The Condition of South Carolina's Estuarine and Coastal Habitats During 1999-2000

Summary Report

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South Carolina Department of Health and Environmental Control

An Interagency Assessment of South Carolina's Coastal Zone

The Condition of South Carolina's Estuarine and Coastal Habitats During 1999 - 2000

Summary Report

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INTRODUCTION

The South Carolina Department of Natural Resources (SCDNR) and the South Carolina Department of Health and Environmental Control (SCDHEC) initiated a major new collaborative coastal monitoring program in 1999 entitled the *South Carolina Estuarine and Coastal Assessment Program* (SCECAP). The program also involves several federal partners, including the US Environmental Protection Agency (USEPA), the National Oceanic and Atmospheric Administration National Ocean Service (NOAA-NOS) Charleston Laboratory, and the US Fish and Wildlife Service (USFWS). The goal of SCECAP is to monitor the condition of the state's estuarine habitats and provide periodic reports to both coastal managers and the public. The program collects multiple measures of water quality, sediment quality, and biological condition at a large number of sites throughout the state's coastal zone each year and integrates those measures into an overall assessment of estuarine habitat condition at each site and the entire coastal zone. The program also expands historical monitoring activities that have primarily focused on open water habitats (e.g. bays, sounds, tidal rivers) to include an assessment of conditions in tidal creeks, which serve as important nursery habitat for most of the state's economically valuable species. Many of these tidal creeks are also the first point of entry for upland runoff and therefore can provide an early indication of stress related to coastal development, agriculture and industrial activities (Holland *et al.*, 1997; Sanger *et al.*, 1999a,b; Lerberg *et al.*, 2000; Van Dolah *et al.*, 2000).

This report summarizes major findings obtained from the first two years of the program. A more detailed technical report (Van Dolah *et al.*, 2002) provides additional data on this monitoring program that may be useful to coastal resource managers and scientists conducting research in South Carolina's estuaries. The study results highlight the value of evaluating tidal creek habitats separately from larger open water bodies due to significant differences observed for many of the measurements taken in each habitat. The study also includes newly developed integrated measures of habitat condition that have not been used previously.

The goal of SCECAP is to monitor the condition of the state's estuarine habitats and provide periodic reports to both coastal managers and the public.

STUDY DESIGN

Approximately 60 stations were randomly selected for sampling each year. All sites were located within the coastal zone extending from the saltwater – freshwater interface to near the mouth of each estuarine drainage basin and extending from the Little River Inlet at the North Carolina border to the Wright River near the Georgia border (Figure 1). The Savannah River is not included in the SCECAP initiative, but is being sampled by the Georgia Coastal Resources Division as part of the USEPA National Coastal Assessment Program.

Tidal creeks serve as important nursery habitat for economically valuable fish and crustacean species.

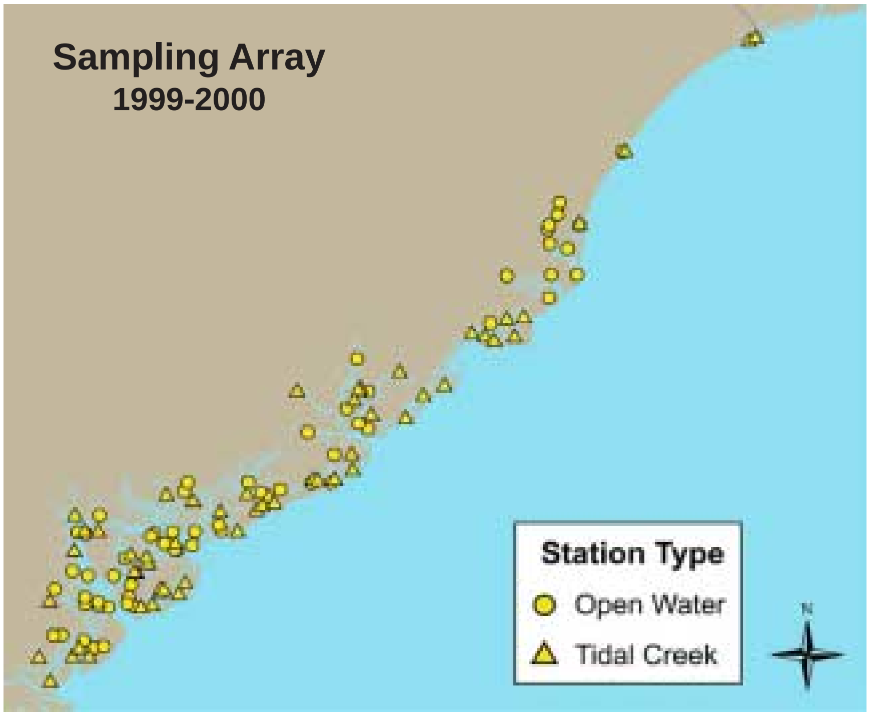


Figure 1. Distribution of open water and tidal creek stations sampled throughout South Carolina's coastal zone during 1999 – 2000.

About half of the stations were located in tidal creeks and the other half were located in larger open water bodies that form South Carolina's tidal rivers, bays and sounds. For the purposes of this program, tidal creeks are defined as those estuarine water bodies less than 100 m (328 ft) in width from marsh bank to marsh bank, with stations limited to the portion of creeks having at least 1 m of water depth at low tide. Using this criteria, approximately 17% of the state's estuarine waters represent creek habitat, with the remaining 83% representing larger open water bodies.

All stations were sampled once during the summer months (mid June through August) for the core monitoring program described in this report. The summer period was selected because it represents a period when some water quality variables may be most limiting and it is the season when many fish and crustacean species of concern are utilizing estuaries as nursery habitat.

Both open water and tidal creek habitats are sampled by SCECAP.

The sampling design used by SCECAP allows statistical estimates of the proportion of South Carolina's overall creek and open water habitat that meet or don't meet defined levels of habitat quality based on (1) state water quality criteria, (2) historical measurements collected in the state's larger open water bodies (SCDHEC, 1998), or (3) other thresholds indicative of sediment contaminant levels that may adversely affect biological condition (Hyland *et al.*, 1999; Van Dolah *et al.*, 1999).

Measurements Taken

Table 1 provides a listing of the water, sediment and biological measurements collected at each site. The primary water quality measurements collected for this program were: dissolved oxygen, biochemical oxygen demand, nutrients (nitrogen and phosphorus), fecal coliform bacteria, and pH levels. These data were compared to state water quality standards or historical data collected by SCDHEC to provide a measure of overall water quality condition. Other important variables, such as temperature, salinity, total organic

Table 1. Listing of measurements and samples collected for the South Carolina Estuarine and Coastal Assessment Program (SCECAP).

Water Quality:

Parameter	Type and Depth
Dissolved oxygen, temperature, salinity, pH, depth (pH at surface only)	instantaneous at surface, mid, bottom
Dissolved oxygen, temperature, salinity, pH, depth	continuous 25-48 hr record, bottom
Secchi disk readings*	instantaneous at surface
Total nitrate-nitrite, TKN, ammonia, total phosphorus	instantaneous at surface
Dissolved nitrate-nitrite, organic nitrogen, ammonia, orthophosphate and silica*	instantaneous at surface
Total Organic Carbon (TOC)	instantaneous at surface
Biochemical Oxygen Demand (BOD_5)	instantaneous at surface
Total alkalinity	instantaneous at surface
Fecal coliform bacteria	instantaneous at surface
Total cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, zinc**	instantaneous at surface

Sediment Quality:

Sediment composition (% sand, silt/clay)	composite sample
Porewater ammonia	composite sample
Total Organic Carbon (TOC)	composite sample
Metals (13)	composite sample
Polycyclic Aromatic Hydrocarbons (PAHs – 24)	composite sample
Polychlorinated biphenyls (PCBs – 27)	composite sample
Pesticides (21)	composite sample
Sediment toxicity – Seed clam assay	composite sample
Sediment toxicity – Microtox assay	composite sample
Sediment toxicity – 10 day amphipod assay*	composite sample

Biological Condition:

Phytoplankton concentration (Chl-a)	instantaneous at surface
Phytoplankton pigment composition (HPLC)	instantaneous at surface
Phytoplankton composition (microscopic exam)***	instantaneous at surface
Benthic community	replicate 0.04 m^2 grabs
Finfish/crustacean community	0.5 km trawls (open water) 0.25 km trawls (creeks)
Tissue contaminant concentrations (target finfish)	composite sample from trawls
Incidence of diseases, deformities in finfish	composite sample from trawls
Juvenile finfish community****	replicate 0.10 km sled tows (creeks)

Habitat Characteristics:

Proximity to upland development	visual assessment
Evidence of litter	visual assessment
Current weather conditions	visual assessment
Creek habitat characteristics****	GIS analysis

* Expansion related to the USEPA National Coastal Assessment Program
** Part of SCDHEC year-round monitoring activities at selected sites
*** Expansion related to the state-wide Harmful Algal Bloom Program
**** Expansion related to USFWS funded Tidal Creek Study

carbon, and turbidity were also included in our assessment of water quality. Some measurements included both instantaneous and time series data.

Sediment samples were collected at every site to provide information on composition, contaminant levels, and toxicity using multiple sediment bioassay tests (Table 1). Bottom dwelling invertebrates living in the sediments (benthos) were also evaluated as one measure of biotic condition. These organisms are an important source of food for many fish, shrimp and crab species, and they have proven to be a good indicator of biotic condition related to elevated contaminant concentrations and poor water quality. A Benthic Index of Biotic Integrity (B-IBI) developed for the southeastern region (Van Dolah *et al*., 1999) was used as the primary measure of biological condition for the 1999-2000 SCECAP survey.

The primary water quality measurements collected for this program were: dissolved oxygen, biochemical oxygen demand, nutrients (nitrogen and phosphorus), fecal coliform bacteria, and pH levels.

Another measure of biotic condition considered in this report was an estimate of phytoplankton concentration as a measure of how the state's waters compare to national guidelines developed by NOAA that may be indicative of estuarine eutrophication (effects of nutrient enrichment). Fish and crustaceans (shrimp and crabs) were also sampled to determine the relative abundance, biomass, and diversity of species among the sites sampled. As more data are collected on these species, a SCECAP goal is to develop a second index of biotic integrity using the fish and crustacean catch data.

FINDINGS

Water Quality

SCDHEC has developed State regulations to protect the water quality of the state for several of the parameters measured by the SCECAP program (SCDHEC, 2001a). These regulations are used for setting permit limits on discharges to waters of the State, with the intent of maintaining and improving surface waters to provide for the survival and propagation of a balanced aquatic community of flora and fauna and to provide for recreation in and on the water. Occasional short-term departures from these conditions will not automatically result in adverse effects to the community and these deviations may occur due solely to natural conditions that the aquatic community is adapted to. Therefore, one goal of SCECAP is to provide additional data on typical conditions observed during the summer months in South Carolina estuarine habitats, especially in those habitats such as tidal creeks that historically have not been sampled by SCDHEC as part of their long-term water quality monitoring program.

As noted previously, the six primary water quality parameters used to develop an integrated measure of overall water quality within the state's coastal waters were dissolved oxygen (DO), biochemical oxygen demand (BOD_5), total nitrogen (TN), total phosphorus (TP), fecal coliform bacteria, and pH. The oxygen measures provide an indication of both oxygen availability (i.e. DO) and consumption (i.e. BOD_5). The nitrogen and phosphorus measures provide the best indication of possible nutrient enrichment (eutrophication) in our estuaries. Fecal coliform bacteria concentrations provide an indication of the suitability of the water for shellfish harvesting and primary contact recreation with regard to the amount of potentially harmful bacteria in the water. Measures of pH provide additional information on conditions that may be stressful for many marine species.

Scientists collect various measures of water quality at each site.

Values of each water quality parameter were compared to standards for the state's saltwaters (SCDHEC, 2001a) where possible. Because SCECAP sampling is limited to a summer index period and generally doesn't include multiple samples over time, the data are not appropriate for use in USEPA 303(d) or 305(b) reporting requirements. Additionally, only a few of the water quality parameters measured for SCECAP have state standards. When standards were not available, values were compared to data compiled over a 5-year period (1993-1997) by the SCDHEC Bureau of Water in their routine statewide Fixed Ambient Surface Water Monitoring Network (SCDHEC, 1998). Values exceeding the 75th percentile of all historical values reported by SCDHEC in the state's saltwaters were considered to be evidence of elevated concentrations; values exceeding the 90th percentile of the historical values were considered to be extreme concentrations. Because the SCDHEC historical database was primarily obtained from larger open water bodies, caution should be used in interpreting data from tidal creek sites since high or low values observed for some parameters in that habitat may represent "normal" conditions. In the future, the SCECAP database will be used to identify normal conditions in tidal creeks using protocols similar to those described by SCDHEC (1998).

This report summarizes conditions related to each of the six primary water quality parameters used by the SCECAP program. More detailed findings, along with information on the other water quality parameters measured for SCECAP, are provided by Van Dolah *et al*. (2002).

Dissolved Oxygen

Dissolved oxygen (DO) is one of the most critical water quality parameters measured in this program. Low dissolved oxygen conditions can limit the distribution or survival of most estuarine biota, especially if these conditions persist for extended time periods. Dissolved oxygen criteria established by the SCDHEC for "Shellfish Harvesting Waters" (SFH) and tidal saltwaters suitable for primary and secondary contact recreation (Class SA saltwaters) is a daily average not less than 5.0 mg/L with a low of 4.0 mg/L (SCDHEC, 2001a). Tidal saltwaters suitable for primary and secondary contact recreation, crabbing and fishing, except harvesting of clams, mussels, or oysters for human consumption (Class SB waters), should have dissolved oxygen levels not less than 4.0 mg/L. Since the SCECAP program was designed to sample only during a summer index period when DO levels would be at their lowest, DO measurements collected in this program approximate short-term worst-case conditions that may not necessarily occur for long time periods. Therefore, these measurements should not be used for regulatory purposes. However, SCECAP data do provide useful measures of average DO concentrations occurring in both tidal creek and open water habitats during a period when DO levels may be limiting, and it identifies areas within the state where this is occurring. Based on the state water quality standards, average DO concentrations > 4 mg/L are considered to be good and values > 5 mg/L are considered to be very good for this time of year. Average DO concentrations < 4 mg/L, but ≥ 3 mg/L are considered to be marginal (i.e. does not meet one portion of the state standards). Average DO concentrations < 3 mg/L are considered to be potentially stressful, especially since most of the sites with DO levels in this range had many measurements that were < 2 mg/L, which represents very low oxygen conditions known to be limiting to many estuarine and marine biota.

Dissolved oxygen (DO) is one of the most critical water quality parameters measured in this program.

The primary measure of dissolved oxygen used for SCECAP was based on a 25-hr average of measurements collected every 15 minutes by water quality meters deployed in the bottom waters of each site. During 1999 and 2000, the average DO concentration at open water stations was 4.9 mg/L and the average DO concentration in tidal creek habitats was 4.1 mg/L (Figure 2). Approximately 91% of the state's open water habitat had good to very good DO levels which

Continuous data collectors are deployed for 25 hours at each station to better evaluate water quality conditions over multiple tidal cycles.

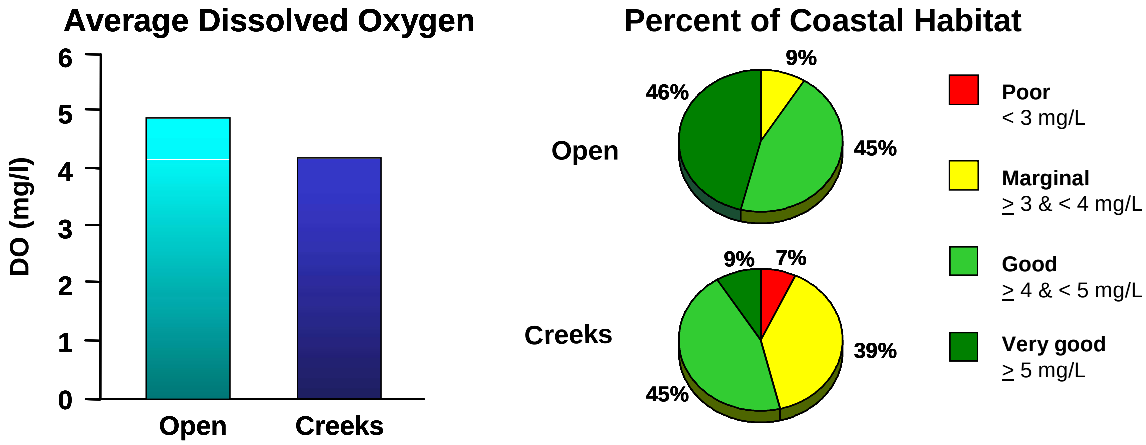


Figure 2. Comparison of the average dissolved oxygen concentrations observed in tidal creek and open water habitats during 1999-2000, and estimates of the percent of the state's coastal habitat representing various DO conditions.

should not be limiting to most species of concern. Only 9% of the open water habitat had marginal DO conditions and none of the open water sites had poor DO concentrations. In contrast, only 54% of the state's tidal creek habitat had good to very good DO conditions, 39% of this habitat had marginal DO concentrations, and 7% had poor DO concentrations that may be limiting to many species.

Since tidal creek habitats generally supported a greater density and diversity of fish and crustaceans than the open water sites (see biological summary), DO measures traditionally obtained by SCDHEC in larger open water may not be indicative of stressful conditions in creeks. However, creeks with poor DO levels (< 3 mg/L on average) may not fully support biological assemblages inhabiting those sites, especially during periods when DO levels are less than 2 mg/L (hypoxic conditions).

pH

Measures of pH provide another indicator of water quality in estuarine habitats. The pH measurements are based on a logarithmic scale, so even small changes in the value can result in significant stress to estuarine organisms (Bamber, 1987, 1990; Ringwood and Keppler, in review). Low pH values can indicate the presence of pollutants (e.g. release of acids or caustic materials) or high concentrations of carbon dioxide (Gibson *et al*., 2000).

Because salinity and alkalinity affect the pH of estuarine waters, SCDHEC has established water quality standards that account for these effects. The pH in Class SA and SB tidal saltwaters should not vary more than one-half of a pH unit above or below effluent-free waters in the same geologic area having a similar salinity, alkalinity and temperature, and values

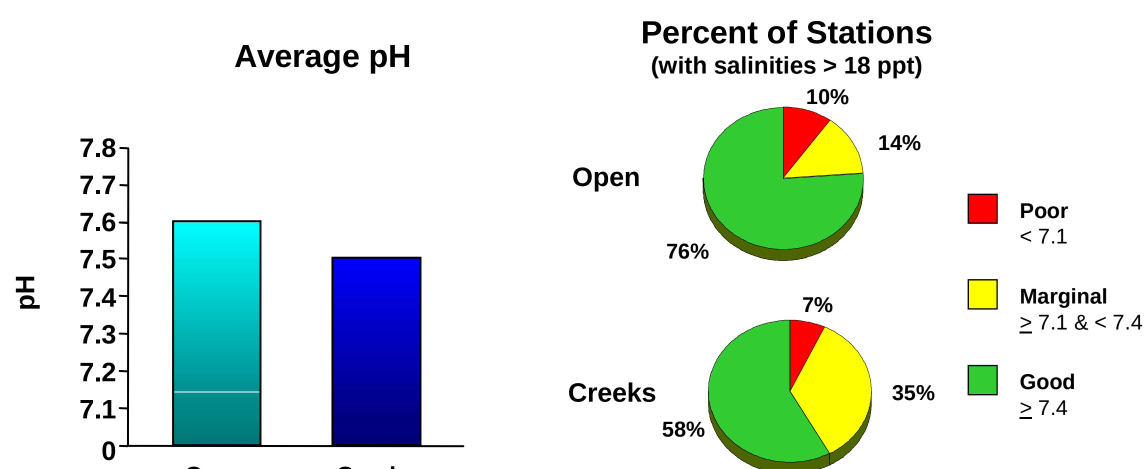


Figure 3. Comparison of the average pH concentrations observed in tidal creek and open water habitats during 1999-2000, and estimates of the percent of the high salinity stations having poor, moderate, or good pH values.

should never be lower than 6.5 or higher than 8.5. Shellfish harvesting waters (SFH) shouldn't deviate more than 0.3 units from pH levels in effluent-free waters.

The pH measurements used to characterize each site were collected from water quality meters deployed for 25 hrs. There were a sufficient number of sites having moderate to high salinities (18 – 40 ppt) to establish pH criteria for the SCECAP program. The majority of these stations were located in areas considered to be pristine environments (e.g. Cape Romain National Wildlife Refuge, North Inlet and Ashepoo, Combahee, and Edisto [ACE] National Estuarine Research Reserve, and SFH class saltwaters). Only a few stations were sampled in 1999-2000 that had lower salinities. These stations were not evaluated for pH since we do not yet have a sufficient database to set criteria for what represents good, marginal, and poor pH levels in that salinity regime. For the SCECAP program, pH values below 7.4 were considered to represent marginal pH conditions and values below 7.1 represented poor conditions (see Van Dolah *et al*., 2002 for criteria methodology).

Low pH values can indicate the presence of pollutants (e.g. release of acids or caustic materials) or high concentrations of carbon dioxide.

The 1999 – 2000 average of pH values measured at tidal creek stations was lower than the average pH value measured at open water stations (Figure 3).

Based on the SCECAP criteria, approximately 24% of the open water sites sampled had marginal or poor pH concentrations compared to about 42% of the tidal creek sites. The pH at these stations may be causing stress for some organisms, particularly at sites with values < 7.1.

Nutrients

Nutrient loading into estuarine waters has become a major concern due to the rapid development that is occurring in the coastal zone of South Carolina and other states. This development results in increased nutrient input from wastewater treatment facilities, some industrial facilities, urban and suburban runoff of fertilizers, vehicle exhaust, etc. Other sources of nutrients include runoff from agricultural fields adjacent to estuarine habitats, riverine input of nutrient-rich waters from inland areas, and atmospheric deposition. High nutrient levels can lead to enrichment or eutrophication of estuarine waters resulting in excessive algal growth including harmful algal blooms (HAB), decreased dissolved oxygen, and other undesirable effects that adversely affect estuarine biota (Bricker *et al.*, 1999).

There are no State or USEPA standards for the various forms of nitrogen (except ammonia) and phosphorus in estuarine waters. Therefore, the SCECAP data were compared to SCDHEC's historical database (SCDHEC, 1998) to identify waters showing evidence of elevated nutrients. Values were also compared with guidelines published by NOAA for estuarine waters (Bricker *et al*., 1999), although it should be noted that those values represent dissolved rather than total nutrient concentrations.

Coastal development results in increased nutrient input from wastewater treatment facilities, some industrial facilities, urban and suburban runoff of fertilizers, vehicle exhaust, ...

Water quality sampling includes instantaneous measures of dissolved oxygen, salintiy, pH, and temperature and water samples for laboratory analysis.

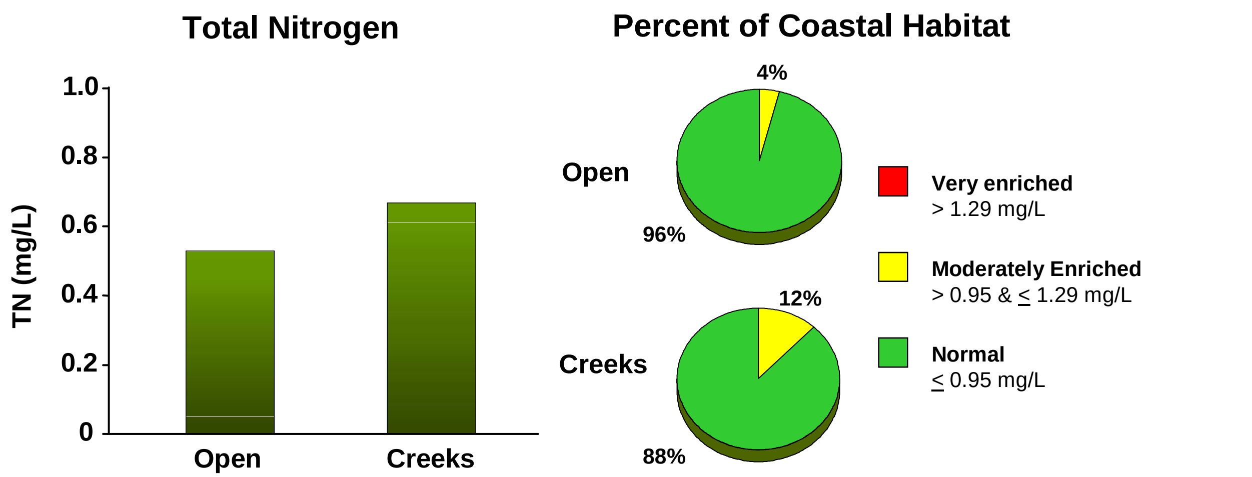


Figure 4. Comparison of the average total nitrogen (TN) concentrations observed in tidal creek and open water habitats during 1999-2000, and estimates of the percent of the state's coastal habitat with TN values representing normal or enriched values relative to SCDHEC historical data.

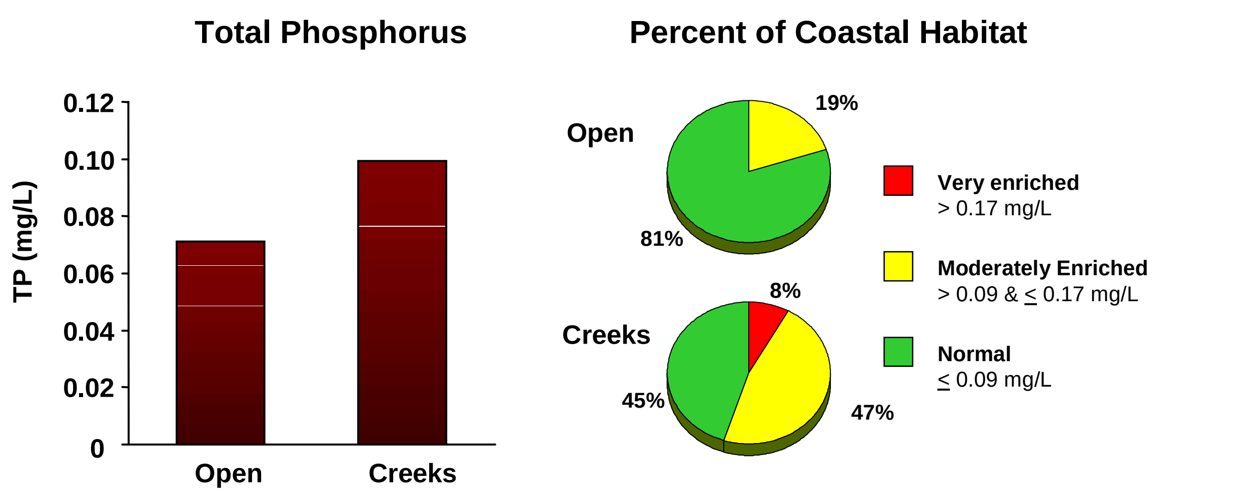


Figure 5. Comparison of the average total phosphorus (TP) concentrations observed in tidal creek and open water habitats during 1999-2000, and estimates of the percent of the state's coastal habitat with TP ranges representing normal, enriched, or highly enriched values relative to SCDHEC historical data.

The average total nitrogen (TN) concentration measured at tidal creek sites was significantly higher than the average concentration measured at open water sites. Approximately 12% of the creek habitat and only 4% of the state's open water habitat had TN concentrations that were considered to be enriched (Figure 4). In 2000, total dissolved nitrogen (TDN) was also measured. None of those samples had high TDN concentrations (> 1.0 mg/L) based on the guidelines developed for coastal waters by NOAA (Bricker *et al.*, 1999) and there was no significant difference in TDN between creek and open water sites.

The average total phosphorus (TP) concentration measured at tidal creek sites was significantly higher than the concentration measured at open water sites (Figure 5). Approximately 47% of the state's tidal creek habitat showed moderate phosphorus enrichment and an additional 8% of that habitat was very enriched with respect to total phosphorus. In contrast, only 19% of the open water habitat showed moderate enrichment and none of the sites had highly enriched phosphorus levels. The higher phosphorus concentrations may represent natural conditions in creek habitats since the historical database was based on sampling in larger open water systems. Additional data collected through this program will help to resolve whether new guidelines for TP enrichment should be considered for creek habitats. Until those data are available, the historical SCDHEC database provides the best record of deviations from normal estuarine water quality conditions.

The average total dissolved phosphorus (TDP) concentration measured in the creek versus open water stations in 2000 were not significantly different. Using the NOAA guidelines (Bricker *et al.*, 1999), none of the open water sites and only two of the creek sites were enriched.

Biochemical Oxygen Demand

The five-day biochemical oxygen demand (BOD_5) is a measure of the amount of oxygen consumed by the decomposition of organic matter, both natural and man-made wastes, in the water column. Although BOD_5 is regulated by National Pollutant Discharge Elimination System (NPDES) permits to protect instream dissolved oxygen, there are no freshwater or saltwater standards for natural waters. Both the SCDHEC water quality monitoring program and the SCECAP program include measurements of BOD_5 in order to obtain information on areas where unusually high values may be occurring. Average BOD_5 concentrations sampled in 1999-2000 were similar at creek and open water sites (Figure 6). However, a slightly higher percentage of the state's tidal creek habitat had BOD_5 levels that exceeded the 75th and 90th percentiles of historical observations when compared to open water habitat. High BOD_5 concentrations may be indicative of poor water quality.

BOD is a measure of the amount of oxygen consumed by the decomposition of organic matter and can be indicative of poor water quality.

Fecal Coliform Bacteria

Coliform bacteria are present in the digestive tracts and feces of all warm-blooded animals. Public health studies have established correlations between adverse human health effects and concentrations of fecal coliform bacteria in recreational, drinking, and shellfish harvesting waters. State fecal coliform standards to protect primary contact recreation require a geometric mean count that does not exceed 200 colonies/100 mL based on five consecutive samples in a 30 day period and no more than 10% of the samples shall exceed 400 colonies /100 mL. To protect for shellfish consumption, the geometric mean can not exceed 14 colonies/100 mL and no more than 10% of the samples shall exceed 43 colonies/100 mL (SCDHEC, 1998). Since only a single fecal coliform count was collected at each site, compliance with the standards cannot be strictly determined, but the data can provide some indication of whether the water body is likely to meet standards. For the SCECAP program, we consider any sample with > 43 colonies/100 mL to represent marginal conditions (i.e. potentially not supporting shellfish harvesting) and any sample with > 400 colonies/100 mL to represent poor conditions (i.e. potentially not supporting primary contact recreation).

Coliform bacteria levels are used to evaluate the suitability of coastal waters for shellfish harvesting and primary contact recreation.

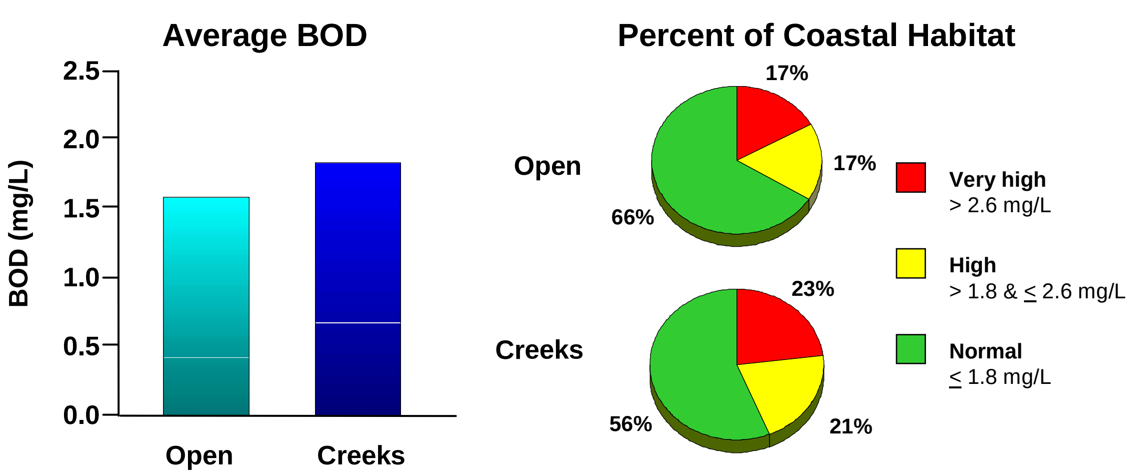


Figure 6. Comparison of the average five-day biochemical oxygen demand (BOD_5) concentrations observed in tidal creek and open water habitats during 1999-2000, and estimates of the percent of the state's coastal habitat representing BOD_5 ranges that were normal, enriched, or highly enriched values relative to SCDHEC historical data.

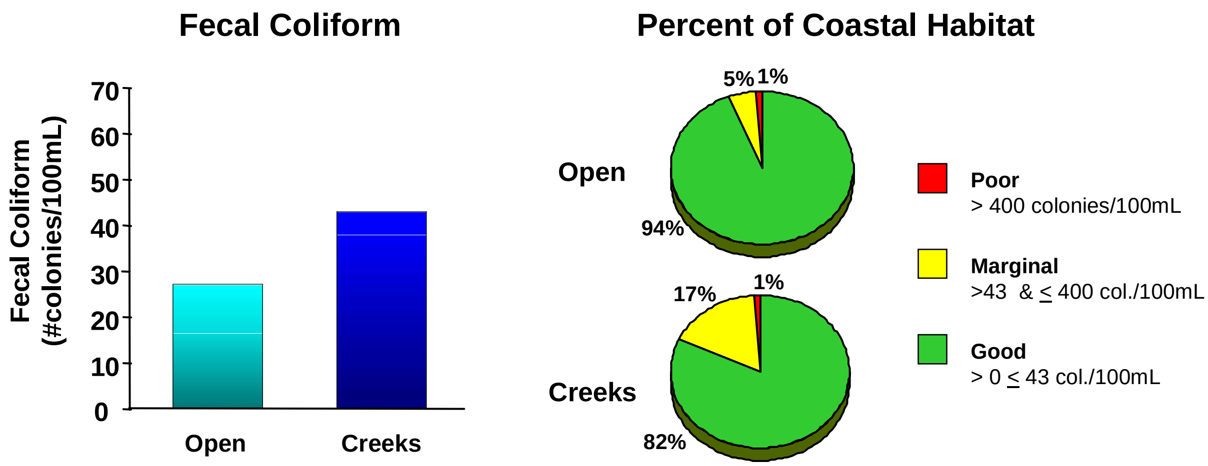


Figure 7. Comparison of the average fecal coliform concentrations observed in tidal creek and open water habitats during 1999-2000, and percent estimates of the state's coastal habitat representing concentrations that are acceptable (green), possibly unsuitable for shellfish harvesting (yellow), or possibly unsuitable for primary contact recreation (red).

Average fecal coliform concentrations were higher in creeks than in open water during 1999 – 2000 (Figure 7). Approximately 17% of the state's creek habitat was marginal and 1% was poor with respect to fecal coliform concentrations. In contrast, only 5% of the open water habitat was marginal and 1% was poor. The higher fecal coliform counts observed in creek habitats is most likely due to the proximity of these small drainage systems to upland runoff from both human and domestic as well as wildlife sources, combined with the lower dilution capacity compared to larger water bodies. Greater protection of tidal creek habitats is warranted in areas where upland sources of waste can be controlled.

Integrated Water Quality Measure

The integrated water quality score developed for the SCECAP program incorporates all six of the water quality measures described above. An explanation of the scoring process is provided by Van Dolah *et al*. (2002). Sites coding as poor (red) generally had four to six of the individual water quality variables coding as poor or marginal. Approximately 5% of the state's creek habitat had poor water quality in 1999-2000, whereas none of the open water habitat had poor water quality (Figure 8). Sites with marginal water quality

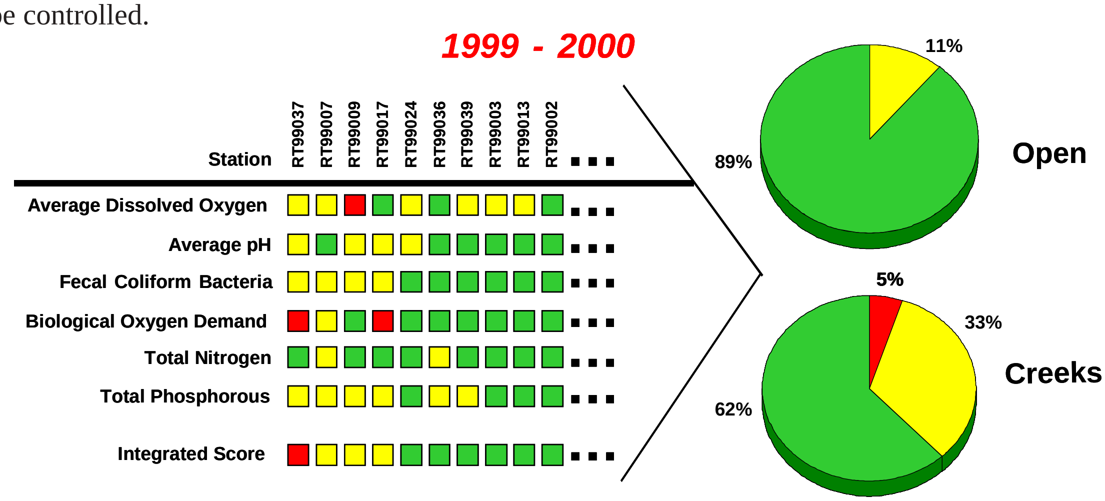


Figure 8. Proportion of the South Carolina's estuarine habitat that ranks as good (green), marginal (yellow), or poor (red) using the integrated water quality score developed for the SCECAP program. The left portion of the figure shows examples of how individual stations coded for each of the six water quality parameters and the average integrated score for each station based on the combined numerical ratings of the six parameters (Van Dolah et al., 2002). The right portion of the figure shows the estimated proportion of water quality conditions for the entire coastal zone of the state.

(yellow) generally had 2-3 parameters coding as marginal or poor. Approximately 33% of the state's creek habitat had marginal water quality conditions compared to approximately 11% of the open water habitat. The higher percentage of poor and marginal water quality conditions in creeks indicates that these habitats are often more stressful environments and may, in part, reflect the relatively greater effect of anthropogenic runoff into these smaller water bodies due to their proximity to upland sources and their lower dilution capacity. However, since many of the creeks with poor water quality were in relatively pristine locations, some of the differences observed between creek and open water sites may simply be the result of using thresholds derived from SCDHEC's historic database, which is composed predominantly of data from open water habitats. Once a larger database is available, our threshold criteria for some of the water quality parameters measured in creek habitats may be changed from those used in this report to reflect the greater natural variability in these habitats.

Sediment Quality

The primary measures of sediment quality used for SCECAP include a collective measure of the concentration of 24 contaminants and results obtained from 2-3 laboratory bioassays that evaluate the toxic effects of those sediments to both invertebrate and microbial organisms. Other sediment characteristics also measured for the program are not summarized here, but are available in the full Technical Report (Van Dolah *et al*., 2002).

Contaminants

The 24 contaminants used to evaluate sediment quality include both trace metals and organic compounds for which there are published bioeffects guidelines based on laboratory and field studies of estuarine and marine organisms (Long *et al*., 1995). None of the sites sampled in 1999-2000 had contaminant concentrations that exceeded values considered to be high (i.e. cause adverse effects in at least 50% of the studies evaluated by Long *et al*., 1995). However, several sites had moderately high concentrations (i.e. cause adverse bioeffects in at least 10% of the studies evaluated by Long *et al*., 1995). More tidal creek sites had elevated contaminants compared to the sites in larger water bodies (15 vs 9 sites). The elevated contaminants included arsenic, cadmium, copper, chromium, and several polycyclic aromatic hydrocarbons (PAHs) commonly associated with fuel combustion, petrochemical industrial effluents, etc. Arsenic is naturally elevated in South Carolina estuarine sediments (Scott *et al*., 1994; 2000; Sanger *et al*., 1999a) and the values observed cannot be attributed solely to anthropogenic stress. Only one site had many contaminants at levels known to cause adverse bioeffects. This station was located in the turning basin of Shipyard Creek, an industrialized drainage basin in Charleston Harbor.

24 contaminants are used to evaluate for possible effects to estuarine animals.

Sediments are collected to test for the presence of contaminants and evaluate the health of bottom-dwelling communities.

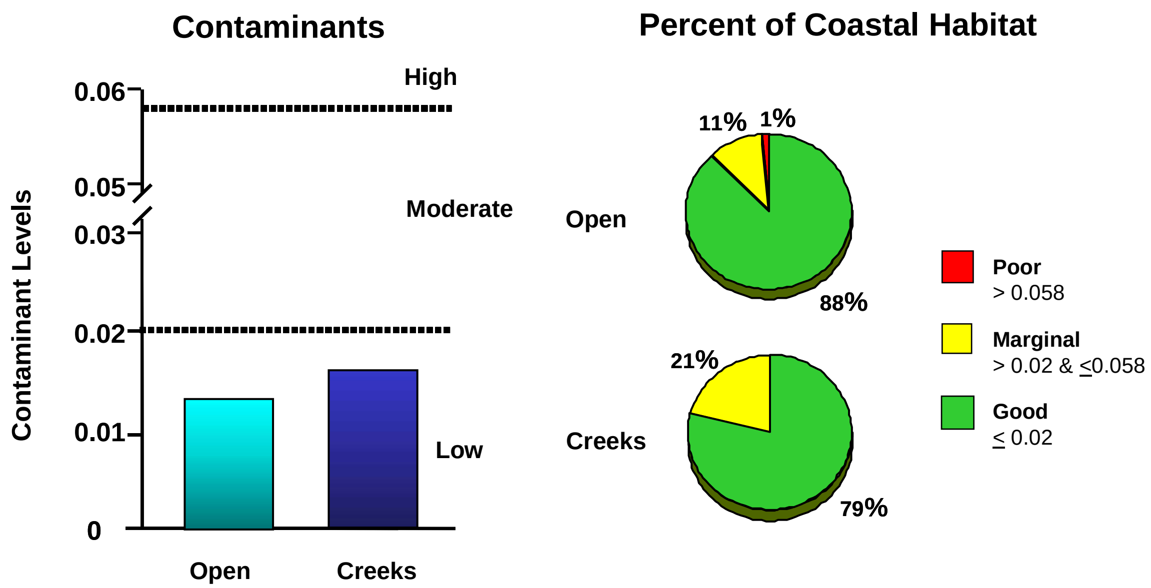


Figure 9. Average cumulative sediment contaminant concentrations at open water and tidal creek sites sampled in 1999 – 2000 and the proportion of the state's coastal habitat having concentrations representing a low, moderate, or high risk of observing stress in benthic communities.

While individual contaminants were elevated at some sites, a better assessment of overall pollution exposure can be derived from the combined concentrations of all 24 contaminants present at a site relative to the bioeffects guidelines for each of those contaminants. Hyland *et al.* (1999) published sediment quality guidelines that have been shown to be predictive of a high, moderate, or low risk of observing adverse effects in bottom dwelling invertebrate communities (benthos) inhabiting southeastern estuaries. Using these guidelines, approximately 21% of the tidal creek habitat assessed in 1999 and 2000 had contaminant concentrations indicative of a moderate risk to bottom-dwelling assemblages (Figure 9). In comparison, only 11% of the open water habitat had similar contaminant concentrations. In both habitats, many of these sites were in developed watersheds. The remaining creek and open water stations sampled in 1999 and 2000 had low contaminant concentrations that would support a healthy bottom community, except for Shipyard Creek, which had a combined chemical concentration that represented a high risk to benthic communities.

Excessive contamination in South Carolina's estuarine sediment is not widespread.

Although there are several locations in South Carolina's estuarine waters known to be polluted, the areal extent of these polluted areas is limited and not likely to be routinely represented in the 60 sites randomly selected for sampling each year. The lack of widespread contamination in South Carolina's estuaries is a positive indication that our estuaries are not experiencing extensive chemical degradation. More importantly, the SCECAP database provides valuable information for determining whether conditions at sites where potential human impacts are occurring are different than typical conditions found in unimpacted tidal creek and open water habitats.

Toxicity

Even if estuarine sediments have high contaminant levels, the contaminants may not be available to biota living in the sediments. Laboratory bioassays are used

Upland development can increase the risk of creating adverse conditions in creeks or open water habitats as indicators of both contaminant bioavailability and potential for toxicity. For SCECAP, two (1999) to three (2000) bioassays were conducted to test for toxicity using marine bacteria, juvenile hard clams, and a small sediment-dwelling crustacean (amphipod). When two or more of the tests showed positive toxicity, the sediment was considered to be poor (high probability of toxicity); one positive test indicated marginal sediment quality and no positive test results indicated good sediment quality. Approximately 7% of the state's creek habitat and 14% of the open water habitat had poor sediment considered to be toxic, with an additional 46% and 30%, respectively, showing some evidence of toxicity (Figure 10).

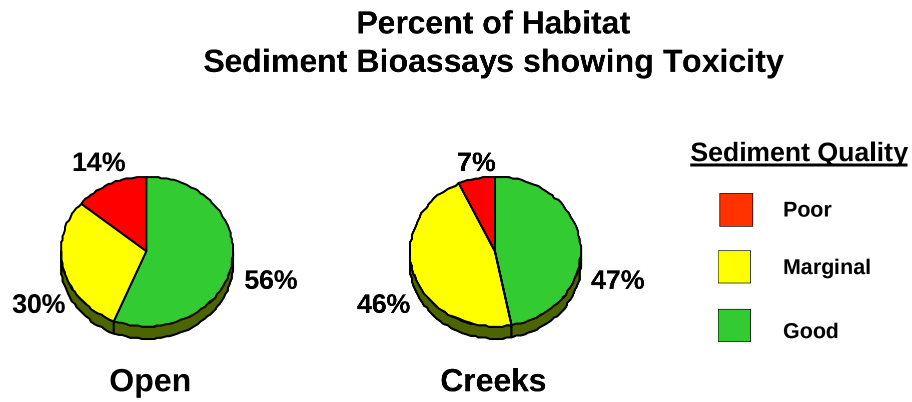


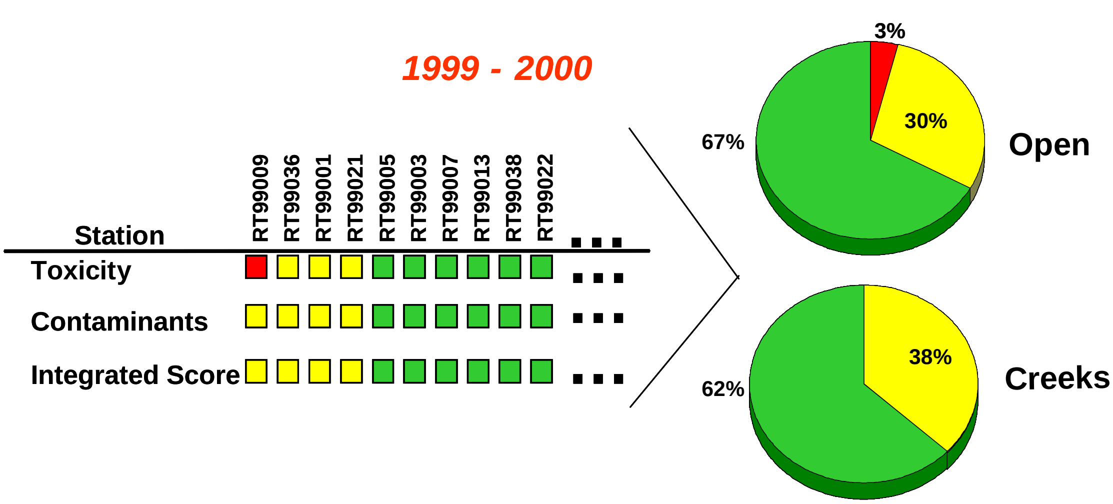
Figure 10. Summary of sediment bioassay results using multiple assays. Two toxic assays represent poor sediment quality, one toxic assay represents marginal sediment quality, and no toxic assays represent good sediment quality.

Integrated Assessment of Sediment Quality

The best estimate of overall sediment quality incorporates the combined measures of sediment contaminant concentrations and the sediment bioassay test results. An overall sediment quality score computed using these measures indicated that none of the state's tidal creek habitat sampled in 1999 - 2000 had poor sediment quality and only about 3% of the state's open water habitat had poor sediment quality (Figure 11). A slightly higher percentage of the state's creek habitat had marginal sediment quality compared to open water areas, but this difference was not significant.

Toxicity tests are used to determine if sediments are detrimental to animal health.

Figure 11. Proportion of South Carolina's estuarine habitat that ranks as good (green), marginal (yellow) or poor (red) using the integrated sediment quality score developed for SCECAP. The left portion of the figure shows examples of how individual stations coded for each sediment quality parameter and the average integrated score for each station based on numerical ratings described by Van Dolah et al. (2002). The right portion of the figure shows the estimated proportion of sediment quality conditions for the entire coastal zone of the state.



Biological Condition

Phytoplankton

Phytoplankton concentrations are measured by SCECAP in the surface waters of South Carolina's estuaries to provide a measure of possible biological response to enriched nutrient concentrations. Because South Carolina does not have any water quality standards that are based on phytoplankton concentrations (measured using chlorophyll-a pigment concentration), SCECAP relies on guidelines that have been published for coastal estuaries by NOAA (Bricker *et al.*, 1999). Using these guidelines, approximately 13% of the state's tidal creek habitat had high phytoplankton concentrations compared to only 3% of the open water habitat (Figure 12). The significantly higher chlorophyll concentrations in tidal creeks may be reflective of the higher nutrient concentrations observed in the creeks, or it may also reflect possible re-suspension of benthic algal mats from the creek bottoms and marsh surfaces that would be less likely to be present in the surface waters of deeper, larger water bodies. Analyses conducted to evaluate whether nutrient concentrations are influencing the chlorophyll-a concentrations showed no clear relationships with total nitrogen (TN) or total phosphorus (TP) concentrations. A stronger relationship between nutrient concentrations and measures of phytoplankton concentrations may become more evident with a larger data set that can be partitioned by tidal stage and time of day. Additional chlorophyll-a data collected through this study and through others studies of harmful algal blooms currently being conducted in South Carolina will provide a much better understanding of what chlorophyll-a concentrations represent "eutrophic" conditions in South Carolina.

Phytoplankton concentrations . . . . provide a measure of possible biological response to enriched nutrient concentrations.

Algal blooms can occur when nutrient concentrations in estuaries are high.

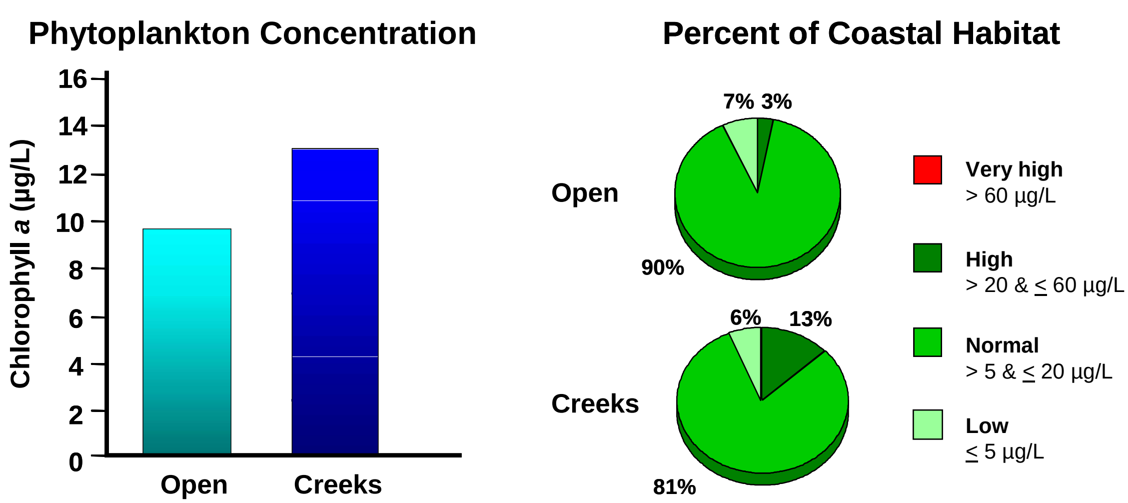


Figure 12. Comparison of the average chlorophyll-a concentrations observed in tidal creek and open water habitats during 1999-2000, and estimates of the percent of the state's coastal habitat representing concentrations that are indicative of possible eutrophication (dark green).

Benthic Communities

Bottom-dwelling (benthic) invertebrate organisms are important because they are near the bottom of the food chain and are common food items for many fish and crustacean species. Benthic organisms are also considered to be excellent indicators of environmental stress because they are sessile and cannot easily avoid exposure to natural or anthropogenic stresses. Characterizing the benthic community in South Carolina coastal habitats is, therefore, essential to the SCECAP program. Using several measures of benthic community condition, Van Dolah *et al.* (1999) recently developed a benthic index of biological integrity (B-IBI) for southeastern estuaries to distinguish between degraded and undegraded environments. Using this B-IBI, the majority of South Carolina's coastal habitat sampled in 1999-2000 had undegraded benthic communities, 12% of both creek and open water habitat showed evidence of some possible degradation, and only 4% of tidal creek habitat and 2% of open water habitat had benthic communities that were degraded (Figure 13).

Benthic organisms are considered to be excellent indicators of environmental stress.

Sediment samples are sieved to collect bottom-dwelling organisms such as the crustacean shown on the left.

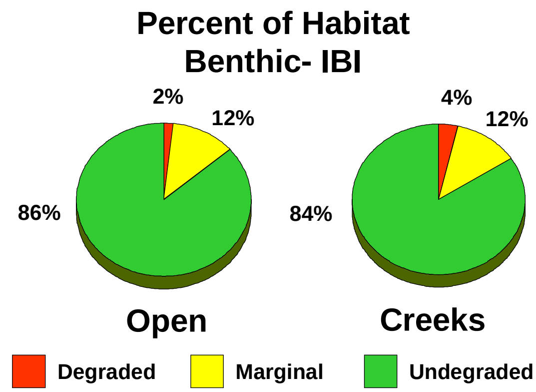


Figure 13. Estimates of the percent of the state's coastal habitat having benthic invertebrate communities representing undegraded, marginally degraded, or degraded conditions.

Finfish and Crustacean Communities

Estuarine waters support a diverse and transitory fish assemblage, with many species often present only during certain seasons or stages of development (Ogburn *et al.*, 1988). Tidal creeks provide critical habitats for many species because these shallow wetland areas supply food, provide refuge from predators, and are valuable habitats that are utilized by the egg, larval, juvenile, and adult stages of a variety of finfish and crustacean species (Joseph, 1973; Mann, 1982; Nelson *et al.*, 1991). Because these organisms are highly motile, they may or may not be suitable as indicators of biotic condition at a particular

Tidal creeks provide food, refuge from predators, and critical habitats for the life cycle development of many species.

Otter trawls are used to collect fish and crustaceans at each site.

Shrimp and spot are typical species collected.

site. However, we consider it important to document the abundance and diversity of the fish and crustaceans at the various sites, with an ultimate objective to define where these communities are limited and, hopefully, develop a second index of biotic integrity using these species. The data are also useful for defining where recreationally and ecologically valuable species are most abundant and diverse, and what specific habitat characteristics are associated with these conditions. Better knowledge of the most productive habitats is critical for protection against human-induced impacts.

The abundance of fish and other organisms was significantly higher in tidal creeks than in open water.

The biota sampled by trawls at tidal creek and open water stations displayed a similar array of species, including many commercially and recreationally important species such as white shrimp, brown shrimp, blue crabs, and spot. Other important species collected in lower abundances included silver perch, Atlantic croaker, weakfish, Atlantic spadefish, mullet, summer flounder, ladyfish, spotted sea trout, pink shrimp, southern flounder, white catfish, Atlantic sharpnose shark, sea catfish, Spanish mackerel, black sea bass, American shad and southern kingfish (whiting). Some of these species are not commonly harvested recreationally in South Carolina, but they are recreationally important in other areas and many are kept as incidental catch by fishermen in this state.

The abundance, biomass and diversity (number of species) of the fish, crustaceans, and other organisms collected in the trawls was significantly higher at tidal creek stations compared to open water stations (Figure 14). This indicates that different criteria should be used for each habitat type when defining whether conditions are poor or normal for these measures. SCECAP staff have identified the 25th and 10th percentile values representing each of these measures in both creek and open water habitats based on the sampling conducted to date (Van Dolah *et al.*, 2002). As more sites are sampled, these threshold values will be refined and evaluated for possible incorporation into an index of biotic integrity.

Contaminant levels in selected fish species were also evaluated beginning in 2000. All of the tissue samples had detectable levels of some contaminants, but only one site (Shipyard Creek, an industrialized drainage basin in Charleston Harbor) had levels that were especially high for fluorene and anthracene, two polycyclic aromatic hydrocarbons. None of the contaminants exceeded Food and Drug Administration (FDA) criteria for safe consumption. In a recent report, the USEPA suggested that southeastern estuaries

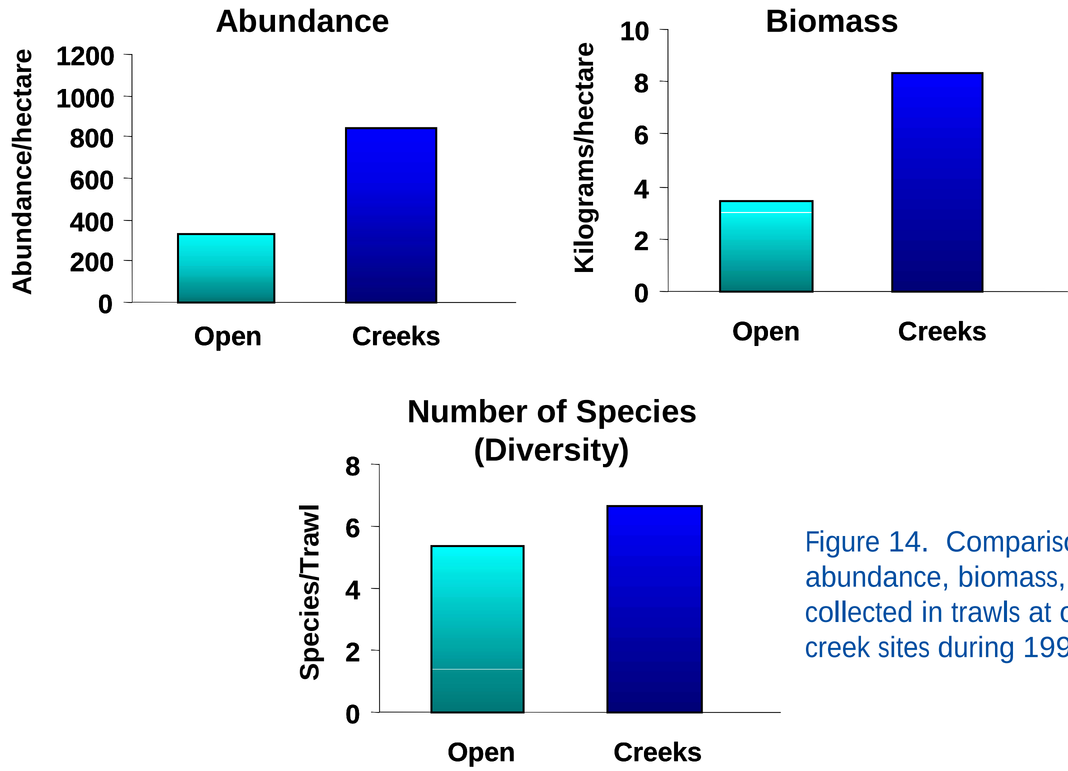


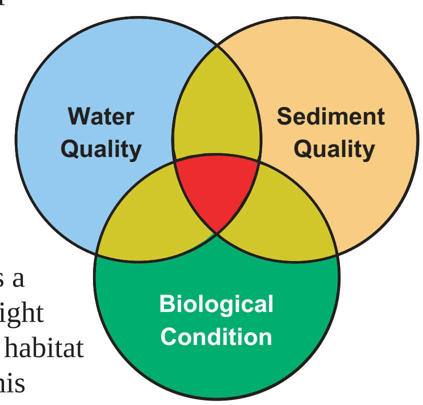
Figure 14. Comparison of the average abundance, biomass, and number of species collected in trawls at open water versus tidal creek sites during 1999-2000.

generally had low tissue contaminant levels compared to the northeast, gulf and west coast regions (USEPA, 2001). The results from the SCECAP data set, although limited to only one year of data, support this evaluation.

Integrated Measure of South Carolina's Estuarine Habitat Quality

A major goal of the SCECAP program is to combine our integrated measures of water quality, sediment quality and biotic condition into an overall assessment of habitat condition at each site sampled, and for the entire coastal zone of South Carolina. An integrated measure of habitat condition is preferred since it provides a better "collective" description of the condition. For example, it is possible for some areas to have poor or marginal water quality based on state standards or historical data, but the conditions may not result in any clear evidence of degraded biotic communities. Many of the state's water quality standards are intentionally conservative to be protective and some contravention of preferred conditions are not severe enough to be a problem. Similarly, marginal or poor sediment quality may not result in degraded biotic condition because the organisms are either not directly exposed to the sediments (e.g. phytoplankton, fish) or because the contaminants are not readily available to the animals. Additionally, some of the more motile organisms may only be exposed temporarily due to their transient movements. When two of the three measures (e.g. water quality and biotic condition) are marginal or poor, there is greater certainty that the habitat may be limiting. When all three measures (e.g. water, sediment, and biota) show evidence of degradation, there is a relatively strong weight of evidence that the habitat is compromised. This "triad" approach to measuring overall habitat quality is commonly used in many monitoring programs assessing the health of coastal environments (e.g. Chapman, 1990; Chapman *et al.*, 1991; USEPA, 2001).

When all three measures (water, sediment, and biota) show evidence of degradation, there is . . strong . . evidence that the habitat is compromised.



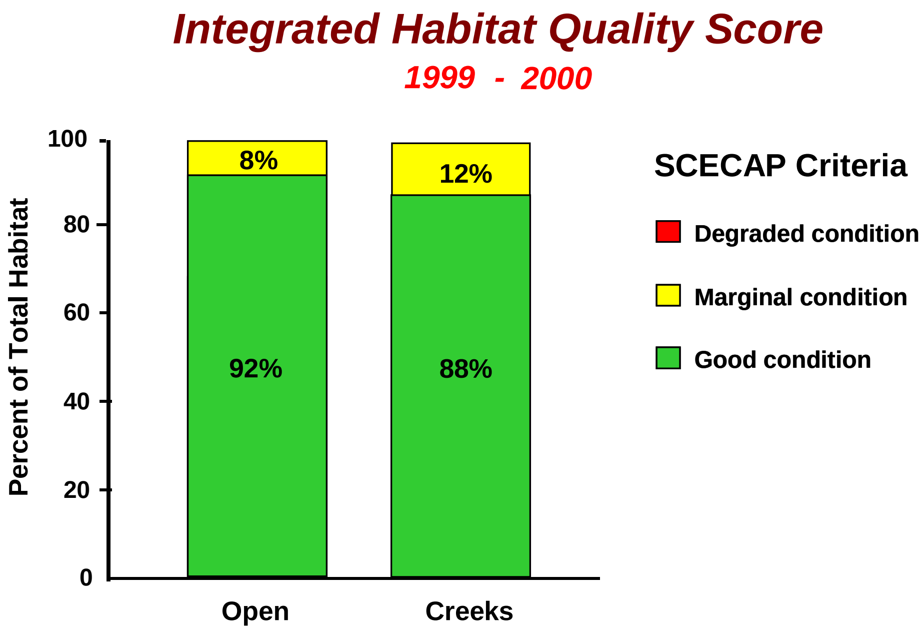
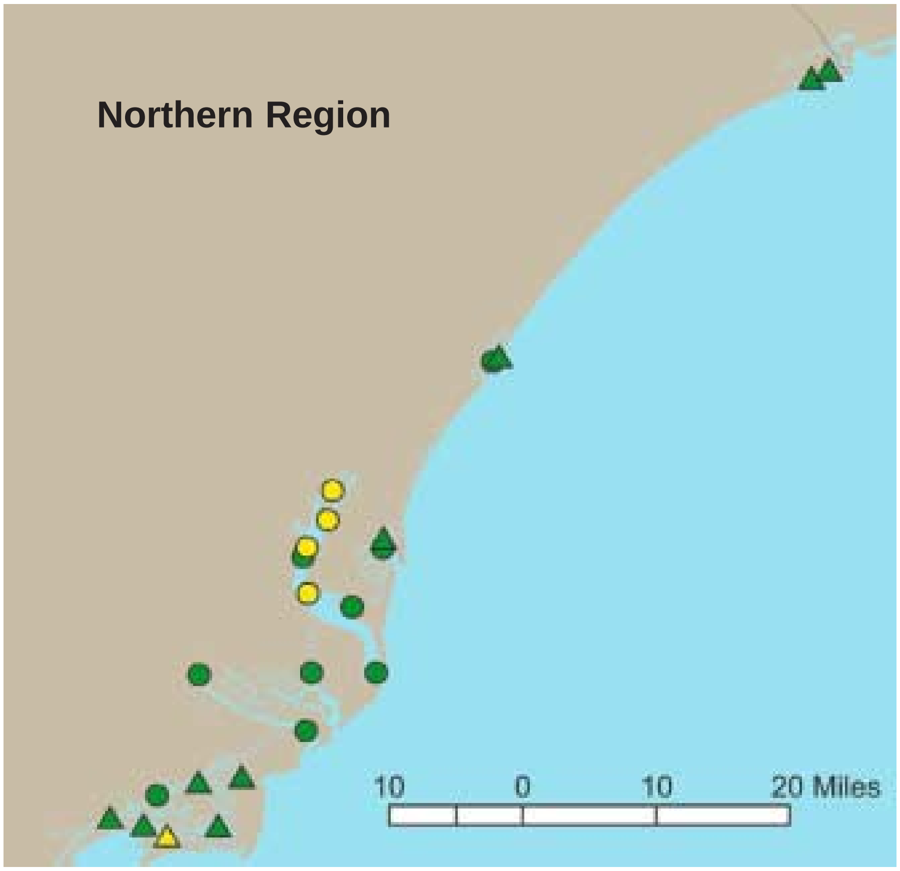


Figure 15. Estimated percentage of South Carolina's estuarine tidal creek and open water habitat that is in good or marginal condition using an average of water, sediment, and biological quality scores developed for SCECAP.

Until more biological data can be collected to define water or sediment quality conditions that result in enriched phytoplankton assemblages, or poor conditions in finfish and crustacean assemblages in South Carolina habitats, the SCECAP program will rely primarily on the Benthic Index of Biotic Integrity (B-IBI) developed for the southeastern region as the best measure of biotic condition. The B-IBI developed for this region has been demonstrated to have a high correspondence with sediment quality conditions.

The integrated measure of habitat quality used for the 1999-2000 assessment of South Carolina's coastal zone indicated that only approximately 12% of South Carolina's tidal creek habitat and 8% of the open water habitat was marginal in quality (Figure 15). None of the state's coastal waters coded as poor based on the stations sampled in 1999 and 2000. The slightly higher incidence of marginal tidal creek habitat compared to open water areas is probably due to a combination of several factors, including closer proximity to upland sources of human-related impacts and greater natural variability in some of the variables measured. As previously noted, many of the water quality threshold values used for this study period are based on historical measurements that were largely collected from larger water bodies in the state rather than from tidal creeks. Higher nutrients and greater oxygen variability may result in some of those sites coding as marginal or poor for water quality, but only about 31% of those stations also had degraded benthic communities. Similarly, only 36% of the stations with marginal



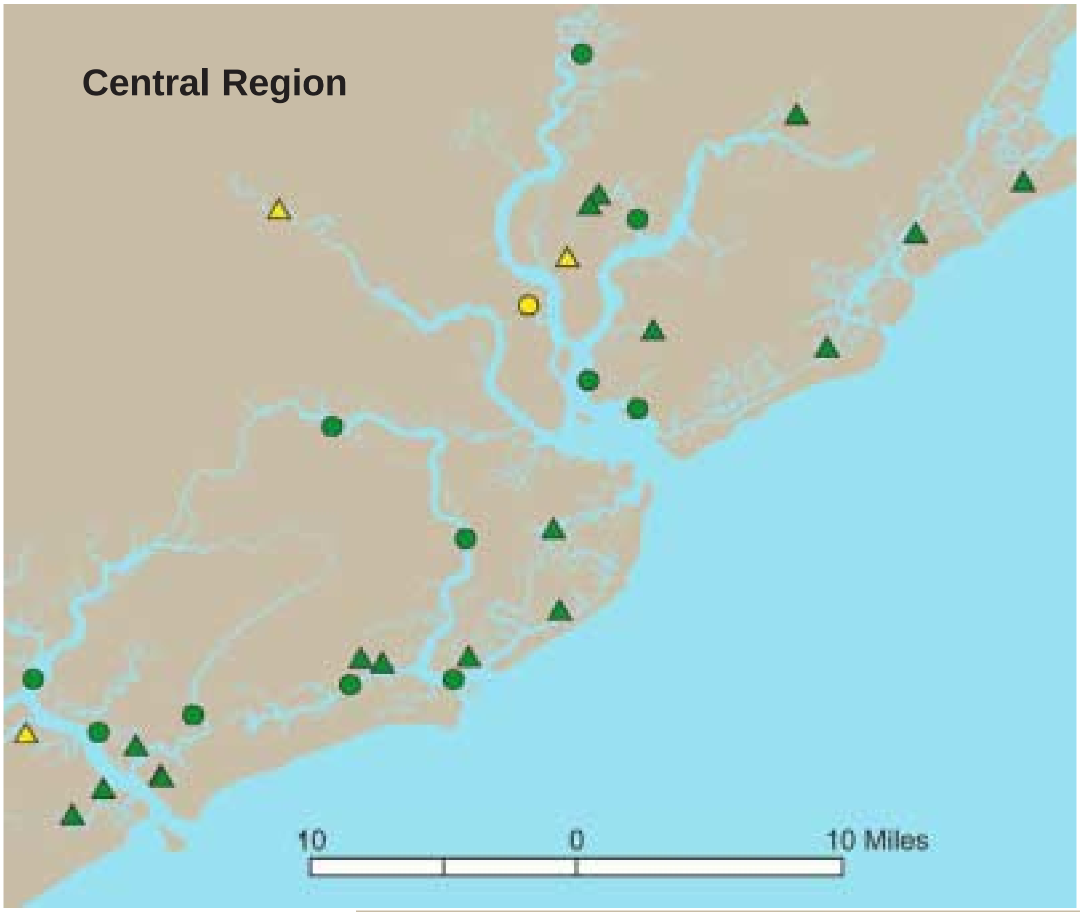
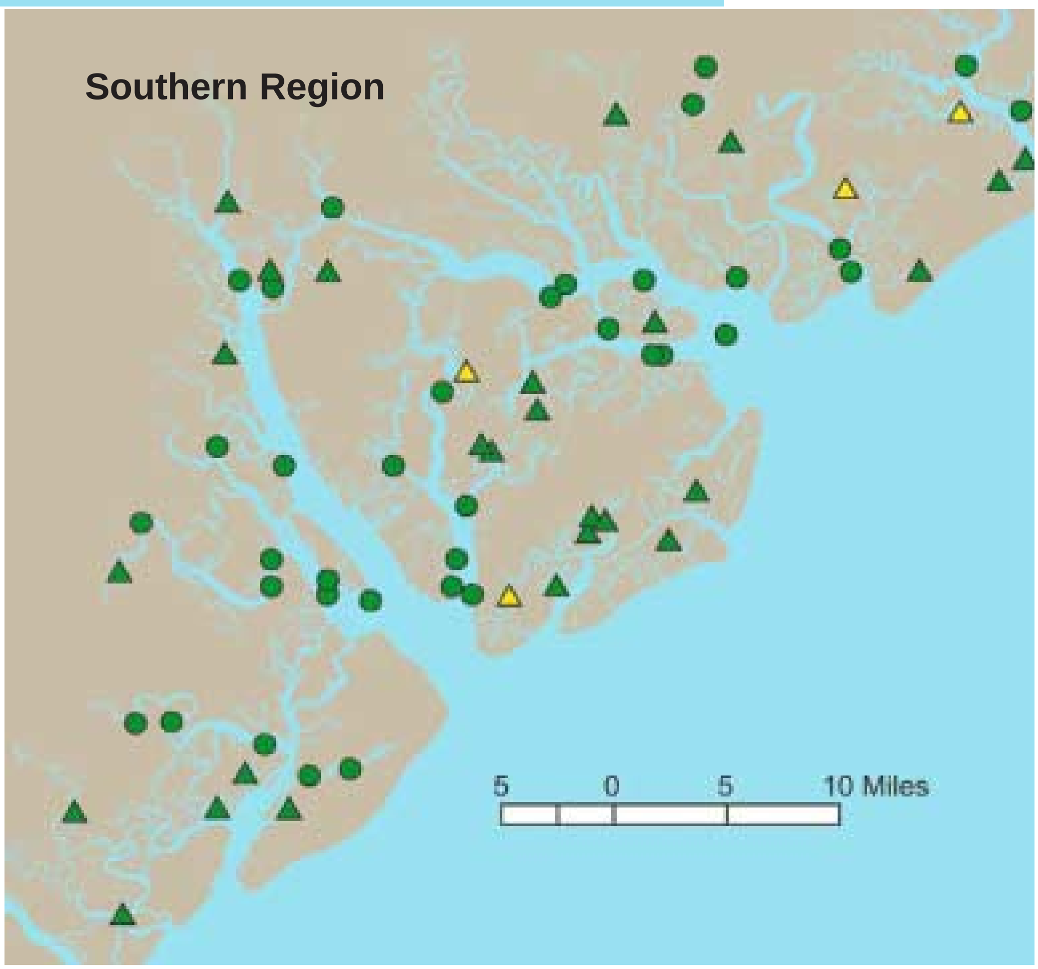
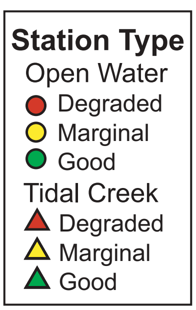


Figure 16. Distribution of open water and tidal creek stations sampled in the northern, central, and southern portion of the State during 1999-2000 that had an overall habitat quality score of “good” or “marginal” based on an integrated measure of water quality, sediment quality and biological condition.





or poor sediment quality also had evidence of a degraded benthic community.

Four of the five marginal stations found in the northern portion of the state were located in Winyah Bay, which is highly industrialized and has commercial port facilities (Figure 16). All but one of those had poor sediment quality and marginal or poor benthic condition, but good water quality. The other marginal site was located in Key Creek off the lower portion of Five Fathom Creek in the Cape Romain area. This site had marginal water quality, sediment quality, and a marginal biotic condition, but there was no clear source of anthropogenic input.

None of the state's coastal waters had a combination of poor water quality, poor sediment quality, and poor biotic condition in 1999 and 2000.

Three of the four sites that coded as marginal in the central portion of the state were located in tidal creeks (Figure 16). All three had poor or marginal water quality, two had poor sediment quality, and two had poor biotic condition along with either poor water quality and/or poor sediment quality. The one open water site that coded as marginal was located in Shipyard Creek, where both industrial and port facilities are located. This site had acceptable water quality, but poor sediment quality and a marginal benthic index.

Even though the majority of stations sampled in 1999-2000 were located in the southern portion of the state, only three tidal creek stations coded as having a marginal overall habitat quality (Figure 16). One of these sites was located near upland development in the Beaufort River. The other two were not very close to developed upland areas and had no clear source of anthropogenic input. The lower incidence of marginal stations in the southern portion of the state may in part be due to the higher tidal flushing in those areas. Additionally, many of the sites sampled in that portion of the state were located in relatively pristine locations, such as the ACE Basin National Estuarine Research Reserve (NERR). More information on each site, and the specific coding of the water quality, sediment quality and B-IBI scores is available in Van Dolah *et al.* (2002).

Some sites near industrial and urban development were found to have marginal habitat quality.

CONCLUSIONS

Results obtained from the 1999-2000 SCECAP survey indicate that most of South Carolina's estuarine habitats are in good condition. Portions of the state's estuaries that coded as marginal were primarily located in developed watersheds, although a few sites had no obvious sources of human influence. Future sampling in subsequent years will provide an indication of whether habitat quality throughout the state is similar over time, or getting worse with increased coastal development pressures. Future sampling will also provide an opportunity to evaluate conditions within some of the larger drainage basins, such as Winyah Bay, Charleston Harbor, Port Royal Sound, or within specific areas of interest such as Georgetown County, Charleston County, Beaufort County, etc., once a large enough database is available. Criteria for defining marginal or poor conditions with respect to the various water quality, sediment quality, and biological measures also will be refined once a larger data set is available.

Finally, the data obtained from the 1999-2000 survey, combined with future data to be collected by the SCECAP program, provides a valuable database on the environmental and biological conditions in tidal creek and open water habitats located in both pristine areas and sites near industrial and residential development. Other studies targeting special areas of concern should find this database extremely useful for comparison with "normal" conditions representing relatively pristine habitats throughout the state's coastal zone, or in a sub-region of the state. The data also provide a better understanding of what values represent normal versus unusual conditions with respect to the various water quality, sediment quality and biological measures considered. This is particularly important for tidal creek habitats, which show clear differences in many of these measures compared to the same measures taken in the larger open water bodies that have been traditionally sampled by the SCDHEC and SCDNR.

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