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Loading of fecal indicator bacteria in North Carolina tidal creek headwaters: Hydrographic patterns and terrestrial runoff relationships

*Curtis H. Stumpf**, *Michael F. Piehler*[1], *Suzanne Thompson*[2], *Rachel T. Noble*[3]

University of North Carolina Institute of Marine Sciences, 3431 Arendell Street, Morehead City, NC 28557, USA

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ABSTRACT

In the New River Estuary (NRE) in eastern North Carolina (NC), fecal indicator bacteria (FIB) levels exceed water quality standards, leading to closure of estuarine waters for shellfishing and classification of parts of the estuary as "impaired" per the Clean Water Act section 303(d) list. As a means to investigate fecal contamination and loading of FIB to the NRE, a continuous automated sampler (ISCO) outfitted with flow modules and water quality probes was placed in four first-order tidal creek headwaters. Total storm discharge and bacterial load for *Escherichia coli* (EC) and *Enterococcus* spp. (ENT) were calculated using graphical volumetric flow calculations and interpolation of FIB measurements over each storm's duration for 10 storms. Mean total load of 10^9– 10^{12} EC and ENT cells (MPN) occurred over the course of each storm. Total storm loading, averaged across all storms, was as much as 30 and 37 times greater than equivalent duration of baseflow loading for EC and ENT, respectively. Within the first 30% of creek storm volume for all storms and all creeks combined, a mean cumulative load of only 37% and 44% of the total EC and ENT cells, respectively, was discharged, indicating these creeks are not demonstrating a 'first flush' scenario for FIB. The median storm Event Mean Concentrations (EMCs) were 6.37×10^2 and 2.03×10^2 MPN/100 mL, for EC and ENT, respectively, compared with median baseflow concentrations of 1.48×10^2 and 4.84×10^1 for EC and ENT, respectively, and were significantly different between base and storm flow events. FIB was correlated with TSS (weak), flow rate (strong), and different stages (base, rising, peak, and falling) of the hydrograph (strong). Pollutographs indicate large intra-storm variability of FIB, and the need for more intensive sampling throughout a storm in order to attain accurate FIB contaminant estimates. Instream sediment concentrations ranged from 5 to 478 (MPN/g) and 13 to 776 (MPN/g) for EC and ENT, respectively, indicating sediment as a source, but a minor reservoir. This overall approach for calculating loading in headwater tidal creeks is detailed. Accurate loading characterization of FIB during storms and dry weather conditions, and understanding intra-storm FIB concentrations, is imperative for understanding patterns of water quality impairment, establishing management planning, and developing appropriate mitigation strategies.

* *Corresponding author*. Tel.: +1 252 726 6841x138; fax: +1 252 726 2426.
E-mail addresses: cstumpf@email.unc.edu (Curtis H. Stumpf), mpiehler@email.unc.edu (M.F. Piehler), sthompson@email.unc.edu (S. Thompson), rtnoble@email.unc.edu (R.T. Noble).
[1] Tel.: +1 252 726 6841x160.
[2] Tel.: +1 252 726 6841x161.
[3] Tel.: +1 252 726 6841x150.

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1. Introduction

Tidal creeks are important conduits of nutrients and contaminants in stormwater runoff to receiving waters (Didonato et al., 2009; Mallin and Lewitus, 2004). Fecal indicator bacteria (FIB), such as fecal coliforms (FC), *Escherichia coli* (EC), and *Enterococcus* spp. (ENT), are used as proxies for pathogens and as the primary means of determining fecal pollution in tidal creeks and estuaries as regulated by the USEPA (1987). Concentrations of FIB in surface waters impacted by stormwater runoff can increase dramatically during rainfall events in comparison to baseline conditions (Shehane et al., 2005; Lipp et al., 2001; Wilkinson et al., 1995). This increase is often due in part to fecal contamination washed from impervious surfaces and terrestrially associated fecal contamination that is scoured from land and transported via stormwater into receiving waters (Mallin et al., 2000; Weiskel et al., 1996; Geldreich et al., 1968). Stormwater runoff can account for a much greater portion of overall FIB loading in creeks when compared to non-event baseflow loading (Krometis et al., 2007; Surbeck et al., 2006; Reeves et al., 2004). Stormwater runoff to receiving waters such as tidal creeks has the potential to impact public health in myriad ways. Tidal creeks in eastern North Carolina (NC) are heavily utilized for shellfish harvesting, boating, fishing, swimming, and, in the New River Estuary (NRE), for amphibious military training. In addition, loading of FIB to headwater portions of tidal creeks will eventually be transported to downstream areas and estuarine receiving waters. Understanding FIB loading characteristics of these tidal creek headwaters is important for overall understanding of estuarine and coastal water quality dynamics and beneficial use impairments.

Many tidal creeks and estuaries in NC are listed as "impaired" due to elevated fecal coliform levels. In eastern North Carolina, previous research has shown that greater than 93% of *E. coli* are fecal coliforms ($n = 3020$, Noble and Kirby-Smith, unpublished data), and therefore EC and FC are used interchangeably for this study. In compliance with section 303(d) of the Clean Water Act (USEPA, 1987), total maximum daily loads (TMDLs) of pollutants are established for each water body based on its designated uses. Fecal contamination, measured through the use of fecal indicator bacteria, is the second most common pollutant responsible for failure of designated use (i.e. impairment) in assessed waters in the United States (Stewart et al., 2007). Within the 1436 km^2 New River Watershed in eastern NC, 11.3 km^2 of estuarine shellfish waters are "impaired" and 62.8 km^2 of freshwater are "stressed" due to fecal contamination, with 163 km^2 of freshwater yet to be assessed for TMDLs (NCDWQ, 2007). Waters designated as "impaired" have FC counts in exceedence of standards for specific beneficial uses such as shellfish harvestings, while "stressed" waters support beneficial use, but are potentially at risk of impairment.

Precipitation patterns in eastern NC consist of episodic events throughout the year and seasonal hurricanes and nor'easters that can contribute large amounts of precipitation over short durations. Dry weather discharges and rainfall associated runoff have led to water quality impairment from FIB in NC creeks and estuaries (Line et al., 2008; Fries et al., 2008; Mallin et al., 2001). Rainfall thresholds (for example, 2.54 cm of rainfall will result in closure of certain shellfish areas in NC based on previous research showing fecal contamination after this threshold rainfall) are used in some areas of NC to protect public health; however, these thresholds were based on few samples, and Coulliette and Noble (2008) noted that the impairment threshold for the Newport River Estuary based on the shellfish fecal coliform standard occurred even before 2.54 cm of rainfall. In addition, differences among rainfall metrics, including rainfall duration and antecedent rainfall result in high levels of variability in the loads of FIB transported to receiving waters during storms.

Studies to specifically examine FIB of headwater tidal creeks and the potential impact on downstream estuarine shellfishing waters in relationship to storm loading are few. An important departure of this study from other published wet weather FIB monitoring studies was the use of automated sampling throughout the duration of a storm (as opposed to the use of single grab samples to represent an entire storm), which allows for a more accurate estimate of cumulative storm load and the Event Mean Concentration (EMC). Additionally, this work was also conducted in rarely sampled headwater tidal creeks, and in primarily undeveloped watersheds, with particular soil characteristics, and highly productive yet impaired shellfishing waters in eastern NC. Previous studies utilizing automated sampling, and examining similar loading characteristics have primarily been conducted in the western United States, in urban creeks, and highly developed/highly impermeable watersheds. Accurate loading characterization of FIB is imperative for management planning and developing appropriate mitigation strategies for shellfishing waters potentially impaired from fecal contamination throughout the United States.

The goal of this study was to examine the loading of *E. coli* (EC) and *Enterococcus* spp. (ENT) over a range of rainfall and dry weather conditions in headwater portions of tidal creeks of the NRE in eastern NC. A bi-monthly and multi-sample flow-paced storm sampling strategy was employed to quantify load during both base and storm flow conditions. The load of FIB was analyzed in relationship to rainfall amount, streamflow, storm duration, and antecedent rainfall. A loading analysis was conducted to determine whether the patterns observed followed a typical "first flush" scenario. Relationships between EC, ENT, and total suspended solids (TSS) were investigated in an effort to understand potential pathways (runoff vs. resuspension of sediment reservoir populations) and begin to understand potential sources (human vs. nonhuman) of fecal contamination. Finally, instream sediments were examined to determine if sediment reservoir populations, resuspended during storm events, were a potentially significant source of FIB to the water column.

2. Materials and methods

2.1. Site description

The New River watershed, located within Onslow County, NC, encompasses 1436 km^2 and contains the NRE, a broad, shallow