THE IMPORTANCE OF CONSIDERING SPATIAL ATTRIBUTES IN EVALUATING ESTUARINE HABITAT CONDITION: THE SOUTH CAROLINA EXPERIENCE

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Abstract. The South Carolina Estuarine and Coastal Assessment Program (SCECAP) was initiated in 1999 to assess the condition of the state's coastal habitats using multiple measures of water quality, sediment quality, and biological condition. Sampling was subsequently expanded to include components required for the National Coastal Assessment (Coastal 2000) Program. Habitats are classified as either "tidal creeks" (< 100 m in width) or larger "open water" bodies. Approximately 30 sites are sampled within each habitat during the summer months using a probability-based random sampling design. Results obtained from the first two years of sampling documented significant differences in several water quality parameters (DO, pH, turbidity, fecal coliform bacteria, total nitrogen, TKN, total phosphorus) and biological measures (chlorophyll-a, finfish and crustacean abundance and biomass, benthic abundance and diversity measures) between the tidal creek and open water habitats. These differences highlight the value of partitioning shallow water habitats separately from the larger open water bodies traditionally sampled in estuarine monitoring programs, especially since tidal creeks serve as critical nursery areas for many species. Based on the differences observed, there is a clear need to identify different physical and biological thresholds for evaluating the condition of each habitat type.

Keywords: water quality, South Carolina, estuarine monitoring, tidal creek, finfish, benthos, sampling design, watershed scale

1. Introduction

Historical estuarine monitoring programs conducted in South Carolina and other coastal states, as well as those conducted over larger regional areas by NOAA and the USEPA, have generally focused on evaluating conditions in relatively large-scale water bodies such as tidal rivers, bays, and sounds (e.g. SCDHEC, 1997a, Carlton *et al.*, 1998; Summers *et al.*, 1993; Strobel *et al.*, 1995; Hyland *et al.*, 1998). Although some of these programs have included sites in smaller watersheds, such as tidal creeks, the number of stations sampled has been very limited.

These small creek watersheds serve as critical nursery habitats for many finfish and crustacean species as well as wading birds (Hackney *et al.*, 1976; Weinstein, 1979; Shenker and Dean, 1979; Ogburn *et al.*, 1988; Dodd and Murphy, 1996). Additionally, tidal creeks are often the first point of entry of non-point source runoff from upland areas. Therefore, these drainage systems can provide an early indication of anthropogenic stress (Holland *et al.*, 1997; Sanger *et al.*, 1999a,b; Van Dolah *et al.*, 2000).

In South Carolina, a comprehensive new monitoring program was initiated in

1999 as a cooperative effort between the Department of Natural Resources (DNR) and the Department of Health and Environmental Control (DHEC). The South Carolina Estuarine and Coastal Assessment Program (SCECAP) significantly expands historical monitoring activities conducted by both agencies in the state's coastal zone and is designed to integrate multiple measures of water quality, sediment quality, and biological condition at a large number of sites sampled each year throughout the state. Due to the importance of tidal creeks as critical estuarine habitats, the program includes an equal level of effort in monitoring conditions in creeks versus the larger open water bodies, even though our analysis of the coastal hydrography indicates that tidal creeks represent only about 17% of the state's estuarine waters.

This paper compares several measures of water quality and biological condition observed in tidal creeks versus larger water bodies during the first two years of SCECAP. The differences we observed highlight the value of including these smaller watersheds in estuarine monitoring programs, and partitioning habitats by spatial scale when interpreting the data.

2. Sampling Design and Methods

Approximately 60 stations were sampled each year throughout the coastal regions of the state (30 in creeks, 30 in larger water bodies) using a probability-based, random tessellation, stratified sampling design for each habitat type (Stevens, 1997; Stevens and Olsen, 1999). New stations were selected each year. Tidal creeks are defined as those estuarine water bodies less than 100 m in width from marsh bank to marsh bank. Open water habitats include all other larger water bodies. Station locations were recorded using a differentially corrected Global Positioning System (GPS). Sites were sampled within ± 3 hrs of mean low water and had a minimum depth of 1 m at low tide to qualify for sampling. All data reported here were obtained during the summer months of 1999 and 2000 (primarily July and August).

Water quality measurements and samples were collected at all stations prior to deployment of other sampling gear. Both instantaneous (surface, mid, bottom) and 25-hour time-series measurements (bottom only) of dissolved oxygen, salinity, and temperature were obtained at each site. Only the bottom time-series data are presented here and were obtained using either Yellow Springs Instruments, Inc. Model 6920 multiprobes or Hydrolab DS-3 and DS-4 datasondes. Measurements were logged at 15-minunte intervals to obtain a record over two complete tidal cycles.

Water quality samples included measures of near-surface concentrations of total nitrate/nitrite nitrogen, total Kjeldahl nitrogen, ammonia, total phosphorus, total organic carbon (TOC), turbidity, biological oxygen demand (BOD_5), and fecal coliform bacteria. All samples were collected at a depth of 0.3 m and stored on ice until they were preserved (nutrient and TOC samples only) for later processing. Laboratory processing of total nutrient samples, total organic carbon, total alkalinity, turbidity, BOD_5 and fecal coliform bacteria were completed at SCDHEC laboratories using standardized procedures described by SCDHEC (1997b, 1997c).

Near-surface (0.3 m) chlorophyll-a samples were also collected during the water quality sampling effort. Samples collected in 1999 were filtered in the field (three replicate 50 ml aliquots) and the filters were placed in centrifuge tubes containing 25 ml of acetone and $MgCO_3$ and stored on ice in the dark. In the laboratory, the samples were centrifuged and the supernatant analyzed on a Turner Model 10-AU fluorometer. In 2000, the chlorophyll-a samples were measured using processing methods described by SCDHEC (2000). Comparison of the two protocols on 1999 samples showed similar results.

Benthic grab samples (8–10) were collected using a stainless steel 0.04 m^2 Young grab sampler to evaluate sediment composition, contaminant levels, toxicity, and benthic community composition. Three of the grab samples were sieved separately through a 0.5 mm sieve and preserved in a 10% buffered formalin-seawater solution with rose bengal stain. Fauna from two of those samples were identified to the lowest possible taxonomic level and the third sample was archived. Surficial sediments (0–5 cm) of the remaining grab samples were composited to obtain samples for analysis of composition, contaminants, and sediment toxicity. Results of those analyses are not presented here.

Fish and large crustaceans (primarily penaeid shrimp and blue crabs) were collected at each site following the benthic sampling to evaluate community composition. Two replicate tows were made at each site using a 4-seam trawl (18 ft foot rope, 15 ft head rope and 3/4 in bar mesh throughout). Trawl tow lengths were standardized to 0.5 km for open water sites and 0.25 km for creek sites. Tows were made only during daylight hours with the current and speeds standardized as much as possible. Tows were limited to periods when the marsh was not flooded (approx. 3 hrs ± mean low water). Catches were sorted to lowest practical taxonomic level, counted, and checked for gross pathologies, deformities or external parasites (not reported here). All organisms were measured to the nearest 1.0 cm and weighed to the nearest 0.01 kg. When more than 30 individuals of a species were collected, the species was sub-sampled.

Statistical comparisons reported here were generally completed using t-tests on non-transformed or transformed (where necessary) data. A Mann-Whitney U test was used if data transformations did not meet t-test criteria. An analysis of the cumulative distribution function (CDF) of the values observed for each parameter was also performed using procedures described by Diaz-Ramos *et al.* (1996). The CDF analyses provide an estimate of the percent of the state's overall creek and open water habitat that fall within ranges of values selected based either on state water quality criteria, or historical measurements collected by DHEC from 1993–

1997 in the state's larger open water bodies (SCDHEC, 1998a) when state water quality criteria were not available.

3. Results and Discussion

Sampling was successfully completed at 57 tidal creek sites and 59 open water sites over the two-year period (Figure 1). Average depth of the tidal creek sites was 2.2 m versus 4.8 m at the open water sites.

Mean values of the various water quality measures documented several statistically significant differences between the two habitats sampled (Table 1). The average bottom dissolved oxygen concentration in tidal creeks was 4.1 mg/L versus 4.9 mg/L at the open water sites. Both averages were below the state water quality standard (based on a daily average not less than 5.0 mg/L and no values below 4.0 mg/L; SCDHEC, 1998b). About 55% of the open water sites and 98% of the tidal creek sites had minimum DO values less than 4.0 mg/L. Based on the CDF analyses, approximately 46% of the state's tidal creek habitat had mean DO concentrations less than 4.0 mg/L compared to only 9% of the open water habitat (Table 2).

The state DO standard is generally based on monthly surface water measures

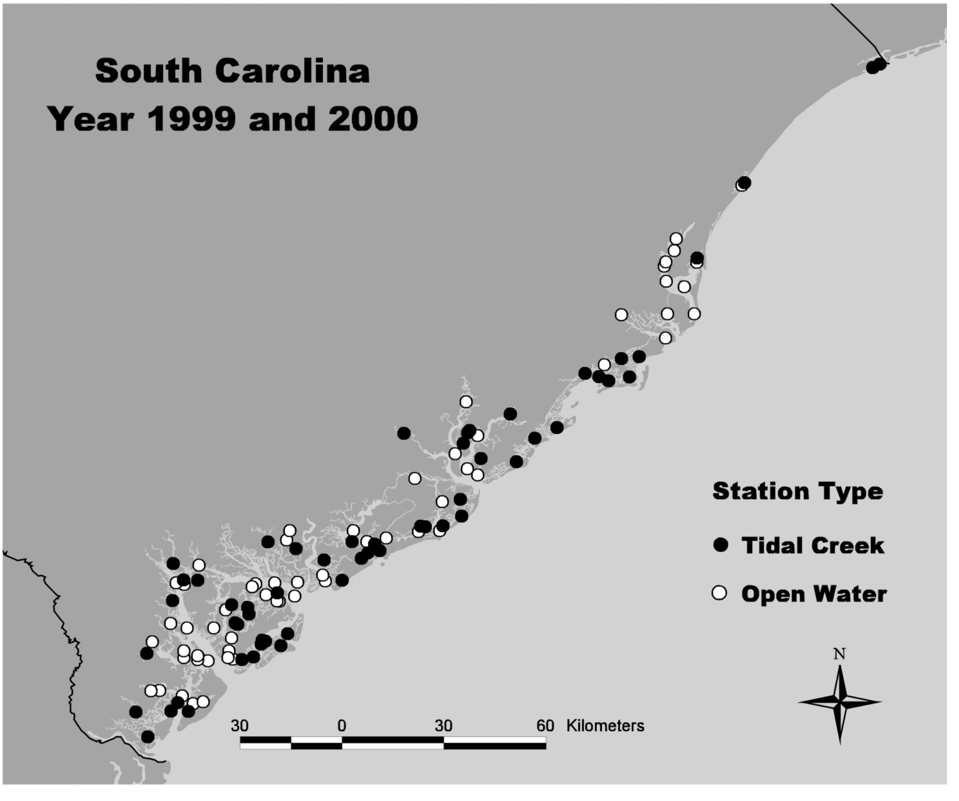

Figure 1. Distribution of SCECAP stations sampled in 1999 and 2000.

Table 1. Summary of mean water quality values collected in tidal creeks and larger open water bodies during 1999 and 2000

Parameter	*Creeks*	*Open*	*Significance*
Dissolved Oxygen (mg/L)	4.1	4.9	$p < .001$
Salinity (ppt)	31.3	27.2	NS
pH	7.5	7.6	$p = .013$
Temperature (°C)	29.9	29.8	NS
BOD_5 (mg/L)	1.8	1.6	NS
TOC (mg/L)	3.6	4.0	NS
Turbidity (NTU)	21.0	14.2	$p < .001$
Fecal Coliform Bacteria	43.0	27.1	$p = .053$
Total Nitrogen (mg/L)	0.65	0.53	$p = .009$
NO_2/NO_3 (mg/L)	0.02	0.04	NS
Ammonia (mg/L)	0.24	0.15	NS
TKN (mg/L)	0.64	0.48	$p < .001$
Total Phosphorus (mg/L)	0.10	0.07	$p < .001$
Chlorophyll-a (µg/L)	12.78	9.68	$p = .022$

collected year-round. Summer-time values would be expected to approach or slightly exceed the lower limit. Collection of bottom water data does not significantly affect our conclusion since we observed very little difference between surface and bottom instantaneous DO measures (mean difference = 0.17 mg/L at open water sites and 0.14 mg/L at tidal creek sites).

Since the majority of creek and open water sites sampled in both years were located in relatively pristine environments, there are clearly natural differences in DO concentrations in the smaller- versus larger-scale watersheds and the existing state standards are not very applicable for the purposes of the SCECAP program. New thresholds of potential DO stress during the summer months need to be developed. Ideally, these should be based on biological response data, but until sufficient data are available to identify DO effects levels, we consider a mean < 4.0 mg/L to be indicative of marginal DO conditions (i.e., average is below state lower limit), and a mean < 3.0 mg/L as evidence of poor DO conditions. Sites with mean DO values < 3.0 mg/L had an average of 26% of the time-series records with values < 2.0 mg/L, which is considered to be stressful for most organisms (USEPA, 1999).

Average measures of biological oxygen demand (BOD_5) in creek and open water habitats were very similar (Table 1) and only slightly above the 50th percentile value (1.4 mg/L) of all BOD_5 measures collected state-wide in 1993–1997 by

Table 2. Summary of the percent of South Carolina's estuarine habitat that represents various water quality conditions based on cumulative distribution function analyses. See text for selection of criteria used to define value ranges.

Parameter	*Criteria*	*Percent of Habitat*	
		Creeks	*Open*
Dissolved Oxygen (mg/L)	≥ 0 < 3	7	0
	≥ 3 < 4	39	9
	≥ 4 < 5	45	45
	≥ 5	9	46
BOD_5 (mg/L)	≤ 1.8	56	66
	> 1.8 ≤ 2.6	21	17
	> 2.6	23	17
Fecal Coliform Bacteria	> 0 ≤ 4	82	94
	> 43 ≤ 400	16	4
	> 400	2	2
Total Nitrogen (mg/L)	≤ 0.95	88	96
	> 0.95 ≤ 1.29	12	4
	> 1.29	0	0
Total Phosphorus (mg/L)	≤ 0.09	45	80
	> 0.09 ≤ 0.17	47	20
	> 0.17	8	0
Chlorophyll-a (µg/L)	> 0 ≤ 5	6	7
	> 5 ≤ 20	81	90
	> 20 ≤ 60	13	3
	>60	0	0

SCDHEC (1998b). Approximately 23% of the state's tidal creek waters and 17% of the open water habitat had BOD_5 values that exceeded the 90th percentile of values observed in the earlier study (Table 2).

Five of the other 11 water quality measures reported here showed significantly higher average values in tidal creeks versus open water habitats and one (pH) showed a significantly lower value (Table 1). The higher turbidity values observed in creeks probably reflects greater tidal mixing in these shallow, well-flushed environments. The higher mean salinity observed in tidal creeks was surprising since these habitats would be expected to have greater freshwater input, lower average salinities, and greater salinity ranges. South Carolina experienced drought conditions during 1999 and 2000 and we would anticipate salinities to be lower in creeks versus the larger water bodies during normal rainfall conditions.

Mean fecal coliform concentrations were significantly higher in tidal creeks compared to open water areas (Table 1). State fecal coliform standards are based on repetitive sampling, and since only one sample was collected at each site, a strict interpretation of the standards is not possible. However, the maximum criteria portion of the standards (43 colonies/100 ml for shellfish harvesting and 400 colonies/100 ml for primary contact recreation), can be used as thresholds for evaluation purposes. Approximately 18% of the state's creek habitat exceeded 43 colonies/100 ml compared to only 6% of the open water habitat (Table 2). Only 2% of either habitat type had fecal concentrations exceeding 400 colonies/100 ml.

The mean total nitrogen (N) value observed in creek habitats was also significantly higher than the average open water concentration (Table 1), but both concentrations were well below the total dissolved N concentration considered to be high (1 mg/L) by Bricker *et al.* (1999). Based on the 5-yr database compiled for South Carolina estuarine water bodies (SCDHEC, 1998a), total N > 0.95 mg/L represents moderately enriched conditions (>75th percentile) and concentrations > 1.29 mg/L represent highly enriched conditions (>90th percentile). Approximately 12% of the state's tidal creek habitat was moderately enriched using these criteria compared to only 4% of the open water habitat (Table 2). No sites were highly enriched.

The average total phosphorous (P) concentrations measured in tidal creeks was slightly above dissolved phosphorous concentration reported by Bricker *et al.* (1999) as "high" concentrations (0.1 mg/L), whereas average P concentrations were lower at the open water sites (Table 1). Based on the five-year database available for South Carolina waters, 47% of the state's creek habitat was moderately enriched (>75th percentile) and 8% was very enriched (>90th percentile). In comparison, only 20% of the state's open water habitat was moderately enriched (Table 2).

The higher turbidity, fecal coliform, and nutrient values observed in tidal creeks would be expected due to the closer proximity of these habitats to sediment, nutrient and fecal inputs resulting from land runoff, combined with the lower dilution capacities in tidal creek versus larger-scale water bodies. Additionally, the shallower depths and strong tidal flushing typically observed in most creeks would tend to re-mix bottom sediments. This bottom re-mixing may have further influenced turbidity and the nutrient measures since most of the creek samples were collected within 2 m of the bottom. The significant differences observed between tidal creeks and open water habitats suggest that different thresholds of enrichment should be developed for each habitat type.

Biological measures also reflected significant differences between the two types of water bodies sampled. Average chlorophyll-a concentrations were significantly higher in creeks versus open water habitats (Table 1). Additionally, our CDF analysis indicated that approximately 13% of the state's tidal creek habitat had > 20 μg/L of chlorophyll-a (Table 2), which is considered to be high by Bricker *et al.* (1999). This higher chlorophyll concentration may be reflective of the higher nutrient concentrations observed in the creeks. It may also reflect possible re-suspension of benthic algal mats from the creek bottoms and marsh surfaces that would not be as likely to be observed in the surface waters of deeper, larger water bodies.

Tidal creeks also supported a significantly higher abundance and biomass of finfish and crustaceans ($p < 0.001$), and a significantly higher number of species per trawl ($p < 0.05$) than observed at the open water sites (Figure 2). In contrast, the mean abundance and mean number of species of benthic infauna was significantly lower at the creek sites compared to the open water sites ($p < 0.1$,abundance; $p < 0.05$, no. spp; Figure 2). The lower benthic measures may reflect the effects of higher predation pressure since the abundance and biomass of demersal biota was 2-4 times higher than observed at the open water sites. Lower DO conditions and other water quality conditions observed in the creeks may have also influenced the benthic fauna, but this is less likely since most creek sites did not experience extended periods (> 6-8 hours) of hypoxic conditions.

As noted for the water quality variables measured, our analysis of several biological measures indicates very different conditions in creeks versus the larger open water bodies. Development of both water quality and biological measures that would be indicative of stress must account for the natural differences associated with large and

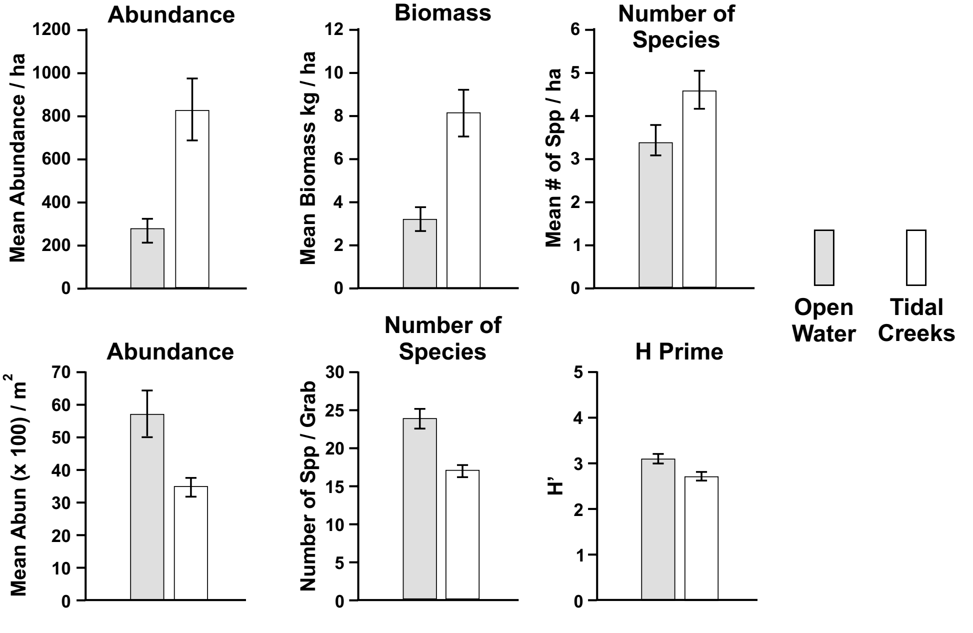

Figure 2. Summary of selected biological measures collected for (top) demersal fish and crustacean assemblages sampled by trawl, and (bottom) benthic assemblages sampled by grab (1999–2000).

small watersheds in order to effectively evaluate habitat quality. Based on our findings in South Carolina's coastal waters: (1) monitoring programs that don't incorporate small watersheds, such as tidal creeks, may miss an important habitat that should be monitored due to the value of these habitats as nursery areas, and (2) programs that do include small watersheds need to recognize the natural differences present between large and small water bodies, and consider partitioning these habitats or risk the strong probability of establishing inappropriate criteria for tidal creeks that could inaccurately identify water body impairment.

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