Estuarine Eutrophication Assessment: A Unifying

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Abstract

Eutrophication is a multidisciplinary problem that provides an integrated setting for teaching basic principles of marine and environmental science. We have used this approach with a wide range of students including those in a precollege summer program and undergraduates enrolled in a one-semester course in marine chemistry. The students test the hypothesis that drainage of storm water runoff via tidal creeks has a significant impact on the surf zone. The tidal creeks sampled vary in their degree of land-use impacts from humans. Students work in teams to sample their selected creek on the ebbing tide and in the adjacent surf zone, one hundred feet north and south of the mouth of the creek. Following laboratory analysis, the students submit formal lab reports. Their results are error checked and compiled into a master spreadsheet to enable comparison with the NOAA eutrophication criteria for estuaries (Bricker et al. 1999). Students then rate the swashes in terms of their present level of eutrophication. Since this study is repeated each semester, long-term trends can also be assessed. This approach is designed to provide experience in developing a sampling plan, collecting water samples, performing standard water quality analyses, presenting results and engaging in collaborative work.

Bricker, S.B., C.G. Clement, D.E. Pirhalla, S.P. Orlando, and D.R.G. Farrow. 1999. National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichments in the Nation's Estuaries. NOAA, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Sciencs. Silver Spring, MD: 71 pp.

Hypothesis

Storm water runoff has a significant effect on the degree of eutrophication in the swashes and surf zone along the Grand Strand of South Carolina.

Eutrophication

- Eutrophication is syndrome caused by nutrient loading, particularly of the elements, nitrogen and phosphorus. These nutrients can come from stormwater runoff containing:
  - Fertilizers
  - Feces (also contains coliform bacteria). Sources of feces include:
    - Humans
    - Pets
    - Livestock
    - Wildlife
- Nutrient loading stimulates algal growth (this algal growth is measured as chlorophyll)
- The resulting organic detritus is decomposed by aerobic heterotrophic bacteria
- Oxygen deficits results (as measured by dissolved oxygen and percent saturations).

SUMMARY OF EUTROPHICATION CRITERIA

Eutrophication is a widespread problem. The US has proposed several sets of criteria for diagnosing the degree of pollution.

Analytes	Estuary **	Rivers*		South Carolina Lakes Class FW$
		Ecoregion XII	Ecoregion XIV	
Phosphorus (ppm P)	0.01	0.04	0.031	0.06
Nitrogen (ppm N)	0.1	0.9	0.7	1.5
Chlorophyll a (ppb)	5	0.4	3.8	40
Turbidity (NTU)	NA	1.9	3	50

*in draft form: Ambient Water Quality Criteria Recommendations from US EPA's Office of Water

Ecoregion XII: Southeastern coastal plain of FLA, GA, MISS, ALA
Ecoregion XIV: SC, NC, VA, MD, DE, NJ, NY, CT, RI, MA, NH, ME
(The coastal plain of SC fits in Ecoregion XII better than Ecoregion XIV)

** in draft form from: National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries (Bricker et al. 1999) from NOAA

$South Carolina: R.61-68 Water Classification and Standards approved 2001. Shown are the criteria for lakes that fall in the Class Freshwater category.

Sampling Strategy

- A total of nine swashes (small tidal creeks) were sampled (some in duplicate)
  - The samples were taken in the swash during an ebbing tide
  - Ssamples were taken in in the surf zone of the ocean.
    - 100 feet north of the mouth of the swash
    - 100 feet south of mouth of swash

This procedure resulted in 42 sampling sites

Samples were collected by the 50 students in MSCI 305: Marine Chemistry in Spring 2001

- Analytes tested included:
  - Eutrophication Benchmarks
    - Dissolved Oxygen and Percent Saturation of Dissolved Oxygen
    - Nitrate + Nitrite
    - Phosphate
    - Chlorophyll
  - Some others
    - Salinity (tracer of fresh water mass)
    - pH (indicator of the degree of organic matter decay)
    - Alkalinity (indicator of the degree of organic matter decay)

Sampling Sites

A number of sites were sampled along the total length of the Grand Strand. These included sites as far north as Little River Inlet and as far south as Dogwood Swash. This ensured produced a picture of the total eutrophication all along the Grand Strand. The sites included:

- Cherry Grove (Little River Inlet)
- Singleton Swash
- Cane Patch Swash
- Deephead Swash
- 30th Avenue North (control, not a swash)
- Withers Swash
- Midway Swash
- Ocean Lakes Swash
- Dogwood Swash

Map views of the locations of the swashes:

Sampling Dates

Due to the large number of samplers, different analytes were sampled for on different days. This allowed for proper collection and analysis of data. Those dates were:

- Dissolved Oxygen, Salinity, Temperature and Bacteria
  - February 28, March 1 and 2, 2001
- pH and alkalinity
  - March 21, 22 and 23, 2001
- Nutrients, Chlorophyll and Bacteria
  - April 4, 5 and 6, 2001

Methods

A number of different methods were used to analyze the samples. These included:

- Dissolved Oxygen by Winkler Titration*
- Salinity by Knudsen Titration
- Temperature by Thermometer
- pH with pH meter
- Alkalinity by Gran Titration*
- Phosphate and Nitrate + Nitrite by Beer's Law*
- Chlorophyll and Phaeopigement by Fluorometry*
- Total and E. Coliforms by Membrane Filtration using HachTM m-Coli Blue media

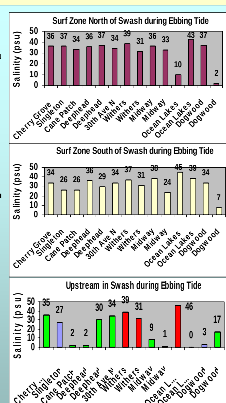
* Parsons, T.R., Y. Maita, and C.M. Lalli. 1984. A Manual of Chemical and Biological Methods for Seawater Analysis. Pergamon Press, N.Y., 173 pp.

DATA

Mean = 31.8 ± 11 psu

Mean = 31.4 ± 9 psu

Mean = 19.7 ± 17 psu



Anova p = 0.023

Salinity (psu)

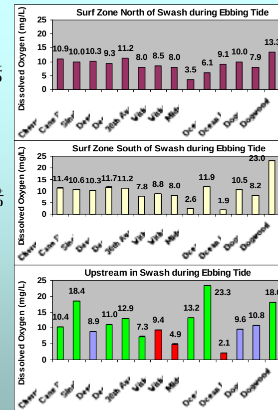
Supersaturated with Dissolved Oxygen
Undersaturated
Saturated

Figure 1: Figure 1 shows the results of the salinity analyses. An anova (p= 0.023) demonstrates that the salinity in the swash was lower than the surrounding ocean salinity indicating the presence of a significant amount of freshwater discharge. The few high values observed in the swash are probably the result of sample collection on a flooding tide. The salinity south of the swashes is somewhat lower than the salinity north of the swashes suggesting that the longshore current carries swash water in a southerly direction.

Mean = 9.0 ± 2.4 ppm DO

Mean = 9.8 ± 4.9 ppm DO

Mean = 11.4 ± 5.5 ppm DO



Anova p = 0.355

Dissolved Oxygen (ppm DO)

Dissolved Oxygen Criteria:
Anoxic: 0 mg/L
Hypoxic: 0 to 2 mg/L
Biological Stress: 2 to 5 mg/L

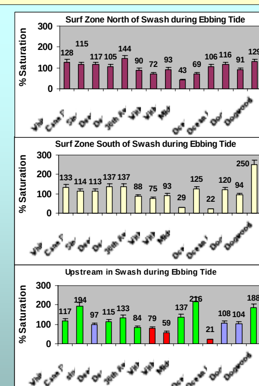
Supersaturated with Dissolved Oxygen
Undersaturated
Saturated

Figure 2: Figure 2 shows the dissolved oxygen content for the swash and the two ocean sites. No significant difference was observed between the mean DO levels amongst the sites (Anova p = 0.355). There are corresponding highs and lows in the ocean sites south of the swash suggesting a southerly longshore current. Three of the surf zone and two of the swash sites had DO concentrations less than 5 ppm, suggesting that marine organisms in these areas would be under biological stress.

Mean = 101 ± 27 % Saturation

Mean = 109 ± 54 % Saturation

Mean = 118 ± 53 % Saturation



Anova p = 0.634
% Saturation of DO

% Saturation = ([DO]observed / [DO]equilibrium) x 100

Values less than 60% are usually considered impaired.

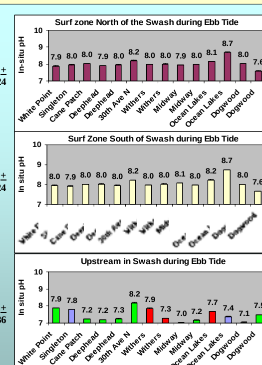
Supersaturated with Dissolved Oxygen
Undersaturated
Saturated

Figure 3: Figure 3 shows the percent saturation of oxygen for the swash and corresponding ocean sites. As with the dissolved oxygen, no significant difference was observed between the swash and the open ocean (Anova p = 0.634). Many of the swashes were supersaturated with oxygen (indicated by the blue line) suggesting the input of oxygen from an algal bloom. Some swashes are undersaturated, suggesting removal of oxygen. This removal may be from aerobic respiration from the decomposition of organic matter (possibly a previous algal bloom).

Mean = 8.01 ± 0.24

Mean = 8.05 ± 0.24

Mean = 7.46 ± 0.36



Anova p = 2 x 10 -6

pH

pH criteria:

Biological stress: <6

Supersaturated with Dissolved Oxygen
Undersaturated
Saturated

Figure 4: Figure 4 shows the pH values for the swashes and corresponding ocean sites. Freshwater systems do not have the bicarbonate buffer system that the ocean has. Therefore, acid additions have the potential to cause pH problems in the swash. The pH values are significantly lower in the swash (Anova p = 2 x 10^{-6}) but none of the sites fall below pH = 6 and hence are not biologically stressful.

Approach For Laboratory Instruction

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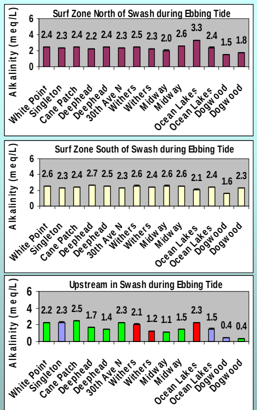


Mean = 2.32 ± 0.41 meq/L

Anova p = 4 x 10^{-4}

Alkalinity (meq/L)

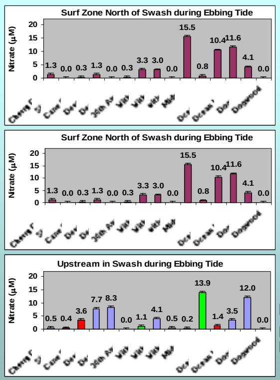
Mean = 2.37 ± 0.26 meq/L

US EPA Alkalinity Criteria:
Not Sensitive: >0.4 meq/L

Mean = 1.64 ± 0.07 meq/L

Supersaturated with Dissolved Oxygen
Undersaturated
Saturated

Figure 5: Figure 5 shows the alkalinity values for the swash and corresponding ocean sites. The alkalinity values are significantly lower between the swash sites and the oceanic sites (Anova p = 4 x 10^{-4}). This is further indication of the lack of a bicarbonate buffer system in the swash. Two of the swash sites fell into the US EPA rank of "sensitive" to impacts of acid rain.



Anova p = 0.59

Nitrate (µM N)

Mean = 3.4 ± 5.0 µM N

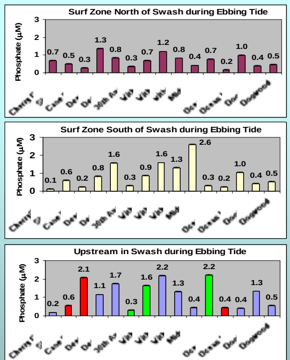
Mean = 2.1 ± 5.3 µM N

Nitrate Criteria:
High: > 70 µM
Medium: 7 to 70 µM
Low: <7 µM

Mean = 3.8 ± 4.6 µM N

Supersaturated with Dissolved Oxygen
Undersaturated
Saturated

Figure 6: Figure 6 shows the nitrate values for the swash and corresponding ocean sites. The mean value in the swash was not significantly different from the ocean (Anova p = 0.59). Five of the swashes and four of the ocean sites fell into the medium level of eutrophication status. The rest suggested a low level of eutrophication.



Mean = 0.65 ± 0.35 µM P

Anova p = 0.15

Phosphate (µM P)

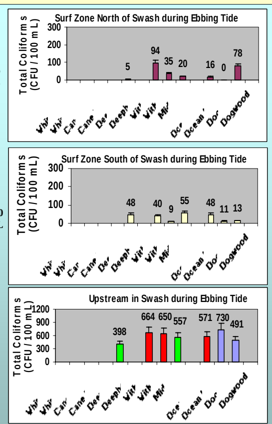
Mean = 0.82 ± 0.69 µM P

Phosphate Criteria:
High: > 3 µM
Medium: 0.3 to 3 µM
Low: <0.3 µM

Mean = 1.09 ± 0.43 µM P

Supersaturated with Dissolved Oxygen
Undersaturated
Saturated

Figure 7: Figure 7 shows the phosphate values for the swashes and corresponding ocean sites. The mean value in the swash was not significantly different from the ocean (Anova p = 0.15). All of the swashes, except one, fell into the medium eutrophication level status. All, but four, of the ocean sites fell into the medium level of eutrophication status. The rest suggested a low level of eutrophication.



Mean = 35 ± 36 CFU/100 mL

Anova p = 8 x 10^{-12}

Total Coliforms (CFU/100 mL)

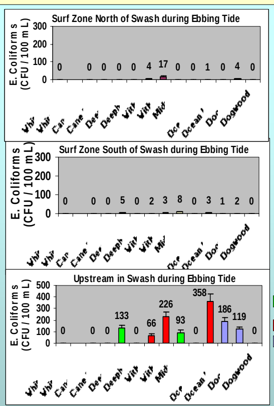
Mean = 32 ± 20 CFU/100 mL

Total Coliforms (CFU/100 mL)
US EPA Criteria:
<200 CFU/100 mL

Mean = 580 ± 110 CFU/100 mL

Supersaturated with Dissolved Oxygen
Undersaturated
Saturated

Figure 9: Figure 9 shows the values for total coliform bacteria in the swash and corresponding ocean. The swash shows significantly elevated levels of bacteria as compared to the ocean (p = 8 x 10^{-12}). Seven of the swashes exceeded the U.S. EPA's swimming water criteria of 200 colony forming units per 100 mL. The lower values in the ocean are reflect the toxic effect of salt on the bacteria.



Mean = 2 ± 5 CFU/100 mL

Anova p = 0.001

E. Coli (CFU/100 mL)

Mean = 2 ± 2 CFU/100 mL

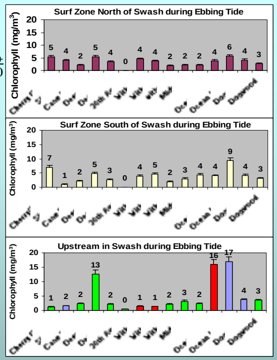
E. Coli
US EPA Swimming Criteria:
<126 CFU/100 mL

Mean = 91 ± 110 CFU/100 mL

Supersaturated with Dissolved Oxygen
Undersaturated
Saturated

Figure 10: Figure 10 shows the values for E. coli in the swash and corresponding ocean sites. As in figure 9, the bacteria levels are higher in the swash as compared to the ocean (p = 0.001). Four of the sites exceeded the US EPA's swimming criteria*. E. coli bacteria are of special note because of its possible pathogenic effect. The lower values in the ocean are reflect the toxic effect of salt on the bacteria. 1) a geometric mean of

*The current critiera are: 1) 126 organisms/100 ml based on several samples collected during dry weather conditions or 2) 235 organisms/100 ml for any single water sample. These limits correspond to approximately 8 gastrointestinal illnesses per 1000 swimmers. (Dufour, Alfred P. 1984. Health effects criteria for fresh recreational waters. EPA-600/1-84-004. Office of Research and Development, USEPA, Washington, DC.)



Mean = 3.44 ± 5.3 (mg/m^3)

Chlorophyll (mg/m^3)
Anova p = 0.38

Mean = 2.06 ± 5.0 (mg/m^3)

Chlorophyll Criteria (mg/m^3):
Hypereutrophic: >60
High: 20 to 60
Medium: 5 to 20
Low: <5 mM

Mean = 4.75 ± 5.5 (mg/m^3)

Supersaturated with Dissolved Oxygen
Undersaturated
Saturated

Figure 8: Figure 8 shows the values for chlorophyll in the swashes and corresponding ocean sites. The mean value in the swash was not significantly different from the ocean (Anova p = 0.38). All the sites are either in the low or medium eutrophication level status. Three of the swashes and seven of the ocean sites fell into the medium level of eutrophication status. The rest suggested a low level of eutrophication.

Conclusions

- The swashes show elevated levels of the following analytes suggesting influence of nonpoint runoff of sewage and/or fertilizers. Nonpoint runoff is the run-off from fields and the ground during rain events.
  - Chlorophyll
  - Nitrate + Nitrite
  - Phosphate
  - Bacteria
  - Dissolved Oxygen (showed levels of supersaturation)
- The swashes have low levels of:
  - pH and alkalinity (due to organic matter decay)
  - salinity (due to the influence of freshwater)

•The evidence for eutrophication includes:

–Chlorophyll (low levels of eutrophication)

–Nitrate + Nitrite (low levels of eutrophication)

–Phosphate (medium levels of eutrophication)

–Dissolved Oxygen (the supersaturated level of dissolved oxygen indicates an algal bloom.)

• The majority of the analytes indicated a southerly flow of the longshore current. This is important in predicting which area of the surf zone will be affected most by the outflow from of the swashes.

• There was evidence of bacterial contamination suggesting that at least some of the nutrient loading was associated with feces.

–Some sites exceeded the swimming standard of 126 CFU/100 mL for E. Coli AND the 200 CFU/100 mL standard for fecal coliforms. (These are US EPA swimming water criteria). These sites include:

▪Deep Head Swash

▪Withers Swash

▪Ocean Lakes Swash

–Elevated levels were observed in the swash AND the surf zone at these sites.

Acknowledgments

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- Environmental Quality Lab, Coastal Carolina University