CFU/100mL at HC-NWB and 4 CFU/100 mL at HC-M (Mallin et al. 2007a). Unfortunately, less than a year before, July 1, 2005, a 3,000,000 gallon (11,355,000 L), sewage spill occurred at station MB-PGR. The spill resulted in extremely high fecal bacteria concentrations in the creek (maximum of 270,000 CFU/100mL), leading to high biochemical oxygen demand causing hypoxia and a large fish kill (Mallin et al. 2007b). Subsequent testing indicated the presence of high concentrations of fecal coliform bacteria present in the sediments. This finding suggested the necessity for sediment sampling following sewage spills. Overall, Hewletts Creek at times has exhibited high fecal coliform bacterial counts in all sites, including both fresh and saltwater creek areas. A recent study performed at the UNCW's Aquatic Ecology Lab indicated human sourced fecal bacteria in water samples taken at station NB-GLR in both June and July of 2006 (Spivey et al. unpublished).

c. Futch Creek

Futch Creek drains into the ICW and is located on the New Hanover-Pender County line. The Futch Creek watershed contains the lowest population (2108), development (42.9%) and impervious surface (6.9%) when compared to both Bradley and Hewletts as well as the other two tidal creeks in the county (Howe, Pages)(Mallin et al. 2000a). In an effort to reduce fecal coliform bacterial concentrations by increasing circulation from the ICW, two channels were dredged at the mouth of Futch Creek during 1995 and 1996. The results of this project included a significant increase in salinity in the creek and significantly lower fecal counts which allowed the lower creek to be reopened for shellfishing (Mallin et al. 2000c). Six stations were sampled by boat during the 2005-2006 year. Three stations at the lower and middle creek (F-4, F-5, and F-8) were in good condition due to fecal bacterial counts testing below both the state standard of 200 CFU/mL for human contact waters as well as the 14 CFU/mL shellfishing standard. The Foy branch station (FOY) displayed higher counts yet still stayed below the state standard for human contact waters. The upper stations, (FC-17, FC-13), had elevated counts with five out of twelve occurrences of fecal coliform counts exceeding the state standard for human contact waters at FC-17. Although the fecal bacterial concentrations in the upper two stations are lower than they were prior to the dredging project, they have increased since the 2004-2005 year. Generally speaking, Futch Creek maintains good water quality when compared to other tidal creeks in the county. Unfortunately, microbiological water quality in the upper portion of the creek is showing signs of degradation (Mallin et al. 2007a). A recent study performed at the UNCW's Aquatic Ecology Lab indicated human sourced fecal bacteria in water samples taken at FC-17 in June of 2006 (Spivey et al. unpublished).

Results

a. Bradley Creek

Optical brightener samples taken at Bradley Creek in September showed a fluorometric range of 7.1-26.5 with three stations (upper north and south branches) yielding > 23 (Table 2). Fecal coliform counts ranged from 1-745 CFU per 100 mL with two stations exceeding the state standard for contact waters. October fluorometric and fecal coliform readings ranged between 4.1 and 17.3 and 4 and 1100 CFU per 100 mL, respectively (Table 2). Station BC-SBU was not sampled during this month due to lack of water. November optical brightener readings ranged from 2.8-24.7 while fecal coliform counts fell between 13 and 169 CFU per 100mL (Table 2). The highest average for optical brightener readings was found in September, while the highest fecal coliform counts occurred in October. The October fecal coliform count of 1100 CFU per 100mL was considered to be an outlier and removed from the data set when statistical analyses were performed. The Pearson's Product Moment analysis determined a correlation coefficient R of 0.696 with probability (p) value of 0.003. Therefore, a significant relationship between optical brightener numbers and fecal coliform bacteria at Bradley Creek was found (Figure 1). A sewage spill occurred in July 2007 in the north branch of Bradley Creek; elevated OB concentrations were seen there in fall 2007 (Table 2).

Table 2. Bradley Creek fecal coliform (FC) and optical brighteners (OB) data. Fecal coliform as CFU /100ml, OB as a mean of three readings.

Date	Site	FC	OB	Stdev
9/21/2007	BC-76	1	7.1	0.1
10/16/2007	BC-76	4	4.1	0.1
11/27/2007	BC-76	13	2.8	0.1
9/21/2007	BC-CR	360	12.6	0.2
10/16/2007	BC-CR	1100	8.2	0.2
11/27/2007	BC-CR	48	11.0	0.2
9/21/2007	BC-NB	147	23.5	0.1
10/16/2007	BC-NB	5	4.9	0.1
11/27/2007	BC-NB	60	4.4	0.1
9/21/2007	BC-NBU	180	23.9	0.2
10/16/2007	BC-NBU	70	17.3	0.3
11/27/2007	BC-NBU	169	21.3	0.2
9/21/2007	BC-SB	43	27.0	0.1
10/16/2007	BC-SB	166	11.7	0.1
11/27/2007	BC-SB	58	13.1	0.1
9/21/2007	BC-SBU	745	26.5	0.5
11/27/2007	BC-SBU	85	24.7	0.6

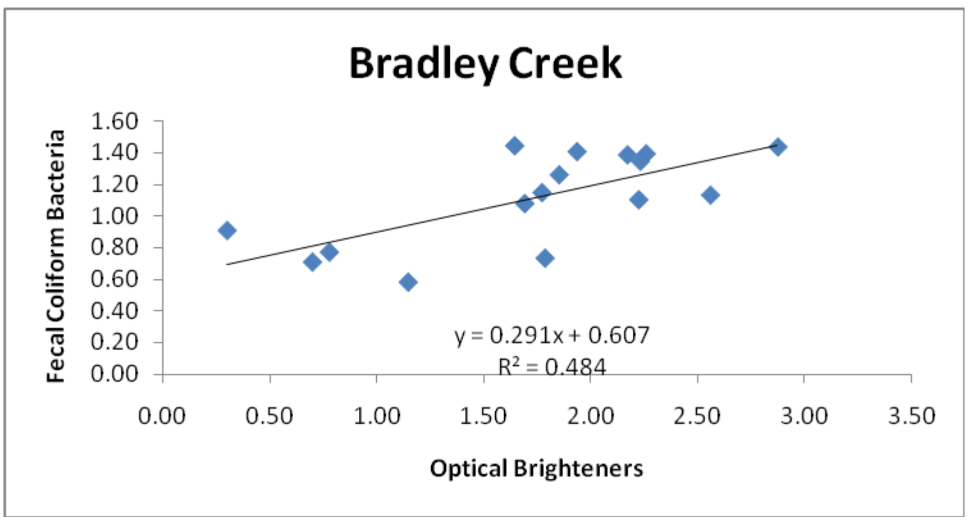


Figure 1. Scatter plot displaying the positive relationship between optical brighteners and fecal coliform bacteria at Bradley Creek (log transformed data).

b. Hewletts Creek

Samples taken at Hewletts Creek during the month of September showed fluorometric values between 2.3 and 25.7 and a fecal coliform range between 4 and 940 CFU per 100 mL with both measurements being the highest out of the three months tested (Table 3). For October, values tested between 2.9 and 25.3 for optical brighteners and 4-940 CFU per 100 mL for fecal coliforms (Table 3). Finally, November fluorometric values ranged between 1.8 and 20.1, while fecal coliforms exhibited 4-427 CFU per 100 mL. The Pearson's Product Moment correlation analysis found a correlation coefficient R of 0.8837 with a critical p value of 0.0001, determining that a significant relationship existed between optical brightener values and fecal coliform bacteria at Hewletts Creek during the time of our study. Regression analysis (Figure 2) indicated that approximately 78% of the variability in fecal coliform counts could be explained by the presence of optical brighteners, indicating human sources of contamination were likely (Figure 2). The middle branch of Hewletts Creek (MB-PGR) is where the greatest impact of the sewage spills occurred and repair work continued through the fall and winter; the OB concentrations were highest there as well (Table 3).

Table 3. Hewletts Creek fecal coliform (FC) and optical brightener (OB) data. Fecal coliform as CFU/ 100ml, OB as the mean of three readings.

Date	Site	FC	OB	Stdev
9/13/2007	HC-2	2	2.3	0.1
10/15/2007	HC-2	24	2.9	0.1
11/25/2007	HC-2	4	1.8	0.1
9/13/2007	HC-3	13	3.2	0.1
10/15/2007	HC-3	4	3.5	0.1
11/25/2007	HC-3	11	2.2	0.1
9/13/2007	MB-PGR	1115	25.7	0.5
10/15/2007	MB-PGR	940	25.3	0.2
11/25/2007	MB-PGR	145	20.1	0.2
9/13/2007	NB-GLR	375	12.7	0.1
10/15/2007	NB-GLR	45	7.6	0.1
11/25/2007	NB-GLR	427	7.5	0.1
9/13/2007	SB-PGR	105	9.0	0.1
10/15/2007	SB-PGR	11	5.8	0
11/25/2007	SB-PGR	169	6.2	0.1

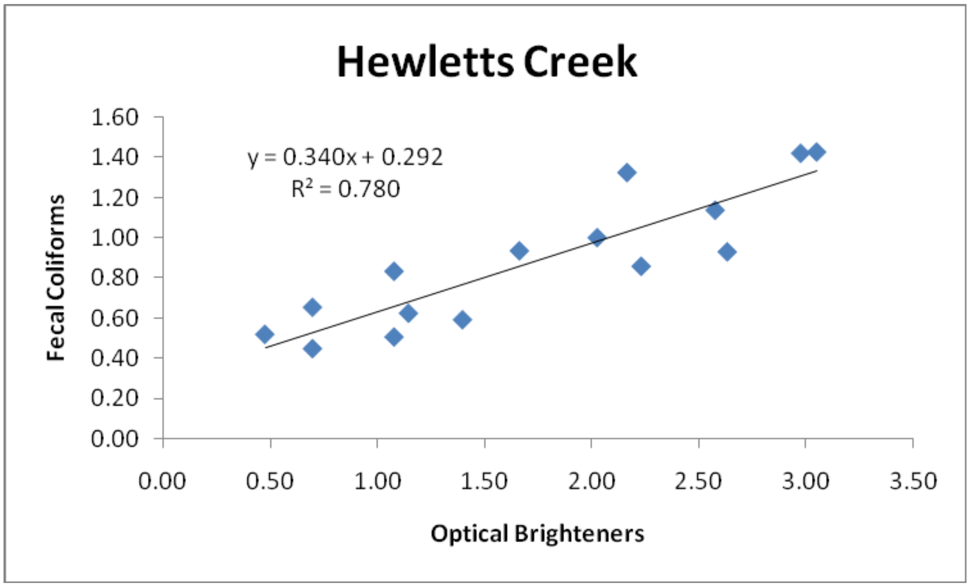


Figure 2. Scatter plot displays the positive relationship between optical brighteners and fecal coliform bacteria at Hewletts Creek (log transformed data).

c. Futch Creek

Samples taken at Futch Creek during the month of September showed low fluorometric values (< 6.4 units). Fecal results ranged between 7 and 135 CFU per 100 mL (Table 4), with the highest value recorded at uppermost station (FC-17). All fecal readings tested within the State standard for contact waters with only one (FC-17) exceeding the state standard for shellfishing. In October, both measures were low (2-3.4) for fluorometric values, and (0-9 CFU per 100 mL) for fecal coliforms (Table 4). In November the fluorometric values were consistent with previous months, however, the fecal data exhibited a surprising contrast at 3800-7000 CFU per 100 mL (Table 4). One possible explanation for the high fecal numbers may be that the first recordable rain event (0.35 inches) in 2.5 weeks occurred within 24 hours of the sampling. Site FC-17 is no longer sampled under the current tidal creeks program and therefore no data are available for that site during the month of November. The Pearson's Product Moment correlation coefficient R was -0.073 and the critical p value was 0.843, therefore meaning that no significant relationship was found between optical brighteners and fecal coliform bacteria at Futch Creek during the time of our study (Figure 3)

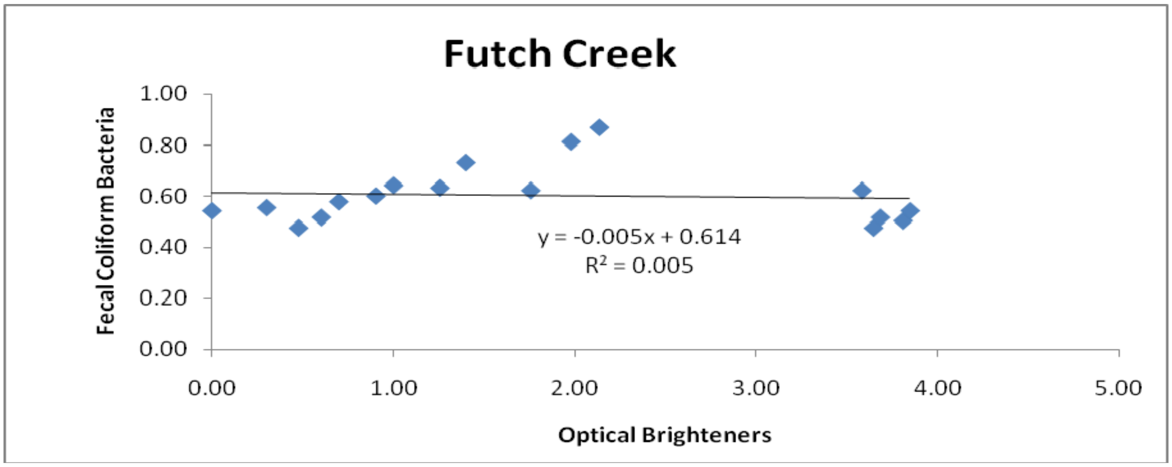


Figure 3. Scatter plot displaying the non-significant relationship between optical brightener values and fecal coliform bacteria at Futch Creek (log transformed data).

Table 2. Futch Creek fecal coliform (FC) and optical brightener (OB) data. Fecal coliform as CFU/ 100ml, OB as mean of three readings.

Date	Site	FC	OB	Stdev
9/13/2007	FC-13	94	5.5	0
10/31/2007	FC-13	1	2.6	0.1
11/16/2007	FC-13	4400	2.0	0
9/13/2007	FC-17	135	6.4	0.1
10/31/2007	FC-17	9	3.4	0
9/13/2007	FC-4	7	3.0	0.1
10/31/2007	FC-4	2	2.0	0
11/16/2007	FC-4	3800	3.2	0.1
9/13/2007	FC-6	56	3.2	0.1
10/31/2007	FC-6	3	2.3	0
11/16/2007	FC-6	6400	2.2	0.1
9/13/2007	FC-8	17	3.3	0.1
10/31/2007	FC-8	0	2.5	0.1
11/16/2007	FC-8	4800	2.3	0
9/13/2007	FOY	24	4.4	0
10/31/2007	FOY	4	2.8	0.0
11/16/2007	FOY	7000	2.5	0.1

d. all Data Combined

A correlation analysis was performed on the entire data set yielding a correlation coefficient R of 0.324348 at a critical p value of 0.0248 indicating that there was a significant correlation between overall optical brighteners and fecal coliform bacteria within the three combined creeks. A scatter plot and regression analysis showed a significant but weak relationship between the combined data sets (Figure 4).

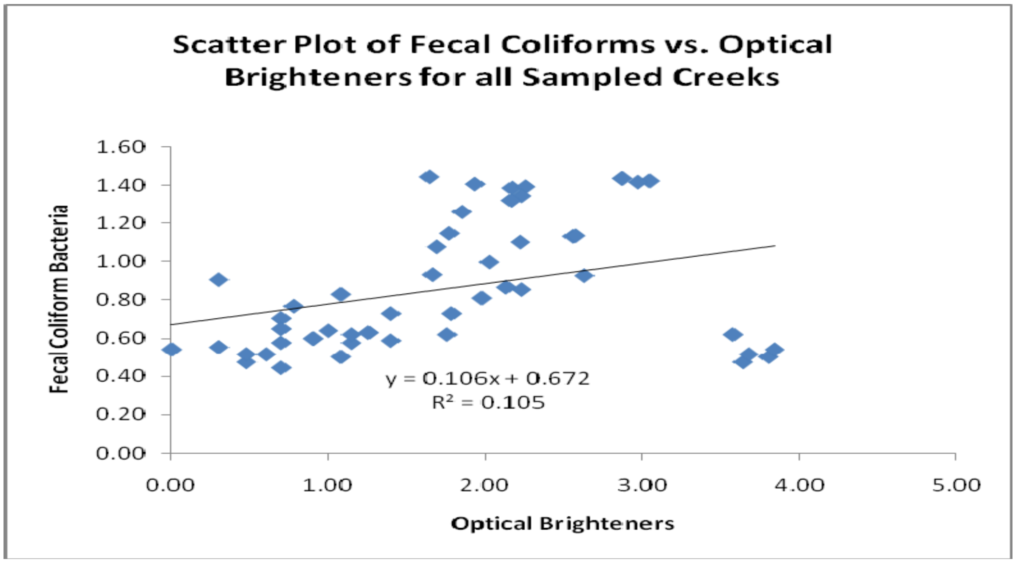


Figure 4. Scatter plot of optical brightener values vs. fecal coliform bacteria when data from all three creeks were combined.

Discussion

The results found at Hewletts Creek and Bradley Creek indicate that the methodology used in this study could be a viable means for locating and measuring human fecal contamination in this region in the future. Hewletts Creek has suffered several sewage spills over the last three years and construction is currently underway on the adjacent sewer line. A past study performed after a major sewage spill in 2005 indicated that fecal and enterococcus bacteria counts will persist in the sediments longer than formerly believed (Mallin et al. 2007b) while optical brighteners degrade slowly if not exposed to UV light. Therefore it is possible that the optical brighteners detected at Hewletts Creek could be sourced from either past or current sewer line leaks.

Several sites at Bradley Creek displayed higher optical brightener values alongside higher counts of fecal coliform bacteria, particularly in the upper north and south branches upstream of Wrightsville Avenue. Although sewage spills have occurred in Bradley Creek over the past few years, non-point source surface run-off had been assumed to be the main source of fecal coliform bacteria presence in this creek. This was due to the high percentage of developed land and impervious cover in the watershed (Mallin et al. 2000b). However, the OB data indicate that sewage or septic system leaks may also be likely sources of fecal bacteria to the creek.

Fluorometric values found at Futch Creek were consistently low each month, with high fecal counts occurring only after a rain event. Our data implies a low likelihood of significant amounts of human sourced fecal bacteria with past data supporting this theory. The septic systems used by Futch Creek residents were examined during a study on the effects of dredging (Mallin et al. 2000c); no infrastructure problems were found at that time. The fecal bacteria found in Futch Creek are most likely coming from the high population of wildlife that reside there.

Optical brighteners are not the only chemicals, synthetic or man-made, that fluoresce. Other substances including organic matter, radiator flush, and a variety of substances from pulp and paper production also fluoresce. Several measures were taken to cut out background fluorescence from organic matter in our fluorometric process as described in the methods. It would be advisable for further experiments to elaborate on this process, searching for additional ways to decrease background fluorescence. Once the fluorometric process has been refined, further studies could be improved upon in three ways. The first improvement would be a thorough investigation of the watershed in question. Maps containing detailed and accurate information on septic system and sewer line locations could be viewed when determining sampling sites. Area residents could be polled for information on past or current sites of possible suspicion. Next, samples could be taken at low tide instead of high tide. Although it may make sampling more difficult, it will decrease dilution caused by high tide, making sources easier to locate. The final step would be to test the fecal coliform samples using one or more chemical, genotypic, or phenotypic methods and determine what kind of animal (human, bird, mammal, ect.) the bacteria was sourced from.

Although a significant relationship was not found between optical brightener values and fecal coliform bacteria counts at Futch Creek, a correlation was identified at Hewletts Creek and Bradley Creek. Due to this finding, this experiment can be considered a viable preliminary resource when developing further experiments involving optical brighteners and fecal coliform bacteria contamination in waterways.

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14.0 Assessment of Key Oyster Reef Characteristics in Pages, Howe, and Hewletts Creeks

Troy Alphin, Martin Posey, Sarah Colosimo, and Anne Markwith

UNCW Benthic Ecology Laboratory
Center for Marine Science

Summary

Oyster reef work as performed by the UNCW benthic Ecology Laboratory is continuing on the tidal creeks, with emphasis on Howe, Hewletts and Pages creeks. There seems to be a good supply of larval oysters into the creeks that settle on all available areas of shell. In 2006 live oyster density was greatest in Howe Creek, but older shell material apparently is rapidly covered by sediments coming in from upstream construction activities. Pages Creek had the highest percent coverage of both live and dead shell material. There were no consistent differences among the three creeks with respect to oyster reef complexity (called rugosity) and condition of the individual oysters. Individual oyster condition was elevated in 2006, but in summer 2005 and 2007 it was comparable to oyster conditions found in some highly impacted systems in Chesapeake Bay. The majority of the oyster population in the tidal creeks appears to be in the sub-legal size range (45-55mm). We expected to see a shift in the size distribution toward a greater percentage of larger (>75mm) oysters since none of the areas sampled are subject to harvest pressure. This does not appear to be the case. The UNCW Benthic Ecology Lab continues to evaluate potential causes of the for the loss of larger size class of oyster. Based on finding reported in 2006 this loss does not appear to be the result of DERMO infections that although highly prevalent, were not intense.

Introduction

In previous reporting periods the UNCW Benthic Ecology Laboratory (BEL) has reported on the distribution and density of benthic infaunal communities, bivalve populations and blue crab populations throughout the New Hanover County Tidal Creeks (Mallin et al. 1994, Mallin et al. 1995, Mallin et al 1996, Mallin et al. 1997, Mallin et al 1998, Mallin et al 2001, Mallin et al 2002, Mallin et al 2003, Mallin et al 2005). The tidal creek systems in New Hanover County, North Carolina, represent a unique resource to this area. These previous studies of the creek systems have provided much needed baseline data to help understand how the tidal creeks function and how that function may be changing through time. By providing a better understand of the key mechanisms that impact the most sensitive trophic linkages planners, resource managers and property owners can adjust future activities to enhance the natural resources that have made the region one of the fastest growing. Each of the tidal creeks in New Hanover County represents a "mini-estuary" ranging in length from 2-5 kilometers, headwaters to mouth, with a unique history of land use and development. The residents of these watersheds consistently ask "why the shellfish beds are closed?" and "is the water safe to swim?" These conversations usually end with "what can I do?". The information we provide is a measurement of the status of the oyster populations in target areas. As stated in our previous report, the southern fishery region continues to suffer from three main problems related to shellfish; 1) Oyster stocks within the southern regions (especially New Hanover and Onslow Counties) are declining, 2) The decline is coincident with the closure of shellfish grounds due to failure of these areas to meet shellfish sanitation standards, 3) Available acreage for shellfish harvest has declined over the last decade, with few indications that it will recover without regulatory help. A review of the shellfish closure history reveals that permanent closures closely track increased development within the watershed. In most cases these developments follow the permitted guidelines; unfortunately the level of impact still seems to be too great to support the active fishery and healthy ecosystems the public wants and managers are tasked to provide.

During the 2006-2007 sampling year, the UNCW Benthic Ecology Laboratory conducted studies of oyster reef health in three target creeks; Pages Creek, Howe Creek, and Hewletts Creek following the same protocols as in previous studies, however this year an additional site in Bradley Creek was sampled at the request of area residents. In previous sampling periods Pages Creek was hypothesized to be the most pristine of the tidal creeks because of its designation as a Primary Nursery Area (PNA). Each of the creek systems is unique with its own history of development and current inputs and stressor to the system. In this report we present the results from summer and winter samplings since 2005. This longer term observations provides a better perspective on the variability in the creek environment.

Methods

Sampling was conducted during summer and winter season since 2005. Oyster populations were sampled in Hewletts Creek, Howe Creek, and Pages Creek during every sampling period and Bradley Creek was sampled once in summer 2007. Three randomly selected oyster reefs were selected in the lower portion of each creek. These are areas that would have traditionally been harvested by local oystermen but now all these locations are above the permanent shellfish closure line. For our purposes this insures that oyster density and coverage estimated by our sampling is not affected by potential harvest pressure. The reefs used for this study are all solitary reefs located in the middle of the creek systems. Since fringing reefs growing along the edge of the marsh may experience interactions between runoff and the surrounding marsh and potential wave refraction, no fringing reefs were sampled for this study. Live oyster density, percent shell cover, size demography, condition, shell height, and reef rugosity (vertical complexity) were measured on three randomly selected oyster reefs in the lower portion of each creek. Previous work and aerial photography indicated that oyster coverage within the three creeks was greatest in the lower kilometer of each, although the extent of coverage varied among creeks. When looking at Figures 1 through 6, letters that differ above the bars indicate that there is a statistically significant difference among the creeks.

Quadrate sampling

Each reef was sampled by random placement of ten 50cm x 50cm square quadrats. Percent shell cover was calculated within the 50cm X 50cm quadrats using a 16 point grid system. In order to determine oyster density, the number of live oysters within each quadrate was counted. Size demography refers to the overall distribution of sizes for live oysters present and was calculated by measuring a random selection of twenty live oysters per quadrat. Percent cover was determined by calculating the number of points that were over live oyster or shell versus non-shell tideflat area; for the purpose of this report both shell hash and live oysters were combined to determine percent cover. For the purposes of this study, size was represented as shell height (long axis of the oyster from umbo to outer edge expressed in mm).

Reef characteristics

Rugosity is a measure of how well a reef is developed (well-developed and growing reefs are generally associated with higher rugosity). As good way to think of rugosity is a measure of the “roughness” of the reef surface. A healthy reef will have oysters of several size classes from recently settled to well established oysters. The recently settled oysters will be small and settle on the underside of some shells and within the shell “matrix” of the established oysters, while the established oysters will generally grow toward the top of the reef. This mix of oyster sizes/ ages also helps create a reef that has both high and low patches within the same reef complex. Reefs with higher rugosity provide greater settlement substrate for oyster larvae and greater habitat for other organisms. Rugosity was measured by random sampling at five points per reef. A 100cm chain was draped across the reef in a straight line. The chain was then measured from end to end and its length recorded. The shorter the length the more rugose or “jagged” (vertically complex) the topography of the reef.

Oyster Condition

Oyster condition was calculated using 30 oysters >75mm shell height. This size class represents oysters that are mature and of legal harvest size. These oysters have been resident within the creek the longest and so may reflect the average conditions within that system. Condition index, a ratio of soft tissue dry weight to internal shell volume, was calculated for each oyster (Lawerence and Scott 1982, Abbe and Albright 2003). This is a measure of soft tissue growth and is considered to be an indicator of oyster health (Austin et al. 1993). In order to determine the internal shell volume, a water displacement method was used. The volume of water displaced for the whole oyster and when the shucked oyster (i.e. empty shell) is placed in a graduated cylinder to determine the internal shell volume. Dry tissue weight was obtained after oyster tissues have been dried for 24 hours at 70°C.)

Results and Discussion

Live oyster density in the lower portion of each creek show a fairly consistent pattern during both winter and summer sampling periods since 2005 (summer ’05 F=10.02 p<0.0001; winter ‘05/’06 NS; summer ’06 F=17.7 p<0.0001; winter ‘06/’07 NS; summer ’07 F=7.42 p<0.001) (Figure 1). Howe Creek shows significantly higher density of oysters compared to Hewletts and Pages Creeks, during each summer period. Increased variability and fluctuations in oyster density during fall and winter periods may also account for the lack of observable difference among creeks in the winter. Larval settlement was observed in all creeks from late summer through fall with recently settled spat observed as late as October in both ’05 and ’06. These settlement events could explain the high variability observed among the creek in the winter sampling periods. However if this were the driving factor for oyster density results we would also expect to see a shift toward smaller oyster sizes on average.

Mean size of oysters showed significant differences during 4 out of 5 sampling periods (summer ’05 F=10.64 p<0.0001; winter ‘05/’06 F=40.3 p<0.0001; summer ’06 F=3.6 p<0.03; winter ‘06/’07 NS; summer ’07 F=7.16 p<0.008) (Figure 2). The mean size indicated here is shell height (distance through the long axis of the oyster through the umbo to the outer edge). The order of difference varies among seasons with no consistent pattern for shell height among the creeks. Winter06/07 was the only season that did not show any difference among creeks. With mean sizes (shell height) falling in the 50-60mm size range this seem to would indicate that many of the oysters sampled may have been recent recruits (within the last 6 months) (Harwell 2004, Artabane 2007). Since these reef systems are relatively free of harvest pressure the question remains as to what is happening to the large size class. Results reported in a previous report (Mallin et al 2006) show the majority of the population in is the 40-55 mm size class. The oysters in the larger size class seem to be dropping out of the population. These finding are consistent with what we might expect from disease for the larger size class but current studies do not support high infection of Dermo in any of the creek systems sampled (Colosimo 2007). These results also seem to be consistent with other outside stressors that impact juvenile and older individuals. Increases in total suspended solids (TSS) and nutrients could help explain the bimodal mortality observed but runoff events seem to be relatively short-term events that are difficult to identify. We should also note that the interactive impacts of intermediate predators that use the reefs as habitat could also impact the size demography previously observed but it is highly unlikely that these predators would have a significant impact on the larger size class of oysters.

Reef rugosity was sampled each season along with other parameters however this characteristic of oyster reefs changes much more slowly than parameters such as live oyster density. When rugosity is evaluated by season there are no detectable differences among the creeks (Figure 3). There appears to be a high degree of variability among the reefs within each creek system. However it is also important to point out that the overall vertical complexity within any of the creeks sampled was relatively low. In the case of rugosity the lowest measurement indicates the greatest degree of complexity, and for these sampling periods 0.6 seems to be the greatest degree of complexity.

Percent shell cover showed a consistent pattern with significant differences in shell cover (within the reef complex) for all seasons sampled. These results showed Howe Creek with consistently less shell cover than either Hewletts or Pages Creeks (summer ’05 $F=17.23$ $p<0.0001$; winter ‘05/’06 $F=8.99$ $p<0.0003$; summer ’06 $F=7.97$ $p<0.0007$; winter ‘06/’07 $F=5.24$ $p<0.007$; summer ’07 $F=4.24$ $p<0.02$)(Figure 4). The order of significance also shows a clear pattern with Pages Creek consistently having the greatest amount of total live and dead shell cover.

Condition index is a measurement of the health of the oysters that uses the ratio of their dry weight to the internal volume of the oysters shell. This measurement provides an indication of how healthy an oyster may be. Presumably healthy oysters will fill a greater amount of the internal volume of the shell while stressed oysters fill less of the available volume. For this study oysters were devided into two size classes large (75mm+ shell height) and small (40-50mm shell height). Analysis conducted among creeks show differences among both size classes and seasons. The large size class of oysters showed significant differences in condition during summer 2006 ($F=108.7$ $p<0.0001$) and winter ‘06/’07 ($F=6.95$ $p<0.002$) (Figure 5). Small size class of oysters showed differences among creeks for summer 2006 ($F=6.82$ $p<0.002$) and 2007 ($F=3.39$ $p<0.02$).

Evaluation of condition among the various sampling periods shows a high degree of variability in the small size class possibly due to the interaction with small internal and rapid growth rate. When we looked at the large size class of oysters we see clear differences between seasons, especially in the 2006 sampling year. The conditions observed in 2006 indicate an increase in soft tissue mass during the 2006 summer period followed by a decline. The condition values indicated in the summer 2005 and 2007 are comparable to those observed within some of the highly impacted systems of Chesapeake Bay (Austin et al. 1993). These finding suggest that impacts to the creek are persistent but the response of 2006 suggest the oyster community can respond quickly to changes in the system and that if measures are taken to improve key water quality conditions (TSS and nutrient inputs) that oysters will respond positively.

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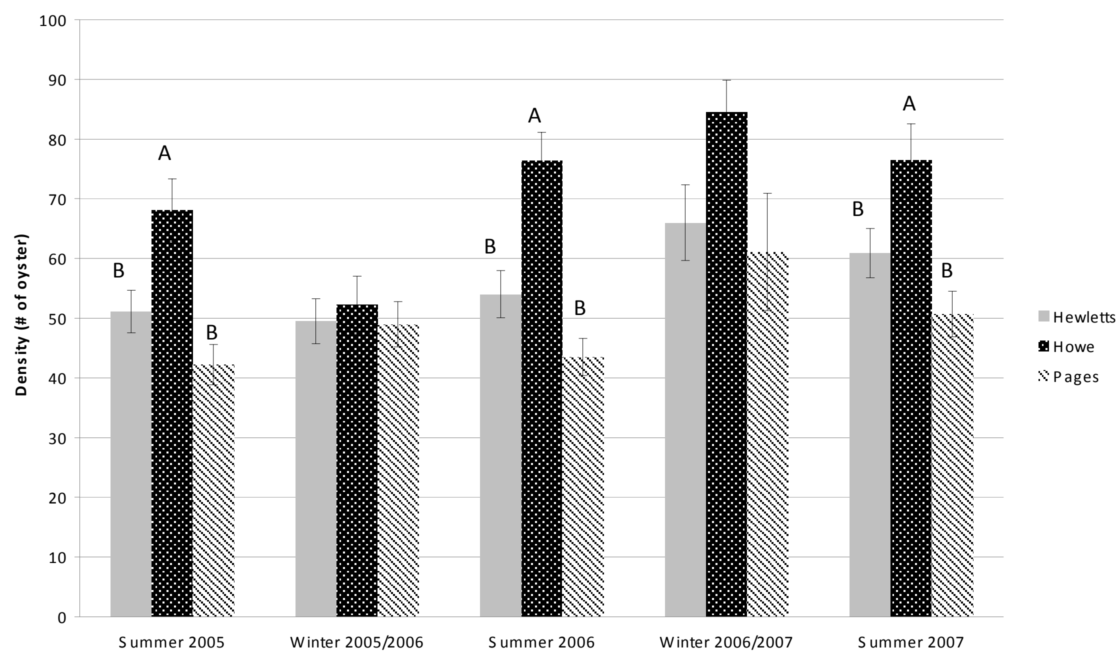

Figure 1. Mean density of oysters by creek for each season. Density is based on 10 replicate quadrats (50cm X 50cm) for each of three reefs from each creek.

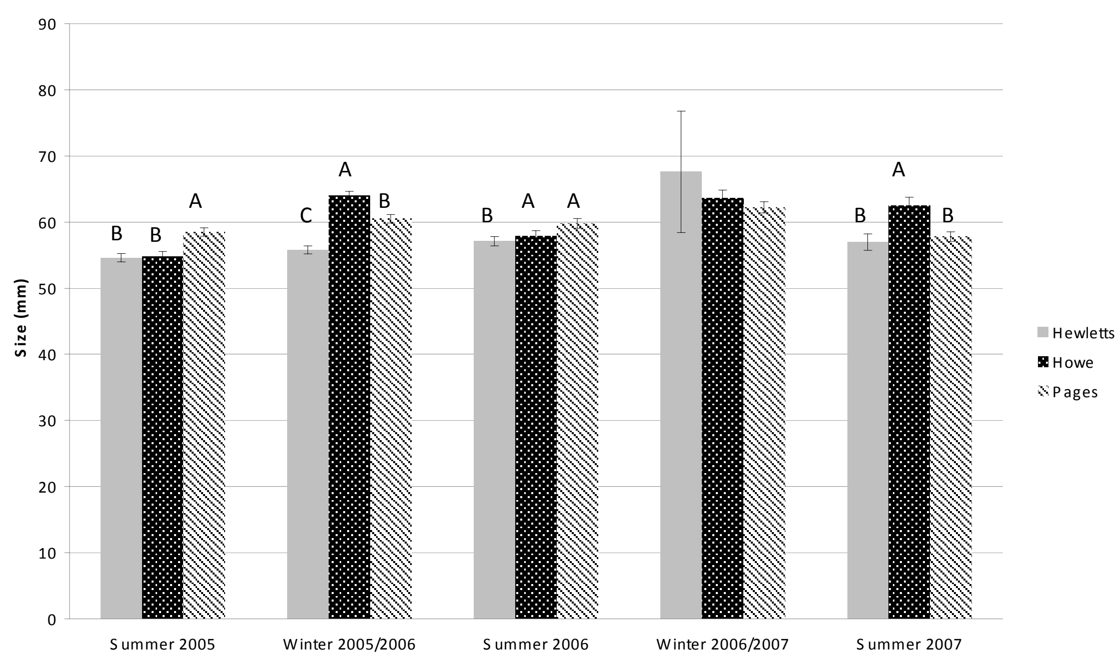

Figure 2. Mean size of oysters by creek for each sampling period. Size is based on shell height (length of the long axis through the umbo). Size is based on a random sampling of 20 oysters from each quadrat sample collected.

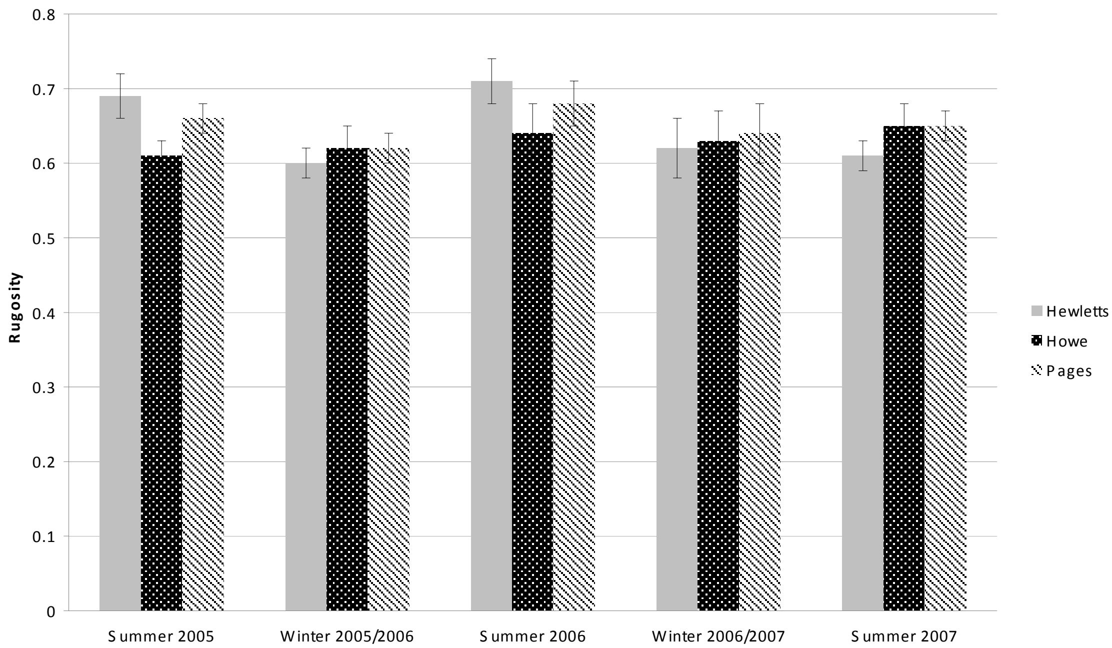

Figure 3. Mean rugosity measurements for each creek. Rugosity is a measure of verticle complexity.

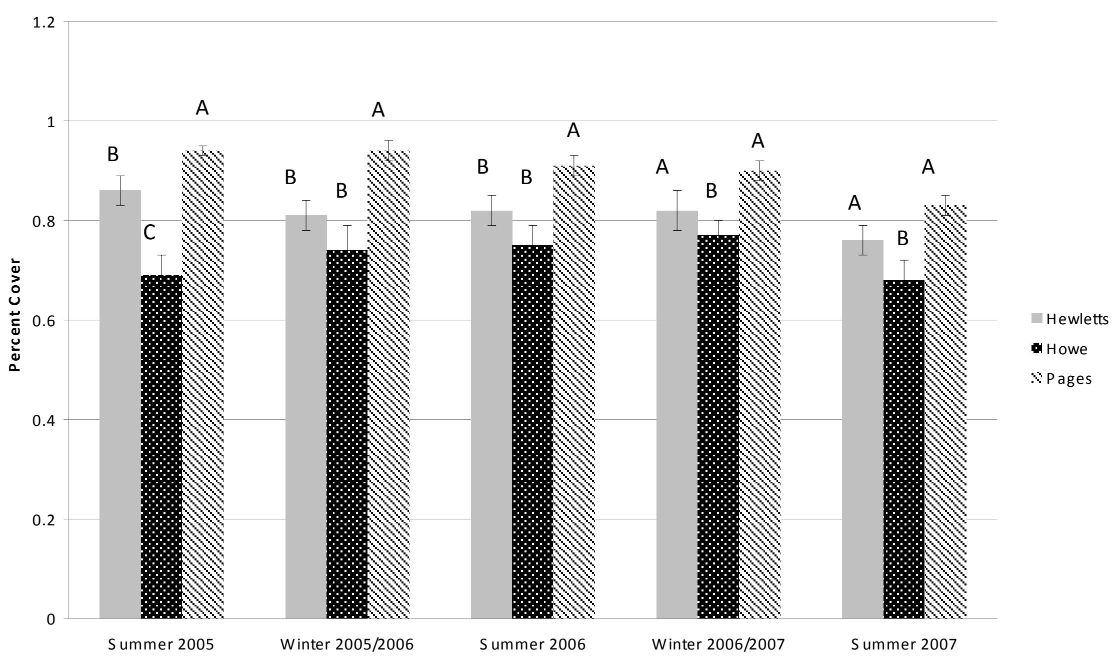

Figure 4. Mean percent cover of shell (both live and dead) among creeks for each season.

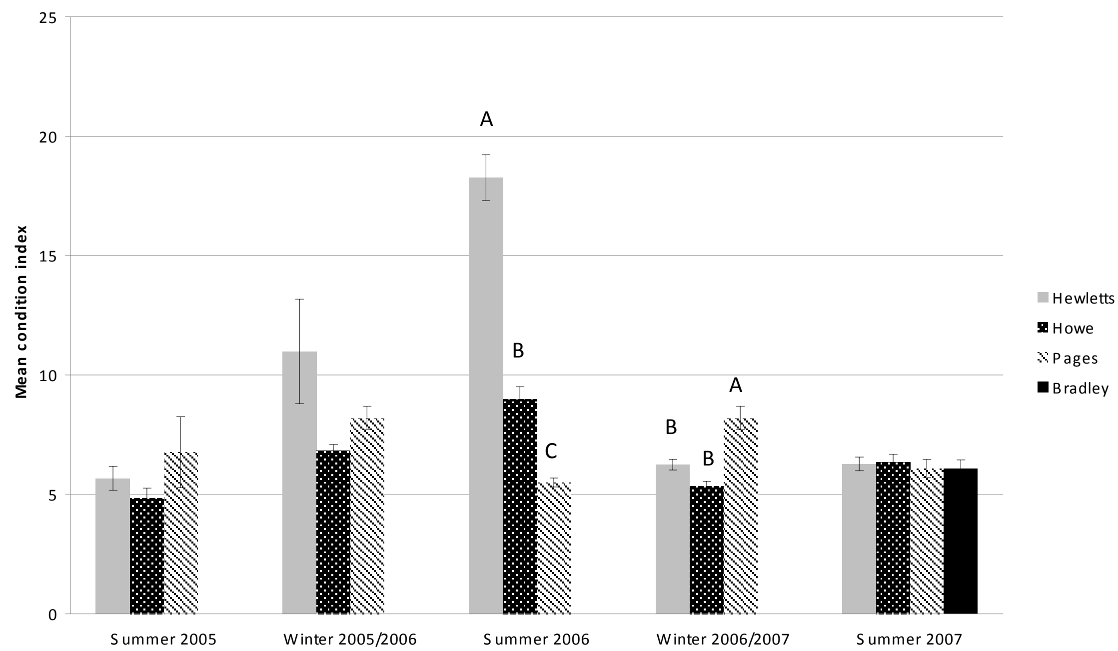

Figure 5. Mean condition index of large size class (75mm +) of oysters from each creek. Condition is based on a calculation of internal volume to soft tissue dry weight.

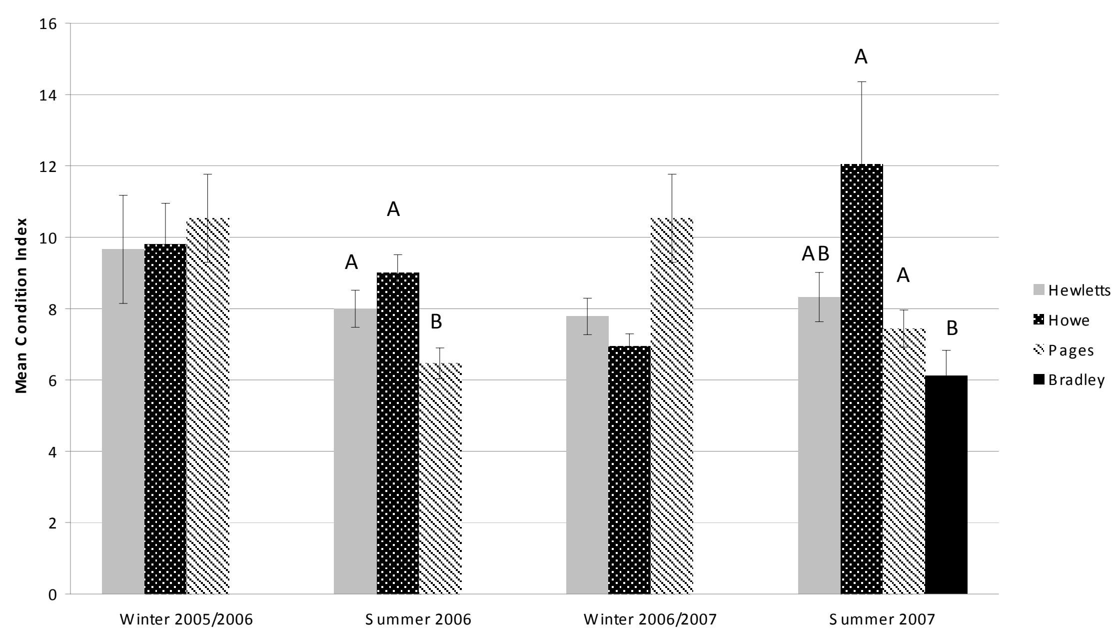

Figure 6. Mean condition index of small size class oysters (40-50mm). Condition index is based on a calculation of internal shell volume to soft tissue dry weight.

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16.0 Acknowledgments

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17.0 Appendix A. North Carolina Water Quality standards for selected parameters (NCDEHNR 1996). We note that these standards are general, and differ with designated water body use. Details can be found at within the N.C. Division of Water quality website at: http://h2o.enr.state.nc.us/csu/documents/ncactable290807.pdf

Parameter	Standard
Dissolved oxygen	5.0 ppm (mg/L)
Turbidity	25 NTU (tidal saltwater) 50 NTU (freshwater)
Fecal coliform counts	14 CFU/100 mL (shellfishing waters), and more than 10% of the samples cannot exceed 43 CFU/100 mL. 200 CFU/100 mL (human contact waters)
Chlorophyll *a*	40 ppb (µg/L)

CFU = colony-forming units
mg/L = milligrams per liter = parts per million
µg/L = micrograms per liter = parts per billion

18.0 Appendix B. UNCW ratings of sampling stations in Wilmington and New Hanover County tidal creek watersheds based on August 2006 – July 2007 data for tidal creeks and January -September 2007 data for Wilmington watersheds, where available, for chlorophyll *a*, dissolved oxygen, turbidity, and fecal coliform bacteria based on North Carolina state chemical standards for freshwater or tidal saltwater.

G (good quality) – state standard exceeded in $\leq$ 10% of the measurements
F (fair quality) – state standard exceeded in 11-25% of the measurements
P (poor quality) – state standard exceeded in >25% of the measurements

Watershed	Station	Chlor *a*	DO	Turbidity	Fecal coliforms*
Barnard's Creek	BNC-RR	G	P	G	G
Bradley Creek	BC-CA	G	P	G	P
	BC-CR	G	G	G	-
	BC-SB	G	F	G	-
	BC-SBU	G	G	G	-
	BC-NB	G	P	G	-
	BC-NBU	G	G	G	-
	BC-76	G	F	G	-
Burnt Mill Creek	BMC-KA1	F	P	G	P
	BMC-KA3	G	P	G	P
	BMC-AP1	F	F	G	P
	BMC-AP3	P	G	G	P
	BMC-WP	P	P	G	P
	BMC-PP	F	P	G	P
Futch Creek	FC-4	G	G	G	G
	FC-6	G	F	G	G
	FC-8	G	F	G	G
	FC-13	G	F	G	G
	FC-17	G	F	G	G
	FOY	G	F	G	G
Greenfield Lake	GL-LC	P	P	F	P
	GL-JRB	G	P	G	P
	GL-LB	F	P	F	P
	GL-2340	G	P	G	P
	GL-YD	F	F	G	P
	GL-P	G	G	G	P

Watershed	Station	Chlor *a*	DO	Turbidity	Fecal coliforms*
Hewletts Creek	HC-2	G	G	G	-
	HC-3	G	G	G	-
	NB-GLR	G	F	G	-
	MB-PGR	G	G	G	-
	SB-PGR	G	F	G	-
	PVGC-9	G	P	G	P
	DB-1	G	P	P	P
	DB-2	F	G	G	P
	DB-3	G	P	F	P
	DB-4	G	P	P	P
Howe Creek	HW-M	G	G	G	G
	HW-FP	G	G	G	G
	HW-GC	G	G	G	G
	HW-GP	G	F	G	G
	HW-DT	G	F	G	P
Motts Creek	MOT-RR	G	P	G	P
Pages Creek	PC-M	G	F	G	G
	PC-OL	G	F	G	G
	PC-CON	G	G	G	G
	PC-OP	G	F	G	G
	PC-LD	G	F	G	G
	PC-BDDS	G	F	G	F
	PC-WB	G	F	G	F
	PC-BDUS	G	F	G	F
	PC-H	G	P	G	F
Smith Creek	SC-23	F	P	F	P
	SC-CH	G	P	F	P
Whiskey Creek	WC-NB	G	G	G	-
	WC-SB	G	G	G	-
	WC-MLR	G	G	G	-
	WC-MB	G	G	G	-

*fecal coliform category used here is based on the human contact standard of 200 CFU/100 mL, not the shellfishing standard of 14 CFU/100 mL.

19.0 Appendix C. GPS coordinates for New Hanover County Tidal Creek stations and the Wilmington Watersheds Project sampling stations.

Watershed	Station	GPS coordinates	
Barnard's Creek	BNC-TR	N 34.16823	W 77.93218
	BNC-CB	N 34.15867	W 77.91190
	BNC-EF	N 34.16937	W 77.92485
	BNC-AW	N 34.16483	W 77.92577
	BNC-RR	N 34.15873	W 77.93795
Bradley Creek	BC-CA	N 34.23257	W 77.86658
	BC-CR	N 34.23077	W 77.85235
	BC-SB	N 34.21977	W 77.84578
	BC-SBU	N 34.21725	W 77.85410
	BC-NB	N 34.22150	W 77.84405
	BC-NBU	N 34.23265	W 77.92362
	BC-76	N 34.21473	W 77.83357
Burnt Mill Creek	BMC-KA1	N 34.22207	W 77.88506
	BMC-KA3	N 34.22280	W 77.88601
	BMC-AP1	N 34.22927	W 77.86658
	BMC-AP2	N 34.22927	W 77.89792
	BMC-AP3	N 34.22927	W 77.90143
	BMC-WP	N 34.24083	W 77.92419
	BMC-PP	N 34.24252	W 77.92510
Futch Creek	FC-4	N 34.30127	W 77.74635
	FC-6	N 34.30298	W 77.75070
	FC-8	N 34.30423	W 77.75415
	FC-13	N 34.30352	W 77.75790
	FC-17	N 34.30378	W 77.76422
	FOY	N 34.30705	W 77.75707
Greenfield Lake	GL-SS1	N 34.19963	W 77.92447
	GL-SS2	N 34.20038	W 77.92952
	GL-LC	N 34.20752	W 77.92980
	GL-JRB	N 34.21260	W 77.93140
	GL-LB	N 34.21445	W 77.93553
	GL-2340	N 34.19857	W 77.93560
	GL-YD	N 34.20702	W 77.93120
	GL-P	N 34.21370	W 77.94362

Hewletts Creek	HC-M	N 34.18230	W 77.83888
	HC-2	N 34.18723	W 77.84307
	HC-3	N 34.19023	W 77.85083
	HC-NWB	N 34.19512	W 77.86155
	NB-GLR	N 34.19783	W 77.86317
	MB-PGR	N 34.19807	W 77.87088
	SB-PGR	N 34.19025	W 77.86472
	PVGC-9	N 34.19165	W 77.89175
	DB-1	N 34.1764	W 77.8775
	DB-2	N 34.1781	W 77.8805
	DB-3	N 34.1799	W 77.8798
	DB-4	N 34.1789	W 77.8752
Howe Creek	HW-M	N 34.24765	W 77.78718
	HW-FP	N 34.25443	W 77.79488
	HW-GC	N 34.25448	W 77.80512
	HW-GP	N 34.25545	W 77.81530
	HW-DT	N 34.25562	W 77.81952
Motts Creek	MOT-RR	N 34.15867	W 77.91605
Pages Creek	PC-M	N 34.27008	W 77.77133
	PC-OL	N 34.27450	W 77.77567
	PC-CON	N 34.27743	W 77.77763
	PC-OP	N 34.28292	W 77.78032
	PC-LD	N 34.28067	W 77.78495
	PC-BDDS	N 34.28143	W 77.79417
	PC-WB	N 34.27635	W 77.79582
	PC-BDUS	N 34.27732	W 77.80153
	PC-H	N 34.27508	W 77.79813
Smith Creek	SC-23	N 34.25795	W 77.91967
	SC-CH	N 34.25897	W 77.93872
Upper and Lower	UCF-PS	N 34.24205	W 77.94838
Cape Fear	LCF-GO	N 34.21230	W 77.98603
Whiskey Creek	WC-NB	N 34.16803	W 77.87648
	WC-SB	N 34.15935	W 77.87470
	WC-MLR	N 34.16013	W 77.86633
	WC-AB	N 34.15967	W 77.86177
	WC-MB	N 34.15748	W 77.85640

20.0 Appendix D. University of North Carolina at Wilmington reports and papers concerning water quality in New Hanover County's tidal creeks.

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