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Tidal Stage Variability of Fecal Coliform and Chlorophyll *a* Concentrations in Coastal Creeks

MICHAEL A. MALLIN*, E. CARTIER ESHAM, KATHLEEN E. WILLIAMS and JANICE E. NEARHOOF

Center for Marine Science Research, University of North Carolina at Wilmington, 7205 Wrightsville Ave., Wilmington, NC 28403, USA

Tidal creeks are shallow estuaries that can be found in any coastal environment, but they are especially prominent in low-energy coastal regions. As the name implies, the principal physical forcing mechanism affecting the ecology of these creeks is tidal variation. Tides serve various biological functions: they provide transport mechanisms for invertebrates (Cronin and Forward, 1979; Brookins and Epifanio, 1985), food supplies to sessile feeders (Carlson *et al*., 1984; Peterson and Black, 1991); and they expose benthic organisms to feeding avifauna (Peterson and Peterson, 1979). However, tidal creeks suffer from a number of anthropogenic impacts. These include eutrophication, turbidity and siltation, and shellfish bed closures due to fecal coliform pollution. Sources of pollutants can include fertilizers, septic system leachates, leaking sewer mains, wild and domestic animal wastes, and runoff. However, the interaction between the tides and anthropogenic inputs has been poorly defined to date.

Fecal coliform bacteria are commonly used as enteric pathogen indicators (Dadswell, 1993). Upon exiting a host's intestinal tract they leave an environment characterized by constant temperature, abundant nutrients, and protection from environmental hazards, to enter an estuarine environment characterized by high variability regarding temperature, irradiance, nutrients, and predators. How fluctuations in tide and salinity affect fecal coliform abundance is an important human health issue, especially in shellfishing waters. Chlorophyll *a* concentration is a commonly-used measure of phytoplankton biomass, which may also be affected by estuarine physical parameters. Insight concerning the influence of tidal variation on ambient concentrations of water quality parameters is critical to understanding both the basic ecology of tidal creeks and the applied aspects of sampling protocols and pollutant mitigation.

The objective of this research was to determine the influence of tidal variation on the concentrations of the water quality parameters mentioned above. Sampling was conducted in three different creeks to identify generally-applicable patterns for these small estuarine systems. Data were gathered during 14 tidal cycles from both euhaline and mesohaline locations. Data from a related project are also presented, comparing water quality at low tide and high tide from a euhaline site on the United States Atlantic Intracoastal Waterway (ICW). Subsequent to this research, an additional study was conducted in the area surrounding one of the stations in an effort to ascertain the sources and magnitudes of pollutant inputs.

All sampling was completed at sites in New Hanover County, North Carolina, USA (34°10′N latitude, 77°55′W longitude), near the City of Wilmington (Fig. 1). A downstream station (HOW) was located on Howe Creek about 0.8 km from the ICW (mean salinity 32‰, range 10–37‰). Station HEW constituted an upstream site on the southern branch of Hewletts Creek, about 2.5 km from the ICW (mean salinity 18‰, range 3–30‰). A second upstream station (FC) was located on Futch Creek, about 2.2 km from the ICW (mean salinity 16‰, range 0–30‰). Stations HEW and FC were in extensive *Spartina alterniflora* marshes whereas site HOW was near a developed area with a narrow fringe of *S. alterniflora*. At the time of sampling the Howe Creek watershed was about 39% developed, the Hewletts Creek watershed was approximately 69% developed, and the FC watershed was about 22% developed (NHCPD, 1993). A fourth sampling site was located on the ICW itself, near the location of the Masonboro Sound National Estuarine Research Reserve. All stations were sampled from docks; mainstem creek station were <2.5 m deep at high tide, and the ICW station averaged 2.0 m in water depth at high tide and 1.0 m deep at low tide.

Sampling was designated as Spring (March–April), Summer (May–August), Autumn (late September–October), and Winter (November–February), based on previously-determined periods of high and low phytoplankton biomass as chlorophyll *a* (Mallin *et al*., 1996).

*Corresponding author.

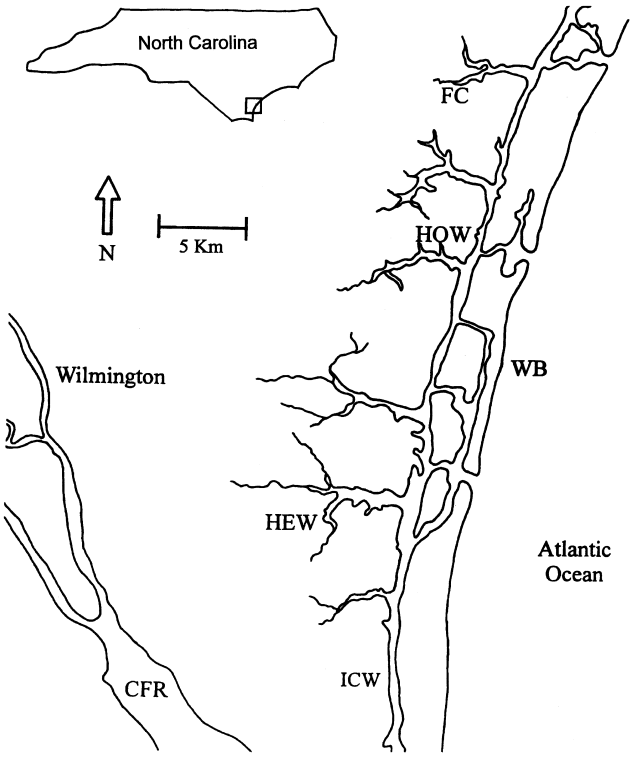

Fig. 1 Location of sampling stations in New Hanover County tidal creeks, North Carolina, USA. FC – Futch Creek; HOW – Howe Creek; ICW – Atlantic Intracoastal Waterway; WB – Wrightsville Beach; CFR – Cape Fear River.

Three tidal cycles were sampled in both Summer and Winter at HOW; three tidal cycles were sampled in Summer and two in Spring at HEW; three tidal cycles were sampled in Autumn at FC; and the ICW was sampled at both high and low tide eight times in both Summer and Winter. For consistency, creek stations were sampled beginning at high tide and hourly until low tide (6–7 samples *per* cycle). To avoid complications from rainfall and runoff, sampling was not conducted during or shortly after rain events.

All samples were collected from near-surface water (0.10 m depth). Fecal coliform samples were obtained using pre-autoclaved glass containers, facing into the streamflow. Samples were kept on ice until analysis (no more than 2 h after collection). Fecal coliforms were analyzed using the mFC technique (APHA, 1995). Samples for chlorophyll analyses were collected in triplicate using acid-washed (10% HCl), 125 ml amber bottles which were stored on ice until processing. Under low light conditions the triplicate samples were filtered (2.4 cm Gelman A/E glass fibre filters) using a manifold equipped with three funnels, with the pooled filtrate stored frozen for later nutrient analysis. The glass fibre filters were wrapped in aluminum foil and frozen for later analysis of phytoplankton biomass, as chlorophyll *a*. Extraction was accomplished by placing the filters in foil-wrapped 15 ml plastic screw-capped centrifuge tubes with 10 ml of 90% acetone solution. The samples were allowed to extract in a refrigerator for 24 h. Chlorophyll *a* quantification was accomplished using the fluorometric method described in Welschmeyer (1994). Turbidity was analyzed in samples collected after January 1995 using a LaMotte turbidity meter, and these data are reported as NTU. Samples at the ICW taken at both high tide and low tide were analyzed for fecal coliforms and chlorophyll *a* as above, and for suspended solids (SS) by dry weight after filtration (Gelman A/E glass fibre filters).

Statistical analysis of tidal cycles was completed using the Statistical Analysis System (SAS) with $a = 0.05$. Correlations were run between parameters for all tidal cycles combined, and also for each individual creek station by season. Low tide and high tide results from sampling the ICW were compared using Student's *t*-tests, first for all Winter samples and then for all Summer samples combined, and also for each parameter and date individually.

On one mid-Summer occasion, each of the tidal creek stations was sampled at high and low tide for phytoplankton taxa analysis by collecting duplicate surface samples in 125 ml amber bottles and field-preserving the samples with Lugol's solution. Phytoplankton were enumerated by placing 0.1 ml of the solution in a Palmer–Maloney cell and counting the entire contents of the cell. An Olympus B201 phase contrast microscope was used, with identifications made at 600× and counts at 300×.

During both Winter and Summer, a pattern emerged in lower Howe Creek of lowest fecal coliform abundance near high tide, and highest abundance at or near low tide (Fig. 2A). High tide concentrations were less than 25 CFU 100 ml^{-1} and low tide concentrations ranged from 100 to 150 CFU 100 ml^{-1}. Fecal coliform abundance during the Spring and Summer tidal cycles for upper Hewletts Creek displayed a pattern of lowest abundance near high tide and highest abundance between mid-to-low tide (Fig. 2B). High tide concentrations ranged from 80 to 100 CFU 100 ml^{-1} and maximal concentrations ranged between 250 and 450 CFU 100 ml^{-1}. In upper FC, lowest coliform abundance occurred at high tide (about 50 CFU 100 ml^{-1}) and highest near low tide (about 1200 CFU 100 ml^{-1}; see Fig. 2C). For all stations combined, fecal coliform abundance was inversely correlated with both salinity and tidal height (Table 1).

Fecal coliform abundance at Howe Creek was inversely correlated with salinity and nearly so with tidal

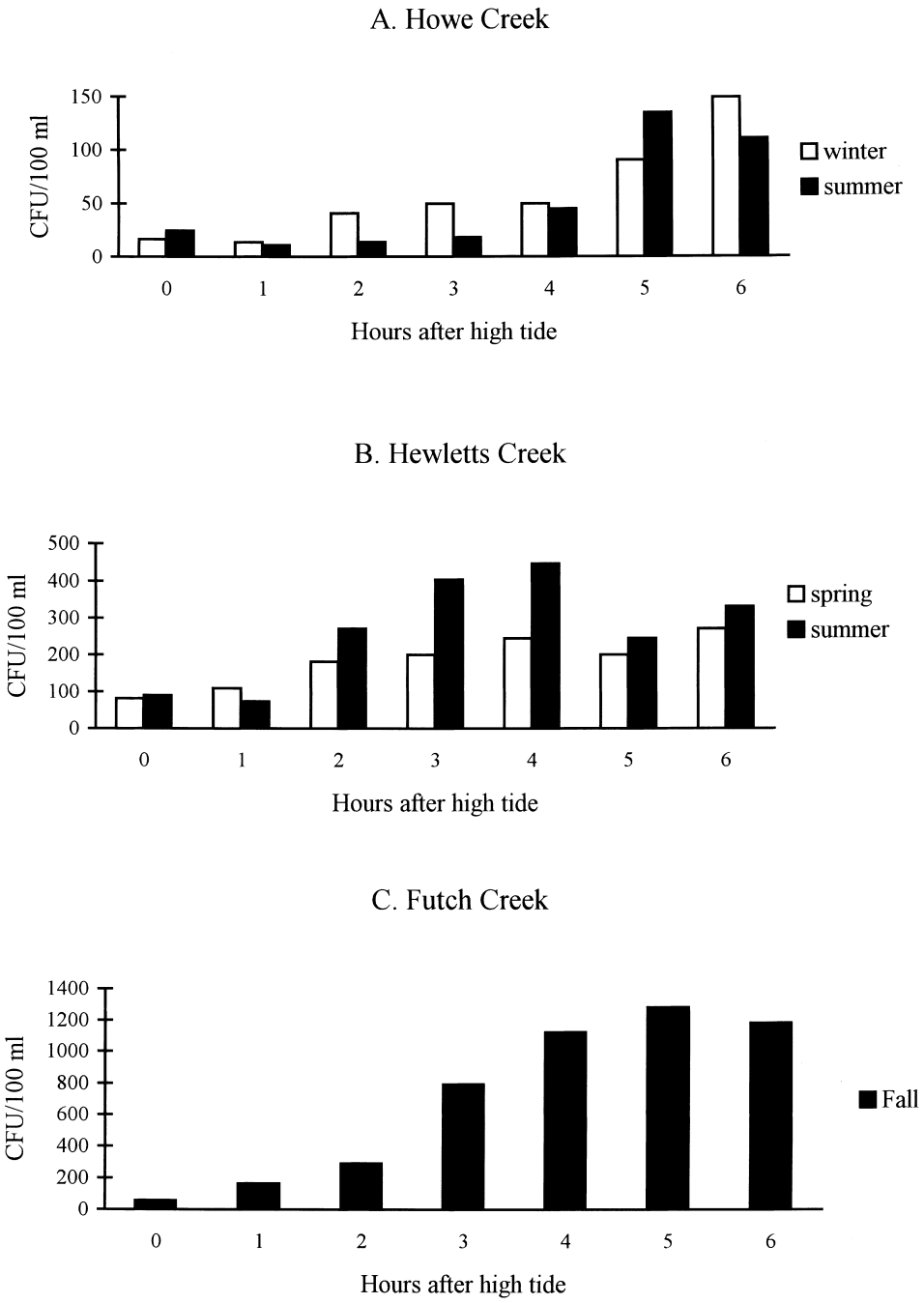

Fig. 2 (A) Geometric mean fecal coliform concentrations over three Winter and three Summer tidal cycles in lower Howe Creek. (B) Fecal coliform concentrations over two Spring and three Summer tidal cycles in upper Hewletts Creek. (C) Fecal coliform concentrations over three Autumn tidal cycles in upper Futch Creek.

height in Summer, and with tidal height in Winter (Table 2). Coliform abundance in Hewletts Creek displayed near-significant correlations with either tidal height or salinity during Summer or Spring ($p = 0.06$–0.12; see Table 3). In FC during the Autumn, fecal coliform abundance showed a highly significant inverse correlation with both tidal height and salinity (Table 4). Season appeared to play little role in fecal coliform abundance, but sampling distance from the creek mouth appeared to have an effect. Fecal coliform abundance was highest closest to low tide at the euhaline station nearest the creek mouth (Fig. 2A), while maximal abundance was between mid-and-low tide at the more mesohaline upstream stations (Fig. 2B and C).

Overall, turbidity was inversely correlated with both tidal height and salinity (Table 1). Turbidity was inversely correlated with both tidal height and salinity in Howe Creek during Summer and Winter (Table 2), and nearly so ($p = 0.076$) with tidal height in FC in Autumn (Table 4).

The increase in the abundance of fecal coliform bacteria in tidal creek waters at or near low tide is probably influenced by several factors. Previous research has shown that fecal coliform abundance in these tidal creeks is greatest in the fresher headwater areas, near potential sources (Esham, 1994; Mallin *et al*., 1996), and that major sources of fecal coliforms to the main creek channels are small feeder creeks in the upper marsh areas (Mallin *et al*., 1996). There is an inverse relationship between fecal coliform abundance and/or survival time and salinity (Hanes and Fragala, 1967; Goyal *et al*., 1977; Solic and Krstulovic, 1992; Mezrioui *et al*., 1995). During the tidal cycles studied here, decreases in salinity of over 20% occurred between high and low tides concurrently with sharp increases in fecal coliform concentrations. Fecal coliform bacteria are often concentrated in sediments of water bodies (Grimes, 1975; Goyal *et al*., 1977; Davies *et al*., 1995; Burkholder *et al*., 1997), and their subsequent reintroduction to the water column by tidal stirring (tidal resuspension) can increase water-column concentrations of such bacteria. The increase in turbidity near low tide tends to support this premise (Table 1). Concentration and dilution of suspended coliform bacteria with changing water levels may also be operative. The falling tide probably imports the abundant headwater stream and feeder creek fecal coliforms to downstream sampling locations. In addition, fecal coliforms which had previously settled out and had been concentrated in sediments are probably resuspended with tidal stirring at low water.

Chlorophyll *a* values in the water column during Summer in lower Howe Creek were lowest at high tide (average 6 $\mu g\ l^{-1}$) and maximal at low tide (average 15 $\mu g\ l^{-1}$ – Fig. 3A). However, the low phytoplankton biomass occurring in cold weather obscured detection of a Winter chlorophyll *a* tidal pattern (Fig. 3A). In upper Hewletts Creek, chlorophyll *a* concentrations during both Spring and Summer were minimal at high tide (5–8 $\mu g\ l^{-1}$) and highest at low tide (40–70 $\mu g\ l^{-1}$ Fig. 3B). In upper FC in the Autumn, maximal chlorophyll *a* concentrations occurred at mid-tide (average 14 $\mu g\ l^{-1}$), with no other notable pattern (Fig. 3C). For all tidal cycles considered collectively, chlorophyll *a* values were inversely correlated with both tidal height and salinity (Table 1). The chlorophyll *a* concentration in Howe Creek was inversely correlated with both tidal height and salinity in Summer but with neither in Winter (Table 2), while chlorophyll *a* levels in Hewletts Creek were inversely correlated with salinity in Summer and with both tidal height and salinity in Spring (Table 3). In FC in the Autumn there was a marginal inverse correlation ($p = 0.051$) between chlorophyll *a* and salinity (Table 4).

The results of the Summer phytoplankton community comparisons varied according to both tide and station. At the euhaline station (HOW), phytoplankton densities were lowest overall, and total phytoplankton densities were about 28% greater at low tide than at high tide (Table 5). The low tide community was dominated by dinoflagellates and pennate diatoms and the high tide community by centric diatoms and cryptomonads. Planktonic taxa were abundant during both tidal stages, but the pennates, including benthic species, dominated at low tide. The most abundant taxa found at low tide were the dinoflagellate *Peridinium aciculiferum*, the cryptomonad *Hemiselmis virescens*, the pennate diatoms *Nitzschia closterium* and *Navicula* spp, and the centric diatom *Chaetocerus* sp. The dominant species at high tide were *Hemiselmis virescens* and the centric diatoms *Skeletonema costatum* and *Chaetocerus* sp.

At Futch Creek (station FC), the salinity was 0‰ at low tide and 17‰ at high tide. There were slightly higher total phytoplankton densities at high tide than at low tide (Table 5). This was largely due to a much greater abundance of tiny pennate diatoms (< 10 μm in length) at high tide. At low tide there were more flagellates, mainly the biflagellated chrysophyte *Olisthodiscus* sp. Other abundant taxa at low tide were *Navicula gregaria*, *Nitzschia aurariae* and *Hemiselmis virescens*. At high tide the community was very diverse, although *Navicula gregaria avicula* and *Nitzschia aurariae* made up approximately 62% of the community by number. *N. gregaria* is listed by Mclntire and Moore (1977) as non-planktonic; *Navicula auraniae* is not listed and may be planktonic.

The salinity at Hewletts Creek (station HEW) varied widely, from 0‰ at low tide to 30‰ at high tide. The overall phytoplankton abundance was more than a order of magnitude greater at low tide (Table 5). The low tide community consisted of 98% flagellates, compared to 87% flagellates at high tide. The most abundant taxa at low tide were *Olisthodiscus* sp. and the crytomonads *Chroomonas minuta* and *Cryptomonas amphioxiae*. Also present in high numbers ($2600\ ml^{-1}$) were non-toxic flagellated stages of the dinoflagellate *Pfiesteria piscicida*, which were observed under light microscopy grazing

TABLE 1
Correlations among physical, chemical and biological parameters analyzed during all tidal cycle studies.[a]

		SAL	CHLA	FC	TURB
TIDE	(*r*)	0.413	−0.275	−0.330	−0.412
	(*p*)	0.001	0.007	0.001	0.007
SAL	(*r*)	1.000	−0.584	−0.627	−0.444
	(*p*)	0.0	0.001	0.001	0.003
CHLA	(*r*)	−0.584	1.000	0.160	0.239
	(*p*)	0.001	0.0	0.319	0.127

[a] Pearson correlation coefficient (*r*)/probability (*p*). $n = 96$ obs. TIDE – tidal height, SAL – salinity, CHLA – chlorophyll *a*, FC – fecal coliforms, TURB – turbidity.

TABLE 2
Correlations among physical, chemical and biological parameters analyzed during Howe Creek in Summer and Winter tidal cycle studies.[a]

		SAL	CHLA	FC	TURB
Summer					
TIDE	(*r*)	0.659	−0.589	−0.428	−0.913
	(*p*)	0.001	0.005	0.053	0.004
SAL	(*r*)	1.000	−0.925	−0.909	−0.840
	(*p*)	0.0	0.001	0.001	0.004
Winter					
TIDE	(*r*)	0.677	−0.340	−0.524	−0.884
	(*p*)	0.001	0.131	0.015	0.008
SAL	(*r*)	1.000	−0.015	−0.346	−0.759
	(*p*)	0.0	0.947	0.125	0.048

[a] Pearson correlation coefficient (*r*)/probability (*p*). $n = 21$ obs. in both seasons. TIDE – tidal height, SAL – salinity, CHLA – chlorophyll *a*, FC – fecal coliforms, TURB – turbidity.

TABLE 3
Correlations among physical, chemical and biological parameters analyzed in Hewletts Creek in Summer and Spring tidal cycle studies.[a]

		SAL	CHLA	FC	TURB
Summer					
TIDE	(*r*)	0.412	−0.317	−0.395	NA
	(*p*)	0.079	0.185	0.094	
SAL	(*r*)	1.000	−0.900	−0.365	NA
	(*p*)	0.0	0.001	0.124	
Spring					
TIDE	(*r*)	0.883	−0.786	−0.502	−0.152
	(*p*)	0.001	0.001	0.067	0.603
SAL	(*r*)	1.000	−0.746	−0.492	0.060
	(*p*)	0.0	0.002	0.074	0.838

[a] Pearson correlation coefficient (*r*)/probability (*p*). $n = 19$ obs. in Summer and $n = 14$ in Spring. TIDE – tidal height, SAL – salinit, CHLA – chlorophyll *a*, FC – fecal coliforms, TURB – turbidity, NA – no data available.

TABLE 4
Correlations among physical, chemical and biological parameters analyzed during Futch Creek Autumn tidal cycle studies.[a]

		SAL	CHLA	FC	TURB
TIDE	(*r*)	0.717	0.036	−0.575	−0.489
	(*p*)	0.001	0.877	0.001	0.076
SAL	(*r*)	1.000	−0.431	−0.746	0.203
	(*p*)	0.0	0.051	0.001	0.486

[a] Pearson correlation coefficient (*r*)/probability (*p*). $n = 21$ obs. TIDE – tidal height, SAL – salinity, CHLA – chlorophyll *a*, FC – fecal coliforms, TURB – turbidity.

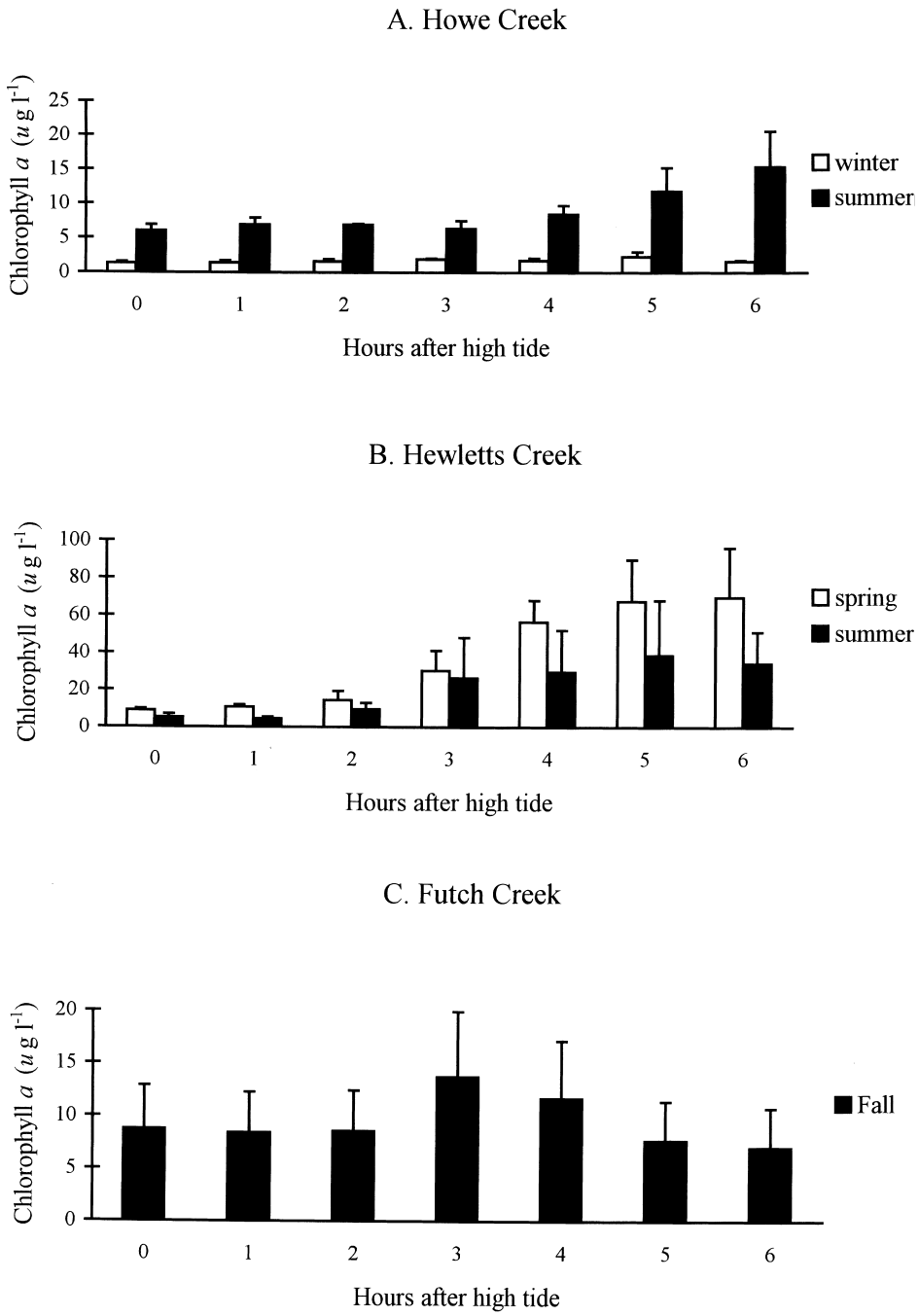

Fig. 3 (A) Mean chlorophyll *a* concentrations (with standard error) over three Winter and three Summer tidal cycles in lower Howe Creek. (B) Mean chlorophyll *a* concentrations over two Spring and three Summer tidal cycles in upper Hewletts Creek. (C) Mean chlorophyll *a* concentrations over three Autumn tidal cycles in upper Futch Creek.

on the cryptomonads by using their peduncles. At high tide the community was very different, and was dominated by *Hemiselmis virescens*, *Pfiesteria piscicida*, and *Gymnodinium* spp.

The trend of maximum chlorophyll *a* concentration at mid to low tide has several possible causes. Tidal marshes are rich in epiphytic and edaphic microalgae (Sullivan and Moncreiff, 1988; Mallin *et al.*, 1992; Coleman and Burkholder, 1995), and the falling tide could import some of this marsh material into the creek channel. Also, the resuspension of sediments near low tide probably imports benthic microalgae from the creek bed into the water column (Baillie and Welsh, 1980; Shaffer and Sullivan, 1988). Changing tide levels may also have a dilution or concentration effect on phytoplankton biomass. Finally, chlorophyll *a* concentrations in tidal creeks are often highest in headwater areas (Laws *et al.*, 1994; Mallin *et al.*, 1996), and it has been

TABLE 5
Phytoplankton abundance at low tide and high tide at three stations, collected on 23 August 1996.[a]

	HOW		FC		HEW	
	Low tide	High tide	Low tide	High tide	Low tide	High tide
Total phytoplankton	2000	1440	7220	7960	26,340	2150
Total dinoflagellates	600	80	210	940	2580	880
Total cryptomonads	300	470	1000	910	13,620	850
Flagellated chrysophytes	40	0	2420	580	9620	80
Flagellated green algae	150	20	90	410	120	60
Pennate diatoms	620	330	3420	4980	400	130
Centric diatoms	290	540	80	140	0	140
Salinity	22	32	0	17	3	30

[a] Abundance are in cells ml^{-1} (mean of two samples).

demonstrated that the falling tide can transport algae from upstream into downstream locations in the open waters of the Newport River Estuary (Litaker *et al.*, 1987, 1993).

The analysis of phytoplankton differences at low and high tides showed that phytoplankton cell counts generally followed the station patterns for chlorophyll *a* biomass shown in Fig. 3. At station HOW, phytoplankton biomass was lowest of the three sites overall, but was greater at low tide than at high tide; cell counts also followed this pattern. At station HEW chlorophyll *a* levels were much greater at low tide than high tide, as was the case with cell counts. At station FC, there was little difference for either phytoplankton biomass or cell counts between tidal extremes, and the biomass was greatest at mid-tide.

Pennate diatoms, which are characteristic of benthic and periphytic habitats (McIntire and Moore, 1977), were abundant only at low tide in the euhaline station HOW (Table 5). While some dinoflagellates and cryptomonads can exist as benthic species, the majority of the flagellates encountered in the present work are common members of the estuarine plankton of this region (Campbell, 1973; Mallin, 1994). Thus, marsh runoff of periphyton into the creeks was not an important contribution to low-tide biomass increases, and tidal stirring of benthic species was probably only important at the euhaline station HOW. At station HEW, the abundance of planktonic flagellates, coupled with the broad differences in salinity and community structure, suggest that tidal importation of denser phytoplankton patches in nutrient-rich upstream areas accounted for the majority of the chlorophyll *a* increases at low tide at this station. At site FC, there was probably some input of benthic microalgae from tidal stirring, but pennate diatoms were more abundant at high tide than at low tide. Different flagellates dominated in the two tidal states, suggesting the importation of species from upstream areas on the falling tide. Thus, for the creeks studie here, it is concluded that tidal stage differences in algal biomass are primarily due to the importation of phytoplankton from richer upstream areas, and are secondarily a result of the entrainment of benthic microalgae by tidal stirring. At the downstream site HOW, phytoplankton was greatest at low tide, whereas at the upstream site FC, maximal biomass occurred near mid-tide. At station HEW, maximum phytoplankton biomass occurred between low and mid-tide. Due to its location in the upper estuary, station FC may have quickly (by mid-tide) received imported phytoplankton on the falling tide from a chlorophyll *a* "maximum" area in the upper creek. At the station closest to the ICW, site HOW, the entire 6 h may have been necessary to bring significant phytoplankton biomass all the way downstream from an upper estuary maximum zone.

Salinity varied little between low and high tide at the ICW site (Table 6). On average, parameters other than salinity were higher at low tide than at high tide, but in some cases this difference was very slight. Comparing seasons, overall concentrations for most parameters were higher in Summer than Winter, and the differences between tides were much greater in Summer. However, due to variability among sampling dates, there were no overall statistically significant differences between tides. When *t*-tests were conducted between tidal stage parameter concentrations for each individual date, several significant differences were detected (Table 7). Fecal coliform concentrations did not differ significantly with tidal state in Winter, but were often significantly greater at low tide during Summer. Chlorophyll *a* values were

TABLE 6
Values for various parameters at low tide (LT) and high (HT) tide during the Winter and Summer at the Atlantic Intracoastal Waterway site. $n = 7$–8 samples in each season.[a]

Parameter	LT Mean	SD	HT Mean	SD
Winter				
Salinity	26.9	5.7	29.4	4.7
FC (CFU 100 ml^{-1})	31.6	32.0	27.5	36.6
CHLA (μg l^{-1})	5.7	2.3	4.0	2.1
SS (mg l^{-1})	38.0	23.9	34.6	30.7
Summer				
Salinity	31.6	4.3	33.3	2.1
FC (CFU 100 ml^{-1})	47.5	41.4	17.5	21.9
CHLA (μg l^{-1})	18.2	9.8	13.0	5.1
SS (mg l^{-1})	92.3	45.1	64.1	39.7

[a] FC – fecal coliforms; CHLA – chlorophyll *a*; SS – suspended solids.

TABLE 7
Summary of significant tidal stage parameter concentration differences at the Atlantic Intracoastal Waterway site during the Winter and Summer.[a]

Paremeter	LT > HT	HT > LT	NSD
Winter			
FC	0	0	8
CLA	6	1	1
SS	3	1	3
Summer			
FC	4	0	4
CLA	5	2	1
SS	3	1	3

[a] (*t*-test, $p < 0.05$, df = 4; 7-8 comparisons) LT – low tide; HT – high tide; NSD – no significant difference. FC – fecal coliforms; CLA – chlorophyll *a*; SS – suspended solids.

usually greater at low tide in both seasons. Suspended solid levels at low tide were generally either greater than or equal to the concentrations at high tide.

The site on the ICW is not normally subject to great salinity changes or the importation of material from riches areas at low tide. The sampling discussed here was conducted from the end of a long dock in a relatively undeveloped area. Thus, subsurface inputs were not likely to be great. Here, tidal stirring is probably the major factor increasing the resuspension of fecal coliforms, chlorophyll *a*, and other particulate matter from the sediments into the water column. The Summer resort towns of Wrightsville Beach and Carolina Beach lie 18 km apart along the ICW, with the sampled station located approximately equidistant between the towns. During Summer there is extensive recreational boat traffic along the waterway, with concomitant increased benthic stirring at low tide.

These tidal patterns have important implications concerning the assessment of water quality parameters in tidal creeks and canals. Samples taken at high tide will tend to provide conservative results, whereas samples taken at or near low tide will generally present a ''worst-case'' scenario. Shellfish waters in the US have a fecal coliform standard of 14 CFU 100 ml^{-1} (USFDA, 1995). In lower Howe Creek, samples collected at high tide indicate that the standard is achieved, whereas samples collected only a few hours later indicate polluted waters. The State of North Carolina standard for chlorophyll *a* is 40 $\mu g\ l^{-1}$ (NCDEHNR, 1994). In Hewletts Creek, high tide samples indicated low to moderately productive waters, while low tide samples indicated eutrophic waters. Thus, natural variability induced by tidal movement should be considered when establishing water quality standards for tidally-influenced systems. When water quality sampling programmes are proposed for shallow, tidally-influenced water bodies, preliminary tidal cycle sampling experiments should be completed. The results could be used to either set up regular sampling times for later monitoring programmes or help explain the implication of results from samples taken during a given tidal state.

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