LINKING PHYTOPLANKTON ASSEMBLAGE VARIABILITY, NUTRIENT LOADING, AND MICROBIAL INDICATORS WITH LAND USE: A 3-YEAR STUDY OF THE ASHEPOO-COMBAHEE-EDISTO (ACE) BASIN, SOUTH CAROLINA

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Abstract

A 3-year study (2008-2011) assessed the effects of land use patterns on phytoplankton growth, community composition, bacterial indicator levels, nutrient utilization, and overall water quality within the Ashepoo-Combahee-Edisto (ACE) Basin, South Carolina (SC). A combined field and experimental approach included seasonal surveys in select tidal creeks representing several land use categories. Seasonal *in situ* nutrient addition bioassays were performed over a two-year period to examine phytoplankton responses to various nutrient forms. Results suggested that the systems were limited by inorganic nitrogen relative to phosphorus, but organic nutrients were likely the key drivers of overall system productivity. Correlations were found between water quality, nutrient levels, phytoplankton, and bacteria with land use. Fecal coliform levels varied substantially with season and location with inland stations having higher concentrations suggesting that local hydrography is important.

Background

- Water quality, defined by the South Carolina Estuarine and Coastal Assessment Program (SCECAP), is based upon state standards or historical records of combined fecal coliform levels, dissolved oxygen, pH, total nitrogen, total phosphorus, and chlorophyll *a*.
- Historic SCECAP sampling within the ACE Basin showed relatively elevated nutrient concentrations, low dissolved oxygen, and elevated fecal coliforms, leading to a greater proportion of ACE Basin habitat ranked 'poor' relative to the state as a whole (Figure 1).
- The degree to which SCECAP observations may vary within the ACE Basin, or relate to nutrient form or land use patterns, and influence biological responses was not known and warranted further investigation.

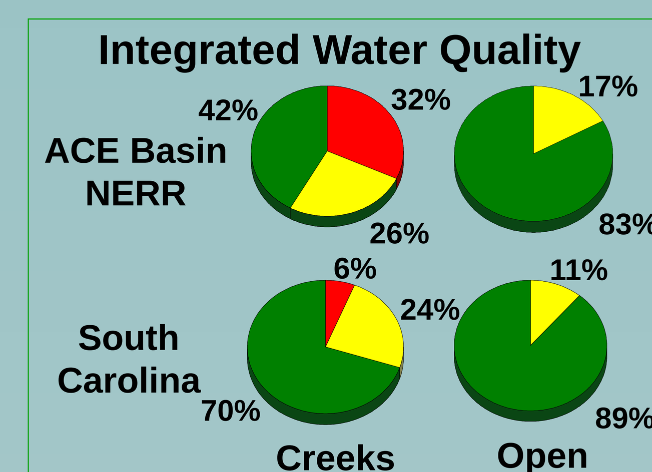

Figure 1. Proportion of estuarine habitat in the ACE Basin NERR and in S.C. as a whole with good (green), fair (yellow), and poor (red) integrated water quality (Bergquist et al 2007).

Objectives and Experimental Approaches

- **Objective 1: Assess SCECAP findings and land use patterns and evaluate water quality, nutrients, and phytoplankton community composition in select watersheds (Figure 2).**

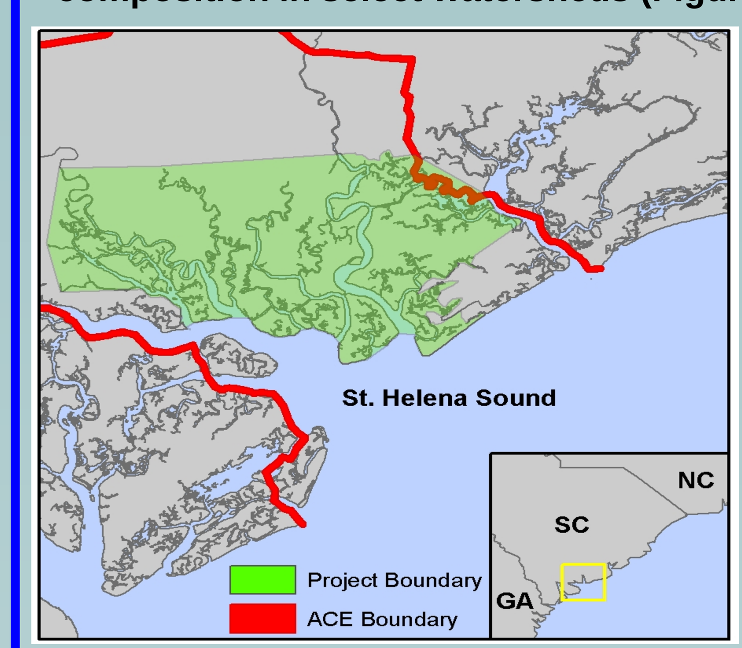

Figure 2. ACE BASIN NERR and project boundaries.

In 2008, 60 randomly selected sites (30 tidal creek, 30 open water) were sampled, including previously sampled SCECAP sites. Standard water quality parameters (temperature, salinity, dissolved oxygen, pH) were recorded, and surface (0.3 m depth) water samples were measured for total nitrogen (TN) and phosphorus (TP), chlorophyll *a*, total coliform, *Escherichia coli*, *Enterococcus* sp., total and volatile suspended solids, and phytoplankton. Land use data from the National Land Cover Database was analyzed using Geographic Information Systems (ESRI ArcGIS 9.3) to create 1 and 2 km station buffers, and proportions of open water, emergent marsh, upland, and wetland were calculated.

In 2009, 10 creeks (4-5 stations/creek) were sampled seasonally based on 2008 results: 7 representing the highest and 3 representing the lowest nutrient and bacterial levels (Figure 3). Parameters measured were the same as 2008, as well as inorganic N and P.

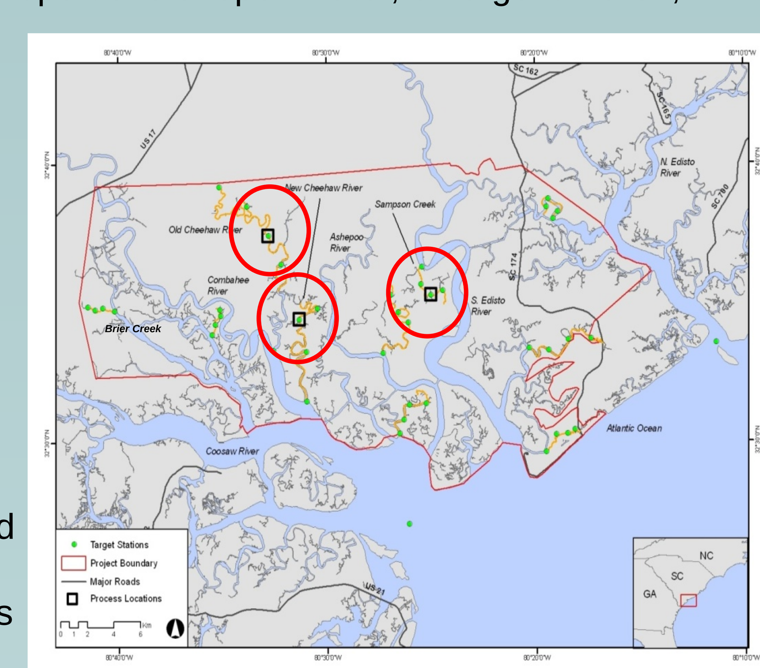

Figure 3. Monitoring stations in 10 focal systems and bioassay locations (red circles).

- **Objective 2: Evaluate trophic status within select creeks as phytoplankton responses to various nutrient conditions.**

Seasonal 48 hr *in situ* nutrient addition bioassays were conducted using surface samples containing natural phytoplankton assemblages collected at mid-ebb tide from 3 creeks representing distinct land use patterns (Figure 3). The New Cheehaw drains salt marsh and unmanaged forest/marsh. The Old Cheehaw drains managed wetlands, unmanaged forest, and agriculture. Sampson Creek drains managed wetlands and salt marsh. Standard water quality parameters were recorded at t = 0, and samples (n = 3) were taken at initial and final time points for nutrients, chlorophyll *a*, HPLC, and phytoplankton. A YSI data sonde was deployed to monitor concurrent water quality.

In 2009-2010, 6 treatments were incubated at the surface and amended with ammonium, nitrate, phosphate, ammonium + phosphate, nitrate + phosphate or no addition (Figure 4). In 2010-2011, organic N (as urea) and urea + P treatments were added to assess the influence of dissolved organic nitrogen on phytoplankton.

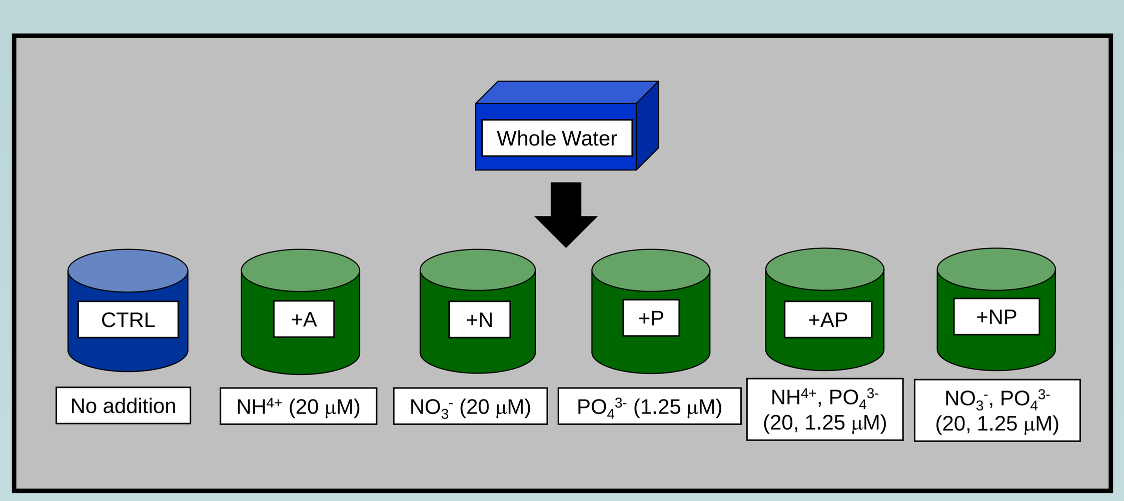

Figure 4. Nutrient addition bioassays: whole water containing natural phytoplankton assemblages were amended with inorganic nutrients. Treatments (in triplicate) were control (CTRL), ammonium (+A), nitrate (+N), phosphate (+P), ammonium + phosphate (+AP), and nitrate + phosphate (+NP). Net growth of phytoplankton was calculated from biomass (chlorophyll a) for total and <20 μm size fractions as $\mu = [\ln(B_t/B_0)]/t$ where μ = growth rate, B_t and B_0 = final and initial biomass, respectively, and t = duration (days).

- **Objective 3: Determine fecal coliform levels at select locations.**

Fecal coliform samples were collected at outfalls connected to and within managed wetlands on an ebb tide from Sampson Creek and select creeks within the Cheehaw River. Reference samples were collected from creeks not directly connected to managed wetlands.

- **Objective 4: Actively engage regional stakeholders through a land use manager workshop.**

Regional managers and stakeholders attended an all-day workshop on June 24, 2011, at the South Carolina Department of Natural Resources Bennett's Point field station. Project findings and a demonstration of field sampling experimentation were presented.

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Results

- **Objective 1: Assess SCECAP findings and land use patterns and evaluate water quality, nutrients, and phytoplankton community composition in select watersheds.**

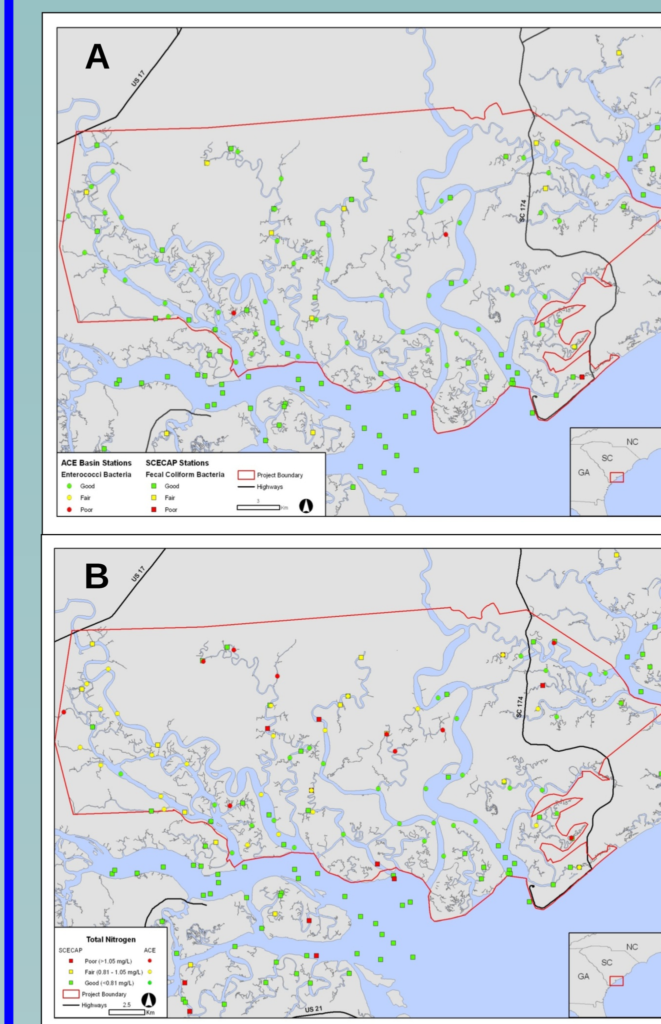

Figure 5. Total nitrogen (A) and Enterococcus (B) from the 60 randomly selected stations (2008).

- Elevated nutrient and bacterial indicators were observed in historical SCECAP sites (Figure 5), and generally occurred in the uppermost portions of long and sinuous creeks.
- TN, TP, and other water quality parameters positively correlated with bacterial indicator levels ($p \leq 0.05$), suggesting similar environmental conditions.
- Land cover was dominated by salt marsh, open water, and upland (Figure 6).
- Nutrient and bacterial indicator levels were positively and often significantly correlated ($p \leq 0.10$), with the proportion of surrounding upland, marsh, and forest are and negatively correlated with open water area (data not shown).
- Total coliform, TN, and TP levels positively and significantly correlated ($p \leq 0.10$) with distance from St. Helena Sound, and negatively with open water and marsh area, likely due to dilution and bactericidal effects of salinity (Figure 7).

Land Cover Category	Percent of Total Area
Upland	2.1 5.9 9.3 14.5
Freshwater/Brackish Marsh	1.7 3.8 4.3 6.8
Salt Marsh	54.5 56.5 55.4 55.1
Open Water	20.6 20.4 20.5 16.5

Land Cover Category	Percent of Upland Area
Evergreen Forest	22.7 31.2 46.5 53.0
Scrub/Shrub	2.5 6.4 8.5 17.0
Estuarine Scrub/Shrub	0.7 2.2 3.0 3.2
Mixed Forest	0.0 0.7 1.2 2.6
Grassland/ Herbaceous	0.0 0.2 0.8 3.7

Figure 6. Median percent land cover values within 500 m (top), 750 m, 1 and 2 km (bottom) for the random station array. Only the most extensive upland cover is shown.

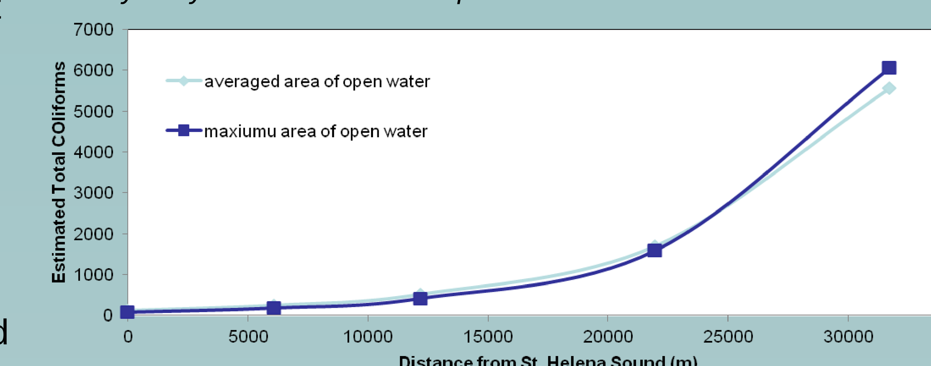

Figure 7. Total coliform levels as a function of open water area and distance from St. Helena Sound.

- **Objective 2: Evaluate trophic status within select creeks as phytoplankton responses to various nutrient conditions.**

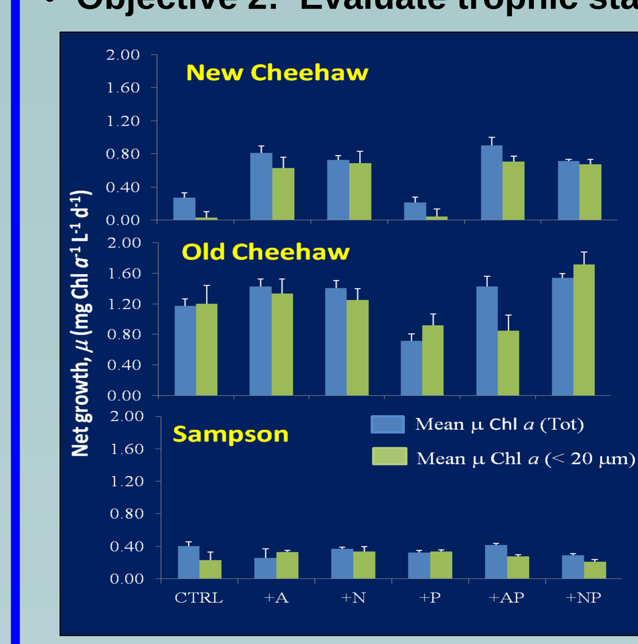

Figure 8. Mean (n = 3 ± SE) phytoplankton growth rates as biomass change (Chl a) in both total and <20 µm size fractions during August and September of 2009.

- Dissolved inorganic and total N:P are typically <16 suggesting N-limitation (P-enrichment; Table 1), and are generally low relative to TN and TP.
- Organic compounds are likely important for phytoplankton growth in the ACE Basin.
- Low N:P in field samples and enhanced phytoplankton growth in N-treatments suggest N-limitation. P does not appear to be co-limiting (Figure 8).
- The Old Cheehaw may be sensitive to N-loading. Sampson appears to have saturated nutrient conditions.

Table 1. Mean (± SD) levels of chlorophyll a (Chl a), inorganic, and total nutrients prior to treatment additions during 2009. Chl a values are μg L^{-1}, and nutrients are µM.

	Chl *a* (Tot)	Chl *a* (<20 mm)	NH_4^+	$NO_2^- + NO_3^-$	PO_4^{3-}	TN	TP	DIN:DIP	TN:TP
June									
New Cheehaw	7.50 (0.13)	5.38 (0.48)	5.81 (1.68)	2.14 (0.07)	1.36 (0.07)	48.11 (11.40)	11.30 (0.99)	5.84 (0.29)	4.26 (0.24)
Old Cheehaw	7.52 (2.29)	5.72 (2.20)	8.42 (0.25)	2.30 (0.01)	2.82 (0.23)	52.35 (10.03)	35.55 (5.31)	3.81 (0.09)	1.47 (0.21)
August/September									
New Cheehaw	8.46 (0.27)	4.36 (0.34)	4.04 (1.24)	12.21 (0.51)	1.99 (0.07)	79.16 (12.16)	4.52 (0.22)	8.16 (0.31)	17.51 (0.16)
Old Cheehaw	3.37 (0.21)	2.08 (0.63)	4.73 (0.89)	8.45 (0.35)	5.36 (0.17)	73.86 (4.68)	7.49 (1.25)	2.46 (0.19)	9.86 (0.07)
Sampson	16.49 (0.71)	12.15 (0.64)	13.42 (2.47)	5.27 (0.16)	2.12 (0.10)	105.48 (5.31)	9.65 (0.56)	8.81 (0.19)	10.93 (0.07)
November									
New Cheehaw	7.22 (0.35)	5.17 (0.17)	5.12 (1.42)	1.30 (0.38)	1.59 (0.08)	31.61 (22.71)	2.56 (0.24)	4.04 (0.41)	12.35 (0.72)
Old Cheehaw	1.79 (0.09)	1.30 (0.07)	4.63 (0.48)	0.72 (0.04)	1.95 (0.04)	50.13 (17.21)	3.78 (0.69)	2.74 (0.12)	13.26 (0.34)

- **Objective 3: Determine fecal coliform levels at select locations.**

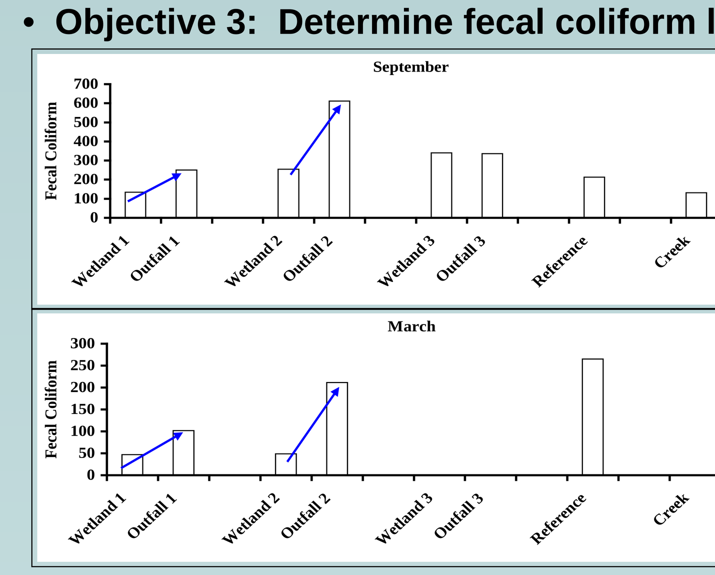

Figure 9. Fecal coliform levels during fall (2010) and spring (2011) in managed wetlands and connected tidal creek outfalls entering the Old Cheehaw River.

- Fecal coliform levels are high in creeks receiving managed wetland outfalls (Figure 9).
- Managed wetlands tended to have lower fecal coliform levels than receiving outfall counterparts (Figure 10).
- Reference creeks within the same systems, not connected to managed wetlands, also show elevated fecal coliform levels.
- It is possible that higher levels of fecal coliform in receiving wetlands is due to resuspension and physical creek characteristics (i.e., creek sinuosity, flow regime).

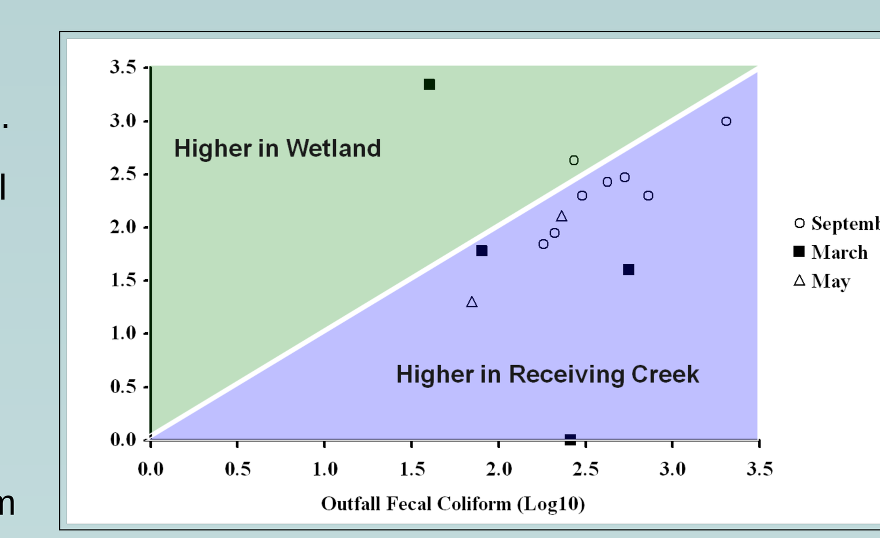

Figure 10. Comparison of fecal coliform levels in managed wetlands and receiving creeks in fall (2010), winter, and spring (2011) (data from all systems sampled).

Conclusions

- Monitoring results confirm SCECAP findings that some creeks within the ACE Basin NERR have elevated levels of nutrients and bacterial indicators relative to the state as a whole.
- ACE Basin systems in this study were enriched in phosphorus, and are vulnerable to eutrophication, especially nitrogen inputs. Organic nitrogen appears to be important for system productivity. **This suggests that nitrogen management is important for promoting good water quality.**
- Creek physical characteristics likely play an important role in locally elevated microbial indicators.