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Author(s): Michael A. Mallint, Lawrence B. Cahoon, R. Patrick Lowe, James F. Merritt, Ronald K. Sizemore, Kathleen E. Williams
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Restoration of Shellfishing Waters in a Tidal Creek Following Limited Dredging

Michael A. Mallin[†], Lawrence B. Cahoon[†], R. Patrick Lowe[‡], James F. Merritt[†], Ronald K. Sizemore[†], and Kathleen E. Williams[†]

[†]Center for Marine Science
Research
University of North Carolina
at Wilmington
Wilmington, NC 28403,
U.S.A.

Email: mallinm@uncwil.edu

[‡]New Hanover County
Planning Department
414 Chestnut St., Suite 304
Wilmington, NC 28401,
U.S.A.

ABSTRACT

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A moderately-developed tidal creek feeding the U.S. Atlantic Intracoastal Waterway was closed to shellfishing for a number of years because of high fecal coliform counts. An investigation was unable to determine an anthropogenic source for the contamination. Because dung piles and other wild animal signs were concentrated in the most affected area of the creek animals were assumed to be a major source of the coliform pollution. Over the years a sandbar had accumulated across the mouth of the creek, impeding flow into the creek. A coalition consisting of a concerned citizen's group, local government, and university scientists obtained permits to conduct limited creek-mouth dredging to improve flushing and increase salinity in polluted areas. Following dredging, fecal coliform counts decreased 35 to 60% creek-wide, with greatest decreases in stations midway up the creek. Nitrate concentrations decreased significantly and turbidity increased significantly at two creek stations. A continuous monitor located midway up the creek recorded higher salinities and less intertidal salinity variability following dredging than before dredging. The North Carolina Division of Marine Fisheries reopened the creek to shellfishing a year after dredging. While dredging proved to lower fecal coliform counts to acceptable levels, it did not remove the source of contamination; rather, it alleviated the symptoms.

ADDITIONAL INDEX WORDS: *Enteric bacteria, turbidity, flushing, estuaries, pollution management.*

INTRODUCTION

A major pollution problem associated with coastal waters in developed areas is excessive fecal coliform bacteria concentrations. Because of human health concerns relatively low concentrations of fecal coliforms (>14 colony-forming units (CFU)/100 mL) are sufficient to close waters to shellfishing (USFDA, 1995). This problem can be exemplified by the case of a rapidly-developing area, New Hanover County, North Carolina, where all tidal creeks were fully or partially closed to shellfishing by December 1991. Area residents expressed concern over declining water quality, potential groundwater pollution, overdevelopment, and a perceived decline in the overall quality of the environment. Thus, the City of Wilmington and New Hanover County devised a Land Use Plan Update in 1991-1992. As a result of this Plan, land use policies were adopted that called for the County and City to "take all necessary actions to prevent further deterioration of estuarine water quality and to bring all coastal waters up to the highest quality possible". This included the protection, preservation and restoration of shellfishing in the tidal creeks and sounds through the development of an Estuarine

Watershed Management Program. This Program addresses estuarine water quality and related land use issues through an innovative public-private collaboration that provides for research and demonstration projects, tidal creek water quality studies, and watershed (land use) management plans. The Program was designed as a collaborative effort among local government, a concerned citizens organization, and academic researchers. Restoration of shellfish waters was considered a priority item under this Program (NHCPD, 1993).

The sources of fecal coliform pollution to shellfishing waters may be anthropogenic or natural (SAYLER *et al.*, 1975; WEISKEL *et al.*, 1996). A well-defined anthropogenic source of fecal coliform pollution can be removed or reduced through technological and/or legal action. However, a natural, or otherwise poorly-defined source may be more problematic to control. The latter situation describes Futch Creek, a tidal creek in southeastern North Carolina that had been closed to shellfishing for a number of years. The sources of fecal coliform pollution to Futch Creek are not clear, but do not appear to be anthropogenic. The New Hanover County Health Department visually inspected 44 on-site septic systems and found all to be in working order (NHCHD, 1993). The Shellfish Sanitation Branch of the North Carolina Department of Environ-

ment, Health, and Natural Resources conducted a shoreline survey and series of dye tracer tests in a selection of septic systems used by residents in the polluted areas. The tracer studies were unable to detect evidence of septic system leakage into the creek (POTTS, 1994). However, visual examination of the area surrounding the most polluted stretches indicated concentrations of animal dung and numerous small mammal trails. Thus, we hypothesized that septic systems were not contributing to the fecal coliform pollution, but wild animals (particularly raccoons) were part of the problem. Lacking a defined source to target for pollution control, participants of the Watershed Management Program determined that physical manipulation of the environment would be an appropriate means to attempt to restore shellfishing waters in this creek. Dye studies indicated that there was very little flow available to dilute contaminants in the creek, and complete tidal flushing did not occur (POTTS, 1994). Over the years a sand bar had built up across the mouth of the creek, in part as a result of heavy boat traffic along the Atlantic Intracoastal Waterway (ICW). It was suggested that this bar was impeding flow and the natural flushing ability of the creek. Thus, limited creek-mouth dredging was proposed to alleviate this condition and restore the shellfishery. The Futch Creek Demonstration Project was designed as a large-scale experiment to test the effect of dredging as a water quality restoration technique. The Northeast New Hanover Conservancy (a non-profit citizens group) applied for and received dredging permits after appropriate State and Federal reviews. The dredging operation was funded by a combination of public and private (Conservancy) funds.

METHODS

Site Description

Futch Creek is located in southeastern North Carolina near the City of Wilmington. The creek drains into the Atlantic Intracoastal Waterway. It has a watershed encompassing approximately 1,193 ha, with about 54% of the watershed developed in 1997, primarily by single-family homes. The creek receives runoff primarily from woodland, suburban areas, home construction sites, and a golf course. The creek proper contains salt marsh in the lower to middle regions (dominated by *Spartina alterniflora*) and oligohaline to freshwater marsh in the upper regions (dominated by *Juncus roemerianus*). Previous studies (MERRITT *et al.*, 1993; Esham, 1994; Mallin *et al.*, 1996) determined that the most polluted areas were Stations FC-13, FC-17 and FC-20, located upstream in the southernmost creek branch (Figure 1).

The south channel was dredged in April 1995 using a clam bucket mounted on a barge. The dredged area was approximately 90 m long by 15 m wide by 2.5 m deep (Figure 1). The north channel was dredged in April and May 1996 by a conventional hydraulic dredge. This channel was approximately 215 m long by 15 m wide by 2.5 m deep (Figure 1). Dredged material was deposited on a nearby spoil island owned by the Conservancy.

Sampling and Analysis

Futch Creek was sampled on a monthly basis from August 1994 through March 1997. Samples were collected by boat at or near high tide from eight locations. Physical parameters (temperature, dissolved oxygen, pH, salinity, and turbidity) were measured at surface and bottom with a Solomat 803PS Multiparameter Water Quality Probe with data displayed on a Solomat 803 Datalogger. Fecal coliform bacteria were sampled by placing a 1.0 L autoclaved glass container in the creek about 0.1 m below the surface facing into the current. Samples were kept on ice until returned to the laboratory (within 3 hr of sampling). Fecal coliform bacteria were quantified using the membrane filtration method (mFC) described in Standard Methods (APHA, 1995) and approved by the North Carolina Department of Environment, Health, and Natural Resources. Samples were not taken if a rain event had occurred within the previous 24 hr. Fecal coliform abundance is expressed as colony-forming units (CFU)/100 mL.

Additional water samples were collected in triplicate on station, stored on ice and returned to the laboratory for nutrient analysis. The samples were filtered through Gelman A/E glass fiber filters (nominal pore size 1.0 μ m) and the filtrate analyzed for nitrate and orthophosphate using a Technicon AutoAnalyzer. Salinity was monitored continuously for identical six-week periods in 1995 and 1996, i.e., before and after the dredging project occurred, using YSI 6000 multiparameter water quality monitors. One of these devices was installed for three consecutive two-week periods between February 3 and March 17 of each year from a dock located between Stations FC-6 and FC-8 (Figure 1). The salinity probe for each monitor was calibrated immediately before each deployment period using YSI salinity standards. The winter deployment period was chosen to minimize problems from fouling of the probe and to avoid artifacts associated with the actual dredging operations and with human activities during the warmer seasons. YSI monitors deployed in 1995 were programmed to take salinity readings each half-hour, and those deployed in 1996 were programmed to take readings each hour.

We tested the hypotheses that there were no significant differences in parameter concentrations before and after dredging. We tested the variables salinity, turbidity, nitrate, orthophosphate, and fecal coliform concentrations for normality using the Shapiro-Wilk test. Salinity and turbidity were normally distributed and differences between periods were tested using the two-sample t-test. Nitrate, orthophosphate and fecal coliform concentrations were non-normally distributed and differences between period were tested using the Wilcoxon Rank Sum test. Statistical analyses were performed using the Statistical Analysis System (SCHLOTZHAUER AND LITTELL, 1987). Since dredging can cause temporary increases in water-column fecal coliform concentrations (GRIMES, 1975), months in which active dredging occurred (April 1995; April and May 1996) were excluded from the analyses.

In an effort to ascertain sources of fecal coliform pollution to the creek, five stations in the upper south branch were sampled on five dates in summer and fall 1995. These sta-

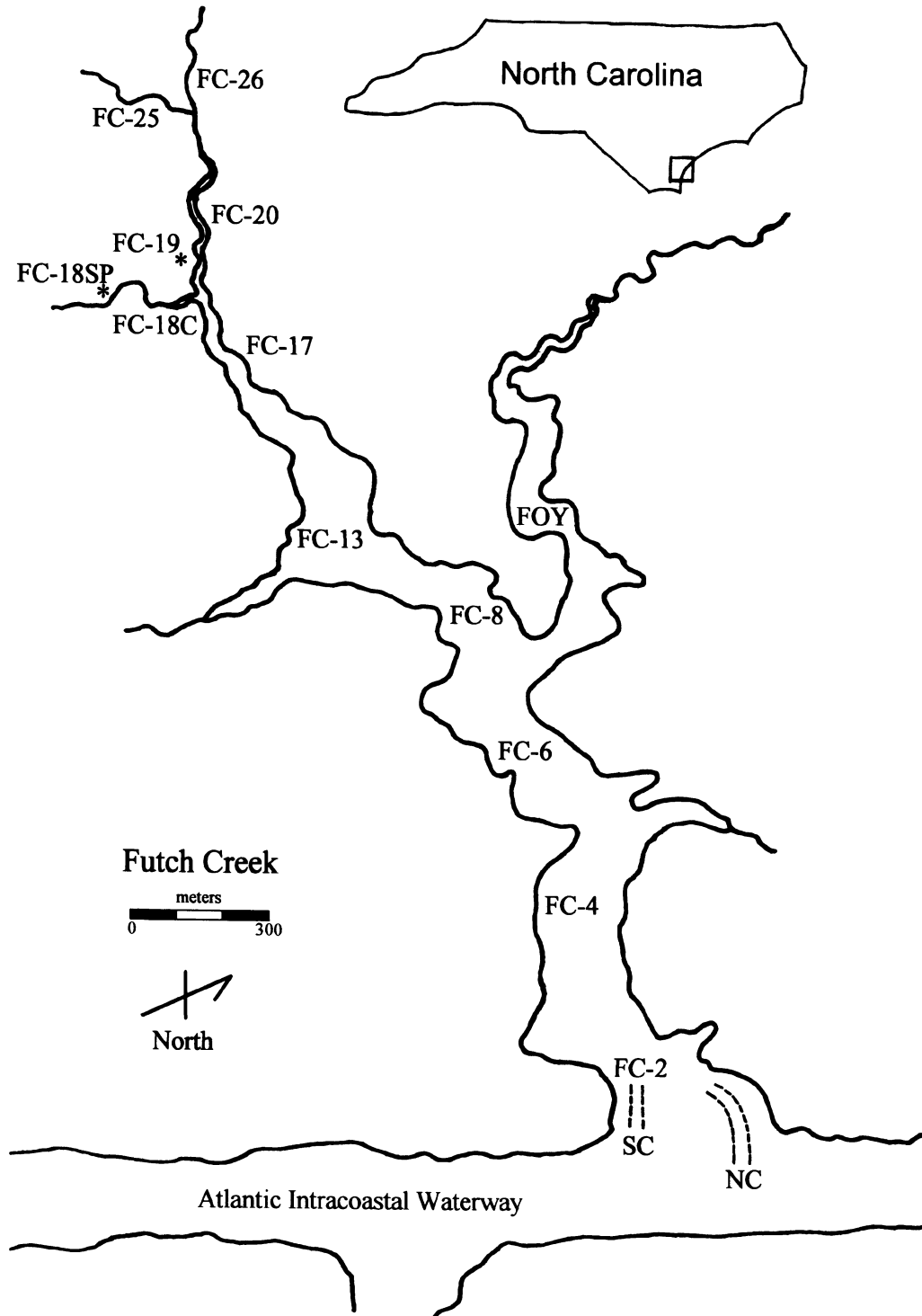


Figure 1. Map of Futch Creek, southeastern North Carolina (N34°20', W77°43'), showing sampling stations and dredged north (NC) and south (SC) channels.

tions were: FC-19, a spring entering Futch Creek between FC-17 and FC-20; FC-18C, a small feeder creek entering Futch Creek just upstream of FC-17; FC-18SP, a spring feeding FC-18CR; FC-25, a headwaters branch draining a small

freshwater marsh; and FC-26, a headwaters branch draining a large freshwater marsh (Figure 1). Samples were collected at low tide for fecal coliform bacteria, salinity, and water temperature.

Table 1. Parameter concentrations by station before and after dredging in Futch Creek, N.C. Data presented as mean \pm one standard deviation. Units are salinity (ppt), turbidity (NTU), nitrate and orthophosphate ($\mu\text{g/L}$), fecal coliforms (CFU/100 mL).

Station	Period	Salinity	Turbidity	Nitrate	Phosphate	Fecal Col.
FC-2	Before	35.5 \pm 3.7	2.1 \pm 0.9	3.6 \pm 2.7	1.3 \pm 1.8	2.8 \pm 4.2
	After	33.4 \pm 2.7	7.2 \pm 4.5*	5.4 \pm 1.1	1.6 \pm 1.9	1.4 \pm 1.2
FC-4	Before	34.6 \pm 4.3	2.3 \pm 1.6	6.2 \pm 5.6	1.3 \pm 1.2	1.6 \pm 2.1
	After	33.0 \pm 2.9	6.1 \pm 4.0*	4.0 \pm 4.5	1.5 \pm 1.7	2.7 \pm 3.1
FC-6	Before	32.8 \pm 5.5	3.6 \pm 2.2	14.2 \pm 12.1*	1.2 \pm 0.8	11.9 \pm 12.2*
	After	32.3 \pm 3.1	5.5 \pm 4.1	8.1 \pm 12.9	1.7 \pm 2.0	5.7 \pm 10.3
FC-8	Before	31.7 \pm 4.4	6.0 \pm 4.6	45.7 \pm 65.0*	1.6 \pm 1.3	22.0 \pm 24.2*
	After	30.8 \pm 3.6	6.9 \pm 5.2	12.2 \pm 11.6	3.6 \pm 5.1	8.7 \pm 19.4
FC-13	Before	27.4 \pm 7.0	8.1 \pm 4.7	72.2 \pm 36.9	2.1 \pm 1.3	106.1 \pm 93.2*
	After	25.8 \pm 6.0	8.8 \pm 8.8	72.3 \pm 78.7	12.2 \pm 38.2	45.0 \pm 75.9
FC-17	Before	27.7 \pm 6.6	5.3 \pm 3.4	181.5 \pm 105.7	3.8 \pm 4.0	375.5 \pm 368.9
	After	27.9 \pm 5.3	6.8 \pm 5.5	144.7 \pm 181.4	22.1 \pm 55.8	193.6 \pm 369.3
FC-20	Before	12.0 \pm 10.6	11.3 \pm 5.5	169.0 \pm 324.8	4.6 \pm 6.7	620.1 \pm 634.4
	After	18.0 \pm 10.0	9.7 \pm 7.1	112.5 \pm 126.4	15.1 \pm 34.1	383.1 \pm 429.5
FOY	Before	27.7 \pm 6.6	5.3 \pm 3.4	54.7 \pm 40.9	2.3 \pm 2.2	46.8 \pm 44.9*
	After	27.9 \pm 5.3	6.8 \pm 5.5	37.0 \pm 29.5	9.2 \pm 19.6	19.3 \pm 21.6

* Indicates significant difference between period, $p = 0.10$ for fecal coliforms and $p = 0.05$ for physical and chemical parameters.

RESULTS

Fecal coliform concentrations showed a decline from pre-dredging levels to post dredging levels ranging from 35% to as high as 60% (Table 1). The most saline stations (FC-2 and FC-4) were low previously due to proximity to the ICW, and the dredging showed little effect (Table 1). However, the mid-creek stations (FC-6, FC-8, FC-13, and FOY) demonstrated the greatest drop in fecal coliform abundance (Table 1). Statistical analysis showed the declines to be significant at these four stations, which are all shellfish habitat. The uppermost stations (FC-17, FC-20) demonstrated decreases in fecal coliform abundance of 48% and 38%, respectively, but post-dredging values remained well above permissible state standards of 14 CFU/100 mL for shellfishing waters and near the standard of 200 CFU/100 mL for recreational contact waters (NCDEHNR, 1994). There was less variability in fecal coliform abundance between April 1995, following dredging, and April 1996 (Figure 2). A fecal coliform peak occurred in May 1996 during the dredging of the north channel (Figure 2). There was another distinct maximum in July following Hurricane Bertha, when the ground was saturated by excessive rainfall, and a smaller peak in September following Hurricane Fran (Figure 2). There appeared to be no seasonality in fecal coliform abundance otherwise.

The North Carolina turbidity standard for tidal waters is 25 NTU (NCDEHNR, 1994). Turbidity is normally low in Futch Creek, well below this standard. However, the dredging activities appeared to increase turbidity creek-wide (Figure 3). Dredging of the south channel in April 1995 increased mean creek turbidity to about 15 NTU for a period of about four months. Dredging of the north channel in April and May of 1996 also initiated high turbidity, possibly maintained by Hurricane Bertha in early July 1996 (Figure 3). Hurricane Fran, in September 1996, had little impact on turbidity. Turbidity after both dredging episodes returned to normal after about four months. There were significant increases in tur-

bidity in the post dredging period at Stations FC-2 and FC-4 (Table 1). These two stations were nearest the dredged channels. However, none of the measured turbidity values exceeded the state standard.

Salinity, as measured simultaneously with fecal coliform sample collection, displayed no statistically significant increases at any station (Table 1). Average salinity at Station FC-20 increased from 12 to 20 ppt following dredging, but high variability precluded a statistical difference. However, continuous monitoring of salinity during identical winter periods before and after dredging showed dramatic differences in the salinity regimes at the mid-creek sampling site (Figure 4). The most obvious difference was the reduction of the amount of variability in salinity over a typical tidal cycle. Salinity varied approximately 18–20 ppt over tidal cycles at the end of dry periods in 1995 (Figure 4a), but varied only 2–4 ppt over tidal cycles at the end of dry periods in 1996 (Figure 4b). Rainfall events during the 1995 monitoring period drove salinity values down below 5 ppt, but in the 1996 period rain events drove salinities no lower than about 28 ppt. These results indicate that Futch Creek was much more thoroughly flushed by high salinity water after dredging of the south channel than before.

Significant decreases in nitrate concentration were noted at the mid-creek Stations FC-6 and FC-8 following dredging (Table 1). Orthophosphate concentrations appeared to increase after dredging, but due to high variability there were no statistically significant differences between periods (Table 1).

On five dates in summer and fall 1996 we sampled a series of springs and surface feeder creeks in the upper south branch. The two springs yielded an average of only 2 and 14 CFU/100 mL, respectively, while the nearest feeder branch yielded an average of 572 CFU/100 mL (Table 2). These data suggest that the fecal coliform contamination does not enter the creek through groundwater inputs. This, in combination

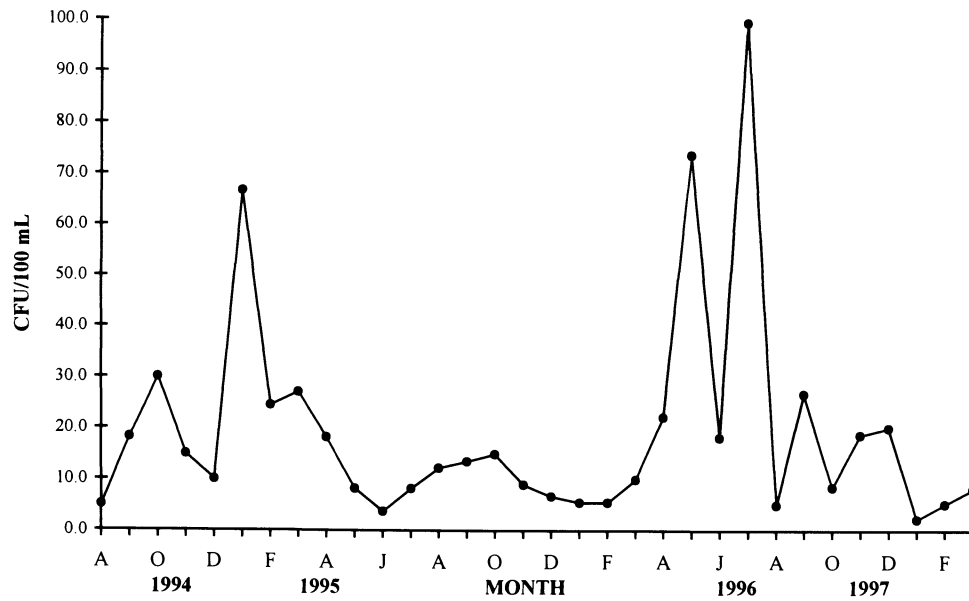


Figure 2. Average fecal coliform concentration (CFU/100 mL) for eight stations in Futch Creek, August 1994–March 1997). Dredging occurred in April 1995 and April–May 1996.

with the visual inspections, dye studies and shoreline survey conducted by the County Health Department and the N.C. Shellfish Sanitation Branch, indicates that septic systems are not a likely source of fecal coliform pollution to this area of the creek. The high coliform counts in the surface feeder branches, in combination with small animal sign and dung

piles, point toward wild animal concentrations as a primary source of fecal coliform pollution to this creek.

DISCUSSION

The North Carolina Division of Shellfish Sanitation maintains a program in which shellfish beds are sampled for a

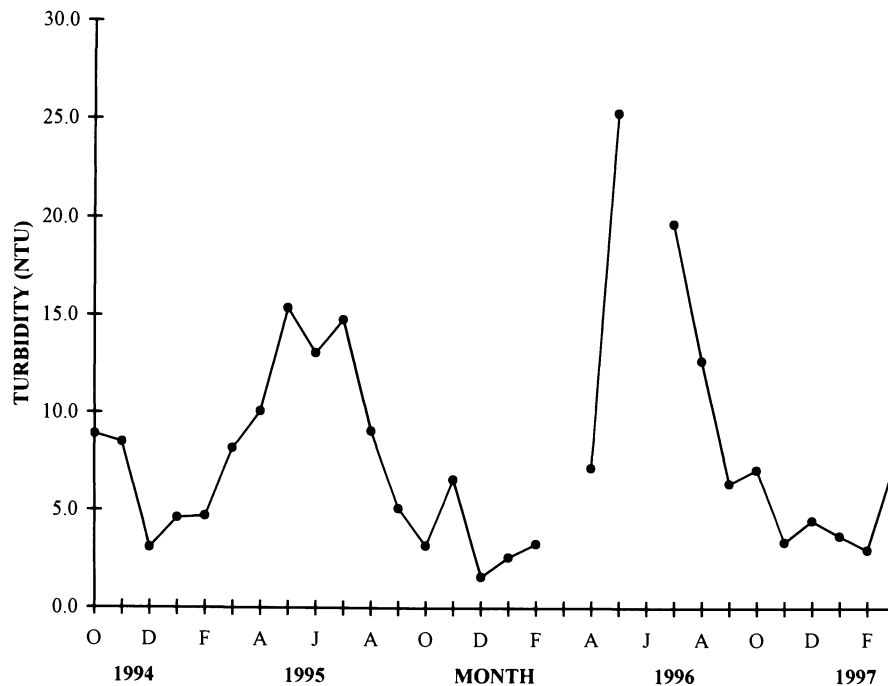


Figure 3. Average turbidity (NTU) for eight stations in Futch Creek, August 1994–March 1997).

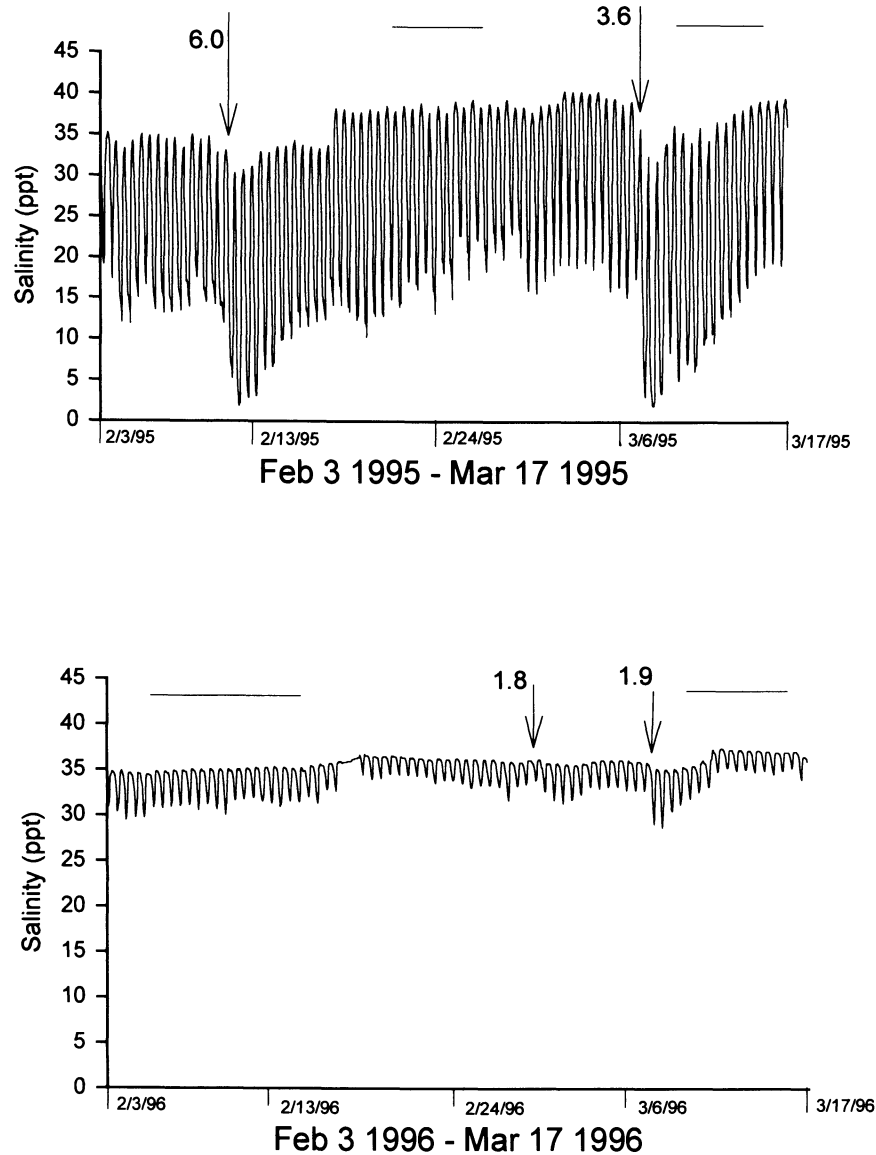


Figure 4. Plots of salinity data collected by stationary monitors deployed at a mid-creek station during the periods February 3–March 17, 1995 (4a) and 1996 (4b). Horizontal bars denote periods of no rain from rainfall records at New Hanover County airport, about 15 km from the site. Arrows denote significant rain events, with one-day accumulations (cm) indicated.

period of ten weeks approximately every three years, and closures are based on these results. Because of the favorable data obtained during the Futch Creek Demonstration Project, the Shellfish Sanitation sampling program for Futch Creek was rescheduled for spring 1996. Based on Shellfish Sanitation monitoring and these research results the main body of Futch Creek (Stations FC-2, FC-4, FC-6, FC-8) was reopened to public shellfishing in May of 1996.

An important question is what factor(s) associated with the dredging accounted for the decrease in fecal coliform abundance? Two likely factors are increased salinity and increased flushing/dilution of creek waters. In numerous situations increased salinity has been found to be detrimental to survival

of fecal coliforms (HANES and FRAGALA, 1967; GOYAL *et al.*, 1977; SOLIC and KRSTULOVIC, 1992; MUNRO *et al.*, 1994; MEZRIQUI *et al.*, 1995). Since salinity increased by 50% in the most polluted creek station following dredging, and increased considerably at the mid-creek location, this was likely an important factor causing reduction of fecal coliforms in the creek. It is likely that greater flushing occurred as well, as indicated by the consistently high salinities measured at mid-creek by stationary monitors. The decreases in nitrate at the mid-creek stations may have resulted from increased dilution / flushing of low nitrate- high salinity water.

Fecal coliform bacteria are known to accumulate (in a viable condition) in the sediments of water bodies, particularly

Table 2. Average fecal coliform concentrations in feeder creeks and springs in upper Futch Creek, summer-fall 1996. Fecal coliforms are geometric means (CFU/100 mL).

Station	Fecal Coliform Concentration
Spring FC-18SP	14
Creek FC-18CR	572
Spring FC-19	2
Creek FC-25	129
Creek FC-26	437

among fine-grained sediments (SAYLOR *et al.*, 1975; GERBA and McLEOD, 1976; LALIBERTE and GRIMES, 1982; WEISKEL *et al.*, 1996, BURKHOLDER *et al.*, 1997). Anthropogenic activities such as dredging can resuspend these organisms into the water column (GRIMES, 1975). The 1995 dredging of the south channel increased turbidity (Figure 3) but did not appear to cause a concurrent increase in fecal coliform abundance (Figure 2). Dredging in April and May 1996 caused increased turbidity (Figure 3) and increased fecal coliform abundance (Figure 2), which subsequently decreased in June. Runoff associated with the hurricanes in July and September of 1996 was responsible for fecal coliform increases as well (Figure 2). The dredging did cause significant increases in turbidity at the two stations closest to the channels. However, average turbidities remained below 10 NTU and individual measurements did not exceed the state standard. Thus, turbidity changes did not appear to have a major impact on creek water quality.

We wish to emphasize that significant fecal coliform decreases occurred after dredging despite two major runoff events (Hurricanes Bertha and Fran) that caused acute decreases in salinity and increases in fecal coliform counts. Thus, we consider our data to be conservative, and suspect that average coliform decreases would have been even greater and salinities higher had the hurricanes not occurred. Despite the success of the dredging project in reopening shell-fishing waters, the source of fecal pollution was not eliminated. As mentioned, feeder streams continue to drain contaminated water into the main body of the creek, and are probably polluted by manure from concentrated wild animal activity. Experiments conducted with dog feces indicated that, under ambient environmental conditions, there was no decrease in fecal coliform densities for as long as 30 days after deposition (WEISKEL *et al.*, 1996). Use of these areas by concentrations of wild animals will lead to a continuous supply of fecal coliforms to the creek. Thus, dredging is not the ultimate cure for the problem, but a mitigative effort that relieves the symptoms of fecal coliform pollution. Should the sand bar at the mouth of the creek rebuild over time, additional dredging may be required to maintain creek fecal coliform concentrations at acceptable levels.

Dredging can be an appropriate tool to improve water quality under certain conditions. In Futch Creek, the area dredged was of limited size, with consequent limited disturbance to the ecosystem. The scope of bacterial pollution was limited as well. In a severely polluted creek, limited dredging might not be nearly as effective. In Futch Creek there was a

definite restriction on flow, probably caused by anthropogenic activities, which was reversed. In an estuary with already-high flow rates, dredging would not be an appropriate action because the amount required to significantly change flow would likely be cost-prohibitive and physically damaging to the ecosystem. In all cases, however, we recommend that sources of bacterial pollution be investigated and dealt with first, if feasible, before major physical manipulations are attempted.

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