Anthropogenic Impacts to Tidal Creeks and Canals

Eutrophication and Fecal Microbial Pollution

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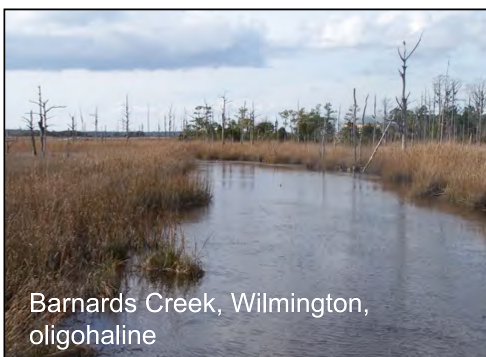
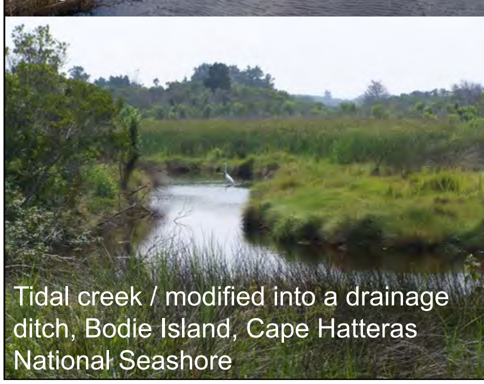


Barnards Creek, Wilmington, oligohaline

Tidal creek, SC, low tide

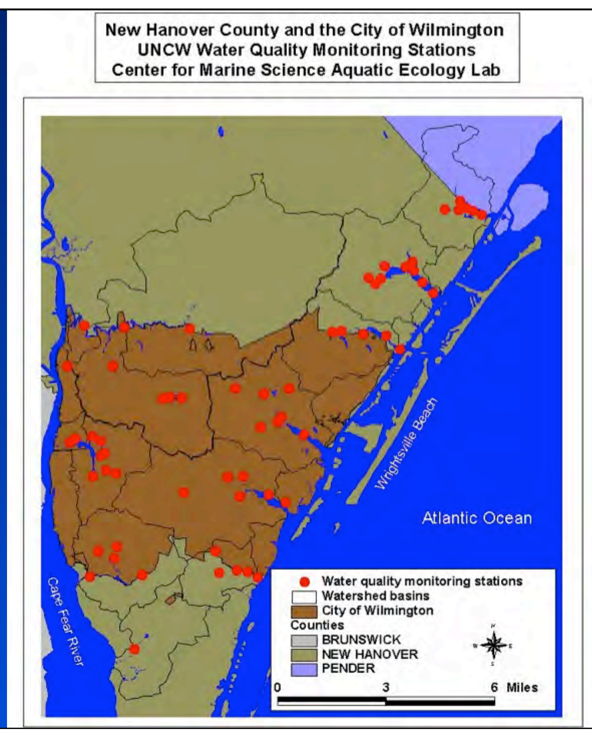


Tidal creek / modified into a drainage ditch, Bodie Island, Cape Hatteras National Seashore

Rural tidal creek, VA Eastern Shore

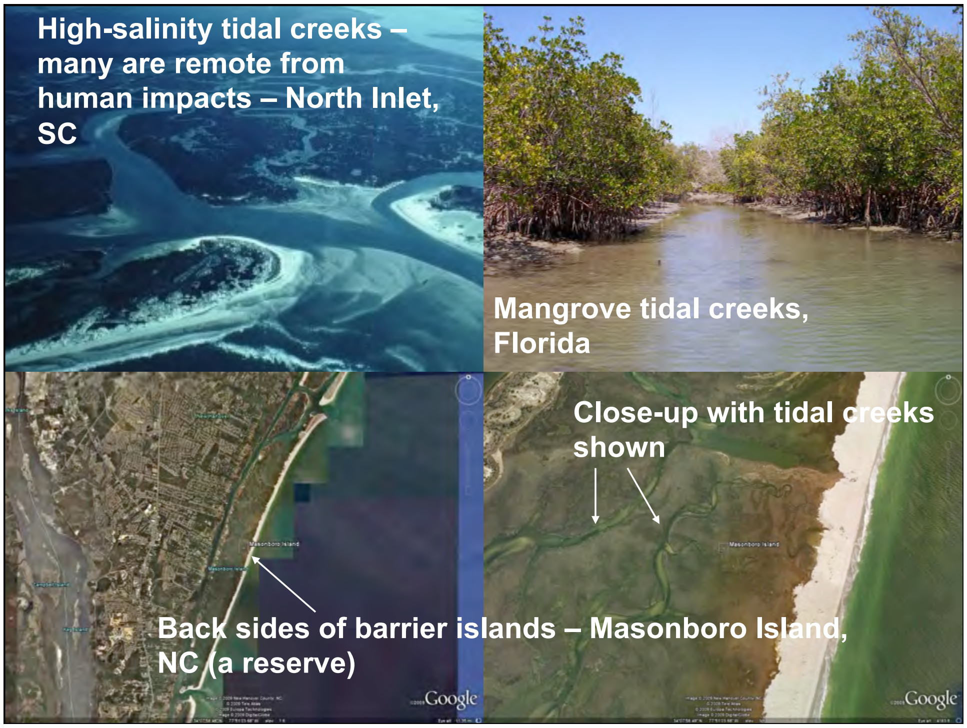
Three basic types of tidal creek

- Upland-draining, mesohaline entering larger estuaries, the ICW, or the ocean. Highly susceptible to anthropogenic loading, well-studied in NC and SC
- Upland-draining fresh to oligohaline creeks that enter rivers or riverine estuaries. Susceptible to anthropogenic loading, but less well studied
- Marine and euhaline tidal creeks in remote / undeveloped salt-marsh and mangrove estuaries (North Inlet for example), also barrier islands. Least susceptible to anthropogenic loading through lack of easy access




Upper Futch Creek, NC, mesohaline
Upper tidal creek, Oregon – a constrained reach
Lower Hewletts Creek, NC
Mouth of Oregon tidal creek at ocean
Upland draining creeks, mesohaline on average, fresh upstream and near-marine at mouth


Tiny Piney Creek, urbanized oligohaline creek in Caswell Beach, NC
Forested freshwater tidal creek off Black River, NC
Town Creek, fresh-oligohaline creek entering Cape Fear River, NC
Freshwater tidal marsh creek, Brunswick Co., NC

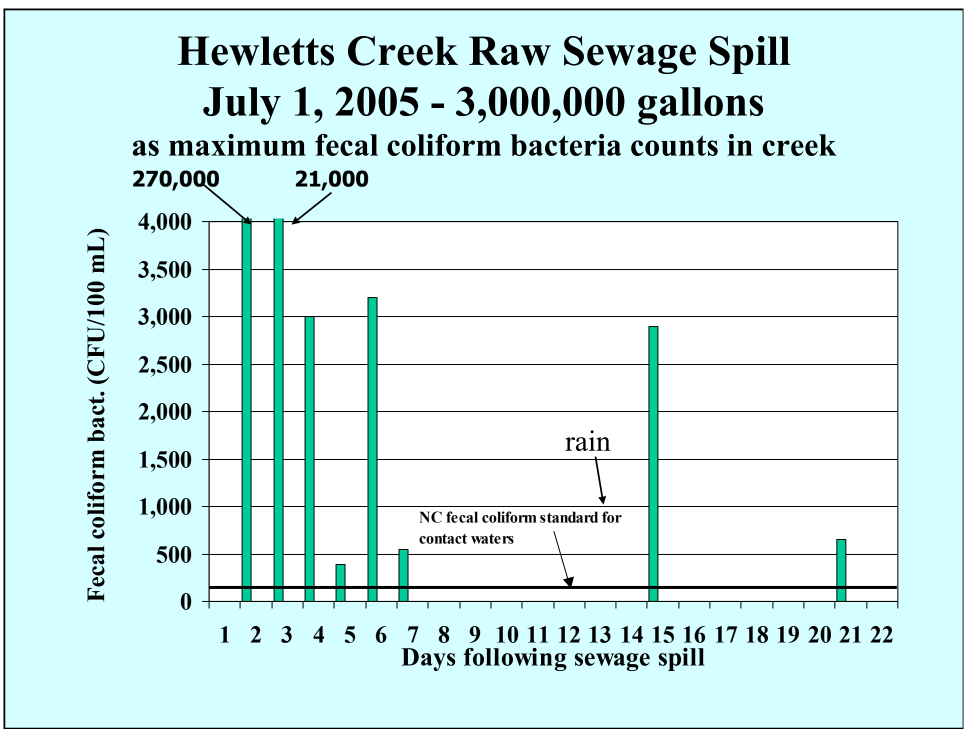


Pollutant sources to tidal creeks

- Sewage spills and leaks (nutrients, fecal microbes
- Septic system leachate (nutrients, fecal microbes)
- Stormwater runoff (nutrients, fecal microbes, herbicides, pesticides, metals, BOD) from residential, commercial, industrial areas, golf courses, agriculture
- Marinas and boats (petrochemicals including PAHs, metals, fecal microbes)
- Springs and seeps (nitrate)
- Atmospheric deposition (nitrate, PCBs, metals)

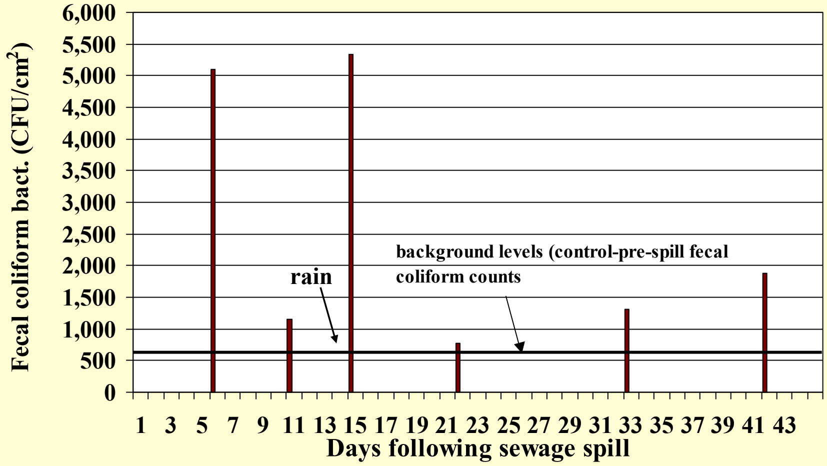
Sewage Spills –
Acute Pollution of Tidal Creeks

- Common in New Hanover and Carteret Counties in North Carolina
- Can be severe (i.e. millions of gallons), leading to closures for shellfishing and human contact
- Symptom of too rapid growth for existing infrastructure?
- Sewage pump station often sited near road crossings of tidal creeks



Hewletts Creek Raw Sewage Spill
July 1, 2005 - 3,000,000 gallons

as maximum fecal coliform bacteria counts in <u>creek sediments</u>



Other Impacts of the Spill

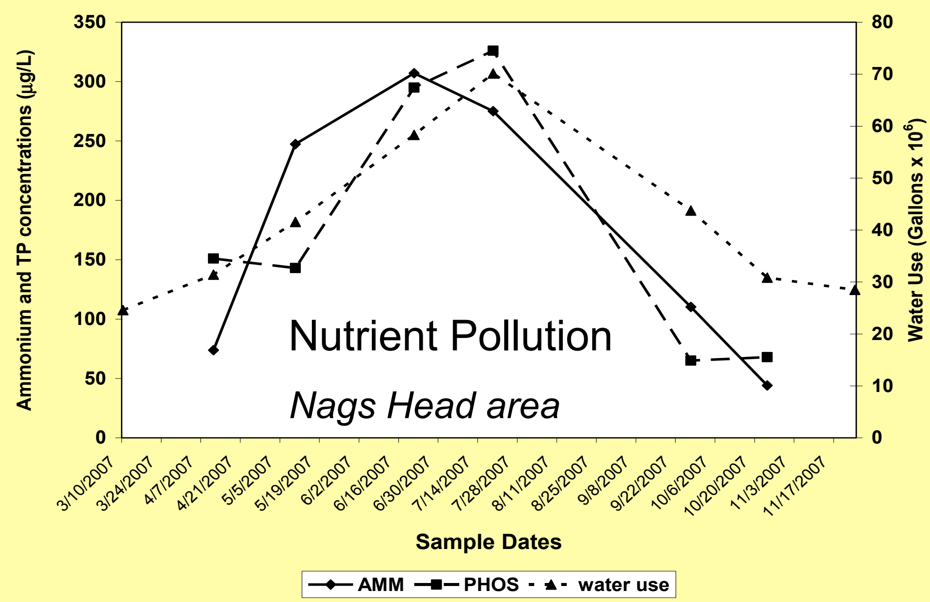
- Raw sewage has high N and P concentrations: the creek responded to this loading by large phytoplankton blooms within 3 days (up to 130 *u*g/L as chlorophyll *a*)
- Raw sewage has a high BOD load: the creek suffered strong hypoxia for several days following the spill, leading to fish kills
- Fecal microbial pollution led to deaths of a number of ducks feeding on dead fish following the spill
- The Atlantic IntraCoastal Waterway was closed to swimming for 3 days while the creek was closed to swimming and shellfishing for several months

LESSONS LEARNED

- **Fecal coliform counts decreased in the water column after a few days, but coliform bacteria in the sediments persisted for over 6 weeks. Bacteria in the sediments are protected from UV radiation from the sun and have abundant nutrients available.**
- **Rainstorms resuspended the bacteria in the water column, weeks later. We have also seen elevated water column counts and human source signals (DNA profiles and optical brighteners) <u>months</u> after sewage spills in Bradley and Hewletts Creeks.**
- **Regulatory agencies need to devise sampling and assessment plans that consider the sediment-associated fecal bacteria (sediments are reservoirs for polluting bacteria)!**

Septic Leachate:
An Important Yet Often Ignored Pollutant Source for Tidal Creeks and Canals

- Brunswick County, NC – fecal bacteria and nutrients, excessive crowding of septic systems (Cahoon et al. 2006); high water table and porous soils cause septic leachate pollution of nearby waterways and shellfish areas aCaswell Beach / Oak Island area, NC (Mallin et al. 2010)
- Florida Keys – nutrients and fecal microbes, pass through porous karst topography into canals then into seagrass beds and open water (Lapointe et al. 1992; Paul et al. 1997)
- Charlotte Harbor, FL and Sarasota Bay area, FL - fecal microbes, outgoing tide draws pollutants through sandy porous soils into creeks and canals (Lipp et al. 1999; 2001a; 2001b)
- North Carolina Outer Banks – Nags Head area is prime example: All homes on septic systems



Ammonium-N and total phosphorus concentrations over time in South Bodie Island tidal creeks, ditches and ponds in and near Cape Hatteras National Seashore, compared with monthly municipal water use for Town of Nags Head; all wastewater treated by septic systems. Both nutrients sig. correlated with water use ($p < 0.05$).

Biological water quality parameters, South Bodie Island, Cape Hatteras National Seashore tidal creeks/ditches, April-October 2007, n = 6 collections, data as mean + standard deviation / range (except for fecal bacteria, expressed as geometric mean / range), BOD5 as mg/L, chlorophyll *a* µg/L, fecal bacteria as CFU/100 mL.

Sites	Chlorophyll *a*	BOD5	Fecal coliforms	*Enterococcus*
D-1	31±15 6-47	4.1±1.5 1.5-6.0	194 29-700	596 220-2,260
D-2	28±13 6-42	4.8±3.3 1.5-11.0	213 49-1,180	443 113-2,680
D-3	38±18 10-55	4.4±1.8 1.5-6.0	216 100-680	348 57-2,480
D-4	36±32 10-86	4.8±2.1 2.0-8.0	305 79-1,720	272 20-4,000
D-5	83±99 6-275	6.5±1.6 5.0-9.0	95 3-940	367 18-2,860

*** Note – *Enterococcus* counts sig. correlated with municipal water use (r = 0.34, p = 0.013)**

Faulty sewage and failed septic systems are development-related pollutant sources!

- **Sewage spills and leaks are common in Wilmington and other rapidly-growing areas; often a signal of poor infrastructure planning by elected officials**
- **Sewage pump stations are often located along tidal creek road crossings (public property) where spills can do a lot of damage**
- **Developers are frequently given permissions to build developments with numerous septic systems in coastal areas with high water tables and sandy, porous soils (Outer Banks!)**

Stormwater Runoff

Non-point source runoff is runoff of pollutants from the land, during and after a rain – generally known as

stormwater runoff

pollution is stored on and conveyed by:

Streets, parking lots, driveways, sidewalks, roofs:

These are built-upon areas, called impervious surfaces

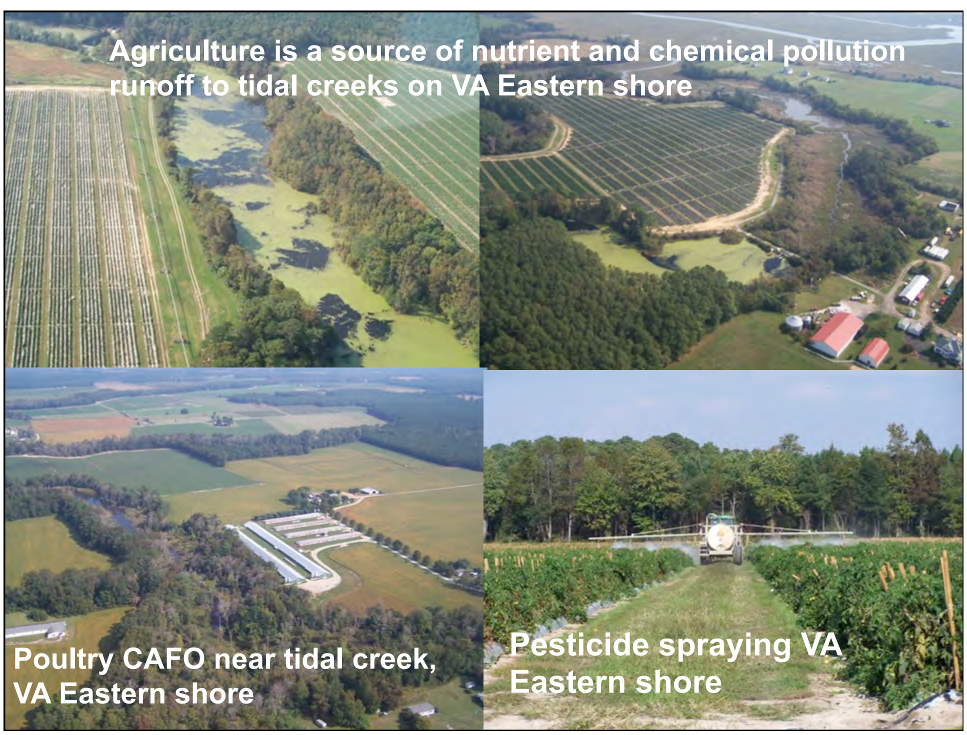
Pollutants in urban stormwater runoff:

Fecal bacteria, TSS, metals, petrochemicals, nitrogen, phosphorus, pesticides, BOD, trash

Pollutants in agricultural stormwater runoff:

Fecal bacteria, TSS, nitrogen, phosphorus, pesticides, herbicides


Urbanization – major source of pollution to upland-draining tidal creeks
Urbanizing creek shore, VA Eastern Shore
CLOSED AREA
UNLAWFUL TO TAKE OYSTERS, CLAMS, OR MUSSELS. SHELLFISH MAY CAUSE SERIOUS ILLNESS IF EATEN.
NC MARINE FISHERIES


Agriculture is a source of nutrient and chemical pollution runoff to tidal creeks on VA Eastern shore
Poultry CAFO near tidal creek, VA Eastern shore
Pesticide spraying VA Eastern shore

Fecal Microbial Pollution: A Chronic Pollutant

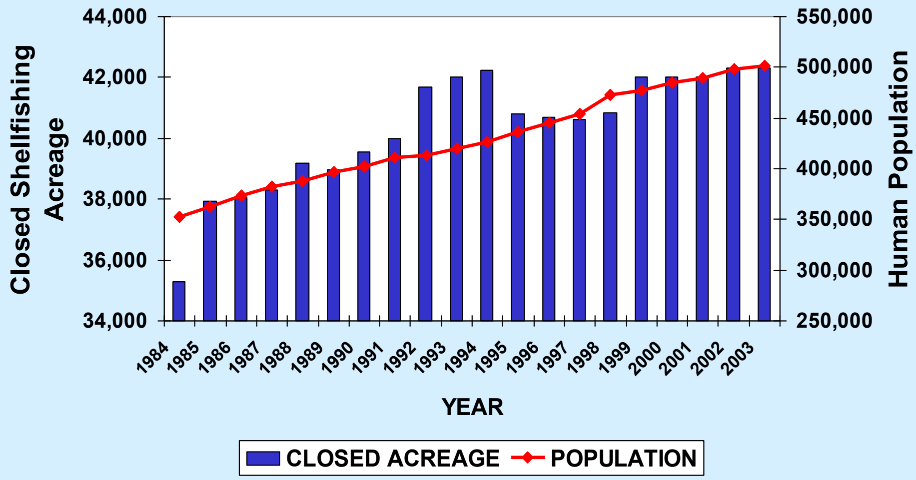
Most widespread pollutant overall for New Hanover County/Wilmington Watersheds (2000-2010) – *fecal bacteria cause illness to swimmers, waders and to people who eat contaminated shellfish. When counts are too high, authorities have to close shellfish beds and beaches*

50-75% of stations were severely impaired (counts exceeded the State standard for human contact waters (200 CFU/100 mL) exceeded State standard 25% of the time.

Principal source – stormwater runoff from urban areas; secondary source sewage spills/leaks

In southeastern NC, increase in shellfish acreage closures are strongly related to increasing human population (1984-2003)

Closed shellfish acreage = 0.0345(human population) + 25,529,
r^2=0.71, $p < 0.001$



CORRELATION BETWEEN GEOMETRIC MEAN FECAL COLIFORM ABUNDANCE AND LAND USE FACTORS FOR

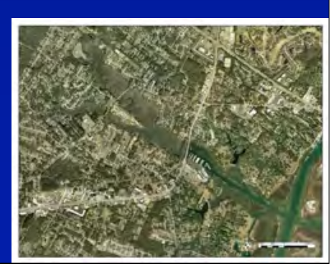
NEW HANOVER COUNTY TIDAL WATERSHEDS

	Population	% Developed	% Impervious
Fecal	0.922	0.945	0.975
Coliforms	0.026	0.015	0.005

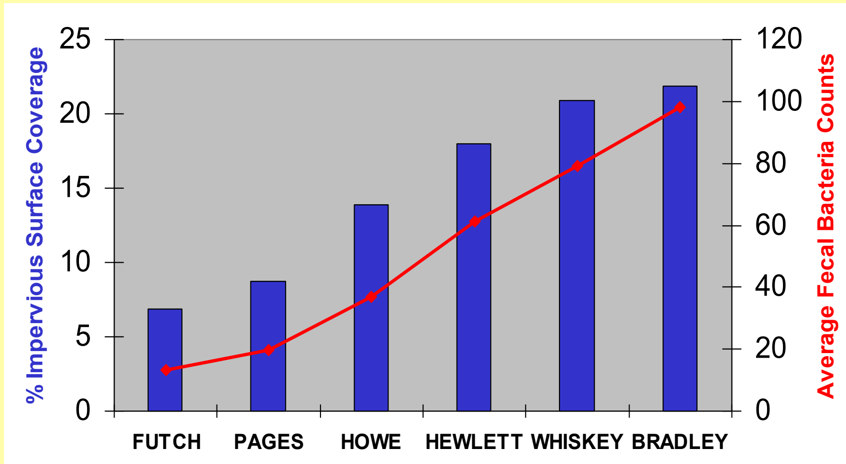
correlation coefficient (r) / probability (p), n = 700 fecal bacteria samples (Mallin et al. 2000)

Left: Futch Creek, 11% IC, open for shellfishing.

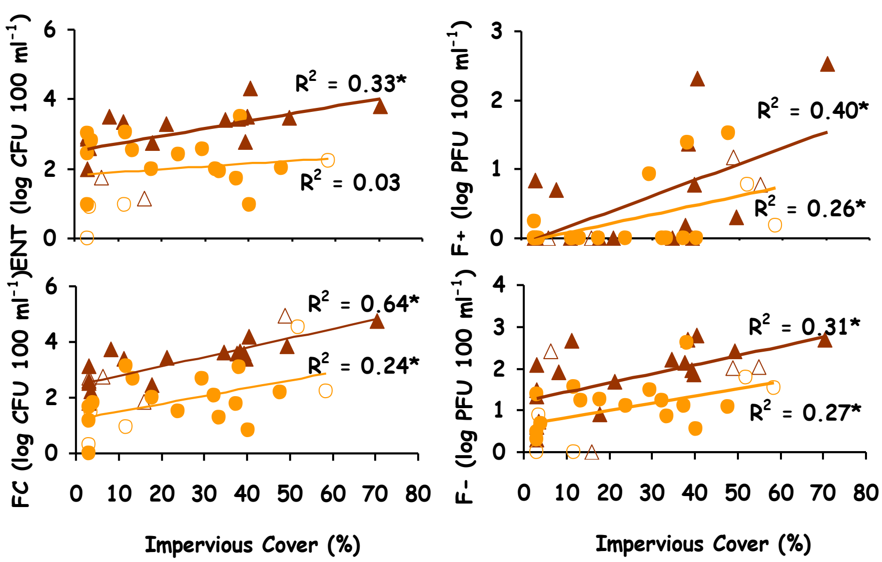
Right: Bradley Creek, 24% IC, closed for shellfishing.



Relationship Between Impervious Surface Coverage (built-upon area) and Fecal Bacteria Counts in Six Coastal North Carolina Watersheds



Futch and Pages Creeks are the only two of these creeks left open for shellfishing



Sanger, D., D. Bergquist, A. Blair, G. Riekerk, E. Wirth, L. Webster, J. Felber, T. Washburn, G. DiDonato, A.F. Holland. 2011. Gulf of Mexico Tidal Creeks Serve as Sentinel Habitats for Assessing the Impact of Coastal Development on Ecosystem Health. NOAA Technical Memorandum NOS NCCOS 136. 64 pp.

What About Sources of Fecal Microbes?

Microbial source tracking in urbanized southeastern NC Tidal Creeks

(Spivey 2009, MS Thesis, UNCW, PCR, *Bacteroides* used

- **6 creeks, 9 stations, 54 samples collected**
- **Human fecal contamination detected at 18% of total samples (human infrastructure problem)**
- **Canine fecal contamination detected at 23% of total samples (stormwater runoff signal)**
- **Ruminant fecal contamination (likely deer, possibly horses as well) detected at 22% of total samples collected (also stormwater runoff signal)**

Fecal Bacteria and Impervious Surfaces

- **Creeks with less than 10% impervious coverage had good water quality, those between 10 and 20% were degraded, and those greater than 20% were severely impaired (Mallin et al. 2000).**

- **Studies in 22 Charleston area coastal watersheds showed similar impacts of impervious area percent coverage for fecal coliform bacteria counts (Holland et al. 2004)**

- **The NC and SC impervious surface and fecal pollution data led to major coastal development rule <u>improvements</u> in NC in 2009 (Senate Bill 1967), lowering allowable untreated coastal impervious levels fom 25% to 12%.**

Fecal microbes in animal waste are also dangerous to humans

Human pathogenic microbes that are found in animal waste

Bacteria

Aeromonas spp.
Campylobacter jejuni.
Clostridium spp.
Escherichia coli 0157:H7
Nocardia spp.
Salmonella spp.
Yersenia enterocolitica

Protozoa

Cryptosporidium parvum
Giardia lamblia
Balantidium coli
Encephalitozoon intestinalis
Enterocytozoon bieneusi

Viruses

Reoviruses
Hepatitis E virus

Berger, P.S. and R.K. Oshiro. (2002). Source water protection: microbiology of source water. *In* "Encyclopedia of Environmental Biology" (G. Bitton, Ed.), Vol. 5, pp 2967-2978. John Wiley & Sons, New York.
Hinton, M. and M.J. Bale. (1991). Bacterial pathogens in domesticated animals and their environment. *Journal of Applied Bacteriology Symposium Supplement* 70: 81S-90S.

SEDIMENTATION AND TURBIDITY caused by stormwater runoff into tidal creeks

- Interferes with shellfish filter feeding
- Interferes with sight-feeding finfish
- Reduces rooted aquatic vegetation (fish habitat)
- Changes bottom habitat
- suspended sediment particles accumulate fecal coliform bacteria, phosphate, ammonium, and other pollutants and transport them downstream (our studies, and several others, have shown strong correlations between fecal bacteria and turbidity and/ or suspended sediments).

Suspended particles, particularly clays, are often associated with pollutants such as fecal coliform bacteria and phosphorus.

Field data correlations (lower Cape Fear Watershed)

Turbidity and fecal coliforms

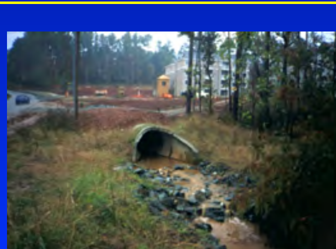
Cape Fear River	r = 0.858, p = 0.001
11 rural streams	r = 0.764, p = 0.0001
5 tidal creeks	r = 0.346, p = 0.001

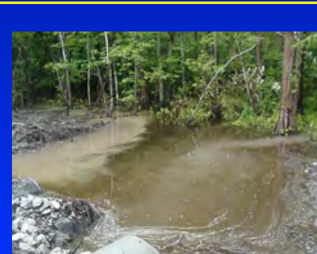
Turbidity and orthophosphate

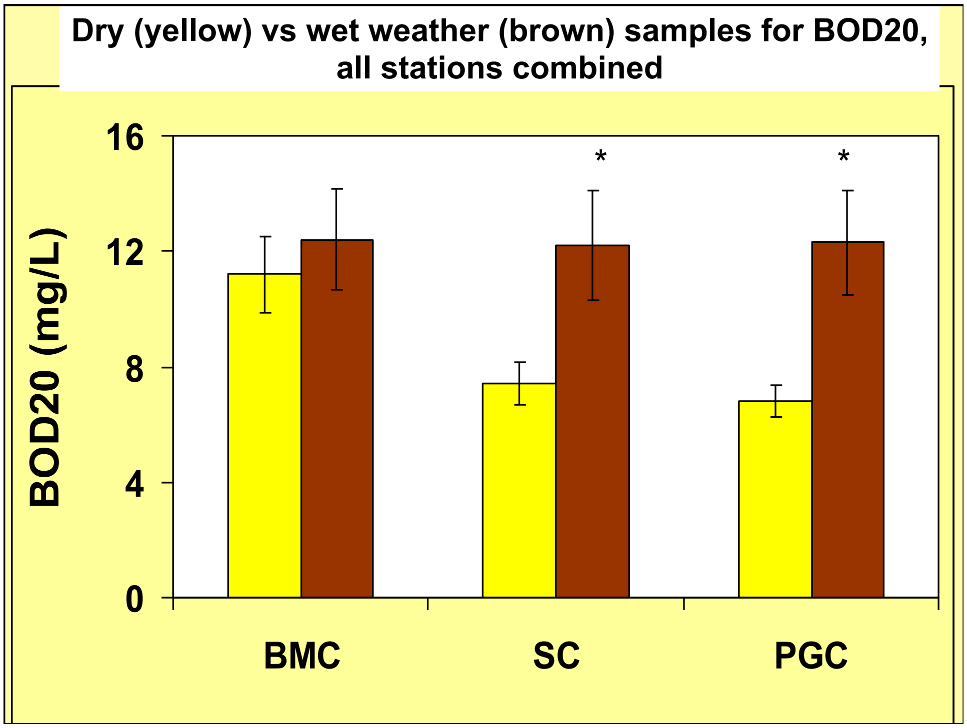
Silver Stream	r = 0.788, p = 0.001
Burnt Mill Creek	r = 0.401. P = 0.035
Echo Farms stream	r = 0.788, p = 0.001
11 rural streams	r = 0.384, p = 0.001

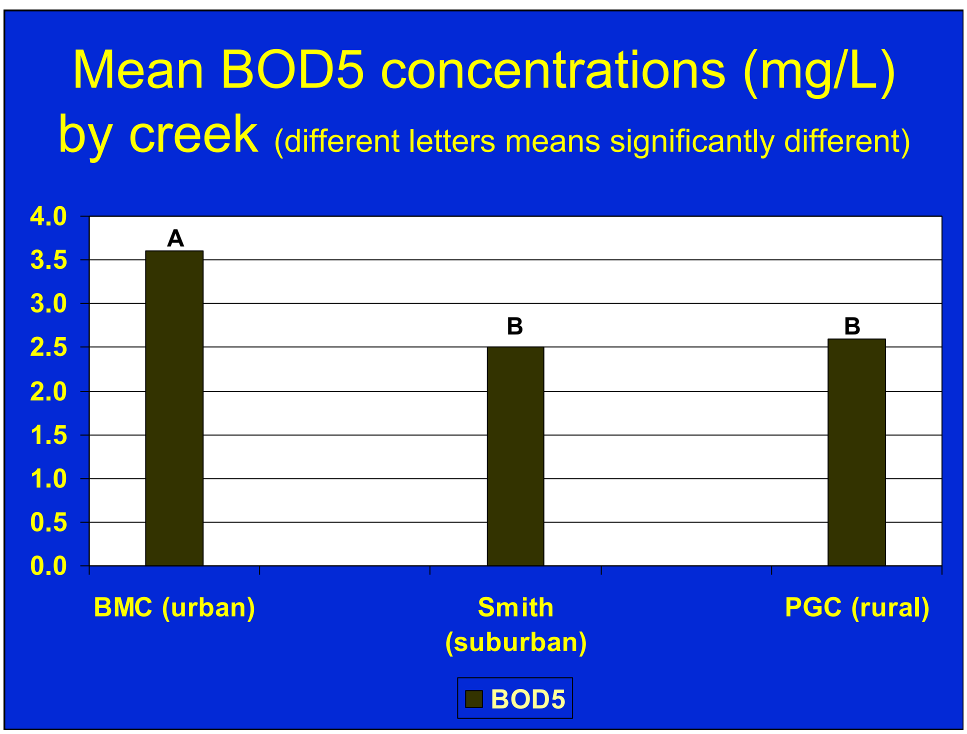
Correlation analyses between rainfall in the 72 hr period preceding sampling and water quality parameters for Burnt Mill, Smith, and Prince Georges Creeks combined (oligohaline tidal creeks)

	Turbidity	TSS	FC	OP	BOD5	BOD20	grease&oil
Rainfall	0.624	0.450	0.576	0.393	0.266	0.565	-0.333
	0.001	0.001	0.001	0.001	0.003	0.001	0.001



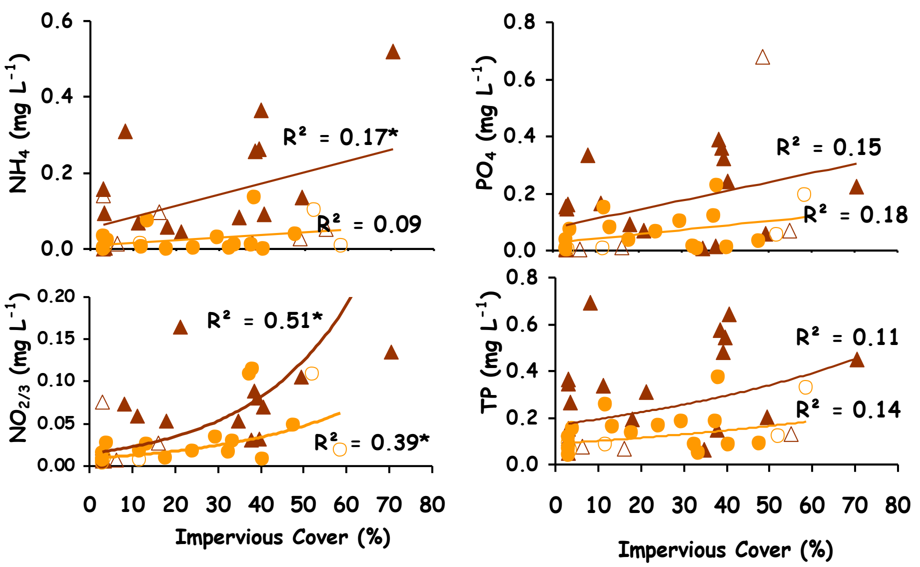



Dry (yellow) vs wet weather (brown) samples for BOD20, all stations combined
BOD20 (mg/L)
16
12
8
4
0
*
*
BMC
SC
PGC


Mean BOD5 concentrations (mg/L) by creek (different letters means significantly different)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
A
B
B
BMC (urban)
Smith (suburban)
PGC (rural)
BOD5

Tidal Creeks Receive Nutrient Inputs and Suffer from Eutrophication

- Nutrient sources include stormwater runoff, sewage spills and leaks, septic system leachate, groundwater inputs, and atmospheric deposition.
- Some studies have found creek nutrient concentrations correlated with watershed development (Sanger et al. 2011)
- Creek eutrophication symptoms include algal blooms, toxic algae, elevated benthic microalgae, and algal contributions to BOD and SOD (hypoxia drivers)



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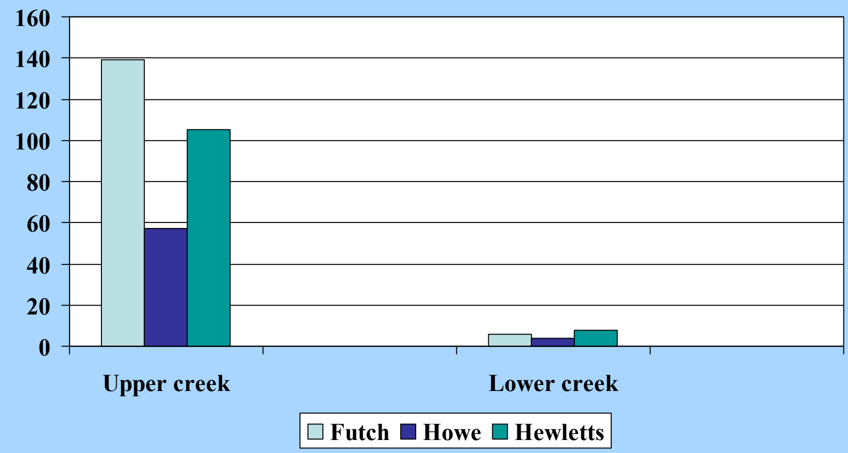
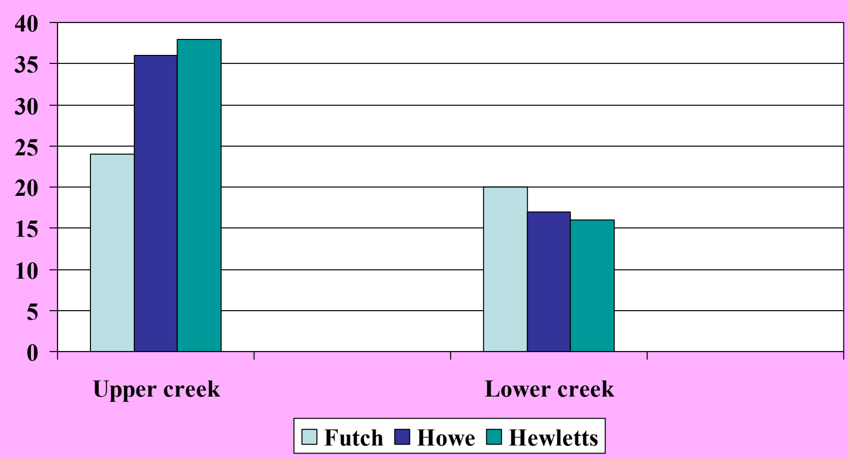
Average nitrate distribution in mesohaline tidal creeks, NC (µg/L)

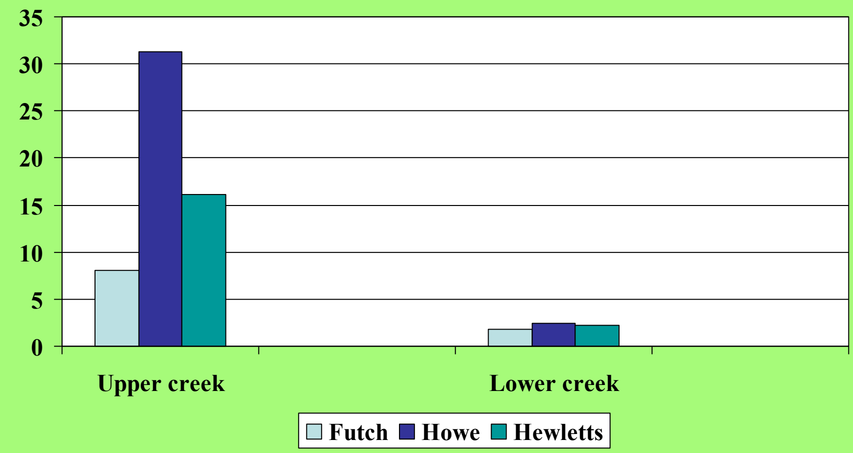


•Tidal creek phytoplankton production is N limited in lower and middle reaches, and may be either N, P or light limited in upper reaches (Mallin et al. 2004)

Average ammonium distribution in mesohaline tidal creeks, NC (µg/L)



Average chlorophyll *a* distribution in mesohaline tidal creeks, NC (µg/L)



Chlorophyll *a* concentrations up to 300 µg/L have been documented in New Hanover County tidal creeks

Algal blooms in tidal creeks can be problematic

There are significant relationships between algal blooms (chlorophyll *a*) and oxygen demand in tidal creeks

New Hanover Co., NC, 6 mesohaline tidal creeks

BOD5 vs Chlor *a*: $r = 0.53$, $p = 0.0001$ (Mallin et al. 2006)

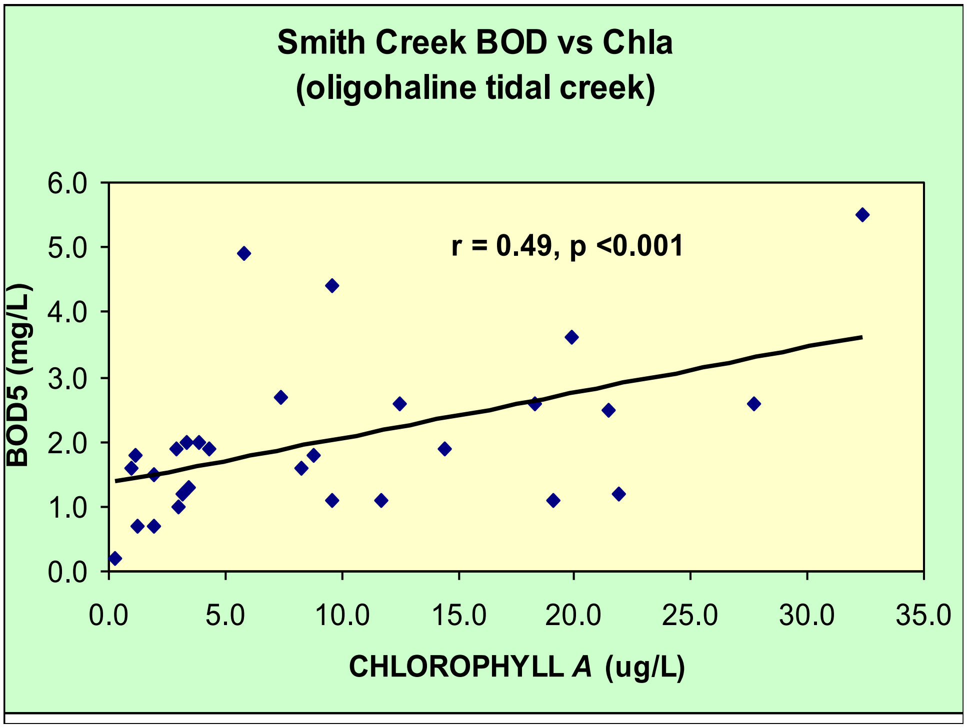
SOD vs Chlor *a*: $r = 0.35$, $p = <0.05$ (MacPherson et al. 2007)

New Hanover Co., NC, 3 oligohaline tidal creeks

BOD5 vs Chlor *a*: $r = 0.29$, $p = 0.001$ (Mallin et al. 2009)

NC Outer Banks, 6 tidal creeks / ditches

BOD5 vs Chlor *a*: $r = 0.66$, $p = 0.0001$ (Mallin and McIver 2008)



Hypoxia – A pollution response variable

- Natural hypoxia occurs seasonally and diurnally in undeveloped as well as developed tidal creeks
- In SC tidal creeks Lerberg et al. (2000) found that frequency of hypoxia was correlated with increasing watershed development
- Hypoxia is exacerbated by anthropogenic inputs:
- Nutrient loading and algal blooms elevate BOD and contribute to hypoxia (Mallin et al. 2006)
- Stormwater runoff contributes BOD materials to tidal creeks, also contributing to hypoxia (Mallin et al. 2009)

Lerberg, S.B., Holland, A.F., Sanger, D.M. 2000. Responses of tidal creek macrobenthic communities to the effects of watershed development. *Estuaries* 23:838-853.

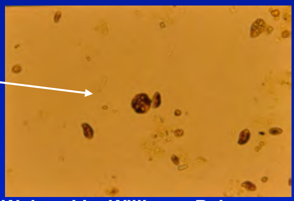
Mallin, M.A., V.L. Johnson, S.H. Ensign and T.A. MacPherson. 2006. Factors contributing to hypoxia in rivers, lakes and streams. *Limnology and Oceanography* 51:690-701.

Mallin, M.A., V.L. Johnson and S.H. Ensign. 2009. Comparative impacts of stormwater runoff on water quality of an urban, a suburban, and a rural stream. *Environmental Monitoring and Assessment* 159:475-491.

Nutrient loading to tidal creeks can stimulate toxic and potentially-toxic algae

- In New Hanover Co. tidal creeks *Pfiesteria* and *Pfiesteria*-like dinoflagellates were significantly correlated ($P < 0.03$) with nitrate, TP and chlorophyll *a* (Mallin et al. 2004)
- In South Carolina tidally-influenced stormwater and golf course ponds fish kills and blooms of toxic algae have been documented (Lewitus et al. 2004).

Pfiesteria feeding on cryptomonads in Hewletts Creek, NC



Lewitus, A.J., Schmidt, L.B., Mason, L.J., Kempton, J.W., Wilde, S.B., Wolny, J.L., Williams, B.J., Hayes, K.C., Hymel, S.N., Keppler, C.J., Ringwood, A.H. 2003. Harmful algal blooms in South Carolina residential and golf course ponds. _Population and Environment_ 24:387-413.

Mallin, M.A., S.H. Ensign, D.C. Parsons, V.L. Johnson, J.M. Burkholder and P.A. Rublee. 2004. Relationship of _Pfiesteria_ spp. and _Pfiesteria_-like organisms to environmental factors in tidal creeks draining urban watersheds. pp 68-70 in Steidinger, K.A., J.H. Landsberg, C.R. Tomas and G.A. Vargo, (Eds.) _XHAB, Proceedings of the Tenth Conference on Harmful Algal Blooms, 2002._

Tidal Canals

- Abundant in Maryland / Delaware bays, along the Outer Banks, very abundant is south and west Florida
- Highly susceptible to anthropogenic loading
- Poorly flushed, dredged lower than parent estuary for boat usage, highly prone to hypoxia
- Sites of hypoxia-related fish kills in Delaware / Maryland
- “Waterfront” property, thus susceptible to runoff of nutrients, fecal microbes, fertilizers, pesticides
- Receiving water for septic system leachate on Outer Banks, Florida Keys, west Florida cities
- Sinks for metals and petrochemicals from anchored boats
- Sinks for metals from corroding construction materials
- Water quality studies on tidal canals are rare in the literature

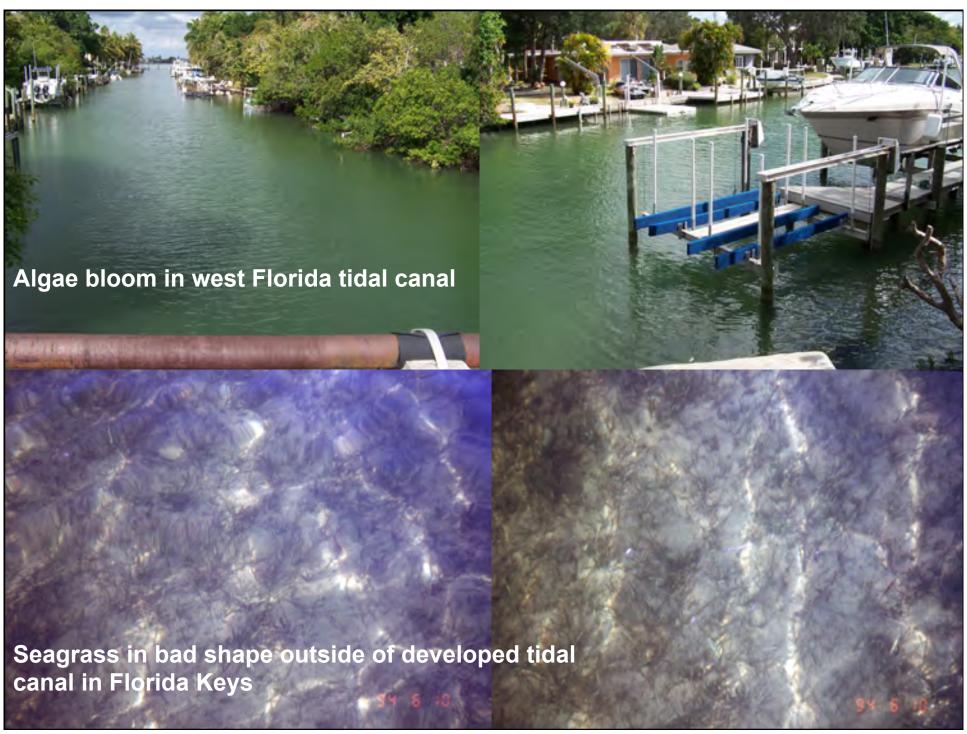

Tidal canal, Wilmington
Stormwater inputs
Dead end tidal canal, Wilmington
Tidal canal, Florida Keys


Corroding metal bulkhead – source of metals to water and sediments
Metal bulkheading – little relief or habitat
Suburban storm drain directly into canal, canals receive fecal bacteria, nutrients, metals, PAHs from auto / boat fuels and oil into a poorly flushed area
Stormwater into tidal canal in rain

Table 9. Comparison of water and sediment quality between dead-end canals and Delaware and Maryland Coastal Bay sites (as area-weighted mean concentrations ± 90% confidence interval) toxicants and metals are sediment concentrations, * signifies significant difference between coastal bays and canals.

Parameter	Coastal Bay sites	Canals
Dissolved oxygen (mg /L)	6.3±0.2	3.8±2.0*
Nitrate (µg-N/L)	11.2±4.2	8.4±9.8
Ammonium µg-N/L)	67.2±15.4	88.2±68.6
Orthophosphate (µg-P/L	12.4±3.1	9.3±6.2
Chlorophyll *a* (µg/L)	12.2±2.0	25.7±7.6*
Benthic chlorophyll *a* (µg/g)	8.1±1.4	31.0±16.6*
Benthic macroinvertebrates		
Abundance (no./m2)	18,724±2,551	1,917±1,354*
Species richness (no./sample)	24.2±1.2	3.6±2.6*
Shannon-Weiner Index	2.73±0.1	0.59±0.49*
Total PAHs (ppb)	232±92	2,061±1,103*
Total PCBs (ppb)	2.89±1.04	19.8±5.5*
Copper (ppm)	9.52±2.81	40.6±10.4*
Silver (ppm)	0.05±0.02	0.12±0.03*
Zinc (ppm)	64.5+16.3	107.9+28.9

Maxted, J.R., Weisberg, S.B., Chaillou, J.C., Eskin, R.A., Kutz, F.W. 1997. The ecological condition of dead-end canals of the Delaware and Maryland coastal bays. *Estuaries* 20:319-327.



Algae bloom in west Florida tidal canal

Seagrass in bad shape outside of developed tidal canal in Florida Keys

Conclusions and Thoughts

- Continental draining mesohaline tidal creeks are highly subject to anthropogenic inputs; serve as sentinels of pollution
- Marine tidal creeks are generally little impacted
- Fresh and oligohaline tidal creeks can be severely impacted – but have been poorly studied compared to the other types
- Fecal microbial pollution is caused by sewage leaks and spills, septic leachate, and stormwater runoff
- Fecal microbial pollution is highly correlated with percent watershed impervious surface coverage

Conclusions and Thoughts continued

- Hypoxia is common in tidal creeks, anthropogenically it is related to algal blooms and urban runoff of BOD materials
- Runoff of nutrients causes blooms in upper creek areas; also toxic algae are present in eutrophic tidal creeks and associated tidal ponds
- Tidal creeks in agricultural areas are understudied; are likely subject to runoff of nutrients from crops and CAFOs, and runoff of fecal microbes from CAFOs
- Tidal canals are very abundant in areas of the mid-Atlantic and Southeast US, yet few water quality studies have been conducted on them