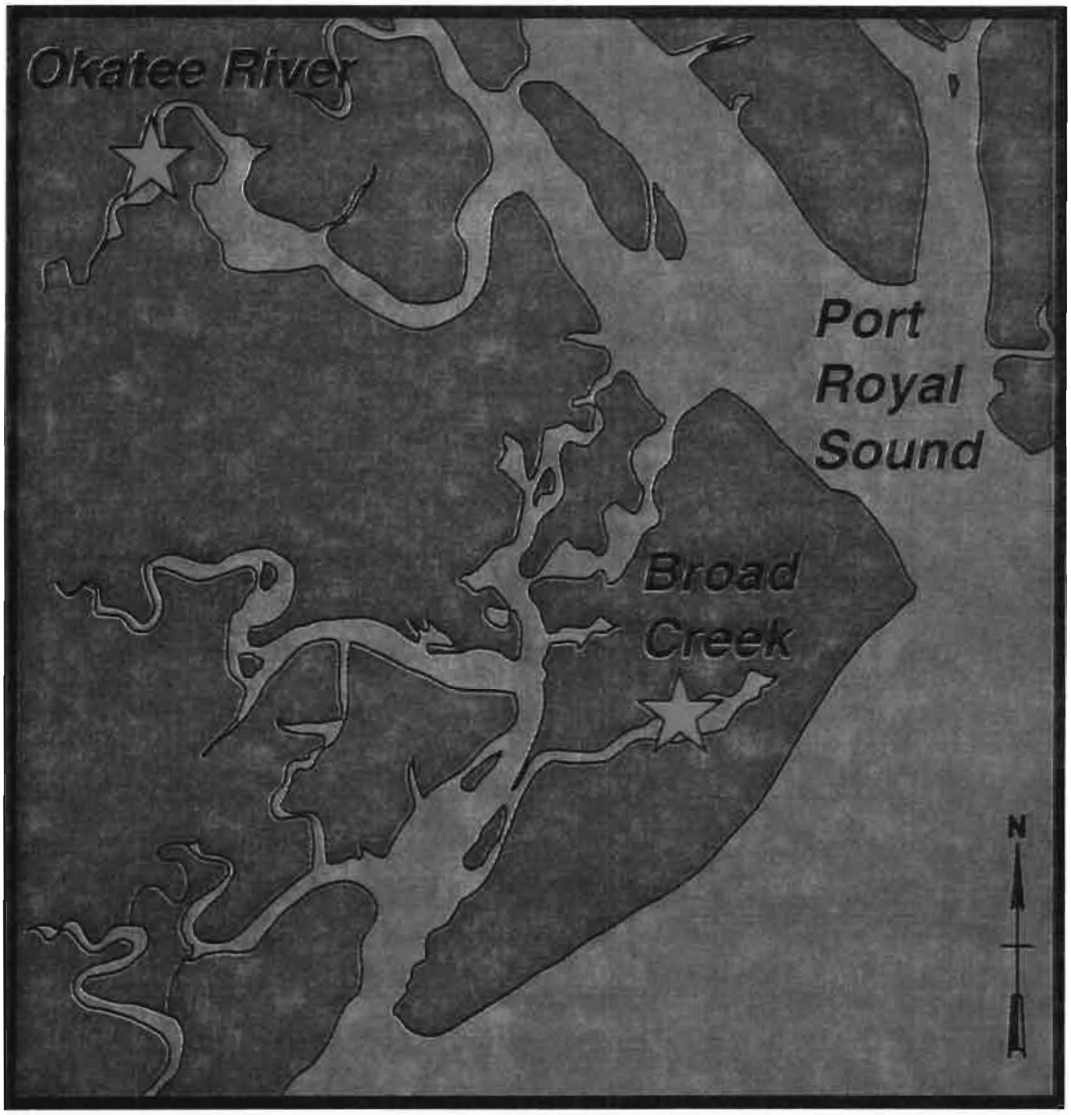
A Baseline Assessment of Environmental and Biological Conditions in Broad Creek and the Okatee River, Beaufort County, South Carolina



Final Report

Prepared by:
South Carolina Department of Health and Environmental Control
South Carolina Department of Natural Resources
NOAA, National Ocean Service

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South Carolina Department of Health and Environmental Control

Final Report

A Baseline Assessment of Environmental and Biological Conditions in Broad Creek and the Okatee River, Beaufort County, South Carolina

Submitted To:

The Beaufort County Council

Edited By:

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Chapter 1
Introduction

By
R.F. Van Dolah and C.E. Sansbury

In 1995, a group of concerned citizens in Beaufort County, now called the "Clean Water Task Force" (CWTF), became alarmed about the increasing closure of estuarine water to shellfish harvesting in their County. This concern led to a meeting with then Governor David Beasley and the South Carolina Department of Health and Environmental Control (SCDHEC) Commissioner, Mr. Doug Bryant, who endorsed the CWTF efforts and agreed to work with that group to address their concerns (CWTF, 1997).

The CWTF convened several meetings in 1996 which brought together concerned citizens, agency staff, and technical experts to discuss and evaluate concerns related to urban development and other land use practices, the effects of point and non-point source runoff into coastal wetlands, boating impacts, methods to control storm water discharges into coastal waters, and programs being conducted by SCDHEC and other agencies to monitor and assess water quality in South Carolina. The CWTF then prepared a final report entitled, *A Blueprint for Clean Water. Strategies to Protect and Restore Beaufort County's Waterways* (CWTF, 1997). This report listed ten major steps and other recommendations that the County and its municipalities should undertake to improve Beaufort County water bodies, with assistance from appropriate state and other government agencies.

One major recommendation was for Beaufort County and the Town of Hilton Head Island to contribute to the performance of a baseline assessment of Broad Creek and the Okatee River. The Broad Creek watershed has extensive urban and suburban development that drains into a relatively small water body. The Okatee River is a comparably sized and relatively undeveloped watershed, but existing and planned developments may significantly alter the character of this water body in the future. The recommended study would be conducted by SCDHEC, the South Carolina Department of Natural Resources (SCDNR) and the National Marine Fisheries Service (NMFS), Charleston Laboratory, which is now part of NOAA's National Ocean Service (NOS).

A scope of work was submitted and approved by the County and the CWTF in 1996. The study was initiated during the summer of 1997 through joint funding provided by the Beaufort County Council and SCDHEC. The study design involved a comprehensive sampling effort to assess water quality, sediment quality, and biological condition in both Broad Creek and the Okatee River using identical sampling protocols. The primary objective of this study was to provide a better understanding of existing conditions in different habitats of each drainage system using an unbiased sampling design. The study was not designed to target specific activities, such as evaluating the effects of marinas, boating activities, urban runoff, etc. Rather, it was designed to evaluate the integrated effects of all activities that may affect the quality of these water bodies. Details of the study design and findings are provided in the following chapters.

Chapter 2
Study Area

By
D.E. Chestnut, R.F. Van Dolah, M. Rhodes

Description of the Study Area:

Both Broad Creek and the Okatee River are located in the Coastal Plains region of South Carolina in Beaufort County. For the purpose of this study, the upper portion of the Okatee River drainage system was selected to assess overall environmental quality and biological condition because it was comparable in size to the Broad Creek estuary. However, most existing Geographic Information System (GIS) land-use data layers available for these drainage systems encompass the entire hydrologic unit (14 digit HUC), which for the Okatee River includes areas not encompassed by the study area. The HUC for Broad Creek generally includes only the study area. Therefore we have utilized the HUC boundary for characterizing land cover features of both systems.

The two primary GIS data sources that were utilized to characterize both drainage systems were the Coastal Change Analysis Program (CCAP) data (Figures 2.1 and 2.3) and the National Wetlands inventory (NWI) of 1989 enhanced by 1994 aerial photography (Figures 2.2 and 2.4). The CCAP data omitted a small portion of land cover data in the upper extent of the Okatee River drainage system which was located in Jasper County. However, the NWI data included this section of the drainage area. Because of differences in the land use classification schemes between these two covers, these different sources of land use information are not directly comparable. Another data source utilized was the Beaufort County Tax Parcel Map and associated database.

Broad Creek drains the major area of Hilton Head Island in the southwestern portion of Beaufort County, SC. The NWI land use data shows the Broad Creek drainage as heavily urbanized, with approximately 80% of the upland area having residential and industrial development (Figure 2.2, Table 2.1). Based on tax map parcel information, the Broad Creek drainage area has more than 30% impervious surface, with roughly half of that being transportation related (Table 2.1, Milt Rhodes, 1999). The bulk of the remaining upland area is classified as forest.

Although the Okatee River is located only a few miles from Hilton Head, the drainage area includes a much lower percentage of impervious surface (15%) and transportation-related impervious surface area (2%) relative to Broad Creek (32% and 16% respectively) based on the tax map parcel data (Table 2.1). The NWI data also indicates a greater amount of agricultural lands than Broad Creek (Table 2.1, Figure 2.4), but with the vast majority of upland area classified as forest.

Despite a large difference in total watershed area, both drainage systems have very similar percentages of wet habitat in terms of open water and estuarine wetlands

(Table 2.1). Tax map parcels also show a surprising similarity in the percentage of upland (taxable) area.

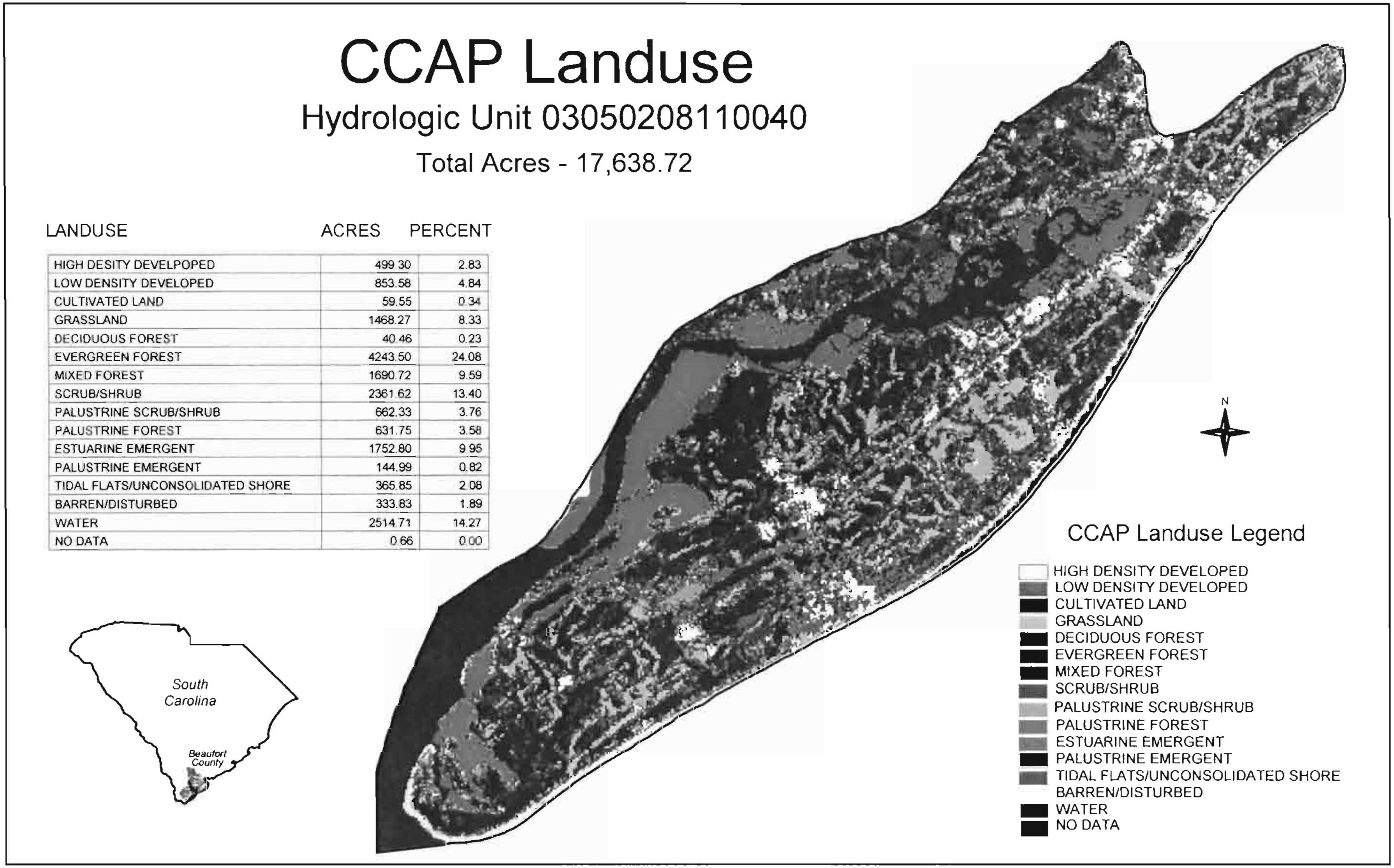
The differences in the amount of residential and industrial development in Broad Creek versus the Okatee River are also evident in the amount of treated wastewater permitted for land application under State permits or direct discharge permitted under the National Pollutant Discharge Elimination System (NPDES) permits and the number of public water supply wells in each watershed. In the Okatee River watershed, there are only three permitted discharges, all of which are land application/spray field no discharge (ND) permits with a total permitted discharge of 0.444 million gallons per day (MGD) (Table 2.2, Figure 2.5) and only 13 public drinking water supply wells (Table 2.3, Figure 2.5). In contrast, the Broad Creek watershed has five 5 permitted discharges, one NPDES direct discharge and four land application/spray field no discharge (ND) permits with a total permitted discharge of 11.19 MGD, and 28 public drinking water supply wells (Tables 2.2 and 2.3, Figure 2.6). Within the Broad Creek watershed, none of the permitted discharges, ND or NPDES, are direct discharges to Broad Creek.

Another reflection of the different development histories in the two drainage systems is in the number of known contaminated groundwater sites. There are only four known contaminated sites in the Okatee River watershed (3 due to underground storage tanks, Table 2.4), and a total of 22 in the Broad Creek watershed (20 due to underground storage tanks and one due to an above -ground storage tank).

General Sampling Strategy:

Due to the diversity of habitats in each area and the likelihood that some habitats are more impacted by land use activities than others, each drainage system was divided into six discrete segments (strata) for sampling (Figures 2.7 and 2.8). These segments each encompassed approximately 1300 meters of mainstem channel in each estuary, beginning at the headwaters and ending at a point where the waters drain into a larger water body. All segments were approximately equal in length. Within each segment, one subtidal river water site (designated as "R"), one tidal creek (designated as "T"), and one oyster bed (designated as "O") were randomly selected. The tidal creeks sampled were of comparable type and were limited to those which receive drainage directly from upland areas. Note that Broad Creek tidal creek site T-2 actually originates in segment number one and has its discharge to Broad Creek near the boundary between segments one and two. No suitable tidal creeks could be found entirely within segment two. Three of the six segments in each drainage system also included one randomly placed intertidal river station (in Broad Creek, segments 1, 4, and 6; in the Okatee River, segments 2, 4, and 6).

The primary objective of this study was to provide a better understanding of existing conditions in different habitats of each drainage system using an unbiased sampling design. The study was not designed to target specific activities, such as evaluating the effects of marinas, boating activities, urban runoff, etc. Rather, it was designed to evaluate the integrated effects of all activities that may affect the quality of these water bodies. The sampling was restricted to the summer months to maximize comparison with existing databases. This is also a period when some water quality variables, such as dissolved oxygen and nutrient concentrations, can be at their worst levels. The sampling effort to assess water quality, sediment quality and biological conditions in the various habitats and river segments is described in detail in the following chapters.



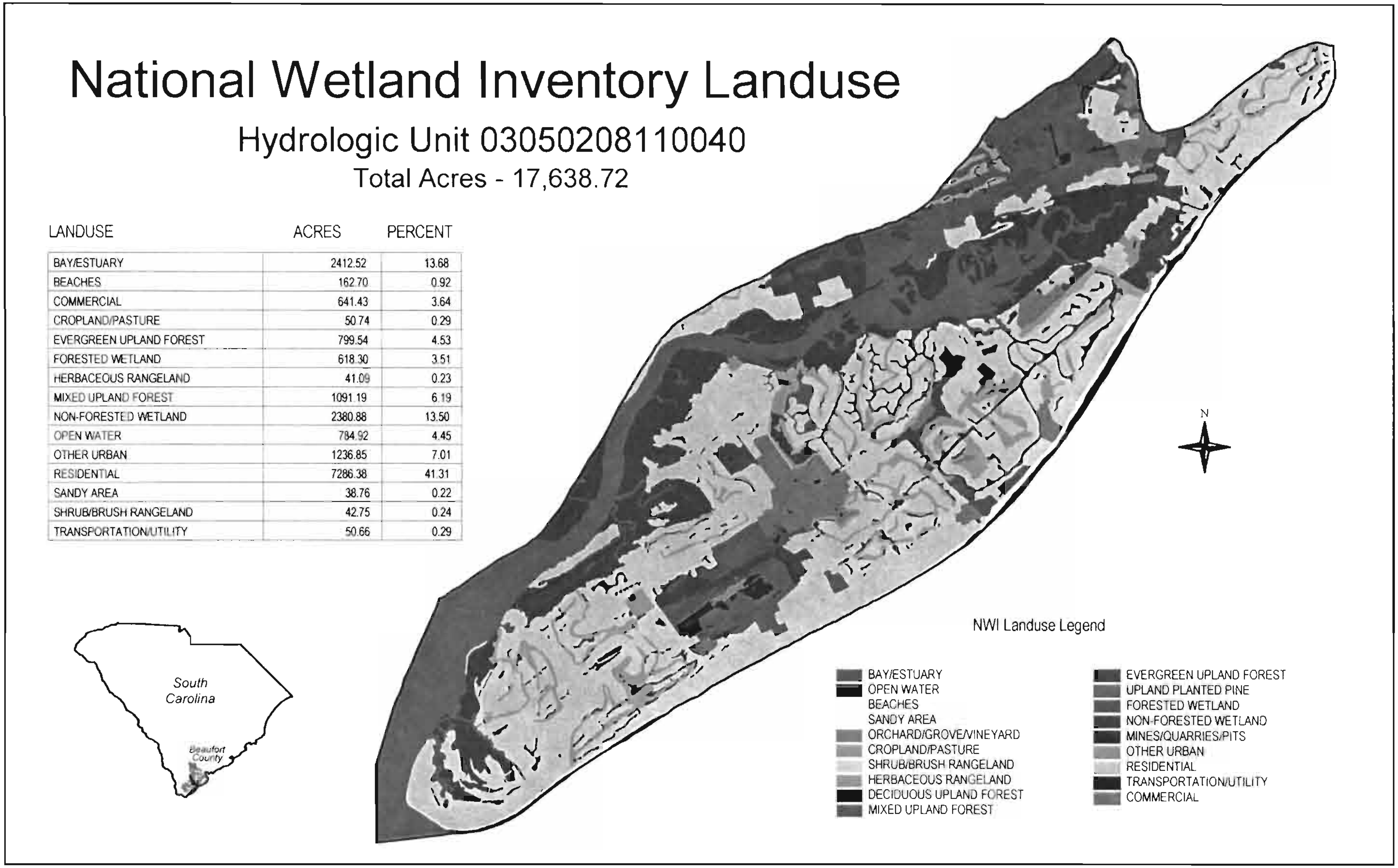
CCAP Landuse

Hydrologic Unit 03050208110040

Total Acres - 17,638.72

LANDUSE	ACRES	PERCENT
HIGH DESITY DEVELPOPED	499 30	2.83
LOW DENSITY DEVELOPED	853.58	4.84
CULTIVATED LAND	59.55	0.34
GRASSLAND	1468.27	8.33
DECIDUOUS FOREST	40.46	0.23
EVERGREEN FOREST	4243.50	24.08
MIXED FOREST	1690.72	9.59
SCRUB/SHRUB	2361.62	13.40
PALUSTRINE SCRUB/SHRUB	662.33	3.76
PALUSTRINE FOREST	631.75	3.58
ESTUARINE EMERGENT	1752.80	9.95
PALUSTRINE EMERGENT	144.99	0.82
TIDAL FLATS/UNCONSOLIDATED SHORE	365.85	2.08
BARREN/DISTURBED	333.83	1.89
WATER	2514.71	14.27
NO DATA	0.66	0.00

Figure 2.1. Coastal Change Analysis Program (CCAP) landuse classification for lower Hilton Head Island watershed.



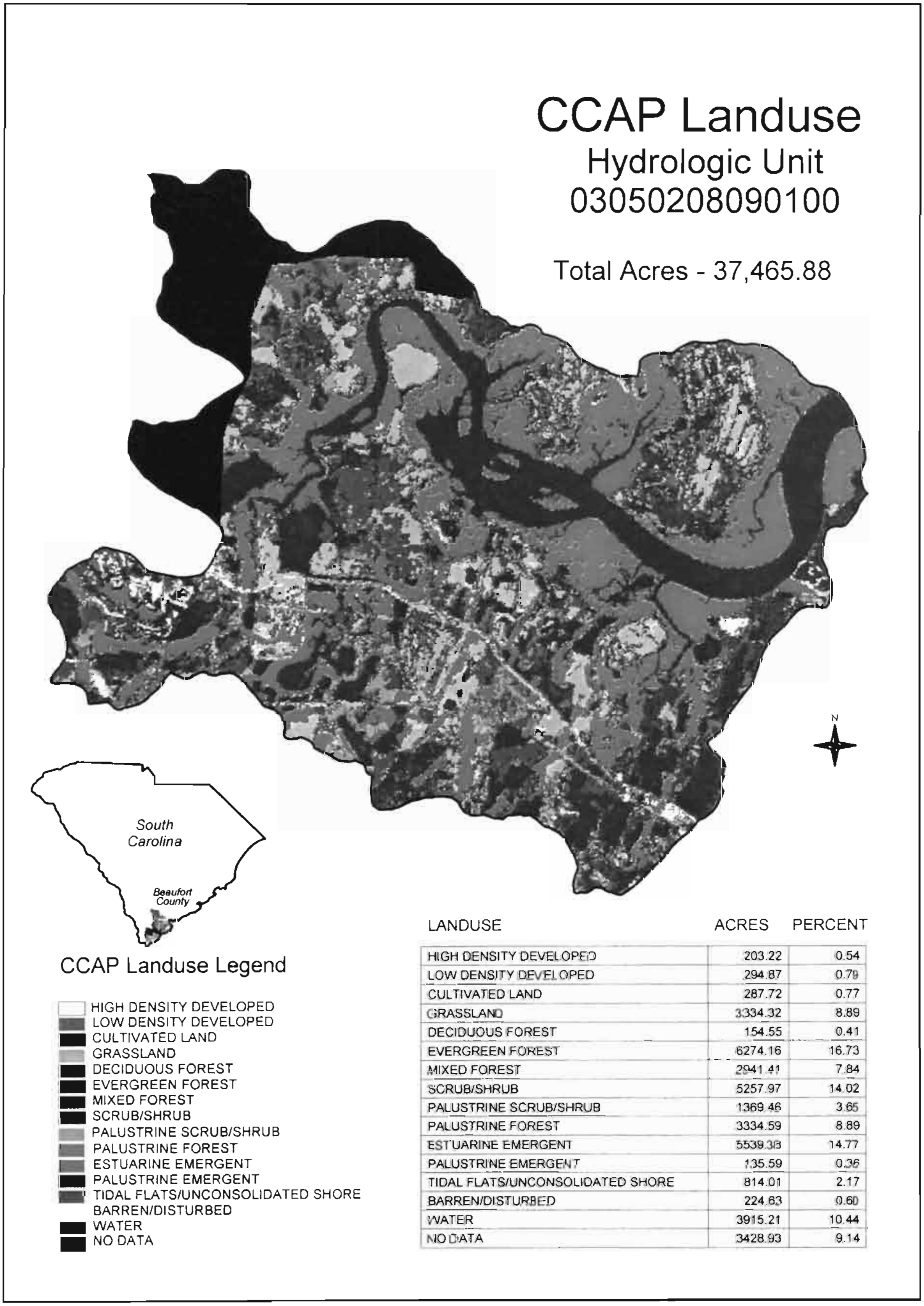
National Wetland Inventory Landuse

Hydrologic Unit 03050208110040

Total Acres - 17,638.72

LANDUSE	ACRES	PERCENT
BAY/ESTUARY	2412.52	13.68
BEACHES	162.70	0.92
COMMERCIAL	641.43	3.64
CROPLAND/PASTURE	50.74	0.29
EVERGREEN UPLAND FOREST	799.54	4.53
FORESTED WETLAND	618.30	3.51
HERBACEOUS RANGELAND	41.09	0.23
MIXED UPLAND FOREST	1091.19	6.19
NON-FORESTED WETLAND	2380.88	13.50
OPEN WATER	784.92	4.45
OTHER URBAN	1236.85	7.01
RESIDENTIAL	7286.38	41.31
SANDY AREA	38.76	0.22
SHRUB/BRUSH RANGELAND	42.75	0.24
TRANSPORTATION/UTILITY	50.66	0.29

Figure 2.2. National Wetlands Inventory (NWI) landuse classification for lower Hilton Head Island watershed.



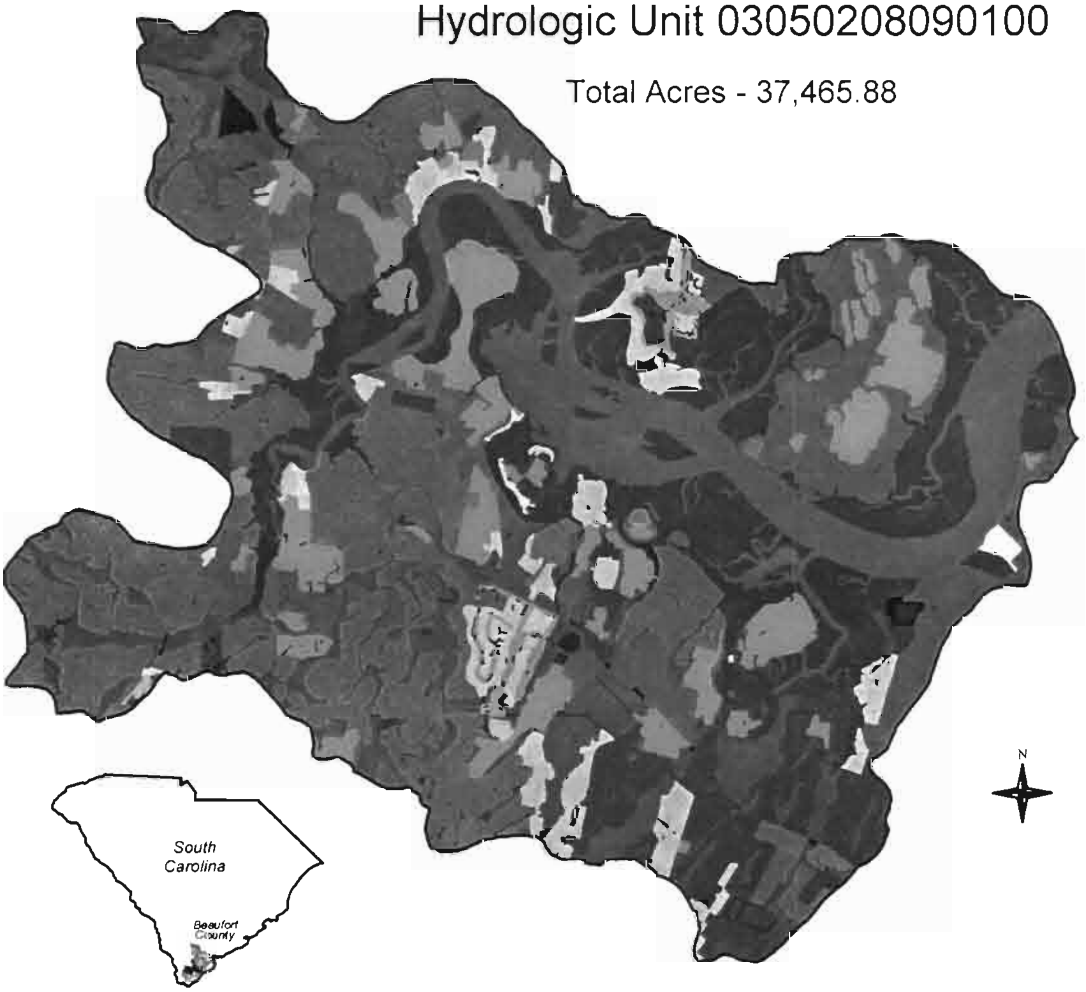
LANDUSE	ACRES	PERCENT
HIGH DENSITY DEVELOPED	203.22	0.54
LOW DENSITY DEVELOPED	294.87	0.79
CULTIVATED LAND	287.72	0.77
GRASSLAND	3334.32	8.89
DECIDUOUS FOREST	154.55	0.41
EVERGREEN FOREST	6274.16	16.73
MIXED FOREST	2941.41	7.84
SCRUB/SHRUB	5257.97	14.02
PALUSTRINE SCRUB/SHRUB	1369.46	3.65
PALUSTRINE FOREST	3334.59	8.89
ESTUARINE EMERGENT	5539.38	14.77
PALUSTRINE EMERGENT	135.59	0.36
TIDAL FLATS/UNCONSOLIDATED SHORE	814.01	2.17
BARREN/DISTURBED	224.63	0.60
WATER	3915.21	10.44
NO DATA	3428.93	9.14

Figure 2.3. Coastal Change Analysis Program (CCAP) landuse classification for the Okatee River watershed. Note unclassified portion of watershed located in Jasper County.

National Wetland Inventory Landuse

Hydrologic Unit 03050208090100

Total Acres - 37,465.88



NWI Landuse Legend

- ▨ BAY/ESTUARY
- ▨ OPEN WATER
- BEACHES
- SANDY AREA
- ▨ ORCHARD/GROVE/VINEYARD
- ▨ CROPLAND/PASTURE
- ▨ SHRUB/BRUSH RANGELAND
- ▨ HERBACEOUS RANGELAND
- ▨ DECIDUOUS UPLAND FOREST
- ▨ MIXED UPLAND FOREST
- ▨ EVERGREEN UPLAND FOREST
- ▨ UPLAND PLANTED PINE
- ▨ FORESTED WETLAND
- ▨ NON-FORESTED WETLAND
- ▨ MINES/QUARRIES/PITS
- ▨ OTHER URBAN
- ▨ RESIDENTIAL
- ▨ TRANSPORTATION/UTILITY
- ▨ COMMERCIAL

LANDUSE	ACRES	PERCENT
BAY/ESTUARY	4132.39	11.03
BEACHES	55.13	0.15
COMMERCIAL	275.27	0.73
CROPLAND/PASTURE	3418.99	9.13
DECIDUOUS UPLAND FOREST	109.27	0.29
EVERGREEN UPLAND FOREST	3549.96	9.48
FORESTED WETLAND	4226.22	11.28
MINES/QUARRIES/PITS	32.43	0.09
MIXED UPLAND FOREST	5532.96	14.77
NON-FORESTED WETLAND	6663.40	17.79
OPEN WATER	220.43	0.59
ORCHARD/GROVE/VINEYARD	76.32	0.20
OTHER URBAN	343.20	0.92
RESIDENTIAL	1766.82	4.72
SANDY AREA	41.30	0.11
SHRUB/BRUSH RANGELAND	172.83	0.46
TRANSPORTATION/UTILITY	51.09	0.14
UPLAND PLANTED PINE	6797.88	18.14

Figure 2.4. National Wetlands Inventory (NWI) landuse classification for the Okatee River watershed. Note Jasper County portion of watershed is included and classified.

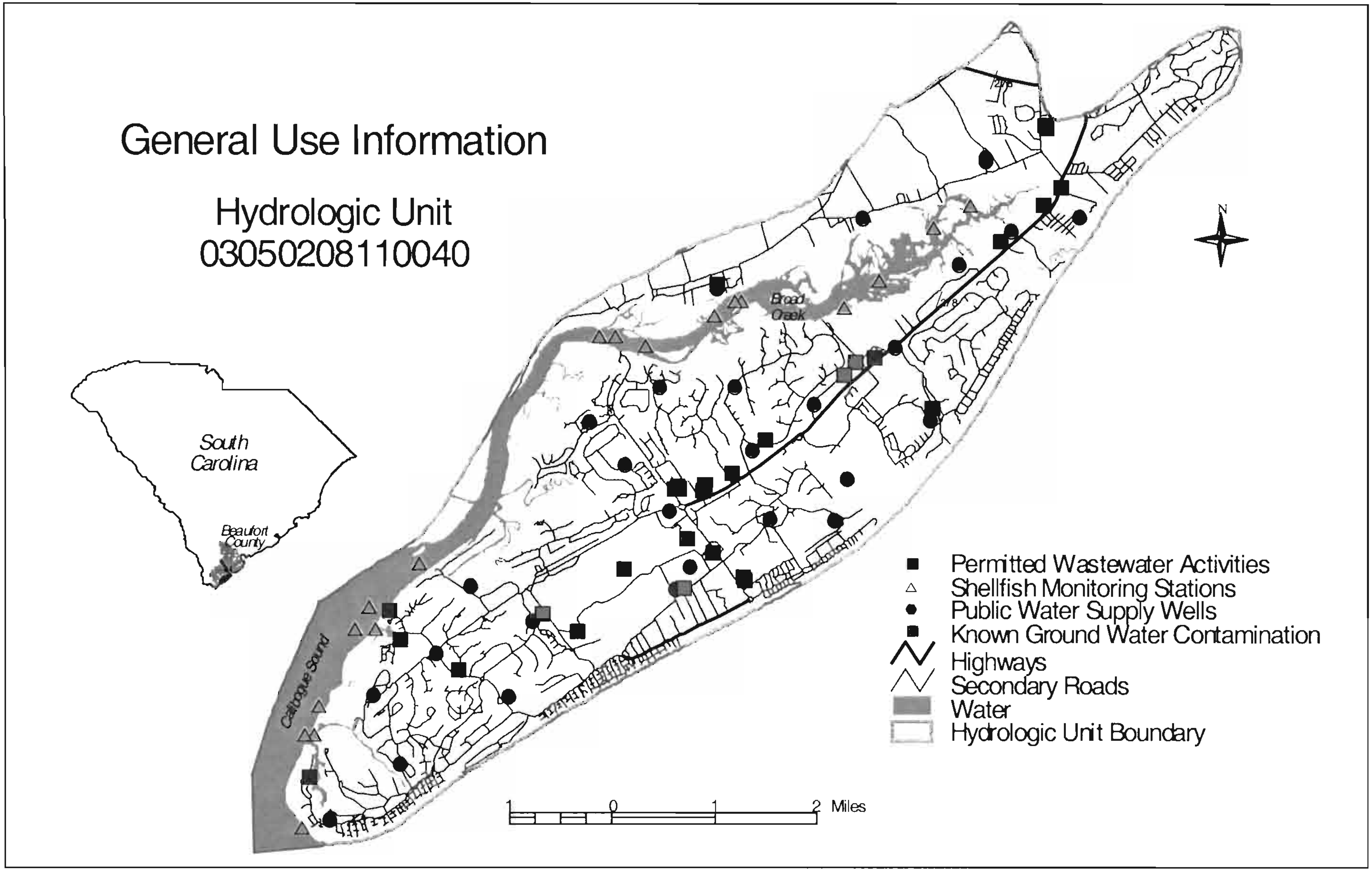


Figure 2.5. Location of other specific development related features and shellfish monitoring sites in the lower Hilton Head Island watershed (see text).

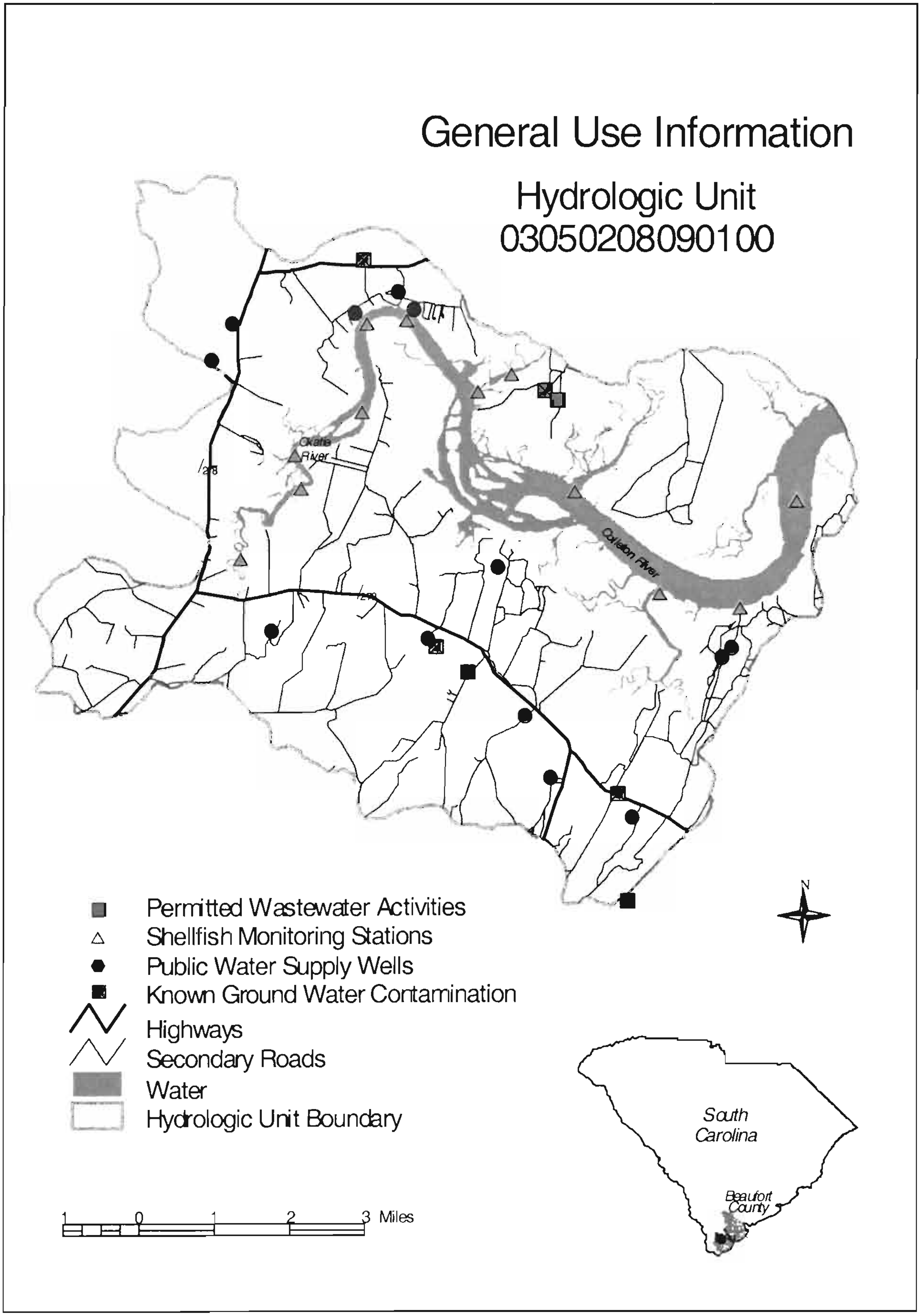


Figure 2.6. Location of other specific development related features and shellfish monitoring sites in the Okatee River watershed (see text).

Broad Creek

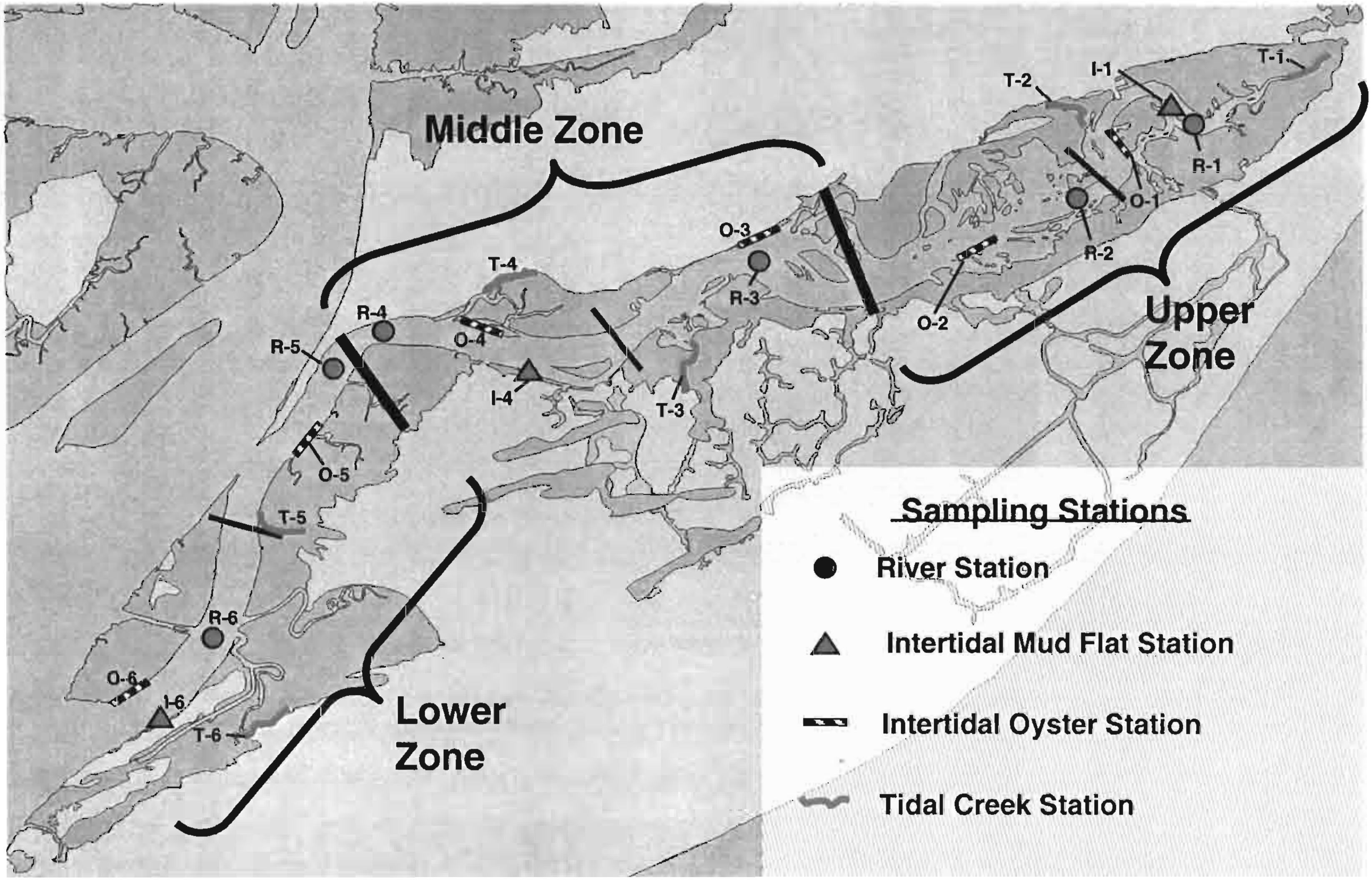


Figure 2.7. Broad Creek sample design.

Okatee River

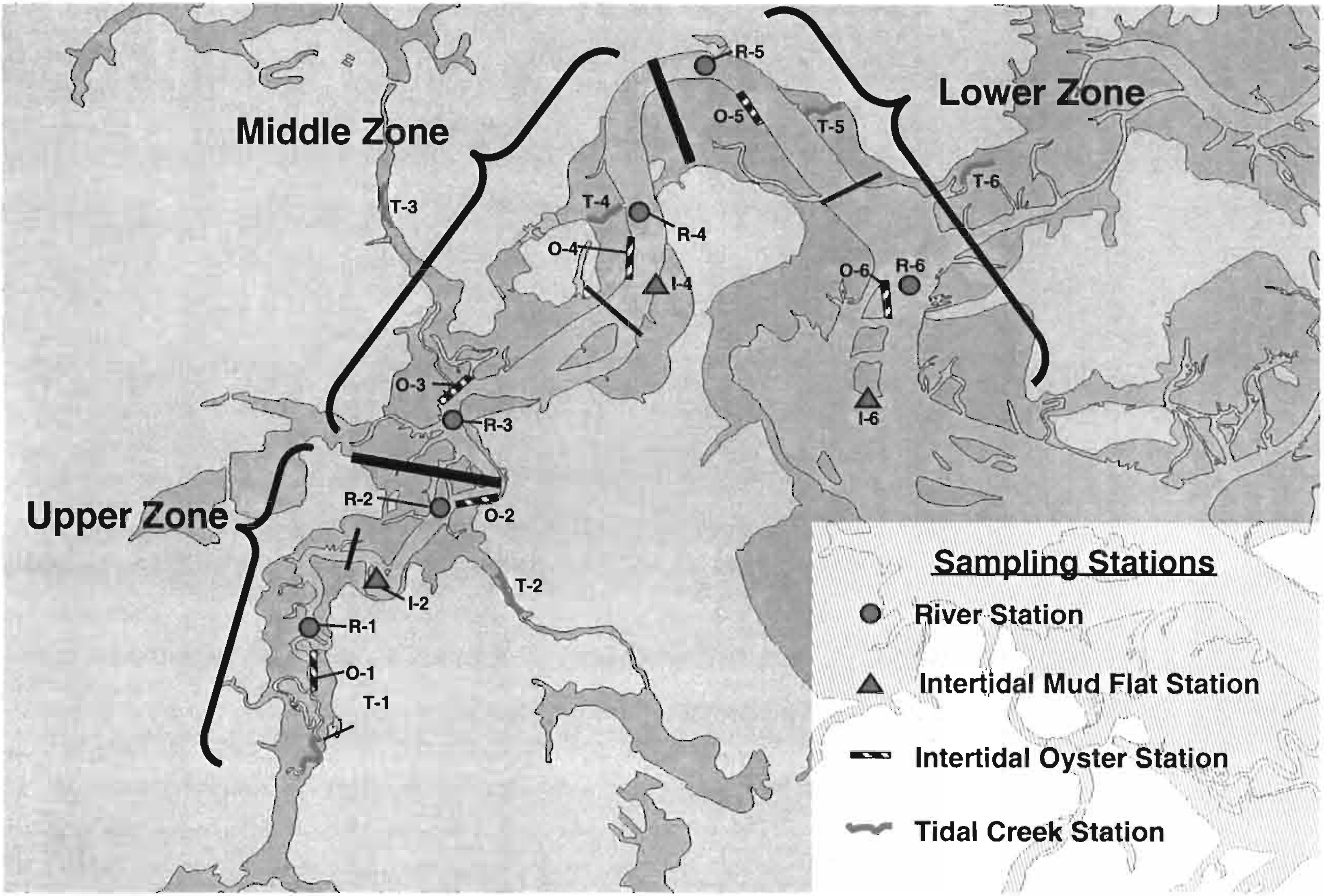


Figure 2.8. Okatee River sample design.

Table 2.1. Summary of land use characteristics for the Broad Creek and Okatee River drainage basins

	Lower Hilton Head (acres)	Lower Hilton Head (proportion)	Okatee (acres)	Okatee (proportion)
Overall Size	17,621		34,076	
Total Wet Area[1]	4,632	26%	10,268	30%
Open Water	2,514	54%	3,915	38%
Estuarine Wetland	2,118	46%	6,353	62%
Forested Wetlands[2]	618	4%	4,226	12%
Total Upland Area[2]	11,443		22,223	
Residential	7,286	64%	1,767	8%
Industrial	1,878	16%	618	3%
Agriculture	51	0.4%	3,419	15%
Upland Forest	1,891	17%	15,990	72%
Total Taxable Land Area[3]	11,479	65%	23,423	69%
Total Impervious Surface[4]	3,716	32%	3,569	15%
Transportation Related Impervious Surface[4]	1,822	16%	428	2%

[1] Coastal Change Analysis Program (CCAP)

[2] National Wetlands inventory (NWI) 1989, enhanced by 1994 aerial photography

[3] Beaufort County Tax Map Parcels

[4] CCAP modified with Tax Map Parcel Data

Table 2.2. State ND permits and National Pollutant Discharge Elimination System (NPDES) permits for the Broad Creek and Okatee River drainage basins

NPDES	Pipe #	Name	# of Spray Sites	Permitted Discharge*
Okatee River Watershed				
ND0069191	001	Beaufort-Jasper Water & Sewer Authority/Bluffton Regional WWTP	2	0.15
ND0061000	001	Beaufort-Jasper Water & Sewer Authority/Rose Hill Plantation	5	0.034
ND0062235	001	Callawassie Development	1	0.26
		Total Permitted Discharge		0.444
Broad Creek Watershed				
ND0013528	001	South Island Public Service District/Long Cove Creek	1	0.225
ND0017141	001	South Island Public Service District/Wexford Plant	1	0.227
ND0063100	001	Broad Creek Public Service District	1	1.588
ND0064033	001	South Island Public Service District	2 + reclaimed	4.15
SC0042501	001	South Island Public Service District		5
SC0042501[a]	002	South Island Public Service District		
SC0042501[a]	003	South Island Public Service District		
		Total Permitted Discharge		11.19

* in Millions of Gallons per day (MGD)

[a] Actually the discharge from wetlands receiving discharge from pipe 001

ND# = No direct discharge to a receiving stream (spray field application)

SC# = Direct discharge to a receiving stream

Table 2.3. Public Drinking Water Supply wells in the Broad Creek and Okatee River drainage basins

System	Well	Description
Okatee River Watershed		
0710003	G07185	Beaufort-Jasper Water & Sewer Authority
0710003	G07186	Beaufort-Jasper Water & Sewer Authority
0710003	G07314	Beaufort-Jasper Water & Sewer Authority
0710003	G07315	Beaufort-Jasper Water & Sewer Authority
0730009	G07160	Maggioni Seafood
0750023	G07177	Okatee River Estates
0760051	G07232	Goethes Mobile Home Park
0770115	G07263	Waddel Mariculture Center
0770675	G07274	Human Development Center
0770875	G07318	Island West
0770902	G07278	Waddel Mariculture
2760006	G27138	Bennets Mobile Home Park
2770904	G27149	Handy Dans II
Broad Creek Watershed		
0720001	G07106	Sea Pines Public Service District
0720001	G07107	Sea Pines Public Service District
0720001	G07108	Sea Pines Public Service District
0720001	G07109	Sea Pines Public Service District
0720001	G07110	Sea Pines Public Service District
0720001	G07111	Sea Pines Public Service District
0720001	G07112	Sea Pines Public Service District
0720001	G07113	Sea Pines Public Service District
0720001	G07114	South Island Public Service District
0720001	G07115	Sea Pines Public Service District
0720001	G07126	South Island Public Service District
0720001	G07127	South Island Public Service District
0720001	G07128	South Island Public Service District
0720001	G07129	South Island Public Service District
0720001	G07131	South Island Public Service District
0720001	G07175	South Island Public Service District
0720001	G07176	South Island Public Service District
0720001	G07187	South Island Public Service District
0720001	G07188	South Island Public Service District
0720006	G07124	Hilton Head Island Public Service District 1
0720006	G07125	Hilton Head Public Service District1
0720009	G07148	Broad Creek Public Service District
0720009	G07149	Broad Creek Public Service District
0720009	G07150	Broad Creek Public Service District
0750020	G07173	Hilton Head Island Utilities III
0760053	G07233	Broad Creek Mhp
0770228	G07267	Abes Restaurant
0770851	G07351	Hilton Head Marina

Table 2.4. Known contaminated groundwater sites in the Broad Creek and Okatee River drainage basins

ID	Description	UST ID	FEATURE
Okatee River Watershed			
606	Beaufort Country Store	15888	UST
590	Callawassie Golf Course	05262	UST
2835	Rose Hill Plantation	00358	OTHER
2370	SCE&G Crew Qtr	00907	UST
Broad Creek Watershed			
2893	Bird Oil Co	13287	AST
2594	Broad Creek Marina	10362	UST
596	Circle K 8100	00992	UST
604	Circle Mobil Station	01006	UST
592	Exxon	01052	UST
603	Harbour Towne Yacht	11753	UST
2589	Hilton Head Texaco	12808	UST
2596	Island Chevron 50172	00975	UST
2597	Island Tire Service	01005	UST
2591	Long Cove Club Assoc	12740	UST
2590	Palmetto Dunes	01022	UST
593	Pantry Store	12174	UST
594	Pantry Store	00995	UST
2598	Plantation Station	18038	UST
2599	Sea Pines Forrest Beach	00922	UST
2895	Sea Pines Plantation	00094	OTHER
1867	Seabrook Of Hilton Head	15372	UST
2595	Singletons Amoco	00978	UST
2592	Sommers 52	12805	UST
602	South Beach Marina	14368	UST
595	Speedway 39	01025	UST
611	Starvin Marvin 106	01027	UST

UST = Underground Storage Tank
AST = Above Ground Storage Tank

Chapter 3
Water Quality

By
D. E. Chestnut, G. I. Scott, B. C. Thompson, L. W. Webster,
A. K. Leight, E. F. Wirth, and M. H. Fulton

Introduction:

An integral component of any study to evaluate the overall quality of estuarine habitats and the resources supported by those habitats is an assessment of the physical, chemical, and biological conditions of the water column. Due to the closure of more than 46,000 acres of shellfish harvesting grounds in Beaufort County, a major focus of the water column biota investigation included a characterization of the potential origin, human versus animal, of the fecal coliform bacteria responsible for these closures.

The waters of the State are classified in regulation to establish resource protection goals for each water body (SCDHEC, 1998a). Water bodies classified as Outstanding Resource Waters (ORW) or Shellfish Harvesting Waters (SFH) receive the highest level of protection.

The entire Okatee River from its headwaters to the confluence with the Colleton River is classified as ORW. Class ORW waters are freshwaters or saltwaters which constitute an outstanding recreational or ecological resource, or those freshwaters suitable as a source for drinking water supply purposes, with treatment levels specified by the Department. No discharges from domestic, industrial, or agricultural waste treatment facilities are allowed to Class ORW waters. Open water dredged spoil disposal areas are also prohibited in Class ORW waters. Because of these prohibitions, Class ORW waters should exhibit conditions that represent a natural state. Specific numeric Standards are those of the water body's classification prior to its reclassification to ORW. In the case of the Okatee River this is Class SFH.

Broad Creek from its headwaters to Calibogue Sound is classified as shellfish harvesting waters (Class SFH). Class SFH waters are tidal saltwaters protected for shellfish harvesting, and are also suitable for primary and secondary contact recreation, crabbing, fishing and the survival and reproduction of a balanced indigenous aquatic community. There are very specific numeric Standards for Class SFH waters to guarantee that these uses are protected in spite of any discharges that may be present.

Methods:

SCDHEC Water Quality Sampling

SCDHEC water quality samples were collected one time at 15 sites in each drainage basin during August 1997. Six sites were located in tidal creeks, six were in subtidal river areas of the larger drainage system, and three were located on intertidal flats of mainstem river system (Figures 3.1 and 3.2). The tidal creek and subtidal river sites were randomly located within each of the six subzones established along the length of each drainage system (see Chapter 2). The intertidal river sites were also randomly selected from the three larger zones representing the upper (headwater), middle and lower (seaward) portions of each drainage system. As stated previously, the primary objective of this study was to provide a better understanding of existing conditions in different habitats of each drainage system using an unbiased sampling design. The study was not designed to target specific activities, such as evaluating the effects of marinas, boating activities, urban runoff, etc. Rather, it was designed to evaluate the integrated effects of all activities that may affect the quality of these water bodies. All station positions were located using differentially-corrected Geographic Positioning Systems (GPS). Sampling in each of the tidal creeks took place near the downstream end of the upper (landward) 300 m section. All water quality samples were collected at or near half tide on an ebbing tide.

The Okatee River was sampled on August 19, 1997, and Broad Creek was sampled on August 20, 1997. This sampling period was characterized by exceptional spring tides with extreme high and low tides. There was a 1.3 inch rainfall the night of August 19, preceding the sampling of Broad Creek. The runoff from this storm coupled with the extreme high tides that inundated more land area closer to upland sources than normal appears to have influenced some of the water quality results for Broad Creek. The Okatee River samples were collected after a period of relatively dry weather.

Instantaneous dissolved oxygen (DO, mg/l), pH (SU), specific conductance (mS/cm), salinity (ppt), and water temperature (^{o}C) were measured *in situ* at a depth of 0.3 meters, representing surface conditions, following standard SCDHEC procedures (SCDHEC, 1997). DO, specific conductance, salinity and water temperature were also measured *in situ* at the bottom and mid-depth at sites greater than one meter deep. Percent dissolved oxygen saturation (%DO Sat) was calculated from *in situ* DO, temperature, and salinity data. Surface samples were collected for analysis of five-day biochemical oxygen demand (BOD_5, mg/l), turbidity (NTU), alkalinity (mg/l), total suspended solids (mg/l), ammonia nitrogen (NH_3+NH_4, mg/l), total Kjeldahl nitrogen (mg/l), nitrate nitrogen (NO_2+NO_3, mg/l), total phosphorus (mg/l), total organic carbon (mg/l), chlorophyll-a (ug/l), and fecal coliform bacteria (# colonies/100 ml). All samples were collected, preserved and transported following standard SCDHEC procedures (SCDHEC, 1997). All analyses were conducted following standard SCDHEC procedures (SCDHEC, 1981, 1994). The results of all analyses are presented in Appendix 3.1, and selected results are summarized in Table 3.1. The positive fecal coliform enumeration media were transferred to the NOS laboratory for *Escherichia coli* typing.

We did not attempt to analyze all possible contaminants in the water column because of their transient nature, being associated more with runoff than continuous sources. Rather, heavy metals and organic compounds were analyzed in the sediments (see Chapter 4) and in the oyster tissue (see Chapter 5) where they would be more likely to accumulate and therefore presented the most likely media for detection.

Throughout this chapter, where measured parameters have no State Standards, values are compared to statistics compiled from other SCDHEC saltwater monitoring data collected from 1993 through 1997 (SCDHEC, 1998b). Terminology used in these comparisons includes an indication of high concentrations, which represent a value greater than 90% of the values measured in other SCDHEC saltwater monitoring data, and an indication of very high concentrations, representing values greater than 95% of the values measured in other SCDHEC saltwater monitoring data (Table 3.2).

SCDNR Hydrolab Deployments

Salinity (ppt), conductivity (mS/cm), pH (SU), temperature (°C), water depth (m), and either dissolved oxygen (DO, mg/l) or percent dissolved oxygen saturation (%DO Sat, percent) or both, depending on the probe, were recorded electronically with a "Datasonde 3" (DS3) multiprobe data logger manufactured by Hydrolab Corporation. Where DO only was measured, %DO Sat was calculated using salinity and temperature (Okatee River sites T-2 and T-5). Conversely, where %DO Sat only was measured, DO was calculated (Okatee River sites R-1, R-2, R-5, R-6 and T-1). Continuous measurements of these parameters were made from a single near-bottom depth at 30-min intervals over approximately a 25-hr period to complete a full set of tidal cycles at six sites located in tidal creeks and six sites in subtidal river areas of the larger drainage system (Figures 3.1 and 3.2). Summaries of all Hydrolab measurements are presented in Appendix 3.2, and selected summary results are summarized in Table 3.3. All raw hydrolab measurements are presented in Appendix 3.3.

In Broad Creek the probes went dry for short periods at tidal creek sites T-1 through T-4. In the Okatee River, the hydrolab record was interrupted at sites T-1, T-3 and to a lesser extent at T-6. Rainfall was reported in the Broad Creek area during the deployment at site R-3. Although there were no rain records available, Okatee River sites T-3 and R-3 were deployed on the same date, and likely were also influenced by rainfall.

Findings:

Dissolved Oxygen:

Oxygen is essential for the survival and propagation of aquatic organisms. If the amount of oxygen dissolved in water falls below the minimum requirements for survival or reproduction, aquatic organisms or their eggs and larvae may die. Dissolved oxygen (DO) varies greatly due to natural phenomena, resulting in daily and seasonal cycles. Different forms of pollution also can cause declines in DO.

Changes in DO levels can result from temperature changes or the activity of plants and other organisms present in a water body. The natural diurnal (daily) cycle of DO concentration is well documented. Dissolved oxygen concentrations are generally lowest in the morning, climbing throughout the day due to the release of oxygen through photosynthesis by aquatic plants and peaking near dusk, then steadily declining during the hours of darkness as it is depleted by plant and animal respiration.

There is also a seasonal DO cycle in which concentrations are greater in the colder, winter months and lower in the warmer, summer months. Flushing, reaeration, and the extent of saltwater intrusion all affect dissolved oxygen values.

Aquatic populations exposed to anoxia (DO<0.3 mg/l) or severe hypoxia (DO<2.0 mg/l) for even brief periods can experience significant mortality. In short exposure laboratory experiments, DO concentrations less than 0.21 mg/l have been shown to be lethal to several benthic invertebrates (Theede, 1973). Long-term chronic effects on survival can result from prolonged exposure to less severe hypoxia.

The State Standard for dissolved oxygen in Broad Creek and the Okatee River is a daily average not less than 5.0 mg/l, with a low of 4.0 mg/l. Compliance with this Standard is generally assessed near the surface. The vast majority of DO data collected during this study were near the bottom, but the observed bottom data can be compared to the Standard for strictly informational purposes. Other research projects in Southeastern estuaries have developed regional near-bottom DO guidelines that were also used to evaluate the data from this study. For the Carolinian Province Environmental Monitoring and Assessment Program - Estuaries (EMAP-E), Hyland et al. (1998) classified a site as "degraded" based on DO if near-bottom dissolved oxygen was less than 0.3 mg/l at any time, less than 2.0 mg/l for 20% or more of the observations, or less than 5.0 mg/l for all observations over a 24-hr time series. Holland et al. (1996) also use the occurrence of %DO saturation of <28% in 20% or more of the observations as an indication of degraded conditions.

Broad Creek:

SCDHEC Instantaneous Measurements:

Surface measurements: One intertidal river site (I-4) had a DO <5.0 mg/l, five tidal creek sites (T-1, T-3, T-4, T-5, T-6) had DO <5.0 mg/l, with three of those also <4.0 mg/l (T-1, T-4, T-6; Appendix 3.1, Table 3.1). All subtidal river sites had DO concentrations greater than 5.0 mg/l.

Bottom measurements: Where bottom measurements were taken (I-6, R-2 through R-6, T-3 and T-6), the conclusions are identical to the surface measurements, suggesting a well mixed water column.

Continuous Bottom Measurements:

Mainstem Sites: A daily mean DO less than 5.0 mg/l was observed at five sites (R-1 through R-5), with values less than 4.0 mg/l occurring at all of those sites as well (Figure 3.3 and 3.4, Appendices 3.2 and 3.3, Table 3.3). At the lower site (R-6) mean

DO was >5.0 mg/l with no values less than 4.0 mg/l. At the most upstream site (R-1) there were four DO values less than 2.0 mg/l (8.3%) and three %DO saturation values less than 28 (6.25%). In general, DO and %DO saturation variance and range decreased from upstream to downstream. None of the sites were classed as "degraded" using the EMAP criteria.

Tidal Creek Sites: The daily mean DO was less than 5.0 mg/l at all six sites, with concentrations less than 4.0 mg/l occurring at all sites as well (Figure 3.3 and 3.4, Appendices 3.2 and 3.3, Table 3.3). T-1 had seven values less than 2.0 mg/l (17.5% of samples) and five %DO saturation values less than 28% (12.5% of the samples). T-4 had one DO value less than 2.0 mg/l, and all values were less than 5.0 mg/l, qualifying as "degraded" under the EMAP protocol. T-5 had 10 values less than 2.0 mg/l with %DO saturation less than 28% (19.6% of samples), and the minimum value was 0.08 mg/l. Therefore, this site also classed as "degraded" under the EMAP criteria.

In general, the variance in DO and %DO saturation was higher in the tidal creeks than in the mainstem (Appendix 3.2). Average %DO saturation was lower in the tidal creeks than in the mainstem.

Okatee River

SCDHEC Instantaneous Measurements:

Surface measurements: The DO at two of the intertidal river sites (I-2 and I-6) was less than 5.0 mg/l, and I-6 was also less than 4.0 mg/l (Appendix 3.1, Table 3.1). Two of the subtidal river sites, R-5 and R-6 both exhibited a DO of less than 4.0 mg/l. DO was less than 5.0 mg/l at two tidal creek sites (T-2 and T-6).

Bottom measurements: Where bottom measurements were taken (I-2, I-6, R-1 through R-6, T-4 and T-6), the findings are identical to the surface measurements, suggesting a well mixed water column.

Continuous Bottom Measurements:

Mainstem Sites: Only the two middle zone sites (R-3 and R-4) had a daily average DO less than 5.0 mg/l, and both had values less than 4.0 mg/l (Figure 3.3 and 3.4, appendices 3.2 and 3.3, Table 3.3). Values less than 4.0 mg/l also occurred at R-1. No DO concentrations less than 2.0 mg/l and no %DO saturation values less than 28% were measured. None of the sites would be classed as "degraded" using the EMAP protocol. Percent DO saturation and maximum DO concentrations were generally higher in the mainstem of the Okatee River than in Broad Creek.

Tidal Creek Sites: Mean daily DO was less than 5.0 mg/l at five out of six sites (T-1 through T-4, and T-6), with values less than 4.0 mg/l occurring at all six sites (Figure 3.3 and 3.4, Appendices 3.2 and 3.3, Table 3.3). Site T-2 had one DO value less than 2.0 mg/l and one %DO saturation less than 28%. None of the sites would be classed as "degraded" using the EMAP protocol. In general, DO and %DO saturation variances were higher at the tidal creek sites relative to the mainstem sites (Appendix 3.2).

pH:

pH is a measure of the hydrogen ion concentration of water, and is used to indicate degree of acidity. The pH scale ranges from 0 to 14 standard units (SU). A pH of 7 is considered neutral, with values less than 7 being acidic, and values greater than 7 being basic. Low pH values are found in natural waters rich in dissolved organic matter, especially in Coastal Plain swamps and black water rivers. The tannic acid released from the decomposition of vegetation causes the tea coloration of the water and low pH. Also, pH decreases with decreasing salinity.

Biota living in habitats that experience wide, rapid shifts in pH may be more susceptible to stress from contaminants because changes in pH can affect adsorption-desorption of metals and organic contaminants in sediments. Changes in pH can also affect cell membrane permeability and the function of certain enzyme systems.

For Broad Creek and the Okatee River the State Standard for pH is not lower than 6.5 or greater than 8.5.

Broad Creek:

SCDHEC Instantaneous Surface Measurements:

Tidal creek site T-4 had a measured pH of 6.45 SU (Appendix 3.1, Table 3.1). There were no other excursions beyond State Standards.

Continuous Bottom Measurements:

The only site which had pH values outside of State Standards was T-1, where values as low as 2.5 were measured (Appendices 3.2 and 3.3, Table 3.3). This pH is extremely low compared to what is normally seen, and was anomalous when compared to the rest of the earlier measurements collected at this site (Appendix 3.3). However, since the Hydrolab met all QA/QC criteria these recorded values are presented and considered valid. It is possible that the probe temporarily malfunctioned at this site. These low values recorded caused the daily average pH to be much lower than any other site and the variance to be much higher. All other values at all sites were within Standards.

Okatee River:

SCDHEC Instantaneous Surface Measurements:

The mainstem site R-6 had a measured pH of 6.2 SU and tidal creek site T-6 was 6.4 SU (Appendix 3.1, Table 3.1). There were no other excursions beyond State Standards.

Continuous Bottom Measurements:

There were no excursions beyond State Standards at any of the sites (Appendices 3.2 and 3.3, Table 3.3).

Total Organic Carbon:

Total Organic Carbon (TOC) is an indicator of the productivity of a watershed. It is a reflection of the products of decomposition of organic materials and the amount of detritus in the water column. TOC is typically greater in swamps and blackwater systems than in other waters. There are no State Standards for TOC, but comparisons can be made to values typically seen at other SCDHEC saltwater monitoring sites (SCDHEC, 1998b).

A two-way Analysis of Variance (ANOVA) indicated that, system-wide, TOC concentrations were higher in Broad Creek than in the Okatee River (Log_{10} transformed, $P < 0.001$). There was a significant interaction between river system and zone. Duncan's Multiple Comparison Test indicated that the elevated TOC was consistent throughout the entire Broad Creek system (no zone differences). In the Okatee River, TOC in the lower zone was lower than both the upper or middle zones. There were no habitat differences in either system, e.g. TOC concentrations were similar in tidal creeks and the mainstem of both systems ($P = 0.523$, two-way ANOVA).

The 1.3 inch rainfall overnight prior to the sampling of Broad Creek coupled with the extreme high tides that inundated more land area closer to upland sources than normal appears to have influenced the TOC results for Broad Creek. TOC in Broad Creek was an order of magnitude greater than any site in the Okatee River except one (Okatee River T-3, Appendix 3.1, Table 3.1). In fact, all mainstem TOC values from Broad Creek exceeded both the mean and the maximum value of 6.62 mg/l and 34 mg/l respectively measured from 1994-1998 at the SCDHEC ambient surface water quality monitoring site MD-174 in Broad Creek. The routine monitoring site is located in study segment four between study sites I-4 and R-4. All TOC concentrations in Broad Creek were greater than what is observed in 95% of all saltwater samples collected by SCDHEC from 1993-1997 (Table 3.2). TOC in the Okatee River was comparable to that seen in other SCDHEC saltwater monitoring data.

Chlorophyll-a:

Chlorophyll-a is an important pigment used by plants to capture the energy in sunlight and convert it to organic plant material through the process of photosynthesis. During the day, plants release oxygen through this process and at night, in the absence of sunlight, plant respiration consumes oxygen. These activities are responsible, in part, for the daily fluctuations in dissolved oxygen concentration. Chlorophyll-a is an indirect measurement of the amount of algal biomass at a given site. There are no State Standards for chlorophyll-a, but values between 20 ug/l and 60 mg/l were considered high in the

NOAA Estuarine Eutrophication Survey (NOAA, 1996). These values are used as a benchmark to indicate waters where there are significant algal populations that could produce nuisance algal blooms that could affect the oxygen dynamics of a system. Values greater than 60 mg/l are considered hypereutrophic (NOAA, 1996) and in imminent danger of algal related problems. These numbers were developed for open water situations and may be overprotective of smaller systems such as Broad Creek and the Okatee River.

There was a consistent effect of zone on cholorphyll-a ($P = 0.022$, two-way ANOVA), with higher concentrations being observed in the upper zones than the lower zones, and the middle zones having more transitional values. The upper zones of these systems are less flushed than the middle and lower zones and the longer residence times provide time for the algal populations to respond to the nutrients present.

No site in either system exceeded 60 mg/l (Appendix 3.1, Table 3.1). In Broad Creek, tidal creek sites T-2, T-3, and T-6 had chlorophyll-a concentrations exceeding 20 ug/l, as did river sites R-1 and R-2 and intertidal river site I-1 (Appendix 3.1, Table 3.1). In the Okatee River system, the chlorophyll-a concentrations at river sites R-1, R-2. and R-3 exceeded 20 ug/l, as did intertidal river site I-4 and tidal creek sites T-3 and T-4.

Nutrients:

Nitrogen and phosphorus are important plant nutrients. Under proper conditions excessive nutrients can contribute to nuisance algal blooms as well as increases in rooted aquatic vegetation. Some groups of aquatic plants and algae can "fix", or capture, nitrogen directly from the atmosphere and convert it to plant biomass. Phosphorus occurs naturally and can be released through the weathering of phosphate deposits, common in some areas of the South Carolina coast. Other sources of nitrogen and phosphorus include wastewater discharges and fertilizers, both man-made and animal wastes (manure). Phosphorus used to be common in many household detergents, but a ban on phosphate containing detergents was enacted in South Carolina in 1992. Total phosphorus (TP) and three forms of nitrogen, ammonia nitrogen (NH_3+NH_4), total Kjeldahl nitrogen (TKN), and nitrate nitrogen (NO_2+NO_3) were measured during this study. There are no State Standards for total phosphorus, total Kjeldahl nitrogen, or nitrate nitrogen (NO_2+NO_3) in saltwater, but comparisons can be made to values typically seen in other SCDHEC saltwater monitoring data (Table 3.2).

Total Phosphorus:

A two-way ANOVA indicated that total phosphorus (TP) concentrations were higher in Broad Creek than in the Okatee River ($P = 0.048$), and were higher in tidal creeks in both systems than at the mainstem sites. Tidal creeks seem to be functioning as conduits delivering nutrients to the main creeks.

In Broad Creek, total phosphorus concentration was high at two intertidal river sites (I-1 and I-4) and one subtidal river site (R-1, Appendix 3.1, Table 3.1). At the tidal creek sites, five of the six sites (T-1 through T-4 and T-6) had high concentrations. In fact, four of the tidal creek sites (T-2 through T-4 and T-6) had very high concentrations.

In the Okatee River, only two tidal creeks (T-1 and T-3) had high total phosphorus concentrations (Appendix 3.1, Table 3.1). There were no values that exceeded the 95th percentile of values seen inother SCDHEC monitoring data.

In general, five of the six Broad Creek tidal creeks showed very high concentrations (0.32 - 0.72 mg/l, next highest at R-1 was 0.21 mg/l) compared to other SCDHEC saltwater monitoring data (Table 3.2). Even though the Okatee River had some high values, the highest was only 0.28 mg/l.

Ammonia:

Ammonia is a form of nitrogen, and in addition to being a potential nutrient, ammonia can be toxic to aquatic life. The State Standard for ammonia varies according to salinity, temperature and pH. Due to lab error, much of the data was lost, thirteen of thirty samples were reported as lab error or interference.

In Broad Creek, none of the samples with valid results exceeded State Standards for ammonia. One subtidal river site (R-2) was greater than 95% of the values seen in other SCDHEC monitoring data (Tables 3.1 and 3.2, Appendix 3.1). All five of the valid tidal creek samples (T-1 through T-4 and T-6) had high concentrations. In fact, four of the tidal creek sites (T-1, T-2, T-4 and T-6) had very high concentrations.

In the Okatee River, none of the samples with valid results exceeded State Standards. Five subtidal river sites (R-2 through R-6) had very high concentrations (Tables 3.1 and 3.2, Appendix 3.1). One tidal creek (T-1) had a high concentration of ammonia and one tidal creek site (T-3) was greater than 95% of the values seen in other SCDHEC monitoring data (Table 3.2).

Total Kjeldahl Nitrogen and Nitrate/Nitrite Nitrogen:

Total Kjeldahl nitrogen (TKN), and nitrate nitrogen (NO_2+NO_3) are also forms of nitrogen, and therefore potential nutrients.

In Broad Creek, TKN was high at tidal creek T-2. At tidal creek site T-4, TKN was very high and nitrate was also high. Nitrate was very high at tidal creek site T-1. All other values were comparable to values observed in other SCDHEC saltwater monitoring data (Tables 3.1 and 3.2, Appendix 3.1). In the Okatee River, TKN was very high at tidal creek site T-3. All other values were comparable to values observed in other SCDHEC saltwater monitoring data (Tables 3.1 and 3.2, Appendix 3.1).

Five-Day Biochemical Oxygen Demand (BOD_5):

Five-day Biochemical Oxygen Demand (BOD_5) is a measure of how much dissolved oxygen is consumed by the decomposition of organic matter, both natural and man-made wastes, in the water column. Although BOD_5 is strictly regulated on National Pollutant Discharge Elimination System (NPDES) permits to protect instream dissolved oxygen, there is no instream State Standard for it. However, comparisons can be made to values typically seen in other SCDHEC saltwater monitoring data (Table 3.2).

In general BOD_5 concentrations in the mainstem of each system decreased from upstream to downstream. In Broad Creek, one intertidal river and one subtidal river site (R-1 and I-1) had very high concentrations of BOD_5, as did one of the tidal creek sites (T-5, Tables 3.1 and 3.2, Appendix 3.1). In the Okatee River, one subtidal river site (R-2) had a high concentration of BOD_5 and one subtidal river site (R-1) had a very high concentration of BOD_5 (Tables 3.1 and 3.2, Appendix 3.1). Tidal Creek site T-3 also had a very high concentration of BOD_5 relative to other SCDHEC saltwater monitoring data.

Turbidity:

Turbidity is an indication of water clarity, which is actually a measurement of how light is transmitted or scattered by a water sample. Cloudy, highly turbid waters can be indicative of increased soil erosion and movement of particulate material from the land surface to a waterbody. This condition is often related to changes in land cover, e.g. clearing for new development, increased impervious surface, removal of forest or crop cover, etc. Increased turbidity can inhibit the growth of algae and rooted aquatic plants through the reduction in light intensity and may be an indicator of increased sedimentation that could impact benthic habitats. There are no saltwater State Standards for turbidity, but comparisons can be made to values typically seen in other SCDHEC saltwater monitoring data (Table 3.2).

In Broad Creek, turbidity was high at one intertidal river site (I-1) and very high at the other two intertidal river sites (I-4 and I-6, Appendix 3.1, Tables 3.1 and 3.2) relative to other SCDHEC saltwater monitoring data. Turbidity was very high at the most upstream subtidal river site (R-1). Turbidity was also very high at two tidal creek sites (T-2 and T-4). In fact, turbidity was extremely high at T-4 with a value of 200 NTU.

In the Okatee River, turbidity was high at one intertidal river site (I-4). At the subtidal river sites, turbidity was high at four subtidal river sites (R-2 and R-4 through R-6) and very high at the other two sites (R-1 and R-3). Two tidal creeks had high turbidity (T-3 and T-5) and two had very high turbidities (T-1 and T-2).

The 1.3 inch rainfall overnight prior to the sampling of Broad Creek coupled with the extreme high tides that inundated more land area closer to upland sources than normal appears to have influenced the turbidity results for Broad Creek. In fact, all mainstem turbidity values from Broad Creek exceeded the mean value of 6.87 NTU measured from

1994-1998 at the SCDHEC ambient surface water quality monitoring site MD-174 in Broad Creek. Five out of nine mainstem sites equaled or exceeded the maximum value of 25 NTU measured over the same period at MD-174. The routine monitoring site is located in study segment four between study sites I-4 and R-4.

Although the rainfall runoff to Broad Creek would have been expected to produce higher turbidities in that system than in the Okatee River system, mainstem turbidity was still greater in the Okatee River than in Broad Creek (P = 0.026, Mann Whitney Rank Sum Test).

Salinity:

Salinity and fluctuations in salinity play important roles in determining the distribution of a variety of aquatic fauna and their various life stages. Wide daily fluctuations in salinity may produce physiologically stressful conditions that exclude certain species or life stages.

In Broad Creek, the probes went dry for short periods at tidal creek sites T-1 through T-4. The mean daily bottom salinities were very similar for both the mainstem and tidal creek sites, however, variances were much greater at tidal creek sites T-1, T-3 and T-6, and somewhat greater at T-4 (Appendices 3.2 and 3.3, Table 3.3). This is due to the much lower daily minimum values. Sites T-1 and T-6 exhibited a daily salinity range greater than 20 ppt, a condition often associated with degraded benthic communities (see Chapter 5 for additional detail).

In the Okatee River, the Hydrolab record was interrupted at sites T-1, T-3 and to a lesser extent at T-6. A pattern very similar to Broad Creek was observed in the Okatee River, with tidal creek sites T-1, T-4 and T-6 showing much greater variance and lower daily minima. Sites T-1 and T-6 exhibited a daily salinity range greater than 20 ppt, a condition often associated with degraded benthic communities (see Chapter 5 for additional detail). Once again, daily mean salinity was very similar between the mainstem and tidal creek sites.

Fecal Coliform Bacteria:

Coliform bacteria are present in the digestive tract and feces of all warm-blooded animals, including humans, poultry, livestock, and wild game species. Diseases that can be transmitted to humans through water or the consumption of shellfish contaminated by improperly treated human or animal waste are the primary concern related to coliform bacteria in the environment. At present, it is difficult to distinguish between waters contaminated by animal waste and those contaminated by human waste.

Public health studies have established correlations between fecal coliform numbers in recreational, drinking, and shellfish harvesting waters and the risk of adverse human health effects. Based on these relationships, the USEPA, the Interstate Shellfish Sanitation Conference (ISSC) and SCDHEC have developed enforceable Standards for surface waters to protect against adverse health effects from various recreational, drinking water, or shellfish consumption uses. Proper waste disposal or sewage treatment prior to discharge to surface waters minimizes this type of pollution.

Urbanization of upland areas adjacent to estuarine ecosystems has resulted in significant inputs of bacterial and chemical contaminants in salt marsh ecosystems of the southeastern US (Vernberg et al., 1993). During the pioneering stages of urban development, human waste disposal needs were met by use of septic tank based technology. As urban development proceeds and critical carrying capacity for human population density is reached, significant inputs of bacterial pollution from septic tank discharges into estuarine ecosystems may result (El-Figi, 1991), often causing closure of shellfish harvesting waters due to the presence of pathogenic bacterial/viral pollution (Leonard,1993). The normal solution to this problem is to construct a central sewer collection system to reduce estuarine inputs from individual septic tank systems (Jolley, 1978).

Vernberg et al. (1996) compared bacterial water quality in two different estuaries in South Carolina, North Inlet, a pristine NOAA National Estuarine Research Reserve and Sanctuary Site, and Murrells Inlet, a highly urbanized estuary located on the southern end of the Myrtle Beach "Grand Strand". Results indicated that 67% of the surface water monitoring stations in Murrells Inlet exceeded the Shellfish Harvesting (SFH) water quality criteria for fecal coliform bacteria (14/100ml) compared to only 33% of the stations in North Inlet. Poor water quality stations in Murrells Inlet were associated with high densities of septic tanks in close proximity to the estuary and other urban activities (marinas, boat landings and roadways). GIS overlays and statistical analysis indicated that regions in Murrells Inlet with high levels of PAHs, near roadways and marinas, also had concomitant high fecal coliform bacteria densities. This suggests that fecal coliform bacterial densities may be affected (due to biostimulation) in areas with high PAH concentrations. Poor water quality in North Inlet was associated with upland areas, where large populations of birds and wildlife reside.

Vernberg et al. (1996) also found that fecal coliform bacterial serotyping of surface waters indicated there were significant differences in the speciation of coliform positive species in surface waters of Murrells Inlet and North Inlet. In urbanized Murrells Inlet, there was a greater occurrence of *E. coli* bacteria, fewer stations that were coliform negative and a reduced number of bacterial species comprising the coliform group, particularly soil-sorbed microbes of the Pseudomonid family. In pristine North Inlet, surface waters had a greater number of coliform negative stations, reduced occurrence of *E. coli* bacteria and an increased number of bacterial species comprising the coliform group with an increased occurrence of soil-sorbed microbes in the Pseudomonad family. The greater diversity/species richness in the coliform group members in North Inlet resulted from the availability of bacteria from the deciduous hardwood forest when compared to upland watersheds in urbanized Murrells Inlet, which contain more monoculture (i.e. lawns with grass and ornamental plants) habitat. These findings clearly indicate that fecal coliform bacteria pollution is associated with urbanization and that closure of shellfish harvesting waters may be perhaps the most significant, quantifiable impact from urbanization.

The current fecal coliform bacterial assay is unable to discern between coliform bacteria from human versus animal sources. While both animal and human sources of bacterial pollution may be a significant human health threat, differentiating between sources is critical in formulating effective environmental management strategies to reduce loading from bacterial pollution sources. Several techniques have been evaluated to potentially discriminate between animal and human sources including Pulsed Field Gel Electrophoresis (PFGE), Fatty Acid Profiling (FAP), ribotyping, Analytical Profiling Index (API) biotyping and Multiple Antibiotic Resistance (MAR) testing. As part of this study Analytical Profiling Index (API) biotyping and Multiple Antibiotic Resistance (MAR) testing were employed to try to determine the probable source(s) of the observed coliforms. In addition, the coliform isolates used in these tests will subsequently be subjected to Pulsed Field Gel Electrophoresis (PFGE) and ribotyping, the results of which will be reported in a separate report.

The positive fecal coliform Most Probable Numbers (MPN) sample results obtained by SCDHEC were transferred to the NOS Center for Coastal Environmental Health and Biomolecular Research at Fort Johnson, SC, for further speciation and biotyping. At the NOS-CCEHBR facility these samples were streaked onto selective agar and different members of the coliform group are identified with Analytical Profiling Index methodologies. *E. coli* bacteria are selectively isolated by this method.

Standards Compliance

The State Standard (SCDHEC, 1998a) for fecal coliform bacteria in Broad Creek and the Okatee River, to protect primary contact recreation (swimming), is a geometric mean 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 total number of samples collected in a 30 day period can exceed 400 colonies/100 ml. To protect for the consumption of shellfish the MPN fecal coliform geometric mean shall not exceed 14 colonies/100 ml, nor shall more than 10% of the samples exceed an MPN of 43 colonies/100 ml (SCDHEC, 1998a).

The analytical method required for the determination of recreational Standard compliance and shellfish harvesting status are different and mutually exclusive. The method employed in this study conformed to USEPA accepted methods, required through State Standards (SCDHEC, 1998a) for water quality evaluation and do not satisfy the methodological requirements for the determination of shellfish harvesting classification.

Because only a single sample was collected at each site, compliance with the Standards cannot be strictly determined, but the observed data can still be compared to the Standard for informational purposes only.

System wide, fecal coliform bacteria concentrations were higher in Broad Creek than in the Okatee River (Log_{10} transformed, $P < 0.001$, T-Test, Figure 3.5). Okatee

River tidal creeks were not significantly different from mainstem Okatee River sites. In Broad Creek, fecal coliform bacteria concentrations in tidal creek sites were higher than in the mainstem sites ($P = 0.007$, Mann Whitney Rank Sum Test). Fecal coliform bacteria concentrations in Broad Creek tidal creeks were also higher than in Okatee River tidal creeks ($P = 0.015$, Mann Whitney Rank Sum Test). When the data from both systems were pooled, tidal creek bacteria concentrations were higher than mainstem concentrations (Log_{10} transformed, $P = 0.006$, T-Test), suggesting that tidal creeks may be acting as conduits to deliver bacteria from the uplands to the mainstem areas. The occcurrence of elevated fecal coliform bacteria concentrations in drainage ditches and the canal systems draining to Broad Creek has been previously documented (SCDHEC, 1996). In Broad Creek, seven sites (46.7%) had MPNs > than the upper detection limits of the test (e.g. > 1600 colonies/100 ml) versus only 1 site (7%) in the Okatee River (Appendix 3.1, Table 3.1).

Broad Creek:

Shellfish Standards: Concentrations greater than 14 colonies/100 ml were measured at all sites (Figures 3.6 and 3.7, Appendix 3.1, table 3.1). In the mainstem, all three intertidal river sites exceeded 43 colonies/100 ml, and four of the six river sites (R-1, and R-4 through R-6) exceeded 43 colonies/100 ml. In the tidal creeks, all values exceeded 43 colonies/100 ml.

Recreational Standards: Concentrations greater than 200 colonies/100 ml were measured at one intertidal river site (I-4), one river site (R-4) and all tidal creek sites (Figures 3.6 and 3.7, Appendix 3.1, Table 3.1). Similarly, R-4 and all tidal creek sites exceeded 400 colonies/100 ml.

Okatee River:

Shellfish Standards: On the mainstem (intertidal river and subtidal river sites), concentrations greater than 14 colonies/100 ml were measured at only two sites, R-1 and R-2, and only one site, R-1, exceeded 43 colonies/100 ml (Figures 3.6 and 3.7, Appendix 3.1, Table 3.1). Five of the tidal creek sites exceeded 14 colonies/100 ml, T-1 through T-5. Of these, only T-1 and T-3 exceeded 43 colonies/100 ml.

Recreational Standards: None of the mainstem (intertidal river and subtidal river sites) sites exceeded 200 colonies/100 ml (Figures 3.6 and 3.7, Appendix 3.1. Table 3.1). Only tidal creek sites T-1 and T-3 exceeded 200 colonies/100 ml, and T-3 was the only site that exceeded 400 colonies/100 ml.

Biotyping Evaluation

The objectives of this portion of the study was to evaluate impacts of urbanization on bacterial water quality in Broad Creek and the Okatee River and to apply new novel techniques such as MAR to potentially determine pollution sources within each watershed.

E. coli is the primary fecal coliform bacterium present in human and animal feces. It is considered the indisputable fecal contamination indicator for warm-blooded animals (Kator and Rhodes, 1994). *E. coli* has been proposed as a replacement indicator for fecal coliforms because of the pervasive presence of other coliform members such as *Klebsiella*, which are not specifically associated with human fecal contamination. Vernberg et al. (1996) reported that the second most dominant member of the fecal coliform group behind *E. coli* was *Klebsiella pneumoniae* in evaluation of estuarine surface waters and oysters from pristine and urban estuaries within SC.

Multiple Antibiotic Resistance (MAR) is a novel technique proposed as a new method for differentiating human versus animal fecal pollution sources (Parveen et al., 1997). This approach is based upon the fact that *E. coli* from wildlife species are lacking in antibiotic resistance while strains from humans will exhibit MAR. Strains from domestic animals will be intermediate in MAR. Parveen et al., (1997) used MAR to 10 antibiotics to evaluate 765 *E. coli* isolates from surface water samples collected from regions of Apalachicola Bay estuary in Florida impacted by point source bacterial pollution (sewage treatment plants) and areas impacted by NPS runoff. Results indicated that 82% of all samples were resistant to one or more antibiotics. The MAR Index was reduced by 50% in comparisons of point and NPS impacted areas. Application of MAR to watersheds in SC would be useful in differentiating human versus wildlife fecal pollution sources. Scott and co-workers at NOAA have used MAR profiling on selected watersheds in SC including the Isle of Palms and 10 different sewage treatment plants. Results have generally indicated significantly higher MAR in urban versus pristine watersheds and similar MAR Index values as reported by Tamplin in urban and pristine areas, dominated by NPS runoff from wildlife.

Methods:

Fecal coliform densities were determined by SCDHEC for the 30 field sites (Broad Creek and Okatee River) and seven sewage treatment plants (Forest Trails = FTSTP; Broad Creek = BC1; Hilton Head = HH1; Long Cove Creek = LC1; Okatee River = OK1; SI = South Island and Wexford Sound = WX1) using the 3 tube MPN method as described by APHA (1984). Samples testing positive for fecal coliforms were then further isolated using selective Violet Red Bile Agar (VRBA). Ten presumptive *E. coli* isolates from each plate, or 15 isolates from the sewage treatment plants, were then picked and inoculated on to Plate Count Agar (PCA) for isolation. Each coliform isolate was identified to genus and species by the Analytical Profiling Index methods (API 20 E test kit bioMerieux). The results for the 10 or 15 individual isolates/sample were statistically analyzed (cumulative proportions) and the proportional distributions of each species comprising the coliform group were determined. Different *E. coli* strains were further identified using the API procedure. An overview of these methods is depicted in Figure 3.8.

Confirmed *E. coli* isolates were tested for multiple antibiotic resistance (MAR) using methods described by Parveen et al. (1997). Each *E. coli* isolate was tested on agar

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Confirmed *E. coli* isolates were tested for multiple antibiotic resistance (MAR) using methods described by Parveen et al. (1997). Each *E. coli* isolate was tested on agar plates containing one of 10 antibiotics, or a control plate without antibiotics. The 10 antibiotics included: ampicillin (10 ul/ml), chlortetracycline (25 ul/ml), kanamycin (25 ul/ml), nalidixic acid (25 ul/ml), neomycin (50 ul/ml), oxytetracycline (50 ul/ml), penicillin G (75 ul/ml), streptomycin (12.5 ul/ml), sulfathiozole (500 ul/ml), and tetracycline (25 ul/ml).

Resulting growth in each antibiotic was compared to growth on a control (no antibiotic) plate. Antibiotic Resistance for each antibiotic was defined as a growth inhibition of <15% in size when compared to the control plate. Sensitivity was defined as growth inhibition that was >15% in size when compared to the control plate. Other MAR end-points measured included: 1) MAR Index (%) for an Isolate = (# antibiotics to which an isolate was resistant/total # antibiotics tested); 2) Site MAR Index = (# antibiotics to which all isolates were resistant/total # antibiotics tested multiplied by the number of isolates/site); and 3) Total # of Antibiotics Resistant = (Total # Antibiotics Resistant for all isolates/site). An overview of these methods is depicted in Figure 3.8.

Results:

Results of API biotyping (Figures 3.9-3.11) indicated that positive fecal coliform samples were comprised primarily of *E. coli* in both Broad Creek and the Okatee River. In Broad Creek (Figure 3.9), all stations (100%) contained *E. coli* compared to only 73% of the sites in the Okatee River (Figure 3.10). In Broad Creek, in addition to *E. coli,* the other species observed included *Klebsiella pneumoniae* (13.3% of the sites), *Klebsiella oxytoca* (6.7%) , *Enterobacter sakazaki* (6.7%), *Enterobacter aerogenes* (6.7%) and unknown bacterial species (33% of the sites). In the Okatee River, in addition to *E. coli,* the other species observed included *Klebsiella pneumoniae* (13.3%), *Enterobacter vulnaris* (13.3%), and unknown bacterial species (6.7%). In addition, 13.3% of the sites were coliform free (MPN $\leq$ 2/100 ml).

The mean overall API coliform "finger prints" for Broad Creek and the Okatee River are depicted in Figure 3.11, along with comparisons from pristine North Inlet (a NOAA National Estuarine Research Reserve and Sanctuary Site) and a highly urbanized, Murrells Inlet Site, located just south of the Myrtle Beach Grand Strand. Note that the mean distribution of *E. coli* in the Okatee River (66%) was just slightly higher than that measured in pristine North Inlet (53%). Similarly, there was a much higher occurrence of *E. coli* in urbanized areas such as Broad Creek (90%) and Murrells Inlet (83%) and the percentage of coliform free sites decreased with increased urbanization (North Inlet --> Okatee River ---> Murrells Inlet ---> Broad Creek). In highly urban areas, the slightly lower occurrence of *E. coli* and small coliform free areas in Murrells Inlet (when compared to Broad Creek) resulted from a green space (undeveloped region) corridor located at the southern (Huntington Beach State Park) end of the estuary. In Broad Creek, a lack of planned green space corridors has resulted in 100% occurrence of *E. coli* bacteria throughout the entire tidal creek watershed. Open spaces in the Okatee River have resulted in a large potion of that watershed where *E. coli* and other coliform bacteria do not occur. The inclusion of green space corridors is important in maintaining the assimilative capacity of tidal creek watersheds.

Analysis of the different *E. coli* bacteria biotypes found at each site (Figure 3.12-3.13) indicated that there were slight differences in the proportion of different *E. coli* types between Broad Creek and the Okatee River. In the Okatee River (Figure 3.13), *E. coli* strain 5144572 was the dominant strain accounting for 69.7% of all *E. coli* present. Note the dominance of this *E. coli* strain at tidal creek, river and intertidal river sites in the Okatee River. The second most dominant strain was *E. coli* type 5044572 (15.1%) followed by *E. coli* type 5144552 (11.1%).

In Broad Creek (Figure 3.12), *E. coli* strain 5144572 was the dominant strain accounting for 35.9% of all *E. coli* present, followed closely by *E. coli* strains 5144552 (32.1%). The third most dominant strain was *E. coli* strain 5044572 (15.3%). Note the more diverse and equitable nature of these three *E. coli* strains at tidal creek, river and intertidal river sites of Broad Creek.

Comparisons of *E. coli* strains in Broad Creek and the Okatee River indicated a clear dominance of one strain (5144572) in the less developed Okatee River watershed compared to co-dominance by three strains (5144572, 5144552 and 5044572) in more urbanized Broad Creek (Figure 3.14). Richards (Dr. Gary Richards, U. S. Department of Agriculture, Delaware State University) has similarly found differential *E. coli* strains in analysis of urban versus rural areas of South Carolina.

Results of Multiple Antibiotic Resistance (MAR) testing indicated that *E. coli* bacteria in Broad Creek had greater resistance to a larger number of antibiotics than the Okatee River (Figures 3.15-3.19 and Tables 3.4-3.6). A total of 7 sites (47%) in Broad Creek tested positive for antibiotic resistance, including 50% of the tidal creek, 50% of the river and 33% of the intertidal river stations (Figure 3.15). The remainder of the Broad Creek sites (53%) tested negative for MAR. In the Okatee River, only three sites (20%) tested positive for antibiotic resistance, including 33% of the tidal creek, none of the river and 33% of the intertidal river stations (Figure 3.15, Table 3.4). The remainder of the Okatee River sites (80%) tested negative for MAR. Site MARs ranged from 0-26.4%, averaging 3.4% in Broad Creek versus a range of 0-5.71%, averaging 1.04% in the Okatee River (Table 3.4). This 69% reduction in MARs was very similar to MAR reductions seen in comparison of developed and undeveloped watersheds in Florida of 47% (Parveen et al., 1997) and in Maryland of 69% (Kaspar et al., 1990) (Table 3.5).

Similarly, the percentage of *E. coli* antibiotic sensitivity was higher in the Okatee River when compared to Broad Creek (Figure 3.16). Most of the tidal creek (67%), river (100%) and intertidal river (67%) stations on the Okatee River had antibiotic sensitive *E. coli* strains, ranging from 73.6-100% sensitivity. Some 1050 out of the 1061 *E. coli* isolates found in the Okatee River (99%) were sensitive to the 10 antibiotics tested (Table 3.4). In Broad Creek, most of the tidal creek (67%), river (50%) and intertidal river (50%) stations had antibiotic sensitive *E. coli* strains, ranging from 50-100% sensitivity. A total of 1394 out of the 1443 *E. coli* isolates in Broad Creek (97%) were sensitive to the 10 antibiotics tested (Table 3.4).

The number of antibiotics to which each MAR positive *E. coli* strain was resistant was greater at several sites in Broad Creek than in the Okatee River (Figure 3.17). In Broad Creek, at sites with positive MARs, the number of antibiotics each strain was resistant to ranged from 1 to 4 antibiotics, averaging 2.14 antibiotics/strain. The dominant antibiotics for MAR in Broad Creek were chlortetracycline, oxytetracycline, and tetracycline (Table 3.4). In the Okatee River at sites with positive MARs, the number of antibiotics each strain was resistant to ranged from 1 to 2 antibiotics, averaging 1.3 antibiotics/strain (Figure 3.17). The dominant antibiotic for MAR in the Okatee River was penicillin G (Table 3.4).

At sewage treatment plants (STPs) sampled in Beaufort County (Tables 3.4 and 3.6), 860 *E. coli* isolates were tested from seven different STPs. A total of 106 isolates (12.3%) were antibiotic resistant, with the dominant MAR resistance found for ampicillin (2%), penicillin G (5%) and the tetracyclines (0.7-1%). The overall MAR Index for individual STPs ranged from 5-22% (Table 3.6), averaging 12.33% (Table 3.4). Note that the highest STP site MAR of 22% for BC-1 (Table 3.6), was quite similar to the highest MAR measured in surface waters at Broad Creek of 26.4% at site R-4 (Figure 3.15). At STPs, the number of sensitive isolates was 754 out of the 860 isolates (88%) (Table 3.4). The number of antibiotics each positive MAR *E. coli* strain was resistant to at STPs ranged from 1-8 antibiotics, averaging 4.7 antibiotics/strain (Table 3.6). At STPs serving the retirement community of Hilton Head Island (BC-1, HH-1 and LC-1) the total number of antibiotics each *E. coli* strain was resistant to ranged from 7-8 antibiotics/strain versus a range of 1-3 antibiotics/strain in other STPs serving the more general population of Beaufort County (OK-1, SI-1 and Wx-1) (Table 3.6).

Comparisons of MAR and MPN results and GIS analysis of land use in each watershed indicated a clear association of areas with high MPNs, high MARs and obvious pollution sources (STPs and septic tanks) in Broad Creek (Figure 3.18). Three distinct regions of high MPNs and MAR were found in Broad Creek including stations I-1 and T-2 (septic tanks), stations T-4, R-4 and R-5 (septic tanks) and stations R-6 and T-6 (STPs land based discharges). In the Okatee River, two regions of high MAR were found at stations T-3 and I-4 (STP land based discharges) and station T-2 (unknown source) (Figure 3.19). The majority of stations in both Broad Creek (53.3%) and the Okatee River (80%) were negative for MAR, suggesting animal pollution sources rather than human pollution sources *per se*. This indicates water quality management strategies must be focused to reduce bacterial loadings from both human and animal sources. Both human and animal pollution sources must be managed, including wildlife, domestic animals and pets. The specific regions with high MARs in each watershed appear to have high spatial correlation with land based human pollution sources.

Water Quality Summary

In an effort to summarize the water quality data, a composite summary score for overall water quality was calculated at each site. This summary score was a total of the number of individual parameters exceeding predetermined threshold values (Table 3.7). Each parameter received a score of one for each of twelve total categories based on the following thresholds: 24-hour average DO less than 5.0 mg/l, fecal coliform bacteria greater than the shellfish Standard of 43 colonies per 100 ml, pH less than 6.5 SU or greater than 8.5, chlorophyll-a greater than 20 mg/l, 24-hour range in salinity greater than 20 ppt, and values exceeding the statewide saltwater 90th percentile for turbitidy, BOD, alkalinity, TKN, nitrate, TP, and TOC. If six or more of the parameters exceeded the established thresholds the site was classified as poor. If three to five parameters exceeded the thresholds a site was classified as fair, and if less than three parameters exceeded threshold levels a site was classified as good.

In Broad Creek, seven of fifteen sites scored as poor, including five of the six tidal creek sites, and six sites scored as fair (Figure 3.20). Only two sites scored as good. TOC and fecal coliform bacteria were elevated system-wide in Broad Creek. Tidal creeks were characterized by low DO, and elevated fecal coliform bacteria and total phosphorus concentrations. The 1.3 inch rainfall overnight prior to the sampling of Broad Creek coupled with the extreme high tides that inundated more land area closer to upland sources than normal appears to have influenced the sampling results for some parameters in Broad Creek, especially TOC.

In contrast, in the Okatee River, only one of fifteen sites scored as poor and nine scored as good (Figure 3.20). Only five sites scored as fair. Turbidity was significantly higher in the Okatee River than in Broad Creek. Tidal creek T-3 in the Okatee River system stands out as the only site receiving a water quality rating of poor. Fecal coliform bacteria at this site included colonies identified as having human sources based on high MAR results.

In general, DO did not meet State Standards. Standards are goals used to set permit limits, not necessarily reflective of natural conditions. Daily mean DO less than 5.0 mg/l was measured routinely in both systems. Only R-6 in Broad Creek, and R-1, R-2, R-5, R-6 and T-5 in the Okatee River met the 24-hour average of 5.0 mg/l. Two tidal creek sites in Broad Creek were classed as degraded based on DO using EMAP protocols, creeks T-4 & T-5.

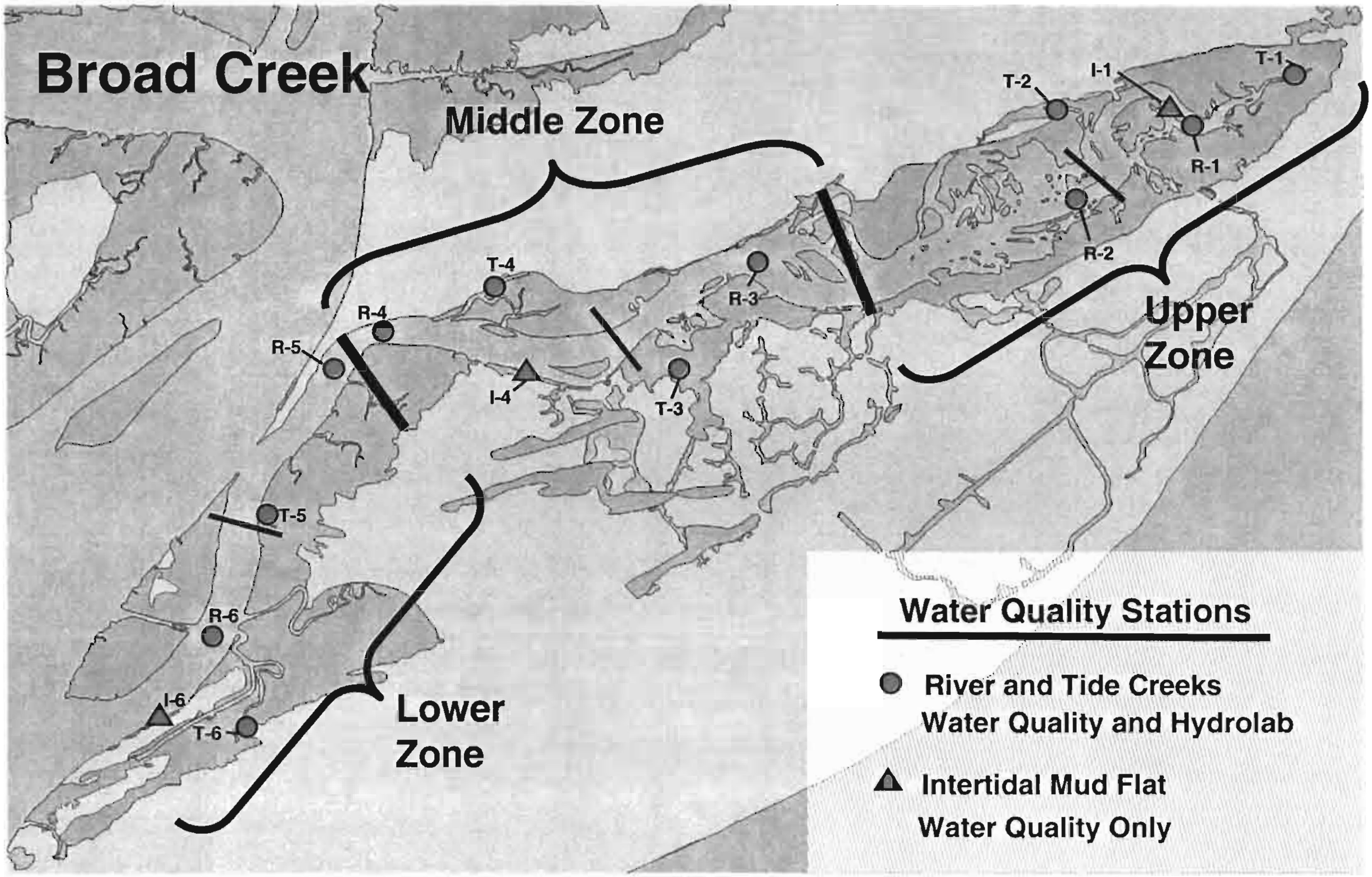


Figure 3.1. Map of Broad Creek stations sampled for water quality and fecal coliform bacteria.

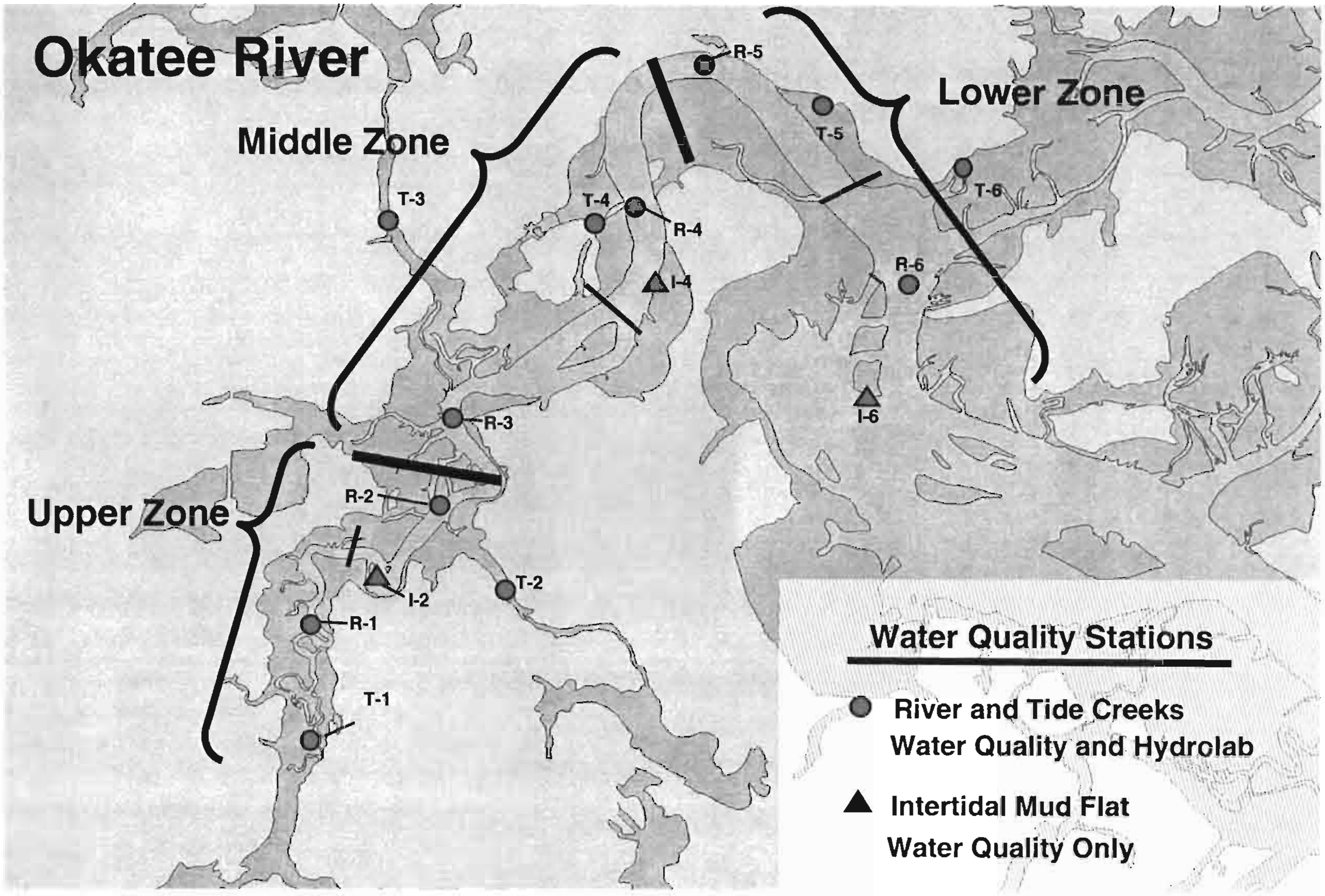


Figure 3.2. Map of Okatee River stations sampled for water quality and fecal coliform bacteria.

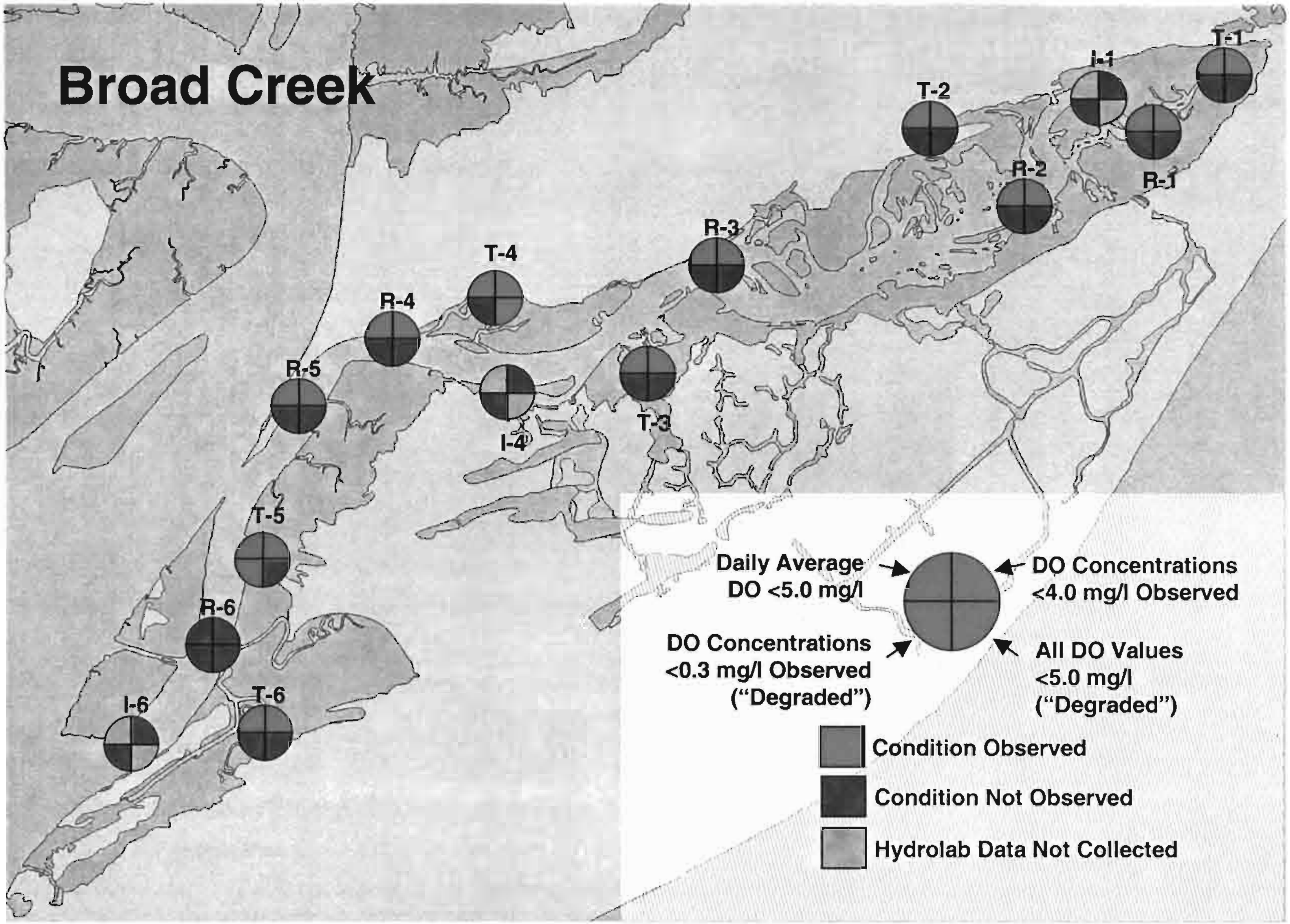


Figure 3.3. Summary of dissolved oxygen data. Where Hydrolab data were not collected, the instantaneous measurements <4.0 mg/l or <0.3 mg/l are graphed.

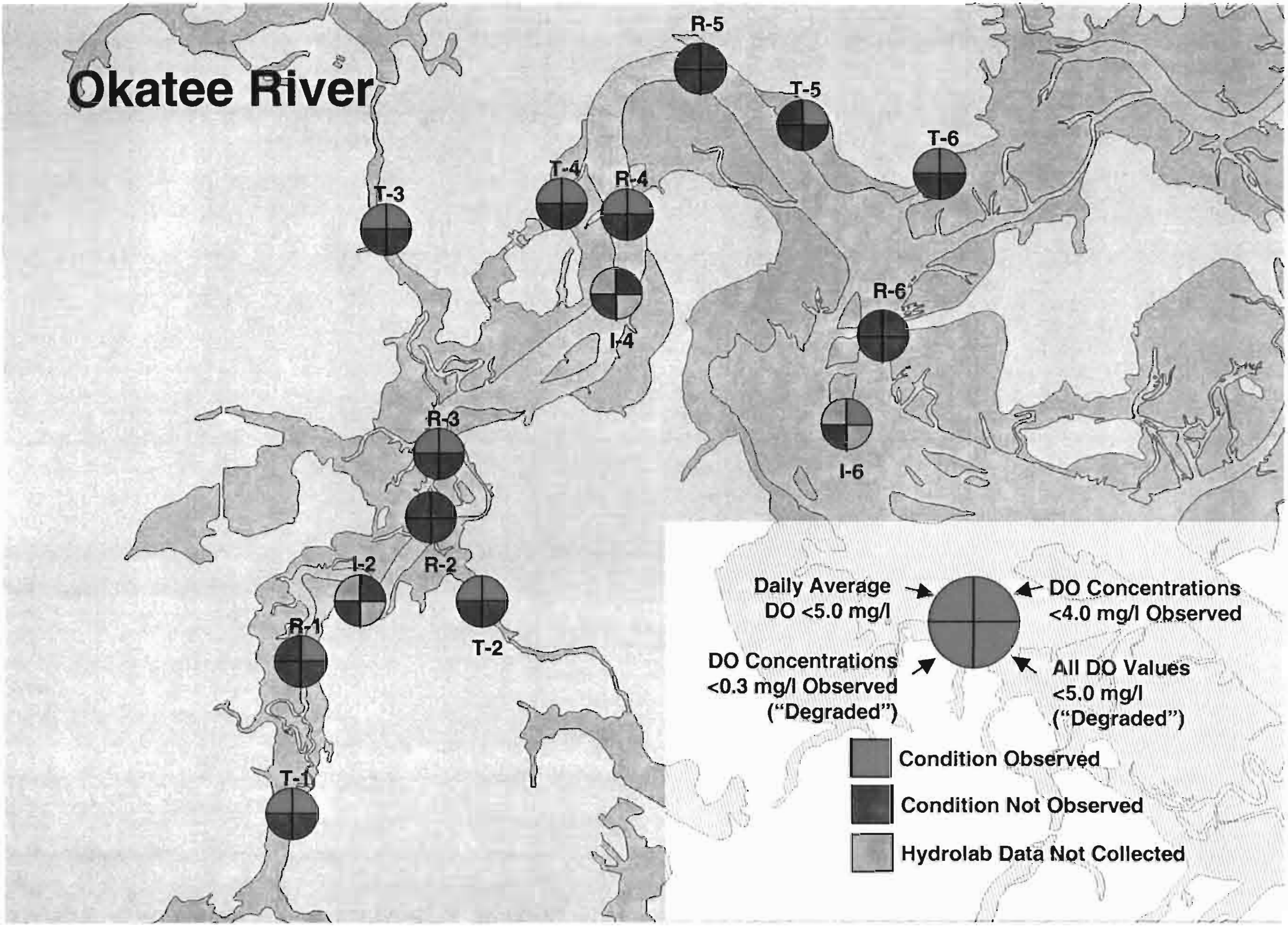


Figure 3.4. Summary of dissolved oxygen data. Where Hydrolab data were not collected, the instantaneous measurements <4.0 mg/l or <0.3 mg/l are graphed.

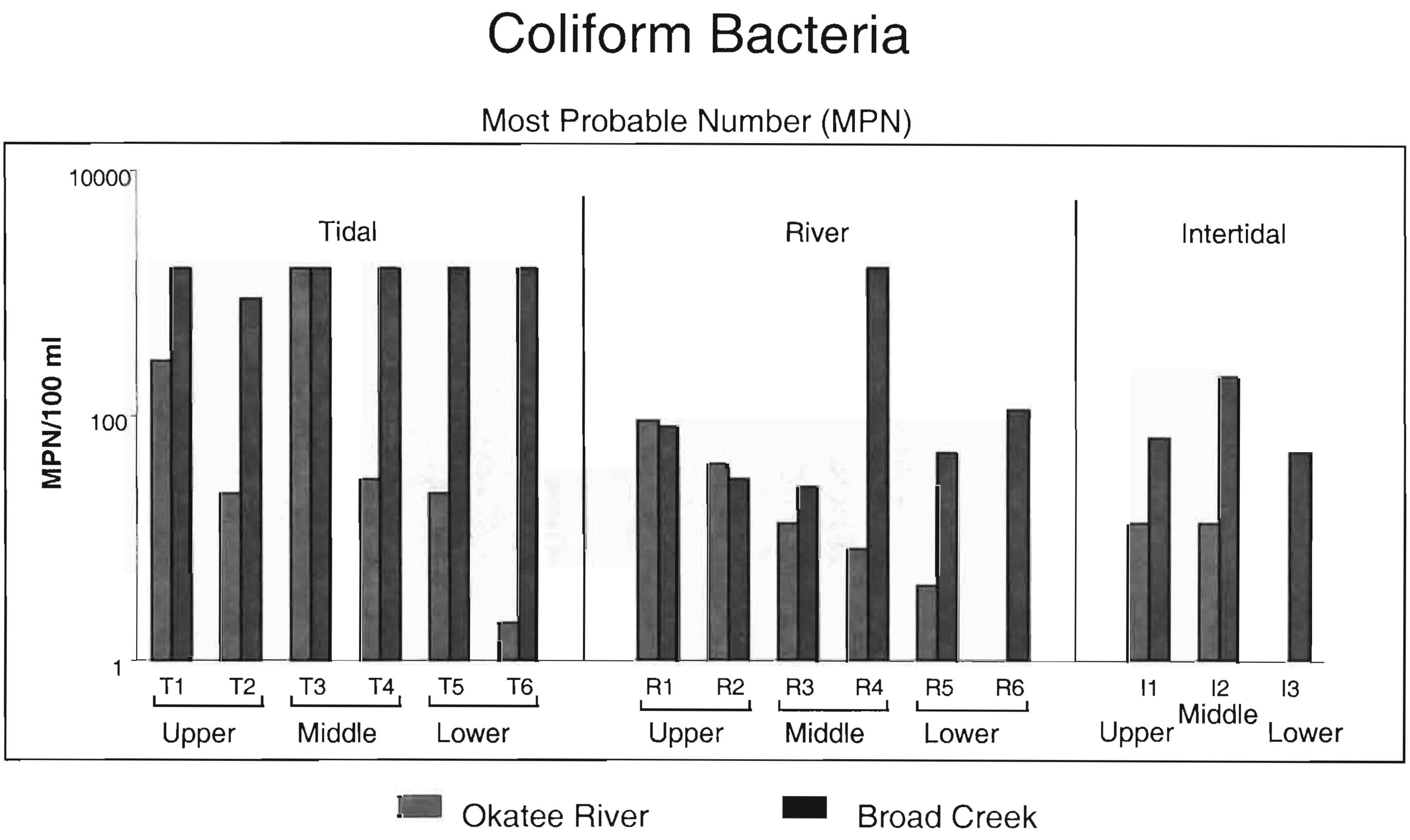


Figure 3.5. Results of fecal coliform Most Probable Numbers (MPNs) measured in Broad Creek and the Okatee River. Note the much higher MPNs in Broad Creek than in the Okatee River at most habitats tested (tidal creeks, river and intertidal sites).

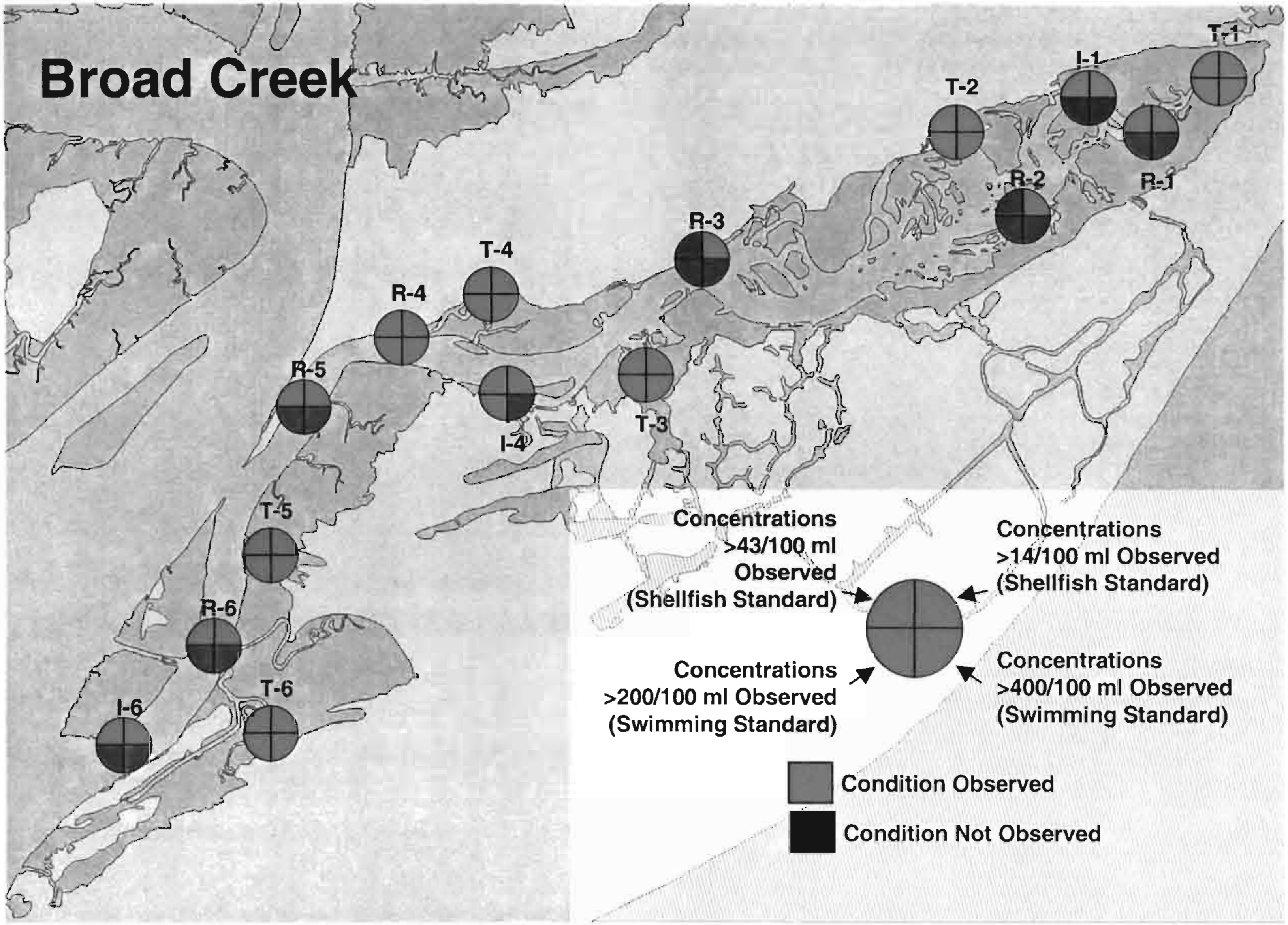


Figure 3.6. Summary of fecal coliform bacteria data for Broad Creek.

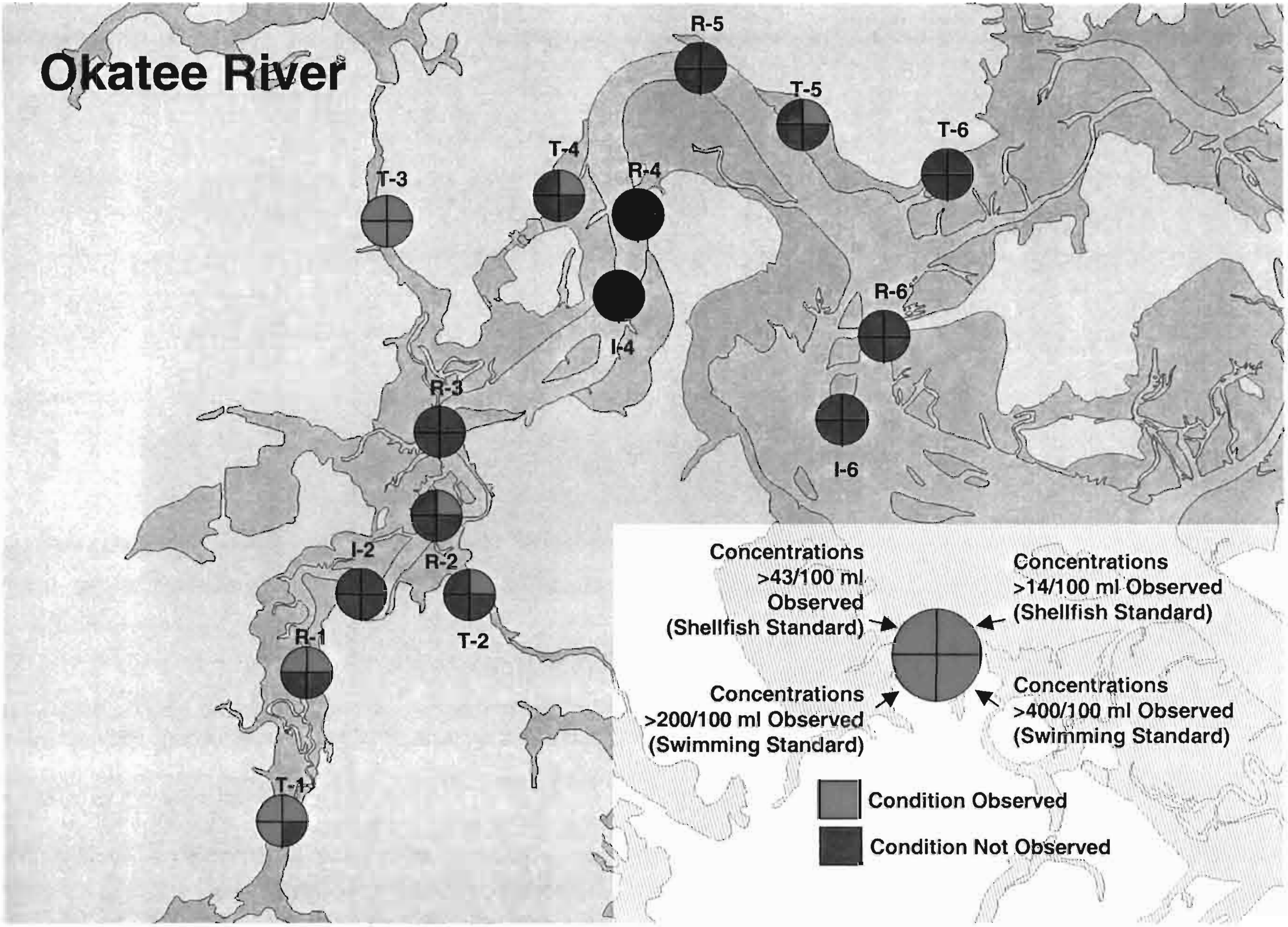


Figure 3.7. Summary of fecal coliform bacteria data for the Okatee River.

METHODS

Sample collection and preparation

♦One sample from each site was collected in a sterile plastic jar in August, 1997.

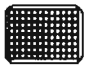
♦Samples were analyzed at the South Carolina Department of Health and Environmental Control (DHEC) for fecal coliform numbers according to standard methods (APHA, 1992). Positive EC tubes were sent to the National Ocean Service (NOS), Charleston Lab for further analysis.

♦A total of 10 isolates from violet red bile agar plates were selected from each surface water sample and 15 isolates were chosen from each of the STP samples.

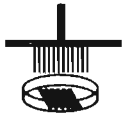
♦The identification of each isolate was confirmed as *E. coli* by API 20 E test kit (bioMerieux Vitek, Hazelwood, MO).

Multiple Antibiotic Resistance:

♦Confirmed *E. coli* isolates were further tested for MAR following the method of Parveen et al., (1997), briefly described below.



♦Isolates were transferred to a 96 well plate containing tryptic soy broth (TSB) and incubated for 4-6 h at 35 °C.



♦The broth cultures were then transferred in duplicate with a 48-prong replicator to Mueller-Hinton agar plates, each containing one of 10 antibiotics, or to a control plate without antibiotics. Plates were incubated 18-24 hours at 35 ° C.

♦The antibiotics and their concentrations in agar were: ampicillin, 10 μl/ml; chlortetracycline, 25 μl/ml; kanamycin μl/ml, 25 μl/ml; nalidixic acid, 25 μl/ml; neomycin, 50 μl/ml; oxytetracycline, 50 μl/ml; penicillin G, 75U/ml; streptomycin, 12.5 μl/ml; sulfathiazole, 500 μl/ml and tetracycline, 25 μl/ml.

♦Resulting growth was measured and compared to the size of the same isolate on the control plate. **Resistance** = less than 15% reduction in colony size on the antibiotic plate compared to the control plate. **Sensitivity** = greater than or equal to 15% reduction in size compared to the control plate. Also calculated were:

♦**MAR index** (%) for an **isolate** = (# of antibiotics to which the isolate was resistant / total # of antibiotics tested) × 100.

♦**MAR index** (%) for a sample **site** = # of antibiotics to which all the isolates were resistant / (number of antibiotics tested × number of isolates per site) × 100.

Figure 3.8. Overview of MPN, API Biotyping and MAR methodologies used in this study.

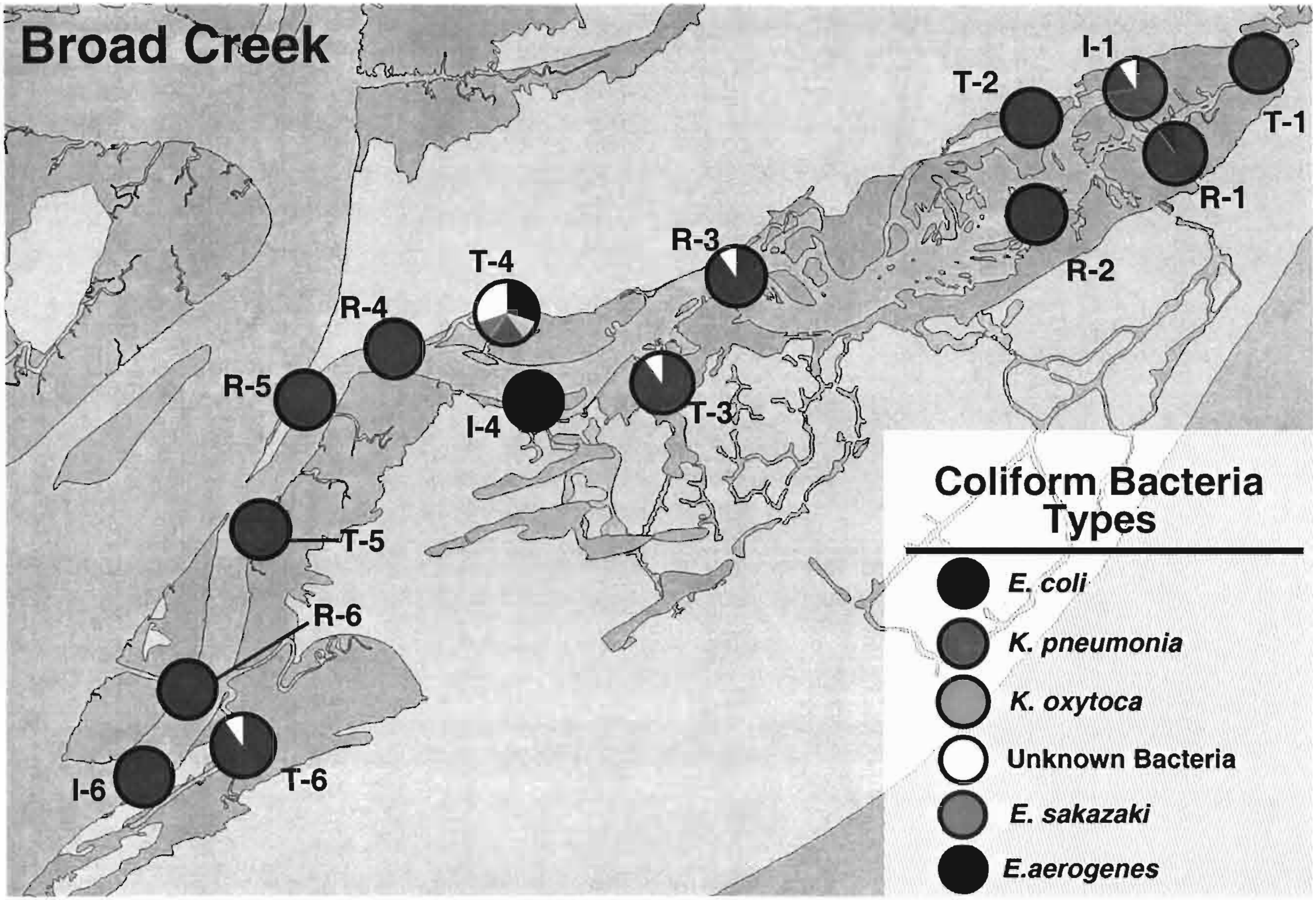


Figure 3.9. Results of API Biotyping measured at each site in Broad Creek. Note that *E. coli* was the dominant fecal coliform bacteria measured at all sites (100%) and that no sites were free of coliform bacteria.

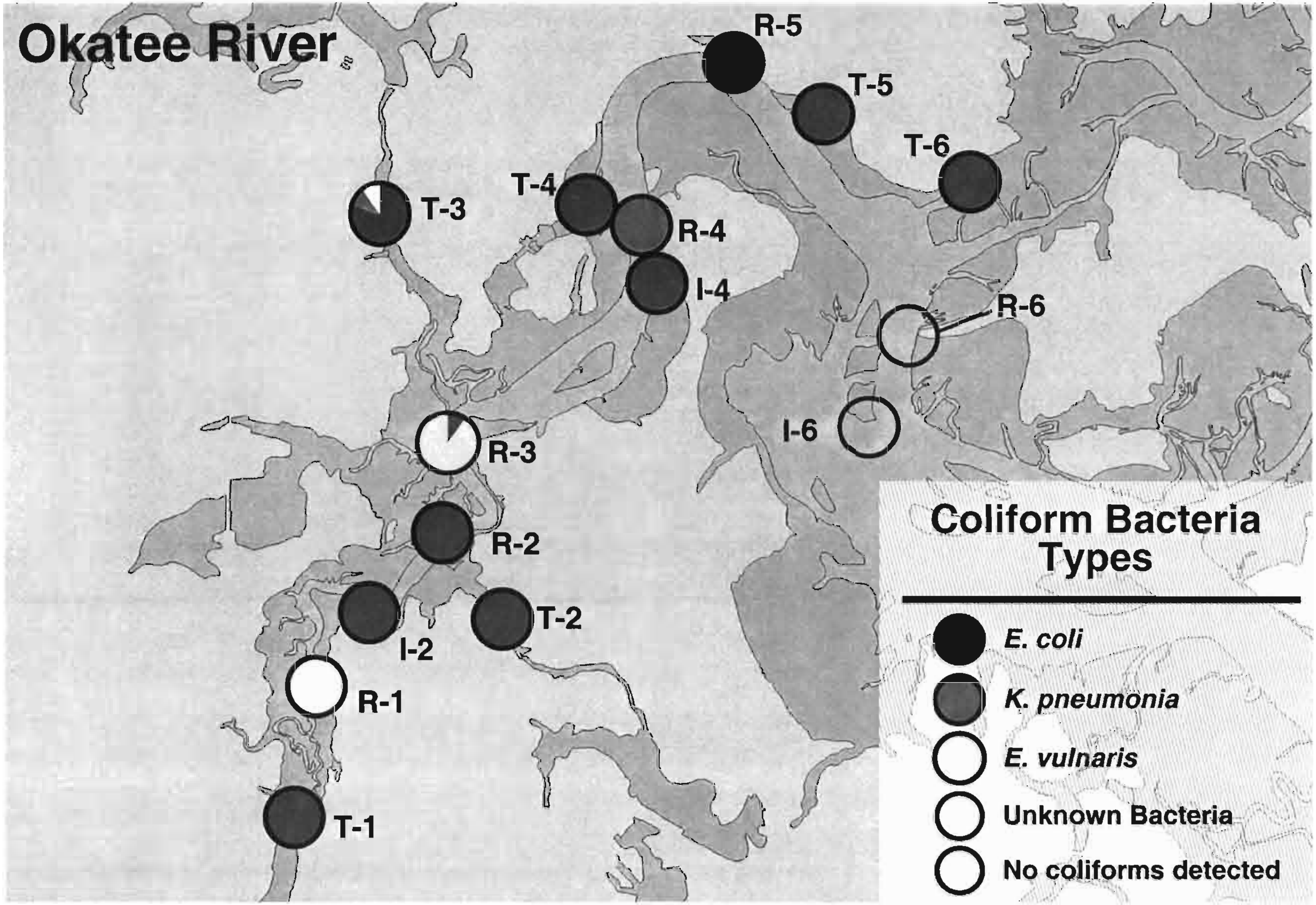


Figure 3.10. Results of API Biotyping measured at each site in the Okatee River. Note that *E. coli* was measured at only 73.3% sites and was the dominant fecal coliform bacteria, and that 13.3% of the sites were free of coliform bacteria.

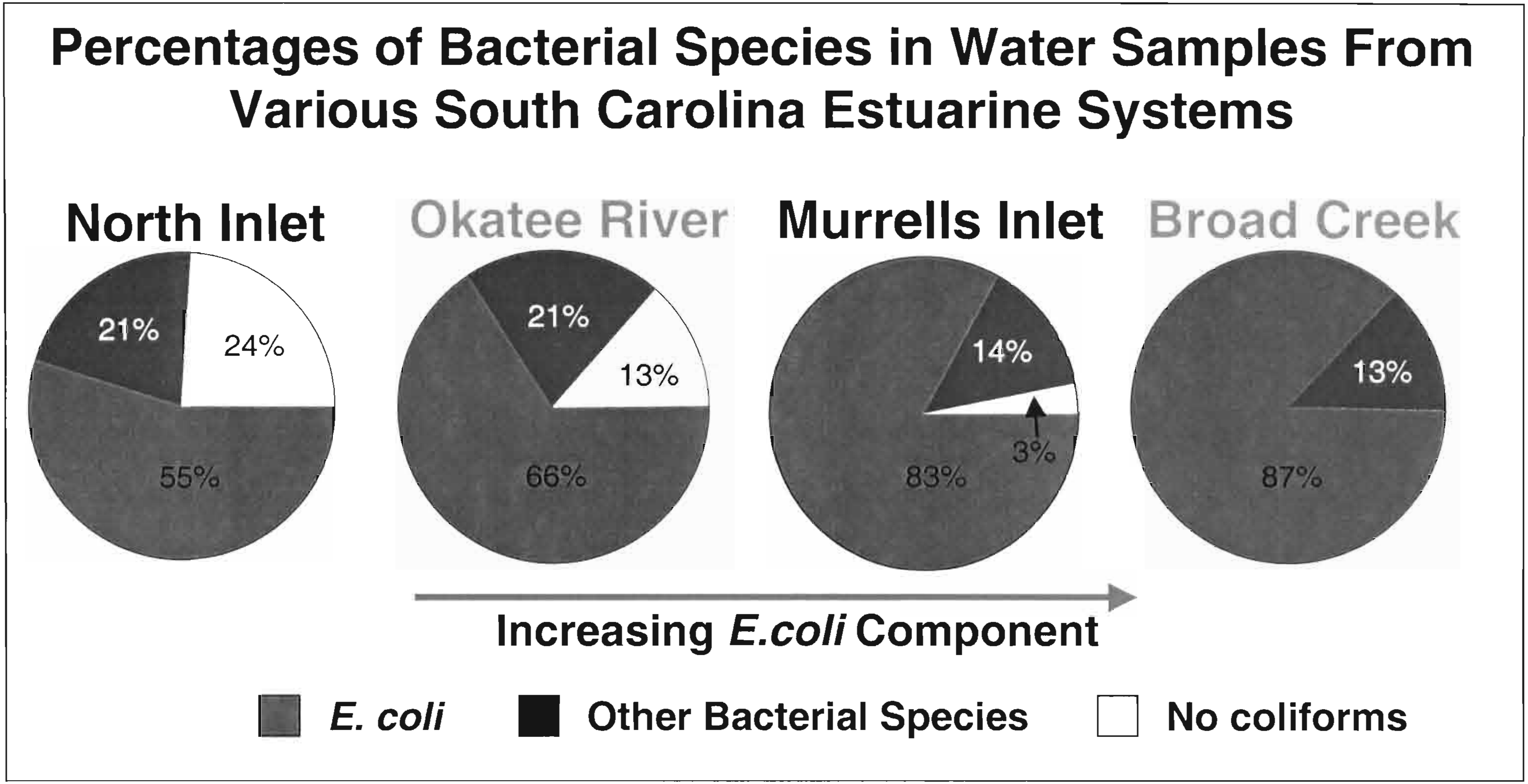


Figure 3.11. Comparison of mean API Biotyping results for all sites in Broad Creek and the Okatee River. Also included for comparison is North Inlet, a pristine NOAA National Estuarine Research Reserve and Sanctuary Site and urbanized Murrells Inlet, located on the southern end of the Myrtle Beach "Grand Strand". Note the increased occurrence of *E. coli* bacteria, as the dominant member of the coliform group and decreased proportion of sites with coliform free samples with increased urbanization. In Broad Creek all sites contained *E. coli* bacteria (100%) versus 73.3% in the Okatee River, a rural area with single family dwellings.

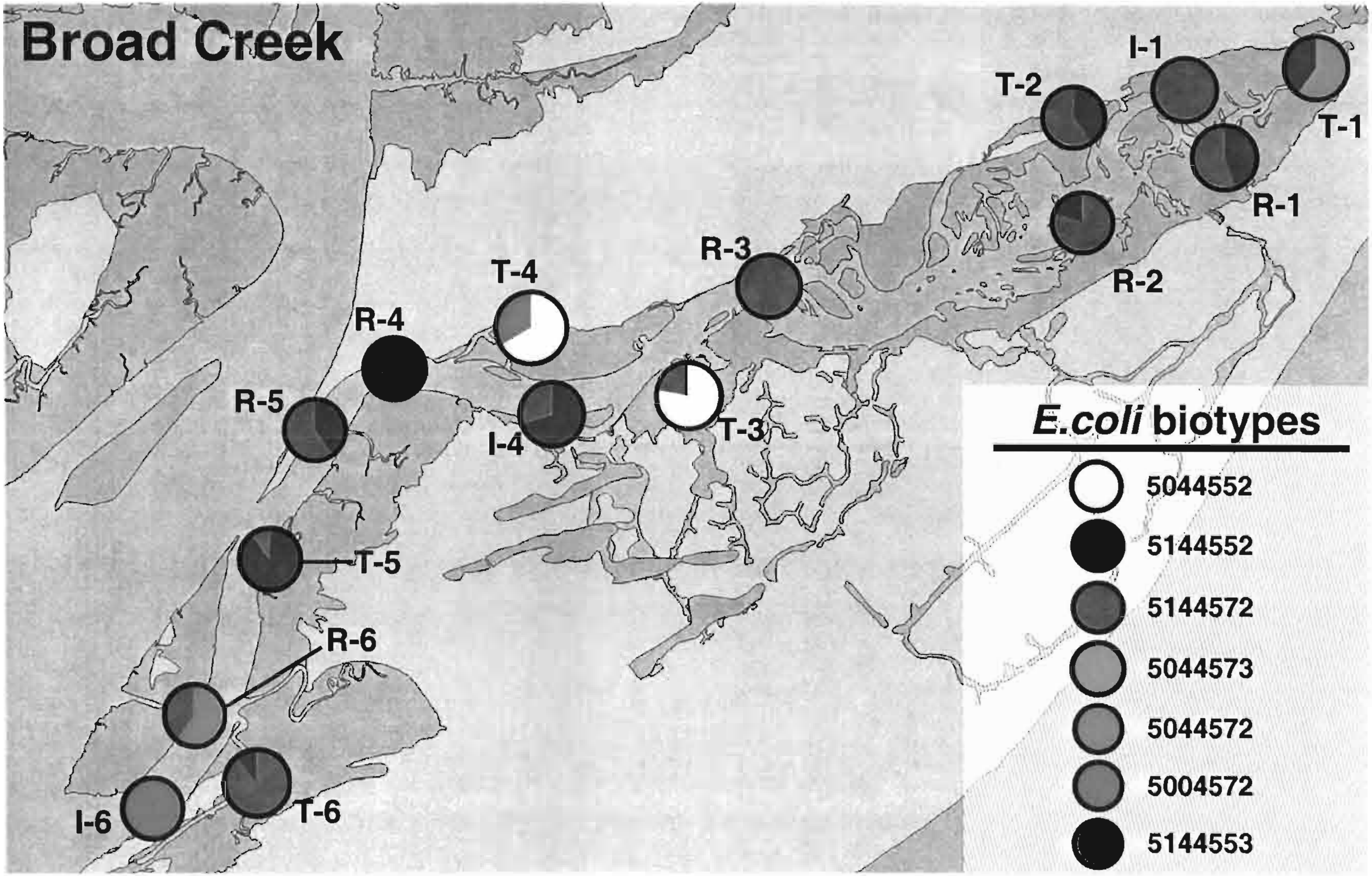


Figure 3.12. *E. coli* bacteria biotypes measured in Broad Creek. Note that API Code 5144572, while the dominant *E. coli* bacteria found in Broad Creek at a majority of the stations sampled (35.9%), was much less prevalent than in the Okatee River (69.7%), and there was much more equitability with several other *E. coli* strains, including 5144552 (32.1%) and 5044572 (15.3%).

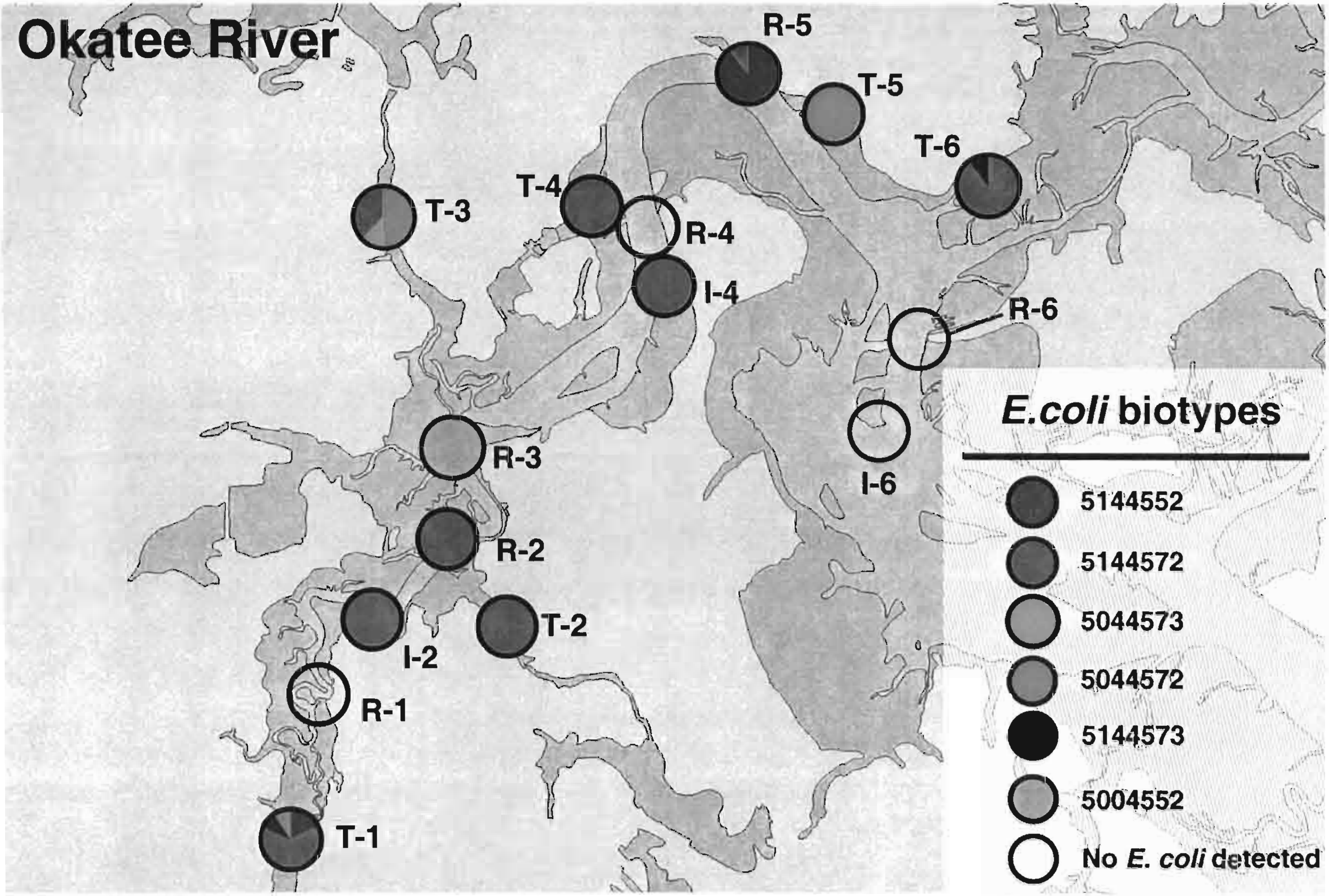


Figure 3.13. *E. coli* bacteria biotypes measured in the Okatee River. Note that API Code 5144572 was the dominant *E. coli* bacteria found in Okatee River at a majority of the stations sampled (69.7%). There was clear dominance by this one API code of *E. coli* in the Okatee River.

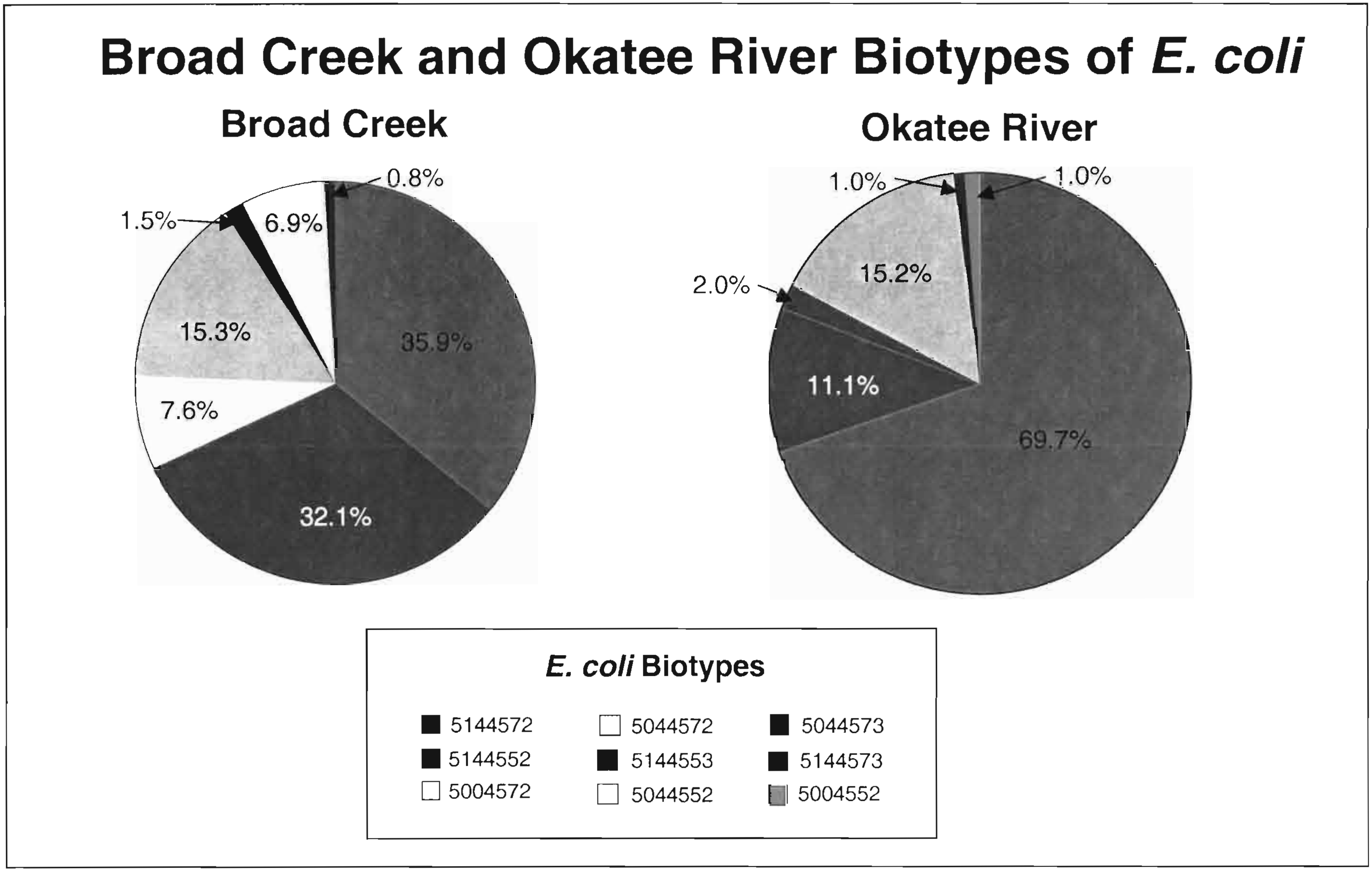


Figure 3.14. A comparison of mean *E. coli* API Codes measured in Broad Creek and the Okatee River. Note the much higher prevalence rate of API code 5144572 in the Okatee River (69.7%) when compared with Broad Creek (35.9%), and the equitability of API codes 5144552 (32.1%) and 5044572 (15.3%) in Broad Creek.

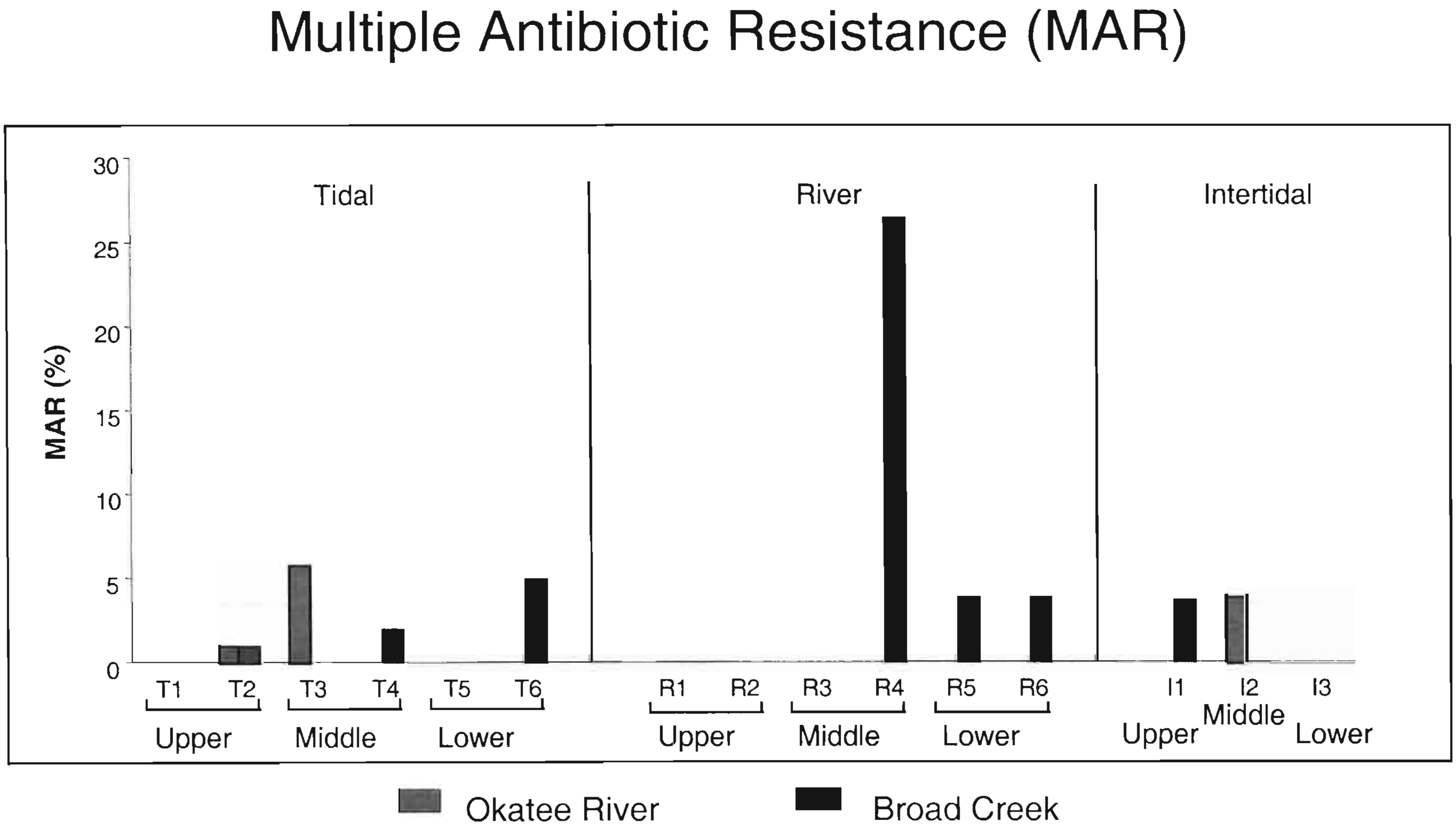

Multiple Antibiotic Resistance (MAR)

Figure 3.15. Multiple Antibiotic Resistance (MAR) Index for each site in Broad Creek and the Okatee River. Note the much higher MAR Index at numerous sites in Broad Creek (n=7 sites) when compared to the Okatee River (n=3 sites).

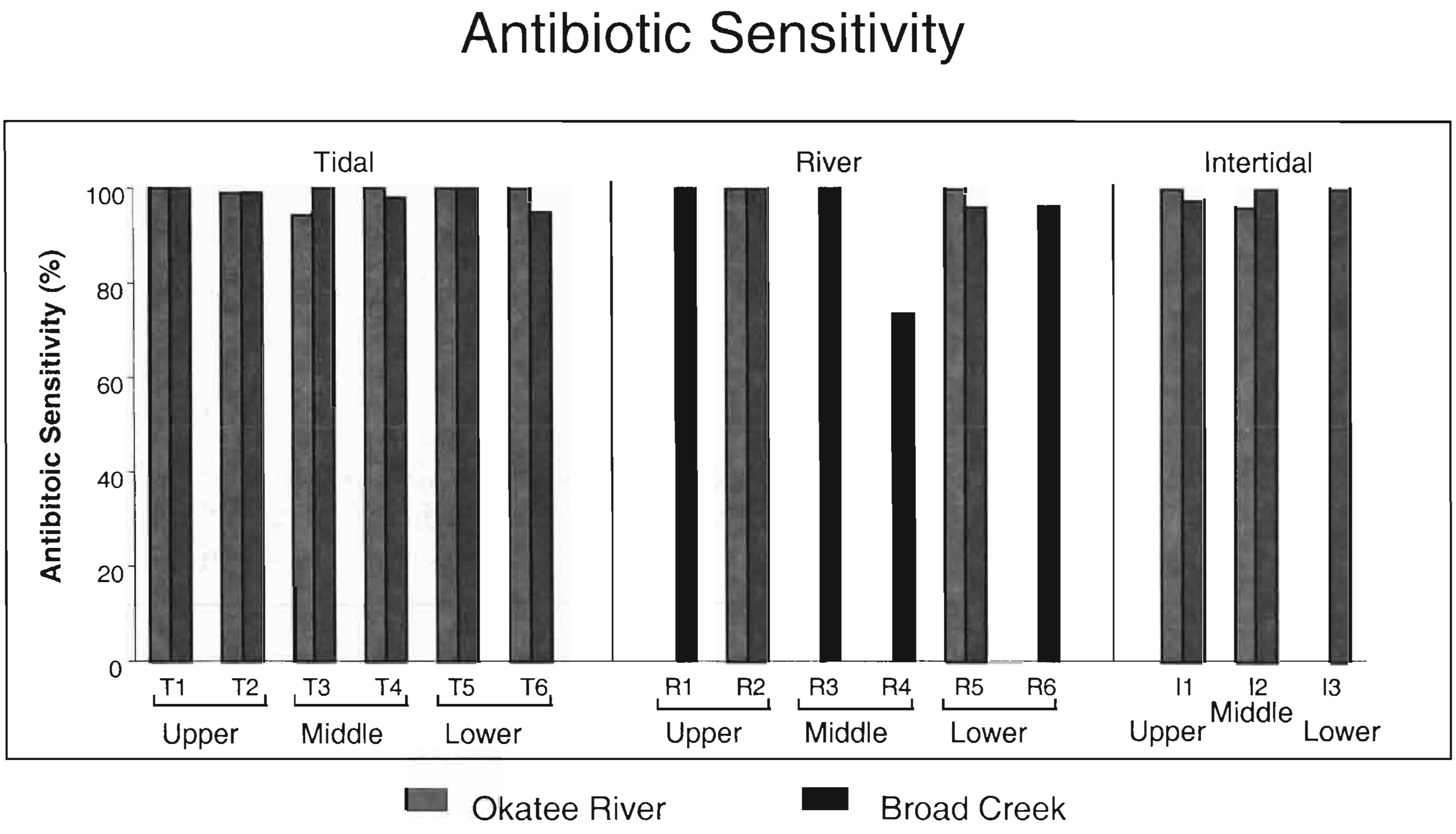


Figure 3.16. MAR Sensitivity for each site in Broad Creek and the Okatee River.

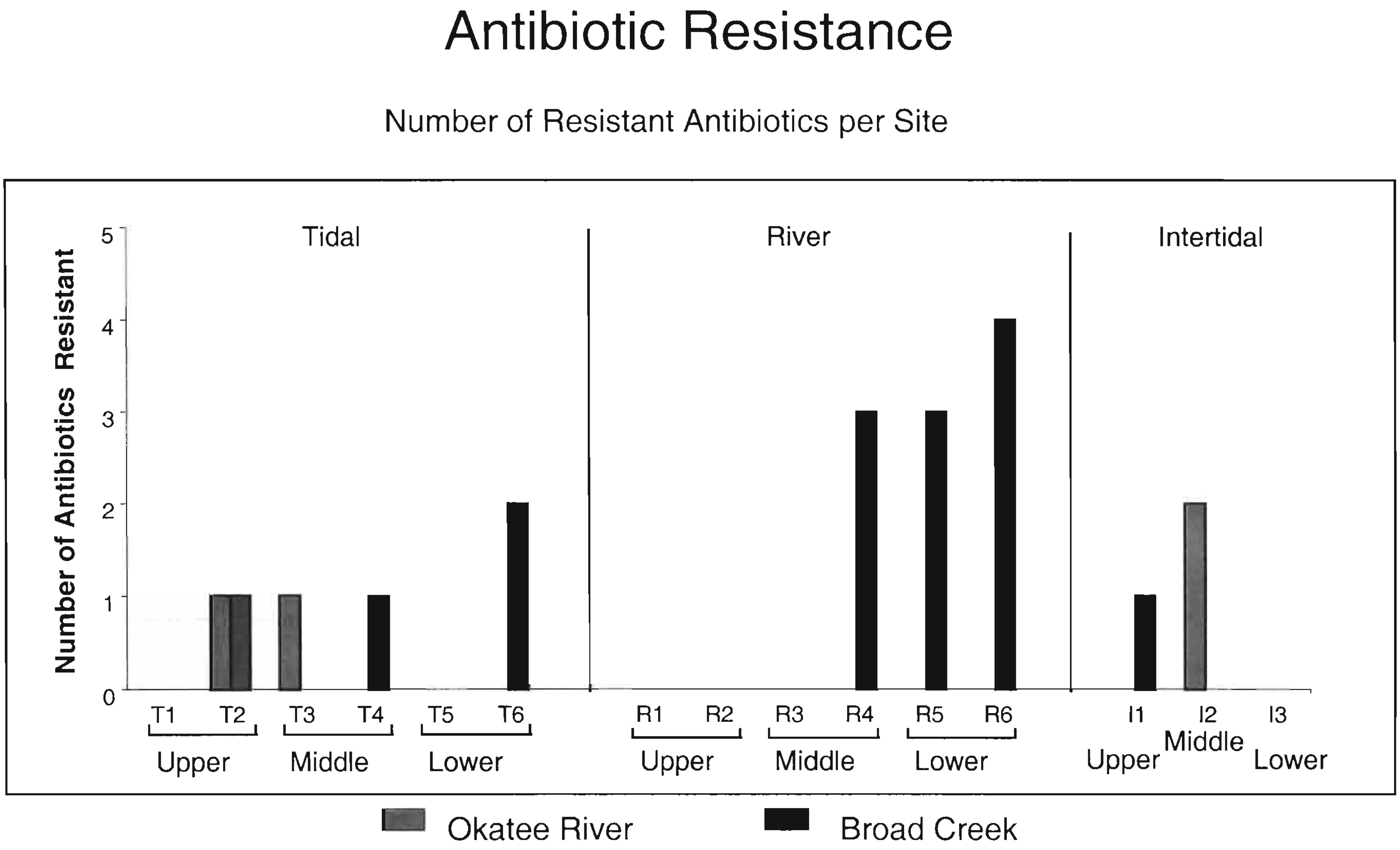
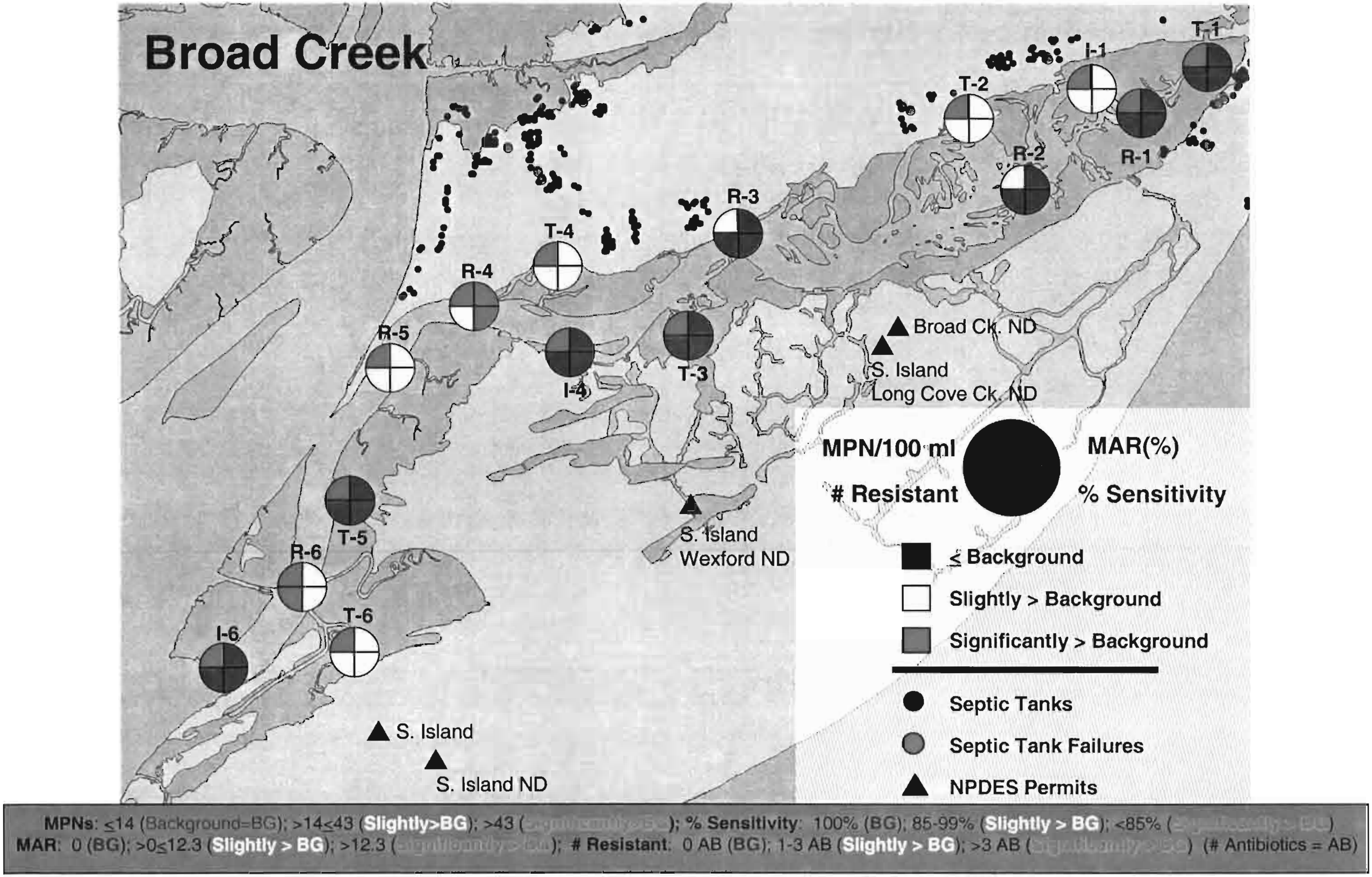


Figure 3.17. A comparison of the number of antibiotics each MAR *E. coli* strain was resistant to in Broad Creek and the Okatee River. Note that the number of resistant antibiotics/strain was much higher in Broad Creek (1-4 resistant antibiotics/strain,averaging 2.14 resistant antibiotics/strain) than in the Okatee River (only 1-2 resistant antibiotics/strain).



MPNs: ≤14 (Background=BG); >14≤43 (**Slightly>BG**); >43 (Significantly > BG); **% Sensitivity**: 100% (BG); 85-99% (**Slightly > BG**); <85% (Significantly > BG)
MAR: 0 (BG); >0≤12.3 (**Slightly > BG**); >12.3 (Significantly > BG); **# Resistant**: 0 AB (BG); 1-3 AB (**Slightly > BG**); >3 AB (Significantly > BG) (# Antibiotics = AB)

Figure 3.18. Coliform bacteria and multiple antibiotic resistance in Broad Creek. Septic tanks (green and red dots) and permitted wastewater disposal sites (blue triangles) indicate a possible correlation of MAR results with wastewater management practices within this region.

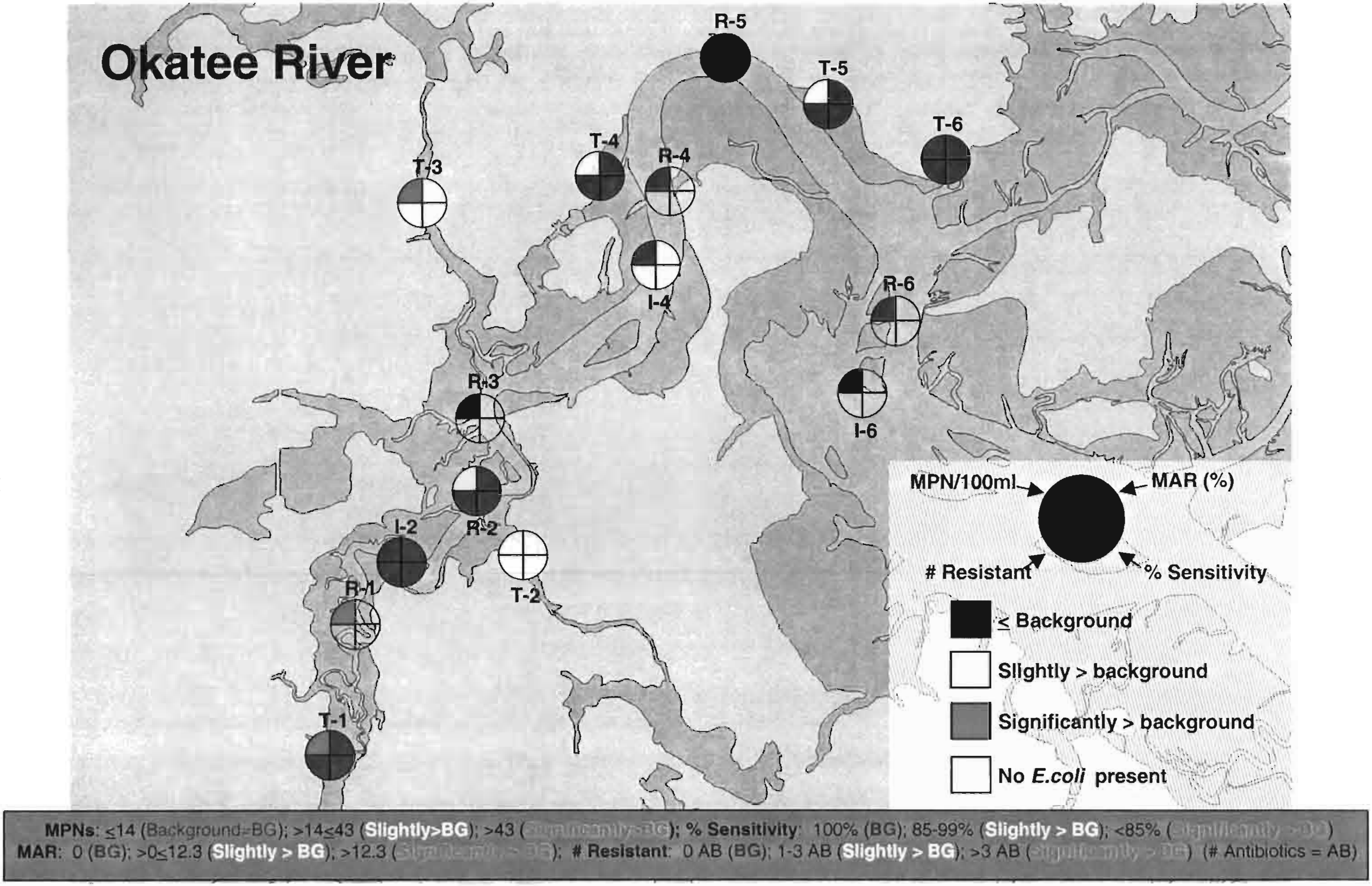


Figure 3.19. Coliform bacteria and multiple antibiotic resistance in Okatee River, indicating relatively low coliform bacterial abundance overall, but with some areas of high coliform counts.

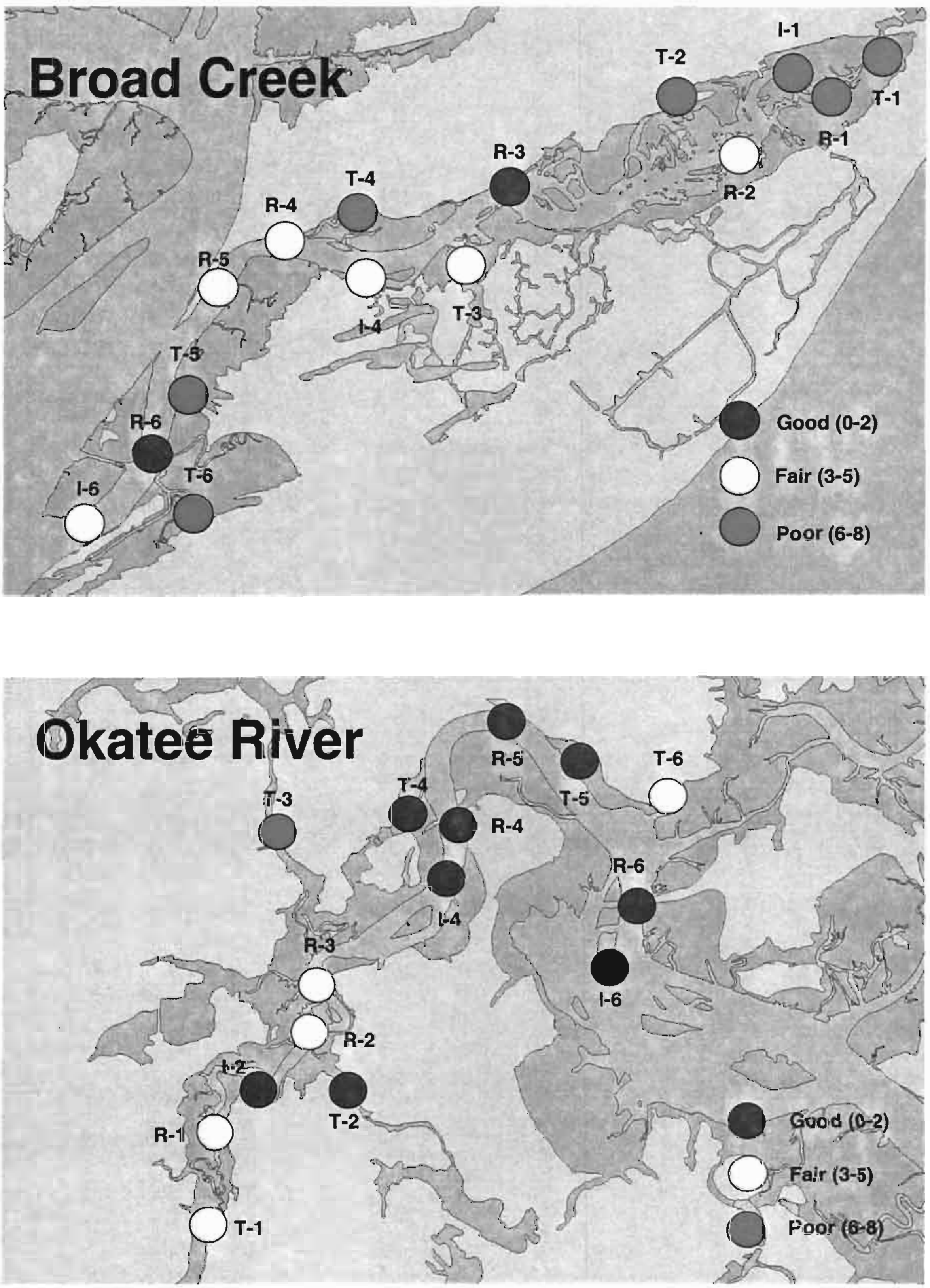


Figure 3.20. Overall water quality summary. See text for scoring explanation.

Table 3.1. Selected water quality results

Station	Sample Depth (m)	Water Temp. °C	Turb. NTU	DO mg/l	DO % Sat	BOD 5-day mg/l	PH SU	Tot. Alkal. CaCO3 mg/l	Salinity ppt	NH3+NH4- mg/l	Total Kelj N mg/l	NO3-NO2 mg/l	Total Phos. mg/l	TOC mg/l	Fecal Coliform /100 ml	Chlor. a ug/l
Broad Creek (8/20/97)																
I-1	0.3	31	32	5.4	72	4.6	7.35	108	25	0.08	0.73	<0.02	0.19	40	65	31.3
I-4	0.3	31	39	4.3	57.3	2.2	7.4	104	27	0.11	0.72	<0.02	0.17	40	210	17.1
I-6	0.3	30.5	37	5.5	71.7	1.8	7.8	107	31	Lab Error	0.44	<0.02	0.1	58	50	9.8
I-6	1.1	30.5		5.6	73.7				31.5							
R-1	0.3	32	45	5.4	73	3.8	7.4	108	24	0.1	0.84	<0.02	0.21	38	80	32.3
R-2	0.3	31.5	20	6.1	81.3	2.4	7.3	108	25.5	0.56	0.57	<0.02	0.15	42	30	25.1
R-2	2	31.5		5.8	77.3				25.5							
R-3	0.3	30	25	5	65.8	1.6	7.1	107	25	Lab Error	0.54	0.02	0.15	38	26	14.1
R-3	11	30		5	65.8				26							
R-4	0.3	30	21	5.8	75.7	1.5	8	107	27	Lab Error	0.46	0.03	0.11	39	1600	16.5
R-4	6	30		5.6	73.7				27							
R-5	0.3	30	20	5.9	77.6	0.8	8.1	106	27	Lab Error	0.4	0.02	0.08	53	50	13.8
R-5	5	30		5.7	75				28							
R-6	0.3	31	23	7.5	100	1.8	8.1	106	29	Lab Error	0.36	<0.02	0.06	40	110	16
R-6	6.5	30		7.3	95.4				29							
T-1	0.3	29	18	3.3	42.3	2	6.7	68	11	0.31	1	0.34	0.19	27	1600	18.1
T-2	0.3	34	75	6.7	93.7	4	7.45	106	25.5	0.68	1.22	<0.02	0.32	44	900	51.1
T-3	0.3	31	7	4.5	59.3	2.4	7.2	86	16	0.14	0.68	0.05	0.35	36	>1600	23
T-3	1.4	31		4.5	59.3				16							
T-4	0.3	28.5	200	2.4	30.4	2	6.45	39	27	0.32	1.6	0.22	0.72	33	>1600	18
T-5	0.3	32	12	4.8	64.9	3.3	7.2	106	28	Lab Error	0.39	<0.02	0.08	46	>1600	9.1
T-6	0.3	29	8.2	3.9	50	2.3	7.1	91	10.5	0.27	0.92	0.07	0.68	42	>1600	32.6
T-6	2	29.5		3.1	39.1				28							

Table 3.1. Selected water quality results

Station	Sample Depth (m)	Water Temp. °C	Turb. NTU	DO mg/l	DO % Sat	BOD 5-day mg/l	PH SU	Tot. Alkal. CaCO3 mg/l	Salinity ppt	NH3+NH4- mg/l	Total Kelj N mg/l	NO3-NO2 mg/l	Total Phos. mg/l	TOC mg/l	Fecal Coliform /100 ml	Chlor. a ug/l
Broad Creek (8/20/97)																
I-1	0.3	31	32	5.4	72	4.6	7.35	108	25	0.08	0.73	<0.02	0.19	40	65	31.3
I-4	0.3	31	39	4.3	57.3	2.2	7.4	104	27	0.11	0.72	<0.02	0.17	40	210	17.1
I-6	0.3	30.5	37	5.5	71.7	1.8	7.8	107	31	Lab Error	0.44	<0.02	0.1	58	50	9.8
I-6	1.1	30.5		5.6	73.7				31.5							
R-1	0.3	32	45	5.4	73	3.8	7.4	108	24	0.1	0.84	<0.02	0.21	38	80	32.3
R-2	0.3	31.5	20	6.1	81.3	2.4	7.3	108	25.5	0.56	0.57	<0.02	0.15	42	30	25.1
R-2	2	31.5		5.8	77.3				25.5							
R-3	0.3	30	25	5	65.8	1.6	7.1	107	25	Lab Error	0.54	0.02	0.15	38	26	14.1
R-3	11	30		5	65.8				26							
R-4	0.3	30	21	5.8	75.7	1.5	8	107	27	Lab Error	0.46	0.03	0.11	39	1600	16.5
R-4	6	30		5.6	73.7				27							
R-5	0.3	30	20	5.9	77.6	0.8	8.1	106	27	Lab Error	0.4	0.02	0.08	53	50	13.8
R-5	5	30		5.7	75				28							
R-6	0.3	31	23	7.5	100	1.8	8.1	106	29	Lab Error	0.36	<0.02	0.06	40	110	16
R-6	6.5	30		7.3	95.4				29							
T-1	0.3	29	18	3.3	42.3	2	6.7	68	11	0.31	1	0.34	0.19	27	1600	18.1
T-2	0.3	34	75	6.7	93.7	4	7.45	106	25.5	0.68	1.22	<0.02	0.32	44	900	51.1
T-3	0.3	31	7	4.5	59.3	2.4	7.2	86	16	0.14	0.68	0.05	0.35	36	>1600	23
T-3	1.4	31		4.5	59.3				16							
T-4	0.3	28.5	200	2.4	30.4	2	6.45	39	27	0.32	1.6	0.22	0.72	33	>1600	18
T-5	0.3	32	12	4.8	64.9	3.3	7.2	106	28	Lab Error	0.39	<0.02	0.08	46	>1600	9.1
T-6	0.3	29	8.2	3.9	50	2.3	7.1	91	10.5	0.27	0.92	0.07	0.68	42	>1600	32.6
T-6	2	29.5		3.1	39.1				28							

Table 3.1. Continued

Station	Sample Depth (m)	Water Temp. °C	Turb. NTU	DO mg/l	DO % Sat	BOD 5-day mg/l	PH SU	Tot. Alkal. CaCO3 mg/l	Salinity ppt	NH3+NH4- mg/l	Total Kelj N mg/l	NO3-NO2 mg/l	Total Phos. mg/l	TOC mg/l	Fecal Coliform /100 ml	Chlor. a ug/l
Okatee River (8/19/97)																
I-2	0.3	32	14	4.3	58.1	2.6	7.3	109	28	Lab Error	0.52	<0.02	0.07	5.1	13	17.1
I-2	0.9	31.1		4.4	58				27							
I-4	0.3	32	30	6.1	82.4	2.2	7	110	29	Lab Error	0.59	<0.02	0.13	5.7	13	21
I-6	0.3	31	7.3	3.1	40.7	1.4	7.1	111	31	0.1	0.36	<0.02	0.09	4.2	<2	6.1
I-6	0.95	30		3.3	42.8				31.5							
R-1	0.3	32.5	70	5.9	79.1	3.4	6.8	104	25.5	Lab Error	0.97	<0.02	0.16	8.5	90	38.5
R-1	1.2	32.3		5.8	78.4				25							
R-2	0.3	32.6	32	5.5	75.3	2.7	7.5	106	27	0.74	0.85	<0.02	0.12	5.2	40	30
R-2	1	32.2		5.4	72.7				27							
R-3	0.3	31.5	45	6	79.7	2.6	7.1	108	27	0.68	0.97	<0.02	0.1	7.2	13	22.8
R-3	2	31.9		5.1	68.9				27							
R-4	0.3	31	31	5.5	73.3	1.8	6.9	108	26	0.42	0.68	<0.02	0.12	6.1	8	15.1
R-4	4	31		5.3	70.7				27.5							
R-5	0.3	30.5	30	3	39.5	1.4	6.9	108	26	0.48	0.68	0.02	0.12	5.7	4	8.9
R-5	5	30.5		2.5	32.9				28							
R-6	0.3	30.5	33	3.5	46.1	1.6	6.2	110	30	0.46	0.76	<0.02	0.1	5.6	<2	10.5
R-6	4	30.5		3.5	46.1				28							
T-1	0.3	29	45	6.4	81.4	1.6	6.9	25	19.5	0.33	0.88	0.1	0.28	8.4	280	9.1
T-2	0.3	32	40	4.7	62.8	1.4	7.25	108	27	Lab Error	0.82	<0.02	0.16	6.6	23	7
T-3	0.3	30.5	30	6.6	86.3	5.9	7.2	91	18	0.14	1.08	<0.02	0.19	10.3	1600	40
T-4	0.3	33.2	13	5	68.5	2.4	7.3	110	28	Lab Error	0.53	<0.02	0.1	6.3	30	24.5
T-4	0.7	31.2		5.2	68.7				28							
T-5	0.3	32	27	5	67.6	1.9	7.4	111	29	Lab Error	0.55	<0.02	0.12	5.9	23	15.1
T-6	0.3	31.1	16	4.6	61.3	1.6	6.4	111	29	Lab Error	0.56	<0.02	0.08	4.7	2	12
T-6	0.8	31		4.6	60.7				29							

Table 3.2. Selected Water Quality Summary Statistics from all SCDHEC Saltwater Monitoring Sites 1993-1997

Parameters	N	50th Percentile	90th Percentile	95th Percentile	MEAN
Alkalinity (mg/l)	2688	79	110	114	72.4
TOC (mg/l)	1016	6.6	16	25	9.33
BOD_5 (mg/l)	3147	1.4	2.6	3.2	1.66
Turbidity (NTU)	3178	9	25	34	13
NH3+NH4 (mg/l)	2785	0.05	0.11	0.25	0.08
TKN (mg/l)	2845	0.59	1.06	1.26	0.68
NO3+NO2 (mg/l)	3348	0.05	0.2	0.28	0.09
TP (mg/l)	3329	0.06	0.16	0.28	0.09

Source: SCDHEC. 1998b.

Table 3.2. Selected Water Quality Summary Statistics from all SCDHEC Saltwater Monitoring Sites 1993-1997

Parameters	**N**	**50th Percentile**	**90th Percentile**	**95th Percentile**	**MEAN**
Alkalinity (mg/l)	2688	79	110	114	72.4
TOC (mg/l)	1016	6.6	16	25	9.33
BOD_5 (mg/l)	3147	1.4	2.6	3.2	1.66
Turbidity (NTU)	3178	9	25	34	13
NH3+NH4 (mg/l)	2785	0.05	0.11	0.25	0.08
TKN (mg/l)	2845	0.59	1.06	1.26	0.68
NO3+NO2 (mg/l)	3348	0.05	0.2	0.28	0.09
TP (mg/l)	3329	0.06	0.16	0.28	0.09

Source: SCDHEC. 1998b.

Table 3.3. Summary of selected Hydrolab readings

	Dissolved Oxygen (mg/l)							Percent Dissolved Oxygen Saturation							Salinity (ppt)					pH (SU)				
Station	N	Min	Max	Range	Avg	N<2	%<2	N	Min	Max	Range	Avg	N<28	%<28	N	Min	Max	Range	Avg	N	Min	Max	Range	Avg
BROAD CREEK																								
R-1	48	1.63	6.63	5	4.222	4	8.33	48	24.5	105.2	80.7	65.72	3	6.25	48	25.8	28.9	3.1	27.97	48	7.13	7.62	0.49	7.415
R-2	51	2.44	5.97	3.53	4.382	0		51	37.8	94.2	56.4	68.14	0		51	27.6	29.5	1.9	28.58	51	7.12	7.46	0.34	7.348
R-3	50	3.53	5.43	1.9	4.622	0		50	54.6	86.0	31.4	72.51	0		50	26.4	29.7	3.3	27.83	50	7.17	7.59	0.42	7.370
R-4	50	3.63	5.68	2.05	4.627	0		50	56.3	89.8	33.5	72.46	0		50	26.5	30.3	3.8	28.08	50	7.18	7.76	0.58	7.419
R-5	51	3.92	5.51	1.59	4.964	0		51	58.4	85.0	26.6	75.68	0		51	29.7	31.8	2.1	30.82	51	7.53	7.91	0.38	7.734
R-6	51	4.25	5.78	1.53	5.085	0		51	64.5	90.1	25.6	78.57	0		51	30.4	33.2	2.8	31.65	51	7.50	7.93	0.43	7.731
T-1	40	0.72	6.09	5.37	3.628	7	17.50	40	10.5	95.5	85.0	54.91	5	12.50	40	6.4	28.7	22.3	24.01	40	2.50	7.33	4.83	5.317
T-2	38	2.20	6.48	4.28	4.298	0		38	33.6	102.7	69.1	66.52	0		38	26.9	28.9	2.0	28.31	38	7.12	7.66	0.54	7.427
T-3	36	2.43	5.10	2.67	3.389	0		36	35.9	77.5	41.6	52.11	0		36	16.6	26.9	10.3	23.43	36	7.44	7.81	0.37	7.668
T-4	35	1.84	4.29	2.45	3.297	1	2.86	35	28.3	67.6	39.3	51.46	0		35	15.2	28.8	13.6	27.05	35	7.44	7.88	0.44	7.656
T-5	51	0.08	8.08	8	3.923	10	19.61	51	1.1	126.8	125.7	59.80	10	19.61	51	30.4	31.9	1.5	31.34	51	6.97	7.80	0.83	7.373
T-6	51	3.11	6.36	3.25	4.700	0		51	42.4	96.5	54.1	69.28	0		51	4.7	31.8	27.1	25.79	51	7.17	7.87	0.70	7.530
OKATEE RIVER																								
R-1	51	3.03	7.00	3.97	5.233	0		51	45.4	111.0	65.6	81.24	0		51	24.5	30.1	5.6	28.98	51	7.10	7.51	0.41	7.349
R-2	50	4.05	6.92	2.87	5.225	0		50	62.3	108.8	46.5	81.02	0		50	29.1	30.2	1.1	29.71	50	7.28	7.53	0.25	7.402
R-3	51	3.27	6.08	2.81	4.310	0		51	51.9	99.0	47.1	69.07	0		51	28.1	29.8	1.7	28.95	51	7.29	7.56	0.27	7.395
R-4	51	3.00	5.88	2.88	4.154	0		51	47.5	95.1	47.6	66.23	0		51	26.7	29.6	2.9	28.60	51	7.34	7.57	0.23	7.423
R-5	50	4.65	6.32	1.66	5.405	0		50	69.6	96.5	26.9	81.89	0		50	30.0	31.2	1.2	30.70	50	7.43	7.57	0.14	7.490
R-6	51	4.62	6.51	1.89	5.441	0		51	68.2	99.5	31.3	82.39	0		51	30.8	31.4	0.6	31.10	51	7.37	7.55	0.18	7.449
T-1	42	2.67	7.03	4.36	4.653	0		42	37.4	100.7	63.3	69.49	0		42	2.4	28.8	26.4	22.74	42	6.90	7.45	0.55	7.246
T-2	49	1.02	6.66	5.64	4.616	1	2.04	49	14.7	105.1	90.3	71.66	1	2.04	49	27.0	30.1	3.1	29.56	49	7.16	7.53	0.37	7.346
T-3	36	3.12	6.67	3.55	3.897	0		36	49.4	108.3	58.9	62.18	0		36	28.1	29.3	1.2	28.79	36	7.32	7.67	0.35	7.438
T-4	50	3.55	7.42	3.87	4.619	0		50	46.0	118.2	72.2	70.93	0		50	10.1	28.3	18.2	23.92	50	6.99	7.72	0.73	7.386
T-5	49	3.13	8.95	5.82	5.466	0		49	44.3	135.9	91.6	82.63	0		49	30.2	31.2	1.0	30.82	49	7.19	7.59	0.40	7.404
T-6	44	3.00	8.10	5.1	4.553	0		44	45.6	114.2	68.6	69.89	0		44	9.1	31.6	22.5	30.45	44	7.14	7.59	0.45	7.343

N<2 = Number of dissolved oxygen measurements less than 2.0 mg/l
%<2 = Percentage of dissolved oxygen measurements less than 2.0 mg/l
N<28 = Number of percent dissolved oxygen values less than 28%
%<28 = Percentage of percent dissolved oxygen values less than 28%

Table 3.4. Summary of MAR results from Broad Creek, the Okatee River and selected Sewerage Treatment Plants in coastal South Carolina. Note that *E. coli* bacteria from STPs were more resistant to larger number of antibiotics than was measured in surface water samples from Broad Creek and the Okatee River. In addition, *E. coli* bacteria in Broad Creek were more resistant to a larger number of antibiotics than those measured in the Okatee River.

	Estuary Type		
Antibiotic	**Undeveloped (Okatee River) n=1061**	**Developed (Broad Creek) n=1443**	**Sewage Treatment Plants n=860**
Ampicillin	0	4 (0.3%)	18 (2%)
Chlortetracycline	0	9 (0.6%)	6 (0.7%)
Kanamycin	0	1 (0.07%)	0
Naladixic Acid	0	1 (0.07%)	1 (0.1%)
Neomycin	0	0	0
Oxytetracycline	0	16 (1%)	9 (1%)
Penicillin G	10 (0.9%)	6 (0.4%)	46 (5%)
Streptomycin	0	0	8 (0.9%)
Sulfathiazole	1 (0.09%)	0	6 (0.7%)
Tetracycline	0	12 (0.8%)	12 (1%)
Number of Sensitive Treatments	1050 (99%)	1394 (97%)	754 (88%)
Number of Resistant Treatments	11 (1%)	49 (3%)	106 (12%)
Overall MAR (%)	1.04	3.40	12.33

Table 3.4. Summary of MAR results from Broad Creek, the Okatee River and selected Sewerage Treatment Plants in coastal South Carolina. Note that *E. coli* bacteria from STPs were more resistant to larger number of antibiotics than was measured in surface water samples from Broad Creek and the Okatee River. In addition, *E. coli* bacteria in Broad Creek were more resistant to a larger number of antibiotics than those measured in the Okatee River.

	Estuary Type		
Antibiotic	**Undeveloped (Okatee River) n=1061**	**Developed (Broad Creek) n=1443**	**Sewage Treatment Plants n=860**
Ampicillin	0	4 (0.3%)	18 (2%)
Chlortetracycline	0	9 (0.6%)	6 (0.7%)
Kanamycin	0	1 (0.07%)	0
Naladixic Acid	0	1 (0.07%)	1 (0.1%)
Neomycin	0	0	0
Oxytetracycline	0	16 (1%)	9 (1%)
Penicillin G	10 (0.9%)	6 (0.4%)	46 (5%)
Streptomycin	0	0	8 (0.9%)
Sulfathiazole	1 (0.09%)	0	6 (0.7%)
Tetracycline	0	12 (0.8%)	12 (1%)
Number of Sensitive Treatments	1050 (99%)	1394 (97%)	754 (88%)
Number of Resistant Treatments	11 (1%)	49 (3%)	106 (12%)
Overall MAR (%)	1.04	3.40	12.33

Table 3.5. Regional comparisons of site MARs at developed and undeveloped watersheds in South Carolina (this study), Florida (Parveen et al., 1997) and Maryland (Kaspar et al.,1990). Note that the percentage MAR in developed and undeveloped watersheds were quite similar (47-69%), despite these regional differences.

	SITE MAR (%)			
Watershed	**Developed**	**Undeveloped**	**% Difference (Dev. vs. Undev.)**	**Reference**
Florida (Appalachicola Bay)	25	13	47	Parveen et al., 1997
Maryland (Anacostia R., Anapolis Harbor, Balitimore Harbor vs. Chester R., Miles R., Wye R., and Love Point)	9	2.8	69	Kaspar et al., 1990
South Carolina (Broad Creek vs. Okatee R.)	3.4	1.04	69	This Study

Table 3.6. MAR results for selected Sewerage Treatment Plants in coastal South Carolina. Note the higher MAR Index and the number of antibiotics to which E. Coli strains were resistant in those STPs servicing retirement communities at Hilton Head (LC-1, BC-1 and HH-1) when compared to those serving more general populations of Beaufort County (OK-1, SI-1 and WX-1).

Antibiotic	**FTSTP FIN. 12/97 (n=2)**	**BC-1 (n=13)**	**HH-1 (n=15)**	**LC-1 (n=15)**	**OK-1 (n=15)**	**SI-1 (n=15)**	**WX-1 (n=13)**
Ampicillin	0	3	3	2	9	1	0
Chlortetracycline	1	3	2	1	0	0	0
Kanamycin	0	0	0	0	0	0	0
Naladixic Acid	0	0	0	1	0	0	0
Neomycin	0	0	0	0	0	0	0
Oxytetracycline	1	4	4	1	9	3	0
Penicillin G	0	10	7	8	0	0	9
Streptomycin	1	3	4	1	0	0	0
Sulfathiazole	0	2	3	1	2	3	0
Tetracycline	1	3	3	1	0	0	0
Total # Resistance	4	28	26	16	20	7	9
Percent Resistant	20%	22%	17%	11%	13%	5%	7%
# Antibiotics Resistant	4	7	7	8	3	3	1

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Ampicillin	0	3	3	2	9	1	0
Chlortetracycline	1	3	2	1	0	0	0
Kanamycin	0	0	0	0	0	0	0
Naladixic Acid	0	0	0	1	0	0	0
Neomycin	0	0	0	0	0	0	0
Oxytetracycline	1	4	4	1	9	3	0
Penicillin G	0	10	7	8	0	0	9
Streptomycin	1	3	4	1	0	0	0
Sulfathiazole	0	2	3	1	2	3	0
Tetracycline	1	3	3	1	0	0	0
Total # Resistance	4	28	26	16	20	7	9
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Table 3.7. Threshold values used to determine overall water quality summary value.

Parameter	**Threshold**
Dissolved Oxygen[1]	24-Hour Average < 5.0 mg/l
pH[1]	<6.5 SU or >8.5 SU
Fecal Coliform Bacteria[1]	>43 colonies/100 ml
Salinity[2]	24-Hour Range >20 ppt
Chlorophyll-a[3]	>20 ug/l
Alkalinity[4]	110 mg/l
Total Organic Carbon[4]	16 mg/l
Five-Day Biochemical Oxygen Demand[4]	2.6 mg/l
Turbidity[4]	25 NTU
Total Kjeldahl Nitrogen[4]	1.06 mg/l
Nitrate/Nitrite Nitrogen[4]	0.2 mg/l
Total Phosphorus[4]	0.16 mg/l

[1] State Standard (SCDHEC, 1998a)

[2] Holland et al. 1996

[3] NOAA (1996)

[4] Statewide 90th Percentile (SCDHEC, 1998b)

Chapter 4
Sediment Quality of Broad Creek and the Okatee River

By
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Introduction:

Recent regional studies of southeastern estuaries have documented degraded sediment and water quality in several of the more developed drainage systems as well as in a few of the relatively undeveloped systems (e.g. NOAA, 1988; 1991; Hyland et al., 1996; Long et al., 1998). Although some of these estuaries have been sampled intensively, the majority have not and the extent of contaminant concentrations is very poorly understood in all but a few of the estuaries. Interpretation of the existing data is further confounded by the variety of sampling and analytical methods used in these studies, which makes it very difficult to evaluate the relationships between land-use patterns and estuarine habitat quality with respect to anthropogenic contaminant concentrations.

Because the southeastern region of the United States is experiencing rapid development of the coastal zone, it is imperative for scientists and coastal zone managers to (1) have adequate knowledge of the current state of our estuaries, and (2) understand the potential impacts of changes in land-use patterns on estuarine habitat quality. Several large-scale studies, such as the NOAA/EPA Environmental Monitoring and Assessment Program (EMAP) and the NOAA Status and Trends (NS&T) Program have attempted to define the condition of southeastern estuaries on a regional scale, but sampling in both of those programs is too limited to adequately assess conditions within a given drainage basin. More intensive sampling has been conducted by numerous researchers from various state, federal, academic and private institutions in many coastal areas of South Carolina and Georgia. However, these data are in different formats and the range of data quality (e.g. detection limits) is quite variable among the studies. Additionally, most of these data sets are not readily accessible or in a form that could easily used by scientists outside those institutions that collected the data.

Background:

Estuarine environments in South Carolina are facing significant developmental pressures which mandates that local, state and federal environmental agencies must take more proactive management of upland development to protect these important ecosystems. These *Spartina alterniflora* estuarine ecosystems are among the most productive ecosystems in the biosphere and are of particular importance in terms of their nursery ground function for finfish and shellfish. Currently, greater than 75% of all finfish and shellfish species are estuarine dependant, using estuarine environments for one or more of their life history stages for development. The dynamic nature of these estuarine environments is matched by the dynamic nature of the life history/development stages of the many species of fish and shellfish utilizing these environments.

Coastal estuaries in South Carolina vary greatly in size, hydrography (e.g. fresh water flushing characteristics) and the amount of terrestrial upland development surrounding each watershed. The smallest estuaries are generally located in the northern third of South Carolina (north of Georgetown-Winyah Bay) and are generally high salinity systems (>35 ppt during dry weather periods), which do not have a major river flowing into each system and are diluted only by runoff from rainfall. As a result of these geographic characteristics, small high salinity estuaries are influenced by land development directly adjacent to the estuary rather than development further inland.

The largest estuaries in the state are located south of Georgetown and include Winyah Bay, Charleston Harbor, St. Helena Sound (e.g. ACE Basin), Port Royal Sound, Calibogue Sound and the Savannah River. These large estuaries have rivers which flow into the estuaries (e.g. riverine estuaries) and generally have substantial urban and industrial development in the surrounding upland terrestrial watersheds. In addition to impacts from adjoining land development within the proximate watershed, these estuaries are greatly influenced by freshwater flow from rivers within each system and resulting salinities are lower then in non-riverine, high salinity estuaries. Moreover, several of these riverine estuaries (e.g. Winyah Bay, Charleston Harbor, Port Royal Sound and the Savannah River) are ports of commerce, with extensive commercial fleets as well as recreational boating activities. Conversely, non-riverine estuaries are surrounded primarily by urban (roadways, infrastructure) and suburban (e.g. housing, service/tourism industries, and marinas) upland development and are generally lacking in industrial development, and contain marinas primarily for recreational boating.

The impact of upland development has not been well studied in South Carolina. While several state and federal monitoring programs have chronicled the levels of selected chemical contaminants at long term monitoring stations, these efforts have generally not been focused on characterizing pollution sources in upland areas in a quantitative manner. Marcus and Scott (1989) summarized data from the SCDHEC trend monitoring data on chemical contamination of sediments and biota (oysters and blue crabs) in 16 estuaries with varying degrees of urban development. Polycyclic aromatic hydrocarbons (PAHs) were the contaminants chosen for study, since they are indicative of urban activities associated with fossil fuel combustion. Results indicated that a significant increase in total PAH sediment concentrations was observed in association with increased amounts of urbanization. Concomitant increased uptake of PAHs was observed in oysters and blue crabs, which was associated with urban runoff. Large metropolitan urban complexes, such as Charleston Harbor and Winyah Bay, had the highest PAH concentrations in sediments and biota measured, whereas small high salinity estuaries, such as North Inlet, a NOAA National Estuarine Research Reserve and Sanctuary (NERRS) site, had the lowest PAH concentrations measured. Also, suburban areas such as in Beaufort County were generally found to have low to moderate PAH concentrations.

PAH pollution may adversely affect living marine resources of estuaries by severely (e.g. acute toxicity) or chronically (e.g. sublethal affects on growth, development and reproduction) affecting resident fauna. Although some estuarine organisms possess methods for detoxifying PAHs by making them water soluble and then excreting the altered chemicals, these processes require energy and therefore are not without metabolic cost to the organisms such as decreased or altered growth, development and reproduction. Decreased reproductive potential may be directly related to "ecological death", since reduced offspring production may ultimately affect population size and structure within a given species and may alter food chain trophic structure for dependent species. Other contaminants associated with urban development such as PCBs, persistent pesticides (e.g. chlordane = termiticide), and trace metals (e.g. Cu = bottom fouling paint in boats) are also of a significant concern.

More recent studies (Fulton et al., 1993; Vernberg et al., 1993; Sanders,1995; Fortner et al., 1996) have attempted to derive more quantitative relationships between land-use and coastal development on estuarine ecosystem health. The Urbanization in Southeast Estuaries (Eco) System (USES) study has studied the effects of coastal development on Murrells Inlet, an estuary highly developed for tourism, and North Inlet, a pristine, undeveloped estuary which is a NOAA NERRS site. The goal of the USES Project was to establish a Geographical Information System (GIS) based land-use model which is linked with fishery based population models to identify urban, nonpoint source (NPS) loading regions within estuaries and to measure resulting effects on living marine resources of commercial, recreational and ecological importance.

Results of the USES Project indicated that significant NPS runoff loading of PAHs and coliform bacteria occurred in watersheds adjacent to terrestrial upland areas. Major sources of PAHs included runoff from parking lots and roadways, and discharges from marinas, while major sources of coliform bacteria appeared to be related to remaining septic tanks within the estuary. Bacteriological "fingerprinting" of coliform positive bacteria clearly indicated that *E. coli* bacteria (e.g. an indicator of human and other mammalian species) densities and prevalence rates were much higher in urbanized Murrells Inlet and that estuarine regions free of coliform bacteria occurred at a rate 6 times higher in pristine North Inlet. Similarly, the highest PAH concentrations in sediments and oysters were found adjacent to transportation corridors and marinas. Highest coliform bacterial densities were found adjacent to areas of significant suburbanization (e.g. residential housing and service industries) and co-occurred with the highest levels of PAHs at frequencies higher than would be predicted from random, chance occurrence. This suggests that coliform bacteria may significantly interact with PAHs, and that fecal coliform bacteria may degrade PAHs in sediments, possibly using the carbon-hydrogen source of the PAHs as a energy source. Marcus and Scott (1989) reported that in laboratory bioassays, fecal coliform bacteria were able to use low concentrations of PAHs as an energy source. Finley et al. (1999) further reported that reduced abundances and altered reproductive output in grass shrimp in Murrells Inlet areas such as in Beaufort County were generally found to have low to moderate PAH concentrations.

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Another important study that provided insight and background on the effects of upland urbanization in estuarine habitats was the Tidal Creek Study conducted by the South Carolina Department of Natural Resources. Small headwater tidal creeks within each river system of the Charleston Harbor estuary were studied and compared with the larger river/harbor regions of the estuary in terms of benthic and pelagic community structure, chemical contaminant loading, toxicological screening, and physicochemical water quality. Major findings of this study include the following: 1) Greatest chemical contaminant loadings occur in the headwater areas of tidal creeks and major pollution sources from urbanization include PAHs, chlordane and some trace metals; 2) Industrial Point source pollution is an additive input to the urban NPS runoff loading pulse; 3) PAH concentrations, which were the dominant urban pollutant found in Murrells Inlet in the USES study, are greatly increased in regions receiving additional industrial discharges; 4) Some industrial discharges have caused pollution of both tidal creek as well as river reaches of Charleston Harbor; 5) Altered physicochemical water quality, in particular alterations in dissolved oxygen and salinity dynamics, occurred in developed watersheds; 6) Grass shrimp abundances were significantly reduced in some urban, suburban, and industrial, and agricultural watersheds; 7) Generally, benthic and pelagic community structures were not altered in comparisons of developed and undeveloped watersheds; and 8) Reduced immune function was observed in mummichogs (*Fundulus heteroclitus*) in developed watersheds. Results from the Tidal Creek project may enable scientists to better discern impacts from coastal development on complex riverine estuaries and have prompted GIS models to be developed which may elucidate interactive effects from multiple stressors, such as percent impervious surface area within each watershed.

Study Objectives:

Results from the USES and Tidal Creek Projects have greatly added to our knowledge of the impacts of urbanization and coastal development. Knowledge of the spatial distributions and effects of chemical contaminants within different watersheds needs further study and synthesis of data in order to better link the effects of land development on the environment. Nowhere is the need more critical than in Beaufort County, South Carolina where population doubling times are around 25 years. In particular, highly develop watersheds such as Broad Creek near Hilton Head, SC, have not been adequately characterized in terms of chemical contaminants. Additionally, rural watersheds which will be rapidly developed in the next 10 years, such as the Okatee River, have not been studied at all.

The objective of this study was to develop sediment contaminants and toxicology baselines for highly developed (Broad Creek) and rural (Okatee River) watersheds in Beaufort County. Specific sub-objectives included:

1) Assessment of the physical sediment characteristics in Broad Creek and the Okatee River including grain size and Total Organic Carbon (TOC);

2) Assessment and comparisons of sediment contaminant concentrations of trace metals, PAHs, pesticides and PCBs in Broad Creek and the Okatee River;

3) Comparisons of measured sediment concentrations of chemical contaminants with Sediment Quality Guidelines;

4) Evaluation of toxicological responses in biota to sediment bound contaminants using a variety of sediment bioassays, and

5) Development of contaminant databases to be used in formulating effective risk reduction strategies for managing chemical contaminant risks from urban NPS runoff.

Bottom Sediment Composition:

Sediment composition was evaluated at each tidal creek, subtidal river, and intertidal river site (Figures 4.1 and 4.2) to provide the physical information needed for interpretation of biological and contaminants data. The distribution of macrobenthic infaunal organisms is directly influenced by sediment type. Feeding and respiratory behaviors of many of these animals are adapted to specific sediment conditions. Consequently, a grain size description of the mixture of sand to silt-clay (mud) is essential to understanding the types of invertebrate communities that are present within a habitat. Total organic carbon (TOC) is derived from both natural and anthropogenic sources. The natural decomposition of vegetation such as salt marsh cord grass represents an abundant source of TOC. Organic carbon is a vital component of the salt marsh ecosystem and serves as a primary source in the food chain. Man-made influences can also contribute to TOC values. Increased surface water run-off from upland development activity can elevate TOC values and lead to organic enrichment.

Both grain size and TOC content can be correlated with the accumulation of contaminants. Fine sediment particles and organic matter bond with contaminants and serve as traps that concentrate pollutants. Since organic material serves as a food source to estuarine biota it also increases the likelihood of consumption or bioavailability of toxic compounds.

Methods:

Sediment composition samples were collected in conjunction with all benthic infaunal samples. See Chapter 5 for a detailed description of field collection methods. A 3.5-cm x 15-cm deep core sample was extracted from each grab sample in the intertidal and subtidal stations or directly adjacent to each biological core in the tidal creeks.

1) Assessment of the physical sediment characteristics in Broad Creek and the Okatee River including grain size and Total Organic Carbon (TOC);

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Replicate sediment composition samples for each site were combined to provide one homogeneous composite sample. To supplement benthic interpretations of tidal creek data, sediment composition samples were collected both as replicates and composites.

In the laboratory, sediment composition samples were analyzed for grain size (% sand, % silt-clay) and TOC (Table 4.1). Grain size analyses consisted of using a modification of the pipette method described by Plumb (1981). TOC was determined by using a modification of methods described by Hyland et al. (1998).

Sediment data were analyzed by various parametric and non-parametric statistical measures as appropriate. Grain size descriptions for each site are based on the inverse relationship between sand and silt-clay (mud). Statistical analyses were performed on the percent occurrence of sand.

Findings:

Subtidal Stations:

Grain size and TOC in surficial sediments collected at the subtidal stations of Broad Creek were not significantly different (p = 0.59, Mann-Whitney Rank Sum Test and p = 0.39, Mann-Whitney Rank Sum Test, respectively) from those collected in the Okatee River (Table 4.2, Figure 4.3). Subtidal sediments from both basins were high in sand content. Broad and Okatee stations both averaged over 90% sand (Table 4.2).

TOC values were also similar between systems ranging from 0.05% to 0.64% (Table 4.2). These are low to normal TOC values for estuarine systems in the Southeast and are not indicative of organic enrichment (Summers et al., 1993). No distributional gradient for sand content or TOC was apparent in either system.

Intertidal Stations:

Intertidal stations were considerably muddier and more variable than the subtidal stations (Figure 4.3). Percent sand values ranged from 5.8% to 68.6%. As with the subtidal sediment, no significant difference was found in sand (p = 0.712, t-test) or TOC (p = 0.742, t-test) content of intertidal sediment between Broad Creek and the Okatee River.

Intertidal sites were the muddiest and contained the highest TOC values of the three habitats. This is characteristic of intertidal shoals and results from the sheltered nature of this area which produces a reduced flushing. Most TOC values were near or above the 2% level used by Summers et al. (1993) to delineate organic enrichment (Table 4.2). However, data presented by Summers et al.(1993) was derived from a subtidal sampling effort. Higher TOC values can be expected from intertidal and tidal creek habitats due to their proximity to upland and salt marsh sources of organic carbon.

Tidal Creek Stations:

The composite samples collected from the tidal creeks were similar in sand and TOC content to the intertidal sites. Sand values were again variable ranging from 10.7% to 85.9 % (Table 4.2). The occurrence of sand in tidal creeks from the two drainage systems was significantly different for non-composited ($p<0.001$, t-test) samples. The large difference in grain size between the two T6 creeks accounted for most of the overall statistical difference between the two watersheds (Figure 4.3). Pair-wise multiple comparisons of creeks 1 through 5 showed no other significant differences. Tidal creeks in the Broad Creek were approximately 24% sandier overall than those in the Okatee River (Table 4.3).

TOC values from the tidal creeks were not significantly different between the two estuaries ($p = 0.132$, Mann-Whitney Rank Sum Test). The range in TOC from 0.53% to 3.10% was typical of that found by Lerberg (1997) and Sanger (1998) regardless of associated upland land-use (i.e. forest versus urban). Tidal creeks exhibited differences within each system; however, no gradients in the distribution of sand and TOC content existed from lower to upper estuary in either system. Similarly, no patterns were clear along the lengths of the tidal creeks (Table 4.2). TOC values were positively correlated with increased silt-clay content ($p<0.001$, $r^2 = 0.803$) throughout the study area.

In summary, sediment grain size was coarser in all tidal creeks and several (2/3) intertidal sites in Broad Creek. Coarser sandier sediments are generally more indicative of erosion of terrigenous sediments associated with increased urbanization. At river sites, both Broad Creek and the Okatee River were sand dominated sediments. TOC was generally equivalent in inter-site comparisons among different microhabitats within each system. Generally, higher TOCs were observed in intertidal sites and some of the tidal creek habitats than in subtidal stations. The fact that sediment TOCs in Broad Creek were not increased when compared to the Okatee River suggests that increased water column TOCs must be enriched in dissolved rather than particulate carbon.

Sediment Contaminants:

Estuarine sediments are repositories for chemicals discharged from land or atmospheric deposition. In sediments, chemical contaminants may bind with carbon in the sediments, adsorb to sediment particles and become dissolved in sediment porewater. Accumulations of chemical contaminants in sediments may result in significant exposure to benthic and epibenthic fauna as compounds may be bioaccumulated by marine organisms and become toxic. Compounds which are persistent, resist biodegradation and are highly lipophilic have the greatest potential to accumulate in sediments, become bioaccumulated by estuarine organisms and exert toxic effects in benthic fauna. Once accumulated in benthos, these compounds may be further bioaccumulated in higher trophic levels, such as crabs, birds and fish. Sediment contaminant profiles may thus provide indications of land-based pollution such as urban and agricultural sources. Specific types of chemical contaminants include trace metals, pesticides, polycyclic

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Sediment Contaminants:

Estuarine sediments are repositories for chemicals discharged from land or atmospheric deposition. In sediments, chemical contaminants may bind with carbon in the sediments, adsorb to sediment particles and become dissolved in sediment porewater. Accumulations of chemical contaminants in sediments may result in significant exposure to benthic and epibenthic fauna as compounds may be bioaccumulated by marine organisms and become toxic. Compounds which are persistent, resist biodegradation and are highly lipophilic have the greatest potential to accumulate in sediments, become bioaccumulated by estuarine organisms and exert toxic effects in benthic fauna. Once accumulated in benthos, these compounds may be further bioaccumulated in higher trophic levels, such as crabs, birds and fish. Sediment contaminant profiles may thus provide indications of land-based pollution such as urban and agricultural sources. Specific types of chemical contaminants include trace metals, pesticides, polycyclic aromatic hydrocarbons (PAHs = combusted petroleum byproducts) and polychlorinated biphenyls (PCBs = electrical transformer insulating fluid).

National studies have been conducted by NOAA and the State of Florida, which have developed national and regional Sediment Quality Guidelines (SQGs) for the U.S. (Long and Markel, 1992; Long et al., 1998) and southeastern U.S. (MacDonald, 1994). These SQGs have summarized all published toxicology and biomonitoring studies for a given contaminant and ranked them from lowest to highest concentration where an adverse effect was observed. Measured sediment contaminant levels may be compared with SQGs to predict potential probability for sediment bound contaminants to cause toxicity in benthic faunal communities.

In this study, selected trace metals, pesticides, PAHs and PCBs concentrations (Table 4.1) were determined in tidal creek, subtidal river, and intertidal river sediments from Broad Creek (n=15 sites; Figure 4.2) and the Okatee River (n= 15 sites; Figure 4.3) using methods as described in the section below.

Methods:

Sediment Sample Collection:

At each site the sampling vessel was piloted to pre-selected station coordinates (latitude and longitude) by use of Global Positioning Systems. At each site where sediments samples were collected, physicochemical water quality was measured with a Hydrolab DataSonde to obtain information on water temperature (°C), pH, salinity (ppt or ‰), conductivity (umhos) and dissolved oxygen concentrations (mg of O_2/L and % saturation).

For sediments, only the upper 3-5 cm of sediment were sampled to ensure sampling of the most recently deposited materials which in turn should be reflective of the recent contaminant history for each site. Sediments were removed from the grab, composited in a stainless steel pot and then were dispensed into pre-cleaned (solvent/acid) containers. All samples were transported to the lab on ice and were stored at -70°C until analysis. Each sediment sample was analyzed for trace metals (Aluminum, Silver, Arsenic, Cadmium, Chromium, Copper, Iron, Mercury, Nickel, Manganese, Lead, Selenium, Tin and Zinc); Polycyclic Aromatic Hydrocarbons (PAHs-24 priority pollutants, plus additional NOAA NS&T list compounds), pesticides (aldrin, atrazine, azinphosmethyl, chlordane and metabolites, chlorpyrifos, chlorthalonil, fenvalerate, dieldrin, DDT and metabolites, endosulfan, heptachlor and metabolites, hexachlorobenzene, lindane ,mirex, and trifluralin) and PCBs (27 PCB congeners and Total PCBs) using methods described below (Table 4.1).

Organic Contaminant Extraction Procedures:

The methods for extraction and sample preparation for organic contaminants (PAHs, PCBs, chlorinated pesticides) in sediments were similar to those of Krahn et al. (1988), Sanders (1995), Fortner et al. (1996) and Kucklick et al. (1997) with a few modifications. Internal standards were added to each sample. The sample was then extracted in a Soxhlet apparatus with 250 ml of CH_2Cl_2 for 18 hours, concentrated by nitrogen blow-down (Turbo Vap, Zymark Instruments) to about 0.5 ml, and was additionally cleaned up by gel permeation chromatography to remove lipids and other high molecular weight compounds.

Polycyclic Aromatic Hydrocarbon (PAH) Analysis:

PAHs were quantified by two methods, capillary GC-ion trap mass spectrometry (ITMS) and High Performance Liquid Chromatography (HPLC) with fluorescence detection using techniques described by Sanders (1995) and Kucklick et al. (1997). Spiked matrix samples (sediments), standard reference materials (SRMs) and blanks were analyzed using both HPLC with fluorescence detection and GC-ITMS. Previous results using this method have indicated spike recovery efficiencies of > 88% (mean for all PAHs) in sediments.

Chlorinated Hydrocarbon Analysis:

Chlorine-containing compounds (organochlorine pesticides and PCBs) were similarly analyzed using gas chromatography with electron capture detection (GC-ECD; Hewlett-Packard-Packard- 5890 series II) using methods described by Kucklick et al. (1997). Both spiked sediments and NIST SRMs were analyzed for organochlorine compounds to obtain information on the reliability of the organochlorines and pesticides data collected (NIST SRM 1941). The overall recovery (mean ± standard deviation) of organochlorines from amended sediments was 102% ± 23% for PCBs and 89% ± 32% for organochlorine pesticides plus metabolites.

Trace Metals Analysis:

Trace metals were analyzed using methods described by Long et al., (1998). A suite of metals (Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Sn, Zn) were analyzed by inductively coupled plasma spectroscopy (ICP). The metals Ag, As, Cd, Pb, and Se were analyzed by graphite furnace atomic absorption (Perkin Elmer 5100 Atomic Absorption Spectrometer with a Zeeman HGA 600 Graphite Furnace). Mercury was analyzed by cold-vapor atomic absorption using a Leeman Labs PS200 mercury analyzer at a wavelength of 253.7 nm. Samples for each analytical method were analyzed in duplicate and averaged. Quality control samples (blanks, spikes and SRMs for sediment) were analyzed with each group of samples for each analytical method. Previously, recoveries for these different analytical methods have averaged (mean ± standard deviation) 95% ± 25% for all trace metals by all methods. All recoveries were within the acceptable confidence limits of the SRM material.

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Acid Volatile Sulfide (AVS) and Simultaneously Extractable Metals (SEM) Analysis:

The general procedure for measuring Acid Volatile Sulfides (AVS) and Simultaneously Extractable Metals (SEM) in sediments were based on Allen et al. (1993) with slight modifications. Spiked recoveries for AVS using this method averaged 85% ± 2.7%.

SEMs were measured in the 50.0-ml aliquot removed from each sediment extract. The acid treatment removes metals which are weakly associated with the sediments and not incorporated in crystalline matrices. Samples were analyzed by ICP for the metals (Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Sn, Zn) using the methods and QA/QC procedures previously described.

Comparison of Contaminant Chemistry Data With Sediment Quality Guidelines:

Determination of the toxicological importance of sediment contaminants may be determined in three basic ways: 1) sediment toxicity tests; 2) biomonitoring of benthos and epibenthos; and 3) comparison of sediment concentrations with national and regional sediment quality guidelines (Long and Markel, 1992; MacDonald, 1993; Long et al., 1995, 1998). This sediment quality triad approach has been the cornerstone of sediment contaminant chemistry risk assessment for the past 12-15 years (Long and Chapman, 1985; Long, 1989). Most studies utilize comparisons with established sediment quality guidelines as the starting point of interpreting the toxicological potential of chemical contaminants found in sediments. For this study, we used guidelines published by Long et al. (1998) and MacDonald (1994). The primary difference between he two methods is that Long et al. (1998) combine both effects and no effects data for each chemical contaminant, while McDonald (1994) classifies data separately into effects and no effects data sets. For a single contaminant, the concentrations causing adverse effects in the identified studies are ranked from the lowest to the highest concentration causing adverse effects. The tenth percentile of this distribution represents a threshold for predicting declining environmental quality, which is termed the Effects Range Low (ERL) (Figure 4.4). The Threshold Effects Level (TEL) represents another estimate of low-level effect concentration. In this method, data are categorized into studies which measured adverse effects and studies finding no adverse effects. TELs are calculated by taking the square root of the product of the fifteenth percentile of the effects data and the fiftieth percentile of ranked no effects data. The median concentration, the fiftieth percentile of the ranked adverse effects concentrations, where all published studies found an adverse effect is a highly probable concentration for predicting declining environmental quality, which is termed the Effects Range Median (ERM) (Figure 4.4). Another measurement of median effects levels, the Probable Effects Level (PEL), is based on categorized data like TELs and is calculated by taking the square root of the product of the fiftieth percentile of the effects data and the eighty-fifth percentile of no effects data. Fulton et al. (1996) compared sediment toxicity tests with a battery of invertebrate species and screening level toxicity tests (Microtox^{TM} and Rototox^{TM}) and found significant agreement between the sediment quality guidelines and the most sensitive species for the three compounds tested (Cd, DDT and Flouranthene).

In addition, methods for evaluating the cumulative effects of multiple, co-occurring compounds have been developed which involve the summing of the ratios of concentrations of individual chemicals divided by their respective ERM or PEL value (Long et al., 1998; Hyland et al., 1999). The summed ratio is then divided by the number of analytes measured to calculate an "ERM/PEL Quotient" (ERM/PEL Q). Hyland et al. (1999) found that the ERM/PEL Q method was accurate in predicting degraded benthic community assemblages in estuaries throughout the southeastern U.S.

Sediment contaminant levels in Broad Creek and the Okatee River were compared with existing sediment quality guidelines by both individual compound and cumulative contaminant comparison methods. Sites with sediments which had individual chemical contaminant concentrations which exceeded ERL/TEL and ERM/PEL guideline levels were identified to indicate that trace metal, pesticide, PAH and PCB concentrations exceeded levels potentially toxic to estuarine organisms. In addition, individual contaminant levels in Broad Creek and Okatee River sediments were compared with peak sediment contaminant levels measured in the ACE Basin, a nearby pristine NOAA National Estuarine Research Reserve and Sanctuary (NERRS) site, to indicate the anthropogenic nature of these sediments. Cumulative ERM/PEL Quotients (ERM/PEL Q) were calculated for each site and sites were considered good (ERM/PEL Q ≤ 0.024), marginal (ERM/PEL Q $> 0.024 \leq 0.077$) or degraded (ERM/PEL Q > 0.077).

Statistical Analysis of Data

Statistical analysis of data involved comparisons of chemical contaminant concentrations, and laboratory toxicity test (Microtox^{TM}, clams and oysters) results between habitats within a watershed (tidal versus intertidal versus river = ***Intrasite Comparisons***) and between watersheds (Broad Creek versus Okatee River = ***Intersite Comparisons***). Statistical analysis methods included the use of parametric [Analysis of Variance (ANOVA) and Multiple Comparison Tests (Dunnets)] for normally distributed data and equivalent nonparametric procedures [Kruskal Wallace (ANOVA) and Distribution Free or Dunns Multiple Comparisons] for non-normally distributed data sets which could not be normally transformed. Only differences which were significant ($p \leq 0.05$) were considered significant.

In addition linear regression and nonlinear, nonparametric (Spearman Rank Correlation) regression analysis were conducted to evaluate the relationships between different variables [contaminant chemistry results including As sediment concentrations, lindane sediment concentrations and Cumulative ERMQ]; Microtox^{TM}, clam and oyster bioassay results; and water quality results). Correlation coefficients [R (Linear Regression) and Rho (Spearman Rank Correlation)] were determined for each pair of level toxicity tests (Microtox^{TM} and Rototox^{TM}) and found significant agreement between the sediment quality guidelines and the most sensitive species for the three compounds tested (Cd, DDT and Flouranthene).

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Findings:

Chemical Contaminants Concentrations in Sediments:

Results of chemical contaminant analysis of sediments generally indicated only minor contamination of sediments in both Broad Creek and the Okatee River (Tables 4.3 - 4.7 and Figures 4.5- 4.6). The results of the contaminant analyses indicated that sediment concentrations of inorganic compounds were generally very low, within regional background concentrations for many contaminants. The only trace metal which had elevated concentrations was arsenic, which exceeded sediment quality guidelines at 9 sites, 4 in the Okatee River and 5 in Broad Creek (Table 4.3). Comparison of the maximum arsenic concentrations in Broad Creek and Okatee River (13.7-14.3 ug/g) with the ACE Basin (14.2 ug/g), a NOAA NERRS site, indicated very similar concentrations (Table 4.7). This suggests that arsenic was from a naturally occurring, background source rather than being an anthropogenic source. Sediments in the southeastern U.S. have a high regional background concentration of As, which often exceeds the ERL/PEL values. Wirth et al. (1996) found that field deployed oysters, downstream of a confined disposal site for dredged sediments, had a field derived EC_{50} for inhibition of spat settlement and condition/gonadal indices of 12.5 ppm arsenic which was very similar to the ERL value of 8.2 ppm. In the Broad Creek and Okatee River, all other trace metals (Cd, Cr, Cu, Pb, Hg, Ni, Ag and Zn) had sediment concentrations comparable to background levels observed for the ACE Basin (Table 4.7). Total trace metal concentrations (Figure 4.5) indicated that there were comparable levels of trace metals throughout Broad Creek and the Okatee River. Highest total metal concentrations were observed at intertidal and tidal sites within each estuary, with lowest concentrations observed at river stations. There were no significant differences observed in total trace metal concentrations between Broad Creek and Okatee River sediments.

PAH sediment concentrations were generally low at all sites, within regional background concentrations for most contaminants. The only PAH found at elevated concentrations was Acenaphthene at one site in Broad Creek (Intertidal Station 6). This concentration exceeded sediment quality guidelines (Table 4.4). Comparison of the maximum concentrations of individual PAHs in Broad Creek and Okatee River (2.43-93.9 ng/g in Broad Creek versus < 1.11 - 96.4 ng/g in the Okatee River) with the ACE Basin (0.50 - 88.9 ng/g) indicated very similar concentrations (Table 4.7). This suggests that most PAHs are the result of atmospheric deposition of combusted petroleum rather than nonpoint source or point source discharges. This also implies that efforts to control NPS runoff from roadways and impervious surface in Broad Creek and Okatee River have been generally successful. Previous studies of marinas in this areas (Marcus et al., 1988) had indicated generally high levels of PAHs within the main areas (e.g. fuel docks and berthing areas) of each marina studied. There was no evidence that PAHs were transported far from marina sites. Results from this study generally support those conclusions by Marcus et al. (1988).

Total PAH concentrations (Figure 4.5) indicated that there were comparable levels of PAHs throughout Broad Creek (mean = 150.7 ± 26.5 ng/g) and the Okatee River (mean = 129.8 ± 20.9 ng/g). Highest total PAH concentrations were observed in intertidal and tidal sites within each estuary, with lowest concentrations being observed in river stations. There were no significant differences observed in sediment total PAH concentrations between Broad Creek and Okatee River.

The results of PCB analyses indicated that sediment concentrations were generally very low (0.07-0.12 ng/g), as 93.3% of the sites in each watershed had nondetectable PCB concentrations (Table 4.5). Detectable PCB concentrations were measured at only 6.7% of the sites within each watershed and measured concentrations were within regional background concentrations. The only PCBs measured were PCB congener 44 in the Okatee River and PCB congener 29 in Broad Creek (Table 4.5). Comparison of the maximum total PCB concentrations in Broad Creek (0.12 ng/g) and Okatee River (0.07 ng/g) with the ACE Basin (< 1.42 ng/g) indicated very similar concentrations (Table 4.7). This suggests that PCB pollution within each watershed is very rare and highly isolated. Total PCB concentrations (Figure 4.6) were comparable throughout Broad Creek and the Okatee River. Detectable total PCB concentrations were only observed sporadically in river and tidal creek sites within each estuary. No detectable concentrations of PCBs were measured in intertidal stations in either watershed. There were no significant differences observed in sediment total PCB concentrations between Broad Creek and Okatee River.

The results of pesticide analyses indicated that sediment concentrations of pesticides were generally very low (<detection limits - 2.78 ng/g) as 26.7% and 40% of the sites in Okatee River and Broad Creek, respectively, had no detectable concentrations (Table 4.6). Detectable pesticide concentrations were measured at 73.3% of the sites in Okatee River and 60% of the sites in Broad Creek. Pesticides measured in Okatee River sediments included lindane, heptachlor, HCB, and mirex. In Broad Creek, sediments contained detectable concentrations of aldrin, dieldrin, lindane, heptachlor and HCB. Surprisingly, no detectable levels of DDT were measured in sediments from either watershed. Generally, measured pesticide concentrations were within regional background concentrations for sediments. The only pesticides detected which were at toxicologically significant concentrations were lindane and dieldrin. Lindane was detected at 10 sites, 4 in Broad Creek and 6 in Okatee River. Elevated dieldrin concentrations were measured at only 1 site in Broad Creek (Table 4.6). Comparison of the maximum concentration for each individual pesticide in Broad Creek and Okatee River with the ACE Basin generally indicated lower or similar concentrations (Table 4.7) in Broad Creek and Okatee River when compared to the ACE Basin, with the exception of lindane and dieldrin in Broad Creek and lindane in Okatee River. This suggests that, generally, pesticide pollution for both watersheds is rare and confined to only a few sites within each watershed. In addition, higher lindane levels were measured at 2 sites (tidal creek station 1 and intertidal station 6) in Broad Creek than levels in the Okatee River,

transported far from marina sites. Results from this study generally support those conclusions by Marcus et al. (1988).

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suggesting a more contemporary urban source of lindane in Broad Creek than Okatee River. Lindane sources in Okatee River may be more historical agricultural uses of lindane. Total pesticide concentrations (Figure 4.6) were comparable throughout Broad Creek and the Okatee River. Highest total pesticide concentrations were observed in tidal creek and intertidal river sites. Lower concentrations of pesticides were measured in river stations in both watersheds. There were no significant differences observed in sediment total pesticide concentrations between Broad Creek (< DL -2.78 ng/g) and Okatee River (< DL - 2.75 ng/g).

Comparison of Contaminant Data With Sediment Quality Guidelines:

ERL/TEL exceedances were observed for arsenic, gamma BHC (lindane) and acenapthene for sites in both Broad Creek (40% of the sites) and the Okatee River (67% of the sites) (Tables 4.3-4.6). The only ERM/PEL exceedances were for lindane in Broad Creek (13.4% of the sites). In Broad Creek, sites with ERL/TEL exceedances included Tidal Creek stations T-1 (lindane) , T-4 (As) and T-5 (As); River station R-5 (lindane); and Intertidal stations I-4 (As) and I-6 (As, lindane, dieldrin and acenaphthene) which also had a PEL exceedance (lindane) (Figure 4.7). In Okatee River, ERL/TEL exceedances included Tidal Creek stations T-4 (As), and T-6 (As); River stations R-1 (lindane), R-2 (lindane), R-3 (lindane), R-5 (lindane), and R-6 (lindane); and Intertidal Stations I-2 (As), I-4 (As) and I-6 (As) (Figure 4.8). Note that the ERL/TEL exceedances for arsenic and lindane were observed in both Broad Creek and Okatee River.

Arsenic contamination was found throughout all habitat types including tidal creek, river and intertidal sites in both the Okatee River and Broad Creek. As previously mentioned, all arsenic concentrations are naturally higher in southeastern estuaries, thus elevated arsenic levels may not necessarily reflect anthropogenic pollution. It is interesting to note that 27 to 33% of sites in Broad Creek and the Okatee River had arsenic concentrations that exceeded the ERL. This is very similar to the 29.2% of sites in the ACE Basin which had arsenic concentrations that exceeded the ERL. In terms of accumulative effects, arsenic accounted for greater than 20% of the ERM/PEL Q in Broad Creek and the Okatee River, which is very similar to the 25% contribution of arsenic to the ERM/PEL Q for the ACE Basin.

Lindane contamination in Broad Creek was confined primarily to stations at the headwaters or mouth of the creek. In the Okatee River, lindane was much more pervasive, possibly due to the large amount of agricultural activity within the region. Sediment with lindane occurred throughout the entire watershed, primarily in river and intertidal stations. Multiple ERL/TEL or ERM/PEL exceedances were only observed at one site in Broad Creek (Intertidal Station 6).

The ERM/PEL Quotient (ERM/PEL Q) determinations indicated that the majority of the contaminant risks in Broad Creek and Okatee River were from arsenic and lindane exposure in sediments (Tables 4.3, 4.6, and 4.8). In Broad Creek, the majority (53.4%) of stations had good sediment quality (ERM/PEL Q ≤ 0.024) (Table 4.8 and Figure 4.9). The remainder of stations had marginal (33.3%) or degraded (13.3%) sediment quality.

In the Okatee River, many (40%) of the stations had good sediment quality (based on findings compiled by Hyland et al. (1999) who found that an ERM/PEL Q ≤ 0.024 generally corresponded with healthy benthic communities) (Figure 4.9). The remainder of stations in the Okatee River (60%) had marginal sediment quality. There were no degraded sites in the Okatee River.

Based upon the ERM/PEL Q approach in Broad Creek the following stations were classified as:

Degraded: T-1, I-6, **Marginal:** T-2, I-4, T-4, R-5, T-5.

All other Broad Creek sites were classified as good (8 sites). Toxicity would not be expected at good sites, whereas toxicity would be expected at degraded sites and a potential exists for toxicity at marginal sites.

In the Okatee River, the following sites were classified as:

Degraded: None **Marginal:** R-1, I-2, T-2, T-4, I-4, R-5, T-5, T-6, I-6

All other Okatee River sites were classified as good (6 sites). No degraded sites were observed in the Okatee River. Toxicity would not be expected at good sites, whereas toxicity would be expected at degraded sites and a potential exists for toxicity at marginal sites.

Sediment Toxicity Tests:

Sediment contaminant chemistry analyses can document the presence of contaminants, but the potential for adverse effects is not readily predictable. The bioavailability of pollutants to organisms is a dynamic component that is the result of complex physical and chemical as well as biological interactions. Laboratory toxicity tests (Microtox^{TM}, seed clam growth, bivalve fertilization, and bivalve development) were used as indicators of potential impacts on the biota and as indirect indicators of contaminant bioavailability (Figure 4.10). Ecotoxicological assessments may be conducted at different levels of biological activity, ranging in complexity from a subcellular to ecosystem level (Figure 4.10). Measurement of effects at biological levels of organization ranging from a cellular to organism level may have high toxicological relevance but low ecological relevance. Conversely, measurement of effects at biological levels of organization ranging from an organismal to ecosystem level may have high ecological relevance but low toxicological relevance. The organismal level of biological organization represents an optimum level of assessment for balancing ecological and toxicological sensitivities. Measurements of adverse effects in sediment bioassays used in this study may not translate directly into adverse toxic effects in field populations of fish and shellfish, but may serve as *early warning indicators* of ecological/toxicological stress.

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All other Okatee River sites were classified as good (6 sites). No degraded sites were observed in the Okatee River. Toxicity would not be expected at good sites, whereas toxicity would be expected at degraded sites and a potential exists for toxicity at marginal sites.

Sediment Toxicity Tests:

Sediment contaminant chemistry analyses can document the presence of contaminants, but the potential for adverse effects is not readily predictable. The bioavailability of pollutants to organisms is a dynamic component that is the result of complex physical and chemical as well as biological interactions. Laboratory toxicity tests (Microtox^{TM}, seed clam growth, bivalve fertilization, and bivalve development) were used as indicators of potential impacts on the biota and as indirect indicators of contaminant bioavailability (Figure 4.10). Ecotoxicological assessments may be conducted at different levels of biological activity, ranging in complexity from a subcellular to ecosystem level (Figure 4.10). Measurement of effects at biological levels of organization ranging from a cellular to organism level may have high toxicological relevance but low ecological relevance. Conversely, measurement of effects at biological levels of organization ranging from an organismal to ecosystem level may have high ecological relevance but low toxicological relevance. The organismal level of biological organization represents an optimum level of assessment for balancing ecological and toxicological sensitivities. Measurements of adverse effects in sediment bioassays used in this study may not translate directly into adverse toxic effects in field populations of fish and shellfish, but may serve as *early warning indicators* of ecological/toxicological stress.

The Microtox^{TM} assay measures the change in respiration of the marine bacterium, *Vibrio fisheri*, as measured by changes in phosphorescent activity (light production). Oyster fertilization and development assays were conducted with sediment elutriates (i.e. seawater extracts of sediments). All of these assays, also based on sublethal endpoints, are potentially very sensitive to contaminants, and can be performed in a relatively short time period (i.e. a few minutes for Microtox^{TM} assay to a few hours for the fertilization assay and 48 hours for the development assay). The clam assay is a more chronic assay. For the 7-day seed clam bioassay, growth of juvenile clams (*Mercenaria mercenaria*) was used as the endpoint, making this a sublethal assay designed to identify the potential for chronic effects. The Environmental Monitoring and Assessment Program (EMAP) for southeastern estuaries (Hyland et al., 1998) documented that the seed clam and Microtox^{TM} assays were the most sensitive of the four methods used.

Methods:

Microtox^{TM} (Microbial) Assay:

The Microtox™ Solid Phase bioassay was performed on whole sediment from each site using the large sample protocol described in the Microtox^{TM} Manual (Microbics Corporation, 1992). At least seven serial dilutions of the sample and three controls were used in each assay. Triplicate assays were performed for each of the sediment samples. The EC_{50} (sediment concentration at which a 50% reduction in light production occurs) was determined for each sample after 5 minutes exposure. For those samples for which an EC_{50} was higher than the highest sediment concentration tested, the sample was designated as having an EC_{50} value greater than the highest concentration tested and was considered toxic. All EC_{50} values were corrected for moisture content using the formula in the Microtox^{TM} Manual (Microbics Corporation, 1992) and reported on a percent dry weight sediment basis. EC_{50} values for individual replicates at each site were pooled (mean +/- standard error) and compared with regional EMAP reference values to determine if sediments at each site were potentially toxic (Ringwood et al., 1995; Hyland et al., 1998). For sediments that had $\geq 20\%$ silt and clay content the toxic threshold was EC_{50} values $\leq 0.2\%$ sediment (dry weight = dw), while sediments with $< 20\%$ silt and clay content had a toxic threshold of EC_{50} values $\leq 0.5\%$ sediment (dw). The percentages of sites with toxic sediments in each watershed (Broad Creek and the Okatee River) were then computed based upon these EMAP toxicity threshold values.

Seed Clam 7-Day Growth Assays:

Seed clam 7-day growth assays were conducted as described by Ringwood and Keppler (1998). Briefly, juvenile clams (*Mercenaria mercenaria*) of approximately 1.0 mm in length (commonly referred to as seed clams, obtained from Atlantic Littleneck Clam Farms, Folly Beach, SC) were exposed to sediments for seven days and the effects on total dry weight were determined. On the day before initiation of an experiment, sediments were press-sieved through a 500 μm screen and approximately 50 ml were added to 4 replicate 250 ml beakers. Control sediments (collected from Folly River, SC) were prepared in the same manner. Seawater was filtered through a 1 µm filter bag, adjusted to 25 ‰ with deionized water, and added to the replicate beakers for a total volume of 200 ml. The sediment suspension was allowed to settle overnight and clams (30 - 50 per replicate) were added the next day. Clams were size-selected prior to use with 500, 710 and 1000 µm sieves in series. Replicate subsets of clams were dried and weighed for initial weight estimates. All experiments were conducted at room temperature (23 - 25°C), with gentle aeration, and all replicates were fed three times during the course of the experiment (a phytoplankton mixture composed of equal volumes of *Isochrysis galbana* and *Chaetocerus gracilis*, cultured at Marine Resources and Research Institute (MRRI) and dialyzed against filtered seawater to remove excess nutrients and other components of the culture media). Reference toxicants (cadmium) tests with clams were conducted to ensure the health of the clams used in each bioassay.

At the end of the 7-day exposure period, clams were sieved from the sediments (or water, in the case of the reference toxicant tests), placed in clean 25 ‰ seawater and allowed to depurate for approximately one hour. Clams were recaptured on a sieve, and rinsed briefly with distilled water to remove excess salt. Dead clams were removed before being processed for growth, although mortalities were less than 10%. The clams were dried overnight (60 - 70°C), counted, weighed on a micro-balance, and growth rates (µg/clam/day) were determined. The effects on growth rates were statistically evaluated using a T-test or Mann-Whitney U test when variances were unequal. Sediments were defined as toxic when the mean growth rate was significantly different from the control sediment growth rate ($p < 0.05$) and < 80% of the control sediment growth rate.

Bivalve Fertilization and Development Assays:

Bivalve fertilization and development assays were conducted as described in Ringwood (1992), using sediment elutriate. Sediment (20 g) from each site were mixed with seawater (200 ml, 25 ‰) and placed on a shaker overnight. The mixtures were then filtered through 1.0 µm glass fiber filters, and three concentrations of the elutriate (100%, 50%, and 20%) as well as seawater controls were used for the assays. For all assays, there were 4 replicate tubes, each containing 10 ml of the elutriate treatments. Eggs and sperm from adult oysters (*Crassostrea virginica*) were stripped from ripe individuals, washed, and counted.

For the fertilization assays, sperm concentrations were adjusted so that the sperm to egg ratio would be 200:1 during the exposures. The sperm were incubated in the elutriate treatments for one hour, and then approximately 2000 eggs were added to each tube. After a two hour incubation period, all treatments were fixed in 10% formalin. A minimum of 200 eggs were counted from each tube, and those that were proceeding towards one or more cleavages were scored as fertilized while unfertilized eggs were scored as abnormal.

added to 4 replicate 250 ml beakers. Control sediments (collected from Folly River, SC) were prepared in the same manner. Seawater was filtered through a 1 µm filter bag, adjusted to 25 ‰ with deionized water, and added to the replicate beakers for a total volume of 200 ml. The sediment suspension was allowed to settle overnight and clams (30 - 50 per replicate) were added the next day. Clams were size-selected prior to use with 500, 710 and 1000 µm sieves in series. Replicate subsets of clams were dried and weighed for initial weight estimates. All experiments were conducted at room temperature (23 - 25°C), with gentle aeration, and all replicates were fed three times during the course of the experiment (a phytoplankton mixture composed of equal volumes of *Isochrysis galbana* and *Chaetocerus gracilis*, cultured at Marine Resources and Research Institute (MRRI) and dialyzed against filtered seawater to remove excess nutrients and other components of the culture media). Reference toxicants (cadmium) tests with clams were conducted to ensure the health of the clams used in each bioassay.

At the end of the 7-day exposure period, clams were sieved from the sediments (or water, in the case of the reference toxicant tests), placed in clean 25 ‰ seawater and allowed to depurate for approximately one hour. Clams were recaptured on a sieve, and rinsed briefly with distilled water to remove excess salt. Dead clams were removed before being processed for growth, although mortalities were less than 10%. The clams were dried overnight (60 - 70°C), counted, weighed on a micro-balance, and growth rates (µg/clam/day) were determined. The effects on growth rates were statistically evaluated using a T-test or Mann-Whitney U test when variances were unequal. Sediments were defined as toxic when the mean growth rate was significantly different from the control sediment growth rate ($p < 0.05$) and < 80% of the control sediment growth rate.

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For the fertilization assays, sperm concentrations were adjusted so that the sperm to egg ratio would be 200:1 during the exposures. The sperm were incubated in the elutriate treatments for one hour, and then approximately 2000 eggs were added to each tube. After a two hour incubation period, all treatments were fixed in 10% formalin. A minimum of 200 eggs were counted from each tube, and those that were proceeding towards one or more cleavages were scored as fertilized while unfertilized eggs were scored as abnormal.

For the developmental assay, approximately 200 fertilized embryos were added to a second series of elutriate tubes and incubated for 48 hours. At the end of 48 hours, all embryos from each tube were scored as normal (i.e. development proceeded to the D-hinged larval stage) or abnormal (i.e. unshelled or abnormal shells, arrested in the early trochophore stage, etc.). The results from both assays were expressed as % controls. Treatments were defined as toxic when the mean response was <80% and statistically significantly different from the controls ($p < 0.05$). These criteria were used for both the fertilization and developmental endpoints.

Findings:

Microtox™

The results of solid phase Microtox™ testing indicated that 73% of the sites in Broad Creek and 40% of the sites in the Okatee River were potentially toxic (Table 4.9 and Figure 4.11). Nationally, NOAA has reported that 47% of all estuarine areas exhibit toxicity in the Microtox™ bioassay. Long et al. (1998) assessed the toxicity of sediment bound chemical contaminants from Winyah Bay, Charleston Harbor and Leadenwah Creek in SC and the Savannah River and Brunswick Harbor estuaries in GA. Results of the solvent extract Microtox™ assay for each estuary indicated that 70% of the sites sampled in Winyah Bay, 42.9% of Charleston Harbor, 20.1% of Leadenwah Creek, 57.1% of the Savannah River estuary and 46.4% of Brunswick Harbor were degraded sites, having significantly lower EC_{50} values than measured at reference sites or sites with minimal levels of chemical contaminants (Long et al., 1998). Similarly, Hyland et al. (1998) reported solid phase Microtox™ toxicity at 19 - 39% of estuarine areas evaluated in the southeastern U.S. (NC, SC, GA and northern FL), averaging 19% of the area, where as Long et al. (1998) reported solvent extract Microtox™ toxicity at 47.7% of estuarine area evaluated in the southeastern U.S. (SC and GA).

Statistical analysis indicated high correlations ($R^2 = 0.37$, $p \leq 0.04$) of Microtox™ bioassay results and ERM/PEL Qs for Broad Creek and Okatee River (Table 4.10). Long et al. (1998) reported similar correlations between Microtox™ bioassay results and cumulative ERM/PEL Qs for Charleston Harbor, Winyah Bay and Leadenwah Creek ($R^2 = 0.27$). Lower correlations between ERMQ and solid phase Microtox™ bioassay results were found in the Savannah River ($R^2 = 0.16$), while higher correlations were found in St. Simon Sound, GA ($R^2 = 0.61$). Hyland et al. (1998) found that in estuaries of the southeastern U.S., Microtox™ toxicity was highly correlated with sediment arsenic ($R^2 = 0.57$) concentrations but not with lindane ($R^2 = 0.12$) concentrations, which were the dominant sediment contaminants in both Broad Creek and Okatee River. Similarly, regression analysis of data from Broad Creek and the Okatee River indicated significant correlations between Microtox™ toxicity and arsenic sediment concentrations (Rho = 0.58), but not with lindane (Table 4.10).
Long et al. (1998) also reported generally high correlations ($R^2 = 0.16$-0.61) for arsenic and solvent extract Microtox™ bioassay results in SC and GA estuaries. Reported Microtox™ EC_{50} values for lindane range from 6,370 - 7,650 mg/L (Qureshi et al., 1982;

Calleja et al., 1994) versus 35 mg/L for As (Qureshi, 1982). This suggests that arsenic was 181-219 times more toxic to *Vibrio fisheri* than lindane. Elevated arsenic sediment concentrations in both Broad Creek and Okatee River were generally higher and more pervasive than lindane (As concentrations = 0.04-14.3 ug/g dw versus lindane concentrations < 0.076 - 2.43 ug/g dw). The maximum arsenic concentration was < 40% of the Microtox^{TM} EC_{50} value measured for arsenic. The maximum lindane concentration was < 0.03% of the Microtox^{TM} EC_{50} value measured for lindane. This would suggest that most of the toxicity may be attributed to arsenic rather than lindane, but neither compound would be the sole cause of toxicity at any given site, since none of the sites had sediment concentrations approaching the EC_{50} values for either compound. Further evidence of this is provided by regression analysis (Table 4.10) which indicated that arsenic and lindane sediment concentrations were inversely related (e.g. arsenic concentrations decreased as lindane concentrations increased or vice versa). This indicates that sources of arsenic and lindane are different (naturally occurring for arsenic versus agricultural/urban for lindane).

Water quality results for Broad Creek and Okatee River were not correlated with Microtox^{TM} results, nor were Microtox^{TM} results correlated with any of the other bioassays (clam or oyster) used in this study (Table 4.10). This lack of correlation between bioassay results is not surprising since each assay endpoint measured different sublethal measures of stress (respiration, growth, fertilization and development) at different taxanomic levels (bacteria, clams and oysters). Long et al. (1998) found only correlation ($R^2 = 0.31$-0.50) between solvent extract Microtox^{TM} bioassay results and sea urchin fertilization and development in evaluating sediment toxicity in estuarine areas of SC and GA.

Another method to evaluate toxicity test results for each bioassay is to examine the occurrence of toxicity relative to sediment quality guidelines at each site. The concordance of toxicity and marginal/degraded sediment quality may indicate if chemical contaminants pose significant risks to living marine resources in each watershed. This was evaluated in this study by examining the occurrence of toxicity relative to sediment quality guideline results for each site. In Broad Creek, only 45.4% of the Microtox^{TM} toxicity was observed at sites with ERL/TEL or ERM/PEL exceedances versus 57.1% in the Okatee River. Similarly, Hyland et al. (1998) reported that 73.6% of the Microtox^{TM} toxicity measured in estuaries of SC, GA, NC and northern FL was observed at stations with high sediment contaminant levels (ERL exceedances). Further evaluation of the Microtox^{TM} toxicity revealed that in Broad Creek, only 54.5% of the Microtox^{TM} toxicity was observed at sites with ERM/PEL Q > 0.024 versus 85.7% in the Okatee River. This suggests that the majority of the effects on *Vibrio fisheri* respiration in the Okatee River were associated with sites with high levels of chemical contaminants. Whereas in Broad Creek, while the majority (54.5%) of sites with effects were associated with high levels of chemical contaminants, a large portion (45.5%) were associated with other effects such as increased ammonia or degraded water quality conditions although water quality was not statistically correlated with Microtox^{TM} results.

Calleja et al., 1994) versus 35 mg/L for As (Qureshi, 1982). This suggests that arsenic was 181-219 times more toxic to *Vibrio fisheri* than lindane. Elevated arsenic sediment concentrations in both Broad Creek and Okatee River were generally higher and more pervasive than lindane (As concentrations = 0.04-14.3 ug/g dw versus lindane concentrations < 0.076 - 2.43 ug/g dw). The maximum arsenic concentration was < 40% of the Microtox^{TM} EC_{50} value measured for arsenic. The maximum lindane concentration was < 0.03% of the Microtox^{TM} EC_{50} value measured for lindane. This would suggest that most of the toxicity may be attributed to arsenic rather than lindane, but neither compound would be the sole cause of toxicity at any given site, since none of the sites had sediment concentrations approaching the EC_{50} values for either compound. Further evidence of this is provided by regression analysis (Table 4.10) which indicated that arsenic and lindane sediment concentrations were inversely related (e.g. arsenic concentrations decreased as lindane concentrations increased or vice versa). This indicates that sources of arsenic and lindane are different (naturally occurring for arsenic versus agricultural/urban for lindane).

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Microtox^{TM} toxicity was greatest in tidal creek habitats in both Broad Creek (100%) and the Okatee River (83.3%) when compared to river (Broad Creek = 50%; Okatee River = 16.7%) and intertidal (Broad Creek = 67%; Okatee River = 0%) habitats. This suggests that toxicity was greatest in sites closest to land based pollution sources (tidal creeks) and depositional environments (tidal creeks and intertidal flats).

Seed Clam Assays :

The results of juvenile clam bioassay indicated that 53% of the sites in Broad Creek and 73% of the sites in the Okatee River had inhibited clam growth (Table 4.11 and Figure 4.12). Reduced growth was observed more frequently in the tidal creek sites, but the majority of these sites had both elevated levels of porewater ammonia (> 14 mg/L) in addition to enriched concentrations of several chemical contaminants. Previous studies based on a more extensive database indicated that ammonia levels greater than 14 mg/L caused toxicity that could not be readily distinguished from contaminants (Ringwood and Keppler, 1998). Toxicity was also observed at all of the intertidal sites in the Okatee River and at two of the three intertidal sites in Broad Creek. No toxicity was observed in the majority of the subtidal sites from both systems.

Within each watershed, only a portion of observed reduced clam growth was attributed to chemical contaminants (arsenic and lindane) at both Broad Creek (33% of the sites) and Okatee River (40% of the sites). Similarly, Hyland et al. (1998) also reported reduced growth in the juvenile clam bioassay at sites representing 39% of estuarine areas evaluated in the southeastern U.S. (NC, SC, GA and northern FL). The remaining toxicity observed in each watershed was potentially attributed to high sediment porewater ammonia concentrations. Further evaluation of measured porewater ammonia concentrations found that only 20% of the sites in Broad Creek and 33% of the sites in Okatee River had reduced clam growth due to high ammonia concentrations (>14 - <30 mg/L). Ringwood and Keppler (1998) reported that ammonia concentrations of < 14 mg/L were not toxic to juvenile clams, while concentrations > 30 mg/L were toxic, with intermediate ammonia levels being potentially toxic.

Statistical analysis indicated high correlations ($R^2 = 0.51$, $p \leq 0.004$) of juvenile clam bioassay results and cumulative ERM/PEL Q for Broad Creek and Okatee River (Table 4.10). In each watershed, these represented sites with ERL/TEL and/or ERM/PEL sediment quality guideline exceedances and reduced clam growth. Hyland et al. (1998) found that in estuaries of the southeastern U.S., juvenile clam toxicity was only highly correlated with sediment porewater sulfide concentrations ($R^2 = 0.41$) but was not highly correlated with any individual sediment contaminant such as arsenic and lindane, which were the dominant sediment contaminants in both Broad Creek and Okatee River. In addition, Hyland et al. (1998) reported that clam toxicity was not statistically correlated with sediment ammonia concentrations.

Water quality results for Broad Creek and Okatee River were not correlated with juvenile clam bioassay results, nor were juvenile clam bioassay results correlated with any of the other bioassays (Microtox^{TM} or oyster) used in this study. This lack of correlation between bioassay results is not surprising since each assay endpoint measured different sublethal measures of stress (respiration, growth, fertilization and development) at different taxonomic levels (bacteria, clams and oysters). Long et al. (1998) found only correlation ($R^2 = 0.31$-0.50) between solvent extract Microtox^{TM} bioassay results and sea urchin fertilization and development in evaluating sediment toxicity in estuarine areas of SC and GA.

In Broad Creek, just 37.5% of the juvenile clam effects were observed at sites with only ERL/TEL or ERM/PEL exceedances versus 36.4% in the Okatee River. If sites with both porewater ammonia and ERL/TEL or ERM/PEL exceedances are considered, 62.5% of the sites in Broad Creek versus 45.5% in the Okatee River had reduced growth in the clams. Similarly, Hyland et al. (1998) reported reduced juvenile clam growth in 39% of the area surveyed in NC, SC, GA and northern FL. Only 38.5% of those areas (representing 15% of the total survey area) had mortality in the juvenile clam toxicity tests measured at stations with high sediment contaminant levels (ERL exceedances). Further evaluation of the reduced juvenile clam growth revealed that in Broad Creek, only 37.5% of the juvenile clam toxicity was observed at sites with ERM/PEL $Q > 0.024$ versus 36.4% in the Okatee River. If sites with both ERM/PEL $Q > 0.024$ and with high porewater ammonia concentrations (> 14 mg/L) are considered, then 75% of the sites in Broad Creek versus 63.6% of the sites in Okatee River exhibited juvenile clam toxicity. This suggests that in Okatee River the majority of the effects on *Mercenaria mercenaria* growth were associated with sites with only high levels of chemical contaminants (36.4%) rather than sites with only high levels of porewater ammonia (18.2%). In Broad Creek, the majority of *M. mercenaria* growth inhibition was associated with sites with only high levels of chemical contaminants (37.5 %) rather than sites with only high levels of porewater ammonia (0%). The effects levels for porewater ammonia (37.5% in Broad Creek versus 27.3% in Okatee River) were generally comparable in both systems. This suggests that chemical contaminant effects were generally similar in comparisons of the Broad Creek and the Okatee River. In the Okatee River, there was greater toxicity from ammonia, but only in tidal creek stations. Regression analysis indicated that clam bioassay results were significantly correlated ($Rho = 0.52$; $P < 0.003$) with sediment As concentrations but not sediment lindane concentrations. This would suggest that clam toxicity was related to sediment arsenic concentrations. Wirth et al. (1996) reported EC_{50} for oyster spat at 12.5 ppm very similar to the range of arsenic concentrations measured at site with arsenic ERL exceedances, which had toxicity in this study.

Juvenile clam toxicity was generally greatest in tidal creek habitats in both Broad Creek (83.3%) and the Okatee River (100%) when compared to river (Broad Creek = 16.7%; Okatee River = 33.3%) stations. High juvenile clam mortality was also measured in intertidal habitats in both Broad Creek (67%) and the Okatee River (100%). This suggests that toxicity was more prevalent in tidal creek habitats closest to land-based pollution sources which generally had higher levels of ammonia in addition to enriched levels of chemical contaminants or in depositional environments (intertidal sites) in larger portions of each watershed.

correlation between bioassay results is not surprising since each assay endpoint measured different sublethal measures of stress (respiration, growth, fertilization and development) at different taxonomic levels (bacteria, clams and oysters). Long et al. (1998) found only correlation ($R^2 = 0.31$-0.50) between solvent extract Microtox^{TM} bioassay results and sea urchin fertilization and development in evaluating sediment toxicity in estuarine areas of SC and GA.

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Oyster Fertilization and Development Assays:

The results of sediment elutriate toxicity tests assessing effects on oyster fertilization or development generally indicated no evidence of toxicity. Only one site in Broad Creek (7%) and none of the sites in the Okatee River had inhibited oyster fertilization, while no sites in either watershed had altered oyster development (Tables 4.12 - 4.13 and Figures 4.13-4.14). In addition, regression analysis (Table 4.10) indicated only a slight correlation between oyster fertilization and sediment arsenic concentrations (Rho = 0.35; $p < 0.0574$). Spatially, toxicity was only observed at Broad Creek tidal creek site T-2. No effects on oyster fertilization or development were observed at intertidal or river sites in either watershed. However, it must be remembered that these assays were conducted with gametes from healthy oysters collected from a generally pristine reference site in the Charleston Harbor area and as a result "healthy" oyster gametes were used. Different results might be obtained if oysters were "less healthy", which would occur under stressful conditions. In addition, the elutriate bioassay approach may only reflect the contaminants that would be eluded under relatively mild conditions. Factors such as pH, salinity, and dissolved oxygen shifts could result in substantially greater release of pollutants from sediments than would be observed under these conditions. As a result, these assays may not reflect the full potential for toxic effects of the habitats on gamete viability of native organisms.

CONCLUSIONS:

The general consensus expressed by scientists planning this study was that the increased urbanization found at the Broad Creek watershed would generally have adverse effects on the environmental quality of the sediment microhabitat in this watershed. Sediment geochemistry results indicated that sediment grain size was generally coarser in all tidal creeks and several (2/3) intertidal sites in Broad Creek when compared to the Okatee River. These coarser, sandier sediments in Broad Creek are generally more indicative of erosion of terrigenous sediments associated with increased urbanization. River sites within both Broad Creek and the Okatee River were sand dominated sediments due to the larger tidal range and greater hydrological environment in river stations, which were more erosional environments. Thus, the extent of urban influences appears to be at the tidal creek and tidal river interface. Similarly, sediment TOC was generally equivalent in inter-site comparisons among different microhabitats within each system. Generally, higher sediment TOCs were observed in intertidal sites and some of the tidal creek habitats than in subtidal stations. The fact that sediment TOCs in Broad Creek were not increased when compared to the Okatee River suggests that the observed increased water column TOCs in Broad Creek must be enriched in dissolved rather than particulate carbon, as particulate carbon would settle out into sediments and be reflected in higher sediment TOC levels. In Broad Creek this was not the case, rather sediment TOC levels were equivalent in comparisons with the Okatee River. This implies a significant groundwater delivery route for increased water column TOC via DOC in groundwater. Urbanization activities, such as increased land application of sewerage may potentially contribute to this source of DOC. Additional study of this issue is warranted in Broad Creek, with a particular emphasis on evaluation of land application practices for sewerage disposal.

Another basic premise of this study was that Broad Creek was more chemically contaminated than the Okatee River due to the increased urbanization found in the Broad Creek watershed. Results of chemical contaminant analysis clearly indicated that Broad Creek was not as chemically contaminated as previously anticipated and that the Okatee River was slightly more polluted than was originally thought. Sediment concentrations of dieldrin, acenapthene, arsenic, and lindane were greater than regional and national SQG thresholds (Table 4.14 and Figures 4.15-4.17). Arsenic concentrations were only slightly elevated relative to SQGs and generally reflected the high regional background levels found in estuarine sediments of the southeastern U.S. (Hyland et al., 1998; Long et al., 1998). Lindane concentrations were elevated in sediments in both watersheds, at concentrations > SQG thresholds and midpoints for toxic effects in both watersheds.

Lindane is a chlorinated hydrocarbon insecticide with a fully chlorinated benzene ring. It is used in both agricultural and urban applications as a soil fumigant and foliar treatment on fruit and nut trees as well as vegetable and ornamental plants (Farm Chemical Handbook, 1992). Pait et al. (1992) found that more than 120,590 pounds of active ingredient pesticides (PAI) were used on the estuarine region draining into St. Helena Sound near Beaufort, SC. Similarly, greater than 138,578 PAI pesticide were applied in upland areas adjoining the estuarine drainage areas of the Broad River versus only 92,976 PAI pesticide which were applied in upland areas adjoining the Savannah River. A comparison of the agricultural watershed size relative to pesticide application rates yielded pesticide usage estimates which ranged from 12,300 PAI/square mile for Broad River to 2875 PAI/square mile for St. Helena Sound to 894 PAI pesticide/square mile in the Savannah River. Agricultural lands account for 22-31% of land-use within each of these three SC watersheds. This clearly indicates the pervasive use of pesticides on agriculture within estuarine drainage areas of Beaufort County. As more agricultural lands are converted to urban areas, the amount of toxic pesticides will be reduced, but other contaminants such as PAHs formed by the combustion of petroleum, may be discharged in urban NPS runoff.

Siewicki (1995) estimated *per capita* PAH loading from urban areas of SC at 0.53 g of fluoranthene/*capita*/year, which was very similar to loading rates for Rhode Island of 0.58 g of fluoranthene/*capita*/year (Hoffman et al., 1983) and for California of 0.53 g of fluoranthene/*capita*/year (Eganhouse and Kaplan, 1981; Eganhouse et al., 1981). Hoffman et al. (1983) found that the flux of fluoranthene from parking lots was estimated at 55 g of petroleum hydrocarbon/hectare/cm of rain or 33 mg of fluoranthene/hectare/cm of rain (Siewicki, 1995). In addition, the antecedent dry weather period did not affect petroleum hydrocarbon loadings (Hoffman et al., 1982; 1983). Persistent organochlorine pesticides, such as lindane, may persist in estuarine sediments after agricultural lands are converted to urban areas, adding to the toxicity potential of sediments as increased PAH discharges occur with urbanization. Surprisingly, only one ERL exceedance was found for PAHs in Broad Creek or the Okatee River. In fact, PAH levels in Broad Creek were comparable to levels found in the ACE Basin. An additional comparison of 10 selected warranted in Broad Creek, with a particular emphasis on evaluation of land application practices for sewerage disposal.

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PAHs commonly measured in another urban watershed, in SC, Murrells Inlet, located just south of the Myrtle Beach Grand Strand, and in North Inlet, a NOAA NERRS site are depicted in Figure 4.15. Note the much higher PAH sediment concentrations in Murrells Inlet when compared to North Inlet, Broad Creek and the Okatee River. In fact, PAH sediment concentrations in Broad Creek and Okatee River were slightly lower than measured in pristine North Inlet, possibly due in part to the higher tidal range found in Beaufort County. In contrast to PAHs, comparison of metals concentrations indicates that there was no evidence of metals enrichment between the two systems (Figure 4.15). The much higher PAH levels found in Murrells Inlet clearly demonstrate the impact of over-development of coastal areas of SC. The much lower PAH levels in Broad Creek sediments and comparability with sediment concentrations in North Inlet and Okatee River, implies that zoning regulations employed in Beaufort County have been effective in reducing PAH loadings in Broad Creek. While high sediment PAH concentrations have been measured in fuel docks and boat-berthing areas of Broad Creek, there was no evidence of PAHs being transported far from marina sites (Marcus et al., 1988). This study supports these conclusions by Marcus et al. (1988) and suggests that marina operators should continue their vigilance in reducing PAH loadings within Broad Creek. The use of setbacks, buffer strips and stormwater retention/detention ponds appear to have been effective in reducing PAH loadings within Broad Creek. Yet, toxicity was measured in Broad Creek sediments, due primarily to ammonia, arsenic, lindane and the cumulative effects of multiple contaminants and/or stressors (Table 4.14).

An evaluation of the overall status of sediment quality (combining sediment chemistry, ERL/ERM and TEL/PEL sediment quality guidelines, and laboratory bioassays) (Table 4.14) indicated that 5 sites in Broad Creek (33%) and 2 sites in Okatee River (13%) were degraded (Figures 4.16 -4.17). Sites in Broad Creek with degraded sediment quality were the result of ERM exceedance (1/5 sites), toxicity in multiple bioassays (3/5 sites) or both (1/5 sites). The sites in the Okatee River with degraded sediment quality were the result of both ERM exceedances (1/5 sites) and toxicity in multiple bioassays (1/5 sites). Additional analysis indicated that 4 sites in Broad Creek (27%) and 9 sites (60%) in the Okatee River had sediments, which were marginally degraded. Sites in Broad Creek and Okatee River with marginally degraded sediment quality were the result of ERL/TEL exceedances or high ERM/PEL Quotients and toxicity in a single bioassay. A total of 6 sites (40% of the sites) in Broad Creek and 4 sites (27%) in the Okatee River had good overall sediment quality.

What this overall evaluation of sediment quality indicates is that in Broad Creek, as it has become more developed, many sites have moved from marginally degraded into the degraded classification of sediment quality. Most of this change in classification was the result of toxicity being observed in multiple bioassays, rather than discriminate increase in any one class of chemical contaminants. The bioassays used in this study were designed to provide evidence of alterations and changes in clam growth, bacterial respiration rate and oyster fertilization/development rates. All of these end-points are sublethal (an effect < death) in nature and provide *"early warning"* indications of faunal stress. Within Broad Creek, there are clear indications of *"early warning"* potential to cause faunal stress based upon these bioassays. This finding is supported by our assessment of the condition of benthic communities in Broad Creek (see Chapter 5) which represent a biological constituent of the estuarine ecosystem that are both closely affiliated with the sediments and sensitive to long-term chronic exposure effects.

In the Okatee River, we see evidence of multiple species faunal stress at only two degraded sites. More sites in Okatee River were marginally degraded rather than degraded, suggesting that sediments do not contain high levels of chemical contaminants which are stressful to marine fauna. Generally, sediment contaminant levels were somewhat higher in Okatee River than was originally anticipated. In particular, sediment concentrations of the persistent pesticide lindane were pervasive in river sediments. For example, in Okatee River where most lindane usage was agricultural, lindane was found in high concentrations in both river sediments and tidal creek sediments. Tidal creek sediments would be closer to the upland agricultural sources, yet lindane was found to be transported away from the original source into river sediments. This spatial distribution pattern was likely due to the long half-life of lindane of 6-22 days in humic peat to 3-22 days in sandy soils (Verschueren, 1996). Persistence will be much greater in anoxic estuarine sediments. Thus, it is important that nonpersistent pesticides be used where possible in existing agricultural areas of the Okatee River. This will prevent additional input of persistent chemical contaminants from agriculture within this watershed. In urban areas, such as residential housing and golf courses, contemporary pesticide usage should also be targeted for nonpersistent pesticides, where possible. The use of nonpersistent pesticides will become more important as the Okatee River watershed is urbanized. Currently, Okatee River is not highly developed and as rapid urban development of this watershed occurs, it will be important to provide adequate zoning regulations to protect this watershed from the discharge of chemical contaminants via urban NPS runoff into the system. In urbanized Broad Creek, it was noted that there is much more widespread degradation of sediment quality and this was undoubtedly the result of increased urbanization around and within the watershed. If urban contaminant discharges of PAHs, trace metals and pesticides via NPS runoff are not adequately controlled in the Okatee River there will the additional introduction of chemical contaminants into sediments within the Okatee River watershed. This urban insult, in combination with the current levels of lindane and arsenic, may adversely affect early warning stress indicators used in this study and may ultimately affect epibenthic and benthic fauna.

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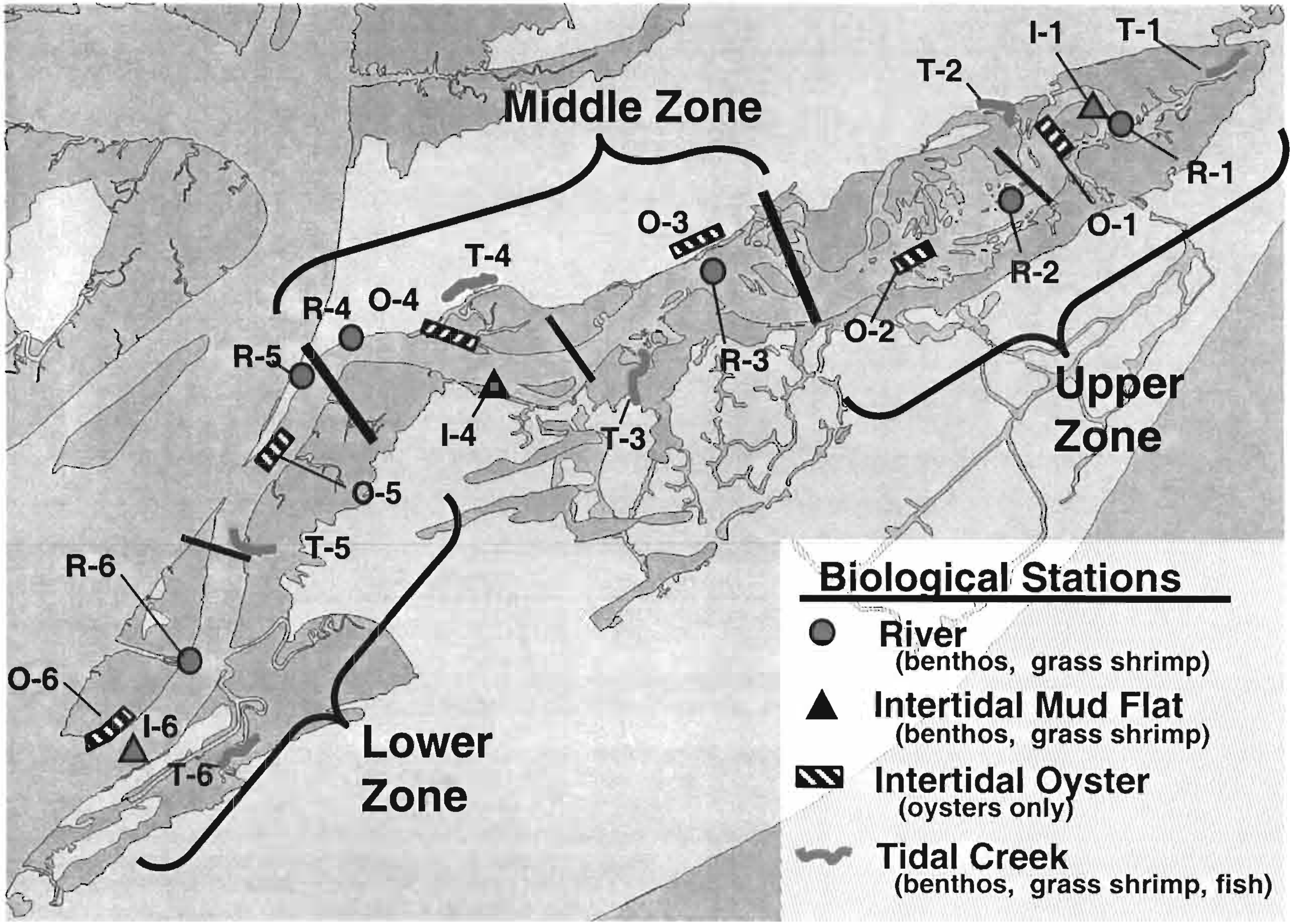


Figure 4.1 Broad Creek sampling sites for chemical contaminants in sediment. Samples were collected from sites where benthos, grass shrimp, and fish were collected.

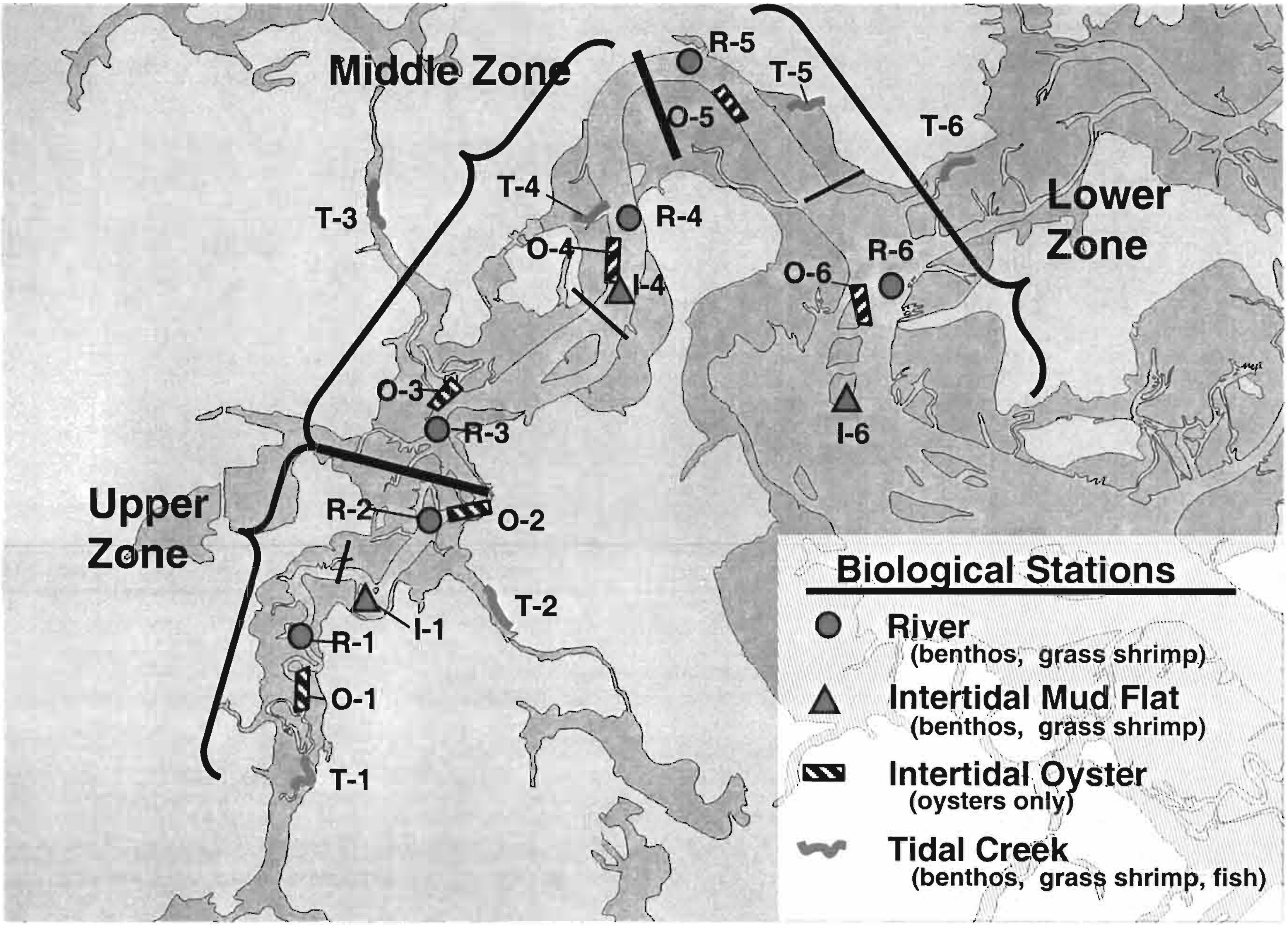


Figure 4.2 Okatee River sampling sites for chemical contaminants in sediment. Sediment samples were collected from sites where benthos, grass shrimp, and fish were collected.

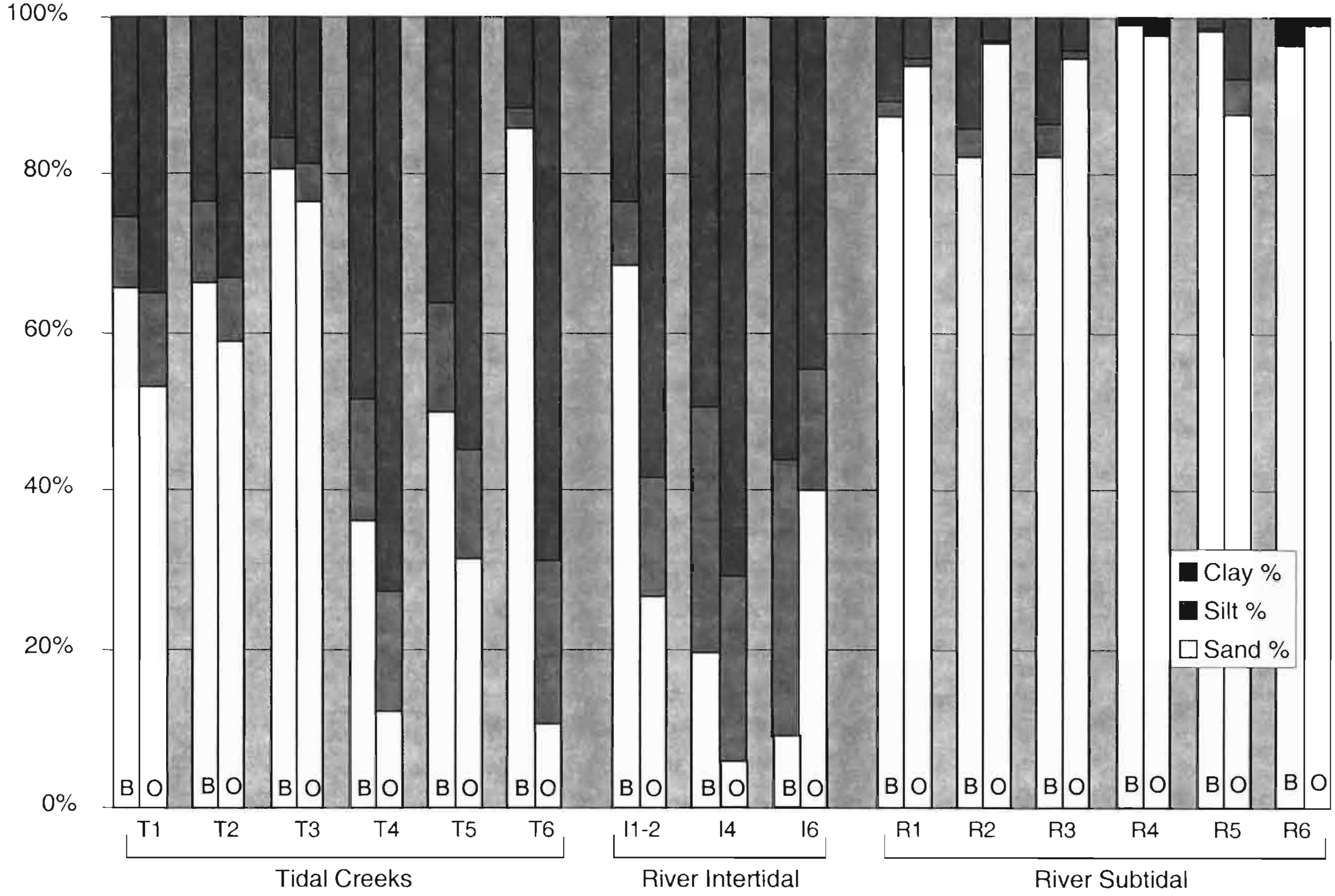


Figure 4.3 Sediment grain size information from composite samples. Note the high sand content in most samples.

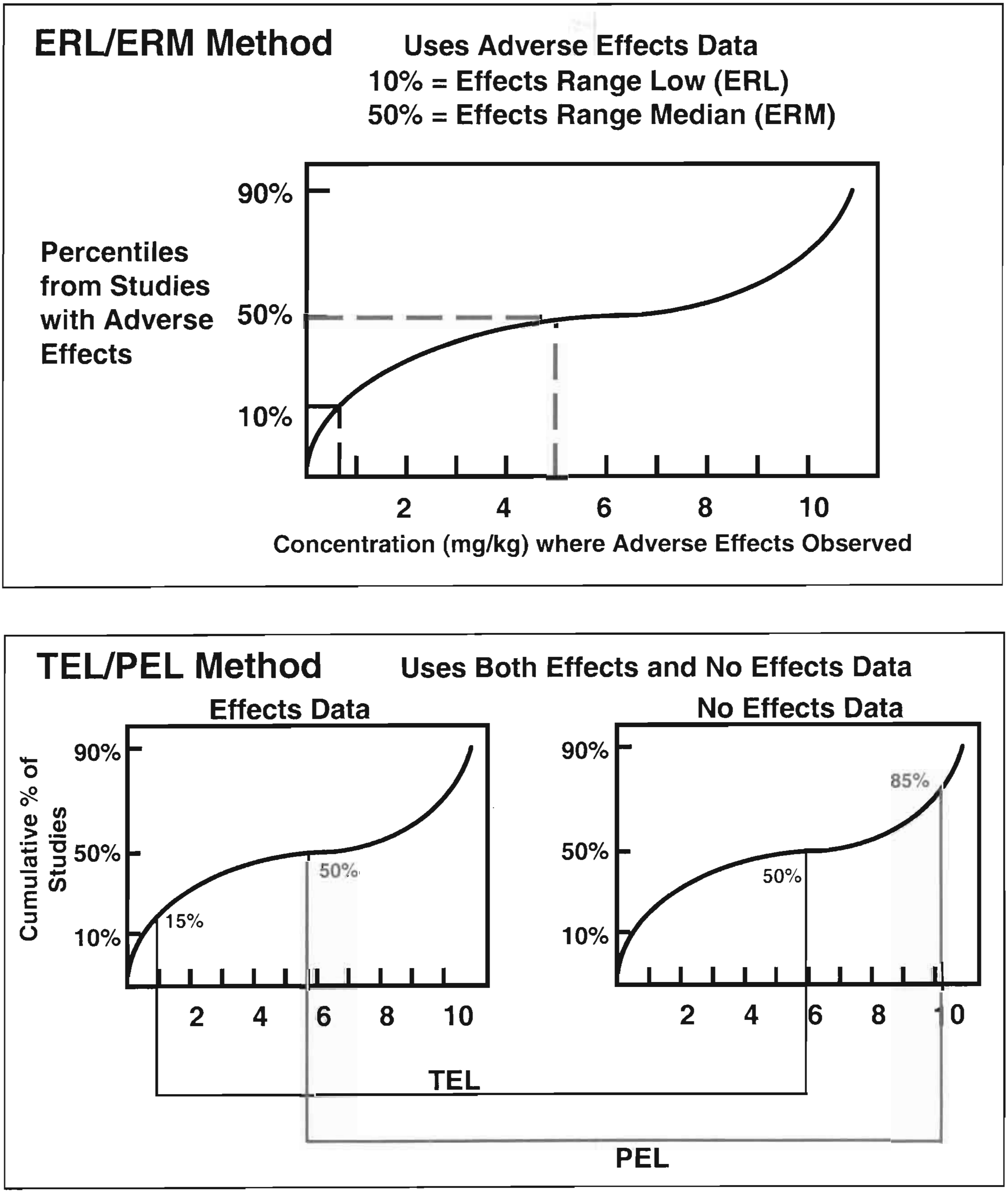
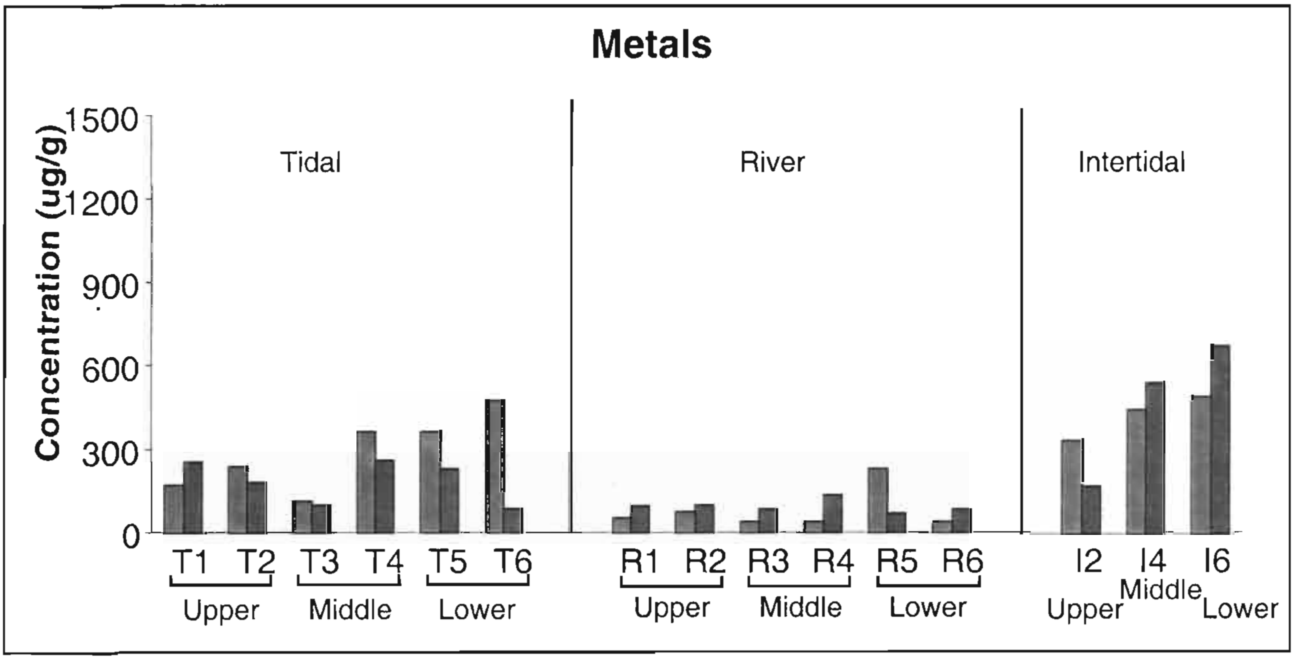


Figure 4.4 Methods for the calculation of Sediment Quality Guidelines (SQGs). The top graph shows the Apparent Effects Threshold methodology for the calculation of ERL and ERM values (Long et al., 1995; 1998). The bottom graph shows the methodology used for the calculation of TEL and PEL values (MacDonald, 1994), which incorporate both adverse and no adverse effects data.



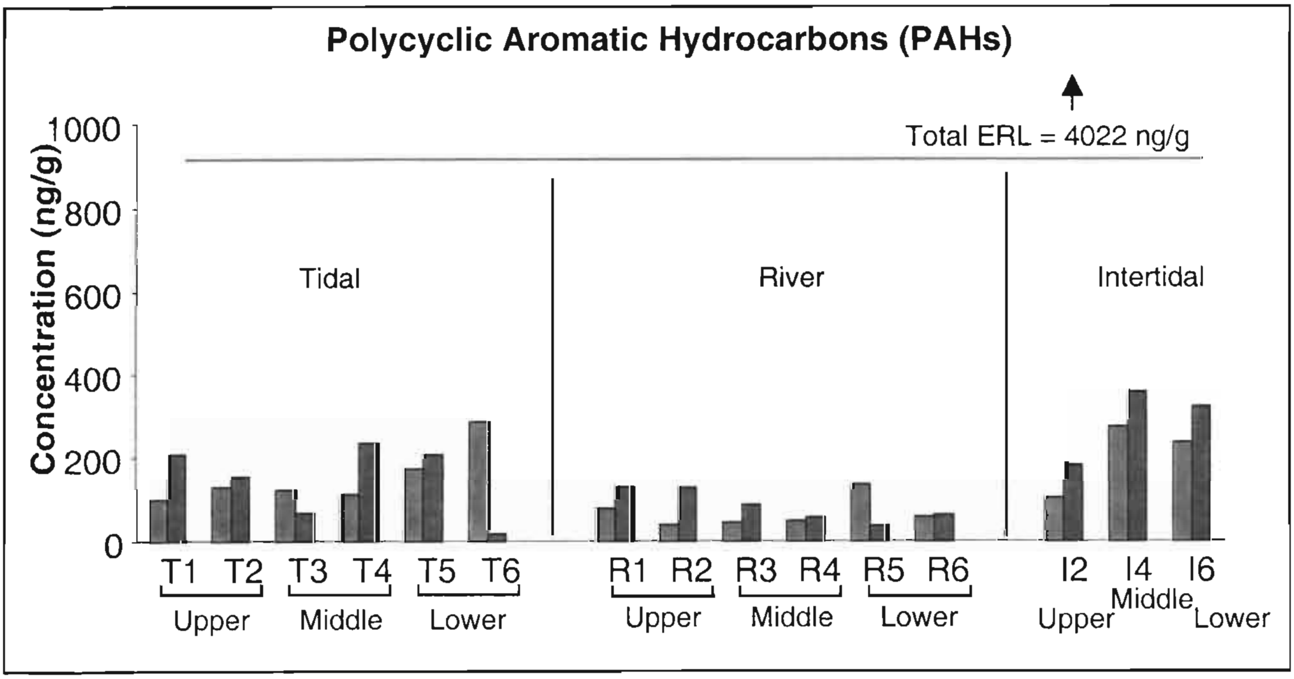
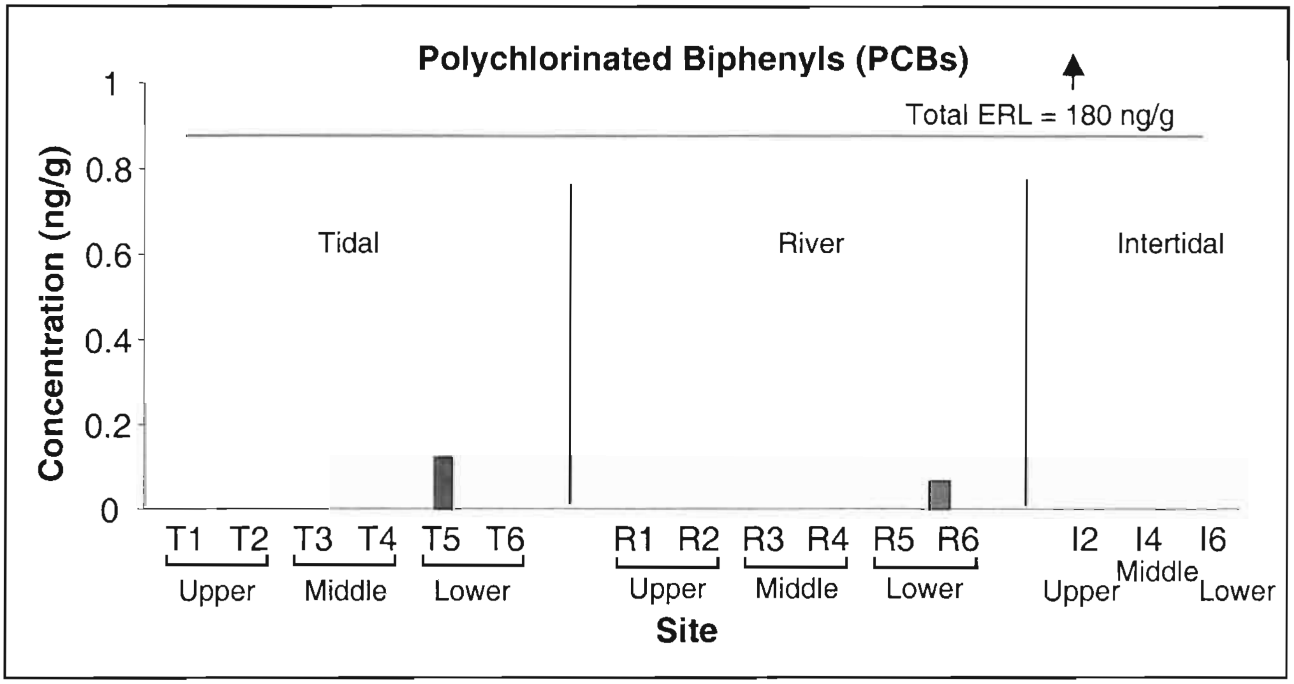


Figure 4.5 Total metals and total PAH concentrations measured at Okatee River (blue bars) and Broad Creek (red bars) sites. Note the comparable levels of metals and PAHs between systems and the low concentration of PAHs overall.



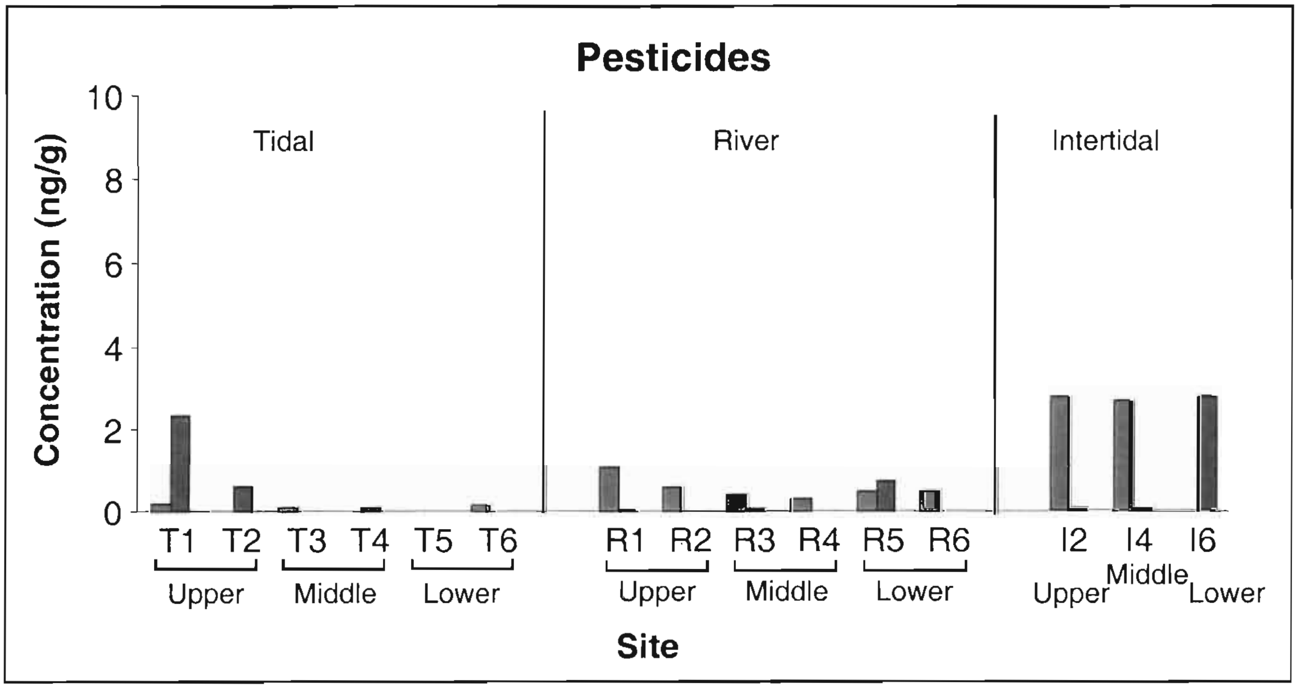


Figure 4.6 Total PCB and total pesticide concentrations measured at Okatee River (blue bars) and Broad Creek (red bars) sites. Note the general absence of PCBs in both systems but the pervasive occurrence of pesticides in both systems.

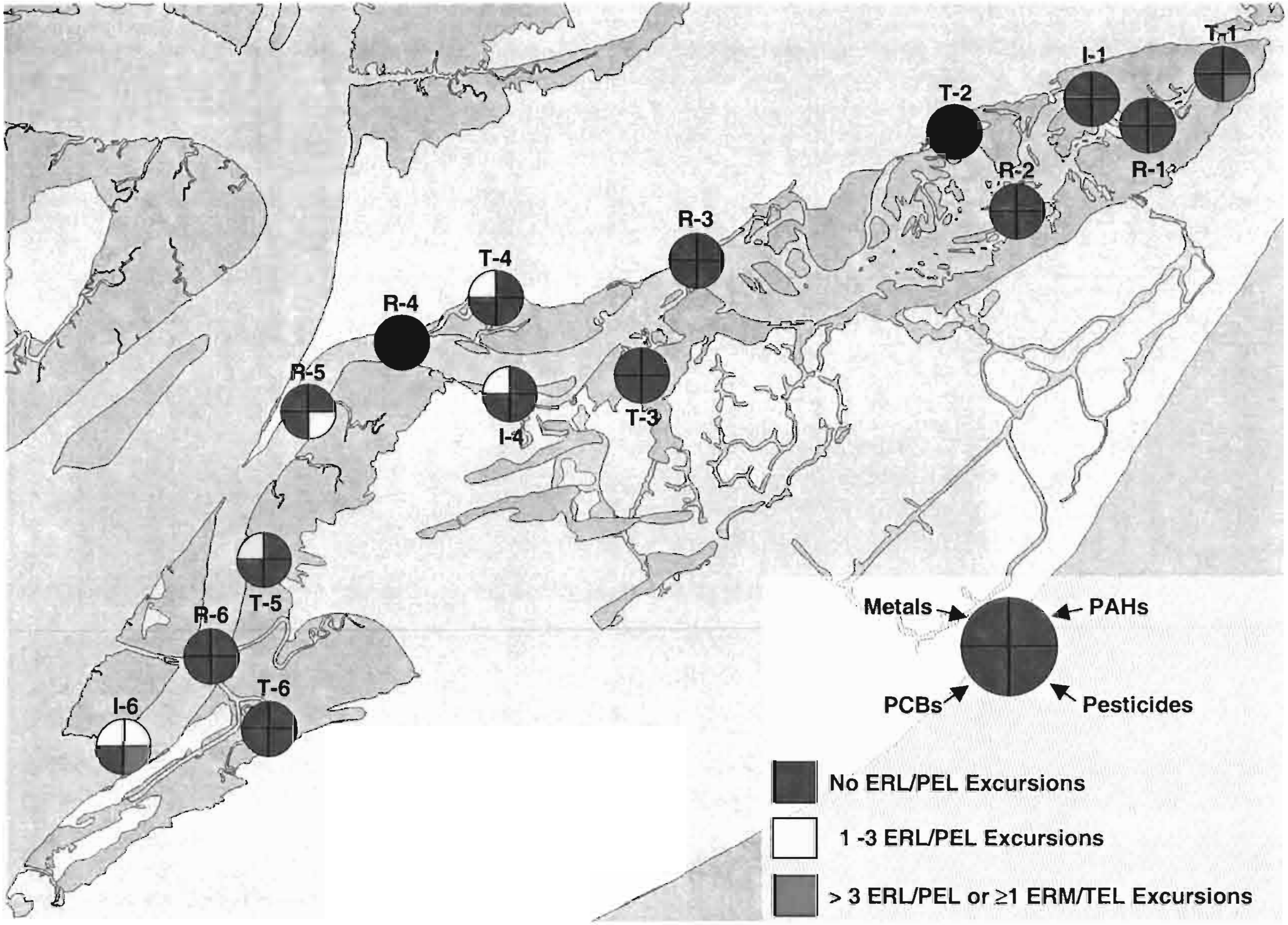


Figure 4.7 Map of Broad Creek showing excursions for Sediment Quality Guidelines (SQGs). Only 40% of the sites had any SQG excursion and only one site had a moderate risk (ERM) excursion.

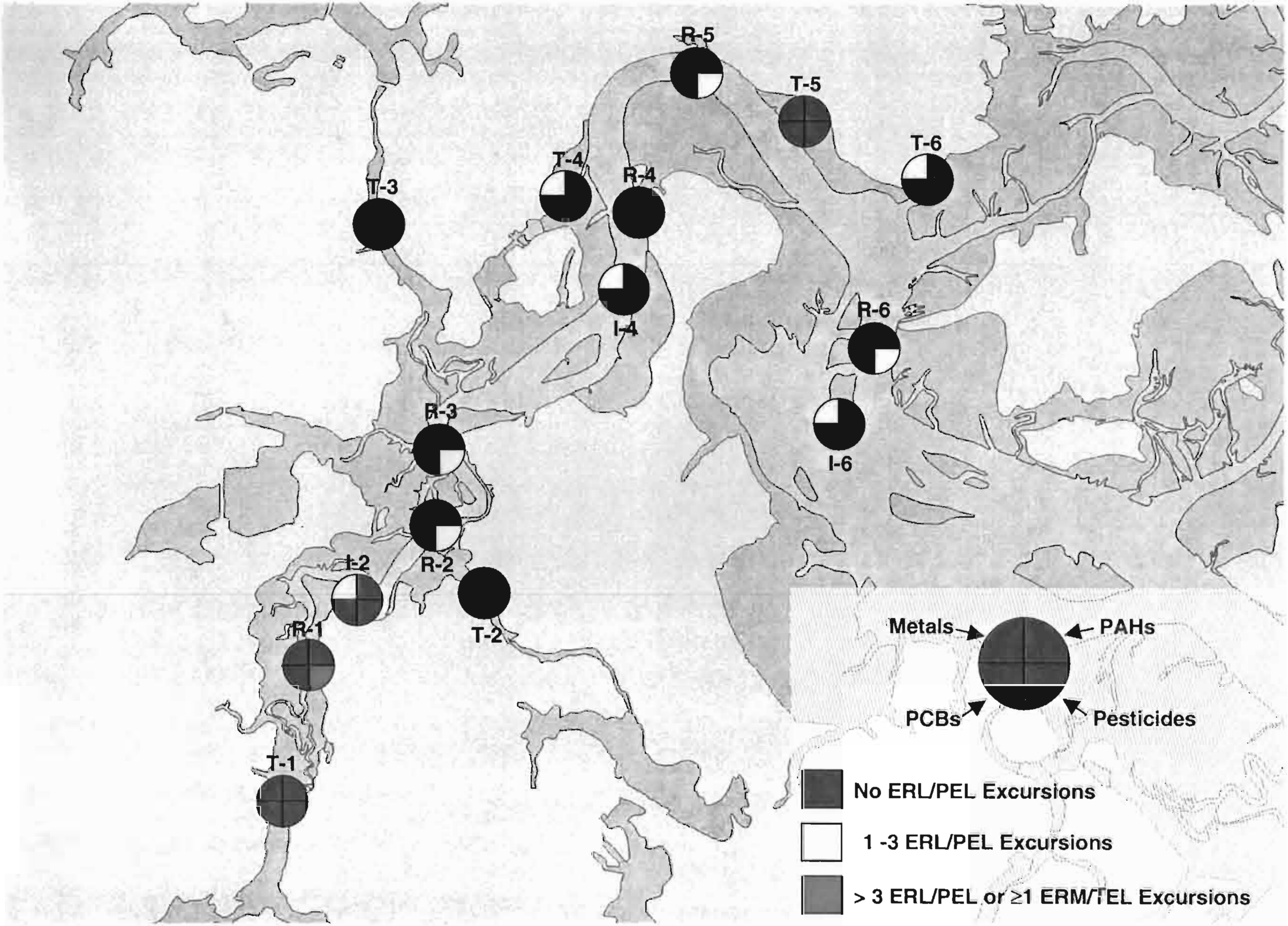


Figure 4.8 Map of Okatee River showing excursions for Sediment Quality Guidelines (SQGs). ERL excursions occurred at 67% of the sites, but no ERM excursions were found.

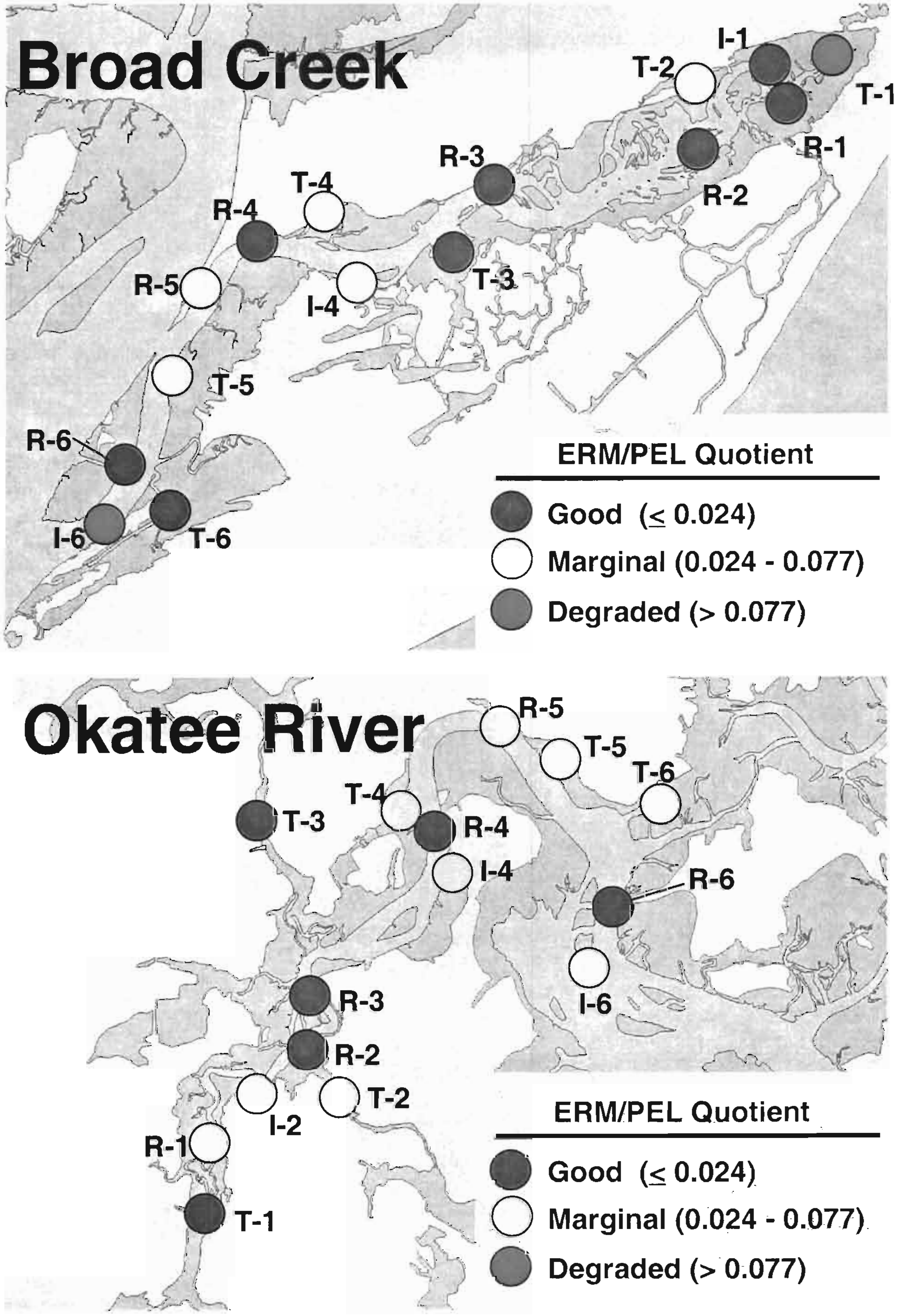


Figure 4.9 Maps showing potential risk of contamination due to overall cumulative sediment contaminant levels.

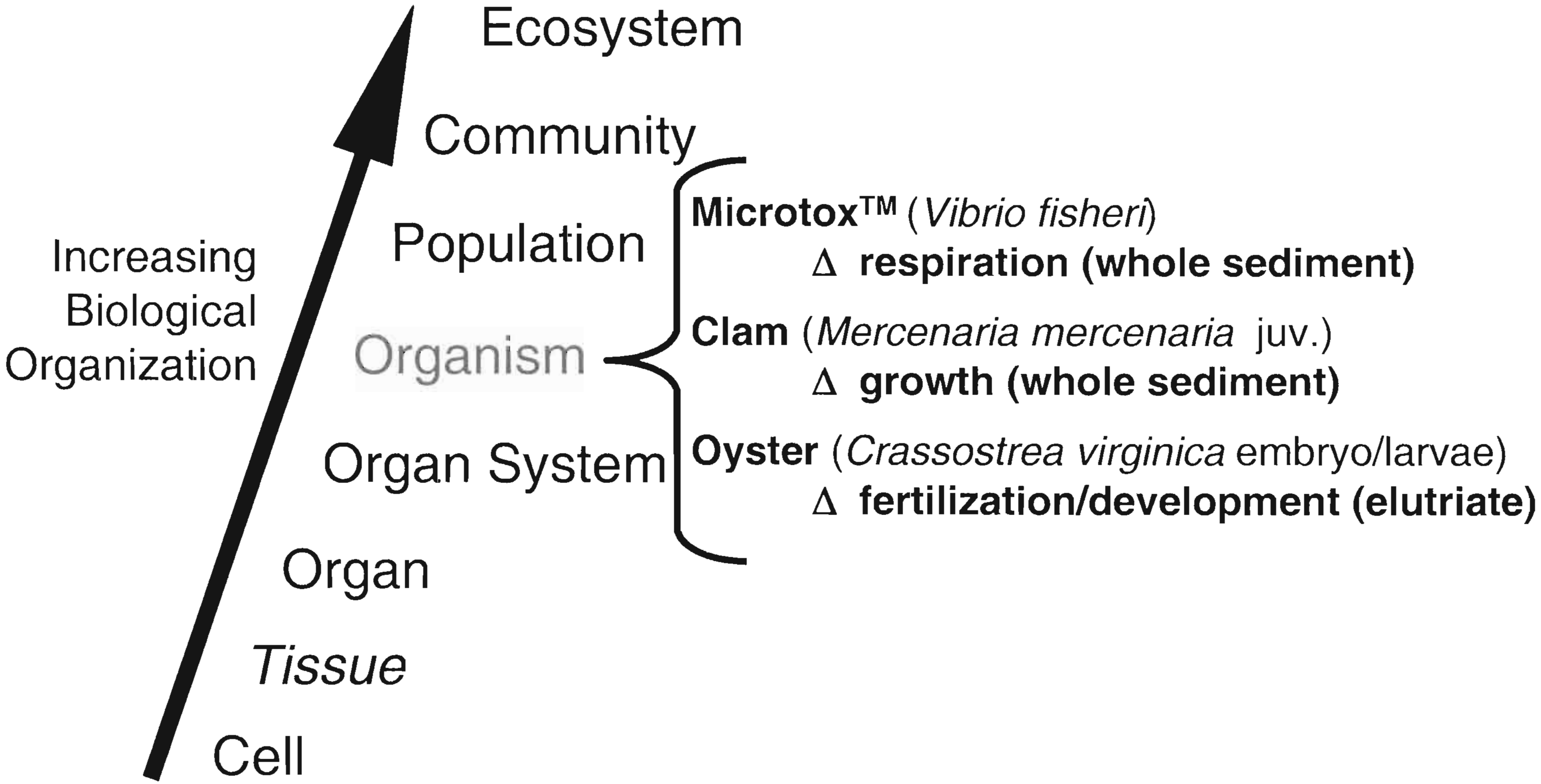


Figure 4.10 Diagram showing the levels of biological organization that may be addressed in toxicity testing. All assays conducted for this study focused on the organismal level, which represents a traditional level between suborganism and population responses.

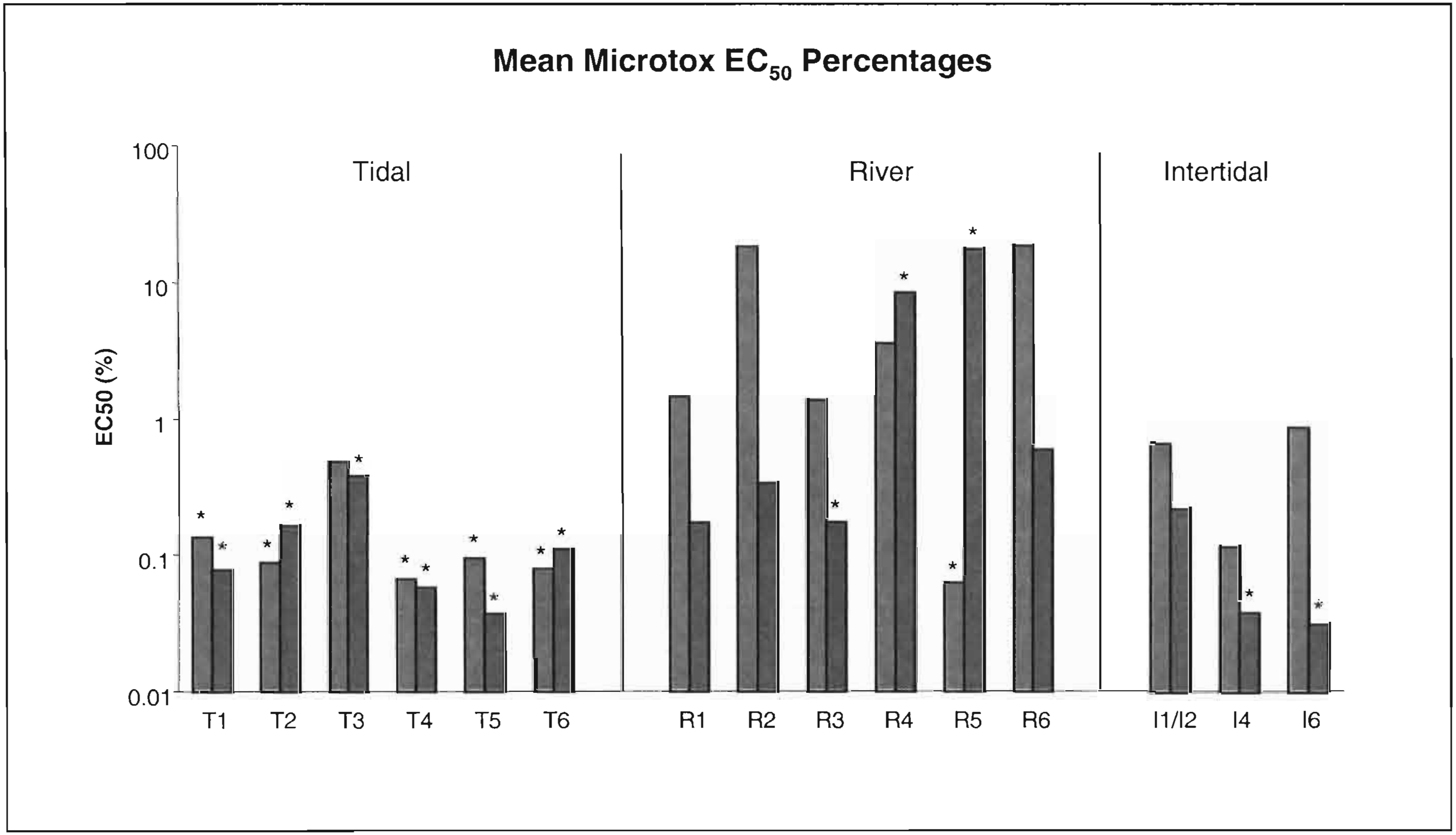


Figure 4.11 Microtox EC_{50} measurements for sediments from the Okatee River sites (blue bars) and Broad Creek (red bars). Asterisks indicate potential toxicity based on comparison to regional EMAP values.

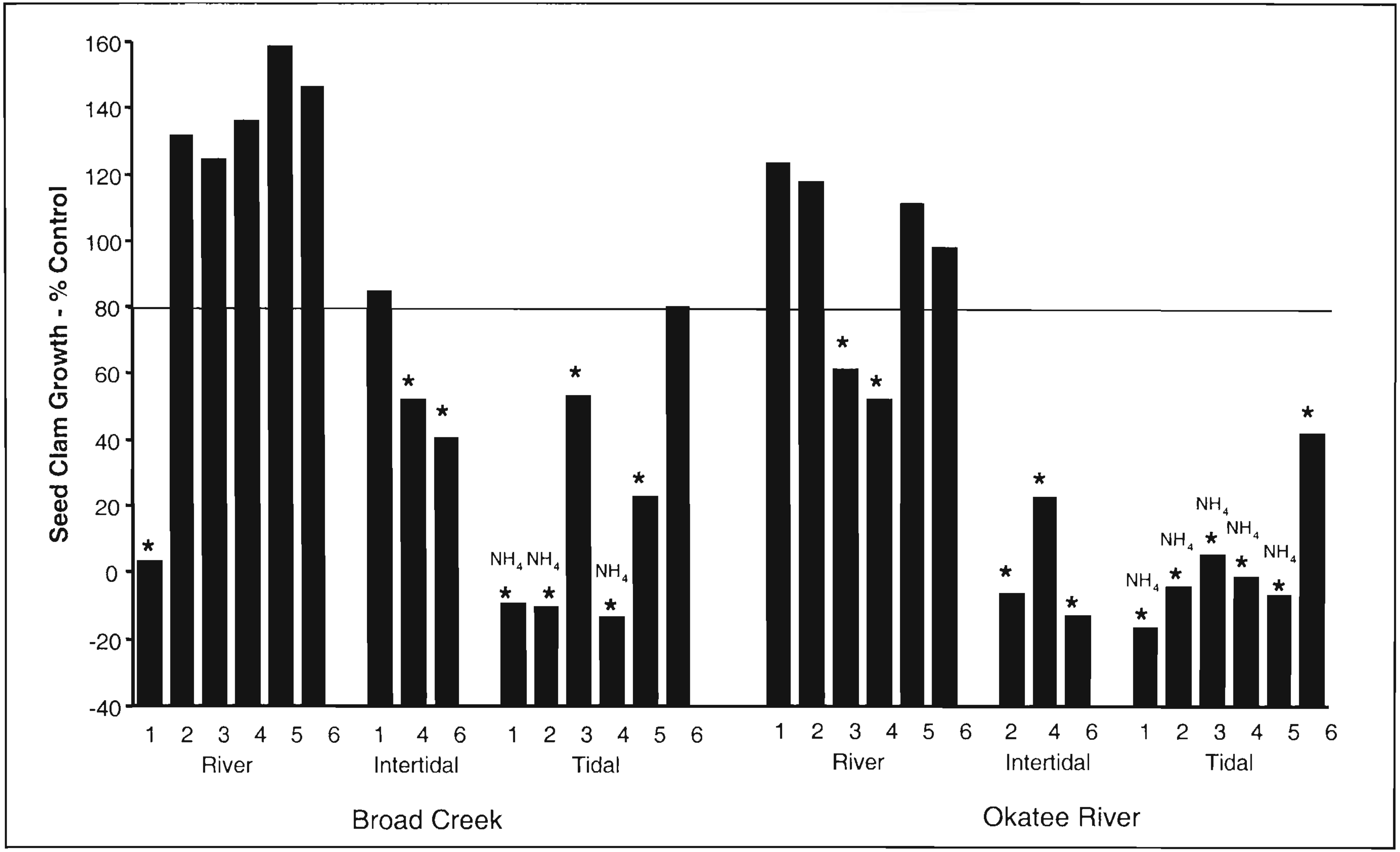


Figure 4.12 Site specific results of seed clam growth assays. Sites were classified as toxic (indicated with an *) when growth was less than 80% of controls and significantly different ($p<0.05$). The sites that had elevated porewater ammonia concentrations are also indicated.

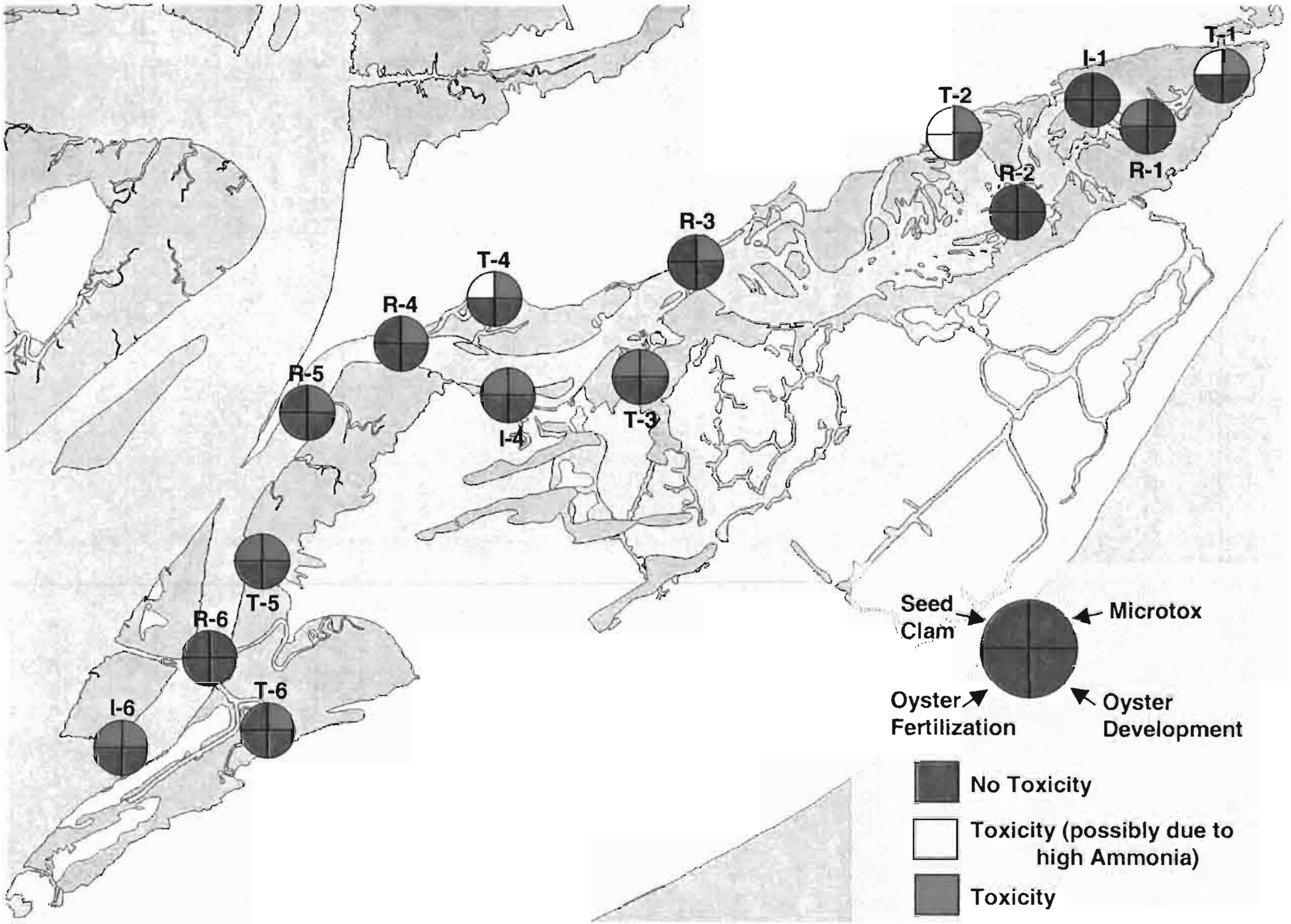


Figure 4.13 Broad Creek toxicity test results.

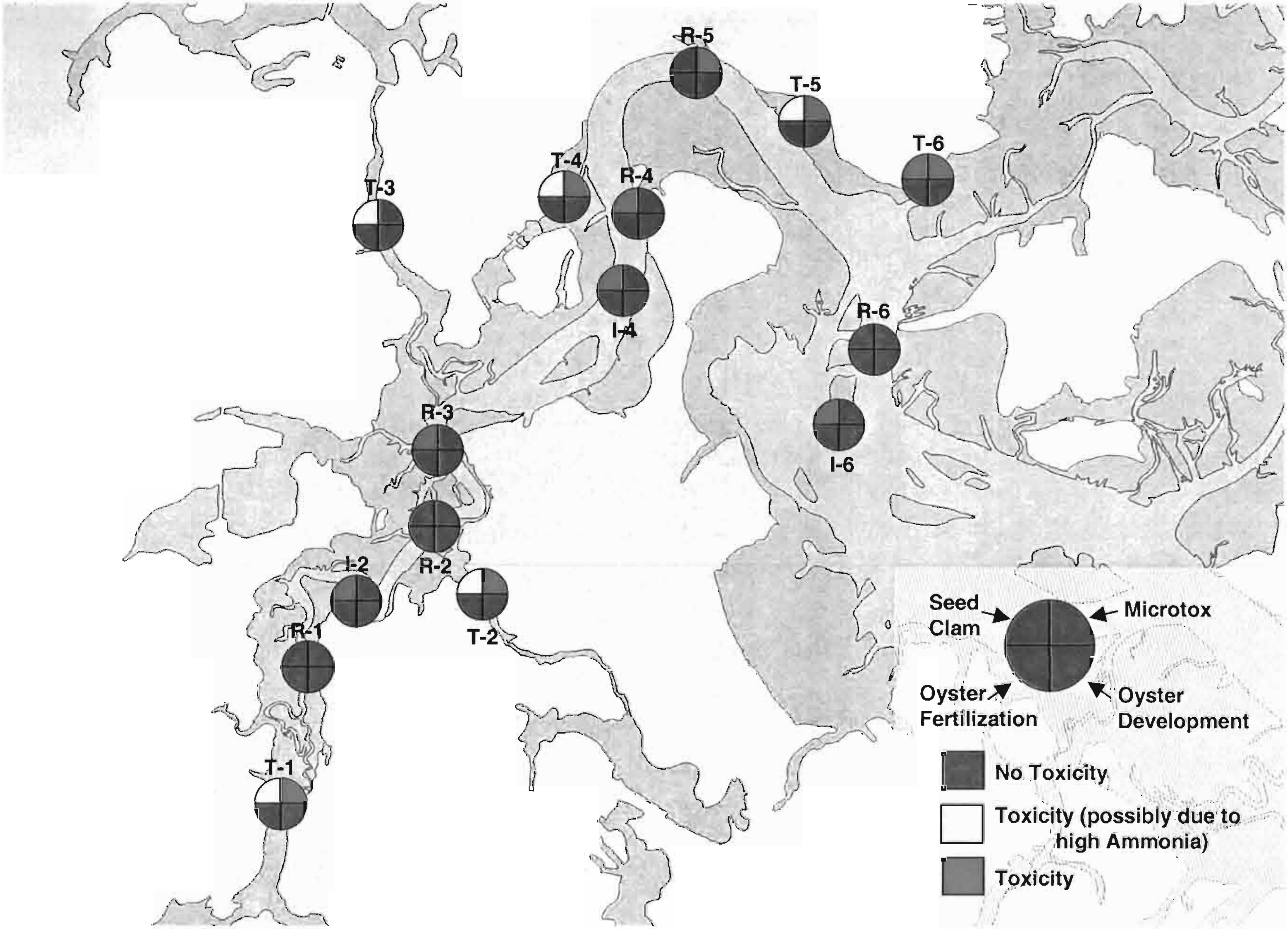
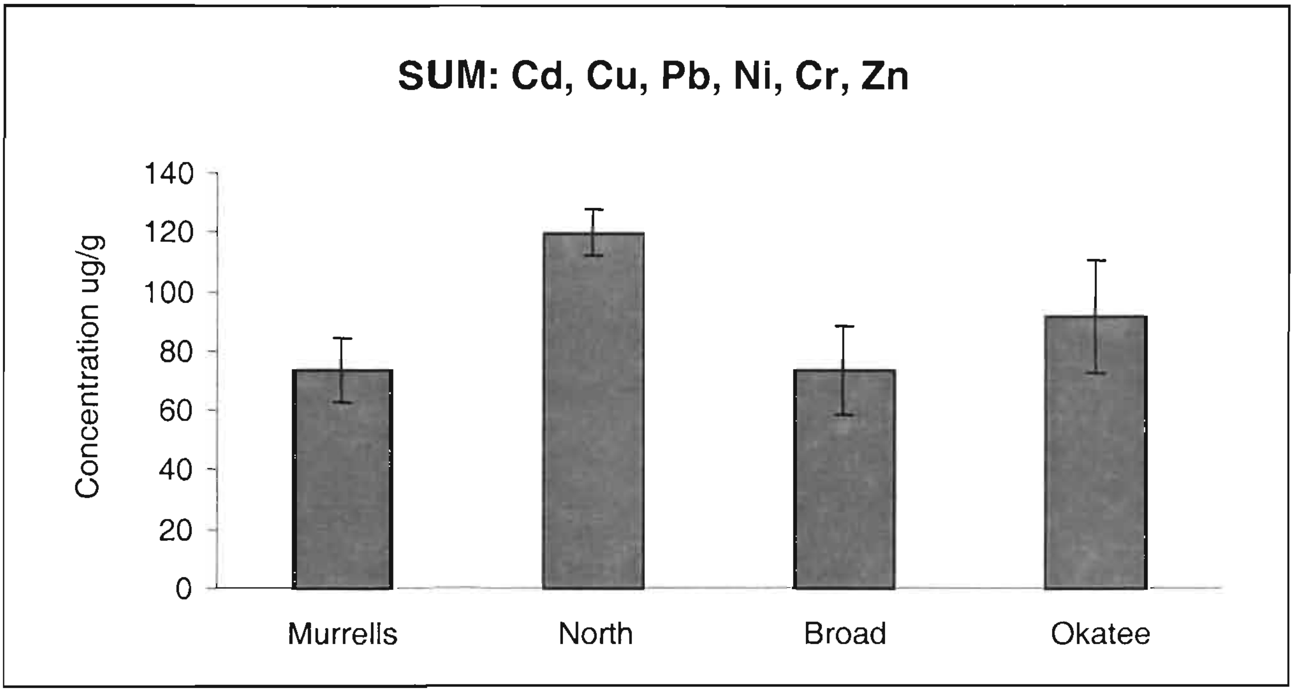


Figure 4.14 Okatee River toxicity test results.



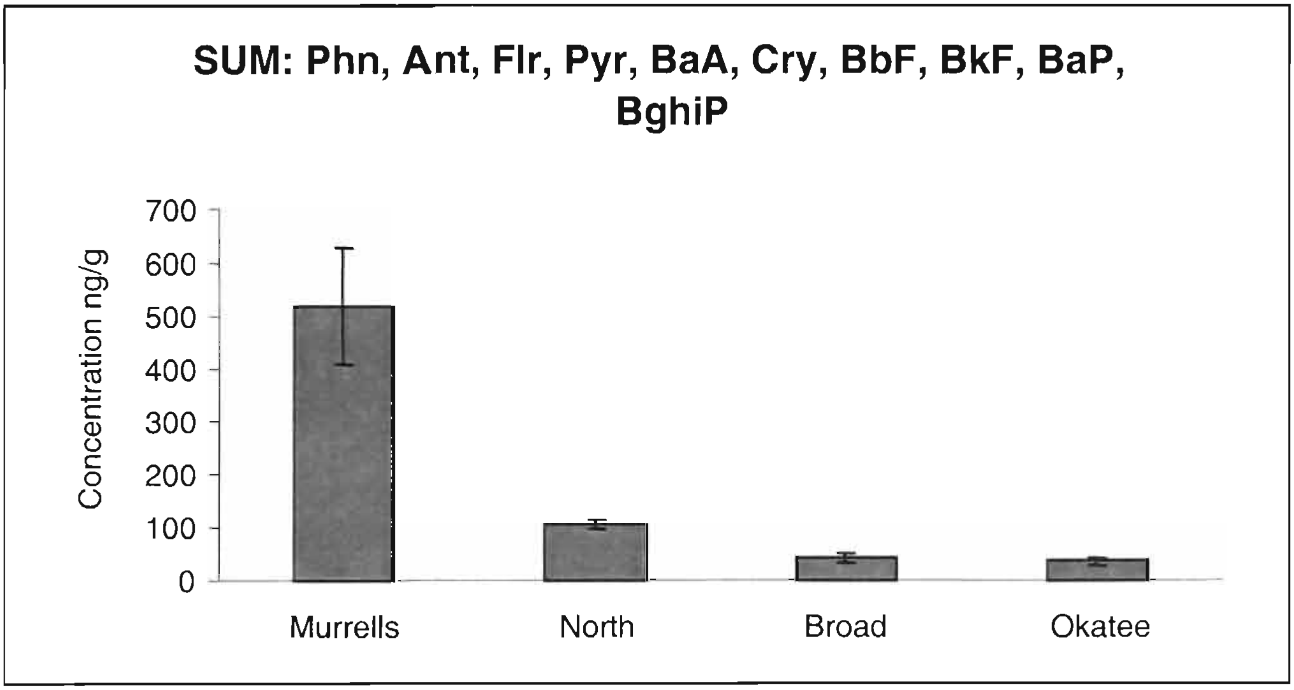


Figure 4.15 Comparison of Metal (top graph) and PAH Levels (lower graph) in Murrells Inlet, North Inlet, Broad Creek and Okatee River, South Carolina (Mean ± SEM).

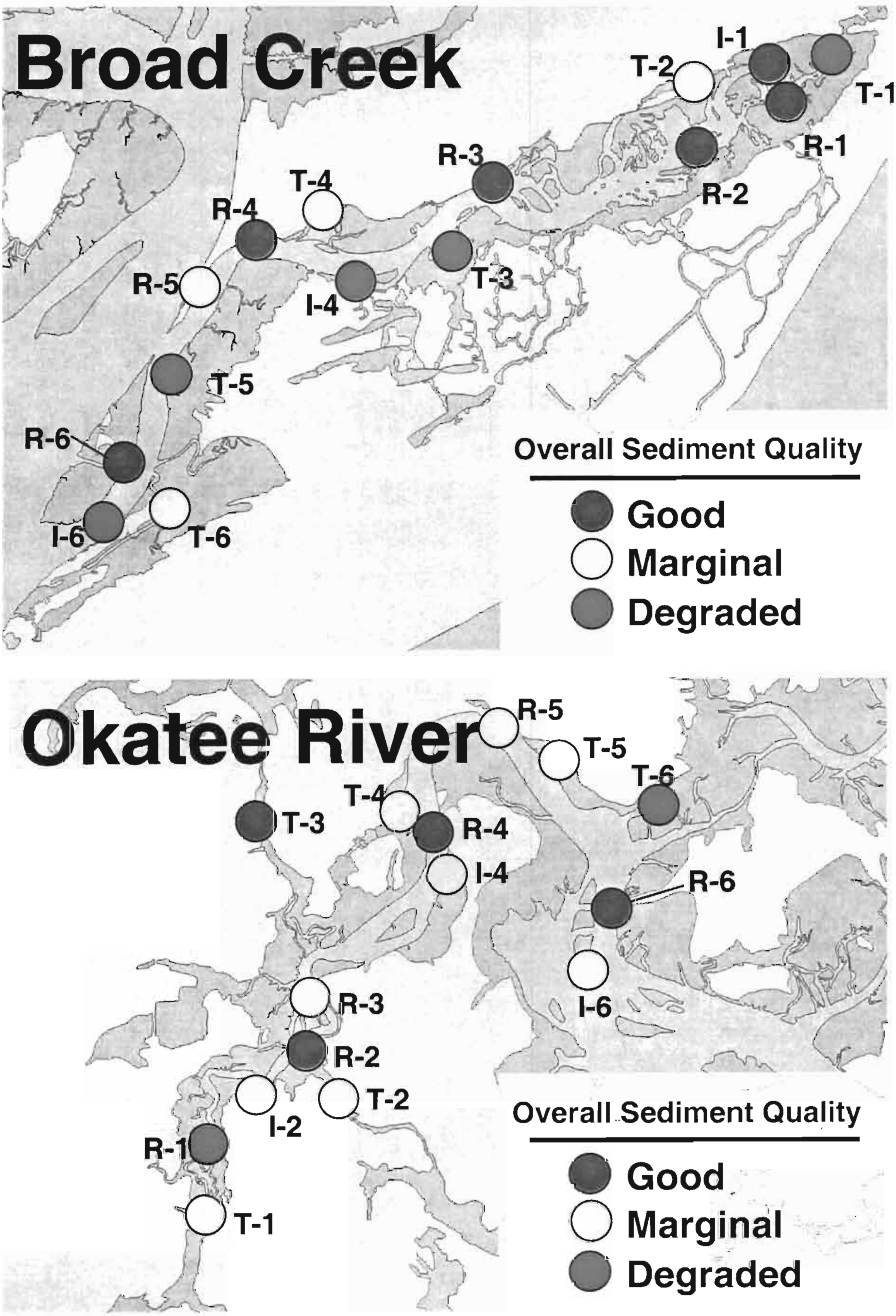
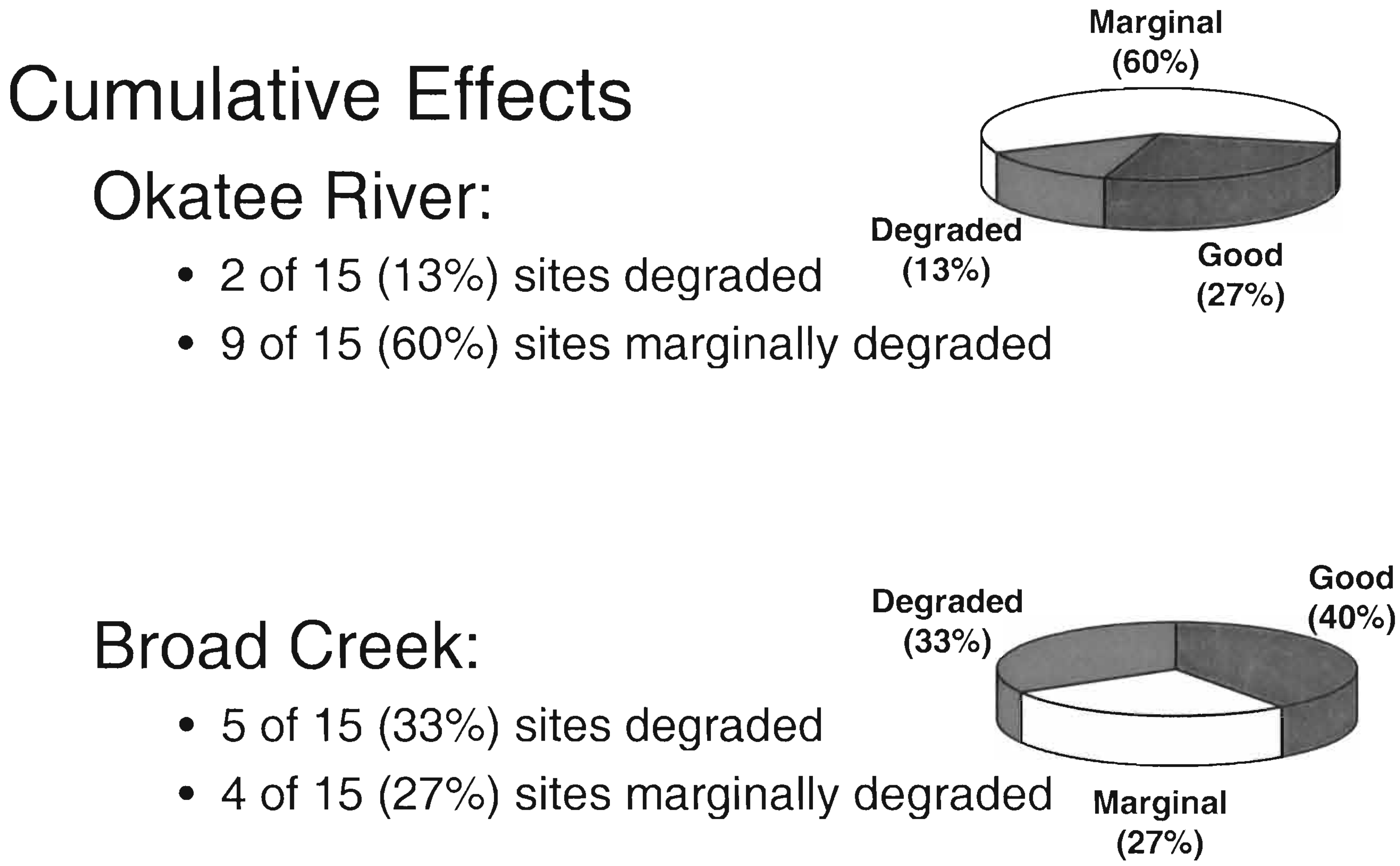


Figure 4.16 Map of Broad Creek and Okatee River showing classifications of overall sediment quality.



Cumulative Effects

Okatee River:

- 2 of 15 (13%) sites degraded
- 9 of 15 (60%) sites marginally degraded

Broad Creek:

- 5 of 15 (33%) sites degraded
- 4 of 15 (27%) sites marginally degraded

Figure 4.17 Overall ratings of the environmental health of Broad Creek and Okatee River based on those parameters measured for the time period studied.

Table 4.1 Summary of the sediment quality parameters examined for the Broad Creek/Okatee River study

Sediment Quality Parameter	Metric/Test	Analyses/Measurement
Physical Sediment Characteristics	Grain Size	% fine grain sediments (mud, silt, & clays) % coarse sediments (sand) total organic carbon (TOC)
Contaminant Chemistry	Trace Metals	Al, As, Cd, Cr, Cu, Pb, Mn, Hg, Ni, Ag, & Zn
	Polycyclic Hydrocarbons	24 analytes
	Polychlorinated Biphenyls	27 congeners
	Pesticides	16 pesticides/analytes
Sediment Toxicity Tests & Bioassays	Microtox (*Vibrio fisheri*)	respiration
	Seed Clam Growth	growth
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Table 4.2 Summary of sediment composition at all sites examined in the Broad Creek and Okatee River. The % sand, silt, and clay are shown, as well as the % total organic carbon (TOC).

Creek	Zone	Station	Sand %	Silt/Clay %	Silt %	Clay %	TOC %
Okatee River	tidal creek	1	53.3	46.7	11.7	35.0	1.53
		2	58.9	41.1	8.2	33.0	1.85
		3	76.5	23.5	5.0	18.5	1.57
		4	12.3	87.7	14.9	72.8	3.10
		5	31.5	68.5	13.7	54.8	2.37
		6	10.7	89.3	20.4	68.9	2.97
	river subtidal	1	93.8	6.2	1.0	5.2	0.14
		2	96.8	3.2	0.4	2.8	0.11
		3	94.9	5.1	0.8	4.2	0.07
		4	97.8	2.2	0.2	2.0	0.11
		5	87.8	12.2	4.4	7.8	0.77
		6	98.9	1.1	0.2	0.9	0.07
	river intertidal	2	26.7	73.3	15.0	58.3	2.00
		4	5.8	94.2	23.4	70.8	2.20
		6	40.0	60.0	15.4	44.5	1.59
Broad Creek	tidal creek	1	65.8	34.2	8.9	25.3	1.79
		2	66.4	33.6	10.0	23.5	1.59
		3	80.6	19.4	4.0	15.4	0.98
		4	36.2	63.8	15.5	48.3	2.50
		5	49.9	50.1	13.8	36.3	2.52
		6	85.9	14.1	2.6	11.5	0.53
	river subtidal	1	87.6	12.4	1.8	10.5	0.36
		2	82.3	17.7	3.5	14.2	0.64
		3	82.4	17.6	4.1	13.6	0.53
		4	99.2	0.8	0.1	0.7	0.05
		5	98.3	1.7	0.3	1.4	0.12
		6	96.4	3.6	0.9	2.7	0.16
	river intertidal	1	68.6	31.4	7.9	23.5	0.91
		4	19.6	80.4	30.9	49.5	2.72
		6	9.1	90.9	34.9	56.0	2.85

Table 4.3 Summary of metal contaminants in sediments collected from Okatee River and Broad Creek. Values are ug/g except for Al (expressed as %). The ∑PC for ERLs and ERMs are shown when As is included or excluded; the % change includes the change in ∑PC values when As is excluded. ERL and ERM values are shown; ERL exceedances are shaded.

STATION		% Al	As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	Mn	∑PC-ERM	∑PC-ERM (-As)	% Change
Okatee River															
Tidal Creek	1	3.10	6.76	0.042	31.7	4.04	11.4	0.053	7.88	<0.02	28.7	80.5	0.55	0.45	17.53
	2	3.20	5.71	0.048	34.8	4.82	12.9	0.057	7.90	<0.02	32.1	146	0.57	0.49	14.34
	3	2.04	4.04	0.036	22.3	2.85	8.66	0.035	4.85	<0.02	20.6	50.1	0.36	0.31	15.82
	4	7.02	**14.0**	0.107	71.2	11.4	22.8	0.104	19.0	<0.02	67.8	159	1.23	1.03	16.25
	5	3.89	8.06	0.058	42.1	6.78	14.4	0.061	10.3	<0.02	38.5	244	0.70	0.59	16.34
	6	6.86	**11.4**	0.106	71.6	11.3	22.8	0.078	18.7	<0.02	66.7	273	1.15	0.99	14.18
Subtidal	1	0.50	0.04	0.04	6.68	0.71	2.29	0.026	1.92	<0.02	6.48	36.4	0.13	0.13	0.41
	2	0.15	1.13	0.036	2.02	0.29	0.16	0.017	1.83	<0.02	3.17	67.6	0.09	0.08	17.06
	3	0.25	0.04	0.036	3.98	0.50	0.38	0.012	1.89	<0.02	4.47	28.3	0.08	0.08	0.62
	4	0.22	0.04	0.03	3.21	0.29	0.38	0.016	1.85	<0.02	3.60	32.6	0.08	0.08	0.61
	5	2.95	3.37	0.386	35.5	4.94	9.98	0.043	8.87	<0.02	34.0	132	0.56	0.52	8.54
	6	0.08	0.07	0.033	1.59	0.28	0.15	0.022	1.77	<0.02	3.46	32.8	0.08	0.08	1.11
Intertidal	2	5.87	**10.4**	0.165	63.7	9.44	19.2	0.074	15.7	<0.02	58.5	159	1.01	0.86	14.68
	4	6.69	**13.0**	0.113	75.7	10.30	19.8	0.068	19.4	<0.02	66.5	240	1.17	0.98	15.94
	6	5.31	**14.30**	0.105	55.2	8.42	18.8	0.063	14.6	<0.02	51.4	328	0.98	0.77	20.87
Broad Creek															
Tidal Creek	1	3.07	6.20	0.064	34.4	11.70	12.7	0.057	7.51	<0.02	32.6	152	0.60	0.51	14.87
	2	2.85	4.92	0.034	29.7	8.81	11.0	0.044	6.87	<0.02	36.9	83.2	0.52	0.45	13.47
	3	1.38	4.58	0.031	15.8	4.67	4.97	0.020	3.79	<0.02	20.0	44.4	0.30	0.24	21.66
	4	3.78	**9.44**	0.073	41.1	9.91	14.6	0.055	10.6	<0.02	46.6	140	0.75	0.62	17.90
	5	3.06	**12.1**	0.031	34.6	6.78	11.3	0.045	8.74	<0.02	35.5	120	0.67	0.49	25.97
	6	1.10	4.60	0.029	12.4	3.25	5.16	0.025	3.34	<0.02	13.8	45	0.27	0.21	24.24
Subtidal	1	1.18	0.726	0.051	14.8	3.88	4.17	0.033	3.68	<0.02	16.0	53.8	0.25	0.24	4.21
	2	0.98	2.81	0.071	13.1	3.19	3.27	0.024	2.88	<0.02	15.7	58.5	0.24	0.20	16.92
	3	0.74	2.01	0.069	9.11	2.52	2.56	0.023	2.31	<0.02	12.7	53.5	0.19	0.16	15.12
	4	0.18	2.62	0.049	2.82	0.51	1.40	0.025	1.37	<0.02	6.72	122	0.14	0.10	27.28
	5	0.16	1.60	0.065	3.31	0.30	0.52	0.014	1.91	<0.02	6.83	57.1	0.12	0.09	19.72
	6	0.48	1.74	0.036	5.96	1.44	2.13	0.018	1.95	<0.02	9.05	72.6	0.14	0.12	17.21
Intertidal	1	2.28	4.79	0.067	26.1	7.66	8.24	0.036	6.83	<0.02	30.9	86.8	0.47	0.40	14.56
	4	6.06	**13.7**	0.073	65.6	17.10	18.9	0.086	17.2	<0.02	70.6	337	1.16	0.96	16.91
	6	6.28	**8.46**	0.078	64.7	13.50	19.9	0.084	18.0	<0.02	66.9	548	1.08	0.95	11.24
ERL			**8.2**	**1.2**	**81**	**34**	**46.7**	**0.15**	**20.9**	**1**	**150**				
ERM			**70**	**9.6**	**370**	**270**	**218**	**0.71**	**51.6**	**3.7**	**410**				

Table 4.3 Summary of metal contaminants in sediments collected from Okatee River and Broad Creek. Values are ug/g except for Al (expressed as %). The ΣPC for ERLs and ERMs are shown when As is included or excluded; the % change includes the change in ΣPC values when As is excluded. ERL and ERM values are shown; ERL exceedances are shaded.

STATION		% Al	As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	Mn	ΣPC-ERM	ΣPC-ERM (-As)	% Change
Okatee River															
Tidal Creek	1	3.10	6.76	0.042	31.7	4.04	11.4	0.053	7.88	<0.02	28.7	80.5	0.55	0.45	17.53
	2	3.20	5.71	0.048	34.8	4.82	12.9	0.057	7.90	<0.02	32.1	146	0.57	0.49	14.34
	3	2.04	4.04	0.036	22.3	2.85	8.66	0.035	4.85	<0.02	20.6	50.1	0.36	0.31	15.82
	4	7.02	**14.0**	0.107	71.2	11.4	22.8	0.104	19.0	<0.02	67.8	159	1.23	1.03	16.25
	5	3.89	8.06	0.058	42.1	6.78	14.4	0.061	10.3	<0.02	38.5	244	0.70	0.59	16.34
	6	6.86	**11.4**	0.106	71.6	11.3	22.8	0.078	18.7	<0.02	66.7	273	1.15	0.99	14.18
Subtidal	1	0.50	0.04	0.04	6.68	0.71	2.29	0.026	1.92	<0.02	6.48	36.4	0.13	0.13	0.41
	2	0.15	1.13	0.036	2.02	0.29	0.16	0.017	1.83	<0.02	3.17	67.6	0.09	0.08	17.06
	3	0.25	0.04	0.036	3.98	0.50	0.38	0.012	1.89	<0.02	4.47	28.3	0.08	0.08	0.62
	4	0.22	0.04	0.03	3.21	0.29	0.38	0.016	1.85	<0.02	3.60	32.6	0.08	0.08	0.61
	5	2.95	3.37	0.386	35.5	4.94	9.98	0.043	8.87	<0.02	34.0	132	0.56	0.52	8.54
	6	0.08	0.07	0.033	1.59	0.28	0.15	0.022	1.77	<0.02	3.46	32.8	0.08	0.08	1.11
Intertidal	2	5.87	**10.4**	0.165	63.7	9.44	19.2	0.074	15.7	<0.02	58.5	159	1.01	0.86	14.68
	4	6.69	**13.0**	0.113	75.7	10.30	19.8	0.068	19.4	<0.02	66.5	240	1.17	0.98	15.94
	6	5.31	**14.30**	0.105	55.2	8.42	18.8	0.063	14.6	<0.02	51.4	328	0.98	0.77	20.87
Broad Creek															
Tidal Creek	1	3.07	6.20	0.064	34.4	11.70	12.7	0.057	7.51	<0.02	32.6	152	0.60	0.51	14.87
	2	2.85	4.92	0.034	29.7	8.81	11.0	0.044	6.87	<0.02	36.9	83.2	0.52	0.45	13.47
	3	1.38	4.58	0.031	15.8	4.67	4.97	0.020	3.79	<0.02	20.0	44.4	0.30	0.24	21.66
	4	3.78	**9.44**	0.073	41.1	9.91	14.6	0.055	10.6	<0.02	46.6	140	0.75	0.62	17.90
	5	3.06	**12.1**	0.031	34.6	6.78	11.3	0.045	8.74	<0.02	35.5	120	0.67	0.49	25.97
	6	1.10	4.60	0.029	12.4	3.25	5.16	0.025	3.34	<0.02	13.8	45	0.27	0.21	24.24
Subtidal	1	1.18	0.726	0.051	14.8	3.88	4.17	0.033	3.68	<0.02	16.0	53.8	0.25	0.24	4.21
	2	0.98	2.81	0.071	13.1	3.19	3.27	0.024	2.88	<0.02	15.7	58.5	0.24	0.20	16.92
	3	0.74	2.01	0.069	9.11	2.52	2.56	0.023	2.31	<0.02	12.7	53.5	0.19	0.16	15.12
	4	0.18	2.62	0.049	2.82	0.51	1.40	0.025	1.37	<0.02	6.72	122	0.14	0.10	27.28
	5	0.16	1.60	0.065	3.31	0.30	0.52	0.014	1.91	<0.02	6.83	57.1	0.12	0.09	19.72
	6	0.48	1.74	0.036	5.96	1.44	2.13	0.018	1.95	<0.02	9.05	72.6	0.14	0.12	17.21
Intertidal	1	2.28	4.79	0.067	26.1	7.66	8.24	0.036	6.83	<0.02	30.9	86.8	0.47	0.40	14.56
	4	6.06	**13.7**	0.073	65.6	17.10	18.9	0.086	17.2	<0.02	70.6	337	1.16	0.96	16.91
	6	6.28	**8.46**	0.078	64.7	13.50	19.9	0.084	18.0	<0.02	66.9	548	1.08	0.95	11.24
ERL			**8.2**	**1.2**	**81**	**34**	**46.7**	**0.15**	**20.9**	**1**	**150**				
ERM			**70**	**9.6**	**370**	**270**	**218**	**0.71**	**51.6**	**3.7**	**410**				

Table 4.4 Summary of concentrations (ng/g) of polycyclic aromatic hydrocarbons (PAHs) found at sites in the Broad Creek and Okatee River sites. Abbreviations for PAHs are described at the bottom. Total PAH concentration, the cumulative ERL, and the cumulative ERM for each site are shown. ERL and ERM values are shown.The one ERL excursion is shaded.

STATION		NAP	2-MN	1-MN	BPN	2,6 DMN	ACY	ACE	2,3,5 TMN	FLO	PHN	ANT	1-MPN	FLU	PYR	BAA	CHR	BBF	BKF	BEP	BAP	PER	IDP	DAHA	BGHIP	Summed Concentration
Okatee River																										
Tidal Creek	1	28.90	23.40	12.20	14.70	<1.71	<0.994	<3.33	<0.915	2.21	6.27	<1.67	<2.12	<2.53	6.29	<3.71	<1.13	5.69	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	99.7
	2	43.80	30.10	17.50	13.60	<1.71	<0.994	<3.33	<0.915	<1.18	5.82	<1.67	<2.12	5.97	4.45	<3.71	<1.13	4.18	<2.68	<2.57	<4.98	4.34	<5.00	<1.11	<3.37	129.8
	3	40.60	29.80	14.60	13.90	<1.71	<0.994	<3.33	<0.915	<1.18	5.38	<1.67	<2.12	<2.53	5.71	<3.71	<1.13	4.57	<2.68	<2.57	<4.98	8.27	<5.00	<1.11	<3.37	122.8
	4	<5.40	8.61	<1.93	17.70	<1.71	<0.994	<3.33	<0.915	<1.18	11.50	3.37	<2.12	13.30	9.62	6.00	<1.13	14.00	5.14	<2.57	7.13	5.49	5.06	<1.11	4.77	111.7
	5	46.50	34.20	19.00	13.00	<1.71	<0.994	<3.33	<0.915	<1.18	9.35	<1.67	<2.12	16.30	11.20	3.80	<1.13	9.97	4.20	5.65	<4.98	<3.10	<5.00	<1.11	<3.37	173.2
	6	96.40	66.90	44.10	26.70	<1.71	<0.994	<3.33	<0.915	<1.18	9.18	2.10	<2.12	9.65	10.30	4.22	<1.13	7.56	<2.68	<2.57	<4.98	5.63	<5.00	<1.11	3.79	286.5
Subtidal	1	23.10	19.50	10.90	4.68	4.72	3.75	3.83	2.18	<1.18	4.32	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	77.0
	2	14.10	12.20	6.60	<2.82	1.80	<0.994	<3.33	1.87	<1.18	2.67	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	39.2
	3	15.90	12.40	7.26	3.42	1.85	<0.994	<3.33	<0.915	1.26	2.52	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	44.6
	4	16.20	13.50	8.54	4.04	<1.71	<0.994	3.81	<0.915	<1.18	3.09	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	49.2
	5	33.80	28.30	18.30	7.58	14.20	1.10	5.81	<0.915	<1.18	6.32	<1.67	<2.12	5.37	4.09	<3.71	<1.13	6.22	4.84	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	135.9
	6	19.00	16.30	9.97	4.60	1.81	<0.994	4.29	<0.915	<1.18	2.70	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	58.7
Intertidal	2	25.00	16.70	9.69	7.02	8.66	2.80	<3.33	2.37	2.88	6.32	<1.67	<2.12	<2.53	6.38	<3.71	<1.13	5.91	5.72	<2.57	<4.98	3.81	<5.00	<1.11	<3.37	103.3
	4	65.60	56.40	32.70	13.30	21.10	<0.994	16.00	4.90	<1.18	16.50	<1.67	<2.12	10.40	8.01	4.37	<1.13	10.20	4.05	4.85	<4.98	7.62	<5.00	<1.11	<3.37	276.0
	6	66.80	49.40	28.00	<2.82	<1.71	<0.994	<3.33	<0.915	<1.18	10.30	<1.67	<2.12	<2.53	10.60	7.68	16.20	18.20	7.07	6.27	5.56	4.48	8.54	<1.11	<3.37	239.1
Broad Creek																										
Tidal Creek	1	26.50	19.10	12.90	8.74	1.75	<0.994	<3.33	<0.915	<1.18	11.40	<1.67	<2.12	16.60	13.80	4.75	<1.13	14.00	4.86	10.80	10.50	32.60	8.80	<1.11	11.70	208.8
	2	38.20	28.50	12.70	34.20	<1.71	<0.994	<3.33	1.55	1.72	5.93	<1.67	<2.12	9.21	6.77	<3.71	<1.13	7.42	<2.68	<2.57	<4.98	4.34	<5.00	<1.11	3.82	154.4
	3	16.70	16.00	10.30	<2.82	5.96	<0.994	<3.33	<0.915	<1.18	5.44	<1.67	<2.12	3.49	3.37	<3.71	2.43	3.61	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	67.3
	4	38.20	37.80	24.70	13.10	21.50	<0.994	8.15	<0.915	<1.18	8.58	4.25	4.01	15.10	11.60	5.83	<1.13	11.60	3.95	6.32	6.09	8.15	<5.00	<1.11	5.07	234.0
	5	42.50	50.00	31.90	17.40	28.10	<0.994	<3.33	2.44	<1.18	6.87	1.79	<2.12	<2.53	8.61	4.28	<1.13	6.99	<2.68	5.34	<4.98	<3.10	<5.00	<1.11	<3.37	206.2
	6	<5.40	<3.02	<1.93	<2.82	<1.71	<0.994	<3.33	<0.915	<1.18	4.97	<1.67	<2.12	<2.53	4.71	<3.71	<1.13	4.35	<2.68	<2.57	<4.98	4.03	<5.00	<1.11	<3.37	18.1
Subtidal	1	37.10	26.90	17.50	7.17	12.10	4.44	7.81	1.23	1.68	4.80	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	3.89	<4.98	3.96	<5.00	<1.11	<3.37	128.6
	2	40.70	29.80	18.80	7.79	9.21	<0.994	8.11	1.23	1.82	4.17	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	2.72	<4.98	3.34	<5.00	<1.11	<3.37	127.7
	3	19.50	15.10	8.55	3.69	6.89	<0.994	3.61	<0.915	<1.18	3.58	<1.67	<2.12	5.01	3.88	<3.71	<1.13	6.48	5.72	<2.57	<4.98	4.63	<5.00	<1.11	<3.37	86.6
	4	18.60	14.70	7.79	4.15	5.95	<0.994	3.99	<0.915	<1.18	2.08	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	57.3
	5	11.90	9.90	5.87	3.43	2.20	<0.994	<3.33	1.96	<1.18	2.15	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	37.4
	6	20.80	15.90	8.92	5.10	3.72	<0.994	4.15	<0.915	1.70	2.47	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	62.8
Intertidal	1	51.50	34.10	19.70	8.22	15.60	<0.994	13.40	<0.915	3.25	6.47	<1.67	<2.12	8.62	6.27	<3.71	<1.13	7.80	3.30	3.53	<4.98	4.06	<5.00	<1.11	<3.37	185.8
	4	86.70	59.20	35.50	21.20	12.90	<0.994	15.20	<0.915	<1.18	9.72	2.86	<2.12	23.40	19.50	9.39	<1.13	18.50	7.89	<2.57	8.90	11.10	7.58	2.87	7.55	360.0
	6	93.90	63.40	37.30	18.70	29.50	3.73	20.70	<0.915	6.66	11.10	3.33	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	7.01	15.50	7.18	<1.11	6.82	324.8
ERL		**160**	**70**				**44**	**16**		**19**	**240**	**85**		**600**	**665**	**261**	**384**				**430**			**63**		**4022**
ERM		**2100**	**670**				**640**	**500**		**540**	**1500**	**1100**		**5100**	**2600**	**1600**	**2800**				**1600**			**260**		**44792**

NAP = Naphthalene; 2-MN = 2-Methylnaphthalene; 1-MN = 1-Methylnaphthalene; BPN = Biphenyl; 2,6, DMN = 2,6 Dimethylnaphthalene; ACY = Acenaphthylene; ACE = Acenaphthene; 2,3,5, TMN = 2,3,5 Trimethylnaphthalene; FLO = Fluorene; PHN = Phenanthrene; ANT = Anthracene; 1-MPN = 1-Methylphenanthrene; FLU = Fluoranthene; PYR = Pyrene; BAA = Benzo(a)anthracene; CHR = Chrysene; BBF = Benzo(b)fluoranthene
BKF = Benzo(k)fluoranthene; BEP = Benzo(e)pyrene; BAP = Benzo(a)pyrene; PER = Perylene; IDP = Indeno(1,2,3-cd)pyrene; DAHA = Dibenz(a,h)anthracene; BGHIP = Benzo(g,h,i)perylene

Table 4.5 Summary of concentrations (ng/g) of polychlorinated biphenyls (PCBs) found at sites in the Broad Creek and Okatee River sites.
at the bottom. Total PAH concentration, the cumulative ERL, and the cumulative ERM for each site are shown. ERL and ERM values are shown.The one ERL excursion is shaded.

STATION		8 (PCB #)	18	28	52	44	118	153	105	128	180	195	206	209	29	50	104	66	87	77	154	188	138	126	187	201	170	101	Summed Concentration
Okatee River																													
Tidal Creek	1	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	3	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	5	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
Subtidal	1	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	3	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	5	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	**0.07**	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	**0.07**
Intertidal	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
Broad Creek																													
Tidal Creek	1	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	3	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	5	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	**0.12**
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	**0.12**	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
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	3	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
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	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00

Table 4.5 Summary of concentrations (ng/g) of polychlorinated biphenyls (PCBs) found at sites in the Broad Creek and Okatee River sites.
at the bottom. Total PAH concentration, the cumulative ERL, and the cumulative ERM for each site are shown. ERL and ERM values are shown.The one ERL excursion is shaded.

STATION		8 (PCB #)	18	28	52	44	118	153	105	128	180	195	206	209	29	50	104	66	87	77	154	188	138	126	187	201	170	101	Summed Concentration
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	3	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	5	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
Subtidal	1	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
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	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	5	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	**0.07**	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	**0.07**
Intertidal	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
Broad Creek																													
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	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	3	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
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	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	**0.12**	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
Subtidal	1	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	3	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	5	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
Intertidal	1	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00

Table 4.6 Concentrations (ug/g) of pesticides found at sites in the Broad Creek and Okatee River sites. Corresponding ERL and ERM values are listed.
All shaded cells exceeded one or more of the Sediment Quality Guidelines.

STATION		2,4'-DDD	2,4'-DDE	2,4'-DDT	4,4'-DDD	4,4'-DDE	4,4'-DDT	Total DDT	Aldrin	Cis-chlordane	Dieldrin	Lindane	Heptachlor	Heptachlor epoxide	Hexachloro-benzene	Mirex	Trans-nonachlor	Summed Concentration
Okatee River																		
Tidal Creek	1	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	0.17	<0.0940	0.17
	2	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	3	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	0.10	<0.157	<0.0940	0.10
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	5	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	0.14	<0.157	<0.0940	0.14
Subtidal	1	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.99**	0.07	<0.102	<0.0620	<0.157	<0.0940	1.06
	2	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.49**	0.10	<0.102	<0.0620	<0.157	<0.0940	0.59
	3	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.35**	0.05	<0.102	<0.0620	<0.157	<0.0940	0.40
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	0.30	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.30
	5	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.39**	0.08	<0.102	<0.0620	<0.157	<0.0940	0.47
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.36**	0.05	<0.102	0.07	<0.157	<0.0940	0.48
Intertidal	2	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	1.19	<0.102	1.56	<0.157	<0.0940	2.75
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	0.28	<0.102	0.14	2.23	<0.0940	2.65
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
Broad Creek																		
Tidal Creek	1	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	0.97	<0.0820	<0.181	**1.36**	<0.0400	<0.102	<0.0620	<0.157	<0.0940	2.33
	2	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	0.34	<0.0820	<0.181	0.26	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.60
	3	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	0.10	<0.157	<0.0940	0.10
	5	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
Subtidal	1	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	0.05	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.05
	2	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	3	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	0.07	<0.102	<0.0620	<0.157	<0.0940	0.07
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	5	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.68**	0.05	<0.102	<0.0620	<0.157	<0.0940	0.72
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
Intertidal	1	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	0.07	<0.157	<0.0940	0.07
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	0.08	<0.102	<0.0620	<0.157	<0.0940	0.08
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	0.15	<0.0820	**0.19**	**2.43**	<0.0400	<0.102	<0.0620	<0.157	<0.0940	2.78
ERL								**1.58**			**0.02**							
ERM								**46.10**			**8.00**							
TEL												**0.32**						
PEL												**0.99**						

Table 4.7 Maximum sediment concentrations found in the Broad Creek and Okatee River for the contaminants analyzed in this study and those found in a similar study for the relatively pristine ACE Basin. The % of sites exceeding the SQGs for an analyte are listed as (%>ERL/TEL, %>ERM/PEL). bdl = below detection limits. * only cis chlordane measured.

Contaminant	Broad	Okatee	ACE
Metals			
Arsenic	13.7 (27%, 0%)	14.3 (33%, 0%)	14.2
Cadmium	0.0782	0.386	0.33
Chromium	65.6	75.7	60.8
Copper	17.1	11.4	8.57
Lead	19.9	22.8	21
Mercury	0.0863	0.104	3.3
Nickel	18	19.4	16.9
Silver	<0.0211	<0.0211	0.02
Zinc	70.6	67.8	57.83
Pesticides			
p,p'-DDE	<0.0330	<0.0330	0.464
DDE (o,p & p,p)	<0.0580	<0.0580	4.64
DDT (o,p & p,p)	<0.144	<0.144	0.952
DDD (o,p & p,p)	<0.243	<0.243	1.04
Total DDT (all 6 isomers)	bdl	bdl	1.04
Chlordane**	<0.0820	<0.0820	<0.082
Dieldrin	0.192 (7%, 0%)	<0.181	<0.181
Gamma BHC (lindane)	2.43 (20%, 7%)	0.99 (33%, 7%)	0.161
PAHs			
2-methylnaphthalene	63.4	66.9	78.9
Acenaphthene	20.7 (7%, 0%)	16	15.9
Acenaphthylene	4.44	3.75	0.5
Anthracene	4.25	3.37	14.8
Benzo(a)anthracene	9.39	7.68	23.8
Benzo(a)pyrene	10.5	7.13	29.8
Chrysene	2.43	16.2	34
Dibenzo(a,h)anthracene	2.87	<1.11	3.5
Fluoranthene	23.4	16.3	16.5
Fluorene	6.66	2.88	6.8
Naphthalene	93.9	96.4	88.9
Phenanthrene	11.1	16.5	21.1
Pyrene	19.5	11.2	67.8
Total PAH	360	286.5	299.0
PCBs			
Total PCBs	0.12	0.07	<1.499

Table 4.7 Maximum sediment concentrations found in the Broad Creek and Okatee River for the contaminants analyzed in this study and those found in a similar study for the relatively pristine ACE Basin. The % of sites exceeding the SQGs for an analyte are listed as (%>ERL/TEL, %>ERM/PEL). bdl = below detection limits. * only cis chlordane measured.

Contaminant	Broad	Okatee	ACE
Metals			
Arsenic	13.7 (27%, 0%)	14.3 (33%, 0%)	14.2
Cadmium	0.0782	0.386	0.33
Chromium	65.6	75.7	60.8
Copper	17.1	11.4	8.57
Lead	19.9	22.8	21
Mercury	0.0863	0.104	3.3
Nickel	18	19.4	16.9
Silver	<0.0211	<0.0211	0.02
Zinc	70.6	67.8	57.83
Pesticides			
p,p'-DDE	<0.0330	<0.0330	0.464
DDE (o,p & p,p)	<0.0580	<0.0580	4.64
DDT (o,p & p,p)	<0.144	<0.144	0.952
DDD (o,p & p,p)	<0.243	<0.243	1.04
Total DDT (all 6 isomers)	bdl	bdl	1.04
Chlordane**	<0.0820	<0.0820	<0.082
Dieldrin	0.192 (7%, 0%)	<0.181	<0.181
Gamma BHC (lindane)	2.43 (20%, 7%)	0.99 (33%, 7%)	0.161
PAHs			
2-methylnaphthalene	63.4	66.9	78.9
Acenaphthene	20.7 (7%, 0%)	16	15.9
Acenaphthylene	4.44	3.75	0.5
Anthracene	4.25	3.37	14.8
Benzo(a)anthracene	9.39	7.68	23.8
Benzo(a)pyrene	10.5	7.13	29.8
Chrysene	2.43	16.2	34
Dibenzo(a,h)anthracene	2.87	<1.11	3.5
Fluoranthene	23.4	16.3	16.5
Fluorene	6.66	2.88	6.8
Naphthalene	93.9	96.4	88.9
Phenanthrene	11.1	16.5	21.1
Pyrene	19.5	11.2	67.8
Total PAH	360	286.5	299.0
PCBs			
Total PCBs	0.12	0.07	<1.499

Table 4.8 Cumulative ERM/PEL and cumulative ERM/PEL Quotients for the analyte classes examined.

		ERM/PEL Quotient				
Station		**Metals**	**PAHs**	**PCBs**	**Pesticides**	**All Analytes**
Okatee River						
Tidal Creek	1	0.061	0.005	0.000	0.000	0.023
	2	0.063	0.006	0.000	0.000	0.025
	3	0.041	0.005	0.000	0.000	0.017
	4	0.137	0.003	0.000	0.000	0.049
	5	0.078	0.007	0.000	0.000	0.031
	6	0.128	0.012	0.000	0.000	0.050
River Subtidal	1	0.009	0.004	0.000	0.332	0.044
	2	0.004	0.002	0.000	0.164	0.021
	3	0.005	0.002	0.000	0.116	0.016
	4	0.002	0.003	0.000	0.100	0.014
	5	0.063	0.006	0.000	0.133	0.040
	6	0.002	0.003	0.000	0.122	0.016
River Intertidal	2	0.112	0.004	0.000	0.000	0.041
	4	0.129	0.013	0.000	0.000	0.051
	6	0.109	0.010	0.000	0.000	0.043
Broad Creek						
Tidal Creek	1	0.066	0.005	0.000	0.456	0.078
	2	0.058	0.006	0.000	0.086	0.033
	3	0.033	0.003	0.000	0.000	0.013
	4	0.084	0.009	0.000	0.000	0.033
	5	0.074	0.008	0.000	0.000	0.030
	6	0.030	0.000	0.000	0.000	0.011
River Subtidal	1	0.027	0.007	0.000	0.000	0.013
	2	0.023	0.007	0.000	0.000	0.011
	3	0.021	0.003	0.000	0.000	0.009
	4	0.008	0.003	0.000	0.000	0.004
	5	0.009	0.002	0.000	0.228	0.030
	6	0.011	0.004	0.000	0.000	0.006
River Intertidal	1	0.052	0.009	0.000	0.000	0.023
	4	0.129	0.016	0.000	0.000	0.052
	6	0.119	0.016	0.001	0.827	0.146

Table 4.9 Mean EC_{50} values for Microtox. Shaded cells indicate sites that were significantly different from regional standards.

STATION		Mean EC_{50}	St. Dev.
Okatee River			
Tidal Creek	1	0.1345	0.0109
	2	0.0878	0.0098
	3	0.4871	0.0511
	4	0.0666	0.0035
	5	0.0947	0.0050
	6	0.0792	0.0101
River Subtidal	1	1.4841	0.1290
	2	18.5737	0.0000
	3	1.4025	0.3467
	4	3.6773	0.3473
	5	0.0624	0.0069
	6	18.9537	0.0000
River Intertidal	2	0.6712	0.1146
	4	0.1163	0.0226
	6	0.8829	0.2069
Broad Creek			
Tidal Creek	1	0.0778	0.0040
	2	0.1652	0.0066
	3	0.3819	0.0994
	4	0.0578	0.0064
	5	0.0371	0.0138
	6	0.1099	0.0155
River Subtidal	1	0.1745	0.0108
	2	0.3435	0.0397
	3	0.1767	0.0270
	4	8.6377	4.1733
	5	17.8586	0.0000
	6	0.6030	0.1752
River Intertidal	1	0.2197	0.0243
	4	0.0382	0.0065
	6	0.0312	0.0099

Table 4.9 Mean EC_{50} values for Microtox. Shaded cells indicate sites that were significantly different from regional standards.

STATION		Mean EC_{50}	St. Dev.
Okatee River			
Tidal Creek	1	0.1345	0.0109
	2	0.0878	0.0098
	3	0.4871	0.0511
	4	0.0666	0.0035
	5	0.0947	0.0050
	6	0.0792	0.0101
River Subtidal	1	1.4841	0.1290
	2	18.5737	0.0000
	3	1.4025	0.3467
	4	3.6773	0.3473
	5	0.0624	0.0069
	6	18.9537	0.0000
River Intertidal	2	0.6712	0.1146
	4	0.1163	0.0226
	6	0.8829	0.2069
Broad Creek			
Tidal Creek	1	0.0778	0.0040
	2	0.1652	0.0066
	3	0.3819	0.0994
	4	0.0578	0.0064
	5	0.0371	0.0138
	6	0.1099	0.0155
River Subtidal	1	0.1745	0.0108
	2	0.3435	0.0397
	3	0.1767	0.0270
	4	8.6377	4.1733
	5	17.8586	0.0000
	6	0.6030	0.1752
River Intertidal	1	0.2197	0.0243
	4	0.0382	0.0065
	6	0.0312	0.0099

Table 4.10 Results of Broad Creek and Okatee River statistical comparsions of the sediment quality parameters measured. Shaded cells indicate statistical sigificance at $\alpha=0.05$.

			Spearman Ranked Correlation Results	
Comparison			coeffiecent of correlation	p value
Sediment Chemistry (cumulative ERM)	vs.	Oyster Fetilization Rate	-0.3798	**0.0385**
		Oyster Development Rate	0.142	0.4493
		Average Growth of Clams	-0.51368	**0.00387**
		Microtox EC_{50}	-0.3741	**0.04173**
		Water Quality	-0.0563	0.76533
		Arsenic	0.64	**0.03**
		Lindane	0.28	0.13
Oyster Fertilization	vs.	Oyster Development Rate	0.22	0.2393
		Average Growth of Clams	0.187	0.3203
		Microtox EC_{50}	0.187	0.3203
		Water Quality	0.229	0.2213
		Arsenic	-0.351	0.0574
		Lindane	-0.0618	0.744
Oyster Development Rate	vs.	Average Growth of Clams	0.00934	0.9587
		Microtox EC_{50}	0.242	0.197
		Water Quality	-0.3	0.1063
		Arsenic	-0.0374	0.842
		Lindane	0.215	0.251
Average Growth of Clams	vs.	Microtox EC_{50}	0.3341	0.7083
		Water Quality	-0.133	0.4793
		Arsenic	-0.525	**0.003**
		Lindane	0.107	0.57
Microtox EC_{50}	vs.	Water Quality	-0.213	0.2563
		Arsenic	-0.58	**0.003**
		Lindane	0.232	0.215
Lindane	vs.	Arsenic	-0.4491	**0.013**

Table 4.11 Results from clam growth bioassays showing average growth per day in mg. Shaded cells indicate growth less than 80% of controls and significantly different ($p<0.05$).

STATION		AVG. GROWTH PER DAY (mg)
Okatee River		
Tidal Creek	1	-3.586
	2	-0.927
	3	1.193
	4	-0.251
	5	-1.470
	6	9.040
River Subtidal	1	10.428
	2	9.953
	3	5.208
	4	4.428
	5	9.415
	6	8.289
River Intertidal	2	-0.561
	4	1.918
	6	-1.092
Broad Creek		
Tidal Creek	1	-2.028
	2	-2.301
	3	11.455
	4	-2.871
	5	4.886
	6	17.293
River Subtidal	1	0.270
	2	11.153
	3	10.543
	4	11.507
	5	13.411
	6	12.397
River Intertidal	1	7.170
	4	4.393
	6	3.413

Table 4.11 Results from clam growth bioassays showing average growth per day in mg. Shaded cells indicate growth less than 80% of controls and significantly different ($p<0.05$).

STATION		AVG. GROWTH PER DAY (mg)
Okatee River		
Tidal Creek	1	-3.586
	2	-0.927
	3	1.193
	4	-0.251
	5	-1.470
	6	9.040
River Subtidal	1	10.428
	2	9.953
	3	5.208
	4	4.428
	5	9.415
	6	8.289
River Intertidal	2	-0.561
	4	1.918
	6	-1.092
Broad Creek		
Tidal Creek	1	-2.028
	2	-2.301
	3	11.455
	4	-2.871
	5	4.886
	6	17.293
River Subtidal	1	0.270
	2	11.153
	3	10.543
	4	11.507
	5	13.411
	6	12.397
River Intertidal	1	7.170
	4	4.393
	6	3.413

Table 4.12 Fertilization rates for oyster gametes exposed to sediment elutriates. Data are expressed as mean % sediment controls (n=4 replicates); standard deviations are shown in parentheses. NA indicates no data available or not applicable.
* = significantly different from control sediments.

Sediment ID	System	Region	Strata	20% Elutriate	50% Elutriate	100% Elutriate
Controls - Set 1	Folly	NA	NA	100.00 (0.87)	100.00 (0.65)	100.00 (0.75)
Controls - Set 2	Folly	NA	NA	NA	100.00 (2.59)	100.00 (0.77)
Controls - Set 3	Folly	NA	NA	100.00 (1.52)	100.00 (0.53)	100.00 (1.15)
OBS1	Okatee	River	1	NA	101.96 (1.71)	100.47 (1.19)
OBS2	Okatee	River	2	NA	101.21 (2.03)	100.95 (1.90)
OBS3	Okatee	River	3	NA	100.44 (0.45)	100.28 (1.84)
OBS4	Okatee	River	4	NA	101.06 (0.43)	100.66 (1.23)
OBS5	Okatee	River	5	99.49 (0.87)	99.88 (0.29)	99.19 (0.29)
OBS6	Okatee	River	6	99.38 (0.62)	98.82 (0.81)	98.21 (0.32)
OBI2	Okatee	Intertidal	2	99.49 (0.96)	98.10 (2.78)	97.75 (0.90)
OBI4	Okatee	Intertidal	4	99.27 (0.55)	98.36 (0.65)	97.94 (0.72)
OBI6	Okatee	Intertidal	6	99.88 (0.48)	98.38 (1.69)	98.18 (1.06)
OBT1	Okatee	Tidal Creek	1	97.55 (1.76)	100.65 (1.80)	98.20 (1.11)
OBT2	Okatee	Tidal Creek	2	102.52 (0.48)	100.92 (1.45)	100.43 (2.30)
OBT3	Okatee	Tidal Creek	3	102.33 (1.78)	100.92 (1.14)	101.15 (1.26)
OBT4	Okatee	Tidal Creek	4	97.93 (0.95)	99.09 (2.07)	97.17 (0.77)
OBT5	Okatee	Tidal Creek	5	100.53 (1.93)	99.05 (1.40)	100.55 (0.70)
OBT6	Okatee	Tidal Creek	6	97.57 (1.83)	99.07 (1.39)	98.57 (1.63)
BBS1	Broad	River	1	NA	98.11 (4.70)	98.59 (1.49)
BBS2	Broad	River	2	NA	101.71 (1.80)	99.81 (1.71)
BBS3	Broad	River	3	99.13 (0.95)	97.98 (2.03)	97.23 (0.65)
BBS4	Broad	River	4	NA	99.35 (1.23)	99.23 (0.65)
BBS5	Broad	River	5	98.99 (1.57)	98.65 (0.68)	98.43 (1.71)
BBS6	Broad	River	6	NA	101.86 (0.69)	99.18 (1.65)
BBI1	Broad	Intertidal	1	NA	99.11 (2.85)	100.99 (1.36)
BBI4	Broad	Intertidal	4	NA	99.73 (1.03)	92.12 (13.23)
BBI6	Broad	Intertidal	6	98.86 (0.76)	98.48 (1.05)	98.17 (1.34)
BBT1	Broad	Tidal Creek	1	97.92 (2.13)	99.73 (1.43)	97.42 (1.29)
BBT2	Broad	Tidal Creek	2	95.56 (1.40)	99.49 (1.51)	**85.17 (2.18)** [A]
BBT3	Broad	Tidal Creek	3	97.92 (1.60)	97.78 (1.95)	100.14 (1.12)
BBT4	Broad	Tidal Creek	4	100.25 (0.68)	101.97 (1.12)	101.05 (0.75)
BBT5	Broad	Tidal Creek	5	99.63 (1.66)	100.49 (0.68)	100.89 (1.30)
BBT6	Broad	Tidal Creek	6	101.57 (0.75)	101.51 (0.80)	100.25 (0.66)

Table 4.13 Development rates for oyster gametes exposed to sediment elutriates. Data are expressed as mean % sediment controls (n=4 replicates); standard deviations are shown in parentheses. NA indicates no data available or not applicable.

Sediment ID	System	Region	Strata	20% Elutriate	50% Elutriate	100% Elutriate
Controls - Set 1	Folly	NA	NA	100.00 (19.61)	100.00 (6.23)	100.00 (3.73)
Controls - Set 2	Folly	NA	NA	NA	100.00 (28.20)	100.00 (23.39)
Controls - Set 3	Folly	NA	NA	100.00 (15.93)	100.00 (9.72)	100.00 (11.13)
OBS1	Okatee	River	1	NA	84.52 (14.03)	110.78 (6.62)
OBS2	Okatee	River	2	NA	117.86 (11.80)	126.57 (10.93)
OBS3	Okatee	River	3	NA	111.90 (12.28)	108.27 (3.17)
OBS4	Okatee	River	4	NA	97.62 (8.85)	104.01 (13.78)
OBS5	Okatee	River	5	120.42 (20.07)	142.64 (8.59)	118.63 (13.53)
OBS6	Okatee	River	6	125.82 (28.81)	132.09 (12.08)	126.77 (21.29)
OBI2	Okatee	Intertidal	2	106.81 (17.27)	101.32 (20.85)	110.49 (20.97)
OBI4	Okatee	Intertidal	4	124.65 (11.56)	115.38 (15.35)	126.77 (25.13)
OBI6	Okatee	Intertidal	6	109.15 (13.64)	112.97 (17.11)	115.42 (14.12)
OBT1	Okatee	Tidal Creek	1	108.46 (18.53)	108.87 (9.24)	103.56 (11.77)
OBT2	Okatee	Tidal Creek	2	112.90 (21.20)	112.70 (18.83)	115.45 (17.81)
OBT3	Okatee	Tidal Creek	3	114.38 (13.80)	103.83 (5.64)	116.63 (6.38)
OBT4	Okatee	Tidal Creek	4	108.25 (8.90)	117.74 (8.14)	101.39 (17.63)
OBT5	Okatee	Tidal Creek	5	100.42 (13.45)	94.15 (11.18)	123.76 (9.09)
OBT6	Okatee	Tidal Creek	6	120.08 (14.60)	107.46 (9.16)	111.29 (11.93)
BBS1	Broad	River	1	NA	111.43 (3.89)	98.25 (25.51)
BBS2	Broad	River	2	NA	129.76 (9.82)	141.35 (20.35)
BBS3	Broad	River	3	96.24 (7.99)	90.11 (16.99)	94.86 (18.82)
BBS4	Broad	River	4	NA	100.48 (8.61)	84.46 (12.95)
BBS5	Broad	River	5	110.80 (5.14)	111.21 (9.96)	105.14 (11.35)
BBS6	Broad	River	6	NA	96.90 (9.54)	90.23 (5.24)
BBI1	Broad	Intertidal	1	NA	100.00 (17.75)	103.26 (10.92)
BBI4	Broad	Intertidal	4	NA	70.24 (17.77)	83.17 (8.99)
BBI6	Broad	Intertidal	6	95.54 (21.85)	122.64 (104.93)	104.93 (19.89)
BBT1	Broad	Tidal Creek	1	114.38 (15.96)	111.29 (4.01)	111.68 (10.53)
BBT2	Broad	Tidal Creek	2	118.18 (9.30)	110.08 (13.58)	103.96 (6.32)
BBT3	Broad	Tidal Creek	3	118.18 (5.37)	111.29 (19.28)	116.24 (6.73)
BBT4	Broad	Tidal Creek	4	109.94 (10.19)	90.32 (12.44)	98.02 (7.69)
BBT5	Broad	Tidal Creek	5	106.55 (2.07)	107.26 (7.42)	105.94 (6.45)
BBT6	Broad	Tidal Creek	6	112.26 (9.70)	110.48 (20.19)	105.35 (8.89)

Table 4.13 Development rates for oyster gametes exposed to sediment elutriates. Data are expressed as mean % sediment controls (n=4 replicates); standard deviations are shown in parentheses. NA indicates no data available or not applicable.

Sediment ID	System	Region	Strata	20% Elutriate	50% Elutriate	100% Elutriate
Controls - Set 1	Folly	NA	NA	100.00 (19.61)	100.00 (6.23)	100.00 (3.73)
Controls - Set 2	Folly	NA	NA	NA	100.00 (28.20)	100.00 (23.39)
Controls - Set 3	Folly	NA	NA	100.00 (15.93)	100.00 (9.72)	100.00 (11.13)
OBS1	Okatee	River	1	NA	84.52 (14.03)	110.78 (6.62)
OBS2	Okatee	River	2	NA	117.86 (11.80)	126.57 (10.93)
OBS3	Okatee	River	3	NA	111.90 (12.28)	108.27 (3.17)
OBS4	Okatee	River	4	NA	97.62 (8.85)	104.01 (13.78)
OBS5	Okatee	River	5	120.42 (20.07)	142.64 (8.59)	118.63 (13.53)
OBS6	Okatee	River	6	125.82 (28.81)	132.09 (12.08)	126.77 (21.29)
OBI2	Okatee	Intertidal	2	106.81 (17.27)	101.32 (20.85)	110.49 (20.97)
OBI4	Okatee	Intertidal	4	124.65 (11.56)	115.38 (15.35)	126.77 (25.13)
OBI6	Okatee	Intertidal	6	109.15 (13.64)	112.97 (17.11)	115.42 (14.12)
OBT1	Okatee	Tidal Creek	1	108.46 (18.53)	108.87 (9.24)	103.56 (11.77)
OBT2	Okatee	Tidal Creek	2	112.90 (21.20)	112.70 (18.83)	115.45 (17.81)
OBT3	Okatee	Tidal Creek	3	114.38 (13.80)	103.83 (5.64)	116.63 (6.38)
OBT4	Okatee	Tidal Creek	4	108.25 (8.90)	117.74 (8.14)	101.39 (17.63)
OBT5	Okatee	Tidal Creek	5	100.42 (13.45)	94.15 (11.18)	123.76 (9.09)
OBT6	Okatee	Tidal Creek	6	120.08 (14.60)	107.46 (9.16)	111.29 (11.93)
BBS1	Broad	River	1	NA	111.43 (3.89)	98.25 (25.51)
BBS2	Broad	River	2	NA	129.76 (9.82)	141.35 (20.35)
BBS3	Broad	River	3	96.24 (7.99)	90.11 (16.99)	94.86 (18.82)
BBS4	Broad	River	4	NA	100.48 (8.61)	84.46 (12.95)
BBS5	Broad	River	5	110.80 (5.14)	111.21 (9.96)	105.14 (11.35)
BBS6	Broad	River	6	NA	96.90 (9.54)	90.23 (5.24)
BBI1	Broad	Intertidal	1	NA	100.00 (17.75)	103.26 (10.92)
BBI4	Broad	Intertidal	4	NA	70.24 (17.77)	83.17 (8.99)
BBI6	Broad	Intertidal	6	95.54 (21.85)	122.64 (104.93)	104.93 (19.89)
BBT1	Broad	Tidal Creek	1	114.38 (15.96)	111.29 (4.01)	111.68 (10.53)
BBT2	Broad	Tidal Creek	2	118.18 (9.30)	110.08 (13.58)	103.96 (6.32)
BBT3	Broad	Tidal Creek	3	118.18 (5.37)	111.29 (19.28)	116.24 (6.73)
BBT4	Broad	Tidal Creek	4	109.94 (10.19)	90.32 (12.44)	98.02 (7.69)
BBT5	Broad	Tidal Creek	5	106.55 (2.07)	107.26 (7.42)	105.94 (6.45)
BBT6	Broad	Tidal Creek	6	112.26 (9.70)	110.48 (20.19)	105.35 (8.89)

Table 4.14 Summary of sediment chemistry findings. For Microtox, T = significant reduction in respiration. For Clam Bioassays, T=toxicity (reduced clam growth) and T*=toxicity (reduced clam growth) possibly due to ammonia. For oyster bioassays, PT = partial toxicity. G = Good, M = marginally degraded and D = degraded.

Okatee River	Station	Contaminants	Microtox	Clam	Oyster	ERM/PEL Q	Overall Sediment Quality
Tidal Creek	1		T	T*		G	M
	2		T	T*		M	M
	3			T*		G	G
	4	As	T	T*		M	M
	5		T	T*		M	M
	6	As	T	T		M	D
River	1	**Lindane**				M	D
	2	Lindane				G	G
	3	Lindane		T		G	M
	4			T		G	G
	5	Lindane	T			M	M
	6	Lindane				G	G
Intertidal	2	As		T		M	M
	4	As		T		M	M
	6	As		T		M	M
Broad Creek							
Tidal Creek	1	**Lindane**	T	T*		D	D
	2		T	T*	PT	M	M
	3		T	T		G	D
	4	As	T	T*		M	M
	5	As	T	T		M	D
	6		T			G	M
River	1			T		G	G
	2					G	G
	3		T			G	G
	4		T			G	G
	5	Lindane	T			M	M
	6					G	G
Intertidal	1					G	G
	4	As	T	T		M	D
	6	As, Acenapthene, **Lindane**, Dieldrin	T	T		D	D

Classification scheme for overall ranking:

Good:	At most, one ERL/TEL exceedance, **or** one toxicity result
Marginal:	At least two indications of potential toxicity (ERL/TEL exceedances or marginal ERM/PELQ and, at most one positive toxicity test result (not related to high ammonia))
Degraded:	One or more ERM/PEL exceedances, **or** at least one ERL/PEL exceedance and at least two positive toxicity test results (not related to high ammonia)

Chapter 5
Biological Resources

By
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Introduction:

A major concern identified by the Clean Water Task Force was to protect biological resources in the estuarine waters of Beaufort County (Clean Water Task Force, 1997). This issue was highlighted by the closure of several hundred acres of shellfish harvesting grounds in 1995, combined with the knowledge that more than 46,000 acres of estuarine habitat in Beaufort County were already closed to this type of activity. Task Force members were also concerned that other estuarine biota may be experiencing problems due to increased pollution and other anthropogenic stresses related to the increased coastal development in the county.

Due to these concerns, a major objective of this study was to evaluate the condition of key biological resources inhabiting several different types of habitats in both Broad Creek and the Okatee River. Our study focused on sampling shellfish and other bottom-dwelling biota that have proven to be good indicators of environmental stress in other studies (Pearson and Rosenberg, 1978; Scott et al., 1992; Dauer, 1993; Fulton et al., 1997; Weisberg et al., 1997; Coen and Luckenbach, 1999; HEED report, 1998; Van Dolah et al., in press). We did not attempt to survey the condition of all the aquatic biota, including the fish and crustacean species that are recreationally or commercially important. Many of these species are transient, which may not be indicative of localized conditions, or they are difficult to capture in sufficient densities that would allow us to adequately assess the condition of those populations in the two drainage systems. Specific biota that were sampled included the following taxa:

1. Macrobenthic communities inhabiting the bottom sediments of both tidal creek and open-water areas of each drainage system,

2. Intertidal oyster (*Crassostrea virginica*) populations at six locations along the length of each drainage system,

3. Grass shrimp (*Palaemonetes pugio*) populations inhabiting the tidal creek and shallow open-water habitats of both systems, and

4. Mummichog (*Fundulus heteroclitus*) fish populations inhabiting the tidal creek habitats of each system.

A description of the study objectives related to each of these biotic resources is provided in the following sections, along with a summary of the methods and results obtained.

Benthic Macrofauna:

The benthic macroinvertebrate communities inhabiting the bottom sediments of Broad Creek and the Okatee River represent a very important biological resource of concern. These organisms include a diversity of worms, crustaceans, mollusks, and other taxa that live in tubes or actively burrow through the sediments. The benthos are an extremely important component of the estuarine and marine food web since they are consumed by a large number of predatory species, including most of the fish and larger crustaceans (e.g. shrimp and crabs) that are harvested for recreational or commercial purposes.

Due to their relatively sessile life habits and their high exposure to the sediments, the benthos also have been documented to be excellent indicators of habitat condition (Pearson and Rosenberg, 1978; Dauer, 1993; Weisberg et al., 1997). Studies in southeastern estuaries have clearly documented that the condition of benthic assemblages is correlated to contaminant exposure and/or degraded bottom water quality, in both open-water habitats and the tidal creeks that drain upland areas (Hyland et al., 1996, 1998; Holland et al., 1996; Lerberg, 1997; Sanger, 1998). As part of a regional assessment of estuarine habitat condition, studies of the benthos have resulted in the development of an Index of Biological Integrity (IBI). This IBI showed a much greater efficiency of correctly classifying sediments which were chemically degraded when compared to various laboratory bioassays that were conducted using the same sediments (Hyland et al., 1998; Van Dolah et al., 1999).

Specific objectives of the benthic macrofaunal assessment were to:

1. Evaluate the composition and condition of macrobenthic assemblages in shallow tidal creek habitats located along the length of each drainage basin,
2. Evaluate the condition and composition of macrobenthic assemblages inhabiting both intertidal and subtidal sediments of open-water habitats located along the length of each drainage basin, and
3. Compare the condition of the macrobenthic assemblages sampled in Broad Creek and Okatee River with studies that have assessed the condition of macrobenthos in other estuarine drainage systems in South Carolina.

Methods:

Samples of the macrobenthos and associated sediments were collected at 15 sites in each drainage basin during August, 1997. Six sites were located in tidal creeks, six were in subtidal mainstem river areas of the larger drainage system, and three were located on intertidal flats along the shoreline of the mainstem river portion of each drainage system (Figures 5.1 and 5.2). The tidal creek and subtidal river sites were randomly located within each of the six subzones established along the length of each drainage system (see Chapter 2). The intertidal flats were also randomly selected from the three larger zones representing the upper (headwater), middle and lower (seaward) portions of each drainage system. All station positions were located using differentially-corrected Geographic Positioning Systems (GPS).

Sampling in each of the tidal creeks was restricted to the upper (landward) 300 m section and followed procedures similar to those described by Holland et al. (1996) and Lerberg (1997). Ten cores (7.6 cm diameter x 15 cm depth) were collected at random locations along the length of the creek section approximately one meter below the mean high water (MHW) level to assess the composition of the benthic community. All cores were collected from non-vegetated sediments. Each core was washed separately through a 0.5 mm sieve and the benthic fauna retained on the sieve were preserved in a 10% buffered formalin-seawater solution for later identification in the laboratory.

Ten smaller core samples (3.5 cm diameter x 15 cm depth) were collected adjacent to the benthic cores for analysis of sediment composition (% sand, silt-clay). Another sample of the surficial sediments (top 3-5 cm) was also obtained adjacent to each benthic core using a stainless spoon for analysis of sediment contaminants, sediment toxicity, acid volatile sulfides (AVS), and pore-water ammonia (See Chapter 4). These latter samples were composited into one sample for each sampling site.

Benthic infaunal assemblages at the subtidal and intertidal stations within the mainstem portion of each drainage system were sampled using procedures similar to those described by Hyland et al. (1998). Six to eight grab samples were collected from an anchored boat using a 0.04 m^2 Young grab, with the boat repositioned between each sample. Three of the samples (generally grabs 1, 3 and 5) were washed through a 0.5 mm sieve to collect the benthic fauna, which were preserved and processed as described above. Prior to sieving each sample, a small core (3.5 cm diameter) was inserted into the grab sample to collect sediments for analysis of grain size (% sand, silt-clay). The remaining grabs were used to collect sediments for analysis of contaminants, sediment toxicity, AVS and pore-water ammonia concentrations. Only the top 3-5 cm of sediments were collected from these grab samples using a stainless steel spoon to form a single composite sample for each station (see Chapter 4 for additional information). Samples from the three intertidal stations were collected at a depth of approximately 1 m below MHW during the period of high tide. Depth varied at the subtidal stations dependent on their location.

All benthic data were analyzed using a variety of parametric and non-parametric statistics to compare the various biological measures considered among drainage systems as well as among stations within each drainage system. Most of these analyses were completed using either one-way or two-way analysis of variance tests (ANOVA) on either the raw data or transformed data if required to meet test criteria. Post hoc comparisons were generally completed using either the Tukey or Bonferonni test (Sigmastat, 1994). When transformations did not correct the data, ANOVAs were completed on ranked values using the Kruskal Wallis test. Statistical comparisons completed between two groups utililized either the t-test or Mann-Whitney U test if assumptions for the parametric test were not met.

Findings:

Subtidal River Stations:

Faunal Abundance:

The overall average abundance of benthic organisms collected at the six subtidal stations in Broad Creek was significantly lower when compared with the Okatee River stations ($p < 0.002$). This was primarily due to the large differences observed among sites at stations R-3, R-4 and R-5 (Figure 5.3). The greatest differences were observed at station R-5 in Broad Creek, where faunal densities were much lower than observed at all other stations sampled in both drainage basins. In contrast, station R-5 of the Okatee River had an unusually high faunal density compared to all of the other sites, primarily due to a very high density of one amphipod species (*Ampelisca vadorum*, Table 5.1).

Even though we observed significant differences among stations in the two drainage systems, most of the stations in both systems had densities similar to those observed at relatively pristine sites with comparable physical conditions in Port Royal Sound and Mackay Creek (Van Dolah et al., 1991; Wendt et al., 1991). Faunal densities in Broad Creek and the Okatee River were also similar to those observed at other "undegraded" stations sampled elsewhere in South Carolina during the summer of 1995 by the Environmental Monitoring and Assessment Program (Hyland et al., 1998).

Subtidal river stations located in the lower portions of each drainage system tended to have higher faunal densities than the stations in the headwater areas (Figure 5.3). For example, animal densities at stations R-1 and R-2 (upper zones) in the Okatee River were significantly lower than densities observed at the other four stations. Similarly, stations R-4 and R-6 in Broad Creek had significantly higher faunal densities than stations R-1 to R-3 (upper half) of that drainage system.

Faunal densities were not correlated with sediment composition (% sand, silt-clay) or average salinities observed at the sites. Both of these variables are known to influence infaunal densities, but there was not a large difference among the sites sampled with respect to these physical/chemical characteristics (see Chapter 4). The relatively reduced faunal densities observed in the upper portions of each drainage system may have been related to greater variances in salinities that are likely to routinely occur at these sites compared to the lower stations. A large variance in salinity causes increased stress in many estuarine species, especially those that are not tolerant of low salinity conditions that would likely occur after major rain events. Our hydrographic sampling did not include a long enough period of record to adequately assess the range of salinity variance that may occur at the stations sampled.

Faunal Diversity:

A statistical comparison of the average number of species collected at the subtidal river stations indicated that the Broad Creek had significantly fewer species per site than the Okatee River when all stations were considered collectively ($p < 0.002$). However, this was primarily due to differences observed at stations R-4 and R-5 (Figure 5.3). Comparisons made within zones indicated that the number of species were similar in both rivers at stations R-1 to R-3 and significantly greater at station R-6 in Broad Creek.

Hyland et al. (1998) provide evidence that stations having fewer than three species/0.04 m^2 grab are often degraded based on other environmental measures (e.g. high sediment contaminants, low dissolved oxygen, or significant sediment toxicity). Only station R-5 in Broad Creek had fewer than three species/grab, and all of the other sites had a substantially greater number of species (average of 10-42 species/grab; Table 5.1). These species richness values are comparable to those observed at a relatively pristine site located in Mackay Creek (Wendt et al., 1991) and at "undegraded" sites in other estuaries of South Carolina, where an average of 8-25 species were collected per grab sample (Hyland et al., 1998).

Estimates of species diversity using the Shannon Weaver H' Index also supports the hypothesis that species diversity was comparable among the two drainage systems, except at station R-5 (Figure 5.3, Table 5.1). The low H' value observed at station R-5 in Broad Creek was most likely due to the very low faunal abundance at this site. In contrast, the low H' value observed at station R-5 of the Okatee River was primarily due to the overwhelming dominance of the amphipod *Ampelisca vadorum*, which reduced the species evenness component at this site.

Hyland et al. (1998) observed that diversity (H') values below 1.0 were indicative of degraded benthic assemblages based on other measures of environmental condition. Only station R-5 in Broad Creek had H' values less than 1 and most of the other sites in both drainage systems had H' values ≥ 2.5 (Table 5.1, Figure 5.3). These values are comparable to stations that were classified as non-degraded or marginal during the EMAP surveys of southeastern estuaries in 1994 and 1995. Neither the H' values or the mean number of species collected per site were correlated with sediment composition or salinity conditions. There also was no clear gradient in the number of species collected per site versus distance from the headwater area of each drainage system. Stations in upper third of Broad Creek (R-1, R-2) had a lower species richness than we observed at stations R-3, R-4 and R-6, but the differences were only significant between stations R-1 and R-2 versus R-6 ($p < 0.05$). In the Okatee River, station R-1 was significantly lower than all other zones ($p < 0.05$), which were not statistically different from each other.

Faunal Composition:

A complete listing of benthic macrofauna collected at each subtidal station is provided in Appendix 5.1. Polychaete worms were the numerically dominant taxa in both the Okatee River and Broad Creek (Figure 5.4, 5.5). The most abundant polychaete species *(Streblospio benedicti)* was found at all 12 river sites (Table 5.1). This species has a very ubiquitous distribution throughout South Carolina estuaries and is often found in highest abundances at sites with a mixture of sand and mud (Van Dolah et al., 1979, 1984, 1990; Lerberg, 1997). Many studies have identified this species as pollution tolerant (Pearson and Rosenberg, 1978; Hyland et al., 1985; Sanger, 1998). The relative density of this species tended to be higher at the Broad Creek sites compared to the Okatee River.

Oligochaete worms were also relatively abundant at four of the stations in the Okatee River and two of the stations in Broad Creek (Figure 5.4, 5.5, Table 5.1). The dominant species was *Tubificuoides wasselli* and unidentified specimens of Tubificidae and Enchytraeidae. The sensitivity of these taxa to pollution stresses is unknown.

At two stations (R-5 in both rivers), amphipods were the most abundant taxa. In the Okatee River, the dominant amphipod was *Ampelisca vadorum*, which was found in unusually high abundance. Little has been documented on the pollution sensitivity of *A. vadorum*, but other ampeliscid species have been shown to be pollution sensitive (ASTM, 1993; Fulton et al., 1997). In Broad Creek, the dominant species was *Protohaustorius bousfeldii*. The pollution sensitivity of this species is also unknown, but amphipods are generally considered to be pollution sensitive organisms (Swartz et al., 1984; ASTM, 1993). However, it should be noted that even though *P. bousfeldii* was the dominant species at this site, the abundance of this species was very low compared to densities of the dominant taxa at other stations in either drainage system.

An evaluation of overall species composition among the sites sampled using a similarity coefficient analysis (Bray Curtis coefficient; Bloom, 1992) indicated several interesting similarities and differences among the sites. Three major station groups were identified based on their degree of overall faunal similarity (Figure 5.6) One group consisted of the three upper stations in Broad Creek (R-1 to R-3) and the uppermost station in the Okatee River (R-1). These results suggest that faunal composition in the headwater areas of the two drainage systems are similar and that faunal complex extends further down Broad Creek than in the Okatee. This may reflect effects from greater freshwater runoff that are typically associated with urbanized systems compared to non-urbanized systems.

The two stations near the mouth of Broad Creek (R-4, R-6) were also very similar to the station nearest the seaward limit of the Okatee River (R-6) and all of these stations were relatively dissimilar to the uppermost stations. This is most probably a reflection of differences in the station salinities and salinity variance since we would anticipate conditions to be more constant and indicative of high salinity habitats in the lower reaches of each system compared to the upper reaches. Stations in the middle portion of the Okatee River (R-2 to R-5) were dissimilar to the comparable sites in Broad Creek with respect to overall similarity. However, with the exception of the relatively depauperate fauna at R-5 in Broad Creek, these differences do not appear to be indicative of pollution stress, *per se*.

Benthic Index of Biological Integrity:

A Benthic Index of Biological Integrity (B-IBI) has recently been developed for use in estuaries of the southeastern U.S. as a measure of biotic condition (Hyland et al., 1998; Van Dolah et al., 1999). This index, which includes several measures of benthic integrity, has proven to accurately classify most sites that are chemically degraded. Another benthic IBI has recently been developed specifically for South Carolina waters. This index uses a very similar approach, but a slightly different combination of benthic metrics (Van Dolah et al., unpublished). Both indices were applied to the benthic community data collected from subtidal sites in this study to determine how the stations ranked (Figure 5.7). The results indicate that only station R-5 in Broad Creek had a benthic assemblage that considered to be moderately degraded using either index. Stations R-1, located at the headwaters of each drainage system, had lower B-IBI scores than the other stations. This may reflect some increase in stress or it may be due to the fact that these stations were very shallow. The benthic index was developed using stations that were generally deeper than these sites, and may not be as applicable at the headwater sites. This was also the case for the SC B-IBI, which did not show as consistent a differential in values between the headwater stations and others located lower in each drainage system. Based on the results of both indices, the majority of stations in both drainage areas did not show evidence of biological degradation.

Intertidal River Stations

Faunal Abundance and Diversity:

The intertidal mud flat stations in both drainage systems generally had a lower abundance and diversity of macrofauna than the subtidal stations (Figures 5.3, 5.8, Appendix 5.1). These differences were anticipated since intertidal habitats are more stressful environments to marine organisms than subtidal habitats due to periodic exposure of the sediments during low tide periods. All sites had infaunal densities above values that have been used to classify degraded sites in subtidal areas using this benthic metric (Hyland et. al., 1998). Additionally, statistical comparisons among all of the intertidal sites showed no significant differences between drainage system ($p > 0.9$) or between zones within each drainage system ($p > 0.5$).

Statistical comparisons of the mean number of species found at the intertidal sites indicated that, overall, there were significantly fewer species at the Broad Creek stations than the Okatee River stations. This difference was primarily due to a significant difference observed between the lower zone stations (I-6). Sediments at the Broad Creek I-6 site had the highest cumulative contaminant level of all the intertidal sites sampled. This may be due to the high density of docks and docked vessels located along that shoreline. Overall sediment contaminant concentrations at that site were above levels that have been demonstrated to result in degraded benthic communities in subtidal areas (Hyland et al., in press). No significant differences were observed in the number of species collected in each drainage system at stations in the upper and middle sampling zones, but Broad Creek sites had consistently fewer species than the comparable Okatee River sites.

Faunal Composition:

The numerically dominant organisms at the intertidal mud flat stations in Broad Creek consisted of a mix of polychaete and oligochaete worms (Figure 5.9, Table 5.2, Appendix 5.1) and the snail *Illyanassa obsoleta.* These species are considered to be tolerant of stressful conditions and polluted sediments, which may account for their higher abundance in this developed watershed. In the Okatee River, the dominant species were polychaete worms (Table 5.2). The most abundant of these polychaetes (*Nereis succinea, Scoletoma tenuis, Leitoscoloposl fragilis*) are also known to be tolerant of pollutants or disturbed conditions. An evaluation of overall faunal composition at the intertidal sites also showed dissimilarity between the Okatee River and Broad sites. Both Broad Creek stations I-6 and I-4 were dominated by species known to be pollution tolerant (e.g. the polychaete *S. benedicti* and the oligochaete, *M. rubroniveous* (see next section). Additionally, stations I-4 and I-6 were the only intertidal sites in both systems that exhibited sediment toxicity in both the Microtox® and seed clam assays. This toxicity could not be attributed to high ammonia levels (see Chapter 4).

The Benthic Index of Biological Integrity (B-IBI) that was developed for subtidal habitats is not applicable to intertidal environments. Comparison of other measures of benthic condition (e.g. abundance, diversity) among the intertidal sites we sampled indicated that all three Broad Creek sites were exhibiting evidence of some benthic stress. This was especially evident at station I-6, which had a much lower diversity of species present than at the comparable sites in the Okatee River. Station I-4 also coded as marginal due to the lower number of species and H' values compared to station I-4 in the Okatee.

Tidal Creek Stations:

A detailed summary of the benthic data collected from tidal creeks is provided in Table 5.3 and Appendix 5.2. A few of the samples contained mobile taxa (e.g. fiddler crabs) and very small organisms (e.g. nematodes) that were poorly sampled by the sampling methods used. These organisms were not included in the data summaries and analyses presented in this section.

Faunal Composition and Abundance:

The benthic fauna inhabiting tidal creeks was numerically dominated by segmented annelid worms, predominately oligochaetes and polychaetes (Figure 5.10). Oligochaetes accounted for 68% of the fauna, and polychaetes accounted for 27%. Mollusks (clams and snails) and crustaceans (crabs and shrimp) accounted for less than 2% of the fauna. We identified 35 benthic taxa from the 112 samples collected (Table 5.3).

Nine taxa (four oligochaetes, four polychaetes, and an unidentified insect) comprised over 90% of the fauna (Table 5.3). About half (48%) of the taxa were found in less than three of the 112 samples. *Monopylephorus rubroniveus*, a small oligochaete (segmented worm), was the most abundant organism in Broad Creek and the Okatee River tidal creeks. *Streblospio benedicti*, a broadly distributed polychaete (another kind of segmented worm), was the second most abundant taxa (Table 5.3).

Monopylephorus rubroniveus and *S. benedicti* are well known for their tolerance to many different kinds of natural and anthropogenic stresses. *Monopylephorus rubroniveus* is the most abundant benthic organism in polluted tidal creeks of Charleston Harbor (Lerberg 1997) and has been classified as a pollution indicative species for South Carolina tidal creeks (Lerberg and Holland, in review). In laboratory experiments, this oligochaete tolerated severe hypoxia for 9 days. *Streblospio benedicti* is also a numerically dominant benthic organisms in Charleston Harbor tidal creeks, particularly undeveloped, forested creeks (Lerberg 1997). This polychaete is tolerant to exposure to low levels of dissolved oxygen, although not as tolerant as *M. rubroniveus* (Llanso, 1991; Llanso 1992).

Mollusks and crustaceans may have been rarely collected from tidal creeks because of the relatively high pore water ammonia levels that were found in the sediments from those sites. The average sediment pore water ammonium level was 16.2 and 20.4 mg/l for creeks draining into Broad Creek and the Okatee River, respectively. Experiments on juvenile hard clams suggest that these biota experience high mortality during short-term acute assays when sediment ammonia concentrations exceed about 15 mg/l (SCDNR, unpublished). Amphipods and many other benthic species experience high mortality when sediment ammonia levels exceed about 30 mg/l. Pore water ammonium levels in other intertidal and subtidal river habitats where mollusks and crustaceans were abundant were an order of magnitude lower than pore water ammonium values in tidal creeks.

The species composition and relative abundance patterns for benthic communities in tidal creeks draining into the Broad Creek and Okatee River were similar to that reported for these critical nursery habitats in other regions of the state (Swearingen 1983; LaSalle et al., 1991; Holland et al., 1997; Lerberg 1997, Sanger 1998). The oligochaetes and polychaetes that numerically dominate these habitats are hardy and productive organisms that provide a prey for juvenile fish and crustaceans. Oligochaetes have particularly high nutritional value and caloric content (Hunter and Arthur 1978; Diaz 1980; Middleditch et al., 1979).

Faunal Diversity and Abundance:

The total number of benthic species collected from the Broad Creek and the Okatee River tidal creeks were similar, 28 and 24, respectively (Table 5.3). In both Broad Creek and the Okatee River, species diversity (H') and cumulative number of benthic taxa (a measure of species richness) tended to be lowest in creeks that experienced the largest salinity range (i.e., creeks T-1 and T-6; Table 5.4). Measures of species diversity including H', cumulative number of taxa per creek, and mean number of taxa per sample were similar between the Broad Creek and the Okatee River (Figure

5.11). The biodiversity data were also similar to the values reported for higher salinity tidal creeks in Charleston Harbor (Holland et al., 1996, Lerberg 1997).

The percent of the tidal creek benthic fauna that were rare taxa was significantly ($p<0.01$) higher in Broad Creek than in the Okatee River (Table 5.3). Many of the rare taxa that were only found in Broad Creek are organisms that prefer stable, higher salinity environments (e.g., the hard clam *Mercenaria mercenaria).* The taxa that were only found in tidal creeks draining into the Okatee River were organisms which prefer lower salinity environments and can tolerate large salinity fluctuations (the oligochaete *Tubificoides heterochaetus* and the isopod *Cyathura polita*).

The overall abundance patterns for tidal creek benthic communities draining into Broad Creek and the Okatee River were similar (Figure 5.11). Highest abundances occurred in creeks that drained headwater regions (creek T-1 in Broad Creek and creek T-1 in the Okatee River) and creeks that drained salt marshes (creeks T-4 and T-5 in Broad Creek; T-5 in the Okatee River). Lowest abundances occurred in creeks T-3 and T-6 in Broad Creek. These sites were considered to be degraded (T-3) or marginal (T-6) in sediment quality and fair (T-3) or degraded (T-6) in water quality.

Effect of Salinity On Benthic Distributions:

Salinity is a major factor affecting the kinds and abundances of benthic organisms in estuarine habitats, including tidal creeks (Carriker 1967, Holland et al., 1987, Lerberg 1997). The lower frequency of occurrence of marine species and the higher abundance of benthic species tolerant of low salinities in Okatee River creeks suggest this system had a lower average salinity and more variable salinity distributions than creeks draining into the Broad Creek. The salinity data collected as part of this study did not support this finding. The average salinity and salinity range information we collected suggested salinity distributions were similar between the two systems (Tables 3.3 and 5.4). This is not surprising. Benthic community composition and their distribution patterns are developed over the life span of the organisms composing the community (months to several years). Whereas, the salinity data only represent conditions that occurred during a short period in the summer of 1997. Long-term salinity data collected by SCDHEC, however, suggests that for most of the 1990s salinity in the Okatee River was slightly higher than that in Broad Creek.

The variability in salinity over a tidal cycle (and presumably with rain events) was much higher for tidal creeks than it was in adjacent subtidal river environments (12.4 vs 2.6 ppt). Tidal creeks have limited capacity to dilute runoff compared to the subtidal river habitats. Creeks that drained large amounts of uplands (creeks T-1 and T-6 in the Broad and Okatee systems) experienced the largest salinity fluctuations (> 15ppt over a normal tidal cycle - Table 5.4). Salinity fluctuations in these ranges would tend to result in tidal creek benthic communities dominated by oligochaetes (Lerberg and Holland, in press; Lerberg, 1997).

When watersheds are developed, the amount of the land surface that is impervious to rain, including roads, parking lots and roofs, increases in proportion to the human population density (Nemo, 1994; Arnold and Gibbons, 1996). The rate and volume of runoff into tidal creeks is generally proportional to the amount of impervious surface in the drainage basin (Kibler et al., 1981; Brown, 1988). The greater the amount of impervious surface the more peaked the runoff and the greater the salinity variance in the tidal creeks during rainfall events and over a normal tidal cycle (Holland et al., 1997). Tidal creeks located in headwater portions of estuaries drain large portions of most coastal watersheds. Salinity distributions in these headwater creeks may fluctuate from full strength seawater to freshwater over a tidal cycle. Very few benthic organisms can tolerate such extreme salinity fluctuations.

Effects of Sediment Characteristics on Tidal Creek Benthic Distributions:

The physical nature of sediments influences the kinds and abundance of benthic organisms in tidal creek habitats (Lerberg and Holland, in press; Lerberg 1997). To evaluate the effects of sediment characteristics on tidal creek benthic distributions and relative abundance, we classified tidal creek samples based on sediment properties as follows: sandy sediments (<20% silts and clays); mixed sediments (20-80% silts and clays); and muddy sediments (>80% silts and clays). Then, we summarized the benthic and sediment data for each creek and class.

Seventy-one percent of the sandy samples occurred in Broad Creek and 81% of the muddy samples occurred in the Okatee River. Samples with mixed sediments were approximately equally distributed between Broad Creek and the Okatee River, 28 and 37 respectively. Half of the creeks consisted of a single sediment class but there were creeks having all sediment classes in both systems.

Sandy sediments were numerically dominated by polychaete worms (84%) with modest oligochaete abundances (15%). Mixed sediments were numerically dominated by oligochaetes (75%) with modest polychaete abundances (23%). Muddy sediments were composed of a mixture of taxa in approximately equal proportions (24% oligochaetes, 33% polychaetes, 14% crustaceans, and 31% insects). Sand habitats had the lowest benthic abundance of all sediment classes (976 individuals/m^2), and mixed sediments had the highest benthic abundance (6,207 individuals/m^2). Benthic abundance values in the mud sediment class were intermediate (2,941 individuals/m^2). Tidal creek animal-sediment distribution patterns in Broad Creek and the Okatee River were similar to those reported for Charleston Harbor (Holland et al., 1996; Lerberg 1997). As the degree of suburbanization development increases, the headwater portions of tidal creeks draining uplands generally shift from soft mixed or muddy sediments to scoured, firm sandy habitats (Lerberg 1997, Sanger et al., 1999 a, b). The higher levels of sand and scoured sediments found in many of the tidal creeks draining into Broad Creek compared to those draining into the Okatee River support the hypothesis that higher levels of watershed development are associated with sandier sediments. The Broad Creek watershed is substantially more developed than the Okatee River watershed.

Assessment of Tidal Creek Environmental Quality

The Tidal Creeks Study conducted by the SCDNR (Holland et al., 1996) concluded that human development of coastal watersheds, including suburbanization (human population densities of >10 individuals per acre; 1-4 units per acre) adversely affected the environmental quality of tidal creek nursery habitats. The degree and magnitude of environmental impacts were proportional to the human population density and the amount of impervious surface in the watershed. Major environmental alterations to tidal creek ecosystems that were identified included the following:

(1) Increases in the rate and volume of freshwater inflow (stress indicator: salinity range over a typical tidal cycle is > 15 ppt);

(2) Frequent exposure to hypoxia (stress indicator: DO values are below 2 mg/l > 20% of the time);

(3) Increases in sediment contaminant concentrations (stress indicator: the ERLQ is > 2 or the ERMQ is > O.5);

(4) Benthic communities that are numerically dominated by pollution indicative oligochaetes, especially *Monopylephorus rubroniveus* (stress indicator: > 70% of the benthic biota are oligochaetes or *Monopylephorus rubroniveus*);

(5) Low benthic biodiversity (stress indicator: H' values < 0.4); and

(6) Depauperate benthic abundance (stress indicator: < 250 benthic organisms/m^2).

The high relative abundance of the oligochaete *Monopylephorus rubroniveus* and low species diversity values that were found in the headwater tidal creeks (T-I) of Broad Creek and the Okatee River indicate that these creeks were degraded in both systems (Table 5.4, Figure 5.12). Anthropogenic stresses that contributed to this degradation included: large salinity ranges, exposure to stressful low dissolved oxygen level, and exposure to chemically contaminated sediments.

Creek T-5 draining into Broad Creek also had a high relative abundance of oligochaetes; 78% of the fauna was *Monopylephorus rubroniveus* (Table 5.4). This creek experienced the lowest dissolved oxygen levels of any creek sampled (<0.1 mg/l) and had biologically stressful low dissolved oxygen values about 20% of the time (Table 5.4). Creek T-5 also had the highest dissolved oxygen measured. The large range in dissolved oxygen values in creek T-5 suggests that the primary producers in this creek, probably benthic microalgae, were experiencing bloom conditions during sampling. The high daytime dissolved oxygen values and low nighttime values are symptomatic of nutrient over-enrichment and algal blooms. Other indicators of stress (e.g., salinity range, sediment contaminant concentrations) were in normal/acceptable ranges for creek T-5.

Several other tidal creeks exhibited salinity fluctuations in stressful ranges (e.g., creek T-6 in Broad creek and creeks T-4 and T-6 in the Okatee River). Creeks T-3 and T-4 in Broad Creek also experienced modest (10-15 ppt over a "normal" tidal cycle) salinity fluctuations. These creeks supported benthic communities that were similar to those in undeveloped, forested reference habitats in the Charleston Harbor area, suggesting that increases in salinity fluctuations alone were not stressful enough to adversely affect benthic resources.

Several tidal creeks in the Okatee River had sediment contaminant levels that were in ranges that may cause biological harm (creeks T-4 and T-6). These creeks, however, supported "normal" benthic communities. This contamination should be considered an early warning that tidal creek sediments are repositories for contaminants (Beeftink et al., 1982, Fletcher et al., 1994, Williams et al., 1994; Sanger et al., 1999 a, b).

General Conclusions of Benthic Community Assessment:

When all of the benthic condition measures are considered collectively, 5 of the 15 sites in Broad Creek and 2 of the 15 sites sampled in the Okatee River were classified as showing evidence of minor or major stress (Figure 5.13). Only one of these sites was located in subtidal waters (R-5 in Broad Creek). We did not observe any obvious physical or chemical conditions that would account for the biotic conditions noted at the subtidal site, and the biota present there did not show evidence of severe stress. Two of the tidal creeks showed evidence of stress in each drainage system, with the effects most probably due to poor water quality conditions (e.g. effects of salinity variance or DO stress). Two additional intertidal stations in Broad Creek (mud flats) also showed evidence of benthic stress that was probably related to pollution effects.

Other sites lower in the system that showed evidence of stress related to environmental variables were the tide creek T-5 and the intertidal mud flats I-4 and I-6 in the lower portion of Broad Creek. Degradation in Creek T-5 was attributed to exposure to "below normal" dissolved oxygen levels, and degradation of the intertidal flat benthic communities was probably due to contaminant stress. All of these sites had degraded sediment quality, with toxicity observed in multiple assays.

The environmental quality and characteristics of the remaining intertidal and subtidal sites in Broad Creek and the Okatee River were similar to conditions in undeveloped forested creek in other parts of the state, with the exception of R-5 in Broad Creek. The other sites would generally be classified as "normal" with respect to the environmental quality measured as well. Among the other sites sampled, the tide creeks T-1 and T-6 in both Broad Creek and the Okatee River exhibited salinity variation that suggested biological degradation may be occurring in these creeks. Evaluation of the benthic data supports this conclusion at the T-1 sites, but not at the T-6 sites.

Oyster Populations:

As noted previously, an evaluation of the condition of oyster beds in Broad Creek and the Okatee River was of special concern to the Task Force members. In addition to their value as a recreational and commercially harvested species, oysters (*Crassostrea virginica*) serve an important ecological role since the beds form living reef structures that support a host of other associated organisms generally not found in surrounding sand or mud habitats (Coen and Luckenbach, 1999; Coen et al., 1999a,b). Studies conducted by the SCDNR have documented that oyster reefs can support resident invertebrate densities of more than 3,100 individuals/m^2 and mobile fish and crustacean densities on oyster habitat can exceed 2,100 individuals/m^2 (Wenner et al., 1996; Coen et al., unpublished). Intertidal oyster reefs are a conspicuous habitat in South Carolina and they contribute significantly to the broader functioning of the inshore waters by improving water quality through their vast filtering ability (Coen and Luckenbach, 1999; Coen et al., 199b). These filter-feeding bivalve molluscs are also excellent candidates for monitoring habitat quality (Farrington, 1983; HEED report, 1998) since they concentrate pathogenic organisms and contaminants.

SCDNR staff has been examining size-frequency relationships, recruitment potential, and disease (MSX and Dermo) levels of native oyster populations as indicators of habitat health, along with estimates of transient and selected resident species (Coen et al., 1999a; Coen and Luchenbach, 1999). These measures appear to provide an excellent indication of habitat health. Sampling of oyster habitats at more than 30 sites around South Carolina has detected large variances among sites, with developed/degraded sites often having marked differences in numbers and size-frequency relationships of oysters, as well as the numbers of mussels (*Geukensia demissa* and *Brachidontes exustus*) associated with the intertidal oyster reef matrix. Therefore, this approach was used to evaluate the oyster beds in Broad Creek and the Okatee River using the same sampling and analysis procedures. The oyster beds were also re-assessed by the DNR Shellfish Management Section using methods that have been used throughout the state, and samples were collected to evaluate the condition of the oysters within each bed.

Specific objectives of the oyster surveys were to:

1. Evaluate the density and size-frequency relationships of the living oysters in different portions of each drainage using replicate samples as a measure of population condition,

2. Assess the incidence and intensity of diseases (MSX and Dermo) in a sub-sample of oysters collected from each site,

3. Measure tissue contaminant concentrations in a sub-sample of oysters collected from each site in order to assess the relative exposure of each bed to pollution,

4. Evaluate the physiological condition of oysters collected from each site as another measure of organism health,

5. Evaluate mussel populations associated with the oyster beds as secondary measure of habitat/water quality, and

6. Re-assess the areal extent of each oyster bed sampled using procedures developed by the DNR's Shellfish Management Section and compare the results with historically collected data.

Methods:

Oyster-Mussel Collections:

Between August 26 and September 11, 1997, 60 quantitative samples were taken at 12 randomly selected sites, with one site located in each of the six sub-zones identified along the length of both drainage systems (Figure 5.1, 5.2). A 20-meter transit line was placed along each shoreline at approximately mean sea level (level with densest oyster populations (approximately 4' below MHW). Five samples (5/site x 12) were then collected at each site by placing a $0.143m^2$ quadrat at pre-selected locations along the transit line. If no oysters were located within a pre-assigned random location, another random position was chosen to ensure that five representative oyster samples were collected from each site. All oysters and sediment were removed to a depth of ~11 cm and then placed in a bag with a label. The specific quadrat placement for each sample was adjusted to maximize the percentage of oyster shell (live and dead) cover within the quadrat.

In the laboratory, a minimum of five oysters from each of the 60 samples were removed for analysis of oyster disease (n = 25/site). These oysters were measured for shell height so that they would be included in the remaining size frequency analysis. Bag contents were then washed to remove sediment and non-molluscan biota. Using calipers, each live oyster (including spat) was measured for shell height (defined as the distance from the umbo to the outermost edge) to the nearest millimeter. All oysters were examined to eliminate dead individuals. During this process, all mussels were removed, counted, and placed in labeled sample jars for later enumeration and measurements. These species were lumped to generate combined mussel total number and biomass values.

All oyster measurements (size-frequency data) were entered into an Access database for initial analysis and plotting. Plots of mean size and total number of live oysters adjusted to a per m^2 basis were generated from the above database using Sigmaplot. Cumulative size frequency distributions (5 mm intervals) were then computed for each of the 60 samples and a 2nd degree polynomial fit was applied to each cumulative frequency distribution. Line parameters (intercept, slope and curvature) for each station were recorded. Statistical (ANOVA) analyses were then performed to evaluate differences among the two drainage systems and among stations within a system.

Oyster Disease Analysis:

A subset of the oysters collected from the 60 samples (see above) were examined for two common oyster diseases (Dermo and MSX; see Bobo et al., 1997 for review). Care was taken so that we could compare infection levels of the two diseases in the same individual to see if there was a correlation between the two.

For *Perkinsus marinus* (Dermo), cell counts were determined using Ray's technique (Ray, 1952) and examined following the procedures outlined in Bobo et al. (1997). For *Haplosporidium nelsoni* (MSX) identifications, prevalence was determined from oyster histological sections fixed in Davidson's AFA, embedded in paraffin and stained in Harris hematoxylin and eosin (Howard and Smith, 1983; Bobo et al., 1997). If the data passed both the normality and equal variance tests, parametric statistical tests were performed (ANOVAs). If the data were not normal but homogeneous, both parametric (ANOVAs) and non-parametric statistics (Kruskal-Wallis [KW] test) were performed to determine differences in *P. marinus* weighted incidence (WI) and % prevalence levels, *H. nelsoni* prevalence levels, and oyster shell heights among stations and river systems. Appropriate Multiple Comparison Tests (either Bonferroni for ANOVAs or Dunn's test for K-W test) were then used to examine means when significance was detected.

Oyster Cellular Responses:

Lysosomal Destabilization:

A neutral red assay was used to evaluate lysosomal integrity (Lowe et al., 1992; Ringwood et al., 1998a). Briefly, cellular suspensions were prepared from pieces of digestive gland tissue (20-40 mg) dissected from individual oysters, and incubated in calcium/magnesium free saline and trypsin to disaggregate the cells. An aliquot of the cell suspension was mixed with neutral red on a microscope slide, covered with a cover slip, and incubated in a humidity chamber at room temperature for 60 minutes. Digestive gland cells (6 to 12 µm in diameter) containing lysosomes were examined with a light microscope (100 X under oil immersion) to evaluate NR retention. Cells with NR retained in lysosomes were scored as stabile and those with NR leaking into the cytoplasm were scored as destabilized. A minimum of 50 cells was counted for each preparation, and the data were expressed as destabilization indices (% destabilized lysosomes per individual oyster).

Lipid Peroxidation:

The thiobarbituric acid (TBA) test was used to measure lipid peroxidation (Gutteridge and Halliwell, 1990). Digestive gland tissues were homogenized in 50 mM potassium phosphate buffer (pH 7.0) and centrifuged (14,000 rpm, 4°C, 5 minutes). A subsample of the supernatant was mixed with tricholoroacetic acid containing TBA and butylated hydroxytoluene, heated at 100°C for 15 min and centrifuged to remove the precipitate. The resulting malondialdehyde (MDA) was detected at 532 nm on a spectrophotometer. Standards were prepared as described by Csallany et al. (1984), and the data were expressed as nM MDA / g wet weight.

Glutathione Concentrations:

Glutathione concentrations of individual oysters were determined by the DTNB-GSSG Reductase Recycling Assay (Anderson, 1985). This assay is a sensitive and specific enzymatic procedure that follows the rate of 5-thio-nitrobenzoic acid (TNB) formation. Digestive gland tissues were homogenized in 5% sulfosalicyclic acid (SSA), and centrifuged (14,000 rpm, 5 min, 4°C). Supernatants were diluted 1:1 with 5% SSA and mixed with the NADPH buffer containing DTNB. GSSG reductase was quickly added and the rate of TNB formation was monitored at 412 nm at 30 seconds intervals for 90 seconds. GSH concentrations were estimated from a standard curve and reported as nM GSH / g wet weight.

Tissue Contaminant Concentrations:

After the randomly selected quadrats had been collected, a minimum of thirty oysters were then collected by hand for tissue analysis from the mid-intertidal portion of the endemic reefs. Attempts were made to collect oysters larger than 7 cm (~ 3 in) in length. Because of the condition of some of the beds, it was necessary to collect smaller sized oysters in larger numbers to ensure sufficient tissue volume for the analyses. Efforts were made to collect the oysters within the predefined 20 m transect where possible. In some cases it was necessary to go beyond the 20 m transect to obtain sufficient numbers of oysters.

Oysters for tissue analysis were transported in coolers to the SCDHEC Aquatic Biology Section Laboratory in Columbia, SC, for sample preparation following standard SCDHEC procedures (SCDHEC, 1999). After processing, the samples were transferred to the SCDHEC Central Laboratory for analysis of constituents listed in Table 5.5. All analyses were conducted following standard SCDHEC procedures (SCDHEC, 1981; 1994).

Wet weight tissue values for detectable metals were compared to statistics derived from other oyster tissue collected by SCDHEC since 1980. Dry weight tissue concentrations were estimated by multiplying the wet weight concentration by 9.986 based on analyses completed by the SCDNR (Ringwood, unpublished). These estimates were compared with the mean value computed from national annual means from 1986 through 1993 reported by O'Connor (1996) from data collected in the NOAA National Status and Trends Program (NS&T).

Evaluation of Changes in Bed Acreage Over Time:

DNR utilized its oyster survey protocol, initiated in the early 1980s to evaluate changes in the study area over time. This resource assessment program was structured to estimate the entire State's intertidal oyster standing crop and cartographically depict the extent of its resource. Each oyster population was also characterized with respect to spatial and morphological features (e.g. percent live, cluster dispersion, volumetric variances, etc., Elliott, 1971). A similar assessment protocol was used during the Broad Creek/Okatee River study to determine changes in oyster bed size and spatial dispersion. Each oyster population was revisited, measured to determine the area covered and characterized by strata. The more conservative volume change is indicated under "live volume," while "total volume" represents the entire habitat, inclusive of dead shell and substrate. Contemporary survey data were then compared to the original in the DNR's oyster survey Geographic Information System (GIS) database.

Findings:

DHEC Shellfish Harvesting Designations:

Because shellfish harvesting pressures may influence conditions observed at the various oyster beds sampled in both drainage systems, it is important to note DHEC's classification of those sites at the time of sampling. Since the original 1997 sampling, some of the beds have changed status. The classifications at the time of the study consisted of *open* beds, where direct harvesting permitted, and *restricted* beds, where harvesting is allowed if the oysters are relayed to other locations and depurated. The status of each site in 1997 was as follows:

Broad Creek		Okatee River	
O-1	Restricted	O-1	Restricted, culture permit
O-2	Restricted	O-2	Restricted
O-3	Prohibited	O-3	Open, culture lease
O-4	Open	O-4	Open, culture lease
O-5	Open, culture permit	O-5	Open, culture lease
O-6	Open, culture permit	O-6	Open, culture lease

Oyster Population Measures:

As noted above, it is important to understand that oyster densities and size-frequency distributions can be affected by past harvesting history, environmental conditions, available substrates for settlement, and recruitment of new oysters to the beds. SCDNR staff has been collecting size-frequency information throughout the state to assess and evaluate the status and trends of South Carolina's oyster resources. These data provide useful reference data for evaluation of bed conditions in the study area compared to other parts of the state. Since sampling occurred in late summer, recruitment success can be inferred from the observed smaller young oyster (or spat) size (e.g., < 10-15 mm shell height) abundance patterns.

Abundance and Size:

All of the oyster beds sampled in Broad Creek and the Okatee River had a relatively low relative abundance of the larger oysters that were of harvestable size (>76 mm or 3" shell height, Figures 5.14, 5.15). Additionally, only the lower stations in each drainage system (O-4 to O-6) had large numbers of small spat less than 15 mm. A comparison of mean oyster size (shell height in mm) showed significant differences ($p < 0.0001$) among the stations (Figure 5.16), with a few clear patterns. Most of the stations (Okatee stations O-2 to O-6, Broad Creek stations O-2, O-3, O-6) were not significantly different. For example, Station O-1 in the Okatee River had the largest oysters out of all 12 stations, with station O-1 in Broad Creek next in size. Notably, both of these sites, and station O-3 in the Okatee, had larger oysters than other populations in Beaufort, Georgetown and Charleston Counties based on recent surveys (mean sizes < 30-35 mm). The mean size of oysters at station O-1 in the Okatee River was also significantly larger than the mean sizes observed at all other stations sampled in both drainage systems, with the exception of station O-1 in Broad Creek and station O-3 in the Okatee River. Station O-1 in Broad Creek had the second largest average sized oysters and they were significantly larger in size than those at stations O-3 to O-5 in Broad Creek and stations O-5 and O-6 in the Okatee. Oysters at Station O-4 in Broad Creek were the smallest on average, being significantly smaller than all other stations except for Stations O-5 in both Broad Creek and the Okatee River.

The total number of live oysters varied considerably in each system, ranging from 38-1,137 individuals/quadrat (or 0.143 m^2) in Broad Creek and 45-727 individuals in the Okatee River. When the five replicate quadrats were summed by station, the total number of oysters in Broad Creek varied from a low of 803 at the uppermost station (O-1, a restricted site) to over 3,971 individuals at station O-5, which had an “open” harvesting status. In the Okatee River, total abundances ranged from a low of 384 at the uppermost station (O-1-restricted site) to over 2,374 individuals at station O-5, a station also designated as “open” to harvesting. In general, mean oyster abundances were greater in Broad Creek than in the Okatee River but mean sizes of the oysters were larger on average in the Okatee River (Figure 5.16).

Size-Frequency Analysis:

A statistical analysis of curve intercept for the size-frequency data showed significant differences between the two drainage systems and between sites within each drainage system ($p < 0.006$ and $p < 0.001$, respectively), with Broad Creek stations having significantly higher values than stations in the Okatee. Stations O-4 to O-6 also had significantly higher intercepts and slopes ($p < 0.01$ for both) than Stations O-1 to O-3 (Appendix 5.3a). The slope of the size-frequency curves was also significantly different among stations ($p < 0.0001$), but not between river systems ($p > 0.1$). These intercept and slope findings suggest that the oyster populations in the lower three stations in each river system had more and smaller oyster individuals than those in the upper three stations. Most of these smaller oysters were perhaps only 1-2 years old.

Statistical comparisons of the size-frequency curve slopes and intercept values within each drainage system also showed some differences (Appendix 5.3b). In Broad Creek there was a significant ($p = 0.0004$) effect of station on both the intercept and slope values. Intercept values at the lower stations O-4 to O-6 were significantly greater than at station O-1. Intercept values at stations O-2 and O-3 were not significantly different from any of the other Broad Creek stations. Slopes at stations O-1 to O-3 were significantly greater than at station O-6. Slopes at Stations O-4 and O-5 were not significantly different from any of the other stations. In the Okatee, there was also a significant station location effect on both slope and intercept values ($P < 0.001$). Stations O-4 to O-6 had significantly higher intercept values than stations O-1 to O-3. Stations O-1 and O-2 had significantly higher slope values than those observed for station O-4 to O-6. The slope at station O-2 was also higher than the slope at O-3. This analysis suggests that there are relatively clear differences between the uppermost and lowermost stations within each watershed. The comparison of population patterns among the two watersheds are less distinct. This could be due to harvesting history, recent disturbance, available substrates, and food availability as indicated by chlorophyll-a concentrations.

Oyster Diseases:

Perkinsus marinus (Dermo)

Our evaluation of the native oysters collected from the Okatee River and Broad Creek revealed *Perkinsus marinus* infections at all stations (Figure 5.17 , Appendix 5.4). This is typical of what we have observed across South Carolina in previous studies (Bobo et al., 1997; Appendix 5.5). In Broad Creek, mean infection intensity levels ranged from 0.76 at station O-5 to 2.04 at station O-3. For the Okatee River sites, mean infection levels ranged from 1.40 at station O-4 to 2.28 at station O-3. The percent of oysters infected (also called prevalence) ranged from 36% to 100% in Broad Creek and 84% to 96% in the Okatee River.

Initially, we used a two-way ANOVA with river system and station as main effects. For *P. marinus*, results were as follows: for prevalence, a significant main effect was detected for station ($p < 0.001$), but not for rivers ($p = 0.2$); for intensity levels, a significant main effect was detected also for station ($p < 0.02$), but not for rivers ($p = 0.61$). For both, however, a significant interaction was observed between river and station ($p < 0.0001$).

Further statistical comparisons indicated that there was a significant difference in the percentage of oysters infected with *P. marinus,* among the Broad Creek stations ($p < 0.001$, K-W). Station O-5 had significantly fewer infected oysters than stations O-1, O-4, O-4 (Figure 5.17 A). For mean infection intensity, significant differences (one-way ANOVA, $p < 0.001$) were detected among stations. Station O-5 had significantly lower intensity levels than all other stations, with the exception of station O-2. Finally, station O-2 was also different than station O-6 (Bonferroni Test). Overall, Broad Creek sites were well within the observed and typical range for observed in South Carolina oysters (Appendix 5.5).

In the Okatee River, the percentage of oysters infected with *P. marinus* was not statistically different among the six sites ($p = 0.884$, K-W; Figure 5.17 B). Although there was a marginally significant difference observed overall among the sites in the mean infection intensity levels ($p < 0.05$, K-W), Dunn's pair-wise comparison tests could not distinguish a significant difference among any two sites compared. As with Broad Creek, the Okatee River sites were well within normally observed disease levels (Bobo et al., 1997, Appendix 5.5).

Observed *P. marinus* infection levels were similar to those observed in other South Carolina oyster populations based upon historical data (Bobo et al., 1997) or based on other sampling efforts conducted during the same time period in 1997 (Shellfish Research Section). *P. marinus* prevalences are typically high (>70%) during August-September, with mean infection levels rarely exceeding 3.00 on a 0-6 scale (Bobo et al. 1997). In our 1996 MRD disease monitoring study, *P. marinus* infections were present in oysters at all of the 52 sites sampled (Appendix 5.5). Sampling for that study occurred during the same period (August and September) as this study. This is a period when the disease prevalence and intensity levels are generally the highest in South Carolina oysters (Bobo et al., 1997, Crosby and Roberts. 1990).

Disease levels were not statistically different among the sites with different DHEC harvesting designations. In Broad Creek, both the highest and lowest infection intensity levels were observed at harvestable stations. In the Okatee River, the highest Dermo infection intensity level (2.28) was observed at a restricted station (O-2) and the lowest infection intensity level (1.40) was observed at an open station (O-4).

Haplosporidium nelsoni (MSX)

Examination of native oysters for the MSX disease also revealed infections at all stations (Figure 5.18, Appendix 5.4). The percentage of infected oysters ranged from 4% to 33% in Broad Creek, with the lowest levels observed at station O-3 and the highest levels observed at O-4 (Figure 5.18 A). In the Okatee River, the percentage of infected oysters ranged from 4%, observed at Stations O-1, O-2, O-4 and O-5 to 12% at station O-3 (Figure 5.18 B).

As with *P. marinus,* we used a two-way ANOVA with river system and station as main effects examining only MSX prevalence. In contrast to Dermo, we observed a significant main effect for river system ($p < 0.013$), but not for stations ($p = 0.53$). However, a marginally significant interaction was observed between river and station ($p < 0.044$).

No statistical differences in prevalence (infection) levels were noted among either the Broad Creek or Okatee River sites ($p = 0.08$, K-W). There were also no statistically significant differences noted between the two river systems, although the Broad Creek oyster beds had slightly higher levels of MSX than Okatee River oyster beds. In terms of infection intensities, 22 of the 148 oysters (or 15%) examined from the six Broad Creek stations were infected, and only 9 of the 149 oysters (or 6%) collected from the Okatee River had MSX. Mean infection intensities in both drainage systems ranged from rare (very few parasites observed) to heavy (more than 5 parasites/400x field).

MSX was also observed at 28 of the 52 stations (54%) sampled during our 1996 summer/fall statewide disease monitoring study (Bobo et al., 1997; Appendix 5.5). These sites included stations within Beaufort County. The mean percentage of infected oysters at those sites ranged from 0 to 32%. The percentage of oysters infected in the Broad Creek and Okatee River stations were also similar to those observed in other South Carolina oyster populations sampled in previous years (Bobo et al., 1997). During our 1994 monitoring study, *H. nelsoni* infections were observed in 11 of the 21 (or 52%) sites sampled across South Carolina, with the mean number of infected oysters ranging from 0% to 42% (Bobo et al., 1997). Finally, there was no apparent relationship between the incidence of MSX in the oyster samples versus the oyster bed status using DHEC's classification in either the Broad Creek or Okatee River drainage system.

Oyster Cellular Responses

Within the past decade, there has been an increasing emphasis on the potential use of biochemical, physiological, and histological indicators as biomarkers of exposure to or effects of anthropogenic impacts (Huggett et al., 1992; Decaprio, 1997). The underlying premise of biomarker tools is that effects at higher levels of organization (populations and communities) represent the net sum of effects on individuals that resulted from alterations in cellular and molecular responses. Therefore, cellular responses should function as indicators for identifying individuals and populations for which conditions have exceeded compensatory mechanisms and are experiencing chronic stress, which if unmitigated, may progress to severe effects at higher levels of organization.

Lysosomes are regarded as valuable indicators of pollutant-induced injury (Moore, 1994). There is a substantial body of literature validating that environmental pollutants (metals and polyaromatic hydrocarbons) cause destabilization of lysosomes (Moore, 1985; Regoli, 1992; Lowe et al., 1995; Ringwood et al., 1998a and 1998b). Glutathione (GSH) is regarded as one of the most important "first-line" defense mechanisms of cells. Glutathione depletion has been observed in mammalian as well as marine organisms, and it has been hypothesized that GSH depletion is both a signal of stress (frequently in response to metals), and a predisposing factor for increased adverse effects (Meister and Anderson, 1983; Viarengo et al., 1991; Regoli and Principato, 1995; Regoli, 1998). Lipid peroxidation (LPx) reflects damage to cell membranes from free radicals. The peroxidation process is also a source of other cytotoxic products that may damage DNA and enzymes (Kehrer, 1993; Yu, 1994).

Recent studies with lysosomal destabilization and glutathione concentrations have indicated highly significant correlations with contaminants (Ringwood et al., 1998a; Ringwood et al., In press). We have developed models in which >30% destabilized lysosomes and GSH concentrations <400 -500 nM/g indicate stress in oysters. These threshold values have been derived from field data based on juveniles and adults from a range of salinities as well as controlled laboratory experiments. The results of studies conducted with native oysters collected from the Okatee River and Broad Creek are summarized in Appendix 5.6 and Figure 5.19. The oyster collection sites do not match up directly with the sediment contaminant data, but the sites that were closest are noted in Appendix 5.6. Most of these sites had only low levels of contaminants. However, examination of the tissue contaminants data (see next section) indicated that one or more metals were present in the oyster tissue samples at elevated levels. These metal concentrations may account for the consistently high (> 30%) lysosomal destabilization rates that we observed at most of the sites. Lysosomal destabilization was significantly elevated at only one site (O-2) relative to the site with the lowest rate. In contrast, there was no evidence of severe GSH depletion, although statistically significant lower GSH levels were observed in oysters from one site in Okatee (O-6) and 2 sites in Broad. Only one site from Okatee River (O-3) had significantly elevated LPx, but LPx levels of oysters from 4 of the 6 Broad Creek sites were significantly elevated. Although we have frequently observed high LPx levels at contaminated sites, this response has not shown good correlation with contaminants. Some of our recent data suggest that elevated LPx may also be related to dissolved oxygen stress.

The elevated levels of lysosomal destabilization along with the high tissue metal concentrations suggest that oysters throughout both systems are showing signs of impaired cellular function. Although the lysosomal data may reflect exposure to contaminants, the maintenance of relatively high GSH levels indicates that oysters are not severely stressed. If the elevated LPx levels indicate DO or oxidative stress, then Broad Creek may be experiencing more DO problems than Okatee. Overall, these results suggest that both systems are showing some signs of exposure to adverse conditions, and Broad Creek oysters may be experiencing both low level contaminant and DO stress. There is no evidence that oyster populations from either system are severely stressed, but the perturbed responses suggest that they may be susceptible to further declines in habitat quality.

Tissue Contaminant Concentrations:

No pesticides, PAHs, or PCBs were detected in any samples from either system. The only metals detected in either system were; arsenic, cadmium, aluminum, manganese, copper, and zinc (Appendix 5.7).

Arsenic was detected only at the two lower zone sites in Broad Creek; O-5 and O-6, at concentrations of 2.4 and 2.2 mg/kg wet weight, respectively (Appendix 5.7). The U.S. Food and Drug Administration (USFDA) has published guidance for deriving a level of concern for human consumption of shellfish due to arsenic and provided an example based on national figures (USFDA, 1993a). At both sites, the wet weight tissue concentration was well below the example level of concern of 86 mg/kg for chronic consumers of shellfish (15 g/person/day). These values were also well within the range of 3.0 – 4.0 mg/kg (USFDA, 1993a) measured by the National Marine Fisheries Service (NMFS), although they were near the top of the range of 0 – 2.8 mg/kg measured by USFDA (1993a).

When converted to dry weight the resulting arsenic concentration at site O-5 was 24 mg/kg and 22 mg/kg at site O-6 (Appendix 5.7). Both of these values were greater than the calculated mean of 9.29 mg/kg computed from O'Connor (1996). The levels are also similar to those observed by Scott (NOS, unpublished) in other parts of the state. Arsenic levels are naturally elevated in South Carolina relative to other parts of the United States due to local geochemistry. Although these values are greater than the national average, the concentrations observed in the oyster tissue do not necessarily mean there is ecological degradation.

Cadmium was detected at all sites in both systems except the two upper zone sites in Broad Creek (O-1 and O-2) and ranged from 0.2 to 0.5 mg/kg wet weight (Table 5.6). USFDA has published guidance for deriving a level of concern for human consumption of shellfish due to cadmium and provided an example based on national figures (USFDA, 1993b). At all sites the wet weight tissue concentrations were well below the example level of concern of 3.7 mg/kg for chronic consumers of shellfish (15 g/person/day). The values also were well below the range of 0.9 – 1.0 mg/kg measured by NMFS (USFDA, 1993b), and within the range of 0.25 – 1.12 mg/kg measured by USFDA (1993b). Additionally, the concentrations we measured were comparable to coast-wide data collected by SCDHEC since 1980 (n = 115, median = 0.4 mg/kg, range 0.2 – 1.6 mg/kg, 90th percentile = 0.7 mg/kg).

When converted to dry weight the resulting range in cadmium concentrations was 2.0 – 5.0 mg/kg, (Table 5.6, Appendix 5.7). Okatee River sites O-1 through O-4 and O-6, and Broad Creek site O-6 in Broad Creek were greater than the calculated mean of 2.68 mg/kg computed from O'Connor (1996). The values were also generally higher than we have noted in other parts of the state (Ringwood, SCDNR unpublished data; Scott, NOS unpublished data). Okatee River cadmium concentrations were significantly greater than Broad Creek ($p = 0.036$). Biological effects related to the presence of high cadmium levels in oyster tissue are not well documented, but the values we observed may be below levels that cause cellular dysfunction based on data obtained by Ringwood, who observed Cd tissue levels > 1.5 mg/kg in oysters that had high (> 30%) lysosomal destabilization.

Aluminum, manganese, copper, and zinc were detected at all sites in both systems. There is no USFDA guidance for human consumption of shellfish related to any of these metals. O'Connor (1996) indicates that aluminum and manganese are not contaminants, *per se*, because their relatively high natural concentrations in the environment are not significantly altered by human activities.

Wet weight copper concentrations ranged from 6.5 – 27 mg/kg (Table 5.6, Appendix 5.7). These concentrations were comparable to coast-wide data collected by SCDHEC since 1980 (n = 115, median = 13 mg/kg, range 3.8 – 130 mg/kg, 90th percentile = 30 mg/kg. When converted to dry weight the resulting range in copper concentrations was 64.9 – 269.6 mg/kg (Table 5.6, Appendix 5.7). Broad Creek sites O-1 through O-5, and site O-6 in the Okatee River were greater than the calculated mean of 123.75 mg/kg computed from O'Connor (1996). It was also in the high range of copper concentrations observed by Wendt et al. (1996) in creeks with high dock densities. There was no significant difference in copper concentrations between the two systems (p = 0.098). The generally higher copper concentrations at most sites in Broad Creek may reflect the much higher boating and marina activity in this system, since most anitfouling paints utilize copper as the bioinhibitor. Biological effects related to the presence of high copper levels in oyster tissue are not well documented, but concentrations greater than 95 mg/kg were found in oysters having cellular dysfunction with respect to having greater than 30% lysosomal destabilization (Ringwood, unpublished). Fresco (1997) found similar elevated Cu uptake in oysters from highly urbanized Murrells Inlet, with highest uptake observed at sites with marinas and high dock density. The high Cu levels observed at station O-6 in the Okatee may have resulted from Cu enrichment due to metal based fungicides used in vegetable farming. Elevated Cu levels have been found in sediments and oysters at sites downstream of major tomato farming areas (Scott et al., 1999)

Wet weight zinc concentrations ranged from 140 – 660 mg/kg (Table 5.6, Appendix 5.7). The value of 660 mg/kg was measured at the Okatee River site O-1 and is in the top 10% of the samples measured coastwide by SCDHEC since 1980 (n = 115, median = 280 mg/kg, range 14 - 1200 mg/kg, 90th percentile = 580 mg/kg). When converted to dry weight the resulting range in zinc concentrations was 1398 - 6591 mg/kg (Table 5.6, Appendix 5.7). All sites except Broad Creek site O-6 were greater than the calculated mean of 1950 mg/kg computed from O'Connor (1996). There was no significant difference in zinc concentrations between the two systems (p = 0.076). Biological effects related to the presence of high zinc levels in oyster tissue are not well documented, but concentrations greater than 1330 mg/kg were found in oysters having cellular dysfunction with respect to having greater than 30% lysosomal destabilization (Ringwood, unpublished).

Evaluation of Changes in Bed Acreage Over Time:

Results of the survey of oyster beds sampled in this study to estimate population size, total shellfish volume, and live oysters are presented in Table 5.7 and compared with similar data obtained in 1984-1985. The change in bottom area or "footprint" of the intertidal bed did not always correspond to the change in shellfish volume, either with respect to total volume (includes dead shell and substrate) or with respect to "live volume". In Broad Creek, the six station total indicated approximately a 21% *increase* in area, but a 17% *decrease* in live volume. In comparison, the cumulative estimate obtained from the six stations in the Okatee River showed a 14% *decrease* in area, and a 41% *decrease* in live volume. In some locations (e.g. O-6 in Broad Creek) the oyster population footprint decreased in area, but increased in total live volume. This trend results from changes in densities, which are characterizations of standing crop spatial dispersions. Oyster densities and the percentage of bed that consists of live oysters is sometimes dependent on whether the beds are open to harvesting or not. In Broad Creek, the upper four beds showed either no change in size (O-2) or an increase in size. Three of these beds were closed to shellfish harvesting at the time of the study. The two lowest beds (O-5, O-6) were open for harvest as a culture permit. Similarly, the four stations in the lower portion of the Okatee River (O-3 to O-6) were also open to shellfish harvests as a culture permit. All but one showed a decrease in size and all four showed a decrease in total live shell volume, perhaps due to harvesting pressure.

Mussel Abundance and Biomass:

Mussels (primarily *Geukensia demissa* and *Brachidontes exustus*) varied significantly among the 12 stations, with total abundance (sum of 5 samples/station) ranging from 0 at Okatee site O-6 to 707 individuals at the Broad site, O-6 (Figure 5.20; Appendix 5.8). Total wet mussel biomass (sum of 5 samples/station) ranged from 0 at Okatee site O-6 to 214 g at the Broad Creek site O-6. Mussels were rare at all of the Okatee stations, with total abundances ranging from only 0 to 14 individuals. In Broad Creek, the total abundance of mussels ranged from 8-707 individuals. Based on water quality data, the sites sampled in this study did not differ significantly in physical factors (salinity, temperatures) nor in other indicators of habitat quality. Hence, the large difference we observed between river systems is unclear. Previously, we have noted that mussels were often rare at sites with poor quality growth (e.g. Warsaw Flats-Beaufort Co.) and poor water quality (e.g., Toler's Cove-Charleston Co.).

General Conclusions of Oyster Population Assessment:

An integrated summary of oyster bed conditions that we observed in Broad Creek and the Okatee River is provided in Figure 5.21. In general, the beds that showed the greatest evidence of some degradation in condition were located in the headwater (upper zone) portions of both drainage basins, when the four primary measures of oyster condition were considered (size and density, disease, cellular response, tissue contaminant levels). None of the beds in either the Okatee River or Broad Creek coded as good (green) for all measures, but it should be noted that this may or may not be due to environmental stress at many of the sites.

The overall size and density of oysters was generally good with respect to current SC conditions in both drainage systems and greater in Broad Creek compared to the Okatee River, which is most likely due to the more restrictive harvesting in Broad Creek. Density and evidence of good recruitment to the beds (indicating bed sustainability) was lowest in the headwaters, where salinity variance is greatest. Oysters cannot survive well at salinities less than 10 ppt (Shumway, 1996). We used the overall number of oysters, which incorporated recent oyster recruitment, as the measure of bed density with sites having > 1,000 live oysters in the five quadrat samples coding as good. Oyster populations were rated 'good' for all Broad Creek sites, with the exception of the uppermost station, 0-1. Similarly, all three lower stations in the Okatee River (O-4, O-5, 0-6), rated as 'good', but the uppermost three were all deemed 'marginal'.

Disease incidence in the oysters was generally similar in both systems and consistent with disease prevalence and infection intensity levels observed elsewhere in the state. All six Okatee sites were given a 'good' rating, whereas only 4 of the 6 stations in Broad (O-1, O-2 , O-3 and O-6) received a 'good' rating due to the higher incidence of MSX at the other sites.

The cellular responses observed in both systems were also similar, but higher than anticipated with respect to one or two of the assays considered, particularly the lysosomal destabilization assay. This may reflect responses to the tissue contaminant levels observed in oyster samples collected from both drainage systems, or to other environmental stresses such as low dissolved oxygen.

The only contaminants detected in the oyster tissue samples were four metals (Cd, Cu, Zn, and As). None of these metals were at alarming levels, but there is evidence that some of the metal concentrations were high enough to elicit sublethal responses with respect to cellular function, and cellular dysfunction was observed at all of the sites sampled in this study. The consistently higher levels of copper in Broad Creek may be reflecting the much higher boating and marina activity in that system compared to the Okatee. Most antifouling paints in use today utilize copper to inhibit the settlement of fouling organisms. The higher levels of cadmium and zinc observed in oysters collected from the Okatee River may reflect the effects of long-term agricultural runoff, since these metals are often utilized in pesticides.

Grass Shrimp Population Assessment:

The grass shrimp, *Palaemonetes pugio,* is a common inhabitant of southeastern and Gulf coast estuaries of North America. These shrimp are a major force in accelerating the breakdown of detritus in the estuary (Welsh, 1975) and are important dietary components for many fish species (Wood, 1967). In South Carolina estuaries, *P. pugio* occur year round at densities ranging from < 1000/50 m of stream in winter to 28,000/50 m of stream in summer. Grass shrimp may comprise 56% of the total macrofaunal stream density on an annual basis (Scott et al., 1992).

Grass shrimp are external brooders with the developing eggs attached to the pleopods of the female until hatching. This makes ecotoxicological population measurements of the adults, larvae and embryos of this species suitable for use in field contaminant assessments in several ways. First, adults can be assessed directly and their sensitivity to waterborne and/or sediment-associated contaminants ascertained. Secondly, during the two-week brooding period, embryos carried by the female are directly exposed to any contaminants present in the water column so that brood counts of eggs in gravid females can be utilized to predict effects in embryos. Finally, enumeration of larval abundance makes determination of the entire life cycle complete. Comparative toxicity testing of different life history stages has indicated that for many environmental contaminants, embryo, larval, post-larval and adult stages have similar sensitivities (; Baughman et al., 1989; Scott et al., 1992; Key, 1995; Lund, 1997).

Scott and co-workers at the NOAA/NOS Charleston Lab have utilized grass shrimp population abundance as an effective method for assessing impacts of agricultural non-point source (NPS) runoff of endosulfan, azinphosmethyl and fenvalerate (Patterson, 1985; Hampton, 1986; and Scott et al., 1992). This species has also been an effective indicator of urban NPS runoff effects (Fulton et al., 1993; Fulton et al., 1996; Finley et al., 1998). Finley et al. (1998) demonstrated that urban and agricultural NPS runoff had a significant effect on adult density and reproduction (e.g. delayed brood and altered sex ratios). In urban areas these effects were correlated with exposure to PAHs and alterations in physicochemical water quality (e.g. salinity and dissolved oxygen) associated with urban development. In agricultural areas, effects were correlated with pesticide runoff of azinphosmethyl. Porter et al. (1995) found that GIS and spatial statistical methods (e.g. krieging) were useful in generating estuarine-wide grass shrimp abundance maps for both adult and larval grass shrimp in urbanized Murrells Inlet, which were reduced by > 85% estuarine wide when compared to pristine North Inlet, a NOAA NERRS site. Additionally, it was possible through data layer overlays of land-use and sediment chemical contaminant data to correlate reduced grass shrimp abundances with known pollution sources (e.g. highway runoff and marinas) within the estuary.

Specific objectives of the grass shrimp population assessment were as follows:

1. Enumerate adult grass shrimp abundance, biomass and sex ratios within tidal creek and river habitats along the length of each drainage basin;

2. Quantify the reproductive output of adult female grass shrimp within tidal creek and river habitats along the length of each drainage basin;

3. Enumerate the larval grass shrimp abundance within tidal creek and habitats along the length of each drainage basin;

4. Compare adult and larval grass shrimp population metrics (e.g. biomass, abundance, sex ratio, egg production/female) between each sub-habitat within each drainage basin; and

5. Compare adult and larval grass shrimp population metrics (e.g. biomass, abundance, sex ratios, egg production/female) between each drainage basin.

Methods:

Grass shrimp (*Palaemonetes* spp.) populations were sampled using a push net at a total of 30 sites, with 15 sites located within each drainage basin (Figures 5.1, 5.2). The sampling procedure, which is described by Scott et al. (1992), involves a push net sampling method that is a modification of the approach described by Welsh (1975). Within each basin, the push netting was conducted at sites that approximated a gradient of pollution and landscape ecology (e.g. tidal creek --> river -->intertidal sites). Previous research on grass shrimp population dynamics (monthly sampling for 12 months) have been conducted around sites with known pollution sources (e.g. Koppers, Diesel and Shipyard Creeks) in Charleston Harbor. Additionally, estuarine wide sampling (e.g. one time random sampling) has been conducted at 30 sites in suburbanized Murrells Inlet, 42 sites in Charleston Harbor, 30 sites in North Inlet, and 34 sites in the ACE Basin. Thus, an extensive historical database (1985-present) exists for grass shrimp population dynamics within South Carolina that was used to compare results in this study.

At each site, three consecutive 25-m lengths of creek were marked with PVC stakes and sampled 2.5 hours prior to low tide. Sampling was conducted either on foot or from a 3-m plastic catamaran with an electric trolling motor. Tows were made along each bank using a push net with a mouth opening of 1,009 cm^2 (approximately 25-cm length x 40-cm width). A 360-µm plankton net 20-cm deep was attached to the back of each net. Tows were made against the tidal current along each bank at, or near the mid-tide period. The contents of the tows from each bank were combined to produce three replicate samples per site. Adult (> 15 mm) and sub-adult (<15 mm) grass shrimp collected in the net were preserved in > 50% ethyl alcohol and stored until processed. Comparisons of tows made on foot versus those made while trolling have found no statistical differences between the two collection methods (Scott, unpublished).

The following parameters were measured for adult grass shrimp: (1) total abundance (*P. pugio*, *P. vulgaris*, *Penaeus* sp. and other species as #/m of stream); (2) total biomass (*P. pugio*, *P. vulgaris*, Penaeus sp. and other species as g/m of creek); (3) *P. pugio* abundance (#/m of stream); (4) *Palaemonetes pugio* biomass (g/m of stream); (5) abundance of male, non-gravid female and gravid female *P. pugio* (#/m of stream); (6) sex ratio of *P. pugio* (% males: nongravid females: gravid females); (7) the number of eggs/female (#/ female) in *P. pugio* and (8) larval *P. pugio* abundance (#/m of stream)

Statistical comparisons of each metric were made, using both intra-site (tidal creek versus river versus intertidal within the Okatee River and Broad Creek and inter-site (tidal creek, river, intertidal) and pooled comparisons for the Okatee River versus Broad Creek) using both non parametric (Wilcoxon; Mann Whitney; Kruskal Wallis) and parametric (ANOVA, Dunns , and Dunnetts) procedures. An alpha level of 0.05 was used to determine statistical significance among sites. Multiple regression analysis was used to assess the effects of variables such as overall sediment quality (sediment toxicity tests, ERM Quotients and ammonia concentrations), overall physicochemical water quality, specific water quality parameters (DO and salinity), specific sediment quality guidelines (ERM Quotients), and benthic faunal densities on different grass shrimp metrics. Both parametric (Linear regression with appropriate data transformation) and non-parametric (Spearman and Pearson Correlations) methods were used. Both correlation coefficients (R^2 and Rho/Tau) were calculated along with P values to determine if regressions were significant ($p < 0.05$).

Statistical comparisons of the grass shrimp population metrics with results from laboratory analytical chemistry results were made to indicate whether population metrics were correlated with chemical contaminant concentrations in sediments, physicochemical water quality alterations or loss of physical marsh/tidal creek habitat. Site and drainage basin comparisons were also performed using various parametric and non-parametric methods to determine patterns for each of the major population parameters. Analysis of grass shrimp indicated the following composition: *P. pugio* 75%, *P. vulgaris* 25%, and *P. intermedius* < 1%. Since *P. pugio* was the dominant species observed in both watersheds all grass shrimp results were classified as *P. pugio* for statistical analysis.

Findings:

Adult Grass Shrimp:

Comparisons of adult grass shrimp abundance indicated that generally there were no significant differences within tidal creek, river and intertidal habitats between Broad Creek and the Okatee River (Figure 5.22, Table 5.8, Appendix 5.9). Pooled stations comparisons (tide creek + river + intertidal) within each watershed indicated a significant ($p < 0.032$) difference in abundance (Figure 5.22), with higher abundances observed in Broad Creek than in the Okatee River. A closer inspection of these data, however, generally indicated that mean abundances and associated variances were quite comparable. The statistical difference noted in pooled abundance may have resulted from the non-parametric procedures used for statistical analysis, which compare median versus mean values. In individual multiple station comparisons, only Broad Creek T-5 had significantly ($p < 0.027$) higher abundance than Okatee River T-4 (Figure 5.23).

P. pugio biomass showed a similar trend, as between watershed comparisons indicated that generally there were no significant differences in tidal creek, river and intertidal habitat comparisons between Broad Creek and the Okatee River (Figure 5.22, Table 5.8). Pooled stations comparisons (tidal + river + intertidal) within each watershed indicated significantly ($p <0.029$) higher biomass in Broad Creek when compared to the Okatee River (Figure 5.22). A closer inspection of these data however, generally indicated that mean biomass and associated variances were quite comparable. As noted for total abundance comparisons, the statistical difference noted in pooled biomass may have resulted from the non-parametric procedures used for statistical analysis, which compares median versus mean values. In individual station comparisons (Figure 5.23), tidal creeks stations T-5 and T-3 in Broad Creek had significantly ($p< 0.0001$) higher biomass than other stations in Broad Creek (T-1,T-2, T-3, T-4 and T-6) and the Okatee River (T-1, T-2,T-3, T-4, T-5 and T-6). At river sites, stations R-2 and R-1 in Broad Creek and stations R-2 and R-3 in the Okatee River had significantly higher biomass than other stations in Broad Creek (R-3, R-4, R-5 and R-6) and the Okatee River (R-1, R-5 and R-6). At intertidal sites, stations I-1 and I-6 in Broad Creek had significantly higher biomass than stations I-1 and I-6 in the Okatee. Similarly, the intertidal station I-4 in the Okatee had significantly higher biomass than the Broad Creek station I-4 and the Okatee stations I-2 and I-6).

The average *P. pugio* size (biomass/density = g/individual) was not significantly different in inter-watershed comparisons of tidal creek, river and intertidal habitats between Broad Creek and the Okatee River (Figure 5.22, Table 5.8). Pooled stations comparisons (tidal + river + intertidal) within and between each watershed indicated that average *P. pugio* size was not significantly different in Broad Creek when compared to the Okatee River (Figure 5.22). In individual station comparisons (Figure 5.23), tidal creek stations were significantly ($p < 0.001$) different in Kruskal-Wallace comparisons between Broad Creek and the Okatee River, although no individual stations were significantly different in multiple pair-wise comparisons.

The percent gravid female *P. pugio* was not significantly different in inter-watershed comparisons of tidal creek and intertidal habitats between Broad Creek and the Okatee River (Figure 5.24, Table 5.8). Mann Whitney U comparisons of river stations were significantly ($p < 0.002$) different, with a higher proportion of gravid females in Broad Creek than the Okatee River. Pooled stations comparisons (tidal + river + intertidal) within and between each watershed indicated that the % gravid female *P. pugio* was not significantly different in the two drainage systems (Figure 5.24). In individual station comparisons (Figure 5.25), the % gravid females was found significantly ($p < 0.0197$) different at river sites using ANOVA and Kruskal-Wallace procedures, although no individual stations were significantly different in pair-wise comparisons (Dunn's).

The number of eggs per female *P. pugio* was not significantly different in inter-watershed comparisons of tidal creek, river and intertidal habitats between Broad Creek and the Okatee River (Figure 5.24, Table 5.8). Pooled stations comparisons (tidal + river + intertidal) within and between each watershed indicated that the number of eggs per female *P. pugio* was not significantly different in Broad Creek when compared to the Okatee (Figure 5.24). When comparisons among stations were made (Figure 5.25), the number of eggs per female was not significantly different among tidal creek sites, but in river and intertidal site comparisons, occasional differences were observed.

Larval Grass Shrimp:

The number of larval *P. pugio* was not significantly different in inter-watershed comparisons of tidal creek, river and intertidal habitats between Broad Creek and the Okatee River (Figure 5.24, Table 5.8, Appendix 5.9). Pooled stations comparisons (tidal + river + intertidal) within and between each watershed indicated that the number of larval *P. pugio* was not significantly different between the two drainage systems (Figure 5.24). In individual station comparisons (Figure 5.25), the number of larval *P. pugio* was not significantly different in tidal creek comparisons between Broad Creek and the Okatee; however, river and intertidal site comparisons were significantly different between Broad and Okatee sites using ANOVA and Kruskal –Wallace tests ($p < 0.004$ and 0.026, respectively, Figure 5.25). No individual site differences were noted in the tidal creeks, but at river and intertidal sites occasional differences were observed between Broad Creek and the Okatee River.

Chemical Contaminant Effects on P. Pugio:

Additional statistical analyses of adult and larval grass shrimp metrics were conducted in which stations in both drainage systems were classified as undegraded (cumulative ERM Quotient < 0.024), marginally degraded (cumulative ERM Quotient > 0.024 ≤ 0.068) and degraded (cumulative ERM Quotient > 0.068) based on criteria described by Hyland et al. (1999). The results indicated that there were no differences in adult grass shrimp abundance, biomass, average size, sex ratios and egg production/female in comparisons of degraded and potentially degraded versus undegraded sites (Figure 5.26). Only larval grass shrimp density was significantly ($p < 0.0001$) different, with degraded sites having lower densities than undegraded sites.

Overall Assessment of Grass Shrimp Populations:

Figure 5.27 depicts an integrated assessment of selected adult and larval grass shrimp metrics at each site within Broad Creek. Significant reductions in biomass were observed in Broad Creek at 5 out of 15 sites and no site had more than one of the four selected grass shrimp metrics reduced when compared to the Okatee River. Six out of 15 sites in Broad Creek had significantly higher biomass than the Okatee sites. One out of 15 sites in Broad Creek had significantly higher biomass and abundance when compared to the Okatee sites. There were no significant differences in the % gravid female sex ratios and larval grass shrimp abundance noted in comparisons of the two drainage systems.

Figure 5.28 depicts an integrated assessment of selected adult and larval grass shrimp metrics at each site within the Okatee River. Significant reductions were noted in biomass when compared to Broad Creek at 11 out of 15 sites (73.3%), but only one site (T4=6.7%) had significant reductions in more than one of the four selected grass shrimp metrics when compared to Broad Creek. Three out of 15 sites (20%) in the Okatee had significantly higher biomass than Broad Creek sites. There were no significant differences in the % gravid female sex ratios and larval grass shrimp abundance noted in comparisons between systems.

Thus, in general grass shrimp populations within both drainage systems seem quite comparable, despite the presence of chemical contaminants, alterations in hydrography and water quality and habitat modifications within each system. When grass shrimp abundance in the two drainage systems were compared with grass shrimp abundance in North Inlet, a NOAA National Estuarine Research Reserve and Sanctuary (NERRS) site, and another pristine site located in Leadenwah Creek in the North Edisto River, numerical abundances were slightly higher in both Broad Creek and the Okatee River (Figure 5.29). However, these differences were not statistically different.

Finfish Collections:

The mummichog (*Fundulus heteroclitus*) is a common and ecologically important fish inhabiting estuaries from the Gulf of St. Lawrence to Texas (Scott and Scott, 1988). As both consumer and prey, the mummichog provides an important link in energy transfer from the marsh surface to subtidal systems (Radtke and Dean, 1979; Weisberg et al., 1981). Its tolerance for variations, even extremes, in temperature, dissolved oxygen, and salinity allow it to thrive throughout estuaries within its geographic range (Bigelow and Schroeder, 1953; Abraham, 1985; Scott and Scott, 1988). In contrast with the wide distribution of the species, individual fish have relatively small home ranges, often on the order of tens of meters (Lotrich, 1975). Consequently, mummichogs have been evaluated as indicators of conditions in the small area that they inhabit (Vogelbein et al., 1990, Holland et al., unpublished data). The objectives of this phase of the study were to compare mummichogs collected from the Okatee River and Broad Creek with respect to the following:

1. A condition index which incorporates size and weight,
2. Prevalence of gross abnormalities, and,
3. Sex ratios of mummichog populations.

Methods:

Mummichogs were collected from the same section of each creek where sediments were collected for analysis of benthic invertebrates (Figures 5.1, 5.2). Commercially available minnow traps constructed of galvanized steel with conical openings approximately 2 cm in diameter were used to collect the mummichogs. Each trap was baited with a 170-gram can of tuna (in water) with holes poked in the top. Typically, traps were fished while the sediment samples were collected, but if sufficient number of mummichogs were not caught they were fished overnight. Mummichogs were stored on ice immediately following collection and frozen upon return to the laboratory.

Mummichogs were processed in the laboratory. Total and standard lengths were measured to the nearest millimeter. Weights were recorded to the nearest 0.1gram. A condition index ([weight /standard length^3]*100,000) was calculated for each mummichog. Sex was determined by coloration, and when necessary, examination of the gonads. All fish were inspected for gross external morphological abnormalities.

Findings:

A total of 1367 mummichogs were collected from the 11 tidal creeks sampled (Appendix 5.10). Mummichogs were not collected from T-6 in Broad Creek, which is located near Calibogue Sound in the lower section of Broad Creek. As a result, this creek was excluded from the analysis. At least 44 mummichogs were collected from each creek.

While abnormalities are present even in healthy populations of fish, rates are generally low. Among the mummichogs we collected, missing eyes and damaged caudal fins were the most commonly observed abnormalities (Table 5.9). Although both conditions represent serious problems for the individual fish, the overall rate of these conditions in our samples was low (about 1.5%). This rate is similar to that observed by Holland et al. (unpublished data) for tidal creeks in the Charleston, SC area. Also, rates of abnormalities among creeks within the Broad Creek and Okatee River were not significantly different (t-test, p = 0.556). Consequently, these conditions probably did not significantly impact populations of mummichogs within the creeks that we sampled.

Sex of most mummichogs (96.4%) was determined by cursory inspection. Mummichogs with no obvious external indication of sex were dissected. For a small proportion of the animals, sex could not be determined following dissection. These mummichogs, which accounted for only 1.3% of the total animals, were considered immature. Generally, populations of mummichogs we sampled had slightly more females than males (51-62%, Table 5.9). However, in the Okatee River T-1 and T-3 these percentages exceeded 75%. Overall, sex ratios of mummichogs were not significantly different between rivers (t-test, p = 0.570).

In general, the condition of mummichogs was similar to that observed by Holland (unpublished data). The condition index averaged 2.38 in the current study (Table 5.9) and 2.40 for Holland. Holland found that the condition index of mummichogs from degraded creeks was significantly lower than mummichogs from creeks that were not degraded. In the present study, we found a difference in condition of mummichogs between creeks of the Okatee and Broad (p = 0.015) watersheds. Larger mummichogs were collected in the tidal creeks of the Broad Creek where the three creeks producing the largest mummichogs were found. These included creeks from the upper (T-1, T-2) and lower section (T-5) of Broad Creek. Four of the five creeks producing mummichogs with the lowest average condition index were located in the Okatee River. These included all creeks from the upper and middle sections of the Okatee River (T-1, T-2, T-3, and T-4). In Broad Creek, the site with the lowest index was T-4. These creeks in both the Okatee River (T-1 to T-4) and Broad Creek (T-6) also had the lowest grass shrimp abundance and biomass. Grass shrimp are known prey items for mummichogs (Scott et. al., 1992).

Overall Conclusions Regarding Mummichog Populations:

Our initial assumption that impacted creeks would have mummichogs with lower condition indices contradicts our results. In fact, the tidal creeks of Broad Creek, which had greater overall evidence of anthropogenic stress than those of the Okatee, produced mummichogs with a higher condition index. This result may be accounted for through closer inspection of contaminant and water quality data. While the degraded creeks in the Holland study were heavily polluted with PAHs and metals, levels in the creeks of our study were much lower, often below threshold bioeffects concentrations. The degraded creeks of the Broad and Okatee systems, in contrast, were organically enriched. This type of enrichment, which can lead to oxygen depletion, results from excessive production due to an overabundance of nutrients. As a species tolerant of low dissolved oxygen concentrations, the increased production may actually benefit the mummichog. Interestingly, a comparison of mummichog condition index with minimum dissolved oxygen value shows a high correlation ($r^2 = 0.635$, $p = 0.036$).

These results suggest that mummichog condition index alone does not provide a clear measure of creek health. However, a more substantial database would be required to confirm or refute this hypothesis. Since interpretation of mummichog condition index may only be possible when data on other important variables (e.g. contaminant concentrations, water quality, condition of food resources, etc.) are available, the examination of these other supporting data sets should be sufficient to evaluate the condition of a creek.

General Conclusions Regarding the Overall Condition of Biota

A basic premise of this study was that the Broad Creek watershed and associated estuarine habitat represented a suburbanized, disturbed ecosystem, and the Okatee River watershed and associated estuarine habitat represented an undeveloped, forested reference ecosystem. The physical-chemical and biological data collected for tidal creeks and open-water habitats in these systems, however, do not support this premise at most of the sites sampled. Rather, our overall assessment of the key invertebrate communities and indicator species sampled in this study indicate that both Broad Creek and the Okatee River generally have healthy biological assemblages that are consistent with other non-degraded estuarine sites that have been sampled in South Carolina.

We did detect some evidence of biological stress that was localized and primarily associated with the headwater portions of both systems. These biological data, combined with the environmental quality data collected at all of the sites, indicate that the headwater areas have degraded environmental quality that may limit the capacity of these systems to support designated uses and perform critical ecological functions. The evidence of degraded environmental conditions was greater in the headwaters of Broad Creek than in the headwaters of Okatee River. In the headwaters of Broad Creek, we found both water and sediment quality problems including exposure to “below normal” low dissolved oxygen levels, exposure to chemically contaminated sediments, and “above normal” salinity variation. Contaminant problems and associated evidence of some biological stress were also found at most of the intertidal mud flat and oyster reef sites sampled throughout Broad Creek; however, these effects generally did not result in a severe degradation of the resources sampled. Rather, the response was limited to evidence of sublethal (cellular) stress in the oyster assemblages, and broader population and community changes in the benthos in the form of communities that were dominated by species known to be tolerant of pollution and other environmental stresses. In many cases, the biological responses we measured in Broad Creek were better than those sampled in the Okatee River (e.g. several grass shrimp metrics, oysters density and size in the lower reaches of Broad Creek, and mummichog size and condition).

In the headwaters of the Okatee, the poor environmental quality was mainly attributable to "above normal" variation in salinity and the biological response was primarily limited to evidence of stress in the benthic invertebrate assemblages inhabiting tidal creek habitats in headwater portions of the River. Other evidence of biological stress was limited to higher than anticipated levels of a few metal contaminants in oyster tissue throughout the drainage system, along with evidence of a sublethal (cellular) response in the oyster populations sampled at those sites. The tissue contaminant levels observed may reflect the effects of non-point source runoff from agricultural fields. Additional runoff from urban developments planned or being built in this watershed may lead to further degradation of these resources, unless both urban and agricultural inputs are controlled.

Of the four types of biological resources sampled, the benthic macrofauna and oyster condition (primarily cellular measures) appeared to show the greatest sensitivity as early warning measures related to anthropogenic stress. These resources should be included in any future assessments of Broad Creek and the Okatee River. Other measures of shellfish condition not included in this study (such as growth rates and other measures of individual condition) should also be considered. While the grass shrimp appeared to be less sensitive to the environmental conditions observed in these systems, they have proven to be sensitive indicators of environmental condition in other areas where they have been studied. The lack of any obvious differences observed between the two drainage systems in the grass shrimp metrics most likely indicates that these systems are fairly similar with respect to their overall quality to support these and other crustacean assemblages. Until more evidence is available to support the usefulness of evaluating condition in mummichog populations, we would not recommend including this measure in future biological assessments.

The lack of sensitivity in grass shrimp and mummichog populations may, in part, be related to their epibenthic nature, residing in the water column at or above the sediment surface. In contrast, the benthic organisms we sampled primarily live within the sediment. Similarly, oysters are in more direct contact with sediments scoured off the bottom and feed on suspended particulate matter, which includes filtering sediment particles. As a result of these ecological differences, benthic and sedentary epibenthic organisms (e.g. oysters) would have greater exposure to sediment-bound contaminants than epibenthic motile organisms, such as grass shrimp and mummichogs. Our results suggest that contaminant effects are confined to sediment exposure and concentrations were not sufficiently high to cause significant exposure to the grass shrimp and mummichogs. However, the benthic community and oyster effects observed provide an "early warning" indicator of ecological effects that should not be ignored. These effects were confirmed at many of the sites by the sub-lethal toxicity assays (e.g. seed clam and Microtox), which provides another early warning signal.

Broad Creek

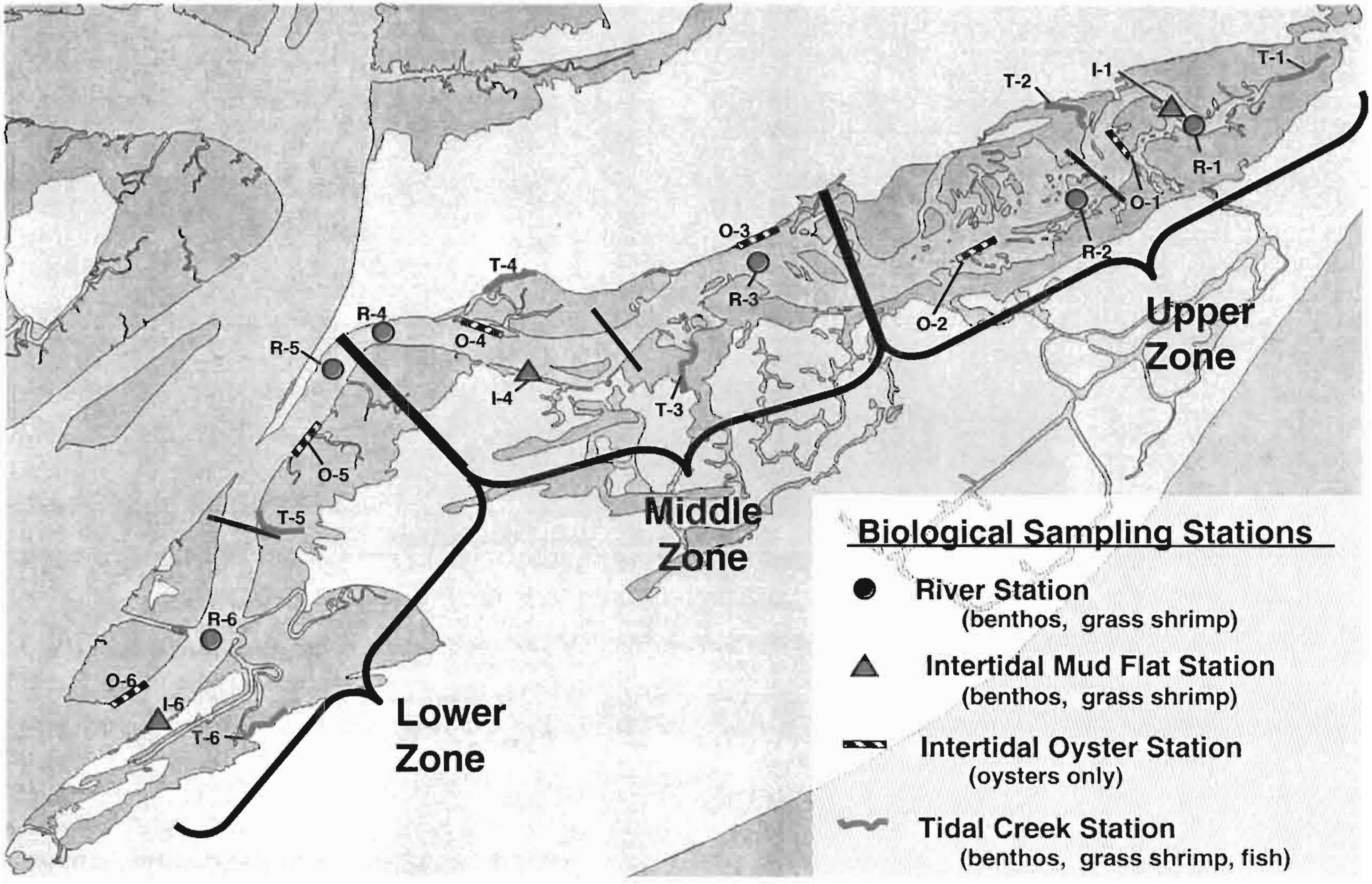


Figure 5.1. Map of Broad Creek stations sampled for biota in 1998.

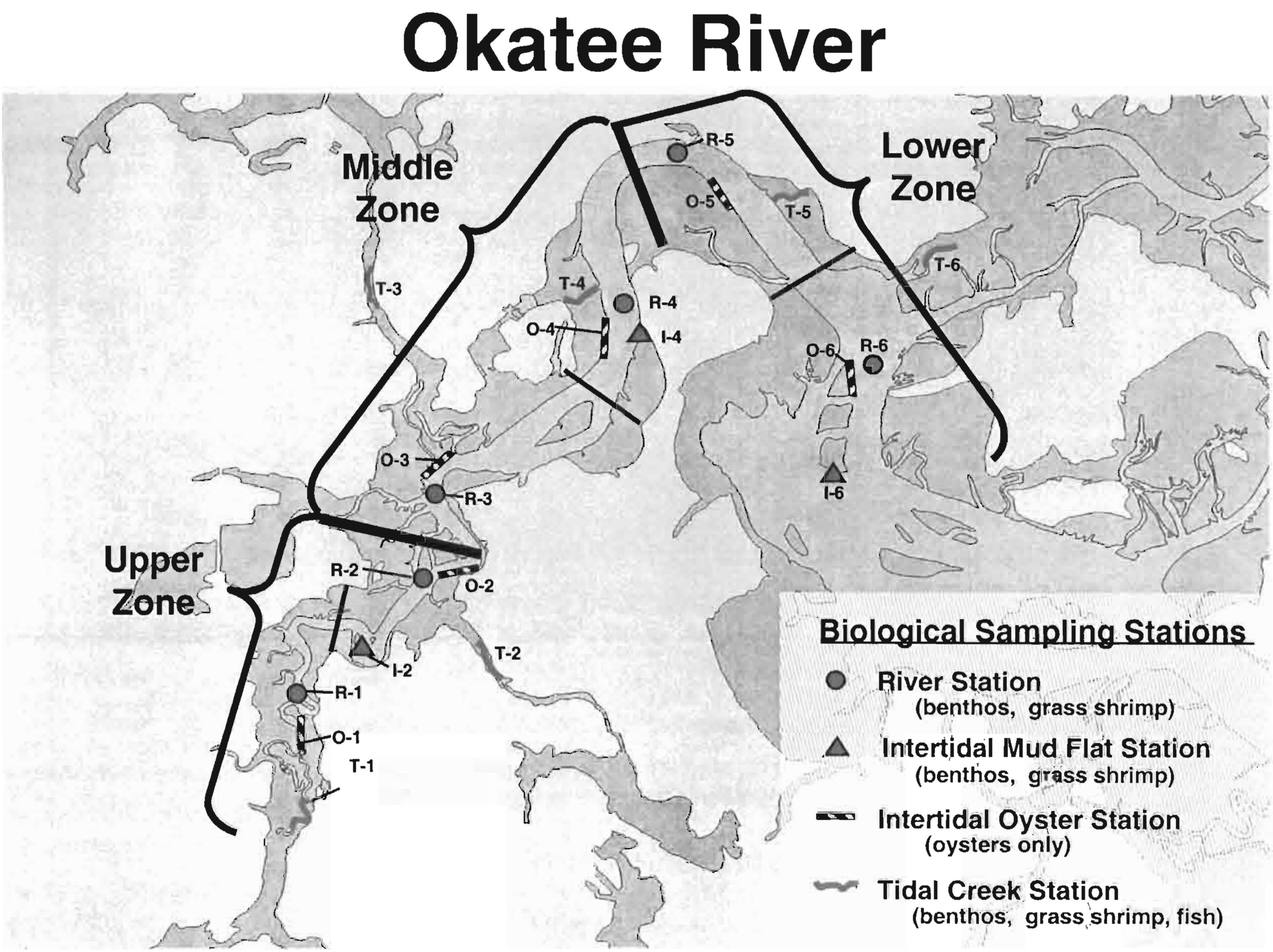


Figure 5.2. Map of Okatee River stations sampled for biota in 1998.

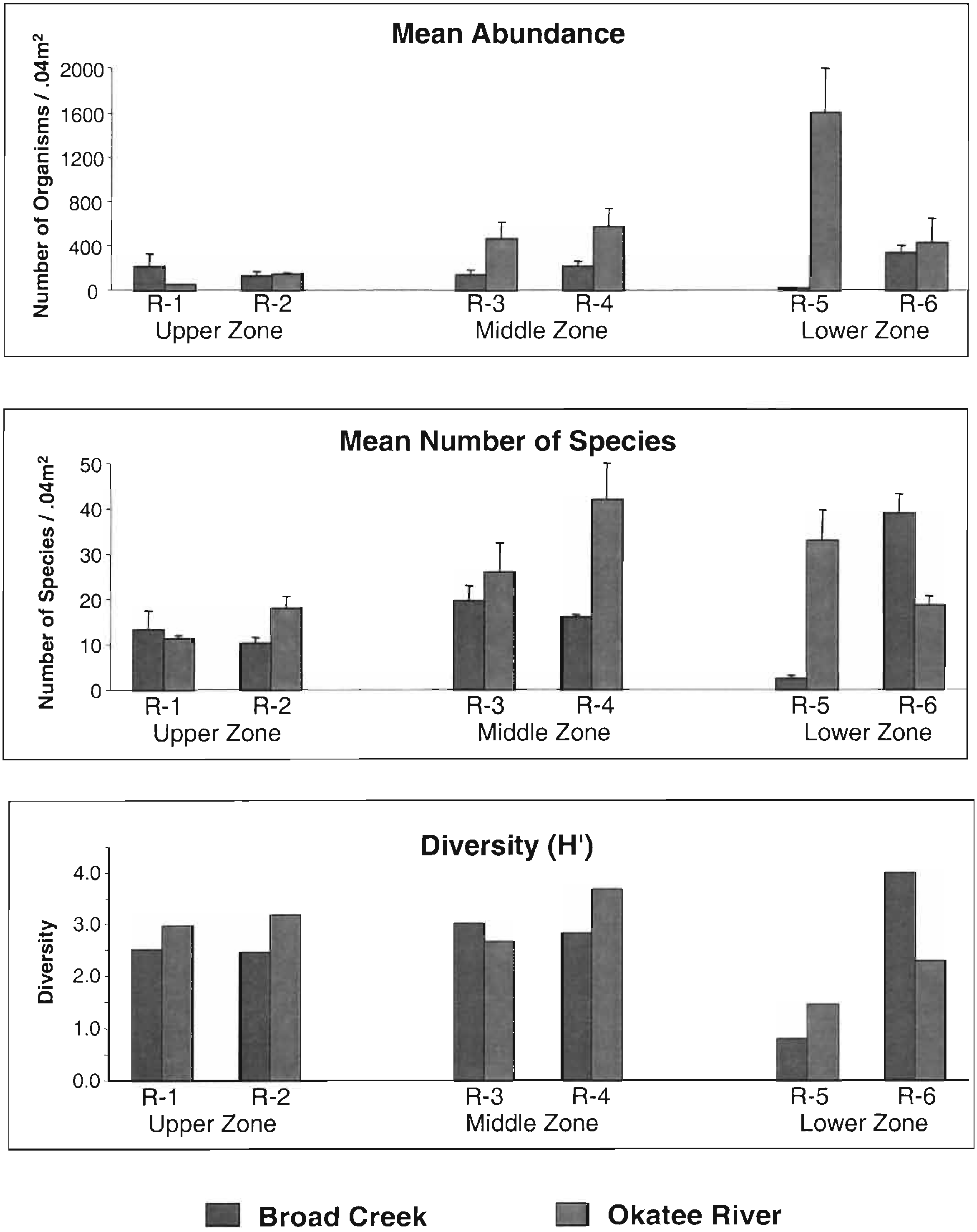


Figure 5.3. Summary of the mean abundance, mean number of species, and species diversity from subtidal river stations in Broad Creek and the Okatee River. Error bars represent 1 standard error.

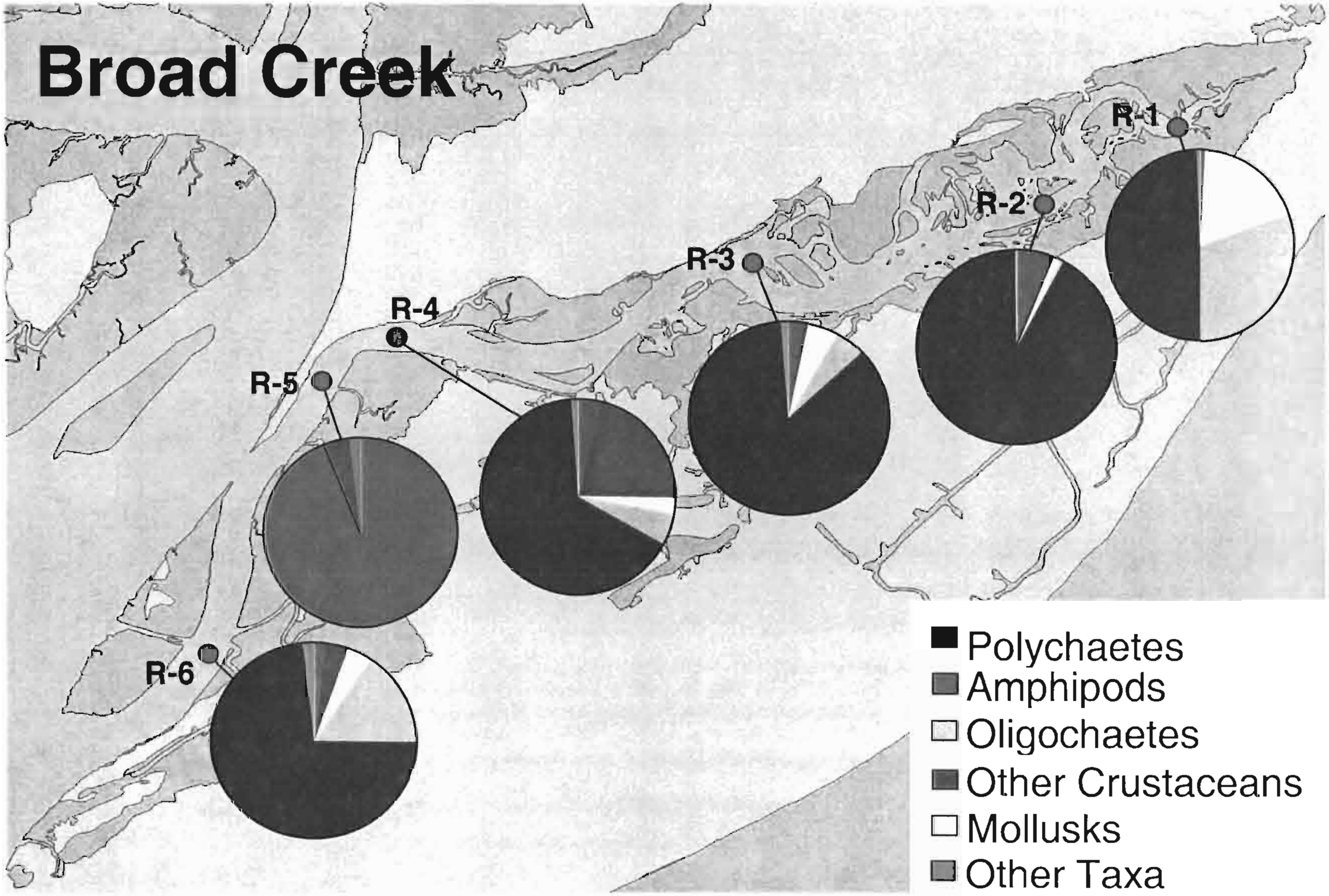


Figure 5.4. Composition of the benthic macrofauna collected from subtidal stations in Broad Creek

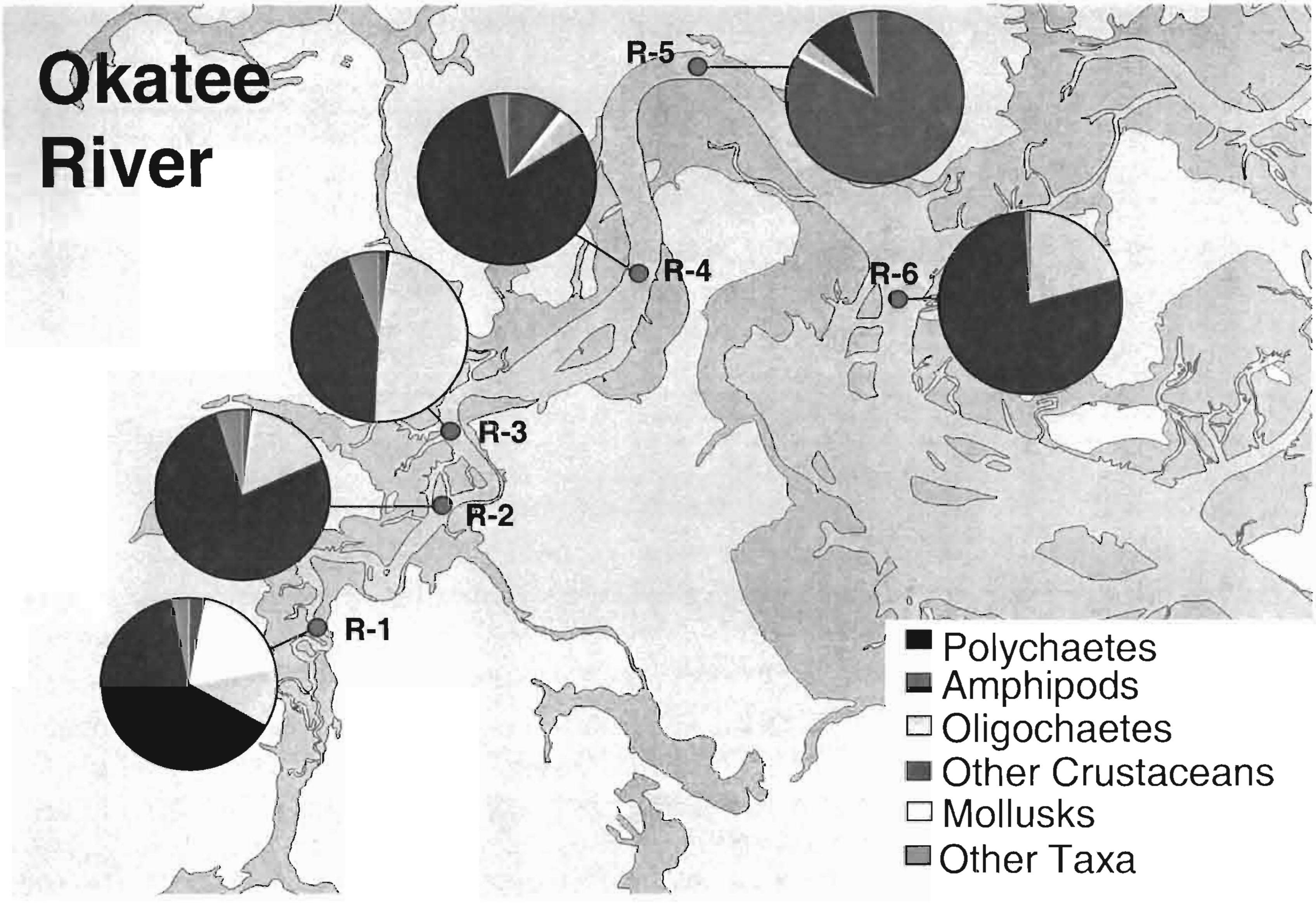
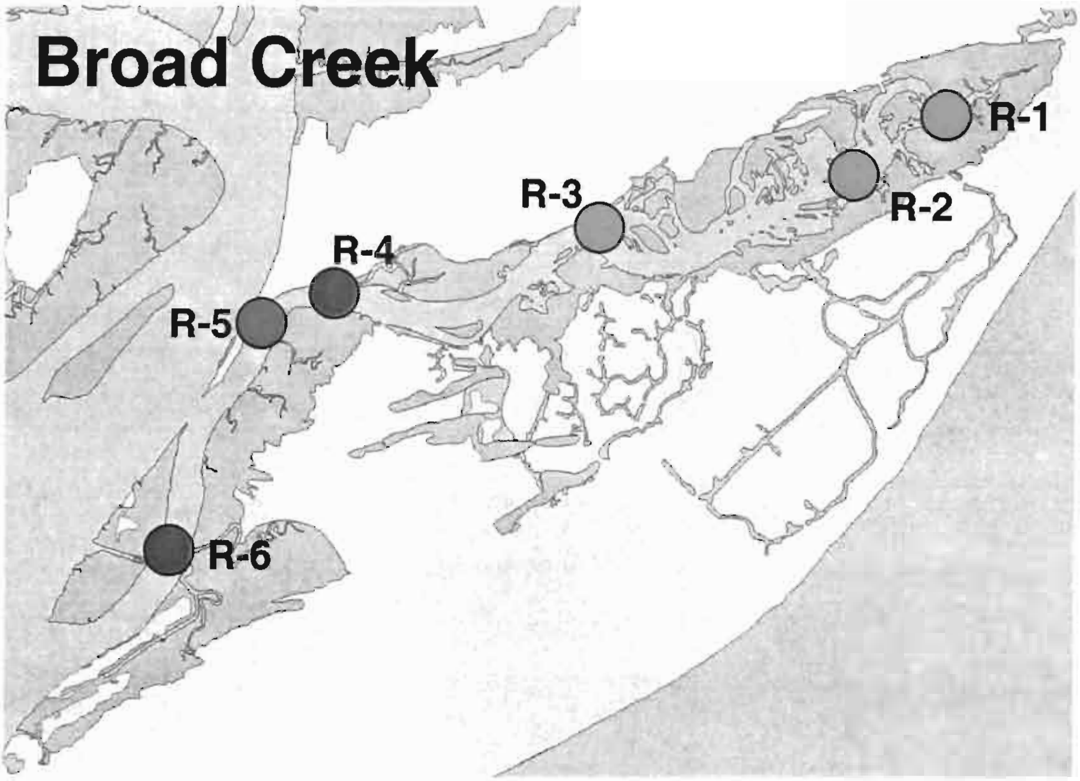


Figure 5.5. Composition of benthic macrofauna collected from subtidal stations in the Okatee River.



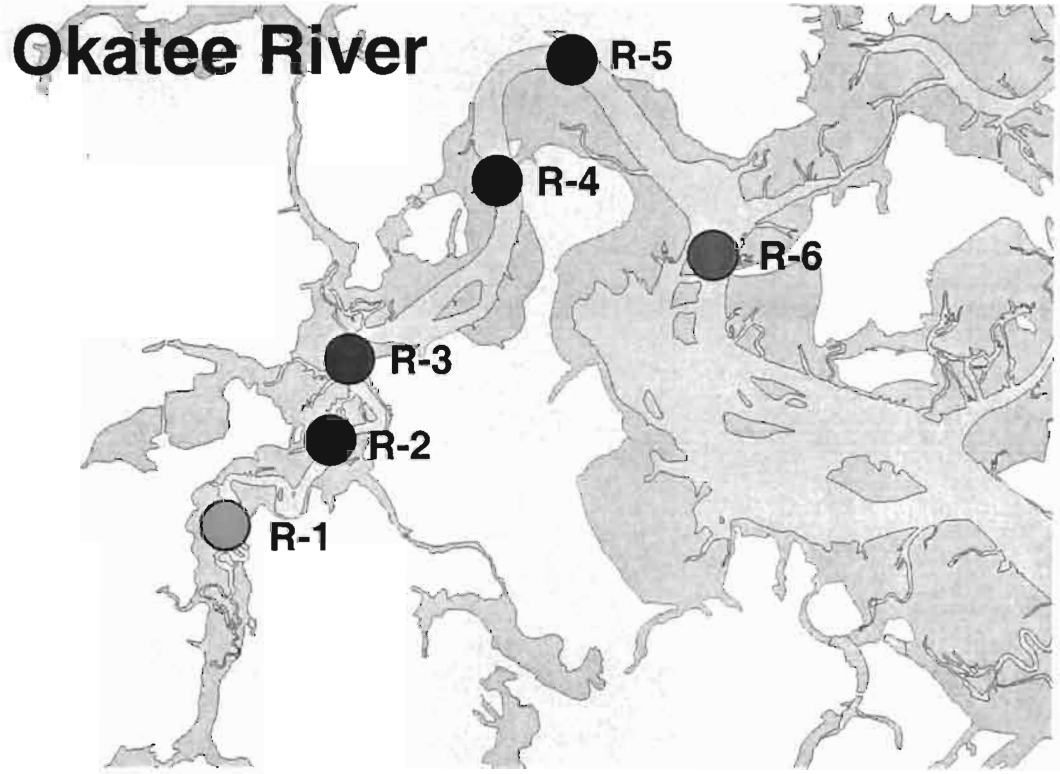


Figure 5.6. Subtidal benthic stations groups which showed greater similarity in faunal composition among sites (same color) than with other site groups (different colors).

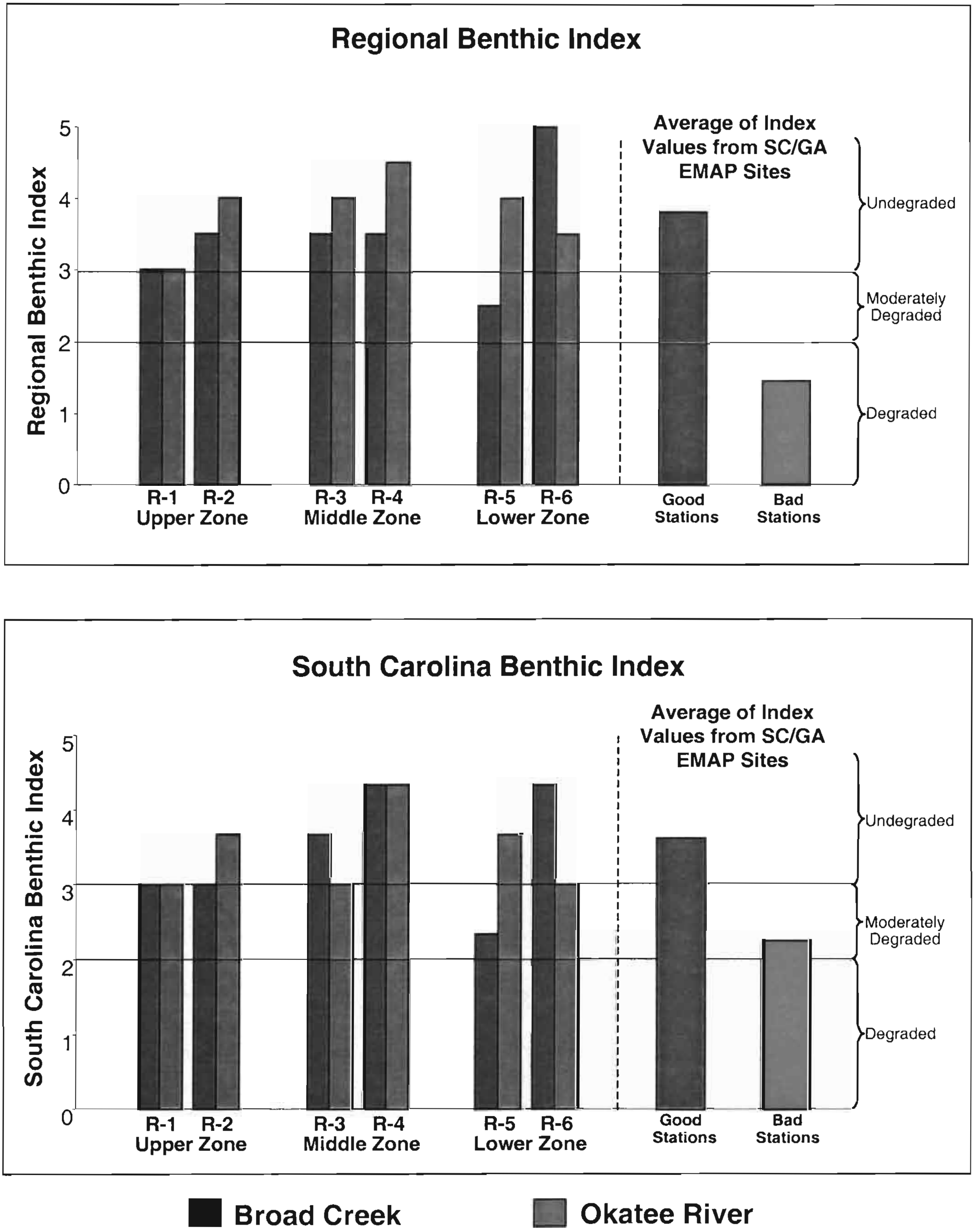


Figure 5.7. Benthic Index of Biological Integrity (B-IBI) results for subtidal river stations sampled in Broad Creek and the Okatee River.

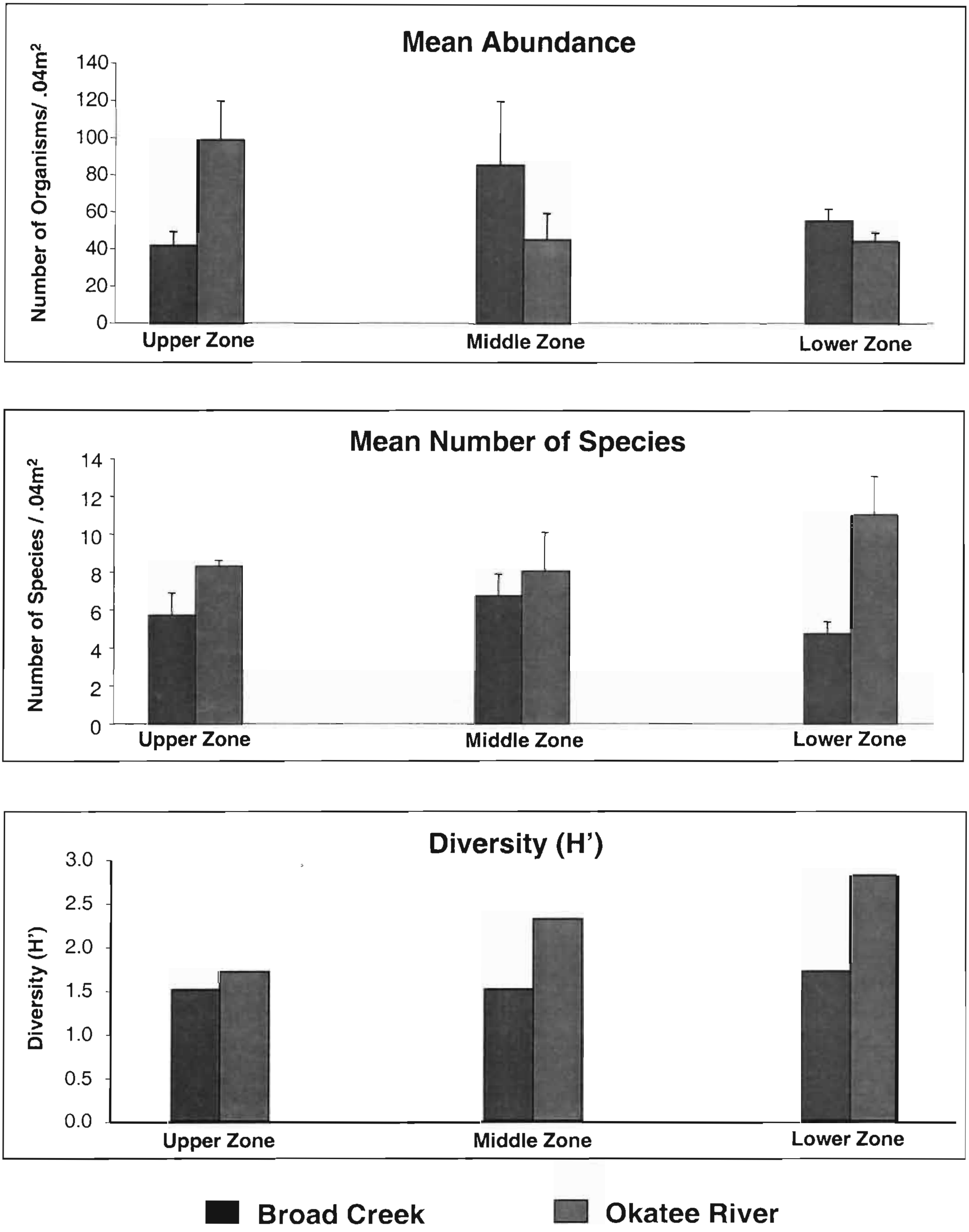


Figure 5.8. Summary of the mean abundance, mean number of species, and species diversity at intertidal mud flats in Broad Creek and the Okatee River. Error bars represent 1 standard error.

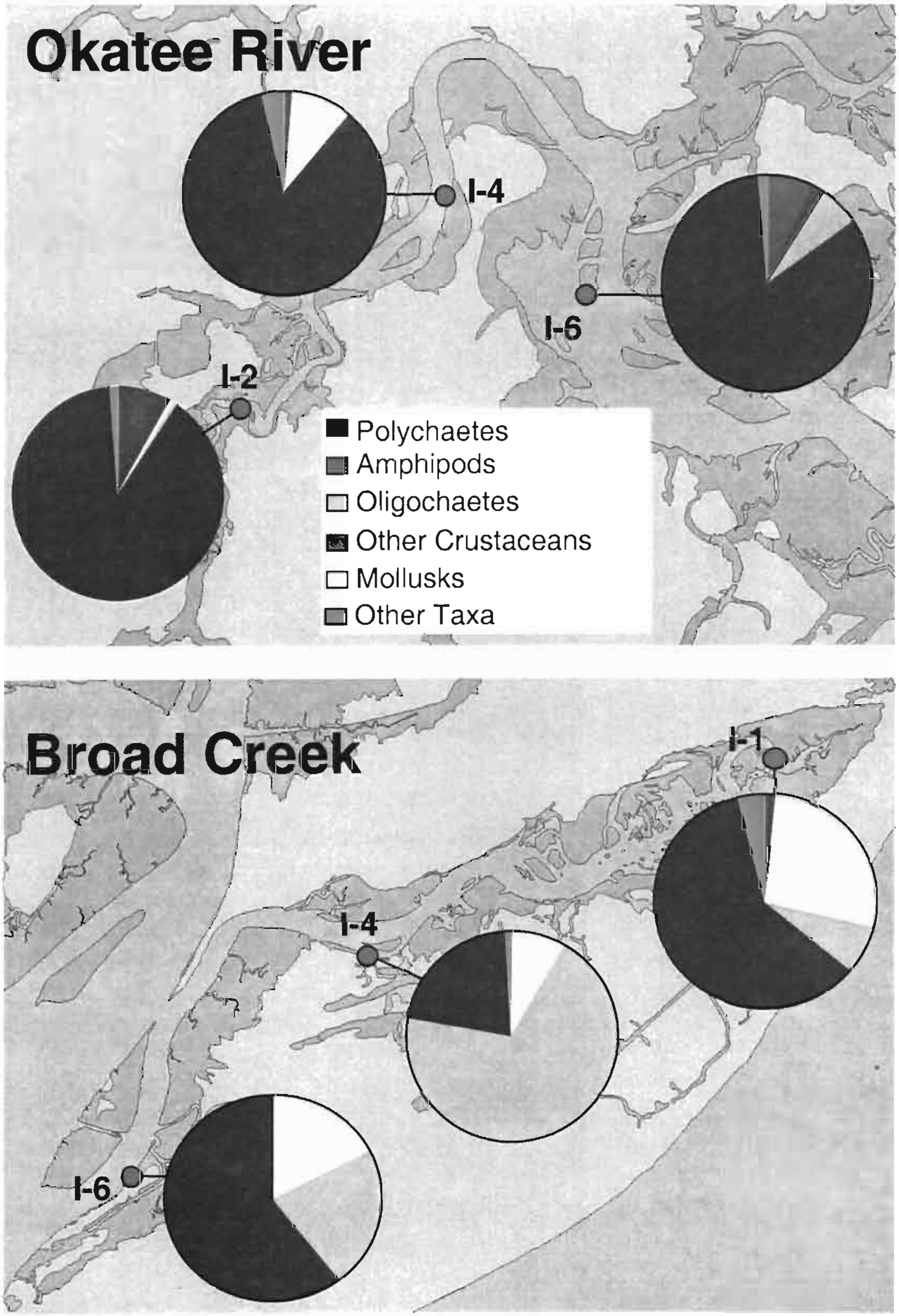


Figure 5.9. Composition of benthic macrofauna collected from intertidal mud flats in Broad Creek and the Okatee River.

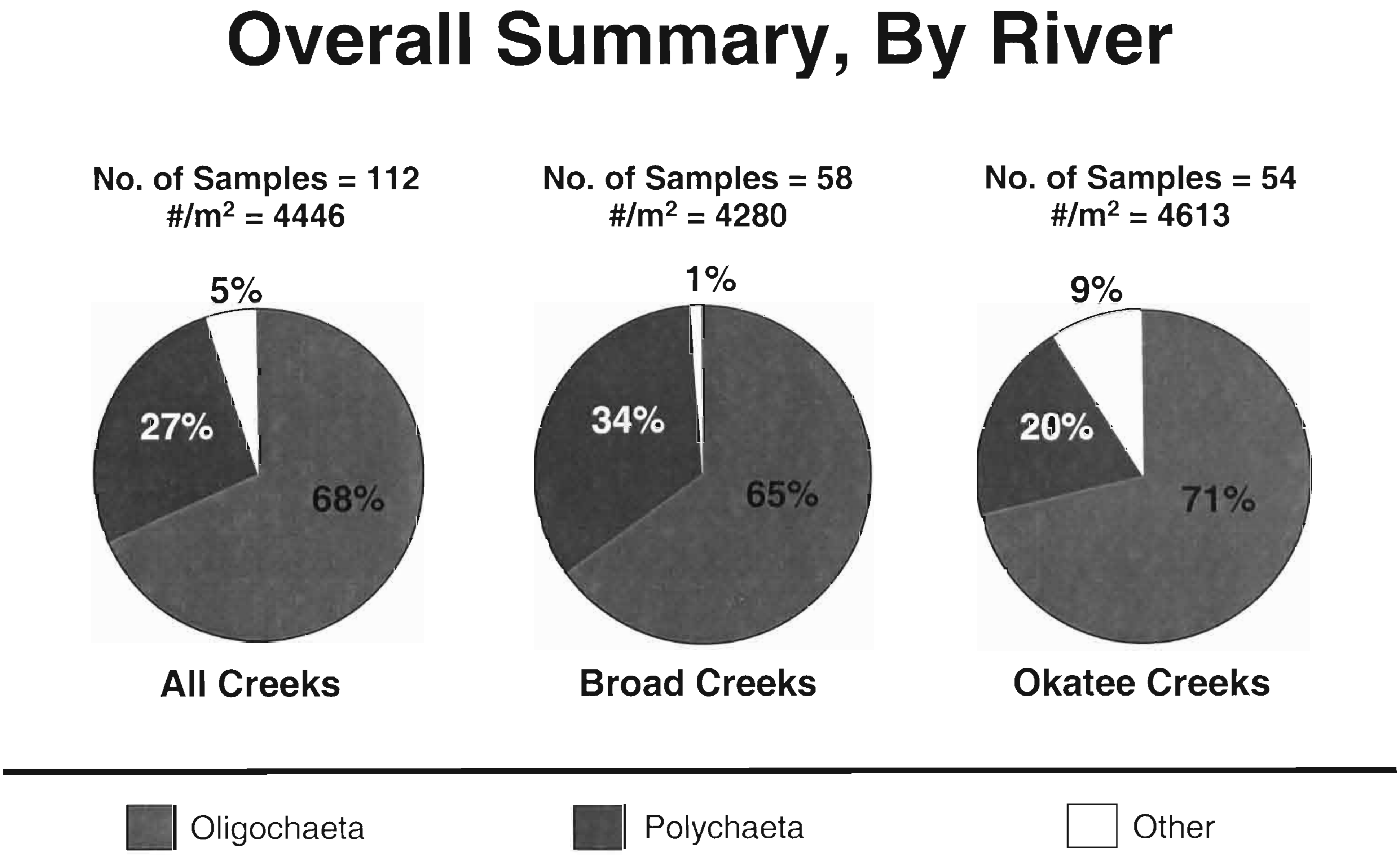


Figure 5.10. Taxonomic composition of benthic communities in tidal creeks of Broad Creek and the Okatee River.

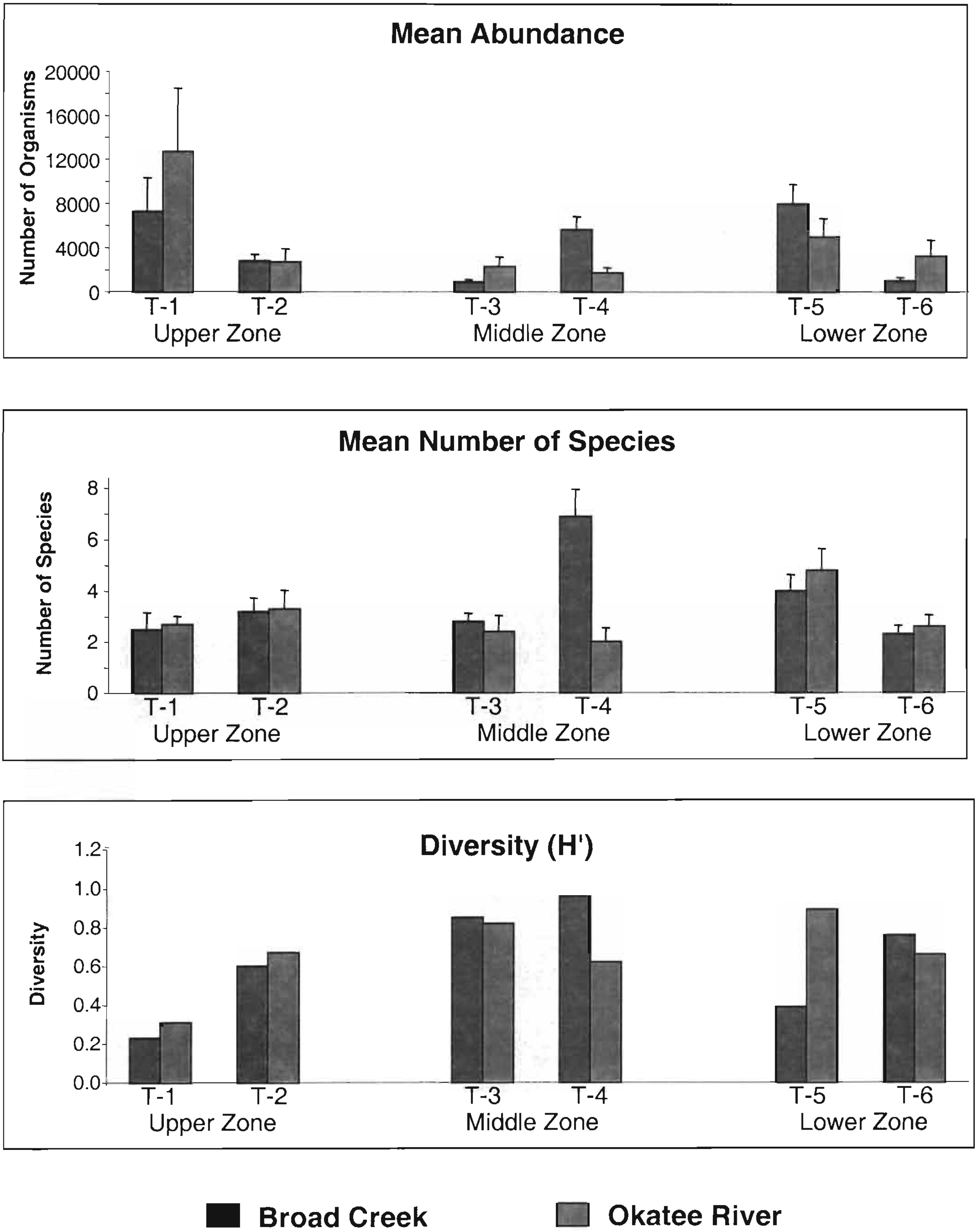


Figure 5.11. Summary of the mean abundance, mean number of species, and species diversity from tidal creeks in Broad Creek and the Okatee River. Error bars represent 1 standard error.

Percent Abundance of
Monopylephorus rubroniveus

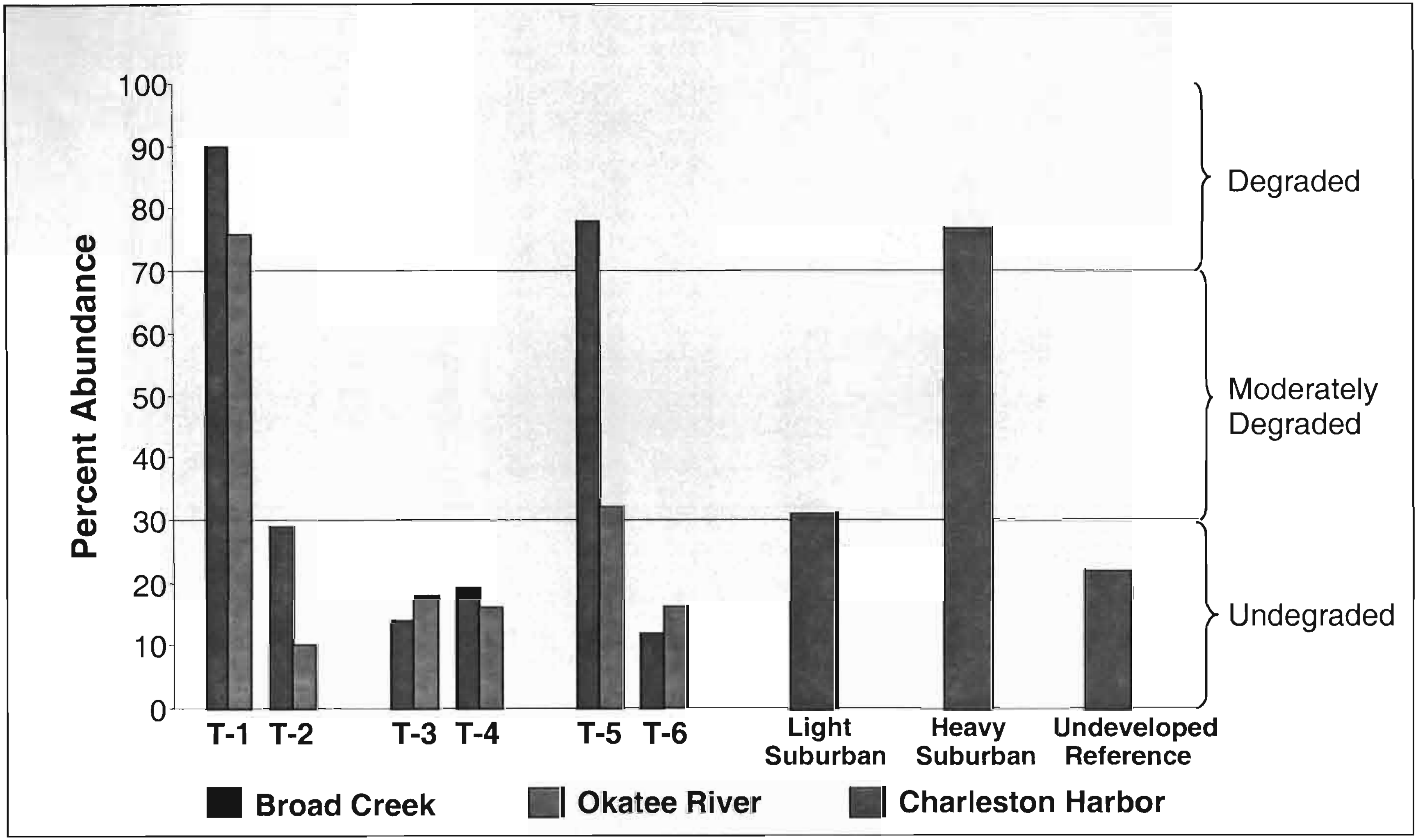


Figure 5.12. Habitat quality results for tidal creeks in Broad Creek and the Okatee River, based on the percent abundance of the oligochaete *Monopylephorus rubroniveus*.

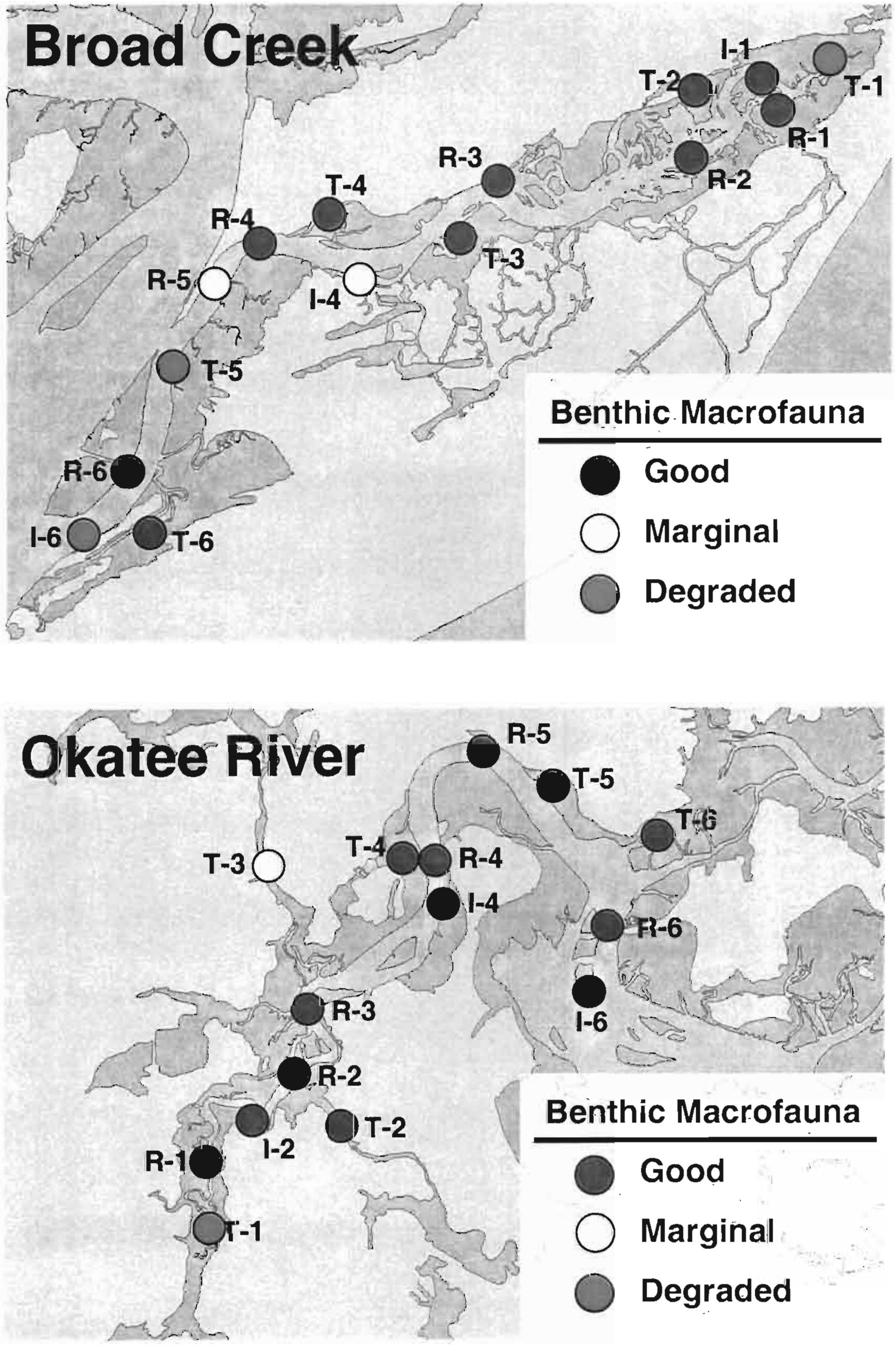


Figure 5.13. Summary of the condition of benthic macrofauna in Broad Creek and the Okatee River.

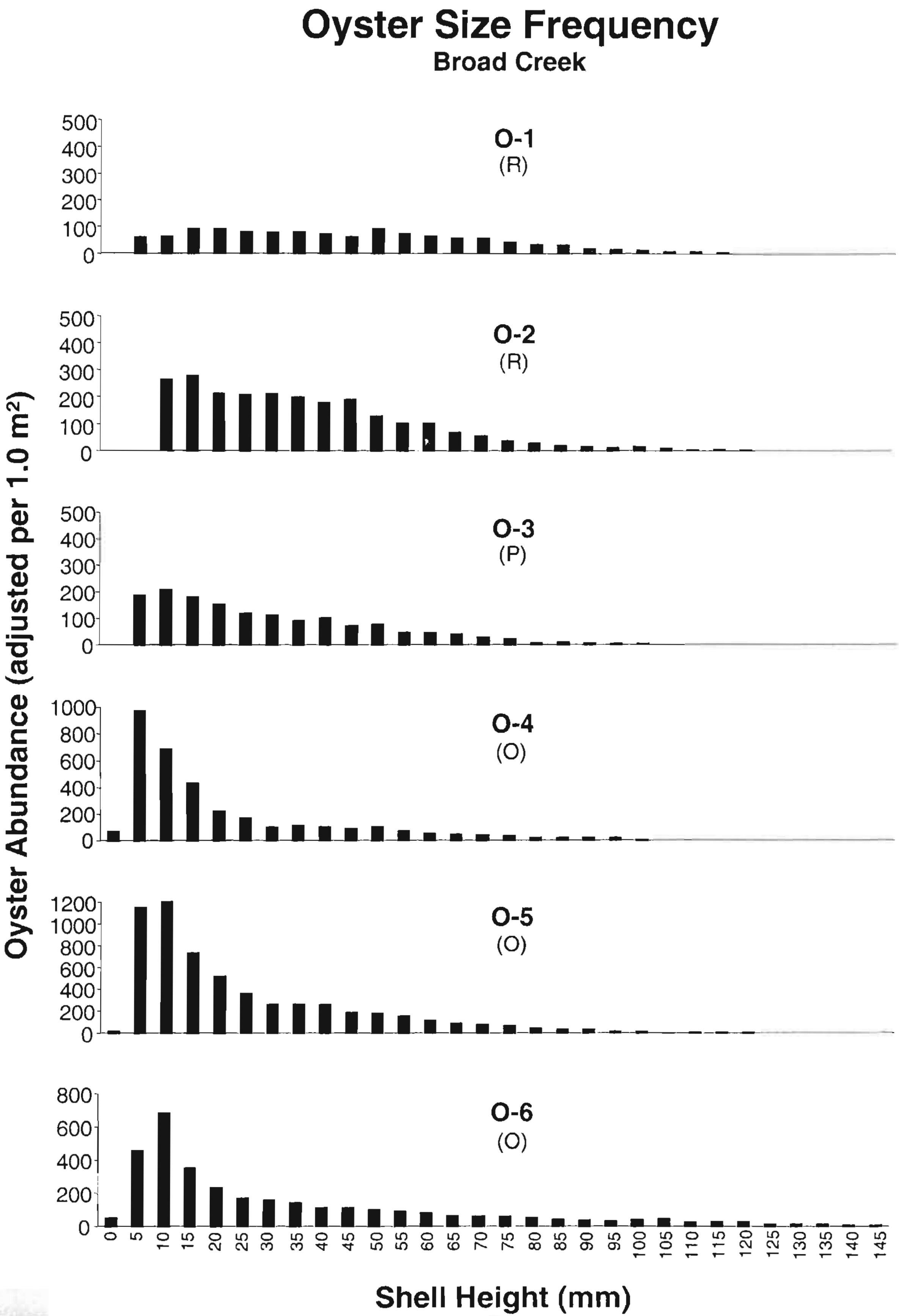


Figure 5.14. Size frequency distribution of live oysters collected in Broad Creek. (R) = Restricted, (O) = Open, (P) = Prohibited.

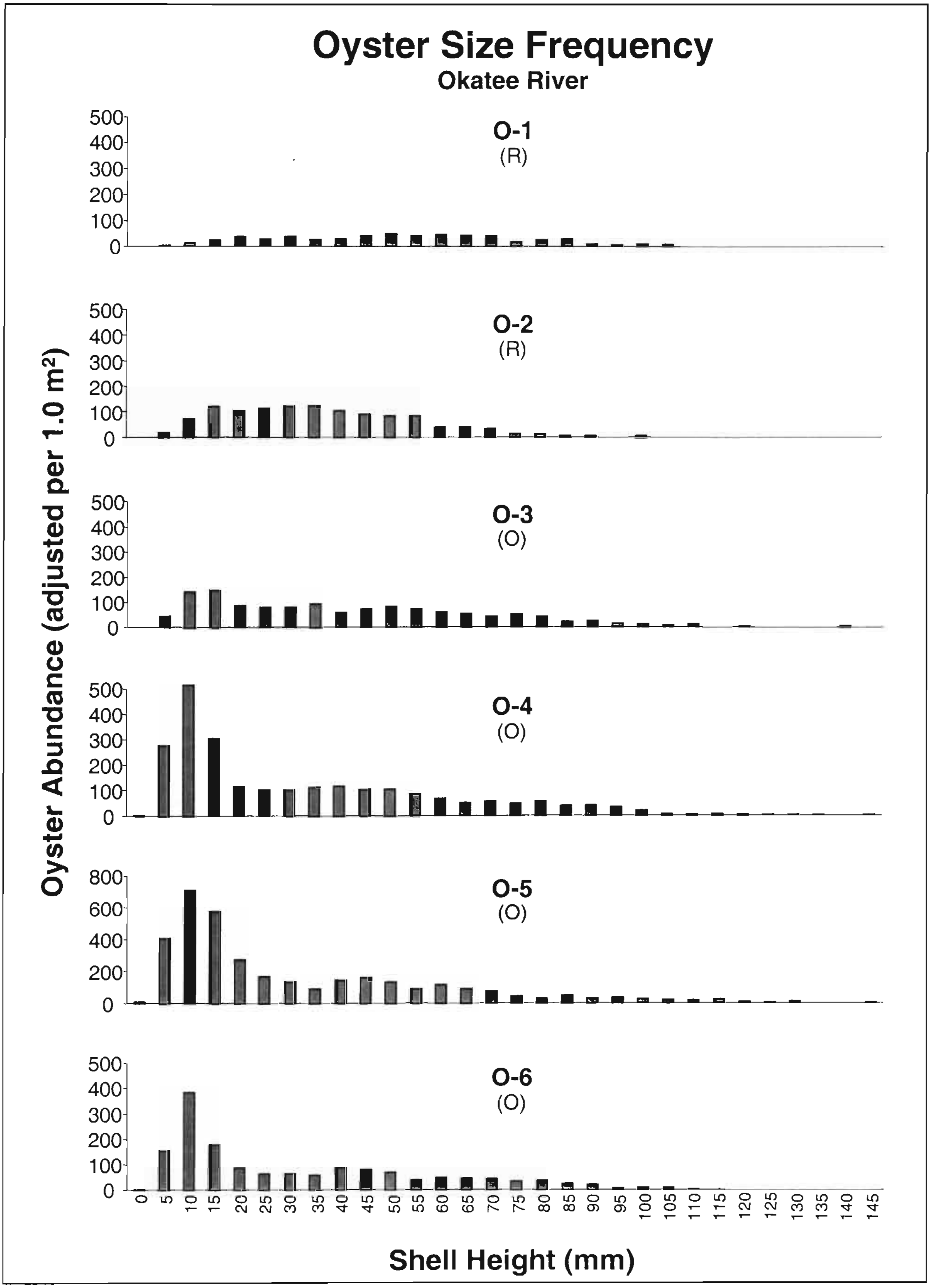


Figure 5.15. Size frequency distribution of live oysters collected in the Okatee River. (R) = Restricted; (O) = Open.

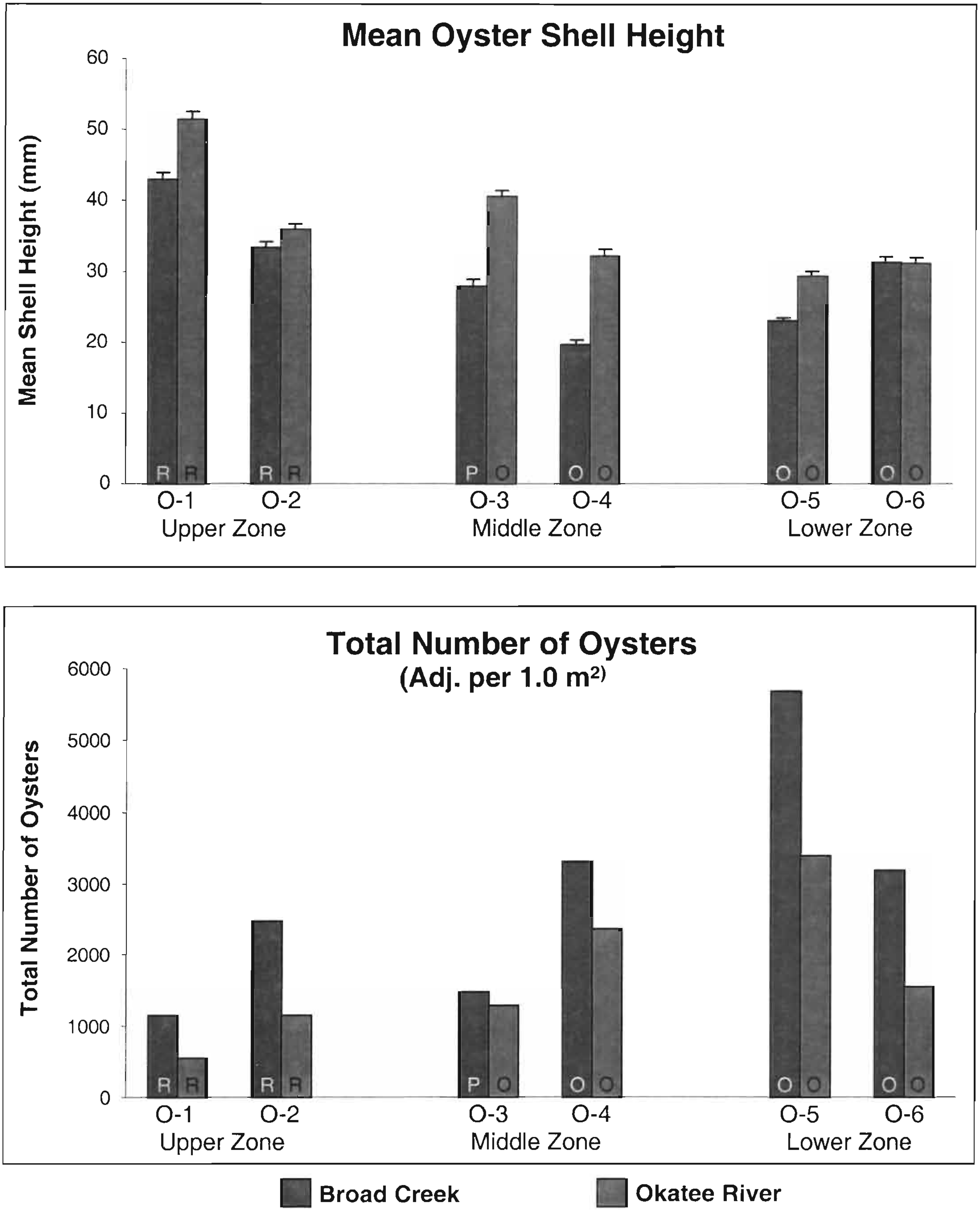


Figure 5.16. Mean oyster shell heights and total number of oysters (summed over 5 samples) at 12 stations in Broad Creek and the Okatee River. R = Restricted; P = Prohibited; O = Open. Error bars represent 1 standard error.

Dermo Prevalence and Intensity

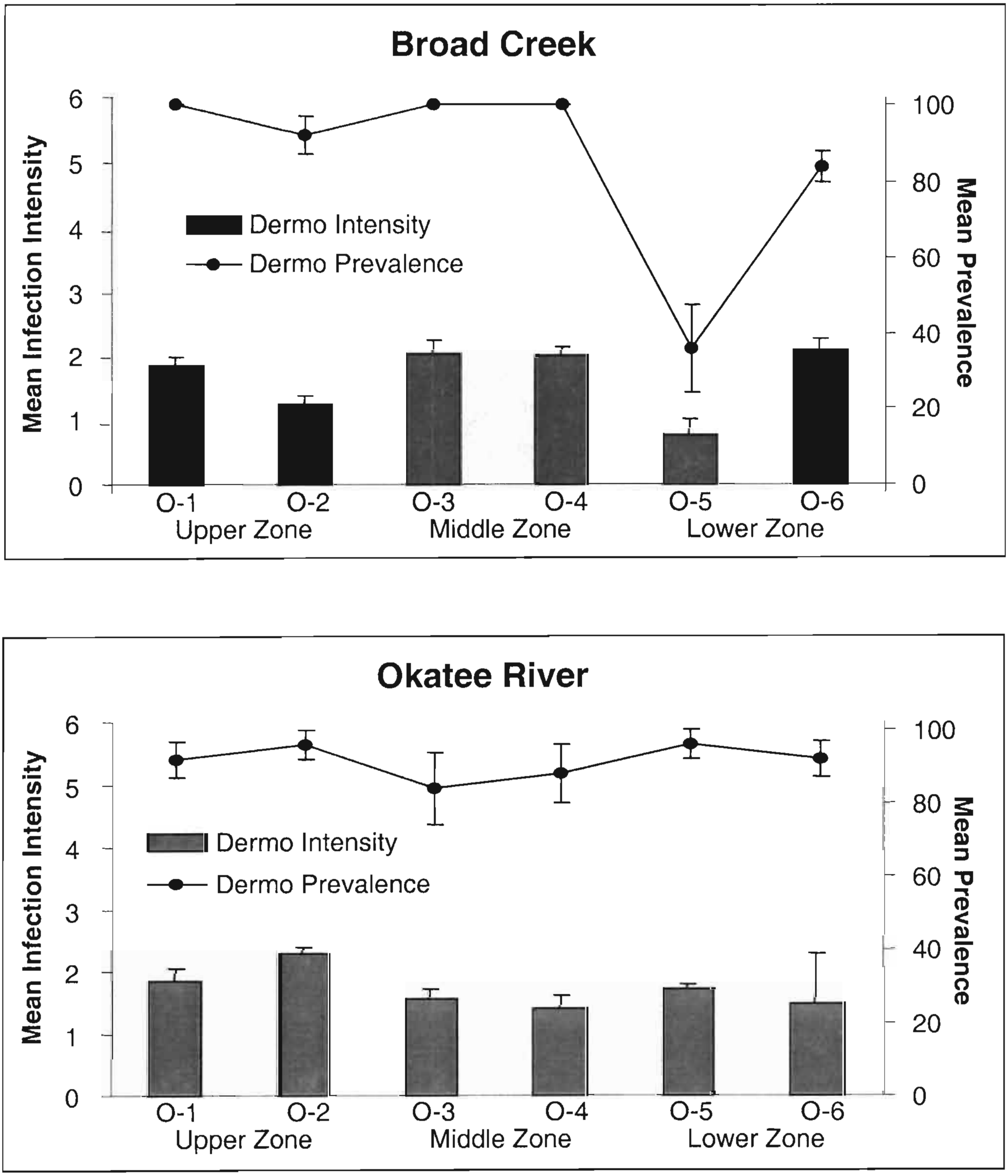


Figure 5.17. The prevalence and intensity of Dermo in oysters sampled in Broad Creek and the Okatee River. Error bars represent 1 standard error.

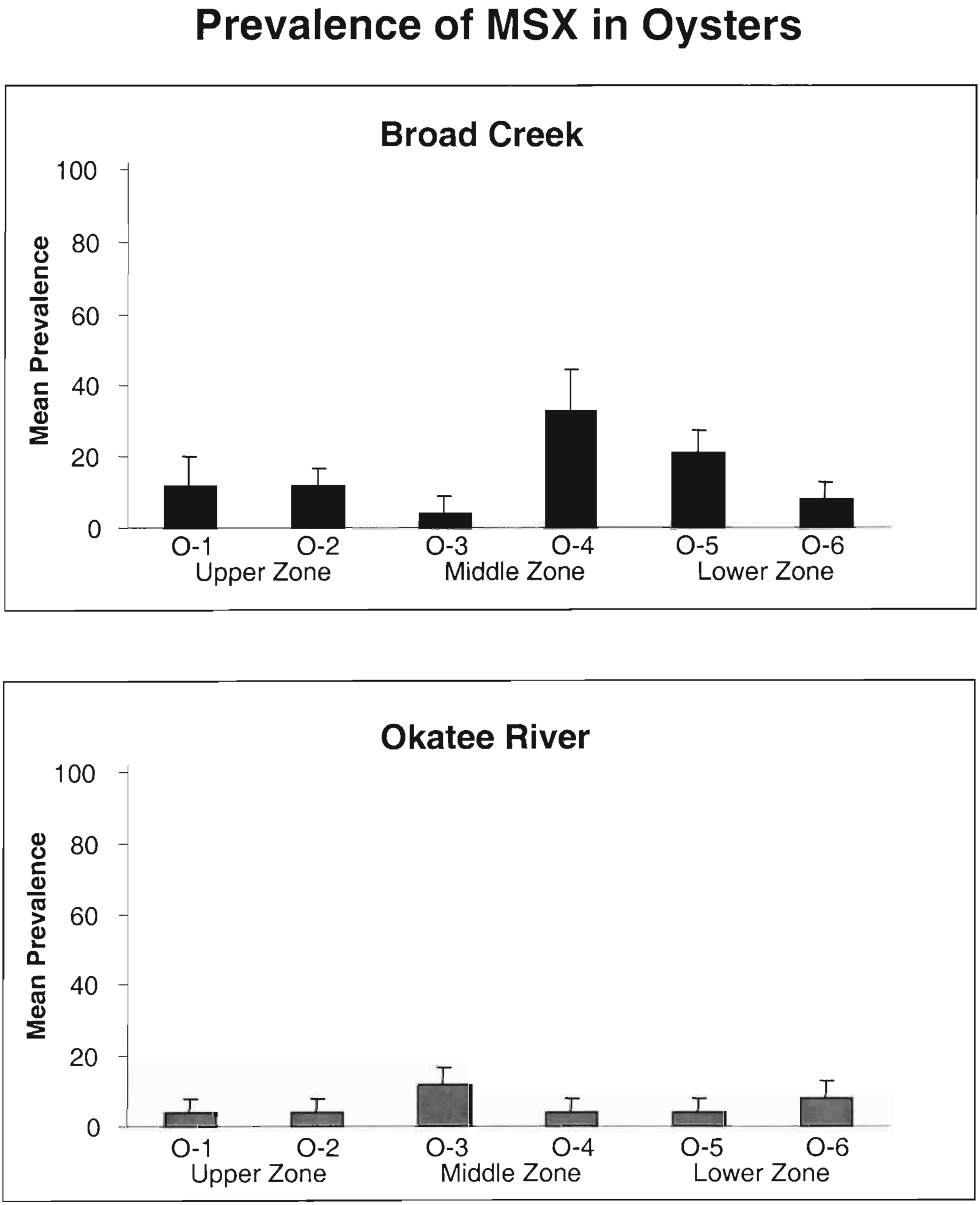


Figure 5.18. Prevalence of MSX in oysters sampled in Broad Creek and the Okatee River during summer 1997. Error bars represent 1 standard error.

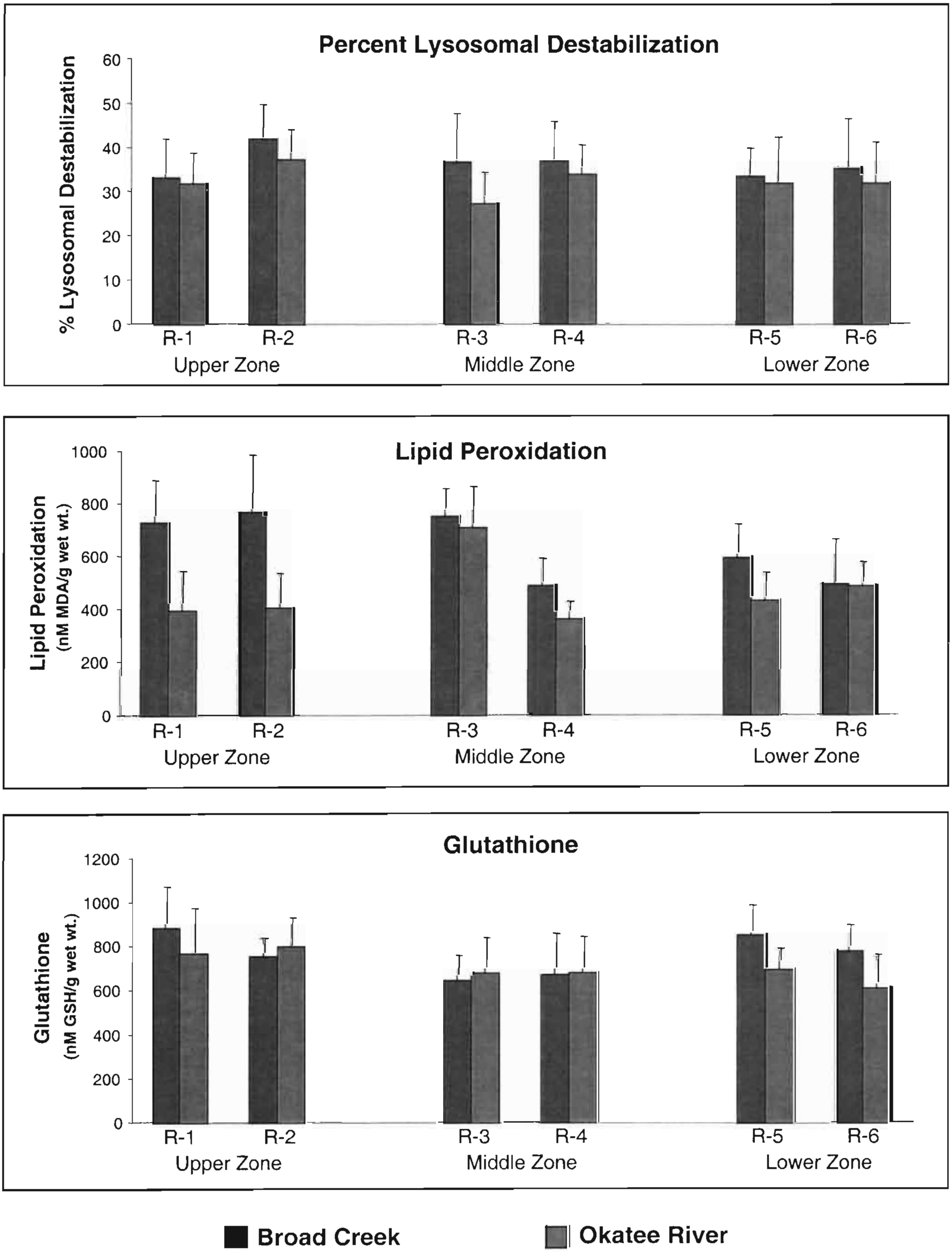


Figure 5.19. Cellular responses of oysters collected from Broad Creek and the Okatee River. A) Percent lysosomal destabilization; B) Lipid Peroxidation; C) Glutathione concentrations. Error bars represent 1 standard deviation.

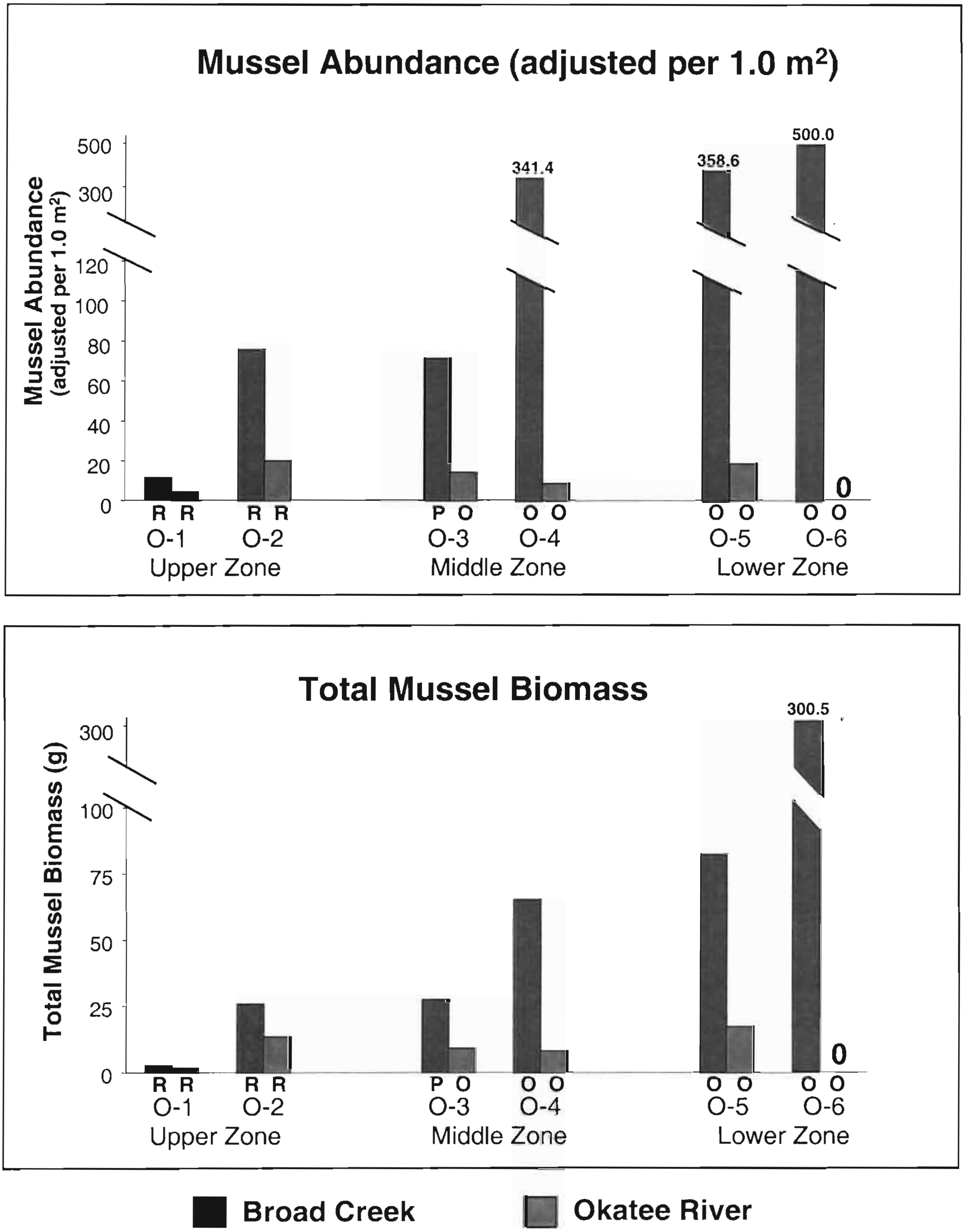
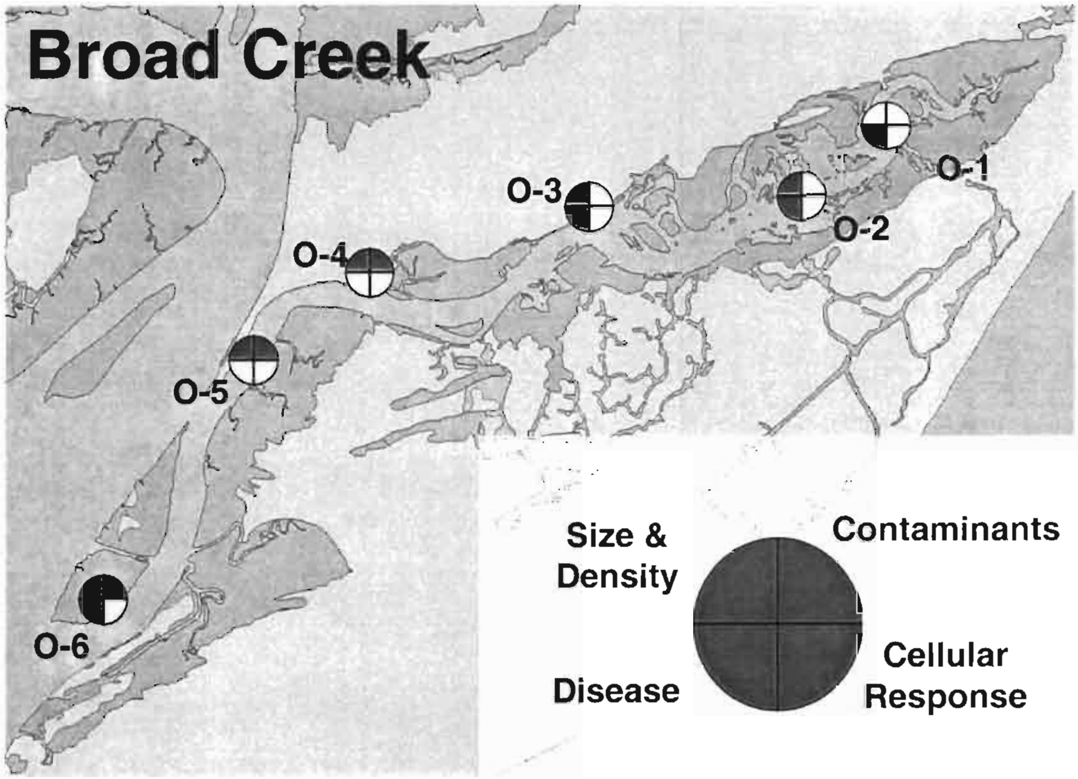


Figure 5.20. Mean mussel biomass at stations sampled in Broad Creek and the Okatee River. R = Restricted; P = Prohibited; O = Open.



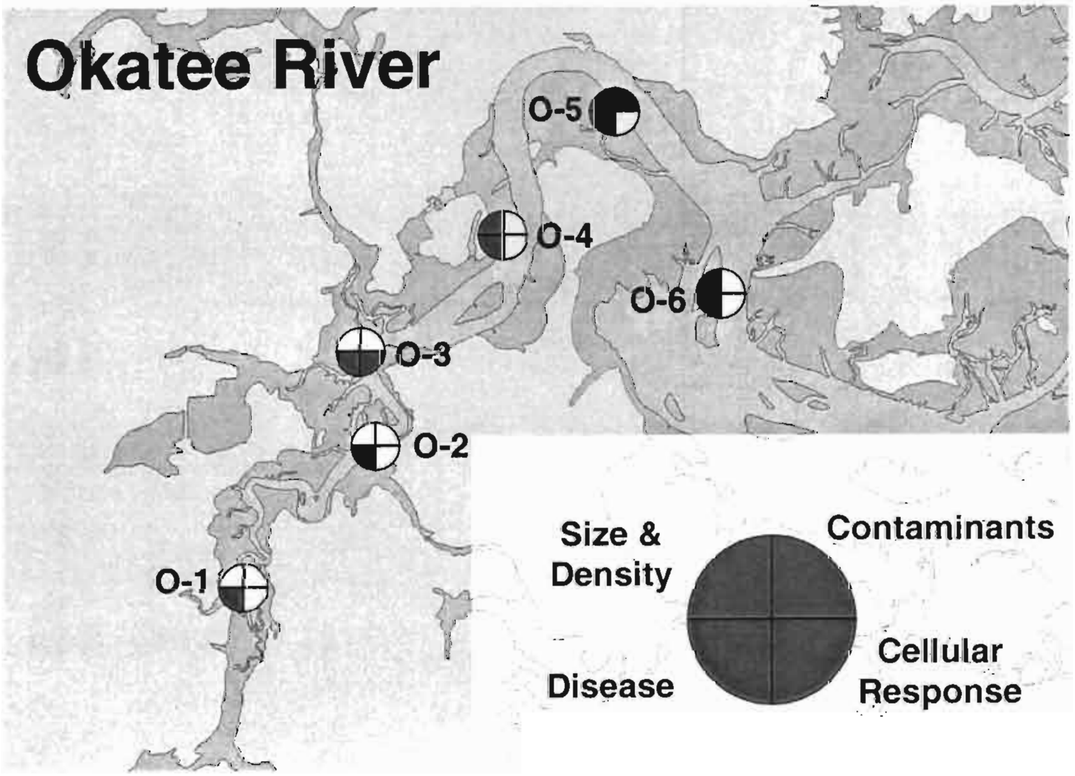


Figure 5.21. Summary of oyster bed condition in Broad Creek and the Okatee River.

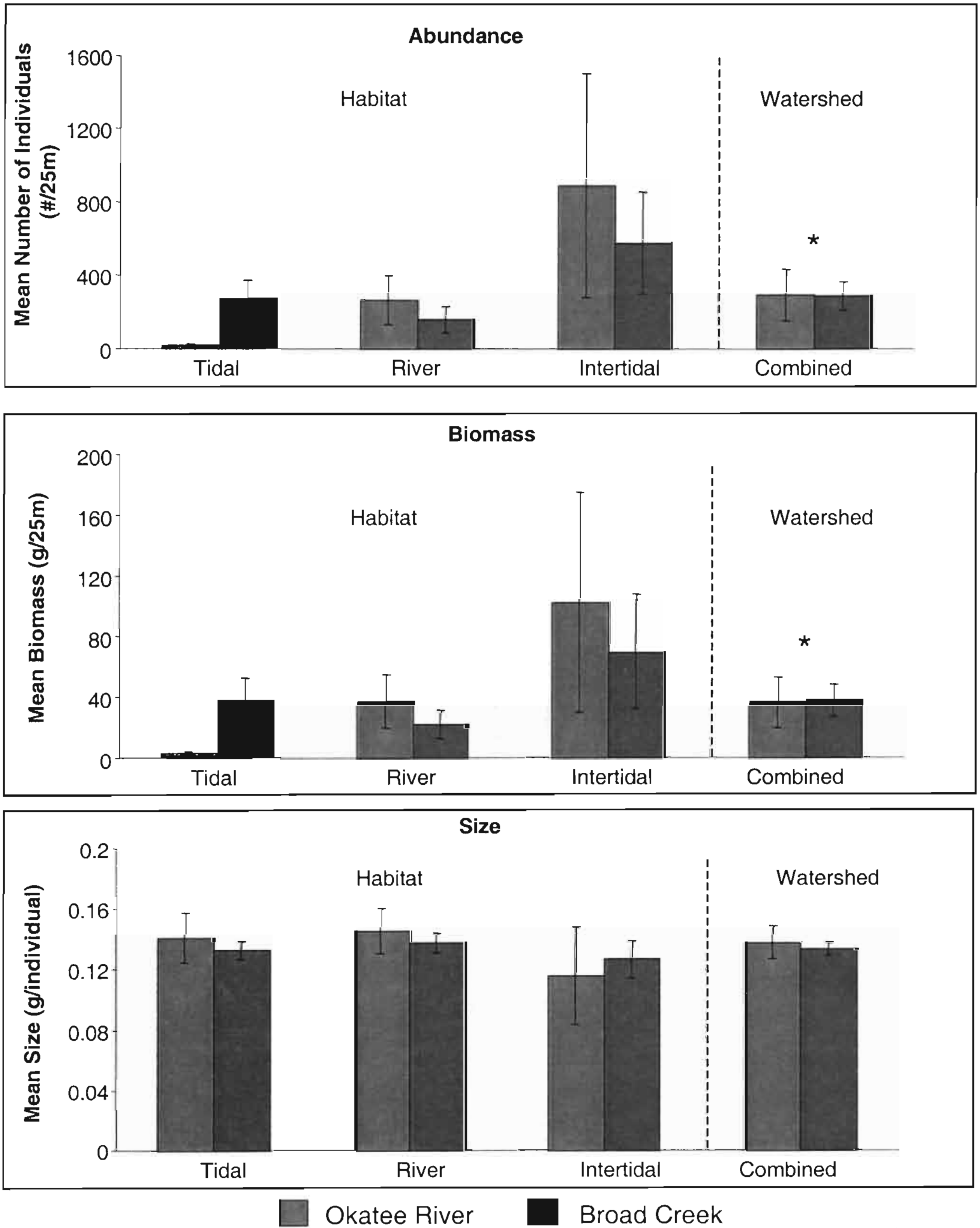


Figure 5.22. Habitat and pooled watershed comparisons of *Palaemonetes pugio* abundance, biomass and size. An asterisk indicates significant ($p<0.05$) difference. Error bars represent ±1 standard error.

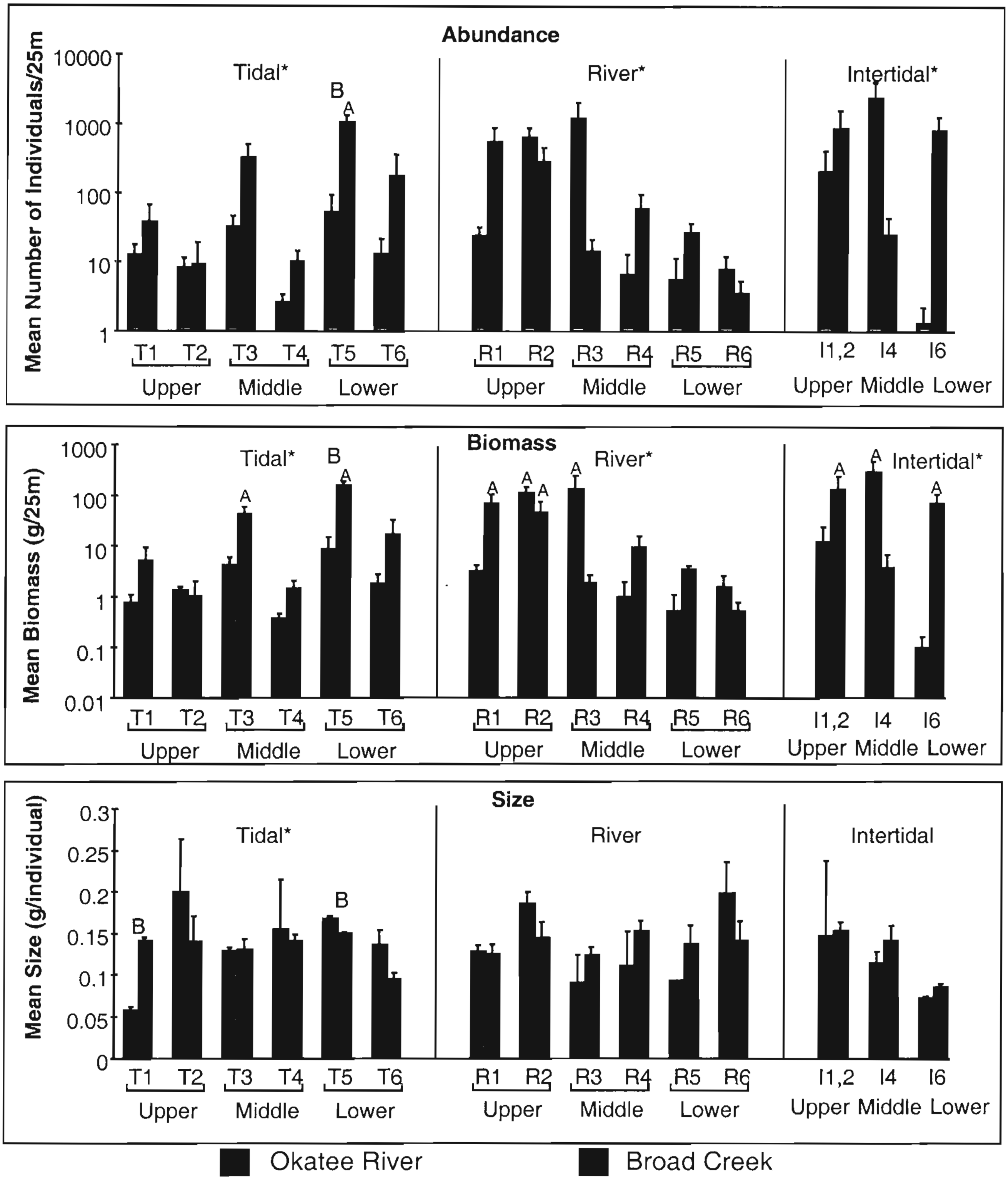


Figure 5.23. Station by station comparisons of *Palaemonetes pugio* abundance, biomass and size. An asterisk indicates significant ($p<0.05$) difference by habitat, "A" indicates significantly ($p<0.05$) greater than 1 or more other sites, and "B" indicates significantly ($p<0.05$) different between systems by corresponding sites. Error bars represent 1 standard error.

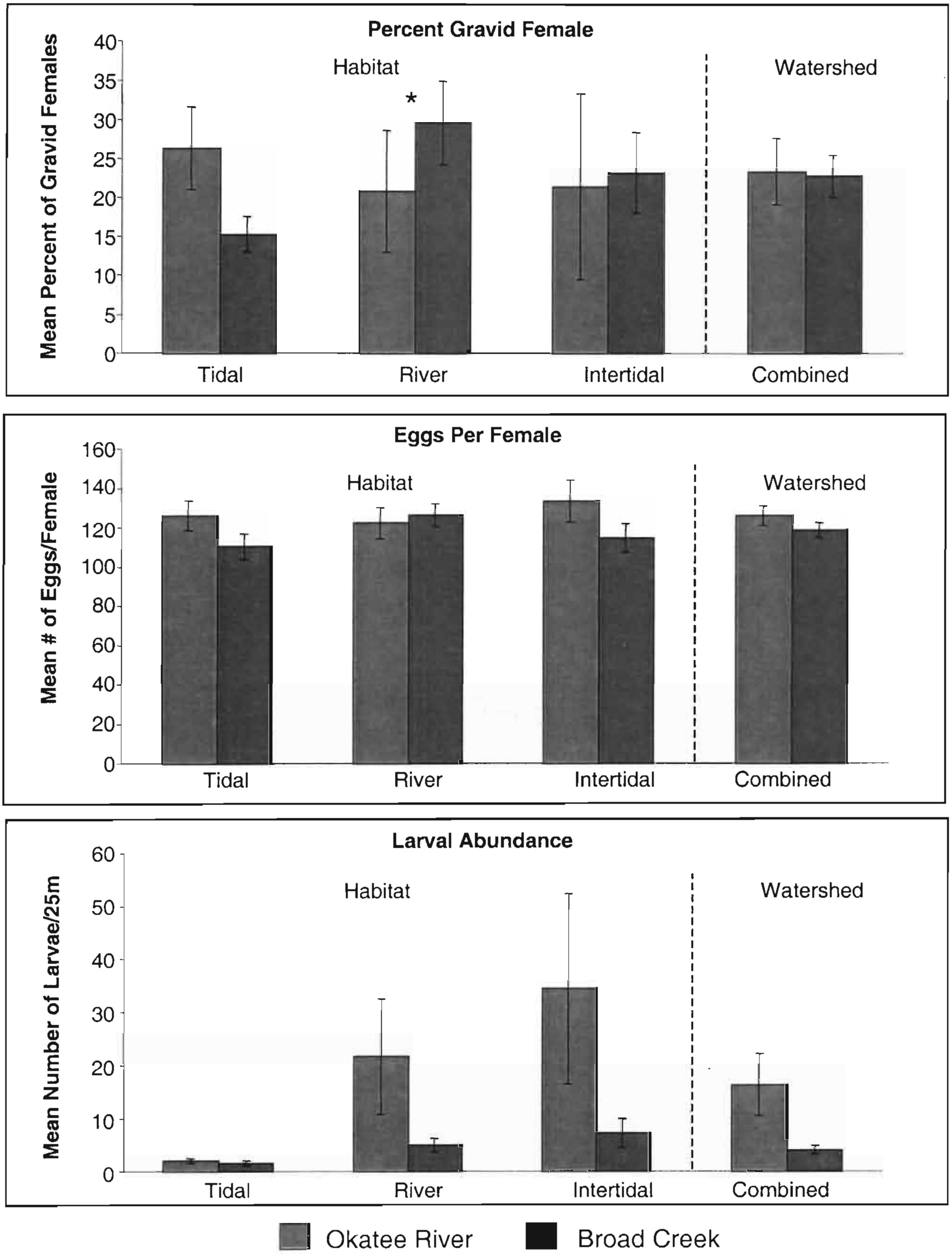


Figure 5.24. Habitat and pooled watershed comparisons of *Palaemonetes pugio* percent gravid females, eggs per female, and larval abundance. An asterisk indicates significant ($p<0.05$) difference. Error bars represent ±1 standard error.

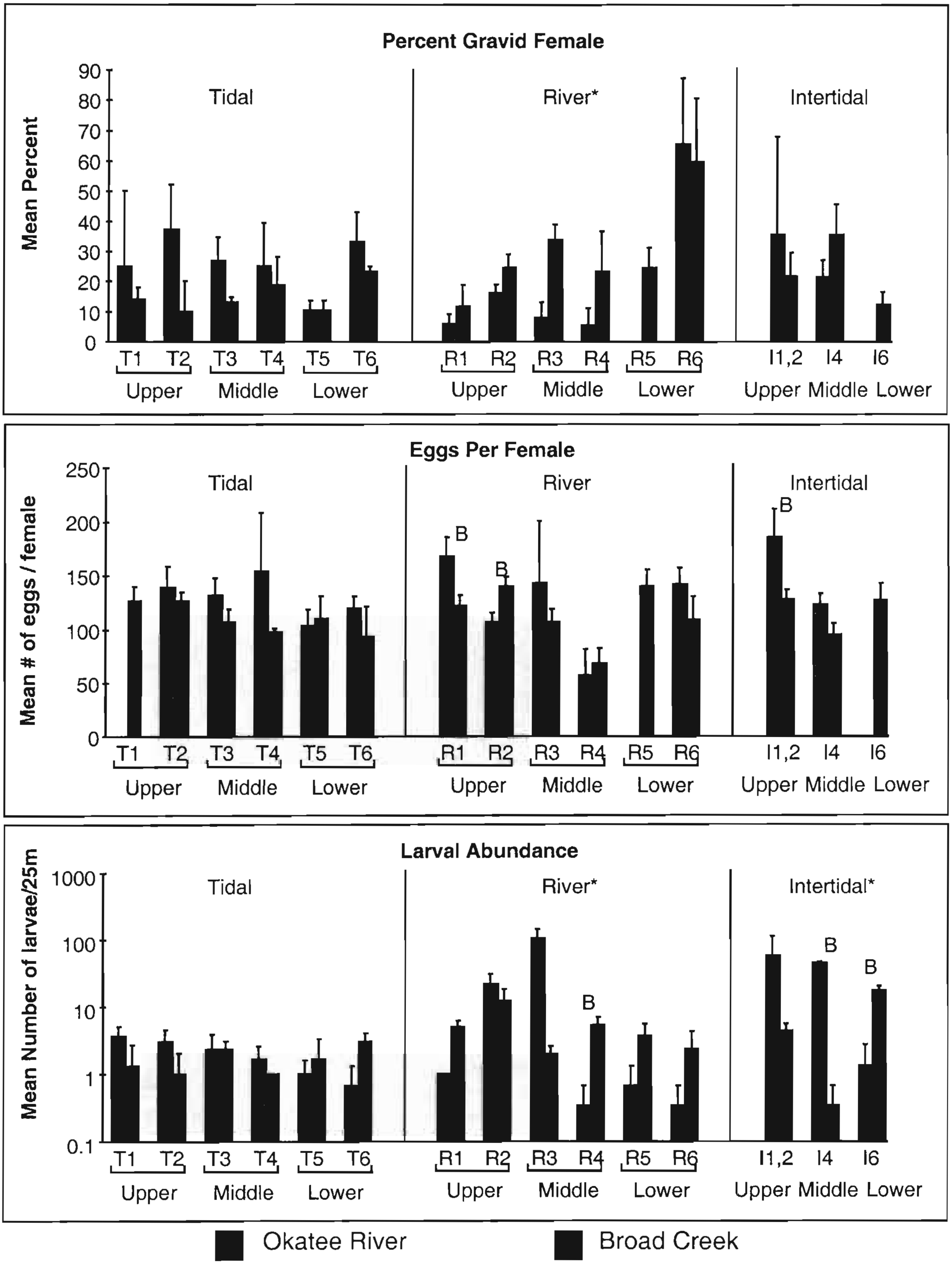


Figure 5.25. Station by station comparisons of *Palaemonetes pugio* percent gravid females, eggs per female and larval abundance. An asterisk indicates significant ($p<0.05$) difference by habitat, "A" indicates significantly ($p<0.05$) greater than 1 or more other sites, and "B" indicates significantly ($p<0.05$) different between systems by corresponding sites. Error bars represent 1 standard error.

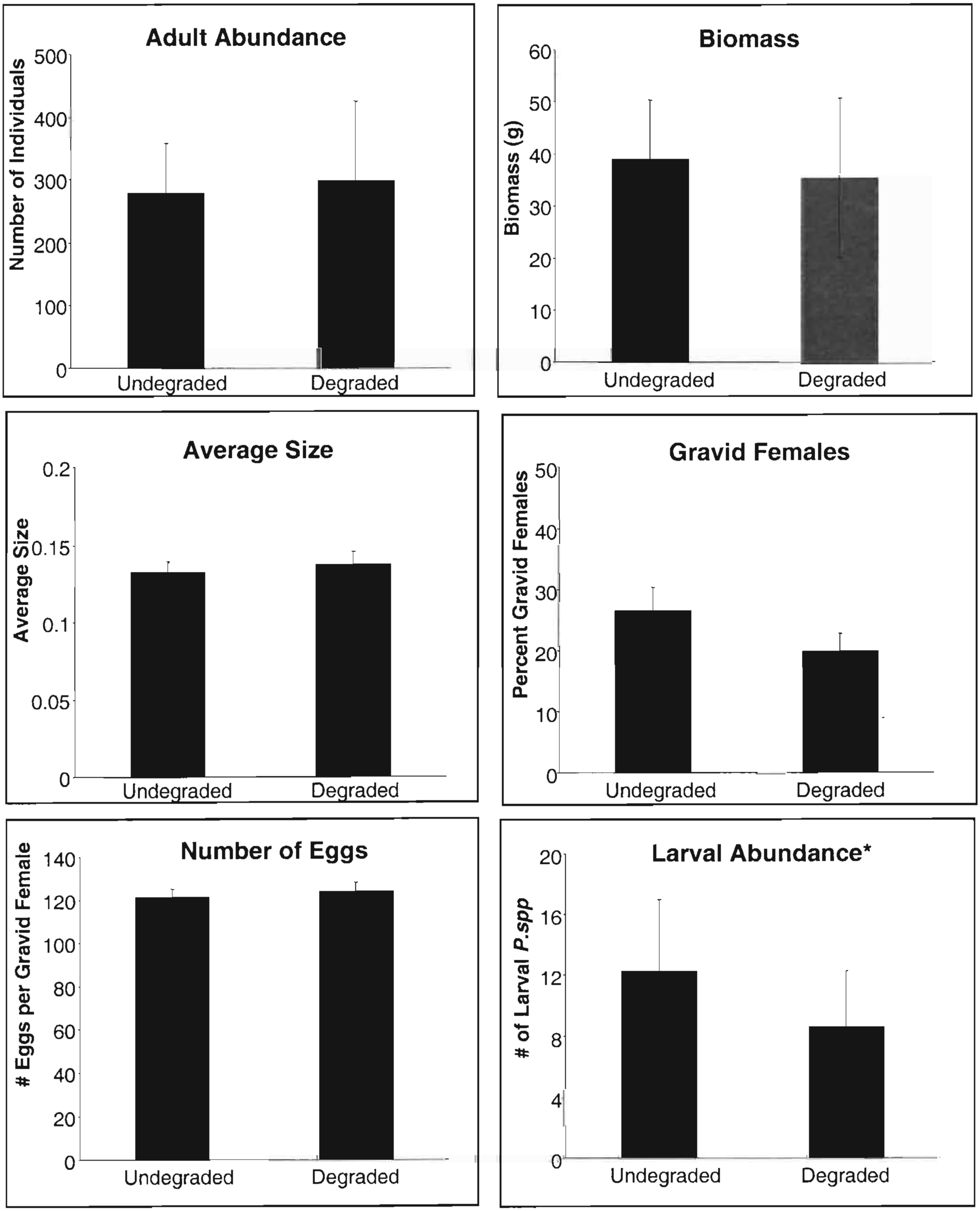


Figure 5.26. Comparison of *Palaemonetes pugio* population metrics at degraded and undegraded sites. An asterisk indicates significant ($p<0.05$) difference. Error bars represent ±1 standard error.

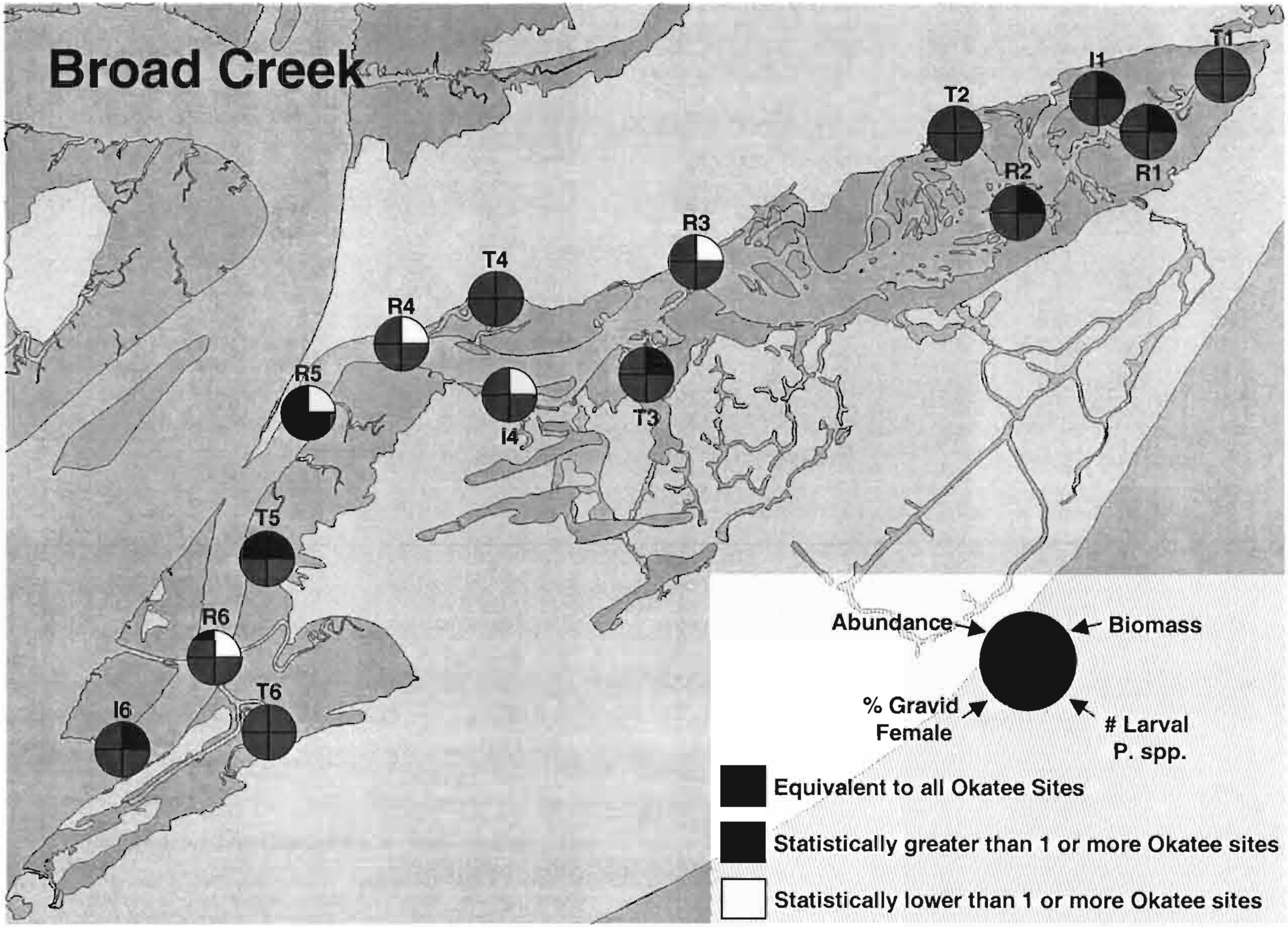


Figure 5.27. Map of Broad Creek showing *Palaemonetes spp*. population metrics relative to the Okatee River.

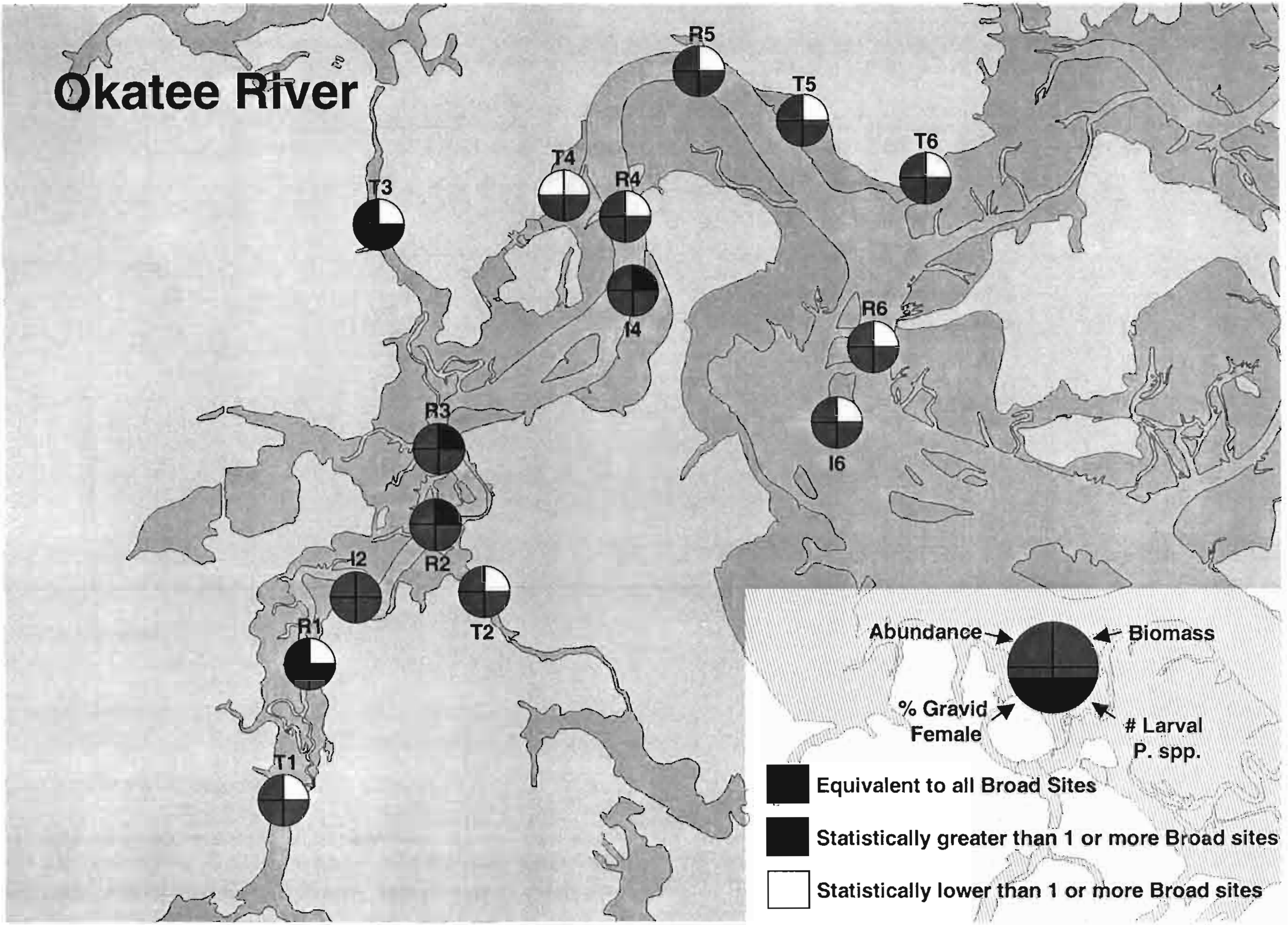


Figure 5.28. Map of Okatee River showing *Palaemonetes spp.* population metrics relative to Broad Creek.

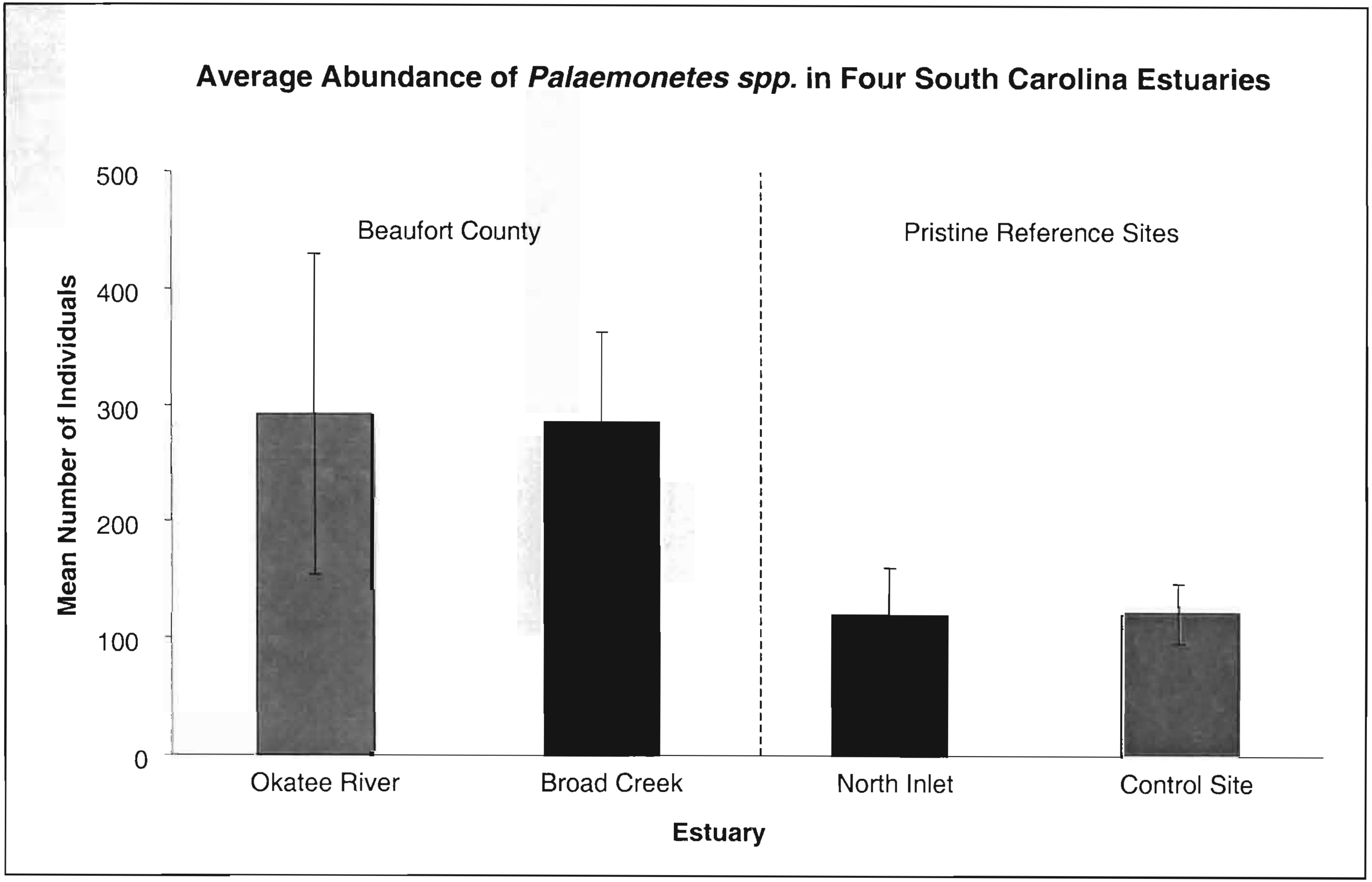


Figure 5.29. Comparison of *Palaemonetes pugio* abundance in Broad Creek and the Okatee River with relatively pristine sites in North Inlet and Leadenwah Creek.

Table 5.1. Ranked abundance of species comprising one percent or greater of the total subtidal community abundance from each system. Figures represent mean number/0.04 m^2. (A=amphipod; P=polychaete; O=oligochaete; M=mollusk; C=other crustacean; T=other taxa)

	Taxon	Broad Creek Stations						Okatee River Stations					
Species	code	1	2	3	4	5	6	1	2	3	4	5	6
Ampelisca vadorum	A	0	0	0	0	0	0	0	0	0	7	1291	0
Streblospio benedicti	P	56	46	45	39	0	86	8	23	50	16	2	3
Parapionosyllis sp.	P	0	0	0	0	0	33	0	0	1	5	0	246
Tubificoides wasselli	O	0	0	0	0	0	13	0	17	220	16	1	5
Exogone dispar	P	0	0	0	0	0	0	0	0	1	202	41	0
Scoletoma tenuis	P	2	22	29	0	0	17	9	23	22	72	26	1
Tubificidae	O	54	0	4	11	0	32	0	1	0	7	37	10
Cirrophorus sp.	P	0	0	0	1	0	0	9	37	73	20	0	3
Mediomastus sp.	P	0	2	0	0	0	17	0	4	4	51	45	0
Streptosyllis sp.	P	0	0	0	59	0	1	0	0	5	1	0	44
Actiniaria	T	1	0	1	2	0	1	0	6	16	4	70	1
Enchytraeidae	O	0	0	0	0	0	5	0	0	0	0	0	69
Scoloplos rubra	P	1	14	19	0	0	0	1	3	5	17	3	0
Caulleriella sp.	P	0	0	0	0	0	13	0	0	7	28	0	5
Leptognatha caeca	T	0	0	0	46	0	0	0	0	0	0	0	0
Ilyanassa obsoleta	M	38	1	0	0	0	0	3	0	0	1	0	0
Heteromastus filiformis	P	19	12	1	0	0	2	3	0	0	0	1	0
Tubificoides brownae	O	10	1	3	0	0	2	6	5	2	1	6	3
Brania sp.	P	0	0	0	10	0	8	0	0	6	0	2	6
Monticellina sp.	P	0	0	0	0	0	16	0	1	0	9	2	0
Polydora sp.	P	19	3	2	0	0	1	0	0	0	0	0	0
Spiochaetopterus costarum	P	0	14	6	0	0	1	0	2	1	0	0	0
Cyathura burbancki	T	0	0	0	1	0	10	0	1	0	6	3	0
Protohaustorius bousfieldi	A	0	0	0	0	17	0	0	0	0	0	0	0
% of total abundance		95.1	89.1	81.2	78.2	81.3	77.0	77.7	85.1	89.7	81.1	95.4	93.4
mean total abundance		212.3	128.3	135.0	215.7	21.3	337.7	52.3	143.0	460.3	570.7	1602.7	426.3
mean # of species		13.3	10.3	19.7	16.0	2.3	39.0	11.3	18.0	26.0	42.0	33.0	18.7
mean H'		2.5	2.5	3.0	2.8	0.8	4.0	3.0	3.2	2.6	3.7	1.4	2.3
mean evenness		0.7	0.7	0.7	0.7	0.5	0.8	0.9	0.8	0.6	0.7	0.3	0.6

Table 5.2. Overall ranked abundance of species comprising one percent or greater of the total intertidal community abundance from each system. Values represent mean number/0.04 m^2. (A=amphipod; P=polychaete; O=oligochaete; M=mollusk; C=other crustacean; T=other taxa)

Species	Taxon code	Broad Creek			Okatee River		
		1	4	6	2	4	6
Streblospio benedicti	P	4	9	28	29	2	8
Monopylephorus rubroniveus	O	0	59	9	1	0	0
Scoletoma tenuis	P	0	0	4	29	12	12
Nereis succinea	P	1	0	0	22	11	0
Ilyanassa obsoleta	M	11	7	10	0	0	0
Leitoscoloplos fragilis	P	0	0	0	6	10	5
Brania sp.	P	16	0	0	0	0	0
Heteromastus filiformis	P	1	8	1	0	0	2
Tubificoides brownae	O	3	0	3	0	0	0
Nemertinea	T	2	1	0	1	2	1
Uca pugilator	C	0	0	0	5	0	0
Gastropoda	M	0	0	0	0	4	0
Decapoda	C	1	0	0	2	0	0
Aphealochaeta sp.	P	0	0	0	0	0	3
Eobrolgus spinosus	A	0	0	0	0	0	3
Tubificidae	O	0	0	0	0	0	3
Leitoscoloplos sp.	P	0	0	0	1	1	0
% of total abundance		92.0	99.2	98.8	97.3	95.5	84.1
mean total abundance		41.7	85.0	55.0	98.7	44.7	44.0
mean # of species		5.7	6.7	4.7	8.3	8.0	11.0
mean H'		1.5	1.5	1.7	1.7	2.3	2.8
mean evenness		0.6	0.6	0.8	0.6	0.8	0.8

Table 5.3. Overall ranked abundance of tidal creeks species. (A=amphipod; P=polychaete; O=oligochaete; M=mollusk; I=isopod; In=insect; T=tanaid)

		Broad Creek				Okatee River			
Species	Taxon code	Average No./m^2	Percent Total	Percent Occurrence	Rank	Average No./m^2	Percent Total	Percent Occurrence	Rank
Monopylephorus rubroniveus	O	2485.4	58.1	65	1	2072.4	44.9	55	1
Streblospio benedicti	P	625	14.6	60	2	201	4.4	25	6
Heteromastus filiformis	P	314.3	7.3	46.7	3	47.5	1	10	11
Tubificidae	O	168.1	3.9	26.7	4	522.7	11.3	43.3	2
Capitomastus aciculatus	P	160.8	3.8	25	5	14.6	0.3	3.3	16
Tubificoides brownae	O	106	2.5	20	6	142.5	3.1	13.3	7
Capitella capitata	P	98.7	2.3	16.7	7	36.6	0.8	10	14
Nereis succinea	P	91.4	2.1	15	8	478.8	10.4	46.7	3
Fabricia sp.	P	58.5	1.4	13.3	9	65.8	1.4	6.7	9
Monopylephorus irroratus	O	54.8	1.3	11.7	10	40.2	0.9	5	12
Eteone heteropoda	P	14.6	0.3	5	11				
Aphealochaeta sp.	P	11	0.3	5	12.5				
Nemertinea	N	11	0.3	5	12.5	54.8	1.2	20	10
Edotea montosa	I	7.3	0.2	3.3	17	3.7	0.1	1.7	21
Glycera americana	P	7.3	0.2	3.3	17				
Laeonereis culveri	P	7.3	0.2	3.3	17	3.7	0.1	1.7	21
Leitoscoloplos sp.	P	7.3	0.2	3.3	17	40.2	0.9	5	13
Marionina spartinae	O	7.3	0.2	3.3	17	7.3	0.2	1.7	17
Polydora cornuta	P	7.3	0.2	3.3	17	3.7	0.1	1.7	21
Sabellidae	P	7.3	0.2	3.3	17				
Ampharetidae	P	3.7	0.1	1.7	24.5				
Corbiculidae	M	3.7	0.1	1.7	24.5	3.7	0.1	1.7	21
Drilonereis longa	P	3.7	0.1	1.7	24.5				
Eulalia sanguinea	P	3.7	0.1	1.7	24.5				
Exogone dispar	P	3.7	0.1	1.7	24.5				
Mediomastus californiensis	P	3.7	0.1	1.7	24.5				
Mercenaria mercenaria	M	3.7	0.1	1.7	24.5				
Sphaerosyllis longicauda	P	3.7	0.1	1.7	24.5				
Tubificoides heterochaetus	O					460.5	10	13.3	4
Colembolla	In					255.9	5.5	3.3	5
Cyathura polita	I					127.9	2.8	18.3	8
Tubificoides wasselli	O					18.3	0.4	3.3	15
Hesionidae	P					3.7	0.1	1.7	21
Leptochelia rapax	T					3.7	0.1	1.7	21
Rhepoxynius epistomus	A					3.7	0.1	1.7	21

Table 5.4. Summary of tidal creek environment quality measures. Values in shaded areas are within ranges that indicate degraded conditions.

Broad Creek

Stress Measure	Tidal Creek Stations						
	T1	T2	T3	T4	T5	T6	Mean
Salinity range	**22.3**	2	10.3	13.6	1.5	**27.1**	12.8
Silt/clay content	34	34	19	30	50	74	40.2
% of time < 2mg/l	18	0	0	3	**20**	0	6.8
ERMQ	**0.078**	0.023	0.013	0.033	0.030	0.011	0.031
% of fauna as oligochaetes	**96**	36	17	39	**80**	13	46.8
% of *Monopylephorus rubroniveus*	**90**	30	12	19	**78**	13	40.3
Species diversity (H')	**0.23**	0.60	0.85	0.96	**0.39**	0.76	1
Benthic abundance (#/m^2)	6,619	3,143	921	5,657	7,983	1,009	4,222
Overall assessment	**Degraded**	Normal	Normal	Normal	**Degraded**	Normal	Normal

Okatee River

Stress Measure	Tidal Creek Stations						
	T1	T2	T3	T4	T5	T6	Mean
Salinity range	**26.4**	3.1	1.2	**18.2**	1	**22.5**	12.1
Silt/clay content	46	41	23	88	6		40.8
% of time < 2mg/l	0	2	0	0	0	0	0.3
ERMQ	0.024	0.025	0.017	**0.049**	0.031	**0.050**	0.032
% of fauna as oligochaetes	**99**	67	**70**	25	50.4	20.9	55.38
% of *Monopylephorus rubroniveus*	**75**	10	18	17	33	10	27.17
Species diversity (H')	**0.31**	0.67	0.82	0.62	0.89	0.66	0.7
Benthic abundance (#/m^2)	12,698	2,719	2,281	1,733	5,000	3,246	4612.8
Overall assessment	**Degraded**	Normal	Normal	Normal	Normal	Normal	Normal

Table 5.5. Contaminant analytes measured in oyster tissue

Metals
Aluminum
Arsenic
Cadmium
Chromium
Copper
Lead
Manganese
Mercury
Nickel
Silver
Tin
Zinc

PAHs
2-Methyl Naphthalene
Acenapthene
Acenapthylene
Anthracene
Benzo(A) Anthracene
Benzo(A) Pyrene
Benzo(B) Fluoranthene
Benzo(Ghi) Perylene
Benzo(K) Fluoranthene
Chrysene
Dibenzo(A,H) Anthracene
Fluoranthene
Fluorene
Naphthalene
Phenanthrene
Pyrene

PCBs
PCB-1016
PCB-1221
PCB-1232
PCB-1242
PCB-1248
PCB-1254
PCB-1260

Pesticides
Aldrin
Alpha Endosulfan
Alpha-BHC
Beta Endosulfan
Beta-BHC
Chlordane
Delta-BHC
Diazinon
Dieldrin
Dursban (Chlorpyrifos)
Endosulfan Sulfate
Endrin
Endrin Aldehyde
Heptachlor
Heptachlor Epoxide
Lindane
P,P'DDD
P,P'DDE
P,P'DDT
Toxaphene

Biological
Percent Fat

Table 5.6 Tissue contaminant concentrations in oyster samples collected from sites in Broad Creek and the Okatee River.

River	Station	Date	Copper Tissue mg/kg Wet Wt	Copper mg/kg Calc. Dry Wt	Zinc Tissue mg/kg Wet Wt	Zinc mg/kg Calc. Dry Wt	Cadmium Tissue mg/kg Wet Wt		Cadmium mg/kg Calc. Dry Wt
Broad	O-1	97/8/26	16	**159.8**	370	**3694.8**	0.2	K	2.0
Broad	O-2	97/8/26	23	**229.7**	340	**3395.2**	0.2	K	2.0
Broad	O-3	97/8/26	27	**269.6**	350	**3495.1**	0.2		2.0
Broad	O-4	97/8/27	16	**159.8**	270	**2696.2**	0.2		2.0
Broad	O-5	97/8/27	15	**149.8**	280	**2796.1**	0.2		2.0
Broad	O-6	97/8/27	6.5	64.9	140	1398.0	0.3		**3.0**
Okatee	O-1	97/9/10	10	99.9	**660**	**6590.8**	0.4		**4.0**
Okatee	O-2	97/9/10	12	119.8	460	**4593.6**	0.3		**3.0**
Okatee	O-3	97/9/10	12	119.8	400	**3994.4**	0.4		**4.0**
Okatee	O-4	97/9/11	12	119.8	380	**3794.7**	0.4		**4.0**
Okatee	O-5	97/9/11	7.4	73.9	230	**2296.8**	0.2		**2.0**
Okatee	O-6	97/9/11	16	**159.8**	410	**4094.3**	0.5		**5.0**

▭ Exceeds mean of annual geometric means reported by O'Connor (1996) for oysters collected from US coastal stations from 1986 - 1993.

▨ Exceeds 90th percentile of wet weight concentration collected from South Carolina by SCDHEC from 1980 - 1997.

K = Below Limit of Detection

Table 5.7. Summary of changes in the areal extent of shellfish beds sampled in Broad Creek and the Okatee River in 1984-85 versus 1997.

	Square Feet			Total Volume (bushels)			Live Volume (bushels)		
Broad Creek	**1984**	**1997**	**% Change**	**1984**	**1997**	**% Change**	**1984**	**1997**	**% Change**
O-1	3,300	6,382	93	359	612	70	148	231	56
O-2	13,200	13,425	2	1,856	1,476	-20	790	548	-31
O-3	3,960	5,755	45	909	538	-41	366	158	-57
O-4	3,600	7,006	95	826	1,114	35	332	396	19
O-5	6,416	5,492	-14	1,327	473	-64	543	68	-87
O-6	3,300	2,730	-17	757	1,181	56	305	666	118
Okatee River	**1985**	**1997**	**% Change**	**1985**	**1997**	**% Change**	**1985**	**1997**	**% Change**
O-1	0*	1,764	NA	0*	174	NA	0*	72	NA
O-2	7,200	10,140	41	860	863	0	321	356	11
O-3	16,440	11,523	-30	1,869	768	-59	736	317	-57
O-4	8,664	4,420	-49	1,060	334	-68	386	138	-64
O-5	3,300	4,373	33	443	272	-39	146	115	-21
O-6	11,050	8,030	-27	1,311	608	-54	493	225	-54

* 1985 survey indicated no intertidal shellfish bed at this site

All data provided by the SCDNR Office of Fisheries Management, Shellfish Management Section.

Table 5.8. Statistical comparisons of Broad Creek and Okatee River grass shrimp samples (a = 0.05 for all tests). Shading indicates significant differences. An asterisk indicates that the test for normality passed (with p > 0.05), but the test for equal variance failed, and a nonparametric test was used for that comparison.

Comparisons	Parameter	Normality	(p value)	Test	Result	(p value)	Multiple Comparison Test	Pairwise Comparisons
System-wide	Abundance	failed	<0.0001	Mann-Wh.	sig. diff.	0.0319		Broad > Okatee
(Okatee vs. Broad)	Biomass	failed	<0.0001	Mann-Wh.	sig. diff.	0.029		Broad > Okatee
	% Gravid Female	failed	<0.0001	Mann-Wh.	no sig. diff.	0.287		
	Larval	failed	<0.0001	Mann-Wh.	no sig. diff.	0.799		
	Average Size	failed	0.0078	Mann-Wh.	no sig. diff.	0.56		
Between Habitats	Abundance	failed	<0.0001	Kruskal-Wallis	no sig. diff.	0.823		
(within Okatee)	Biomass	failed	0.0036	Kruskal-Wallis	no sig. diff.	0.831		
	% Gravid Female	failed	0.029	Kruskal-Wallis	no sig. diff.	0.359		
	Larval	failed	<0.0001	Kruskal-Wallis	no sig. diff.	0.235		
	Average Size	failed	0.0134	Kruskal-Wallis	no sig. diff.	0.217		
Between Habitats	Abundance	failed	<0.0001	Kruskal-Wallis	no sig. diff.	0.27		
(within Broad)	Biomass	passed	0.0541	1 way ANOVA	no sig. diff.	0.282		
	% Gravid Female	passed	0.0611	1 way ANOVA	no sig. diff.	0.542		
	Larval	failed	0.0205	Kruskal-Wallis	sig. diff.	0.0084	Dunn's	River > Tidal
	Average Size	passed	0.2106	1 way ANOVA	no sig. diff.	0.631		
Tidal Data	Abundance	failed	0.0022	Mann-Wh.	no sig. diff.	0.174		
(Okatee vs Broad)	Biomass	* passed	0.1883	Mann-Wh.	no sig. diff.	0.137		
	% Gravid Female	failed	0.0106	Mann-Wh.	no sig. diff.	0.216		
	Larval	failed	<0.0001	Mann-Wh.	no sig. diff.	0.428		
	Average Size	failed	0.0013	Mann-Wh.	no sig. diff.	1		
River Data	Abundance	failed	<0.0001	Mann-Wh.	no sig. diff.	0.373		
(Okatee vs Broad)	Biomass	failed	0.001	Mann-Wh.	no sig. diff.	0.468		
	% Gravid Female	failed	0.0023	Mann-Wh.	sig. diff.	0.035		Broad > Okatee
	Larval	failed	<0.0001	Mann-Wh.	no sig. diff.	0.2		
	Average Size	* passed	0.385	Mann-Wh.	no sig. diff.	0.718		
Intertidal Data	Abundance	failed	0.0486	Mann-Wh.	no sig. diff.	0.4799		
(Okatee vs Broad)	Biomass	passed	0.3483	t-test	no sig. diff.	0.4083		
	% Gravid Female	passed	0.1209	t-test	no sig. diff.	0.683		
	Larval	passed	0.2446	t-test	no sig. diff.	0.1792		
	Average Size	passed	0.084	t-test	no sig. diff.	0.7439		

Table 5.9. Summary of population metrics collected for mummichog (*Fundulus heteroclitus*) populations

		Broad Creek					**Okatee River**					
Metric	Station	T-1	T-2	T-3	T-4	T-5	T-1	T-2	T-3	T-4	T-5	T-6
Condition Index	avg	2.46	2.41	2.38	2.32	2.58	2.36	2.27	2.30	2.28	2.35	2.39
	std	0.27	0.20	0.22	0.24	0.21	0.24	0.15	0.17	0.17	0.31	0.21
Total Length	avg	59.43	52.55	51.52	62.87	66.01	49.96	47.09	45.92	43.27	57.32	44.56
	std	12.88	11.66	11.63	12.96	13.09	8.55	4.47	6.46	6.87	13.81	6.18
Standard Length	avg	48.55	42.87	41.97	51.02	54.23	41.06	38.00	36.98	34.86	46.09	36.17
	std	10.60	9.64	9.62	10.93	10.95	7.63	3.73	5.26	5.80	11.16	5.02
Weight	avg	3.28	2.25	2.14	3.60	4.71	1.82	1.28	1.25	1.05	2.84	1.21
	std	2.27	1.72	2.02	2.49	2.97	1.19	0.37	0.75	0.46	2.89	0.50
Abnormalities	% abnormal	0.78	0.00	0.71	4.46	1.08	3.92	0.00	3.37	0.00	6.38	0.00
Sex Ratio	M : F	49:77	99:129	118:163	50:60	96:90	10:41	23:29	39:135	14:26	18:29	22:31
Sample Size	m	49	99.0	118	50	96	10	23	39	14	18	22
	f	77	129.0	163	60	90	41	29	135	26	29	31
	I	2	1.0	0	2	0	0	4	4	4	0	1
	total	128	229	281	112	186	51	56	178	44	47	54
	% female	60.2	56.3	58.0	53.6	48.4	80.4	51.8	75.8	59.1	61.7	57.4

Chapter 6
Summary and Recommendations

General Study Conclusions:

The overall assessment of the water, sediment and biological quality of Broad Creek and the Okatee River is summarized in Figures 6.1 and 6.2. The results of this integrated assessment clearly indicate some degradation in Broad Creek and comparatively less degradation in the Okatee River based on the benchmarks used for the various analyses. In Broad Creek, 20% of the sites sampled were clearly degraded and 53% of the sites exhibited marginal conditions. In contrast, 40% of the Okatee River sites were considered to have marginal quality overall, with the remaining 60% of the sites considered to be in good condition. Evaluation of sites based on depth and proximity to land runoff sources clearly indicated that the shallow water sites (tidal creeks and intertidal flats) exhibited more degraded characteristics than the deeper subtidal river habitats in both systems. A much greater level of degradation was noted in the shallow areas of Broad Creek compared to the Okatee River (Figure 6.2).

In general, degraded water quality was more apparent in Broad Creek compared to the Okatee River. This was due primarily to fecal coliform bacteria concentrations, and elevated nutrient and total organic carbon concentrations. The 1.3 inch rainfall overnight preceding the water quality sampling in Broad Creek, coupled with the extreme high tides that inundated more land area closer to upland sources than normal appears to have had an influence on some of the water quality results for this creek. On the day water quality was sampled in Broad Creek, fecal coliform bacteria concentrations in excess of State Shellfish Harvesting Standards were widespread, thirteen of the fifteen sites (87%) exceeded 43 colonies per 100 ml. Concentrations in all six tidal creeks were also greater than the State Standards for swimming. Biotyping of the fecal coliform samples that had *E. coli* indicated that Broad Creek had both a higher incidence of *E. coli* in the samples and a higher percentage of strains that were indicative of human sources than the Okatee River. There was also a clear association of areas with high *E.coli* counts related to human sources and obvious pollution sources (e.g. land application of treated wastewater, septic tanks) in Broad Creek. However, the majority of stations in both Broad Creek (53.3%) and the Okatee River (80%) were negative for the multiple antibiotic resistance tests used for typing probable sources. This suggests that animal pollution sources are a major contributor of the fecal coliform levels observed in both systems. At the tidal creek and subtidal river sites in Broad Creek, total phosphorus was elevated relative to other SCDHEC saltwater monitoring sites. Total organic carbon was elevated relative to other SCDHEC saltwater monitoring sites at all sites in Broad Creek and in general an order of magnitude greater than the values observed in the Okatee River. In fact, turbidity and TOC concentrations in Broad Creek were near or in excess of the maximum values seen in SCDHEC Ambient Surface Water Quality Monitoring data collected in Broad Creek from 1994-1998.

A composite water quality summary score based on State Standards and other threshold values was used to summarize the water quality data. Overall water quality in Broad Creek was scored as poor at 47% of the sites, fair at 40% of the sites, and good at only 13% of the sites. Although turbidity in the Okatee River was elevated relative to other SCDHEC saltwater monitoring sites, water quality was generally better than Broad Creek based on the composite score. Only 7% of the sites scored as poor, 33% scored as fair, and 60% of the sites scored as good.

Evaluation of sediment quality was based on the frequency of excursions of sediment quality threshold or midpoint concentrations that have been shown to be correlated with degraded benthic invertebrate communities, or direct measurement of toxicity in sediment bioassays. A basic premise of this study was that Broad Creek was more chemically contaminated than the Okatee River due to the increased urbanization found in the Broad Creek watershed. Chemical contaminant analyses of sediments clearly indicated that Broad Creek was not as chemically contaminated as was expected and the Okatee River was slightly more polluted than was originally thought. Sediment contaminant concentrations at sites in both Broad Creek and the Okatee River occurred at concentrations that have been shown to be correlated with degraded benthic invertebrate communities. Only two sites in Broad Creek and one site in the Okatee River had contaminant concentrations that exceeded sediment quality guideline midpoints for toxic effects. Overall sediment quality indicated that there were five degraded sites in Broad Creek (33%) versus only two degraded sites (13%) in the Okatee River. Four sites in Broad Creek (27 %) and nine sites (60%) in Okatee River had sediments that were marginally degraded. Six sites (40% of the sites) in Broad Creek and four sites (27%) in Okatee River had good overall sediment quality.

Elevated arsenic and lindane concentrations were major contributors to many conclusions of marginal or degraded conditions. Arsenic (As) is commonly found in the sediments of South Carolina at concentrations similar to levels found in Broad Creek and the Okatee River. The arsenic concentrations observed generally reflected the high background levels found in estuarine sediments of the southeastern U.S. and are probably not entirely due to anthropogenic inputs. Lindane concentrations were elevated in sediments in both watersheds at concentrations greater than sediment quality thresholds and midpoints for toxic effects. Lindane is a chlorinated hydrocarbon insecticide used in both agricultural and urban applications as a soil fumigant and foliar treatment on fruit and nut trees as well as vegetable and ornamental plants (Farm Chemical Handbook, 1992). Persistent organochlorine pesticides, such as lindane, may persist in estuarine sediments long after agricultural lands are converted to urban areas, adding to the toxicity potential of sediments as increased pollutant discharges occur with urbanization. This long-term persistence may explain in part both the occurrence and spatial distribution of observed degradation in Broad Creek and the Okatee River.

Concentrations of other organic contaminants, including polycyclic aromatic hydrocarbons (PAHs), were generally low, as only one site in Broad Creek had sediment quality threshold excursions for a single PAH. In general, PAH concentrations in Broad Creek and the Okatee River were lower or comparable to sediment PAH concentrations measured in pristine NOAA National Estuarine Research Reserves and Sanctuaries in South Carolina (North Inlet and the ACE Basin). Comparisons of Broad Creek sediment PAH concentrations with other suburbanized areas of SC (Murrells Inlet) indicated much lower levels in Broad Creek, possibly resulting from the land use planning restrictions placed on development on Hilton Head Island, SC, to control nonpoint source runoff. Beaufort County should continue strict land use planning and zoning requirements to help minimize water quality impacts. This should be particularly enforced on the Okatee River, due to the relatively high concentrations of lindane and arsenic, which already exists there.

The biggest difference in sediment quality observed was the apparent transition of marginally contaminated sites in Broad Creek to degraded sites. This may be directly related to increased urbanization in this area which has resulted in inputs of chemical contaminants. Most of the toxicological effects observed appear to be the result of cumulative impacts from multiple stressors rather than one individual contaminant *per se*. This is a classical urbanization effect, as previous studies (Fulton et al, 1993, 1997) have noted that urbanization is a process of both contaminant loadings, changes in hydrography and the water cycle (both surface and groundwater), and habitat loss/modification. Benthic and grass shrimp population assessments generally indicated that there were only marginal impacts observed in both Broad Creek and the Okatee River, with greatest effects observed in benthic organisms in direct contact with sediment contaminants. This suggests that environmental quality is at a point in Broad Creek where further environmental degradation may result in more pervasive impacts within this watershed. Further, this points to the importance of properly managing development of the Okatee watershed, to minimize urbanization impacts.

In general, the biological communities evaluated in this study showed no evidence of substantial degradation compared to other estuarine habitats in South Carolina with similar characteristics. Of the four types of biological assemblages considered, the benthic invertebrate communities showed the clearest evidence of a response to degraded water and/or sediment quality that was observed in either drainage system. These effects were primarily limited to a dominance by species known to be tolerant of pollution and other environmental stresses. The effects were largely limited to a few sites, including four tidal creeks (two in each system) and two intertidal mud flats (Broad Creek only). Two of four tidal creeks that showed the greatest evidence of stress were located in the uppermost (headwater) portion of each drainage system. These areas tend to be subjected to greater salinity fluctuations compared to other creeks and habitats located lower in the estuary, which may account for most of the alterations observed. In addition, alterations in impervious land surface may lead to increased freshwater loading, which may cause greater fluctuations in salinity. Low dissolved oxygen and contaminant stress may also account for some of the alterations in faunal composition observed in the Broad Creek drainage basin. The elevated contaminant levels observed in two of the intertidal flats (depositional habitats) sampled in Broad Creek probably accounts for the dominance of pollution tolerant species observed there, but the overall changes in community structure and composition were not especially severe. Although the benthic assemblages were not severely degraded at most of the sites sampled, the changes observed serve as an "early warning" ecological signal that upland activities are beginning to affect the biological resources present in the shallow water habitats of these drainage systems.

The oyster populations were the only other biota that showed some evidence of adverse effects in both drainage systems. The effects were primarily limited to evidence of cellular dysfunction and accumulation of a few metal contaminants in the oyster tissue sample. These conditions were pervasive in both Broad Creek and the Okatee River, which would suggest that the higher level of upland development in Broad Creek was not having any clear deleterious effects on oyster population health. While higher than anticipated, in our opinion, the chemical contaminant levels observed in the oyster tissue of both systems were not evidence of a major chemical contaminant loading problem. However, it does serve as an early warning signal that land runoff may be the cause of the contaminant levels observed. The poorer overall condition of the oyster beds observed in the headwaters of both drainage systems may reflect the effects of higher salinity fluctuations there, but some of these effects would be anticipated in the headwaters of many drainage systems, regardless of the surrounding upland development. Increased freshwater runoff from upland modifications to the landscape will only serve to exacerbate this situation.

In summary, a large number of environmental quality and biological condition measures were examined in both Broad Creek and the Okatee River. Although we observed differences among many of these measures, both within and between the two drainage systems, many of the environmental and biological measures appear to be consistent with other non-degraded estuarine sites that have been sampled in South Carolina, especially in the open water, subtidal portions of Broad Creek. Creek. The tidal creeks and flats showed greater evidence of stress related to both water quality and biotic condition. Because the Broad Creek watershed is more heavily developed than that of the Okatee River, contaminant levels and evidence of biotic stress were less than anticipated, possibly due to the land use planning restrictions established for Hilton Head Island development to control non-point source runoff. While the Okatee River had fewer sites that showed evidence of anthropogenic stress, some problems were noted in the headwater areas, and past agricultural practices in the Okatee River drainage may have contributed to the higher than anticipated contaminants concentrations observed.

Recommendations:

Our primary objective in this study was to determine baseline conditions of the water, sediment and biological quality of the Broad Creek (developed) and Okatee River (undeveloped) estuaries. However, our study findings also provide an opportunity to suggest some approaches that Beaufort County and the Town of Hilton Head may want to consider in order to reduce adverse effects on the estuarine wetland habitats in these two drainage systems. These recommendations may also apply to other drainage systems in the County.

Bacterial Loading Problems:

As noted in Chapter 3, we found clear evidence of increased bacterial loading from human sources in Broad Creek and some limited areas of the Okatee. There was also evidence of animal sources of fecal coliform bacteria in both systems. Possible solutions to alleviate some of these loadings are as follows:

- *Evaluate sewage treatment facilities and land disposal activities to ensure that they are not a major source of the observed fecal coliform bacteria concentrations.*

  Land application of treated effluent is the most common disposal practice on Hilton Head Island. This practice assists the recharge of underground aquifers both directly and by reducing the use of limited groundwater supplies. This treated effluent meets applicable standards at the time of final treatment. However, final treatment often takes place at a time and location different from the time and site of application. The possibility of significant multiplication and regrowth of fecal coliform bacteria in the nutrient-rich mixture prior to application needs to be investigated. Overland runoff from land application sites are prohibited by SCDHEC permits. Groundwater monitoring at the land application sites, and submittal of said data to SCDHEC, is required by permit. This existing data should be reviewed by a geohydrologist to evaluate groundwater as a potential pathway of fecal contamination. An evaluation of fecal coliform contributions from septic tanks and stormwater runoff directly to the creek and lagoon/canal systems should be further studied to quantify their contributions.

  A related question that should be examined is whether treated effluent to be land applied should be treated to Shellfish Harvesting Standards for fecal coliform bacteria, rather than the less stringent swimming Standards. If the question of potential overland runoff and groundwater contributions from land application sites as a direct source of fecal coliform bacteria to Broad Creek can be eliminated, this would not be an issue.

- *Consider options for increasing sewer hookups for those properties currently on septic tank systems, especially in the Broad Creek drainage system.*

  The results of this study show that portions of Broad Creek adjacent to high densities of septic tanks have elevated fecal coliform bacteria concentrations that show evidence of some human contribution. This suggests that fecal coliform bacteria concentrations may be lowered, and perhaps some shellfish beds could be opened, if neighborhoods on septic tanks could be connected to wastewater treatment facilities and the tile fields eliminated.

- *Evaluate Best Management Practices, including buffers, to reduce nonpoint source runoff and manage stormwater runoff.*

Nonpoint source runoff has previously been shown to be a source of fecal coliform bacteria to Broad Creek (SCDHEC, 1996). The ditches, creeks and lagoon/canal drainage systems also contribute fecal coliform bacteria even under dry weather conditions. Statewide, nonpoint sources of fecal coliform bacteria are more important than treated wastewater as a source of water quality impairment. This study has shown the added influence of stormwater runoff and upland inundation due to extreme high tides.

Nationally, studies are lacking which have verified in an integrated fashion the overall effectiveness of watershed protection strategies such as buffer width, set back distance and percent impervious surface within a watershed. All of these methods are used to formulate a *Cumulative Risk Reduction* (CRR) strategy for managing urbanization impacts within a watershed. Studies are needed which would evaluate the effectiveness of current CRR strategies employed on developed watersheds in Beaufort County such as Broad Creek. This would allow development of statistical models, which could test the importance of each risk reduction strategy in terms of bacterial loadings. While buffer width is very important, the activities permitted within buffer zones may be equally important. Studies should be conducted to evaluate current buffer effectiveness, activities within each buffer and to determine the importance of factors such as buffer width, vegetation/view corridors and wildlife corridors. Wildlife corridors may be of great importance as the majority of the fecal coliform pollution within Broad Creek and the Okatee River was negative for antibiotic resistance and may potentially be wildlife in origin. As coastal watersheds are urbanized, maintenance of a vegetated waterfront buffer zone invites/attracts wildlife to those areas. Compressed wildlife populations will tend to live in the remaining green spaces and will often use marsh habitat areas for defecation, using the terrestrial upland for feeding and nesting activities. For example, wildlife such as raccoons will defecate in the marsh and often become the primary source of fecal coliform bacteria in affected tidal creeks. It is important that buffer and green space design have wildlife corridors that lead away from the vegetated buffer areas adjacent to tidal creeks. This would allow and encourage wildlife feeding and defecation activities at a distance away from estuarine tidal creeks. While raccoons may still feed on oysters and defecate in the marsh, the location of alternative upland terrestrial food sources in wildlife corridors may ultimately reduce fecal coliform loadings from wildlife sources. Similar strategies may be employed for other wildlife sources such as deer, muskrat and birds. As stated previously, the existing groundwater monitoring well data associated with the treated wastewater land application sites should be reviewed by a geohydrologist to evaluate groundwater as a potential pathway of fecal contamination. An evaluation of fecal coliform contributions from septic tanks and stormwater runoff directly to the creek and lagoon/canal systems should be further studied to quantify their contributions. This will enable the Town and County governments to make more effective decisions on future urban development within the County in terms of wastewater disposal or treatment.

Cumulative risk reduction strategies could be effective in urban areas including reducing the amount of impervious surfaces, use of detention basins or retention ponds, BMPs for yards and lawns, the inclusion of properly designed green space corridors and the planting of trees and other vegetative cover in critical drainage areas near streams. Most of this effort could be consolidated with a countywide stormwater utility plan. This will require a substantial public education program on the importance of urban NPS runoff control and how stormwater utilities can prevent/manage environmental impacts of urban NPS runoff.

- *Increase public education related to the problems of bacterial loading from non-human sources on estuarine waters.*

Many people do not realize that much of the bacterial loading problem can come from nonpoint source runoff of fecal material from pets, domestic animals, and local wildlife such as raccoons, other small fur-bearing animals, and birds, especially seagulls and other shorebirds attracted to non-natural food sources left by humans. When these sources are located close to estuarine habitats, they can result in significant bacterial loading to small drainage areas. Ensuring that trash dumpsters located next to waterways (e.g. at boat landings, etc.) are kept closed, discouraging feeding of birds, eliminating runoff from equestrian and other domestic animal facilities, and avoiding the creation of green spaces that would tend to concentrate wildlife next to estuarine wetlands are just a few ways to reduce bacterial loading from these sources.

- *Monitor and enforce the use of marina pumpout facilities.*

Although we found no evidence that marina facilities were contributing to the bacterial loading problem observed in Broad Creek, this drainage system supports a considerable amount of boating activity, with many boats having marine sanitation devices (MSD). The Town of Hilton Head recognizes that the surface waters of Broad Creek are important economic and recreational resources. Town officials share residents concerns related to the degradation of water quality in Broad Creek as indicated by recurrent closures of areas to shellfish harvesting. They believe it directly threatens the environment and has resulted in negative economic impacts to the community. Therefore the Town of Hilton Head and its citizenry initiated an application for a No Discharge Zone (NDZ) designation for Broad Creek. Designation of Broad Creek as an NDZ would prohibit direct discharge to the creek from marine sanitation devices (MSDs) and would require disposal at a sanitary waste pumpout facility. There are presently four such marinas with pumpout facilities in Broad Creek: Palmetto Bay Marina, Wexford Lock Harbor Marina, Broad Creek Marina, and Shelter Cove Marina.

The request to have Broad Creek designated as a No Discharge Zone has been approved by the United States Environmental Protection Agency Region IV pursuant to Section 312(f)(3) of the Clean Water Act and Federal Regulation 40 CFR 140.4.

The SCDHEC Board concurred and forwarded the measure to the legislature for approval. Action on the measure is expected during the current legislative session. A strong public education campaign, combined with enforcement, would help to ensure that boaters are not part of the source of the fecal bacterial levels observed in Broad Creek. With the increased number of registered boats forecast for the state over the next 10 years, it may be wise to evaluate the need for this type of designation elsewhere in Beaufort County.

Also, with regard to pumpout facilities, SCDHEC's Office of Ocean and Coastal Resource Management works in concert with the U.S. Fish and Wildlife Service in the administration of the Clean Vessel Act Marina Pumpout Grant Program in South Carolina. This program provides for a 75/25 cost sharing between the federal government and the marina operators for the installation, maintenance, or repair of marina pumpout facilities. Through this program monies are available for the construction of new facilities, the renovation of existing facilities, the purchase of portable pumpout units, the purchase of boat-mounted pumpout facilities, and to provide operation and maintenance monies. All of these grants not only provide for pumpout facility improvements, they also provide an educational component that is designed to educate the boaters about the importance of using pumpout stations and about their locations and availability. Standardized signage is also provided under these programs, as well as a guidebook and educational programs. This grant program could provide the resources for improvements and maintenance of existing pumpout facilities or additional pumpout facilities as resident boat registration increases.

Nutrient Loading:

- *Evaluate groundwater loading as a significant source of nutrient levels observed in Broad Creek.*

Total organic carbon (TOC) and total phosphorus appeared to be elevated in Broad Creek relative to the Okatee River. However, the 1.3 inch rainfall overnight preceding the water quality sampling in Broad Creek had an influence on the TOC results for this creek.

Land application of treated effluent is the most common disposal practice on Hilton Head Island. This practice assists the recharge of underground aquifers both directly and by reducing the use of limited groundwater supplies. Overland runoff from land application sites are prohibited by SCDHEC permits. Groundwater monitoring at the land application sites, and submittal of said data to SCDHEC, is required by permit. This existing data should be reviewed by a geohydrologist to evaluate groundwater as a potential pathway of excess nutrient loading. An evaluation of nutrient loading from septic tanks directly to the creek and lagoon/canal systems should be further studied to quantify their contributions.

This will be of particular importance in siting future residential developments which have golf courses with land applied treated wastewater as a focal part of development. In general, the more landward (away from sensitive tidal creek watersheds) land application sites are located, the greater the assimilative capacity of the soils and watershed dynamic for land application of treated wastewater will be, as there will be a greater buffer distance between the application site and the receiving stream. After review of existing groundwater data, additional modelling and research (monitoring and assessment) may be needed to better predict the potential impacts of groundwater loading in the landscape of this region. If impacts are observed, mitigation steps may include reductions in volumes of treated wastewater applied, further treatment of wastewater prior to land application or a combination of both methods.

- *Evaluate land disposal activities, nonpoint source, and stormwater runoff to determine their relative contributions of nutrients*

Elevated total organic carbon and total phosphorus in Broad Creek relative to the Okatee suggests development-related inputs to this system. Nonpoint source discharges to the system should be monitored for nitrogen and phosphorus loads. This study has shown the added influence of stormwater runoff due to the 1.3 inch rainfall overnight preceding the water quality sampling in Broad Creek. Studies should be conducted to evaluate current buffer effectiveness, activities within each buffer and to determine the importance of factors such as buffer width, vegetation/ view corridors and wildlife corridors. Additionally, stormwater runoff directly to the creek and lagoon/canal systems should be monitored to quantify its contributions. The Cumulative Risk Reduction (CRR) approach discussed under Bacterial Loading Problems applies to nutrient loading as well. As part of such a strategy, nutrient loading from malfunctioning septic tanks directly to the creek and lagoon/canal systems should be further studied to quantify their contributions. This will enable the city and county governments to make more effective decisions on future urban development within the county in terms of wastewater disposal or treatment.

- *Educate the public on nonpoint source runoff effects*

Research has clearly shown that reductions of nonpoint source runoff must utilize a cumulative risk reduction strategy. For agricultural nonpoint source runoff this has included methods such as Integrated Pest Management (IPM), selection of less toxic pesticides, Best Management Practices (BMPs) for tillage and soil conservation and retention ponds. Scott et al. (1999; 1992) reported that this method resulted in substantial reductions in *instream* pesticide concentrations (89-90%) for agricultural areas which utilized this approach. This will require education of farmers in Beaufort County to further develop this type of program. Similar cumulative risk reduction strategies will be effective in urban areas including reducing the amount of impervious surfaces, use of detention basins or retention ponds, BMPs for yards and lawns including amounts and types of fertilizers and lawn care products used, the inclusion of properly designed green space corridors and the planting of trees and other vegetative cover in critical drainage areas near streams. Most of this effort could be consolidated with a County-wide stormwater utility plan. This will require a substantial public education program on the importance of urban NPS runoff control and how stormwater utilities can prevent/manage environmental impacts of urban NPS runoff. This educational effort should be geared at both the new homeowner and at retrofitting existing residential areas. A review of BMPs currently used for golf courses in the region may also be appropriate, so as to evaluate and routinely (e.g. every 5 years) update these BMPs on a regular basis.

Contaminants:

- *Educate the public on the likely sources of contaminants to estuarine waters in Beaufort County and ways to reduce the problem.*

The most frequently detected anthropogenic chemical contaminants were pesticides (e.g. lindane) and PAHs, with highest concentrations being measured in the urbanized Broad Creek watershed. This finding underscores the importance of reducing the sources and types of pesticides used in residential areas. Pesticides can be controlled in several ways. First and foremost, urban and agricultural areas should follow the recommended procedures described above for controlling NPS runoff. In addition, public education of the risks from pesticides is equally important. Homeowner associations may wish to annually or semi-annually meet with Clemson Extension Service personnel to review recommended pesticide and fertilizer application treatments for urban pest controls such as termites, fire ants and mole crickets. When possible, natural biological treatments (e.g. microbial pesticides or natural predator treatments) are preferred over traditional chemical treatments, and nonpersistent pesticides are preferable over persistent pesticides. In addition, in critical buffer zones around tidal creeks, further consideration should be given to the use of the least toxic and least persistent pesticides for pest control in these areas.

Control of PAHs from roadways and marinas is also a critical issue. The marina association in Beaufort County should be encouraged to continue their pro-active risk communication approaches in communicating environmental boating issues to the public. Consumer education on the importance of pumpout facilities for bacterial pollution control; proper fueling procedures, operation and maintenance of outboard engines to reduce PAH pollution in waterways; recommended antifouling paints; and the higher fuel efficiency and low pollution emissions of new outboard engine technology should be among the important messages communicated to the public. In addition, marinas should be encouraged to develop their own environmental friendly marina standards for operations above those required by current local, state and federal law. Development of A "Bay Safe Marina" Program by marina operators which would allow participating marinas meeting those operational standards set forth by the Beaufort County Marina Association to display and advertise that they are a “Bay Safe Marina” could also be considered. This would include development of stricter standards for pumpout facilities, fueling operations and boat yard work. Similar programs could be developed by farmers (e.g. “Bay Safe Farms”) and residential developers. Inclusion of the public in developing these "Bay Safe" programs will be vital to their success.

Water Management:

- *Control freshwater inflow in headwater areas of estuarine drainage systems.*

As noted in Chapter 5, most marine and many estuarine species are not well adapted to endure large fluctuations in salinity conditions. When salinity levels get below 10 ppt, many species, including oysters, cannot survive well, especially if those conditions occur frequently or for extended periods of time. The effects of freshwater runoff are more pronounced in small drainage systems and the upper ends (headwaters) of larger drainage systems, which often receive the greatest loads of freshwater runoff compared to areas more seaward and are often larger and therefore experience less dilution than the headwater areas. In order to avoid the adverse effects of large fluctuations in salinity related to freshwater runoff from rain events, Beaufort County should look at the best approaches to increase retention of excess water from developments and improved regulation of water from the retention ponds to create more stable flow conditions where feasible. This might be achieved by creating larger retention ponds with active flow control devices. It should be noted that the extensive network of retention ponds in the Hilton Head Island area might be one reason that we did not observe a higher incidence of chemical contaminants and related adverse effects in Broad Creek compared to other highly developed estuarine systems that have been studied elsewhere in the state.

Future Monitoring:

- *Continue to evaluate conditions at periodic intervals.*

We strongly urge the county to continue to monitor environmental and biological conditions in these two drainage systems, and increase their efforts to evaluate estuarine conditions elsewhere. This study provides an excellent baseline assessment of the two estuaries studied that can be used for comparison in future studies. The frequency of sampling may vary dependent on the variables considered. For example, water quality conditions are generally less expensive to monitor than sediment quality and biological condition, which tend to be more stable and would not need to be monitored as frequently. As part of the water quality monitoring effort, future assessments should include monitoring directed at identifying contents of the effluents from retention ponds, especially bacterial levels, nutrient levels, and dissolved oxygen conditions. Analyses of effluents from the retention ponds should encompass significant rainfall events. Evaluation of runoff from land application sites and potential septic tank contributions are other areas for potential study.

We recommend that monitoring be conducted a minimum of every five years for water and sediment quality. This could include some biological monitoring as well, but a large biological monitoring effort could probably be limited to less frequent time periods (e.g. every 10 years or every 5 years for selected components such as the oysters and possibly the benthos for selected sites). The special studies noted above (e.g. retention pond effluents, groundwater, monitoring areas receiving discharges from permitted disposal activities) should be implemented as soon as feasible and should be done at more frequent intervals than the larger scale surveys.

- *Establish a Citizens Watch Program*

Citizens Watch and Water Watch Programs have proven to be effective in other areas and give the interested community members a sense of ownership and purpose. These programs have been quite varied in scope, and vary from simple reporting of violations in wetland areas to active participation in monitoring conditions. Beaufort County and the Clean Water Task Force should evaluate programs that have been implemented in other areas and resolve what might work best for their situation. At the very least, an advertisement campaign should be initiated to educate the general public on the existing programs that have been established by the SCDNR and SCDHEC (e.g. SCDHEC Water Watch, SCDNR Operation Game Thief, etc) and promote their active participation in reporting violations.

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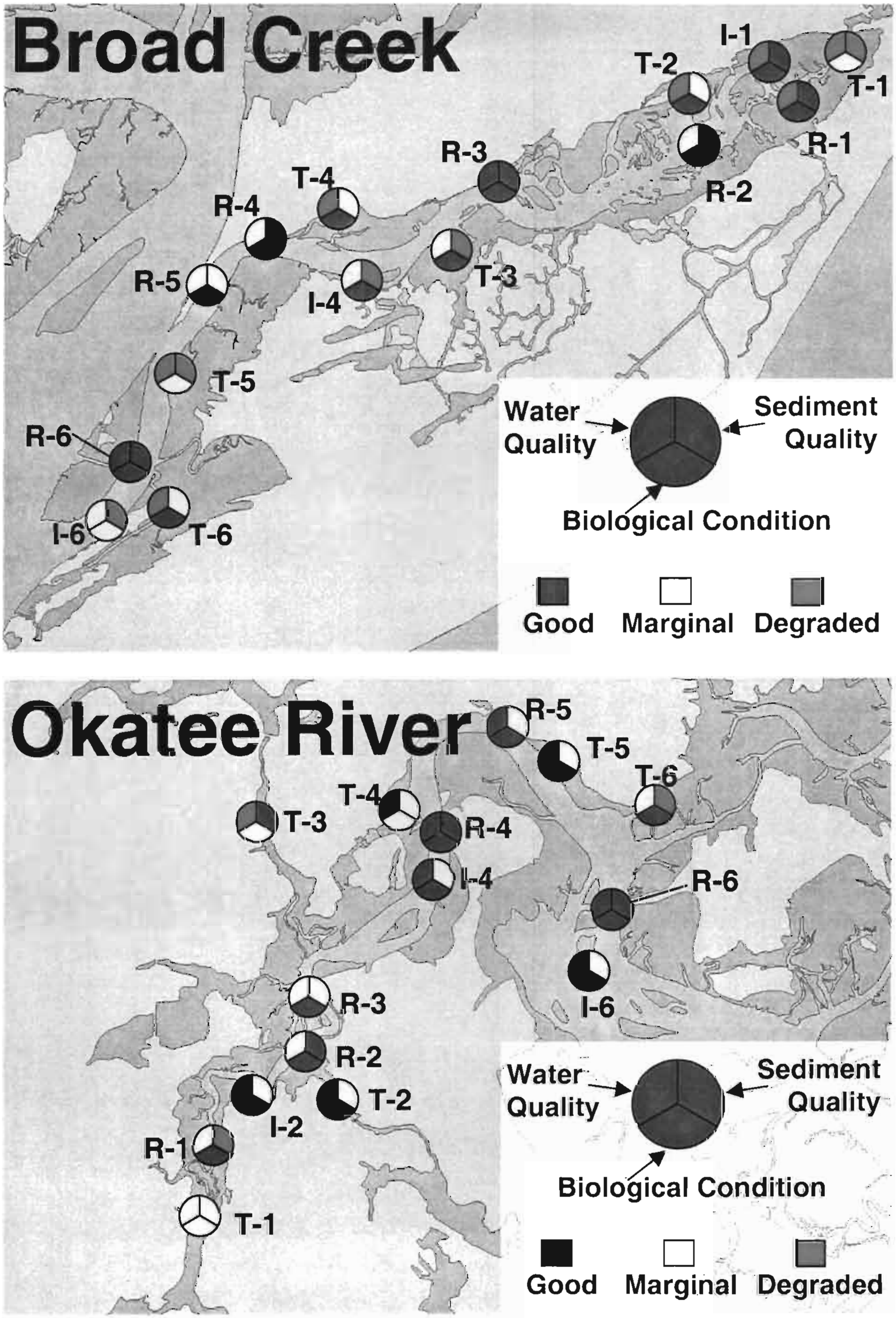

Figure 6.1 Summary of overall site conditions based on water quality, sediment quality, and biological condition.

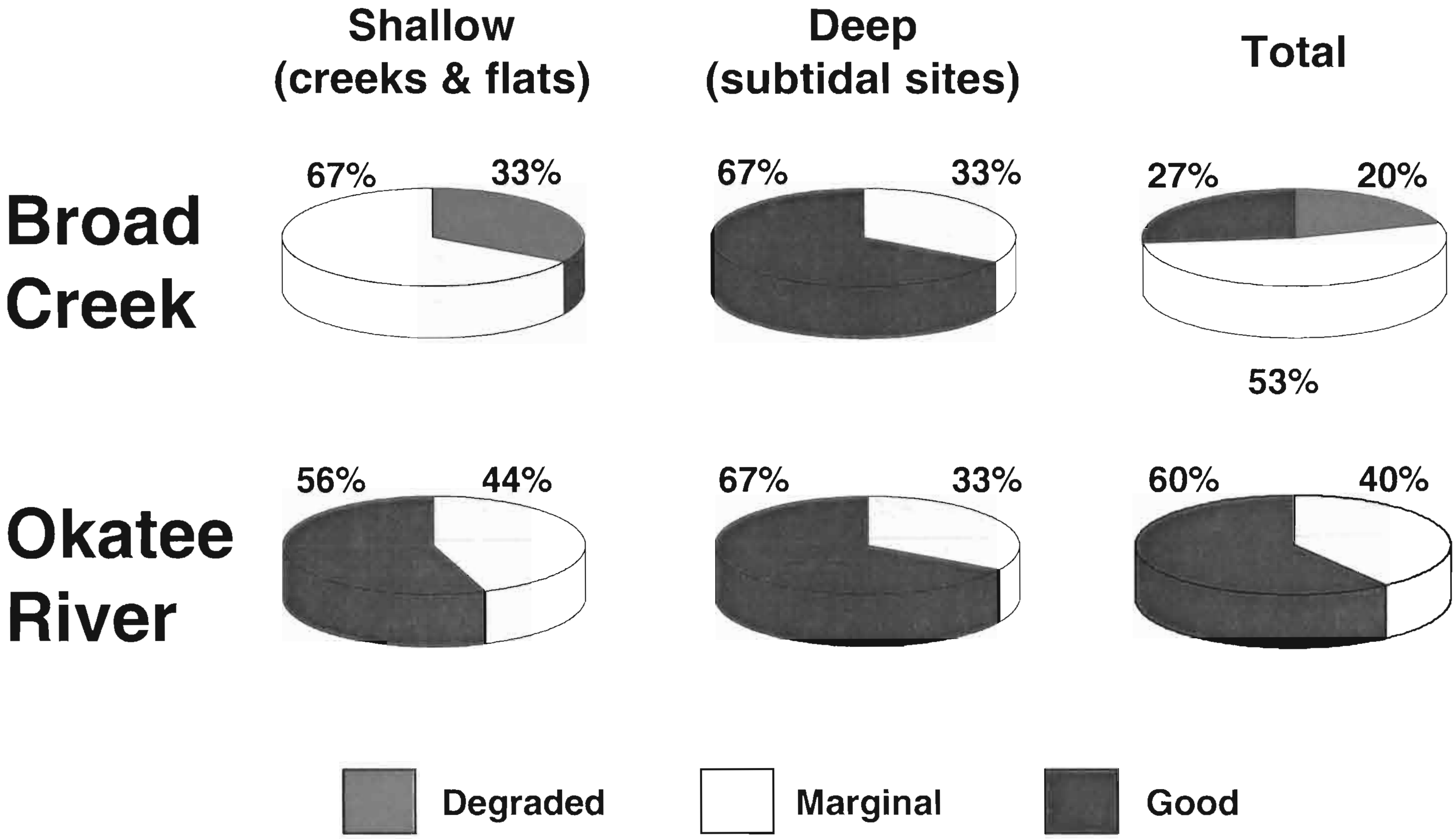

Figure 6.2. Summary of overall conditions based on water quality, sediment quality, and biological conditions.

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Appendices

Appendix 3.1. Water quality analytical results

STATION	DATE	TIME	82048 DEPTH OF SMPL METERS	00002 HSAMPLOC % FROM RT BANK	00010 WATER TEMP CENT	00020 AIR TEMP CENT	00041 WEATHER WMO CODE 4501	00067 TIDE STAGE CODE	00076 TURBIDITY TRBIDMTR NTU	00300 DO MG/L	00301 % DO SAT SATURATION PERCENT	00310 BOD 5 DAY MG/L	00400 PH SU	00402 CONDUCTIVITY UMHOS/CM		00410 ALKALINITY CACO3 MG/L	00480 SALINITY PPTH
BROAD CREEK																	
INTERTIDAL																	
I-1	8/20/97	1445	0.3	50	31	37	0		32	5.4	72	4.6	7.35	42000		108	25
I-4	8/20/97	1330	0.3	50	31	37	0		39	4.3	57.3	2.2	7.4	47000		104	27
I-6	8/20/97	1330	0.3	99.9	30.5	33	1	2000	37	5.5	71.7	1.8	7.8	50000	L	107	31
I-6	8/20/97	1332	0.65		30.5					5.5	72.4			50000	L		31.5
I-6	8/20/97	1331	1.1		30.5					5.6	73.7			50000	L		31.5
SUBTIDAL																	
R-1	8/20/97	1450	0.3	50	32	37	0		45	5.4	73	3.8	7.4	42000		108	24
R-2	8/20/97	1440	0.3	50	31.5	35	1	2000	20	6.1	81.3	2.4	7.3	44000		108	25.5
R-2	8/20/97	1441	1		31.5					5.9	78.7			44000			25.5
R-2	8/20/97	1442	2		31.5					5.8	77.3			44000			25.5
R-3	8/20/97	1420	0.3	50	30	36	1	2000	25	5	65.8	1.6	7.1	43000		107	25
R-3	8/20/97	1426	5.5		30					4.9	64.5			44000			26
R-3	8/20/97	1424	11		30					5	65.8			44000			26
R-4	8/20/97	1345	0.3	70	30	35	1	2000	21	5.8	75.7	1.5	8	46000		107	27
R-4	8/20/97	1351	3		30					5.7	75			46000			27
R-4	8/20/97	1350	6		30					5.6	73.7			46000			27
R-5	8/20/97	1325	0.3	80	30	34	1	2000	20	5.9	77.6	0.8	8.1	45000		106	27
R-5	8/20/97	1328	2.5		30					5.7	75			47000			27.5
R-5	8/20/97	1326	5		30					5.7	75			47000			28
R-6	8/20/97	1300	0.3	60	31	34	1	2000	23	7.5	100	1.8	8.1	48500		106	29
R-6	8/20/97	1301	3		30					7.3	95.4			48500			29
R-6	8/20/97	1259	6.5		30					7.3	95.4			48500			29
TIDE CREEK																	
T-1	8/20/97	1422	0.3	50	29	29	1		18	3.3	42.3	2	6.7	11500		68	11
T-2	8/20/97	1455	0.3	50	34	36	1	2000	75	6.7	93.7	4	7.45	43500		106	25.5
T-3	8/20/97	1415	0.3	50	31	37	1		7	4.5	59.3	2.4	7.2	28500		86	16
T-3	8/20/97	1417	0.7		31					4.5	59.3			28000			16
T-3	8/20/97	1416	1.4		31					4.5	59.3			28500			16
T-4	8/20/97	1325	0.3	50	28.5	30	1		200	2.4	30.4	2	6.45	42000		39	27
T-5	8/20/97	1300	0.3	50	32	37	0		12	4.8	64.9	3.3	7.2	48000		106	28
T-6	8/20/97	1300	0.3	50	29	37	1		8.2	3.9	50	2.3	7.1	18000		91	10.5
T-6	8/20/97	1302	1		29					3.6	45.5			34000			16.5
T-6	8/20/97	1301	2		29.5					3.1	39.1			45500			28

K = Actual value below detection limits

L = Actual value exceeds test limits

Appendix 3.1. Water quality analytical results

STATION	DATE	TIME	00530 TSS TOT NFLT MG/L	00610 NH3+NH4- NTOTAL MG/L	00625 TKN N MG/L	00630 NO2&NO3 N TOTAL MG/L		00665 PHOS-TOT MG/L P	00680 T ORG C C MG/L	31615 FECAL COLIFORM MPNECMED /100ML		32209 CHLOROPHYLL A UG/L
BROAD CREEK												
INTERTIDAL												
I-1	8/20/97	1445	50	0.08	0.73	0.02	K	0.19	40	65		31.3
I-4	8/20/97	1330	57	0.11	0.72	0.02	K	0.17	40	210		17.1
I-6	8/20/97	1330	45	INTERFERENCE	0.44	0.02	K	0.1	58	50		9.8
I-6	8/20/97	1332										
I-6	8/20/97	1331										
SUBTIDAL												
R-1	8/20/97	1450	68	0.1	0.84	0.02	K	0.21	38	80		32.3
R-2	8/20/97	1440	41	0.56	0.57	0.02	K	0.15	42	30		25.1
R-2	8/20/97	1441										
R-2	8/20/97	1442										
R-3	8/20/97	1420	41	INTERFERENCE	0.54	0.02		0.15	38	26		14.1
R-3	8/20/97	1426										
R-3	8/20/97	1424										
R-4	8/20/97	1345	33	INTERFERENCE	0.46	0.03		0.11	39	1600		16.5
R-4	8/20/97	1351										
R-4	8/20/97	1350										
R-5	8/20/97	1325	29	INTERFERENCE	0.4	0.02		0.08	53	50		13.8
R-5	8/20/97	1328										
R-5	8/20/97	1326										
R-6	8/20/97	1300	59	INTERFERENCE	0.36	0.02	K	0.06	40	110		16
R-6	8/20/97	1301										
R-6	8/20/97	1259										
TIDE CREEK												
T-1	8/20/97	1422	26	0.31	1	0.34		0.19	27	1600		18.1
T-2	8/20/97	1455	110	0.68	1.22	0.02	K	0.32	44	900		51.1
T-3	8/20/97	1415	10	0.14	0.68	0.05		0.35	36	1600	L	23
T-3	8/20/97	1417										
T-3	8/20/97	1416										
T-4	8/20/97	1325	96	0.32	1.6	0.22		0.72	33	1600	L	18
T-5	8/20/97	1300	17	INTERFERENCE	0.39	0.02	K	0.08	46	1600	L	9.1
T-6	8/20/97	1300	12	0.27	0.92	0.07		0.68	42	1600	L	32.6
T-6	8/20/97	1302										
T-6	8/20/97	1301										

K = Actual value below detection limits
L = Actual value exceeds test limits

Appendix 3.1. Water quality analytical results

STATION	DATE	TIME	82048 DEPTH OF SMPL METERS	00002 HSAMPLOC % FROM RT BANK	00010 WATER TEMP CENT	00020 AIR TEMP CENT	00041 WEATHER WMO CODE 4501	00067 TIDE STAGE CODE	00076 TURBIDITY TRBIDMTR NTU	00300 DO MG/L	00301 % DO SAT SATURATION PERCENT	00310 BOD 5 DAY MG/L	00400 PH SU	00402 CONDUCTIVITY UMHOS/CM		00410 ALKALINITY CACO3 MG/L	00480 SALINITY PPTH	00530 TSS TOT NFLT MG/L
OKATEE RIVER																		
INTERTIDAL																		
I-2	8/19/97	1415	0.3	50	32	40	2	2000	14	4.3	58.1	2.6	7.3	48000		109	28	20
I-2	8/19/97	1416	0.5		31.5					4.5	59.3			37000			27	
I-2	8/19/97	1417	0.7		31.5					5.6	74.7			47000			26.5	
I-2	8/19/97	1418	0.9		31.1					4.4	58			47000			27	
I-4	8/19/97	1430	0.3	1	32	37	2	2000	30	6.1	82.4	2.2	7	50000		110	29	44
I-6	8/19/97	1325	0.3	1	31	35	1	2000	7.3	3.1	40.7	1.4	7.1	50000	L	111	31	10
I-6	8/19/97	1326	0.95		30					3.3	42.8			50000	L		31.5	
SUBTIDAL																		
R-1	8/19/97	1500	0.3	50	32.5	35	2	2000	70	5.9	79.1	3.4	6.8	45000		104	25.5	110
R-1	8/19/97	1501	1		32.3					5.9	79.1			45000			25	
R-1	8/19/97	1502	1.2		32.3					5.8	78.4			45000			25	
R-2	8/19/97	1601	0.3	50	32.6	37	1	2000	32	5.5	75.3	2.7	7.5	46000		106	27	51
R-2	8/19/97	1602	1		32.2					5.4	72.7			46000			27	
R-3	8/19/97	1543	0.3	40	31.5	39	1	2000	45	6	79.7	2.6	7.1	46000		108	27	78
R-3	8/19/97	1547	1		31.8					5.2	69.6			46000			27	
R-3	8/19/97	1545	2		31.9					5.1	68.9			46000			27	
R-4	8/19/97	1508	0.3	60	31	39	1	2000	31	5.5	73.3	1.8	6.9	44500		108	26	48
R-4	8/19/97	1530	2		31					4.8	64			46000			27	
R-4	8/19/97	1520	4		31					5.3	70.7			47000			27.5	
R-5	8/19/97	1420	0.3	60	30.5	39	1	2000	30	3	39.5	1.4	6.9	47000		108	26	54
R-5	8/19/97	1424	2.5		30.5					2.8	36.8			47000			28	
R-5	8/19/97	1422	5		30.5					2.5	32.9			47000			28	
R-6	8/19/97	1334	0.3	60	30.5	39	1	2000	33	3.5	46.1	1.6	6.2	47000		110	30	51
R-6	8/19/97	1348	2		30.5					3.5	46.1			47000			27	
R-6	8/19/97	1345	4		30.5					3.5	46.1			47000			28	
TIDE CREEK																		
T-1	8/19/97	1517	0.3	50	29	34	1		45	6.4	81.4	1.6	6.9	18000		25	19.5	50
T-2	8/19/97	1452	0.3	50	32	35	2	2000	40	4.7	62.8	1.4	7.25	46500		108	27	56
T-3	8/19/97	1443	0.3	50	30.5	34	1		30	6.6	86.3	5.9	7.2	12225		91	18	53
T-4	8/19/97	1355	0.3	50	33.2	40	2	2000	13	5	68.5	2.4	7.3	48000		110	28	23
T-4	8/19/97	1356	0.5		31.2					5 1	67.6			48000			28	
T-4	8/19/97	1357	0.7		31.2					5.2	68.7			48000			28	
T-5	8/19/97	1400	0.3	50	32	36	2	2000	27	5	67.6	1.9	7.4	50000	L	111	29	42
T-6	8/19/97	1315	0.3	50	31.1	40	0	2000	16	4.6	61.3	1.6	6.4	49000		111	29	24
T-6	8/19/97	1316	0.6		31					4.6	60.7			49000			29	
T-6	8/19/97	1317	0.8		31					4.6	60.7			49000			29	

K = Actual value below detection limits
L = Actual value exceeds test limits

Appendix 3.1. Water quality analytical results

STATION	DATE	TIME	00610 NH3+NH4- NTOTAL MG/L	00625 TKN N MG/L	00630 NO2&NO3 N TOTAL MG/L		00665 PHOS-TOT MG/L P	00680 T ORG C C MG/L	31615 FECAL COLIFORM MPNECMED /100ML		32209 CHLOROPHYLL A UG/L
OKATEE RIVER											
INTERTIDAL											
I-2	8/19/97	1415	LAB ERROR	0.52	0.02	K	0.07	5.1	13		17.1
I-2	8/19/97	1416									
I-2	8/19/97	1417									
I-2	8/19/97	1418									
I-4	8/19/97	1430	LAB ERROR	0.59	0.02	K	0.13	5.7	13		21
I-6	8/19/97	1325	0.1	0.36	0.02	K	0.09	4.2	2	K	6.1
I-6	8/19/97	1326									
SUBTIDAL											
R-1	8/19/97	1500	LAB ERROR	0.97	0.02	K	0.16	8.5	90		38.5
R-1	8/19/97	1501									
R-1	8/19/97	1502									
R-2	8/19/97	1601	0.74	0.85	0.02	K	0.12	5.2	40		30
R-2	8/19/97	1602									
R-3	8/19/97	1543	0.68	0.97	0.02	K	0.1	7.2	13		22.8
R-3	8/19/97	1547									
R-3	8/19/97	1545									
R-4	8/19/97	1508	0.42	0.68	0.02	K	0.12	6.1	8		15.1
R-4	8/19/97	1530									
R-4	8/19/97	1520									
R-5	8/19/97	1420	0.48	0.68	0.02		0.12	5.7	4		8.9
R-5	8/19/97	1424									
R-5	8/19/97	1422									
R-6	8/19/97	1334	0.46	0.76	0.02	K	0.1	5.6	2	K	10.5
R-6	8/19/97	1348									
R-6	8/19/97	1345									
TIDE CREEK											
T-1	8/19/97	1517	0.33	0.88	0.1		0.28	8.4	280		9.1
T-2	8/19/97	1452	LAB ERROR	0.82	0.02	K	0.16	6.6	23		7
T-3	8/19/97	1443	0.14	1.08	0.02	K	0.19	10.3	1600		40
T-4	8/19/97	1355	LAB ERROR	0.53	0.02	K	0.1	6.3	30		24.5
T-4	8/19/97	1356									
T-4	8/19/97	1357									
T-5	8/19/97	1400	LAB ERROR	0.55	0.02	K	0.12	5.9	23		15.1
T-6	8/19/97	1315	LAB ERROR	0.56	0.02	K	0.08	4.7	2		12
T-6	8/19/97	1316									
T-6	8/19/97	1317									

K = Actual value below detection limits

L = Actual value exceeds test limits

Appendix 3.2. Hydrolab data summary statistics.

	Dissolved Oxygen (mg/l)								Percent Dissolved Oxygen Saturation								Salinity (ppt)					
Station	N	Min	Max	Range	Avg	Var	N<2	%<2	N	Min	Max	Range	Avg	Var	N<28	%<28	N	Min	Max	Range	Avg	Var
BROAD CREEK																						
R-1	48	1.63	6.63	5	4.222	1.9935	4	8.33	48	24.5	105.2	80.7	65.72	532.001	3	6.25	48	25.8	28.9	3.1	27.97	0.606
R-2	51	2.44	5.97	3.53	4.382	0.9660	0		51	37.8	94.2	56.4	68.14	245.441	0		51	27.6	29.5	1.9	28.58	0.291
R-3	50	3.53	5.43	1.9	4.622	0.3326	0		50	54.6	86.0	31.4	72.51	92.051	0		50	26.4	29.7	3.3	27.83	1.169
R-4	50	3.63	5.68	2.05	4.627	0.3004	0		50	56.3	89.8	33.5	72.46	79.959	0		50	26.5	30.3	3.8	28.08	1.703
R-5	51	3.92	5.51	1.59	4.964	0.1255	0		51	58.4	85.0	26.6	75.68	36.151	0		51	29.7	31.8	2.1	30.82	0.525
R-6	51	4.25	5.78	1.53	5.085	0.1682	0		51	64.5	90.1	25.6	78.57	46.783	0		51	30.4	33.2	2.8	31.65	0.690
T-1	40	0.72	6.09	5.37	3.628	2.0214	7	17.50	40	10.5	95.5	85.0	54.91	514.605	5	12.50	40	6.4	28.7	22.3	24.01	41.109
T-2	38	2.20	6.48	4.28	4.298	1.4947	0		38	33.6	102.7	69.1	66.52	399.880	0		38	26.9	28.9	2.0	28.31	0.227
T-3	36	2.43	5.10	2.67	3.389	0.4598	0		36	35.9	77.5	41.6	52.11	103.698	0		36	16.6	26.9	10.3	23.43	15.733
T-4	35	1.84	4.29	2.45	3.297	0.3792	1	2.86	35	28.3	67.6	39.3	51.46	103.684	0		35	15.2	28.8	13.6	27.05	6.505
T-5	51	0.08	8.08	8	3.923	3.5516	10	19.61	51	1.1	126.8	125.7	59.80	867.162	10	19.61	51	30.4	31.9	1.5	31.34	0.178
T-6	51	3.11	6.36	3.25	4.700	0.7866	0		51	42.4	96.5	54.1	69.28	233.428	0		51	4.7	31.8	27.1	25.79	41.898
OKATEE RIVER																						
R-1	51	3.03	7.00	3.97	5.233	1.2911	0		51	45.4	111.0	65.6	81.24	351.753	0		51	24.5	30.1	5.6	28.98	1.945
R-2	50	4.05	6.92	2.87	5.225	0.8673	0		50	62.3	108.8	46.5	81.02	229.523	0		50	29.1	30.2	1.1	29.71	0.107
R-3	51	3.27	6.08	2.81	4.310	0.7342	0		51	51.9	99.0	47.1	69.07	210.623	0		51	28.1	29.8	1.7	28.95	0.292
R-4	51	3.00	5.88	2.88	4.154	0.6791	0		51	47.5	95.1	47.6	66.23	192.200	0		51	26.7	29.6	2.9	28.60	0.463
R-5	50	4.65	6.32	1.66	5.405	0.1957	0		50	69.6	96.5	26.9	81.89	56.435	0		50	30.0	31.2	1.2	30.70	0.093
R-6	51	4.62	6.51	1.89	5.441	0.1956	0		51	68.2	99.5	31.3	82.39	55.535	0		51	30.8	31.4	0.6	31.10	0.031
T-1	42	2.67	7.03	4.36	4.653	1.4484	0		42	37.4	100.7	63.3	69.49	359.972	0		42	2.4	28.8	26.4	22.74	73.106
T-2	49	1.02	6.66	5.64	4.616	1.5633	1	2.04	49	14.7	105.1	90.3	71.66	406.020	1	2.04	49	27.0	30.1	3.1	29.56	0.474
T-3	36	3.12	6.67	3.55	3.897	0.6083	0		36	49.4	108.3	58.9	62.18	168.500	0		36	28.1	29.3	1.2	28.79	0.136
T-4	50	3.55	7.42	3.87	4.619	1.1294	0		50	46.0	118.2	72.2	70.93	349.363	0		50	10.1	28.3	18.2	23.92	42.748
T-5	49	3.13	8.95	5.82	5.466	1.5883	0		49	44.3	135.9	91.6	82.63	403.123	0		49	30.2	31.2	1.0	30.82	0.059
T-6	44	3.00	8.10	5.1	4.553	0.7836	0		44	45.6	114.2	68.6	69.89	175.936	0		44	9.1	31.6	22.5	30.45	22.126

N<2 = Number of dissolved oxygen measurements less than 2.0 mg/l

%<2 = Percentage of dissolved oxygen measurements less than 2.0 mg/l

N<28 = Number of percent dissolved oxygen values less than 28%

%<28 = Percentage of percent dissolved oxygen values less than 28%

Appendix 3.2. Continued

Station	pH (SU)						Temperature (^{o}C)						Depth (m)					
	N	Min	Max	Range	Avg	Var	N	Min	Max	Range	Avg	Var	N	Min	Max	Range	Avg	Var
BROAD CREEK																		
R-1	48	7.13	7.62	0.49	7.415	0.0167	48	27.32	33.02	5.70	29.381	1.2207	51	0.00	1.90	1.90	0.900	0.4880
R-2	51	7.12	7.46	0.34	7.348	0.0090	51	28.99	30.98	1.99	29.721	0.2742	51	0.00	1.90	1.90	0.900	0.4880
R-3	50	7.17	7.59	0.42	7.370	0.0165	50	29.32	31.22	1.90	30.121	0.3373	50	3.30	7.10	3.80	5.624	1.4582
R-4	50	7.18	7.76	0.58	7.419	0.0310	50	29.10	30.93	1.83	29.937	0.2212	50	1.80	5.70	3.90	4.138	1.3514
R-5	51	7.53	7.91	0.38	7.734	0.0124	51	26.83	28.58	1.75	27.842	0.2881	51	4.60	6.50	1.90	5.600	0.3572
R-6	51	7.50	7.93	0.43	7.731	0.0172	51	27.59	29.03	1.44	28.325	0.2543	51	4.60	6.50	1.90	5.600	0.3572
T-1	40	2.50	7.33	4.83	5.317	1.6187	40	26.50	32.31	5.81	29.178	1.9362	51	0.00	1.95	1.95	0.917	0.5168
T-2	38	7.12	7.66	0.54	7.427	0.0155	38	27.64	33.76	6.12	29.350	2.1640	51	0.00	1.46	1.46	0.574	0.3185
T-3	36	7.44	7.81	0.37	7.668	0.0099	36	29.30	32.01	2.71	30.540	0.5878	51	0.00	2.02	2.02	0.840	0.5788
T-4	35	7.44	7.88	0.44	7.656	0.0201	35	26.15	33.22	7.07	30.018	1.1281	51	0.00	2.17	2.17	0.944	0.6912
T-5	51	6.97	7.80	0.83	7.373	0.0526	51	22.88	29.88	7.00	26.860	4.7518	51	0.29	2.02	1.73	1.167	0.3908
T-6	51	7.17	7.87	0.70	7.530	0.0549	51	24.73	29.09	4.36	27.210	1.8049	51	0.05	1.97	1.92	1.125	0.4065
OKATEE RIVER																		
R-1	51	7.10	7.51	0.41	7.349	0.0111	51	28.62	32.25	3.63	29.848	1.1082	51	0.20	2.80	2.60	1.580	0.7212
R-2	50	7.28	7.53	0.25	7.402	0.0043	50	28.67	30.89	2.22	29.621	0.3947	50	0.90	3.80	2.90	2.634	0.8309
R-3	51	7.29	7.56	0.27	7.395	0.0048	51	29.89	32.31	2.42	30.909	0.5257	51	2.00	5.30	3.30	3.986	1.1168
R-4	51	7.34	7.57	0.23	7.423	0.0048	51	29.57	32.07	2.50	30.736	0.5486	51	1.30	4.50	3.20	3.259	1.0617
R-5	50	7.43	7.57	0.14	7.490	0.0015	50	26.48	28.97	2.49	27.921	0.6701	50	3.40	5.80	2.40	4.844	0.6188
R-6	51	7.37	7.55	0.18	7.449	0.0015	51	26.22	29.02	2.80	27.760	0.6642	51	2.50	5.40	2.90	4.375	0.6083
T-1	42	6.90	7.45	0.55	7.246	0.0208	42	26.28	31.86	5.58	29.493	1.8065	51	0.00	2.10	2.10	0.998	0.5714
T-2	49	7.16	7.53	0.37	7.346	0.0083	49	26.35	33.98	7.63	29.647	2.0160	51	0.00	2.40	2.40	1.243	0.7421
T-3	36	7.32	7.67	0.35	7.438	0.0074	36	29.97	32.08	2.11	30.769	0.2817	52	0.00	1.97	1.97	0.805	0.5255
T-4	50	6.99	7.72	0.73	7.386	0.0435	50	25.06	32.04	6.98	29.820	3.6792	50	0.03	2.57	2.54	1.235	0.7538
T-5	49	7.19	7.59	0.40	7.404	0.0095	49	22.41	30.04	7.63	27.586	2.6405	51	0.00	2.30	2.30	1.280	0.5976
T-6	44	7.14	7.59	0.45	7.343	0.0081	44	27.05	30.40	3.35	28.008	0.4041	52	0.00	1.94	1.94	0.904	0.4779

Appendix 3.3. Hydrolab results, Broad Creek site R-1

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
100000	1.7	7.41	28.8	60.9	28.33	90397	44.5	4.01	14.3
103000	1.8	7.42	28.8	61.9	28.36	90397	44.5	4.08	14.3
110000	1.7	7.43	28.8	62.8	28.4	90397	44.5	4.13	14.3
113000	1.6	7.43	28.7	66.7	28.54	90397	44.3	4.38	14.3
120000	1.4	7.44	28.5	70.7	28.73	90397	44.1	4.63	14.4
123000	1.2	7.46	28.4	76.9	29.01	90397	43.9	5.02	14.3
130000	1	7.47	28.1	82.1	29.3	90397	43.5	5.34	14.3
133000	0.6	7.46	27.7	83.7	29.76	90397	43	5.41	14.3
140000	0.4	7.48	27.9	84.4	29.97	90397	43.2	5.44	14.3
143000	0.2	7.48	27.4	89.8	30.57	90397	42.6	5.74	14.3
150000	0	7.48	26.7	94.8	31.18	90397	41.6	6.02	14.3
153000	0	7.45	25.8	93.9	31.71	90397	40.4	5.94	14.3
160000	0								
163000	0								
170000	0	7.53	26.3	99.5	33.02	90397	41.1	4.76	14.3
173000	0.1	7.59	26.9	103.6	32.03	90397	41.8	6.48	14.3
180000	0.2	7.61	27	105.2	31.5	90397	42	6.63	14.3
183000	0.4	7.62	27.3	102.7	30.9	90397	42.4	6.53	14.3
190000	0.7	7.6	27.6	100.2	30.58	90397	42.8	6.39	14.3
193000	1	7.56	27.9	93.2	30.16	90397	43.2	5.98	14.3
200000	1.2	7.53	28.2	85.2	29.7	90397	43.7	5.5	14.2
203000	1.4	7.55	28.4	86.2	29.61	90397	44	5.56	14.3
210000	1.6	7.53	28.5	80.5	29.42	90397	44.1	5.21	14.2
213000	1.7	7.53	28.7	78.3	29.35	90397	44.3	5.07	14.3
220000	1.9	7.51	28.7	75.2	29.37	90397	44.3	4.87	14.3
223000	1.9	7.51	28.8	72.3	29.29	90397	44.4	4.68	14.3
230000	1.8	7.5	28.6	73	29.34	90397	44.3	4.73	14.3
233000	1.7	7.49	28.6	73	29.33	90397	44.2	4.73	14.3
0	1.5	7.45	28.5	67.5	29.31	90497	44.1	4.38	14.3
3000	1.3	7.41	28.4	63.5	29.33	90497	44	4.12	14.3
10000	1.1	7.35	28.2	56.1	29.35	90497	43.7	3.64	14.3
13000	0.8	7.27	28	45.3	29.33	90497	43.4	2.94	14.3
20000	0.5	7.23	27.9	37.2	29.28	90497	43.2	2.42	14.3
23000	0.3	7.24	28	37.3	29.15	90497	43.4	2.43	14.2
30000	0.1	7.18	27.5	30.4	29.22	90497	42.8	1.98	14.2
33000	0	7.14	27	27.7	29.14	90497	42	1.82	14.2
40000	0	7.13	26.5	26	28.81	90497	41.3	1.72	14.2
43000	0								
50000	0	7.2	26.8	30.8	27.32	90497	41.7	2.09	14.2
53000	0	7.17	27.4	24.5	28.44	90497	42.5	1.63	14.2
60000	0.2	7.28	27.2	39.4	28.7	90497	42.3	2.6	14.2
63000	0.4	7.24	27.5	35.3	28.46	90497	42.7	2.33	14.2
70000	0.6	7.31	27.9	42.5	28.62	90497	43.2	2.8	14.2
73000	0.9	7.31	28	43.3	28.58	90497	43.4	2.85	14.2
80000	1.1	7.35	28.4	47.8	28.65	90497	43.9	3.14	14.2
83000	1.3	7.38	28.5	52.3	28.69	90497	44.1	3.42	14.2
90000	1.5	7.41	28.7	56.3	28.64	90497	44.3	3.69	14.2
93000	1.7	7.43	28.7	57.8	28.57	90497	44.4	3.79	14.2
100000	1.8	7.44	28.8	57.3	28.48	90497	44.5	3.76	14.2
103000	1.8	7.48	28.9	61	28.45	90497	44.6	4.01	14.2
110000	1.8	7.47	28.8	58.5	28.33	90497	44.5	3.85	14.2

Appendix 3.3. (Continued). Hydrolab results, Broad Creek site R-2

Time HHMMSS	Depth meters*	pH units	Salinity ppt	DO % saturation	Temp °C	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
103000	1.7	7.12	29	62.6	28.99	90397	44.8	4.07	15
110000	1.8	7.31	29	63.5	29.01	90397	44.8	4.13	14.9
113000	1.7	7.33	29	63.7	29.01	90397	44.8	4.14	15
120000	1.6	7.34	28.8	65.9	29.07	90397	44.4	4.29	14.9
123000	1.4	7.35	28.5	70.1	29.23	90397	44.1	4.55	14.9
130000	1.2	7.36	28.5	74.2	29.41	90397	44	4.8	14.9
133000	1	7.37	28.4	77.1	29.55	90397	43.9	4.99	14.9
140000	0.6	7.38	28.1	80.8	29.79	90397	43.6	5.21	14.9
143000	0.4	7.39	28	81.8	30.05	90397	43.4	5.26	14.9
150000	0.2	7.41	27.7	89.6	30.35	90397	43	5.73	14.9
153000	0	7.43	27.6	92.8	30.7	90397	42.9	5.91	14.9
160000	0	7.44	27.6	94.2	30.98	90397	42.8	5.97	14.9
163000	0	7.45	27.6	91	30.96	90397	42.9	5.76	14.9
170000	0	7.43	27.7	91.5	30.9	90397	43	5.8	14.9
173000	0	7.45	28	91.8	30.68	90397	43.4	5.84	14.9
180000	0.1	7.45	28.1	93	30.6	90397	43.6	5.91	14.9
183000	0.2	7.45	28.3	88.4	30.29	90397	43.7	5.65	14.9
190000	0.4	7.44	28.3	86.7	30.23	90397	43.9	5.54	15
193000	0.7	7.46	28.5	88.2	30.21	90397	44.1	5.64	14.9
200000	1	7.43	28.6	81.1	29.89	90397	44.2	5.2	14.9
203000	1.2	7.43	28.8	79.4	29.87	90397	44.5	5.09	14.9
210000	1.4	7.43	29	76.5	29.78	90397	44.8	4.91	14.8
213000	1.6	7.43	29.2	74.8	29.73	90397	45	4.8	14.8
220000	1.7	7.43	29.3	74.1	29.71	90397	45.1	4.75	14.8
223000	1.9	7.44	29.4	72.8	29.69	90397	45.3	4.67	14.8
230000	1.9	7.43	29.3	72.3	29.69	90397	45.2	4.64	14.8
233000	1.8	7.43	29.3	72.3	29.71	90397	45.1	4.63	14.8
0	1.7	7.4	28.9	71.1	29.73	90497	44.6	4.57	14.8
3000	1.5	7.38	28.7	69.8	29.75	90497	44.4	4.49	14.8
10000	1.3	7.34	28.7	65.6	29.77	90497	44.3	4.22	14.8
13000	1.1	7.3	28.5	60	29.79	90497	44.1	3.86	14.8
20000	0.8	7.28	28.5	57.5	29.77	90497	44.1	3.7	14.8
23000	0.5	7.26	28.3	53	29.77	90497	43.9	3.41	14.8
30000	0.3	7.23	28.2	49.1	29.71	90497	43.6	3.17	14.8
33000	0.1	7.2	28.1	45.9	29.77	90497	43.6	2.96	14.8
40000	0	7.17	28	40.8	29.67	90497	43.4	2.63	14.8
43000	0	7.18	27.9	50.5	29.61	90497	43.3	3.27	14.8
50000	0	7.16	28.1	37.8	29.65	90497	43.5	2.44	14.8
53000	0	7.18	28.2	41.6	29.47	90497	43.7	2.7	14.8
60000	0	7.19	28.4	42.5	29.49	90497	44	2.75	14.8
63000	0.2	7.22	28.5	46	29.39	90497	44.1	2.98	14.8
70000	0.4	7.25	28.6	51.2	29.41	90497	44.3	3.31	14.8
73000	0.6	7.27	28.7	53.1	29.41	90497	44.3	3.44	14.8
80000	0.9	7.29	28.8	55.5	29.39	90497	44.5	3.59	14.7
83000	1.1	7.32	28.9	57.8	29.36	90497	44.6	3.74	14.7
90000	1.3	7.35	29.1	61.3	29.25	90497	44.9	3.97	14.7
93000	1.5	7.36	29.2	61.9	29.21	90497	45.1	4	14.7
100000	1.7	7.38	29.3	63.3	29.13	90497	45.2	4.1	14.7
103000	1.8	7.39	29.4	63	29.09	90497	45.3	4.08	14.7
110000	1.8	7.41	29.4	63.2	29.06	90497	45.4	4.09	14.7
113000	1.8	7.42	29.5	63.6	29.04	90497	45.4	4.12	14.7

*Depths are from zone 1 since probe malfunctioned here

Appendix 3.3. (Continued). Hydrolab results, Broad Creek site R-3

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp °C	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
123000	7	7.53	29.3	73	29.54	82197	45.2	4.66	12.9
130000	6.8	7.48	28.9	72.2	29.64	82197	44.7	4.62	12.8
133000	6.6	7.44	28.6	71.7	29.74	82197	44.2	4.59	12.9
140000	6.2	7.41	28.2	73.4	30.04	82197	43.7	4.68	12.9
143000	5.9	7.44	27.9	82.4	30.58	82197	43.3	5.21	12.9
150000	5.5	7.37	27.3	80.6	30.6	82197	42.5	5.12	12.9
153000	5.2	7.37	27.1	82.5	30.83	82197	42.1	5.22	12.9
160000	4.8	7.34	26.9	81.5	30.95	82197	41.8	5.16	12.9
163000	4.3	7.33	26.6	81.9	30.99	82197	41.5	5.18	12.9
170000	3.7	7.35	26.6	83.3	31.15	82197	41.4	5.26	12.9
173000	3.4	7.35	26.5	84.1	31.2	82197	41.3	5.31	12.9
180000	3.3	7.35	26.4	86	31.22	82197	41.2	5.43	12.9
183000	4.1	7.33	26.6	80.6	31.11	82197	41.4	5.1	12.9
190000	4.5	7.33	26.6	81.5	31.11	82197	41.4	5.15	12.9
193000	5	7.33	26.7	80.8	30.95	82197	41.6	5.12	12.9
200000	5.3	7.34	26.9	80.5	30.89	82197	41.9	5.1	12.9
203000	5.6	7.34	27.2	79	30.77	82197	42.2	5	12.9
210000	6	7.39	27.7	79.8	30.62	82197	42.9	5.06	12.9
213000	6.3	7.4	27.8	79.2	30.52	82197	43.2	5.02	12.9
220000	6.5	7.46	28.3	80.7	30.42	82197	43.8	5.11	12.9
223000	6.8	7.54	28.9	82.5	30.22	82197	44.7	5.22	13
230000	6.9	7.56	29.1	82.5	30.16	82197	44.9	5.22	12.9
233000	7.1	7.57	29.3	82.3	30.14	82197	45.1	5.2	12.9
0	7	7.59	29.5	81.1	30.04	82297	45.5	5.13	12.9
3000	6.8	7.59	29.5	79.6	30	82297	45.5	5.04	12.9
10000	7	7.53	29.1	78.9	30.06	82297	44.9	5	12.9
13000	6.7	7.51	29	78.6	30.1	82297	44.7	4.99	12.9
20000	6.5	7.42	28.5	71.9	30.04	82297	44.1	4.58	12.9
23000	6.2	7.34	28.2	66	29.88	82297	43.7	4.22	12.9
30000	5.9	7.3	27.8	65.4	29.94	82297	43.1	4.19	12.9
33000	5.5	7.26	27.5	59.9	29.96	82297	42.6	3.84	13
40000	5.1	7.2	27.2	58.2	29.82	82297	42.2	3.74	12.9
43000	4.7	7.19	26.9	59.5	29.82	82297	41.8	3.84	12.9
50000	4.2	7.18	26.8	58.6	29.76	82297	41.7	3.78	12.9
53000	3.8	7.17	26.7	56.9	29.66	82297	41.6	3.68	12.9
60000	3.4	7.17	26.6	54.6	29.72	82297	41.5	3.53	12.9
63000	3.5	7.17	26.6	57.4	29.76	82297	41.5	3.71	12.9
70000	3.9	7.17	26.7	58.7	29.86	82297	41.6	3.79	12.9
73000	4.4	7.18	26.6	58.2	29.7	82297	41.5	3.77	12.9
80000	4.9	7.19	26.8	58	29.8	82297	41.7	3.75	12.9
83000	5.3	7.21	27	60	29.76	82297	42	3.87	12.9
90000	5.7	7.24	27.4	61.1	29.76	82297	42.5	3.93	12.9
93000	6	7.29	27.8	64.5	29.6	82297	43.1	4.15	12.9
100000	6.4	7.32	28.1	65	29.56	82297	43.5	4.18	12.9
103000	6.6	7.39	28.7	67.8	29.32	82297	44.4	4.36	12.9
110000	6.8	7.46	29.1	70.7	29.32	82297	45	4.54	12.9
113000	7	7.47	29.2	71.1	29.32	82297	45	4.56	12.9
120000	7.1	7.5	29.4	72.8	29.32	82297	45.3	4.67	12.9
123000	7	7.54	29.6	74.5	29.38	82297	45.6	4.76	12.9
130000	7	7.55	29.7	74.3	29.38	82297	45.7	4.75	12.9

Appendix 3.3. (Continued). Hydrolab results, Broad Creek site R-4

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
103000	5.4	7.66	30.1	78	29.12	82097	46.2	5	12.9
110000	5	7.69	30.2	77.8	29.1	82097	46.4	4.98	12.9
113000	5.4	7.69	30.1	78.5	29.12	82097	46.3	5.03	13
120000	5.3	7.61	29.6	73.8	29.2	82097	45.6	4.73	13
123000	5.1	7.52	29.1	70	29.26	82097	44.9	4.5	13
130000	4.8	7.46	28.5	71.2	29.52	82097	44.1	4.57	13
133000	4.5	7.4	28	71.4	29.7	82097	43.4	4.58	13
140000	4.1	7.35	27.5	68.8	29.88	82097	42.7	4.42	13
143000	3.8	7.31	27.1	68.7	30.1	82097	42.2	4.4	13
150000	3.4	7.28	26.9	69	30.28	82097	41.9	4.41	13
153000	3	7.28	26.7	71.3	30.48	82097	41.6	4.55	13
160000	2.7	7.28	26.6	73.5	30.66	82097	41.4	4.68	13
163000	2.2	7.3	26.7	77.1	30.85	82097	41.6	4.89	13
170000	2	7.31	26.6	78.1	30.93	82097	41.5	4.95	13
173000	2.5	7.29	26.5	78.1	30.87	82097	41.4	4.95	13
180000	3	7.27	26.7	71.4	30.66	82097	41.5	4.55	13
183000	3.3	7.29	26.8	73	30.6	82097	41.7	4.65	13
190000	3.7	7.34	27.1	76.8	30.54	82097	42.2	4.88	13
193000	4.1	7.38	27.4	77.5	30.48	82097	42.5	4.93	13
200000	4.5	7.42	27.7	80.5	30.38	82097	43	5.11	13
203000	4.8	7.51	28.4	82.5	30.26	82097	43.9	5.23	13
210000	5.1	7.54	28.6	82.9	30.1	82097	44.3	5.27	13
213000	5.3	7.56	28.9	81.6	29.98	82097	44.7	5.18	13
220000	5.5	7.62	29.5	82.5	29.8	82097	45.4	5.24	13
223000	5.7	7.69	29.9	86.3	29.72	82097	46	5.48	13
230000	5.6	7.74	30.2	89.2	29.7	82097	46.4	5.65	13
233000	5.4	7.76	30.3	89.8	29.7	82097	46.6	5.68	13
0	5.5	7.74	30.2	88.6	29.7	82197	46.4	5.61	13
3000	5.3	7.66	29.8	83.8	29.74	82197	45.8	5.32	13
10000	5	7.56	29.1	78.3	29.88	82197	44.8	4.98	13
13000	4.8	7.48	28.5	73.6	30	82197	44	4.69	13
20000	4.4	7.42	28	72.8	30.08	82197	43.4	4.64	13
23000	4.1	7.35	27.5	69.5	30.1	82197	42.7	4.44	13
30000	3.7	7.3	26.6	66.5	30.12	82197	41.5	4.27	13
33000	3.3	7.25	26.7	62.8	30.1	82197	41.6	4.03	13
40000	3	7.21	26.8	60.9	30.1	82197	41.8	3.91	13
43000	2.6	7.19	26.7	58.7	30.06	82197	41.6	3.77	13
50000	2.1	7.19	26.8	56.7	29.94	82197	41.7	3.65	13
53000	1.8	7.18	26.7	56.3	29.9	82197	41.6	3.63	13
60000	2.2	7.18	26.7	57.5	29.86	82197	41.6	3.71	13
63000	2.8	7.18	26.8	57.3	30	82197	41.7	3.69	13
70000	3.2	7.2	27	58.8	29.98	82197	41.9	3.78	13
73000	3.6	7.23	27.2	60.9	29.88	82197	42.3	3.92	13
80000	4	7.28	27.5	62.6	29.74	82197	42.7	4.03	13.1
83000	4.4	7.31	27.8	63.6	29.66	82197	43.1	4.09	13
90000	4.7	7.39	28.5	66.8	29.46	82197	44.1	4.29	13
93000	5	7.45	28.8	68.7	29.42	82197	44.5	4.41	13
100000	5.2	7.48	29	70.3	29.38	82197	44.8	4.51	13
103000	5.4	7.54	29.5	72.8	29.4	82197	45.5	4.66	13
110000	5.6	7.61	29.9	76	29.38	82197	46	4.85	12.9

Appendix 3.3. (Continued). Hydrolab results, Broad Creek site R-5

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
130000	5.9	7.78	31.1	77	28.33	90497	47.6	5	14.2
133000	5.8	7.76	30.9	77.5	28.35	90497	47.4	5.04	14.2
140000	5.6	7.72	30.7	75.6	28.4	90497	47.1	4.92	14.2
143000	5.4	7.68	30.5	75.5	28.42	90497	46.8	4.92	14.2
150000	5.2	7.66	30.2	76	28.46	90497	46.5	4.95	14.2
153000	5	7.64	30	76.8	28.47	90497	46.1	5.01	14.2
160000	4.9	7.63	29.8	78	28.48	90497	45.9	5.09	14.2
163000	4.7	7.63	29.7	78.9	28.49	90497	45.8	5.15	14.2
170000	4.7	7.64	29.8	77.1	28.58	90497	45.9	5.03	14.2
173000	4.8	7.64	29.8	79.5	28.53	90497	45.9	5.18	14.2
180000	4.9	7.64	29.8	79.7	28.51	90497	45.9	5.2	14.2
183000	5.2	7.65	30	76.9	28.51	90497	46.2	5.01	14.2
190000	5.4	7.71	30.4	82.8	28.48	90497	46.7	5.38	14.2
193000	5.5	7.7	30.4	79.8	28.45	90497	46.7	5.19	14.2
200000	5.7	7.74	30.7	81	28.41	90497	47.1	5.27	14.2
203000	5.9	7.79	31	83.5	28.36	90497	47.5	5.43	14.2
210000	6	7.84	31.4	83.2	28.27	90497	48	5.4	14.3
213000	6.2	7.87	31.5	83.9	28.23	90497	48.2	5.45	14.3
220000	6.2	7.9	31.7	85	28.22	90497	48.4	5.51	14.3
223000	6.4	7.91	31.8	84.8	28.19	90497	48.6	5.5	14.2
230000	6.4	7.91	31.8	82.6	28.18	90497	48.6	5.36	14.3
233000	6.4	7.9	31.8	82.7	28.11	90497	48.6	5.37	14.2
0	6.2	7.89	31.7	82.6	28.11	90597	48.5	5.37	14.2
3000	6.1	7.86	31.6	81.7	28.07	90597	48.3	5.32	14.2
10000	5.9	7.82	31.4	79.3	28.01	90597	48	5.17	14.1
13000	5.7	7.77	31.1	77.6	27.93	90597	47.6	5.08	14.1
20000	5.6	7.71	30.8	74.7	27.85	90597	47.2	4.91	14.2
23000	5.4	7.67	30.5	72.1	27.75	90597	46.9	4.75	14.2
30000	5.2	7.63	30.3	70.1	27.64	90597	46.5	4.63	14.1
33000	5	7.6	30.1	68.9	27.55	90597	46.3	4.57	14.1
40000	4.8	7.59	30	68.4	27.49	90597	46.1	4.54	14.1
43000	4.6	7.58	29.9	67.5	27.44	90597	46	4.49	14.1
50000	4.6	7.53	30.1	58.4	26.83	90597	46.2	3.92	14.1
53000	4.6	7.56	29.9	63.7	27.2	90597	46	4.25	14.1
60000	4.7	7.57	29.9	66.7	27.25	90597	46	4.45	14.1
63000	4.9	7.58	30	66.5	27.3	90597	46.1	4.43	14.1
70000	5.2	7.64	30.5	67.6	27.23	90597	46.8	4.49	14.1
73000	5.4	7.63	30.5	67	27.3	90597	46.8	4.45	14.1
80000	5.6	7.65	30.6	67.5	27.28	90597	47	4.48	14.1
83000	5.7	7.69	30.9	69	27.19	90597	47.4	4.58	14.1
90000	6	7.78	31.3	72.1	27.28	90597	48	4.76	14.1
93000	6.1	7.8	31.5	73.8	27.15	90597	48.2	4.88	14.1
100000	6.2	7.81	31.5	74	27.17	90597	48.3	4.89	14.1
103000	6.3	7.85	31.7	76.3	27.26	90597	48.5	5.03	14.1
110000	6.4	7.86	31.8	76.3	27.31	90597	48.6	5.03	14.1
113000	6.5	7.88	31.8	75.7	27.42	90597	48.6	4.97	14.1
120000	6.4	7.87	31.8	75.1	27.42	90597	48.7	4.94	14.2
123000	6.3	7.86	31.7	77.5	27.33	90597	48.5	5.1	14.1
130000	6.2	7.84	31.6	76.9	27.24	90597	48.3	5.07	14.1
133000	6	7.81	31.4	76.8	27.24	90597	48.1	5.08	14.1
140000	5.8	7.78	31.2	78	27.28	90597	47.7	5.16	14.1

Appendix 3.3. (Continued). Hydrolab results, Broad Creek site R-6

Time HHMMSS	Depth meters*	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
130000	5.9	7.82	32.1	80.9	28.84	90497	49	5.18	14.7
133000	5.8	7.79	31.8	78.7	28.86	90497	48.7	5.04	14.8
140000	5.6	7.75	31.5	77.7	28.86	90497	48.2	4.99	14.7
143000	5.4	7.69	31.2	77.2	28.84	90497	47.7	4.97	14.7
150000	5.2	7.67	31.2	81.1	28.86	90497	47.7	5.22	14.7
153000	5	7.65	30.9	80.5	28.92	90497	47.4	5.18	14.7
160000	4.9	7.63	30.7	79.5	28.98	90497	47.1	5.12	14.7
163000	4.7	7.61	30.6	79.8	29.03	90497	47	5.13	14.7
170000	4.7	7.61	30.5	78.6	29.03	90497	46.9	5.06	14.8
173000	4.8	7.59	30.4	77.9	28.99	90497	46.7	5.02	14.7
180000	4.9	7.59	30.6	76.3	28.99	90497	47	4.92	14.7
183000	5.2	7.62	30.7	80.4	28.98	90497	47.1	5.18	14.7
190000	5.4	7.67	31	82.9	28.92	90497	47.5	5.34	14.7
193000	5.5	7.73	31.4	82.3	28.86	90497	48	5.29	14.7
200000	5.7	7.76	31.6	82.7	28.86	90497	48.3	5.31	15
203000	5.9	7.78	31.7	84.5	28.82	90497	48.5	5.42	14.7
210000	6	7.8	31.9	83.9	28.8	90497	48.7	5.38	14.6
213000	6.2	7.8	31.9	83	28.82	90497	48.8	5.32	14.7
220000	6.2	7.85	32.3	86.3	28.68	90497	49.3	5.53	14.7
223000	6.4	7.89	32.6	87.5	28.64	90497	49.7	5.6	14.7
230000	6.4	7.92	32.8	90.1	28.52	90497	49.9	5.78	14.7
233000	6.4	7.93	32.9	86.5	28.48	90497	50.1	5.55	14.7
0	6.2	7.92	32.8	88.9	28.47	90597	50	5.7	14.7
3000	6.1	7.9	32.7	87.4	28.5	90597	49.8	5.61	14.6
10000	5.9	7.84	32.2	83.9	28.59	90597	49.1	5.39	14.7
13000	5.7	7.76	31.7	78.8	28.39	90597	48.5	5.09	14.6
20000	5.6	7.71	31.7	72.3	28.05	90597	48.4	4.71	14.7
23000	5.4	7.67	31.5	70.3	27.92	90597	48.2	4.59	14.6
30000	5.2	7.63	31.3	69.3	27.86	90597	48	4.53	14.6
33000	5	7.6	31	69.1	27.95	90597	47.5	4.52	14.6
40000	4.8	7.56	30.8	68.2	27.94	90597	47.2	4.47	14.6
43000	4.6	7.54	30.7	67.7	27.94	90597	47	4.44	14.6
50000	4.6	7.52	30.5	66.3	27.94	90597	46.8	4.35	14.6
53000	4.6	7.5	30.5	64.5	27.76	90597	46.8	4.25	14.6
60000	4.7	7.5	30.5	65.8	27.88	90597	46.9	4.32	14.6
63000	4.9	7.53	30.6	67.2	27.86	90597	47	4.42	14.6
70000	5.2	7.57	31	68.8	27.73	90597	47.5	4.52	14.6
73000	5.4	7.66	31.5	72.4	27.9	90597	48.2	4.73	14.6
80000	5.6	7.68	31.6	72.3	27.82	90597	48.3	4.72	14.6
83000	5.7	7.69	31.6	72.6	27.69	90597	48.3	4.76	14.6
90000	6	7.73	31.8	75.4	27.84	90597	48.7	4.92	14.6
93000	6.1	7.76	31.9	76.2	27.96	90597	48.7	4.96	14.6
100000	6.2	7.81	32.2	79.8	28	90597	49.2	5.18	14.6
103000	6.3	7.87	32.7	83.3	27.86	90597	49.8	5.4	14.6
110000	6.4	7.9	32.9	85.3	27.72	90597	50.1	5.54	14.5
113000	6.5	7.92	33	84.9	27.64	90597	50.3	5.52	14.6
120000	6.4	7.93	33.2	84.5	27.59	90597	50.5	5.49	14.6
123000	6.3	7.92	33.1	84.6	27.61	90597	50.4	5.5	14.6
130000	6.2	7.9	32.7	85.9	27.77	90597	49.9	5.58	14.6
133000	6	7.85	32.4	82.7	27.92	90597	49.4	5.37	14.6
140000	5.8	7.78	31.9	80.2	27.92	90597	48.7	5.22	14.7

*Depths are from zone 5 since probe malfunctioned here

Appendix 3.3. (Continued). Hydrolab results, Okatee River site R-1

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l (calculated)	Batt volts
110000	2.5	7.21	29.9	66.8	28.62	90397	46.1	4.38	15
113000	2.5	7.25	30	67.6	28.68	90397	46.1	4.43	14.9
120000	2.1	7.28	29.9	70	28.83	90397	46.1	4.58	14.8
123000	2	7.3	29.8	73.8	28.92	90397	45.9	4.82	15
130000	2	7.32	29.6	76.4	29.15	90397	45.6	4.98	15
133000	1.8	7.36	29.5	85.2	29.46	90397	45.5	5.52	15
140000	1.3	7.39	29.4	89.9	29.79	90397	45.3	5.80	15
143000	1.2	7.42	29.3	96.2	30.03	90397	45.1	6.19	14.9
150000	0.9	7.45	29	102.2	30.51	90397	44.7	6.53	14.9
153000	0.6	7.46	28.5	106.7	31.09	90397	44.1	6.78	14.9
160000	0.4	7.46	27.6	107.6	31.69	90397	42.8	6.80	14.9
163000	0.2	7.46	25.4	107.6	32.03	90397	39.8	6.84	14.9
170000	0.2	7.46	24.5	100.4	32.09	90397	38.5	6.41	14.9
173000	0.2	7.42	26.5	102.2	32.25	90397	41.3	6.44	14.9
180000	0.5	7.47	27.6	110.2	31.85	90397	42.8	6.95	14.9
183000	0.8	7.49	28.6	110.8	31.57	90397	44.2	6.98	14.9
190000	1.2	7.51	28.9	111	31.35	90397	44.7	7.00	14.9
193000	1.4	7.49	29.2	107.1	31.09	90397	45	6.77	14.9
200000	1.7	7.5	29.4	106.1	30.93	90397	45.3	6.72	14.8
203000	1.9	7.47	29.5	100.9	30.6	90397	45.5	6.42	14.9
210000	2.1	7.44	29.6	97	30.4	90397	45.6	6.19	14.9
213000	2.3	7.44	29.7	96.1	30.32	90397	45.8	6.14	14.9
220000	2.5	7.44	29.8	94.4	30.21	90397	45.9	6.04	14.9
223000	2.6	7.43	29.8	92.2	30.13	90397	45.9	5.90	14.9
230000	2.8	7.42	29.9	91	30	90397	46.1	5.84	14.9
233000	2.6	7.41	29.9	89.1	29.97	90397	46	5.72	14.9
0	2.4	7.4	29.9	86.8	29.91	90497	46	5.57	14.9
3000	2.4	7.41	29.8	87.2	30.01	90497	45.8	5.59	14.8
10000	2.3	7.39	29.7	86	30.03	90497	45.7	5.52	14.8
13000	2	7.39	29.6	84.7	29.97	90497	45.6	5.44	14.8
20000	1.6	7.36	29.5	80.3	29.9	90497	45.5	5.17	14.8
23000	1.3	7.34	29.4	76.7	29.88	90497	45.3	4.94	14.8
30000	1.1	7.32	29.3	74.3	29.8	90497	45.1	4.80	14.8
33000	0.9	7.28	29.3	68.5	29.68	90497	45.2	4.43	14.8
40000	0.6	7.22	28.8	59.5	29.45	90497	44.6	3.87	14.8
43000	0.4	7.16	27.3	52.5	29.2	90497	42.4	3.46	14.8
50000	0.2	7.13	24.9	48.4	28.89	90497	39.1	3.25	14.8
53000	0.3	7.1	25.4	45.4	29.04	90497	39.8	3.03	14.8
60000	0.5	7.15	27.8	50.6	29.03	90497	43.1	3.33	14.8
63000	0.7	7.2	28.9	56.9	29.08	90497	44.6	3.72	14.8
70000	1.1	7.23	29.1	59.1	29.02	90497	45	3.87	14.8
73000	1.4	7.25	29.4	61.7	28.97	90497	45.3	4.03	14.8
80000	1.6	7.26	29.6	62.1	28.85	90497	45.5	4.06	14.8
83000	1.8	7.28	29.7	64.8	28.94	90497	45.7	4.23	14.7
90000	2.1	7.29	29.8	65.6	28.89	90497	45.8	4.29	14.7
93000	2.3	7.29	29.9	66.4	28.84	90497	46	4.34	14.7
100000	2.5	7.3	30	67.3	28.73	90497	46.1	4.40	14.7
103000	2.7	7.32	30	69.1	28.65	90497	46.2	4.53	14.7
110000	2.8	7.32	30.1	69.7	28.63	90497	46.2	4.57	14.7
113000	2.8	7.33	30.1	71.1	28.69	90497	46.3	4.65	14.7
120000	2.5	7.34	30.1	70.2	28.62	90497	46.3	4.60	14.7

Appendix 3.3. (Continued). Hydrolab results, Okatee River site R-2

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l (calculated)	Batt volts
120000	3.6	7.28	30.1	65.3	28.67	90397	46.3	4.27	13.9
123000	3.4	7.31	30.1	70.2	28.79	90397	46.2	4.59	13.9
130000	3.2	7.32	30	73.2	28.86	90397	46.1	4.78	13.9
133000	3	7.36	29.8	79.9	29.1	90397	45.9	5.20	13.9
140000	2.8	7.39	29.7	84.9	29.34	90397	45.7	5.51	13.9
143000	2.4	7.42	29.5	90.9	29.66	90397	45.5	5.87	14
150000	2.1	7.44	29.5	96.1	29.89	90397	45.4	6.19	14
153000	1.7	7.47	29.3	100.4	30.21	90397	45.2	6.44	13.9
160000	1.3	7.48	29.2	103.4	30.51	90397	45.1	6.60	13.9
163000	1.1	7.5	29.1	105.2	30.76	90397	44.9	6.69	13.9
170000	0.9	7.51	29.1	105.8	30.89	90397	44.9	6.72	14
173000	1.1	7.51	29.1	106.7	30.88	90397	44.9	6.78	14
180000	1.6	7.53	29.3	108.8	30.75	90397	45.2	6.92	14
183000	1.9	7.51	29.4	106.3	30.65	90397	45.3	6.76	14
190000	2.2	7.5	29.5	103.2	30.5	90397	45.4	6.58	14
193000	2.5	7.49	29.5	101.5	30.41	90397	45.5	6.48	14
200000	2.8	7.5	29.6	102	30.38	90397	45.6	6.51	14
203000	3	7.47	29.7	97	30.18	90397	45.8	6.21	14
210000	3.2	7.47	29.8	95.9	30.09	90397	45.8	6.14	14
213000	3.4	7.44	29.9	90.1	29.91	90397	46	5.79	14
220000	3.5	7.43	29.9	86.6	29.79	90397	46	5.57	14
223000	3.7	7.42	30	84.4	29.71	90397	46.2	5.43	14
230000	3.7	7.42	30.1	82.5	29.63	90397	46.3	5.32	14
233000	3.7	7.41	30.1	75.1	29.62	90397	46.3	4.84	14
0	3.7	7.42	30.1	81.9	29.58	90497	46.3	5.28	14
3000	3.6	7.42	30	83	29.63	90497	46.1	5.35	14
10000	3.3	7.42	29.9	84.3	29.7	90497	46	5.43	13.9
13000	3.1	7.43	29.8	86	29.83	90497	45.8	5.53	13.9
20000	2.9	7.41	29.7	82.7	29.8	90497	45.7	5.33	13.9
23000	2.6	7.4	29.6	81	29.8	90497	45.6	5.22	13.9
30000	2.2	7.39	29.5	78.3	29.77	90497	45.4	5.05	13.9
33000	1.9	7.37	29.4	74.8	29.7	90497	45.3	4.83	14
40000	1.5	7.35	29.4	70.5	29.62	90497	45.3	4.56	14
43000	1.2	7.33	29.4	67.5	29.54	90497	45.3	4.37	14
50000	1	7.32	29.3	64.5	29.48	90497	45.3	4.19	14
53000	1.2	7.31	29.4	62.3	29.33	90497	45.3	4.05	14
60000	1.5	7.33	29.5	64.5	29.34	90497	45.4	4.19	14
63000	1.8	7.34	29.5	66.3	29.37	90497	45.5	4.30	14
70000	2.2	7.33	29.6	65.1	29.24	90497	45.7	4.23	14
73000	2.4	7.33	29.7	64.8	29.22	90497	45.7	4.21	14
80000	2.6	7.34	29.8	64.3	29.13	90497	45.8	4.18	14
83000	2.8	7.35	29.8	65.4	29.02	90497	45.9	4.26	13.9
90000	3.1	7.35	29.9	65.9	28.98	90497	46	4.30	13.9
93000	3.3	7.35	30	65.8	28.93	90497	46.2	4.29	13.9
100000	3.5	7.35	30.1	65.6	28.89	90497	46.3	4.28	14
103000	3.6	7.36	30.1	65.6	28.86	90497	46.3	4.28	13.9
110000	3.7	7.37	30.2	66.4	28.8	90497	46.4	4.33	13.9
113000	3.8	7.38	30.2	65.7	28.79	90497	46.5	4.29	14
120000	3.7	7.38	30.2	64.3	28.75	90497	46.4	4.20	14
123000	3.7	7.39	30.2	69	28.77	90497	46.5	4.51	13.9

Appendix 3.3. (Continued). Hydrolab results, Okatee River site R-3

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
100000	4.9	7.29	29.4	55.1	30.14	82097	45.4	3.48	14.7
103000	5.1	7.3	29.5	54.5	30.17	82097	45.4	3.44	14.7
110000	5.2	7.31	29.6	54.5	30.14	82097	45.6	3.44	14.7
113000	5.3	7.31	29.8	54.1	30.12	82097	45.9	3.41	14.7
120000	5.3	7.32	29.8	51.9	30.12	82097	45.9	3.27	14.7
123000	5.3	7.31	29.8	53.5	30.13	82097	45.9	3.38	14.7
130000	5.1	7.37	29.6	65.6	30.81	82097	45.6	4.09	14.8
133000	4.8	7.38	29.6	67.4	30.91	82097	45.5	4.2	14.6
140000	4.6	7.38	29.4	70.2	30.98	82097	45.3	4.37	14.6
143000	4.3	7.42	29.2	78.5	31.31	82097	45.1	4.87	14.7
150000	4	7.51	28.9	93.3	31.8	82097	44.6	5.75	14.6
153000	3.7	7.56	28.7	94	32.07	82097	44.3	5.77	14.7
160000	3.3	7.46	28.4	91.3	31.87	82097	43.9	5.64	14.7
163000	2.9	7.48	28.3	89.8	32.04	82097	43.7	5.53	14.7
170000	2.5	7.49	28.1	92.9	32.18	82097	43.5	5.72	14.7
173000	2.2	7.5	28.2	93.1	32.28	82097	43.6	5.72	14.7
180000	2.1	7.5	28.1	90.1	32.31	82097	43.6	5.53	14.7
183000	2.4	7.52	28.1	99	32.25	82097	43.6	6.08	14.7
190000	2.9	7.49	28.3	93.3	32.14	82097	43.7	5.74	14.6
193000	3.3	7.47	28.4	87.9	31.92	82097	44	5.42	14.6
200000	3.6	7.46	28.5	86	31.79	82097	44.1	5.31	14.6
203000	3.9	7.46	28.7	83.4	31.7	82097	44.3	5.16	14.6
210000	4.2	7.45	28.9	80.6	31.46	82097	44.6	5	14.6
213000	4.4	7.43	29	76.4	31.33	82097	44.8	4.74	14.6
220000	4.6	7.44	29.2	76.8	31.24	82097	45.1	4.77	14.6
223000	4.9	7.45	29.3	77.4	31.16	82097	45.2	4.81	14.6
230000	5.1	7.44	29.4	75	31.03	82097	45.3	4.67	14.6
233000	5.2	7.43	29.4	71.6	30.86	82097	45.3	4.47	14.6
0	5.3	7.42	29.6	68.4	30.79	82197	45.5	4.27	14.6
3000	5.3	7.41	29.6	62.6	30.75	82197	45.6	3.91	14.6
10000	5.2	7.41	29.7	66.1	30.73	82197	45.7	4.13	14.6
13000	5	7.42	29.6	68	30.72	82197	45.6	4.25	14.6
20000	4.8	7.4	29.4	66.6	30.71	82197	45.4	4.17	14.6
23000	4.5	7.39	29.3	65.6	30.7	82197	45.2	4.11	14.6
30000	4.3	7.36	29.1	63.1	30.57	82197	44.9	3.96	14.6
33000	4	7.33	28.8	58.8	30.42	82197	44.5	3.71	14.6
40000	3.7	7.33	28.7	57.4	30.46	82197	44.4	3.63	14.7
43000	3.3	7.32	28.6	57.4	30.4	82197	44.2	3.63	14.7
50000	2.8	7.32	28.5	57.6	30.45	82197	44.1	3.64	14.5
53000	2.5	7.33	28.4	56.1	30.38	82197	44	3.55	14.5
60000	2.2	7.33	28.3	56.4	30.38	82197	43.9	3.57	14.5
63000	2	7.34	28.3	56	30.34	82197	43.8	3.55	14.5
70000	2.1	7.34	28.2	56.3	30.46	82197	43.7	3.56	14.5
73000	2.7	7.34	28.4	57.8	30.38	82197	43.9	3.66	14.5
80000	3.2	7.34	28.5	56.8	30.41	82197	44.1	3.59	14.5
83000	3.5	7.34	28.6	56.7	30.34	82197	44.3	3.59	14.5
90000	3.9	7.35	28.7	57.1	30.45	82197	44.4	3.61	14.5
93000	4.1	7.34	29	56.5	30.25	82197	44.8	3.57	14.5
100000	4.4	7.35	29.2	55.9	30.09	82197	45.1	3.54	14.5
103000	4.6	7.35	29.3	54.5	30.01	82197	45.2	3.46	14.5
110000	4.8	7.35	29.3	53.5	29.89	82197	45.2	3.39	14.5

Appendix 3.3. (Continued). Hydrolab results, Okatee River site R-4

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
113000	4.2	7.36	29.2	55.9	30.35	82197	45.1	3.52	14.5
120000	4.4	7.37	29.5	56.5	30.2	82197	45.4	3.56	14.5
123000	4.5	7.36	29.5	55.3	30.11	82197	45.5	3.49	14.5
130000	4.5	7.36	29.5	47.5	30.08	82197	45.5	3	14.5
133000	4.5	7.36	29.6	53.5	30.1	82197	45.6	3.38	14.5
140000	4.4	7.38	29.4	58.6	30.39	82197	45.3	3.69	14.5
143000	4.1	7.38	29	62	30.7	82197	44.8	3.89	14.5
150000	3.9	7.39	28.7	64.2	30.89	82197	44.4	4.02	14.5
153000	3.6	7.41	28.6	69.3	31.12	82197	44.2	4.33	14.5
160000	3.3	7.46	28.5	75.9	31.32	82197	44	4.72	14.5
163000	3	7.49	28.3	83.6	31.48	82197	43.7	5.2	14.5
170000	2.6	7.54	28.2	90.7	31.73	82197	43.6	5.62	14.5
173000	2.2	7.55	28	93.9	31.85	82197	43.4	5.81	14.5
180000	1.8	7.57	28	95.1	31.95	82197	43.3	5.88	14.5
183000	1.5	7.57	27.9	95	32.03	82197	43.2	5.87	14.5
190000	1.4	7.56	27.8	87.3	32.07	82197	43.1	5.39	14.5
193000	1.7	7.56	27.9	93.8	32.02	82197	43.3	5.79	14.5
200000	2.2	7.54	28.1	91.7	31.85	82197	43.5	5.67	14.5
203000	2.6	7.53	28.2	86.8	31.72	82197	43.7	5.38	14.5
210000	2.9	7.51	28.3	83.4	31.65	82197	43.7	5.17	14.5
213000	3.2	7.5	28.4	80.7	31.54	82197	44	5.01	14.5
220000	3.4	7.46	28.6	74	31.44	82197	44.2	4.6	14.5
223000	3.7	7.44	28.7	70.5	31.3	82197	44.3	4.39	14.5
230000	3.9	7.44	28.8	69	31.19	82197	44.6	4.3	14.5
233000	4.1	7.43	29.1	69.1	31.12	82197	44.9	4.31	14.5
0	4.3	7.42	29.2	65.3	30.99	82297	45	4.07	14.5
3000	4.4	7.43	29.3	63.3	30.88	82297	45.2	3.95	14.5
10000	4.5	7.44	29.5	60.1	30.82	82297	45.4	3.75	14.5
13000	4.5	7.43	29.5	58.6	30.81	82297	45.5	3.66	14.4
20000	4.5	7.43	29.4	63.6	30.76	82297	45.4	3.98	14.5
23000	4.3	7.42	29.2	64.5	30.8	82297	45.1	4.03	14.5
30000	4	7.42	28.9	65.4	30.86	82297	44.6	4.1	14.4
33000	3.8	7.42	28.6	65.5	30.84	82297	44.2	4.11	14.4
40000	3.5	7.42	28.4	65.1	30.73	82297	44	4.1	14.4
43000	3.2	7.41	28.2	64.5	30.61	82297	43.7	4.07	14.6
50000	2.8	7.4	27.3	63.6	30.5	82297	42.4	4.04	14.5
53000	2.4	7.39	26.8	61.9	30.35	82297	41.7	3.96	14.4
60000	2	7.38	26.7	59.8	30.22	82297	41.6	3.84	14.4
63000	1.7	7.36	27.9	56.7	30.05	82297	43.2	3.62	14.4
70000	1.4	7.35	28.1	53.8	29.88	82297	43.6	3.44	14.4
73000	1.3	7.34	28.1	48	29.75	82297	43.5	3.08	14.4
80000	1.7	7.34	28.2	52.8	29.8	82297	43.7	3.38	14.4
83000	2.1	7.35	28.3	53.4	29.71	82297	43.8	3.42	14.4
90000	2.6	7.36	28.5	54.1	29.57	82297	44	3.47	14.4
93000	2.9	7.36	28.6	54.4	29.67	82297	44.2	3.48	14.4
100000	3.2	7.36	28.7	53.4	29.76	82297	44.3	3.41	14.4
103000	3.5	7.36	28.8	52.7	29.94	82297	44.5	3.35	14.4
110000	3.7	7.37	28.9	53.5	30	82297	44.7	3.4	14.4
113000	4	7.36	29.1	53.2	30.03	82297	44.9	3.37	14.4
120000	4.2	7.37	29.2	53.3	30.05	82297	45.1	3.37	14.4
123000	4.1	7.38	29.5	54.1	29.96	82297	45.4	3.43	14.4

Appendix 3.3. (Continued). Hydrolab results, Okatee River site R-5

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l (calculated)	Batt volts
133000	5.4	7.45	30.8	75.8	28.62	90497	47.2	4.95	13.8
140000	5.2	7.45	30.8	77.7	28.69	90497	47.2	5.06	13.7
143000	5	7.47	30.7	81.5	28.73	90497	47.1	5.31	13.8
150000	4.8	7.48	30.6	84.3	28.8	90497	47	5.49	13.8
153000	4.6	7.48	30.5	84.7	28.87	90497	46.9	5.51	13.9
160000	4.3	7.48	30.4	85.8	28.9	90497	46.7	5.59	13.9
163000	4	7.48	30.3	87.6	28.93	90497	46.6	5.70	13.9
170000	3.7	7.49	30.3	89.1	28.95	90497	46.5	5.80	13.9
173000	3.5	7.5	30.2	90.1	28.95	90497	46.4	5.87	13.9
180000	3.5	7.5	30.2	90.7	28.97	90497	46.5	5.90	13.9
183000	3.8	7.51	30.3	91.9	28.92	90497	46.6	5.98	13.9
190000	4.1	7.51	30.4	91.5	28.92	90497	46.7	5.96	13.9
193000	4.4	7.51	30.5	90.7	28.86	90497	46.8	5.91	13.9
200000	4.6	7.52	30.6	92.4	28.85	90497	46.9	6.01	13.9
203000	4.9	7.52	30.6	89.8	28.74	90497	47	5.86	13.9
210000	5.1	7.53	30.7	90.9	28.62	90497	47.1	5.94	13.9
213000	5.3	7.57	30.8	96.5	28.44	90497	47.3	6.32	13.8
220000	5.5	7.55	30.8	91.7	28.34	90497	47.3	6.01	13.9
223000	5.6	7.55	30.9	91.4	28.3	90497	47.3	5.99	13.8
230000	5.8	7.54	30.9	89.6	28.28	90497	47.3	5.88	13.8
233000	5.8	7.52	30.9	84.7	28.25	90497	47.4	5.56	13.9
0	5.8	7.54	30.9	85.5	28.18	90597	47.4	5.62	13.9
3000	5.8	7.56	30.9	91.1	28.11	90597	47.4	5.99	13.8
10000	5.7	7.53	30.9	86.6	28.22	90597	47.4	5.69	13.8
13000	5.5	7.52	30.9	85.6	28.2	90597	47.4	5.62	13.8
20000	5.3	7.52	30.8	85.3	28.17	90597	47.3	5.61	13.9
23000	5.1	7.51	30.7	85.5	28.11	90597	47.1	5.63	13.9
30000	4.9	7.49	30.4	82.2	28.05	90597	46.7	5.43	13.9
33000	4.6	7.47	30	79	27.97	90597	46.2	5.23	13.9
40000	4.3	7.45	30.2	77	27.8	90597	46.4	5.11	13.9
43000	4	7.44	30.4	74.9	27.6	90597	46.7	4.98	13.9
50000	3.7	7.43	30.4	73.2	27.44	90597	46.7	4.88	13.9
53000	3.5	7.43	30.4	71.8	27.32	90597	46.7	4.80	13.9
60000	3.4	7.43	30.5	69.6	27.24	90597	46.8	4.65	13.9
63000	3.6	7.43	30.5	71.8	27.18	90597	46.8	4.81	13.9
70000	3.9	7.43	30.6	72	27.24	90597	46.9	4.81	13.9
73000	4.2	7.43	30.6	72	27.29	90597	47	4.81	13.9
80000	4.4	7.43	30.8	70.9	27.08	90597	47.2	4.75	13.9
83000	4.7	7.45	30.8	72.8	27.16	90597	47.3	4.87	13.9
90000	4.9	7.45	30.9	72.7	26.94	90597	47.4	4.88	13.9
93000	5.1	7.46	31.1	73	26.67	90597	47.6	4.91	13.9
100000	5.3	7.48	31.1	74.4	26.48	90597	47.7	5.02	13.9
103000	5.5	7.49	31.1	75.6	26.53	90597	47.7	5.10	13.8
110000	5.7	7.5	31.2	76.6	26.62	90597	47.7	5.16	13.9
113000	5.8	7.5	31.1	77	26.8	90597	47.7	5.17	13.8
120000	5.8	7.5	31.1	77.4	26.9	90597	47.7	5.19	13.9
123000	5.8	7.51	31.1	76.3	26.94	90597	47.7	5.11	13.9
130000	5.8	7.51	31.1	78.6	26.92	90597	47.7	5.27	13.9
133000	5.7	7.5	31.1	79	27.02	90597	47.7	5.29	13.8
140000	5.5	7.5	31.1	78.8	26.95	90597	47.7	5.28	13.8

Appendix 3.3. (Continued). Hydrolab results, Okatee River site R-6

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l (calculated)	Batt volts
140000	4.7	7.37	31	79	28.59	90497	47.5	5.15	14.7
143000	4.5	7.39	31	76.8	28.63	90497	47.5	5.01	14.7
150000	4.3	7.4	31	79.7	28.68	90497	47.5	5.19	14.7
153000	4.1	7.41	30.9	81	28.76	90497	47.4	5.27	14.7
160000	3.8	7.43	30.9	85.5	28.82	90497	47.4	5.56	14.7
163000	3.5	7.45	30.8	88.2	28.89	90497	47.3	5.73	14.7
170000	3.2	7.46	30.8	90.1	28.97	90497	47.2	5.85	14.7
173000	2.9	7.47	30.8	92.8	29.02	90497	47.2	6.02	14.7
180000	3	7.48	30.8	94.5	29.01	90497	47.2	6.13	14.7
183000	3.4	7.48	30.8	93.5	28.89	90497	47.2	6.07	14.7
190000	3.8	7.47	30.8	89.1	28.73	90497	47.3	5.80	14.7
193000	4	7.52	31	96.7	28.59	90497	47.5	6.31	14.7
200000	4.3	7.55	31	99.5	28.43	90497	47.5	6.51	14.7
203000	4.5	7.54	31	99.2	28.34	90497	47.6	6.50	14.7
210000	4.7	7.52	31.1	94.8	28.3	90497	47.6	6.21	14.7
213000	4.9	7.49	31	89.6	28.28	90497	47.6	5.87	14.7
220000	5	7.46	31.1	85.9	28.33	90497	47.6	5.62	14.6
223000	5.2	7.46	31.1	85.3	28.25	90497	47.7	5.59	14.7
230000	5.1	7.46	31.1	83.8	28.02	90497	47.7	5.51	14.6
233000	5.1	7.45	31.1	82.6	28.19	90497	47.7	5.42	14.6
0	5	7.47	31.1	84	27.88	90597	47.7	5.54	14.6
3000	5.2	7.46	31.1	83.8	28.04	90597	47.7	5.51	14.6
10000	5.2	7.46	31.1	84.9	28.05	90597	47.7	5.58	14.6
13000	5.1	7.46	31.1	84.1	28.05	90597	47.7	5.53	14.6
20000	4.8	7.47	31.1	85.9	27.95	90597	47.7	5.66	14.6
23000	4.6	7.46	31.1	83.6	27.8	90597	47.7	5.52	14.6
30000	4.4	7.45	31.1	82.5	27.72	90597	47.7	5.46	14.6
33000	4.1	7.44	31.1	81.3	27.65	90597	47.7	5.38	14.6
40000	3.8	7.44	31.1	80.4	27.63	90597	47.6	5.32	14.6
43000	3.4	7.42	31	78.3	27.64	90597	47.5	5.19	14.6
50000	3.2	7.41	30.9	76.9	27.61	90597	47.4	5.10	14.6
53000	2.9	7.4	30.9	75.8	27.58	90597	47.3	5.03	14.6
60000	2.5	7.39	31	71.7	27.12	90597	47.5	4.79	14.6
63000	3.3	7.4	31	75.1	27.3	90597	47.5	5.00	14.6
70000	3.6	7.38	31.3	68.2	26.22	90597	47.9	4.62	14.6
73000	3.9	7.4	31.3	68.3	26.34	90597	47.9	4.62	14.6
80000	4.1	7.42	31.3	73.3	26.53	90597	47.9	4.94	14.5
83000	4.4	7.43	31.4	74.2	26.32	90597	48	5.01	14.6
90000	4.6	7.44	31.3	75.8	26.38	90597	48	5.12	14.5
93000	4.8	7.44	31.3	77	26.65	90597	47.9	5.18	14.6
100000	5	7.44	31.3	77.5	26.78	90597	47.9	5.20	14.6
103000	5.1	7.44	31.3	76.8	26.89	90597	47.9	5.14	14.6
110000	5.3	7.43	31.3	76.4	26.91	90597	47.9	5.11	14.6
113000	5.4	7.44	31.3	76.8	27.05	90597	47.9	5.13	14.6
120000	5.1	7.44	31.3	75.3	26.99	90597	47.9	5.03	14.6
123000	5	7.44	31.3	75.1	27.2	90597	48	5.00	14.6
130000	5.4	7.45	31.3	78.1	27.11	90597	47.9	5.21	14.6
133000	5.3	7.45	31.3	79.1	27.13	90597	48	5.28	14.5
140000	5.1	7.47	31.3	82.8	27.16	90597	48	5.52	14.5
143000	4.9	7.49	31.3	85.8	27.18	90597	47.9	5.72	14.5
150000	4.6	7.49	31.3	85.6	27.18	90597	47.9	5.70	14.5

Appendix 3.3. (Continued). Hydrolab results, Broad Creek site T-1

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
93000	1.61	7.26	28.3	52.8	27.85	90397	43.8	3.52	14.7
100000	1.74	7.31	28.4	58.6	28.04	90397	44	3.89	14.7
103000	1.82	7.33	28.5	61.5	28.14	90397	44.1	4.07	14.7
110000	1.8	7.33	28.5	62.4	28.18	90397	44.1	4.13	14.7
113000	1.69	7.32	28.2	66.8	28.42	90397	43.7	4.41	14.7
120000	1.53	7.3	27.7	70.1	28.87	90397	43	4.6	14.7
123000	1.32	7.25	26.6	74.6	29.53	90397	41.5	4.87	14.7
130000	1.03	7.21	25.2	76.4	29.72	90397	39.4	5.02	14.7
133000	0.71	7.11	22.4	57.3	29.07	90397	35.5	3.87	14.7
140000	0.42	7.04	16.9	54.2	28.92	90397	27.6	3.79	14.7
143000	0.17	6.9	7.6	53.2	28.05	90397	13.13	3.99	14.7
150000	0								
153000	0								
160000	0								
163000	0								
170000	0								
173000	0								
180000	0.19	2.5	11.9	39.7	32.31	90397	20	2.7	14.6
183000	0.46	3.28	19.4	59.2	32.17	90397	31.2	3.86	14.6
190000	0.74	4.36	23.6	69.7	32.1	90397	37.2	4.44	14.6
193000	0.98	4.6	25	76.4	32.05	90397	39.2	4.83	14.6
200000	1.2	4.72	26.4	86.7	31.85	90397	41.2	5.45	14.6
203000	1.39	4.7	27.5	95.5	30.68	90397	42.8	6.09	14.6
210000	1.57	4.77	28.1	89.3	29.95	90397	43.6	5.74	14.7
213000	1.75	4.89	28.3	84.9	29.68	90397	43.9	5.48	14.7
220000	1.89	5.02	28.5	82.3	29.55	90397	44	5.31	14.6
223000	1.95	5.04	28.5	78.6	29.49	90397	44.1	5.08	14.6
230000	1.91	5.04	28.4	76.9	29.49	90397	44	4.98	14.6
233000	1.8	5	28.4	70.9	29.49	90397	43.9	4.59	14.6
0	1.65	4.91	27.7	63.9	29.56	90497	43	4.14	14.6
3000	1.46	4.75	27.3	46.5	29.59	90497	42.4	3.02	14.6
10000	1.2	4.59	26.4	29.1	29.43	90497	41.2	1.91	14.6
13000	0.85	4.52	24.4	30.8	29.67	90497	38.4	2.04	14.6
20000	0.52	4.43	21.5	33.5	29.82	90497	34.2	2.24	14.6
23000	0.3	4.16	10.8	41	28.48	90497	18.3	2.99	14.6
30000	0.06	4.19	6.4	36.1	28.17	90497	11.31	2.72	14.6
33000	0								
40000	0								
43000	0								
50000	0								
53000	0								
60000	0.09	5.27	9.2	20.7	26.5	90497	15.8	1.58	14.5
63000	0.35	4.96	19.1	11.2	27.85	90497	30.8	0.79	14.6
70000	0.62	4.81	22.8	10.5	28.03	90497	36.1	0.72	14.5
73000	0.9	4.61	24.9	16.3	27.94	90497	39.1	1.1	14.6
80000	1.11	4.58	26.4	19.9	27.83	90497	41.2	1.34	14.6
83000	1.27	4.62	27.3	28.8	27.92	90497	42.5	1.93	14.5
90000	1.44	4.7	28	44	28.08	90497	43.4	2.93	14.6
93000	1.62	4.71	28.5	51.4	28.2	90497	44.1	3.4	14.6
100000	1.78	4.77	28.6	56.5	28.22	90497	44.3	3.73	14.6
103000	1.87	4.83	28.7	58.1	28.22	90497	44.4	3.84	14.6

Appendix 3.3. (Continued). Hydrolab results, Broad Creek site T-2

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
103000	1.34	7.39	28.7	59.7	28.15	90397	44.4	3.94	14.6
110000	1.28	7.38	28.7	58	28.14	90397	44.3	3.84	14.6
113000	1.14	7.4	28.6	61.7	28.3	90397	44.2	4.07	14.6
120000	0.95	7.42	28.4	68	28.48	90397	44	4.48	14.6
123000	0.74	7.46	28.1	77.6	28.81	90397	43.6	5.09	14.6
130000	0.5	7.46	27.8	84.7	29.44	90397	43.1	5.5	14.6
133000	0.21	7.51	27.6	95.7	30.9	90397	42.9	6.07	14.6
140000	0	7.53	27.3	95.8	32.31	90397	42.5	5.95	14.6
143000	0	7.49	26.9	81.6	33.76	90397	41.9	4.96	14.6
150000	0								
153000	0								
160000	0								
163000	0								
170000	0								
173000	0								
180000	0	7.62	27.7	78.8	32.77	90397	42.9	4.85	14.6
183000	0	7.66	27.6	102.7	31.25	90397	42.8	6.48	14.6
190000	0.25	7.63	27.9	100.3	30.89	90397	43.2	6.36	14.6
193000	0.5	7.59	28	96	30.81	90397	43.4	6.09	14.6
200000	0.74	7.57	28.1	93.6	30.53	90397	43.6	5.96	14.6
203000	0.97	7.54	28.4	88.6	30.08	90397	43.9	5.68	14.6
210000	1.16	7.51	28.6	83.4	29.75	90397	44.2	5.37	14.6
213000	1.32	7.5	28.7	80.1	29.6	90397	44.3	5.17	14.6
220000	1.43	7.49	28.7	77	29.51	90397	44.3	4.97	14.6
223000	1.46	7.48	28.7	73.1	29.47	90397	44.4	4.72	14.6
230000	1.39	7.47	28.7	72.4	29.48	90397	44.3	4.67	14.6
233000	1.25	7.44	28.6	69	29.51	90397	44.3	4.45	14.6
0	1.06	7.42	28.5	65.6	29.56	90497	44.1	4.24	14.6
3000	0.85	7.39	28.4	61.5	29.79	90497	43.9	3.96	14.6
10000	0.6	7.29	28.2	47	29.78	90497	43.7	3.03	14.5
13000	0.32	7.19	28.3	36.4	29.29	90497	43.8	2.37	14.6
20000	0.03	7.14	28.3	33.6	28.69	90497	43.8	2.2	14.6
23000	0	7.12	28.2	33.6	28.19	90497	43.7	2.22	14.5
30000	0								
33000	0								
40000	0								
43000	0								
50000	0								
53000	0								
60000	0								
63000	0	7.33	27.8	39.9	27.64	90497	43.1	2.68	14.5
70000	0.15	7.31	28.1	43.4	28.27	90497	43.6	2.87	14.5
73000	0.42	7.3	28.2	43.7	28.01	90497	43.7	2.9	14.5
80000	0.63	7.3	28.3	44.5	27.94	90497	43.9	2.96	14.5
83000	0.82	7.31	28.5	46.1	27.9	90497	44	3.06	14.5
90000	1.03	7.36	28.7	52.5	28.06	90497	44.4	3.48	14.5
93000	1.22	7.4	28.8	57.9	28.09	90497	44.5	3.83	14.6
100000	1.34	7.45	28.9	58.6	28.05	90497	44.6	3.88	14.6
103000	1.39	7.46	28.9	55.5	28	90497	44.7	3.68	14.5
110000	1.39	7.45	28.9	50.4	28.04	90497	44.6	3.33	14.5
113000	1.37	7.47	28.9	59.8	28.05	90497	44.6	3.95	14.5

Appendix 3.3. (Continued). Hydrolab results, Broad Creek site T-3

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
120000	2.02	7.65	26.7	46	29.95	82197	41.6	2.96	15.1
123000	1.9	7.67	26.8	45	29.97	82197	41.7	2.9	15.1
130000	1.7	7.68	26.8	42.2	29.99	82197	41.7	2.72	15
133000	1.45	7.66	26.7	40.7	30.01	82197	41.5	2.62	15.1
140000	1.18	7.66	26.3	46.7	30.07	82197	41	3.01	15.1
143000	0.91	7.74	25.9	57.2	30.31	82197	40.5	3.68	15.1
150000	0.63	7.44	17.4	51.3	31.52	82197	28.3	3.4	15.1
153000	0.32	7.49	17.4	65.5	31.56	82197	28.2	4.34	15.1
160000	0.04	7.51	16.6	74.5	31.75	82197	27.2	4.94	15.1
163000	0								
170000	0								
173000	0								
180000	0								
183000	0								
190000	0								
193000	0								
200000	0.15	7.68	17.2	77.5	32.01	82197	28.1	5.1	15
203000	0.46	7.64	17.3	72.1	31.93	82197	28.1	4.74	15
210000	0.77	7.62	17.3	69.3	31.84	82197	28.2	4.57	15
213000	1.05	7.73	24.1	58.3	31.12	82197	38	3.74	15
220000	1.31	7.74	25.1	56.2	30.99	82197	39.3	3.59	15
223000	1.53	7.74	25.6	56.1	30.86	82197	40	3.58	15
230000	1.71	7.74	26	53.6	30.74	82197	40.5	3.42	15.1
233000	1.85	7.74	26.2	52.4	30.66	82197	40.9	3.34	15
0	1.93	7.74	26.4	51.5	30.61	82297	41.2	3.28	15
3000	1.91	7.74	26.7	47.6	30.58	82297	41.5	3.04	14.9
10000	1.78	7.74	26.7	47.7	30.59	82297	41.6	3.04	15
13000	1.56	7.73	26.7	45.6	30.59	82297	41.6	2.91	15
20000	1.32	7.7	26.6	43.1	30.59	82297	41.5	2.75	15
23000	1.04	7.61	26.2	41.2	30.67	82297	40.9	2.63	15
30000	0.76	7.46	19.4	37.4	31.17	82297	31.2	2.46	14.9
33000	0.46	7.58	19.6	53.4	31.45	82297	31.5	3.5	15
40000	0.17	7.54	18.7	63	30.97	82297	30.2	4.18	14.9
43000	0								
50000	0								
53000	0								
60000	0								
63000	0								
70000	0								
73000	0								
80000	0								
83000	0.14	7.6	18.5	43.6	29.93	82297	29.9	2.95	14.9
90000	0.45	7.55	18.3	39.8	29.83	82297	29.7	2.7	14.9
93000	0.78	7.54	18.4	35.9	29.81	82297	29.8	2.43	14.9
100000	1.08	7.71	24.5	47.5	29.3	82297	38.5	3.13	14.9
103000	1.35	7.73	25.3	48.3	29.35	82297	39.6	3.17	14.9
110000	1.58	7.76	25.8	49.9	29.5	82297	40.4	3.26	14.9
113000	1.76	7.77	26.2	54.8	29.65	82297	40.9	3.56	14.9
120000	1.89	7.79	26.4	52.6	29.78	82297	41.2	3.4	14.9
123000	1.96	7.81	26.6	54.8	29.88	82297	41.5	3.53	14.9
130000	1.93	7.8	26.9	53.6	29.9	82297	41.8	3.45	14.9

Appendix 3.3. (Continued). Hydrolab results, Broad Creek site T-4

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
100000	2.08	7.7	28.7	56.1	29.38	82097	44.4	3.61	15.3
103000	2.16	7.71	28.8	51.7	29.42	82097	44.4	3.32	15.3
110000	2.15	7.66	28.7	49.3	29.44	82097	44.3	3.17	15.3
113000	2.04	7.68	28.6	50.7	29.53	82097	44.2	3.26	15.3
120000	1.84	7.67	28.4	52.3	29.72	82097	44	3.34	15.2
123000	1.58	7.55	28.1	42.3	29.64	82097	43.5	2.72	15.3
130000	1.31	7.52	27.7	41.7	29.77	82097	43	2.68	15.3
133000	1.01	7.52	26.8	50.5	30.39	82097	41.7	3.23	15.3
140000	0.69	7.48	26.1	54.1	30.92	82097	40.7	3.44	15.3
143000	0.36	7.44	25.8	44.6	31.21	82097	40.3	2.82	15.3
150000	0								
153000	0								
160000	0								
163000	0								
170000	0								
173000	0								
180000	0								
183000	0								
190000	0.29	7.49	21	54.7	33.22	82097	33.5	3.45	15.2
193000	0.63	7.58	26.2	64.2	32.2	82097	40.8	3.99	15.2
200000	0.95	7.63	26.6	60.1	30.74	82097	41.5	3.82	15.2
203000	1.23	7.71	27.1	64.4	30.6	82097	42.2	4.09	15.2
210000	1.51	7.77	27.8	65.6	30.47	82097	43.1	4.16	15.2
213000	1.74	7.84	28.3	67.6	30.35	82097	43.8	4.29	15.2
220000	1.94	7.86	28.5	67.3	30.26	82097	44	4.27	15.2
223000	2.09	7.87	28.5	66	30.18	82097	44.1	4.19	15.2
230000	2.17	7.88	28.6	61.4	30.13	82097	44.2	3.9	15.2
233000	2.15	7.84	28.6	57.7	30.15	82097	44.2	3.66	15.2
0	2	7.81	28.4	54.2	30.18	82197	44	3.44	15.2
3000	1.79	7.75	28.2	55.2	30.21	82197	43.7	3.51	15.2
10000	1.53	7.66	27.9	46.8	30.26	82197	43.3	2.98	15.2
13000	1.27	7.62	27.7	38.9	30.21	82197	43	2.48	15.1
20000	0.98	7.58	27	43.3	29.87	82197	41.9	2.79	15.1
23000	0.67	7.5	26.4	36.9	29.61	82197	41.1	2.4	15.1
30000	0.31	7.44	26	28.3	29.56	82197	40.7	1.84	15.1
33000	0								
40000	0								
43000	0								
50000	0								
53000	0								
60000	0								
63000	0								
70000	0								
73000	0.17	7.44	15.2	37.3	26.15	82197	25.1	2.75	15
80000	0.54	7.45	25.1	31.3	28.63	82197	39.3	2.08	15
83000	0.85	7.53	26.4	40.8	29.66	82197	41.2	2.64	15
90000	1.15	7.64	27.1	49	29.83	82197	42.1	3.16	15.1
93000	1.43	7.7	27.6	51.1	29.75	82197	42.8	3.28	15.1
100000	1.65	7.79	28.2	54.1	29.66	82197	43.7	3.47	15.1
103000	1.87	7.82	28.4	55.9	29.67	82197	43.9	3.58	15.1
110000	2.01	7.84	28.4	55.8	29.67	82197	44	3.57	15

Appendix 3.3. (Continued). Hydrolab results, Broad Creek site T-5

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
123000	1.71	7.8	31.2	58.9	27.91	90497	47.8	3.86	14.5
130000	1.58	7.71	31.1	70.2	27.95	90497	47.6	4.59	14.6
133000	1.41	7.63	31	88.7	28.05	90497	47.5	5.8	14.5
140000	1.21	7.59	30.8	95	28.34	90497	47.2	6.18	14.5
143000	0.96	7.54	30.8	97.3	28.64	90497	47.2	6.3	14.5
150000	0.71	7.52	30.9	98	29.28	90497	47.4	6.27	14.6
153000	0.5	7.41	30.9	126.8	29.55	90497	47.3	8.08	14.5
160000	0.37	7.47	30.9	57	29.79	90497	47.3	3.62	14.5
163000	0.32	7.4	30.9	76	29.88	90497	47.4	4.81	14.5
170000	0.3	7.37	30.9	71.6	29.84	90497	47.4	4.54	14.6
173000	0.29	7.34	31	69	29.74	90497	47.5	4.38	14.5
180000	0.3	7.31	31	63.2	29.62	90497	47.5	4.02	14.5
183000	0.53	7.26	31	58.2	29.3	90497	47.5	3.72	14.6
190000	0.78	7.27	30.9	64.3	29.01	90497	47.4	4.13	14.5
193000	1.01	7.32	30.8	69.8	28.69	90497	47.3	4.51	14.5
200000	1.23	7.44	30.4	79.1	28.05	90497	46.7	5.18	14.5
203000	1.43	7.47	30.5	78.5	28.11	90497	46.9	5.14	14.5
210000	1.58	7.56	31.1	81.1	28.17	90497	47.7	5.28	14.5
213000	1.73	7.61	31.4	80.8	28.11	90497	48.1	5.26	14.5
220000	1.87	7.64	31.6	55.3	27.96	90497	48.3	3.61	14.5
223000	1.97	7.6	31.6	79.6	27.89	90497	48.4	5.19	14.5
230000	1.99	7.59	31.7	75.2	27.77	90497	48.4	4.92	14.5
233000	1.98	7.52	31.7	67.9	27.5	90497	48.4	4.46	14.5
0	1.9	7.48	31.7	64	27.1	90597	48.4	4.24	14.5
3000	1.77	7.44	31.6	54.5	26.81	90597	48.4	3.62	14.5
10000	1.61	7.36	31.6	49.3	26.38	90597	48.3	3.3	14.5
13000	1.42	7.27	31.5	44.2	25.92	90597	48.1	2.99	14.5
20000	1.19	7.16	31.4	38.2	25.17	90597	48	2.62	14.5
23000	0.93	7.09	31.5	35.4	24.42	90597	48.2	2.46	14.5
30000	0.66	7.07	31.7	33.3	23.86	90597	48.5	2.33	14.5
33000	0.46	7.05	31.7	26	23.7	90597	48.5	1.83	14.5
40000	0.38	7	31.8	16.6	23.53	90597	48.7	1.17	14.5
43000	0.34	7	31.8	12.3	23.43	90597	48.7	0.87	14.5
50000	0.33	6.99	31.9	7	23.28	90597	48.7	0.49	14.4
53000	0.32	6.97	31.9	6.1	23.17	90597	48.7	0.44	14.4
60000	0.31	6.98	31.9	2	22.97	90597	48.8	0.14	14.4
63000	0.32	6.98	31.8	1.1	22.88	90597	48.6	0.08	14.4
70000	0.57	7.01	31.9	3.5	22.91	90597	48.8	0.25	14.4
73000	0.82	7.04	31.7	23.4	23.32	90597	48.5	1.66	14.4
80000	1.06	7.09	31.4	21.9	23.98	90597	48	1.53	14.4
83000	1.29	7.35	30.5	51.5	25.73	90597	46.9	3.52	14.4
90000	1.48	7.47	30.8	64.4	26.73	90597	47.2	4.31	14.4
93000	1.62	7.53	31.3	71.6	26.85	90597	48	4.77	14.4
100000	1.76	7.54	31.5	74.7	26.93	90597	48.2	4.96	14.5
103000	1.9	7.55	31.7	77.9	27.08	90597	48.4	5.15	14.4
110000	1.99	7.56	31.7	78.7	27.2	90597	48.5	5.19	14.5
113000	2.02	7.56	31.7	72.8	27.24	90597	48.5	4.8	14.4
120000	2	7.53	31.7	79.5	27.25	90597	48.5	5.24	14.4
123000	1.91	7.53	31.6	86.6	27.43	90597	48.4	5.69	14.4
130000	1.78	7.52	31.6	92.4	27.61	90597	48.3	6.06	14.4
133000	1.62	7.55	31.4	99.4	27.83	90597	48.1	6.5	14.4

Appendix 3.3. (Continued). Hydrolab results, Broad Creek site T-6

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
130000	1.61	7.72	31	81.8	28.1	90497	47.5	5.34	14.5
133000	1.43	7.71	30.7	89.1	28.28	90497	47.1	5.81	14.4
140000	1.23	7.67	29.7	89.8	28.45	90497	45.8	5.87	14.5
143000	0.99	7.59	28.1	87.2	28.56	90497	43.5	5.74	14.5
150000	0.76	7.5	25.8	85.5	28.71	90497	40.4	5.69	14.5
153000	0.56	7.42	22.8	80.7	28.79	90497	36.1	5.46	14.5
160000	0.37	7.38	22.2	76	28.97	90497	35.2	5.14	14.5
163000	0.21	7.37	20.8	77.6	29.09	90497	33.2	5.29	14.5
170000	0.15	7.36	18.7	80.4	29.05	90497	30.2	5.54	14.5
173000	0.19	7.34	17.2	79.1	28.87	90497	28.1	5.52	14.5
180000	0.31	7.33	16.6	70.4	28.67	90497	27.2	4.95	14.5
183000	0.5	7.33	18.3	72.9	28.83	90497	29.7	5.06	14.5
190000	0.72	7.35	20.5	70.4	28.75	90497	32.8	4.83	14.5
193000	0.94	7.39	22.2	70.4	28.68	90497	35.3	4.79	14.5
200000	1.15	7.53	25.1	85.8	28.6	90497	39.4	5.75	14.5
203000	1.36	7.66	29.2	86.6	28.42	90497	45	5.68	14.5
210000	1.52	7.69	30.4	79.9	28.23	90497	46.6	5.22	14.4
213000	1.66	7.72	30.9	77.4	28.09	90497	47.3	5.06	14.4
220000	1.78	7.77	31.2	76.2	27.97	90497	47.8	4.98	14.4
223000	1.88	7.8	31.5	76.3	27.83	90497	48.2	4.99	14.4
230000	1.92	7.82	31.6	76	27.76	90497	48.3	4.97	14.4
233000	1.91	7.82	31.7	69.9	27.66	90497	48.5	4.58	14.4
0	1.86	7.81	31.7	74.6	27.51	90597	48.5	4.9	14.4
3000	1.77	7.72	31.5	68.5	27.26	90597	48.2	4.52	14.4
10000	1.64	7.66	31.4	65	27.02	90597	48.1	4.31	14.4
13000	1.46	7.57	31	59.1	26.65	90597	47.6	3.96	14.4
20000	1.23	7.49	29.8	57.1	26.57	90597	45.9	3.86	14.4
23000	0.97	7.38	27.6	54	26.45	90597	42.8	3.7	14.4
30000	0.74	7.28	25	49.4	26.14	90597	39.2	3.46	14.4
33000	0.54	7.23	22.1	48.3	25.8	90597	35.2	3.46	14.4
40000	0.35	7.21	21.8	46.8	25.8	90597	34.7	3.36	14.4
43000	0.18	7.2	19.2	49.2	25.62	90597	30.9	3.6	14.4
50000	0.06	7.18	16.9	49.3	25.39	90597	27.6	3.67	14.4
53000	0.05	7.17	4.7	48.1	25.01	90597	8.33	3.88	14.3
60000	0.16	7.18	14.4	43.3	24.9	90597	23.8	3.3	14.3
63000	0.35	7.19	14.7	43	24.73	90597	24.2	3.28	14.3
70000	0.56	7.2	16.2	43.7	24.8	90597	26.6	3.3	14.3
73000	0.79	7.22	18.8	42.4	24.85	90597	30.4	3.15	14.4
80000	1.01	7.24	22	42.6	24.85	90597	35	3.11	14.4
83000	1.24	7.41	27	52.2	25.32	90597	42	3.66	14.4
90000	1.44	7.58	29.9	62.5	26.26	90597	46	4.24	14.4
93000	1.59	7.64	30.6	66	26.56	90597	47	4.44	14.4
100000	1.71	7.71	31.1	69.7	26.69	90597	47.7	4.66	14.4
103000	1.83	7.76	31.4	72.7	26.7	90597	48.1	4.85	14.4
110000	1.93	7.8	31.6	75.9	26.79	90597	48.3	5.05	14.4
113000	1.97	7.84	31.7	76.5	27.03	90597	48.5	5.07	14.4
120000	1.96	7.86	31.8	78.5	27.2	90597	48.6	5.18	14.4
123000	1.89	7.87	31.7	85.5	27.32	90597	48.4	5.64	14.4
130000	1.8	7.81	31.5	84.1	27.23	90597	48.3	5.56	14.4
133000	1.66	7.79	31.3	89.2	27.35	90597	48	5.89	14.4
140000	1.46	7.78	30.9	96.5	27.57	90597	47.4	6.36	14.4

Appendix 3.3. (Continued). Hydrolab results, Okatee River site T-1

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l (calculated)	Batt volts
103000	1.7	7.19	28.4	55.2	28.37	90397	43.9	3.67	13.8
110000	1.9	7.22	28.4	57.9	28.54	90397	43.9	3.83	13.8
113000	1.9	7.24	28.6	61.5	28.75	90397	44.2	4.05	13.8
120000	1.9	7.25	28.6	61	28.8	90397	44.2	4.02	13.8
123000	1.8	7.25	27.9	66.5	29	90397	43.2	4.38	13.9
130000	1.6	7.25	27.6	69.3	29.25	90397	42.8	4.56	13.9
133000	1.4	7.26	26.8	74	29.48	90397	41.7	4.87	13.8
140000	1.1	7.28	25.3	82	29.92	90397	39.7	5.40	13.8
143000	0.8	7.33	22	92.2	30.01	90397	34.9	6.17	13.8
150000	0.4	7.37	14.1	98.9	29.92	90397	23.4	6.93	13.8
153000	0.1	7.35	4.6	94.6	29.49	90397	8.24	7.03	13.9
160000	0								
163000	0								
170000	0								
173000	0								
180000	0								
183000	0.1	7.1	3.4	66.2	30.99	90397	6.16	4.83	13.9
190000	0.3	7.27	9.4	87.1	31.46	90397	16.1	6.10	13.8
193000	0.6	7.43	19.7	100.2	31.86	90397	31.6	6.59	13.9
200000	0.9	7.45	24.1	100.7	31.83	90397	38	6.47	13.8
203000	1.1	7.45	26.4	99.1	31.62	90397	41.1	6.31	13.9
210000	1.3	7.44	27.5	96.3	31.34	90397	42.7	6.12	13.9
213000	1.5	7.44	28	93.9	31.04	90397	43.4	5.98	13.9
220000	1.7	7.43	28.3	91	30.81	90397	43.7	5.81	13.9
223000	1.9	7.41	28.3	87.3	30.59	90397	43.8	5.59	13.9
230000	2	7.4	28.5	84.4	30.42	90397	44.1	5.42	13.9
233000	2.1	7.39	28.6	82	30.32	90397	44.2	5.27	13.9
0	2	7.38	28.6	80.5	30.31	90497	44.2	5.17	14
3000	1.9	7.35	27.9	77.7	30.26	90497	43.3	5.02	13.9
10000	1.7	7.31	27.9	73.7	30.22	90497	43.2	4.76	13.9
13000	1.5	7.26	27.2	68.5	30.21	90497	42.3	4.44	13.8
20000	1.2	7.2	26.4	62.5	30.08	90497	41.2	4.08	13.9
23000	1	7.14	25.3	56.9	29.95	90497	39.6	3.75	13.8
30000	0.6	7.08	19.5	50.3	29.63	90497	31.4	3.44	13.8
33000	0.3	7.02	9.2	46.9	28.73	90497	15.8	3.44	13.8
40000	0	7.04	2.4	54.6	27.43	90497	4.42	4.26	13.8
43000	0								
50000	0								
53000	0								
60000	0								
63000	0	7.07	3.1	53.3	26.28	90497	5.57	4.23	13.8
70000	0.3	6.9	6.1	43.1	26.79	90497	10.8	3.33	13.8
73000	0.6	6.94	17.3	37.4	27.77	90497	28.1	2.67	13.8
80000	0.8	7.03	23.2	39.7	28.12	90497	36.6	2.73	13.8
83000	1	7.1	26.1	43.2	28.28	90497	40.7	2.91	13.8
90000	1.2	7.15	27.5	47.7	28.42	90497	42.6	3.18	13.8
93000	1.4	7.19	28.2	51.1	28.56	90497	43.6	3.39	13.8
100000	1.6	7.22	28.5	54.2	28.53	90497	44.1	3.59	13.8
103000	1.8	7.24	28.6	55.9	28.41	90497	44.3	3.71	13.8
110000	1.9	7.25	28.7	58.1	28.41	90497	44.4	3.85	13.8
113000	2	7.28	28.8	62	28.5	90497	44.5	4.10	13.8

Appendix 3.3. (Continued). Hydrolab results, Okatee River site T-2

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO mg/l	Temp ºC	Date MMDDYY	DO % saturation (calculated)	Batt volts
113000	2.3	7.22	30.1	3.89	28.65	90397	59.41	13.5
120000	2.2	7.23	30	3.86	28.68	90397	58.94	13.5
123000	2	7.29	29.9	4.43	28.94	90397	67.90	13.5
130000	1.8	7.36	29.9	5.16	29.4	90397	79.68	13.5
133000	1.6	7.38	29.8	5.54	29.63	90397	85.83	13.5
140000	1.3	7.45	29.7	6.06	29.97	90397	94.35	13.5
143000	0.9	7.49	29.5	6.48	30.52	90397	101.68	13.5
150000	0.6	7.46	29.3	6.34	31.2	90397	100.46	13.6
153000	0.2	7.44	29.2	6.15	31.96	90397	98.58	13.5
160000	0	7.42	28.9	5.46	33	90397	88.83	13.5
163000	0	7.31	27.5	3.57	33.77	90397	58.35	13.5
170000	0							
173000	0	7.26	27	2.03	33.98	90397	33.20	13.5
180000	0	7.51	29.3	6.5	31.65	90397	103.74	13.6
183000	0.4	7.53	29.3	6.66	30.93	90397	105.08	13.5
190000	0.7	7.48	29.3	6.32	30.66	90397	99.28	13.5
193000	1	7.46	29.5	6.04	30.41	90397	94.60	13.5
200000	1.2	7.46	29.6	6.08	30.33	90397	95.16	13.5
203000	1.4	7.45	29.7	5.97	30.25	90397	93.37	13.5
210000	1.7	7.44	29.7	5.84	30.13	90397	91.16	13.5
213000	1.9	7.43	29.8	5.71	29.99	90397	88.98	13.5
220000	2.1	7.4	29.9	5.43	29.81	90397	84.41	13.5
223000	2.2	7.39	30	5.31	29.72	90397	82.47	13.5
230000	2.3	7.39	30	5.22	29.66	90397	81.00	13.5
233000	2.4	7.38	30.1	4.87	29.63	90397	75.57	13.5
0	2.3	7.37	30	4.93	29.58	90497	76.40	13.5
3000	2.1	7.37	30	4.98	29.58	90497	77.17	13.4
10000	1.9	7.36	29.9	4.82	29.54	90497	74.60	13.5
13000	1.7	7.33	29.9	4.6	29.49	90497	71.14	13.5
20000	1.4	7.31	29.8	4.34	29.38	90497	66.96	13.4
23000	1.1	7.28	29.8	4.02	29.21	90497	61.85	13.5
30000	0.8	7.22	29.7	3.42	28.95	90497	52.37	13.5
33000	0.4	7.18	29.6	2.99	28.54	90497	45.45	13.5
40000	0.1	7.16	29.5	2.67	28.06	90497	40.25	13.4
43000	0	7.17	28.8	2.17	27.42	90497	32.24	13.5
50000	0							
53000	0	7.23	27.1	1.02	26.35	90497	14.74	13.4
60000	0	7.24	29.1	3.15	28.41	90497	47.65	13.4
63000	0.3	7.29	29.5	3.94	28.94	90497	60.26	13.5
70000	0.7	7.29	29.5	4.04	29.01	90497	61.86	13.5
73000	0.9	7.29	29.6	4.07	29.06	90497	62.40	13.5
80000	1.2	7.3	29.7	4.14	29.06	90497	63.51	13.5
83000	1.4	7.31	29.8	4.2	28.99	90497	64.39	13.5
90000	1.6	7.32	29.8	4.26	28.93	90497	65.25	13.5
93000	1.8	7.32	29.9	4.26	28.89	90497	65.24	13.5
100000	2	7.32	30	4.23	28.86	90497	64.79	13.5
103000	2.2	7.32	30.1	4.27	28.85	90497	65.42	13.5
110000	2.3	7.32	30.1	4.23	28.81	90497	64.77	13.5
113000	2.3	7.32	30.1	4.02	28.8	90497	61.54	13.5
120000	2.4	7.35	30.1	4.09	28.73	90497	62.54	13.5
123000	2.3	7.34	30	4.38	28.37	90497	66.54	13.5

Appendix 3.3. (Continued). Hydrolab results, Okatee River site T-3

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
93000	1.21	7.36	28.7	58.5	30.44	82097	44.4	3.69	15.3
100000	1.43	7.35	28.9	52	30.41	82097	44.6	3.28	15.3
103000	1.64	7.35	29	53.1	30.4	82097	44.7	3.35	15.2
110000	1.82	7.37	29.1	53.1	30.36	82097	45	3.35	15.3
113000	1.95	7.38	29.3	54.2	30.37	82097	45.1	3.41	15.3
120000	1.97	7.39	29.3	55.8	30.42	82097	45.2	3.51	15.3
123000	1.85	7.38	29.3	53.6	30.52	82097	45.1	3.37	15.3
130000	1.63	7.37	29.2	49.8	30.6	82097	45	3.12	15.3
133000	1.36	7.36	29.1	52.8	30.7	82097	44.9	3.31	15.2
140000	1.11	7.39	29	60.7	30.91	82097	44.8	3.8	15.2
143000	0.84	7.46	28.8	74	31.35	82097	44.5	4.6	15.3
150000	0.55	7.55	28.4	90.4	31.76	82097	44	5.59	15.3
153000	0.24	7.67	28.2	108.3	32.08	82097	43.6	6.67	15.2
160000	0								
163000	0								
170000	0								
173000	0								
180000	0								
183000	0								
190000	0								
193000	0								
200000	0.19	7.63	28.1	81.6	31.59	82097	43.5	5.07	15.2
203000	0.47	7.58	28.3	79.4	31.59	82097	43.7	4.93	15.2
210000	0.76	7.56	28.5	76.9	31.5	82097	44.1	4.77	15.2
213000	0.97	7.54	28.6	74	31.41	82097	44.2	4.6	15.2
220000	1.19	7.52	28.7	70.2	31.28	82097	44.4	4.37	15.1
223000	1.42	7.51	28.9	70.3	31.17	82097	44.6	4.38	15.1
230000	1.63	7.5	29	65.6	31.09	82097	44.7	4.09	15.1
233000	1.82	7.48	29.1	67.4	31.02	82097	44.9	4.2	15.1
0	1.93	7.47	29.2	65.2	30.86	82197	45.1	4.08	15.1
3000	1.96	7.46	29.2	64.5	30.84	82197	45	4.03	15.1
10000	1.82	7.42	29.1	56.9	30.88	82197	45	3.55	15.1
13000	1.59	7.41	29.1	51	30.86	82197	44.9	3.19	15.2
20000	1.33	7.38	29	49.8	30.79	82197	44.8	3.12	15.1
23000	1.07	7.39	28.8	55.7	30.58	82197	44.4	3.51	15
30000	0.81	7.35	28.7	52.2	30.43	82197	44.3	3.3	15.1
33000	0.54	7.32	28.3	49.4	30.17	82197	43.8	3.14	15.1
40000	0.22	7.33	28.1	50.4	29.97	82197	43.6	3.22	15.1
43000	0								
50000	0								
53000	0								
60000	0								
63000	0								
70000	0								
73000	0								
80000	0								
83000	0.09	7.44	28.1	57.5	30.07	82197	43.5	3.67	15
90000	0.38	7.41	28.4	56.6	30.3	82197	43.9	3.59	15
93000	0.66	7.41	28.6	57	30.22	82197	44.3	3.61	15
100000	0.91	7.42	28.7	57.9	30.26	82197	44.4	3.67	15
103000	1.15	7.42	28.8	57.1	30.27	82197	44.5	3.62	15
110000	1.37	7.42	29	55.6	30.22	82197	44.7	3.52	15

Appendix 3.3. (Continued). Hydrolab results, Okatee River site T-4

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	SpCond mS/cm	DO mg/l	Batt volts
120000	2.37	7.47	28.1	65.7	30.49	82197	43.6	4.16	15
123000	2.52	7.46	28.2	64	30.55	82197	43.6	4.05	15.1
130000	2.57	7.46	28.2	63.3	30.57	82197	43.7	4	15
133000	2.46	7.45	28.2	63.9	30.57	82197	43.7	4.04	15
140000	2.25	7.53	28.1	78.6	30.83	82197	43.5	4.94	15
143000	2.01	7.6	28	90.2	31.12	82197	43.4	5.65	15
150000	1.78	7.66	28	100.6	31.39	82197	43.4	6.28	15
153000	1.53	7.7	27.9	109.3	31.71	82197	43.2	6.79	15
160000	1.26	7.72	27.6	113.7	31.94	82197	42.9	7.04	14.9
163000	0.94	7.72	27.1	117.4	32.04	82197	42.2	7.29	15
170000	0.59	7.67	25.8	118.2	31.82	82197	40.3	7.42	15
173000	0.31	7.51	22.5	108.2	31.27	82197	35.6	6.98	15
180000	0.16	7.32	18.2	92.7	30.78	82197	29.5	6.19	14.9
183000	0.09	7.21	15.1	81.1	30.48	82197	24.9	5.54	14.9
190000	0.06	7.14	13.2	72.1	30.22	82197	22	5	14.9
193000	0.04	7.09	11.9	65.4	29.96	82197	20	4.59	14.9
200000	0.03	7.04	11	58.6	29.69	82197	18.7	4.15	14.9
203000	0.33	7.05	13.5	61.2	29.82	82197	22.5	4.27	14.8
210000	0.71	7.44	26	71.6	31.18	82197	40.6	4.54	15
213000	1.02	7.54	27.7	83.1	31.5	82197	42.9	5.18	14.9
220000	1.28	7.56	27.9	84	31.49	82197	43.3	5.23	14.9
223000	1.5	7.55	28	81.7	31.35	82197	43.4	5.1	14.9
230000	1.72	7.53	28.1	78.9	31.23	82197	43.6	4.93	14.9
233000	1.93	7.52	28.1	75.8	31.14	82197	43.5	4.75	14.9
0	2.13	7.5	28.2	72	30.94	82297	43.7	4.52	14.9
3000	2.31	7.49	28.2	69	30.79	82297	43.7	4.34	14.9
10000	2.42	7.48	28.3	66.9	30.74	82297	43.8	4.21	14.9
13000	2.43	7.47	28.3	62.7	30.79	82297	43.8	3.95	14.9
20000	2.31	7.46	28.3	65.3	30.73	82297	43.8	4.11	14.9
23000	2.11	7.45	28.2	65.5	30.63	82297	43.7	4.13	14.9
30000	1.88	7.43	28.2	63	30.39	82297	43.7	3.99	14.9
33000	1.65	7.4	28.2	60.7	30.08	82297	43.6	3.87	14.9
40000	1.4	7.37	28.1	58.3	29.69	82297	43.5	3.74	14.9
43000	1.11	7.33	27.8	55.9	29.31	82297	43.1	3.62	14.9
50000	0.77	7.27	26.9	54	28.72	82297	41.9	3.55	14.9
53000	0.44	7.19	24.4	52.5	27.82	82297	38.3	3.56	14.9
60000	0.23	7.12	19.7	52.2	26.94	82297	31.7	3.69	14.9
63000	0.14	7.07	15.3	51.8	26.21	82297	25.3	3.8	14.8
70000	0.1	7.05	13	50.2	25.72	82297	21.7	3.78	14.8
73000	0.08	7.03	11.5	48.9	25.35	82297	19.4	3.74	14.8
80000	0.07	7.02	10.7	47.7	25.14	82297	18.1	3.67	14.8
83000	0.07	7.01	10.1	46	25.06	82297	17.2	3.56	14.8
90000	0.29	6.99	11.3	46.5	25.37	82297	19	3.56	14.8
93000	0.7	7.35	26	54.1	27.81	82297	40.6	3.63	14.8
100000	1.01	7.44	27.9	62.7	29.37	82297	43.2	4.05	14.8
103000	1.28	7.46	28.1	64.2	29.61	82297	43.5	4.13	14.8
110000	1.51	7.47	28.2	65.4	29.83	82297	43.7	4.18	14.8
113000	1.74	7.49	28.3	67.4	30.05	82297	43.8	4.3	14.8
120000	1.96	7.51	28.3	71.5	30.31	82297	43.8	4.54	14.8
123000	2.16	7.52	28.3	72.8	30.46	82297	43.8	4.6	14.8

Appendix 3.3. (Continued). Hydrolab results, Okatee River site T-5

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO mg/l	Temp ºC	Date MMDDYY	DO % saturation (calculated)	Batt volts
133000	1.8	7.41	30.8	5.43	28.63	90497	83.22	13.5
140000	1.6	7.44	30.8	5.89	28.8	90497	90.52	13.5
143000	1.4	7.45	30.7	6.09	28.84	90497	93.60	13.5
150000	1.2	7.48	30.6	6.46	29.06	90497	99.59	13.5
153000	0.9	7.56	30.6	7.28	29.55	90497	113.13	13.5
160000	0.6	7.59	30.5	7.53	29.99	90497	117.79	13.5
163000	0.3	7.46	30.5	6.1	30.04	90497	95.50	13.5
170000	0.1	7.29	30.4	4.53	29.85	90497	70.66	13.5
173000	0	7.25	30.3	4.24	29.68	90497	65.92	13.5
180000	0.1	7.27	30.3	4.34	29.15	90497	66.90	13.6
183000	0.3	7.22	30.6	3.56	29.28	90497	55.08	13.4
190000	0.5	7.44	30.5	5.83	28.87	90497	89.55	13.5
193000	0.8	7.53	30.7	6.73	28.86	90497	103.47	13.5
200000	1.1	7.51	30.6	6.49	28.66	90497	99.40	13.5
203000	1.3	7.48	30.6	6.13	28.65	90497	93.87	13.4
210000	1.5	7.51	30.8	6.4	28.6	90497	98.04	13.5
213000	1.7	7.51	30.8	6.36	28.5	90497	97.26	13.5
220000	1.9	7.49	30.9	6.1	28.45	90497	93.26	13.5
223000	2	7.46	30.9	5.83	28.41	90497	89.08	13.5
230000	2.2	7.45	30.9	5.55	28.27	90497	84.60	13.5
233000	2.2	7.44	30.9	5.33	28.06	90497	80.97	13.5
0	2.3	7.42	30.9	5.16	28.08	90597	78.41	13.5
3000	2.2	7.41	30.9	5.16	27.94	90597	78.23	13.5
10000	2.1	7.38	30.9	4.82	27.66	90597	72.74	13.5
13000	1.9	7.36	30.9	4.32	27.51	90597	65.03	13.5
20000	1.7	7.35	31	4.51	27.26	90597	67.65	13.5
23000	1.5	7.32	31	4.15	26.63	90597	61.59	13.5
30000	1.2	7.3	31.1	3.84	25.84	90597	56.27	13.5
33000	0.9	7.28	31.1	3.53	25.4	90597	51.34	13.5
40000	0.6	7.26	31.2	3.49	24.8	90597	50.27	13.5
43000	0.3	7.2	31.1	3.16	24.3	90597	45.10	13.4
50000	0.1	7.19	30.9	3.13	23.91	90597	44.32	13.4
53000	0							
60000	0							
63000	0.1	7.3	30.2	3.57	22.41	90597	49.03	13.3
70000	0.4	7.29	30.7	4.13	24.99	90597	59.51	13.3
73000	0.7	7.35	30.6	4.76	26.55	90597	70.39	13.4
80000	0.9	7.37	30.8	5.05	26.54	90597	74.75	13.4
83000	1.2	7.4	30.7	5.42	26.9	90597	80.67	13.4
90000	1.4	7.41	30.8	5.55	27.08	90597	82.90	13.4
93000	1.6	7.43	31	5.68	26.89	90597	84.67	13.4
100000	1.8	7.42	31	5.65	26.84	90597	84.15	13.4
103000	2	7.42	31.1	5.77	26.87	90597	86.03	13.4
110000	2.1	7.43	31.1	5.96	26.98	90597	89.03	13.4
113000	2.2	7.43	31.1	6.12	27.09	90597	91.59	13.4
120000	2.3	7.43	31	6.24	27.2	90597	93.50	13.4
123000	2.3	7.44	31.1	6.53	27.24	90597	97.97	13.4
130000	2.3	7.45	31.1	6.82	27.33	90597	102.47	13.4
133000	2.1	7.5	31	7.59	27.7	90597	114.68	13.4
140000	1.9	7.45	31	6.58	27.58	90597	99.22	13.4
143000	1.7	7.58	31	8.95	28	90597	135.90	13.4

Appendix 3.3. (Continued). Hydrolab results, Okatee River site T-6

Time HHMMSS	Depth meters	pH units	Salinity ppt	DO % saturation	Temp ºC	Date MMDDYY	DO mg/l	Batt volts
120000	0.2	7.25	31.2	94.9	28.62	91197	6.09	14
123000	0.42	7.37	31.1	82	28.36	91197	5.29	14
130000	0.67	7.34	31.3	73.4	27.72	91197	4.78	14
133000	0.9	7.37	31.4	76.6	27.84	91197	4.98	14
140000	1.11	7.38	31.4	78.1	27.82	91197	5.07	14
143000	1.31	7.38	31.5	77.4	27.8	91197	5.03	14
150000	1.49	7.39	31.5	77.3	27.8	91197	5.02	14
153000	1.64	7.38	31.5	75.4	27.81	91197	4.9	14
160000	1.77	7.39	31.5	75.6	27.91	91197	4.91	14
163000	1.89	7.4	31.5	75.8	27.91	91197	4.92	14
170000	1.94	7.4	31.5	75.5	27.93	91197	4.9	14
173000	1.93	7.41	31.5	76.7	27.96	91197	4.97	14
180000	1.86	7.41	31.5	74	27.97	91197	4.79	14
183000	1.7	7.42	31.5	77.9	28.05	91197	5.04	14
190000	1.49	7.41	31.5	77.4	28.2	91197	5	14
193000	1.27	7.4	31.5	77.5	28.43	91197	4.98	14
200000	1.06	7.38	31.5	75	28.6	91197	4.81	14
203000	0.81	7.36	31.5	73.7	28.66	91197	4.72	14
210000	0.54	7.32	31.5	68.3	28.68	91197	4.37	14
213000	0.29	7.25	31.5	59.5	28.53	91197	3.82	14
220000	0.03	7.19	31.5	51.1	28.22	91197	3.3	14
223000	0							
230000	0							
233000	0							
0	0							
3000	0.14	7.23	31.6	51.6	27.21	91297	3.39	14
10000	0.41	7.3	31.5	62.1	27.69	91297	4.04	14
13000	0.65	7.32	31.2	65.4	27.85	91297	4.25	14
20000	0.88	7.35	31.4	68.8	27.92	91297	4.46	14
23000	1.09	7.36	31.5	68.9	27.9	91297	4.47	14
30000	1.29	7.37	31.5	69.8	27.9	91297	4.52	14
33000	1.46	7.37	31.5	69.2	27.91	91297	4.49	14
40000	1.6	7.37	31.5	69.5	27.82	91297	4.51	14
43000	1.73	7.38	31.5	69.7	27.81	91297	4.53	14
50000	1.81	7.38	31.5	69.4	27.8	91297	4.51	14
53000	1.85	7.39	31.5	69.5	27.79	91297	4.51	14
60000	1.81	7.37	31.6	63.5	27.77	91297	4.13	14
63000	1.69	7.37	31.5	66.6	27.75	91297	4.33	14
70000	1.49	7.31	31.6	61.3	27.59	91297	4	14
73000	1.27	7.26	31.6	54.5	27.43	91297	3.56	14
80000	1.04	7.23	31.6	51.8	27.3	91297	3.4	14
83000	0.79	7.19	31.6	48.2	27.19	91297	3.17	14
90000	0.53	7.15	31.6	45.6	27.05	91297	3	14
93000	0.26	7.14	31.5	46.9	27.16	91297	3.08	14
100000	0.05	7.16	9.2	48.4	27.55	91297	3.6	14
103000	0							
110000	0							
113000	0							
120000	0							
123000	0.03	7.59	9.1	114.2	30.4	91297	8.1	14
130000	0.29	7.49	31.2	93.2	30	91297	5.84	14
133000	0.53	7.39	31.2	73.9	28.72	91297	4.73	14

Appendix 5.1. Total abundance of each species in all intertidal mud flat and subtidal stations sampled. Figures represent total number/0.12 m^2. (A=amphipod; P=polychaete; O=oligochaete; M=mollusk; C=other crustacean; T=other taxa)

		Broad Creek Stations									Okatee River Stations								
	Taxon	intertidal			subtidal						intertidal			subtidal					
Species	code	1	4	6	1	2	3	4	5	6	2	4	6	1	2	3	4	5	6
Ampelisca vadorum	A	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	20	3873	0
Streblospio benedicti	P	12	26	84	169	137	135	117	0	258	86	7	23	25	68	151	48	6	9
Parapionosyllis sp.	P	0	0	0	0	0	0	0	0	100	0	0	0	0	1	3	16	1	739
Scoletoma tenuis	P	0	1	12	7	67	86	0	0	52	88	35	36	28	68	67	217	77	4
Tubificoides wasselli	O	0	0	0	0	0	0	1	0	40	0	0	0	0	50	660	49	2	16
Exogone dispar	P	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	605	123	0
Tubificidae	O	0	0	0	163	0	11	32	0	96	0	0	8	0	3	1	22	110	30
Cirrophorus sp.	P	0	0	0	0	0	0	3	0	0	0	0	0	27	112	219	60	1	10
Mediomastus sp.	P	0	0	0	0	7	0	0	0	52	0	0	0	1	13	12	152	136	1
Streptosyllis sp.	P	0	0	0	0	0	0	177	0	2	0	0	0	0	0	14	3	0	132
Actiniaria	T	0	0	0	4	0	4	6	0	4	0	0	0	0	17	47	13	210	4
Enchytraeidae	O	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	206
Ilyanassa obsoleta	M	33	20	29	115	2	0	0	0	0	0	0	0	10	0	0	3	0	0
Monopylephorus rubroniveus	O	0	176	28	0	0	0	1	0	1	2	0	0	0	0	0	0	0	0
Scoloplos rubra	P	0	0	0	3	42	57	0	0	0	0	0	0	2	8	15	51	10	1
Caulleriella sp.	P	0	0	0	0	0	0	0	0	38	0	0	2	1	0	20	83	0	16
Heteromastus filiformis	P	4	24	2	56	36	4	0	0	7	0	0	7	10	1	1	0	3	0
Brania sp.	P	48	0	0	0	0	0	31	0	25	0	0	0	0	0	19	0	7	17
Leptognatha caeca	C	0	0	0	0	0	0	137	0	0	0	0	0	0	0	0	0	0	1
Tubificoides brownae	O	9	1	8	30	2	8	0	0	5	0	0	0	17	14	6	3	17	9
Nereis succinea	P	2	1	0	4	0	0	0	0	0	66	33	1	1	0	1	3	2	0
Sphaerosyllis longicauda	P	0	0	0	0	0	3	2	0	10	0	0	0	0	0	4	61	5	1
Monticellina sp.	P	0	0	0	0	0	0	0	0	47	2	0	2	0	2	0	26	5	0
Polydora sp.	P	5	0	0	58	9	6	0	0	4	0	0	0	0	0	0	0	0	0
Nemertinea	T	5	2	0	0	0	0	2	1	14	3	5	2	5	2	7	0	21	6
Spiochaetopterus costarum	P	1	0	0	1	41	17	0	0	2	0	0	0	1	6	2	0	0	0
Corophium simile	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	36	0
Gastropoda	M	0	0	0	0	0	3	0	0	0	1	13	0	8	0	0	3	39	0
Leitoscoloplos fragilis	P	0	0	0	0	0	0	0	0	0	17	31	14	1	0	0	0	0	0

Appendix 5.1. Continued

		Broad Creek Stations									Okatee River Stations								
	Taxon	intertidal			subtidal						intertidal			subtidal					
Species	code	1	4	6	1	2	3	4	5	6	2	4	6	1	2	3	4	5	6
Cirratulidae	P	0	0	0	0	2	2	17	0	0	0	0	0	0	14	18	0	2	0
Protohaustorius bousfieldi	A	0	0	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0	0
Paracaprella tenuis	A	0	0	0	0	0	1	0	0	0	0	0	0	0	0	5	30	10	0
Streptosyllis pettiboneae	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	43
Terebellidae	P	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	15	0	0
Scolelepis texana	P	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20	0	0	0
Achelia sawayai	T	0	0	0	0	0	0	0	0	0	0	0	0	0	1	19	13	0	0
Ampelisca abdita	A	0	0	0	0	17	3	0	0	5	0	0	0	0	0	0	7	1	0
Ammotheidae	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	24	0	0
Aphealochaeta sp.	P	0	0	0	0	0	11	2	0	0	0	0	10	0	0	0	1	1	3
Podarkeopsis levifuscina	P	0	0	0	0	0	0	0	0	2	1	0	2	0	1	0	6	16	0
Pelecypoda	M	0	0	0	1	0	3	0	0	0	0	0	0	12	2	2	3	4	0
Decapoda	C	2	1	0	0	0	0	0	0	1	6	1	1	4	1	5	3	1	0
Aricidea wassi	P	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0
Tellina alternata	M	0	0	0	0	0	0	11	0	11	0	0	0	0	0	0	0	0	0
Exogone sp.	P	0	0	0	0	0	1	0	0	18	0	0	0	0	0	2	0	0	0
Diopatra cuprea	P	0	0	0	0	2	0	0	0	1	0	2	0	0	3	9	2	1	0
Littorina irrorata	M	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0
Corophium aquafuscum	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	4	0
Rhepoxynius epistomus	A	0	0	0	0	0	0	13	6	0	0	0	0	0	0	0	0	0	0
Lysianopsis alba	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	5	3
Mediomastus californiensis	P	0	0	0	0	0	9	1	0	6	0	0	2	0	0	0	0	0	0
Tharyx sp.	P	0	0	0	0	0	1	8	0	4	0	0	5	0	0	0	0	0	0
Brania wellfleetensis	P	0	0	0	0	0	0	5	0	10	0	0	0	0	0	1	0	0	1
Sphaerosyllis sp.	P	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	1	0
Corophium acherusicum	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3	7	0
Glycera americana	P	0	0	0	3	1	4	0	0	3	0	2	2	0	0	0	1	0	0
Hesionidae	P	0	1	0	0	0	0	0	0	0	0	0	2	0	1	3	7	2	0
Polydora cornuta	P	0	0	0	2	0	0	0	0	0	0	0	0	0	0	12	1	1	0
Tharyx acutus	P	0	0	0	0	0	1	1	0	6	1	0	0	0	0	2	5	0	0

Appendix 5.1. Continued

	Taxon	Broad Creek Stations									Okatee River Stations								
		intertidal			subtidal						intertidal			subtidal					
Species	code	1	4	6	1	2	3	4	5	6	2	4	6	1	2	3	4	5	6
Aricidea sp.	P	0	0	0	3	10	2	0	0	0	0	0	0	0	0	0	0	0	0
Uca pugilator	C	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0
Aricidea fauveli	P	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	2
Ampelisca verrilli	A	0	0	0	2	0	0	0	0	1	0	0	0	0	5	5	0	0	0
Arabella mutans	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	5	0
Edotea montosa	C	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	2	6	0
Nereidae	P	1	0	0	3	0	0	1	0	4	0	1	0	0	0	0	0	2	0
Eulalia sanguinea	P	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0
Lembos smithi	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	7	0
Nucula proxima	M	0	0	0	0	0	7	1	0	2	0	0	0	0	0	0	0	0	0
Eobrolgus spinosus	A	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0
Erichthonius brasiliensis	A	0	0	0	0	7	2	0	0	0	0	0	0	0	0	0	0	0	0
Marionina spartinae	O	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	1	0	3
Aricidea cerruti	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Crepidula fornicata	M	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	5	0	0
Eupolymnia sp.	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	7	0
Leitoscoloplos sp.	P	0	1	0	0	0	0	0	0	0	4	3	0	0	0	0	0	0	0
Scolelepis sp.	P	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0
Sphaerosyllis taylori	P	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	6
Sphenia antillensis	M	0	0	0	0	0	2	4	0	1	0	0	0	0	0	0	1	0	0
Acanthohaustorius intermediu	A	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
Batea catharinensis	A	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3	3	0
Goniadides sp.	P	0	0	0	0	0	2	0	0	5	0	0	0	0	0	0	0	0	0
Paracaprella sp.	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	0	0
Paranaitis speciosa	P	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
Parapionosyllis longicirrata	P	0	0	0	0	0	0	6	0	0	0	0	0	0	0	1	0	0	0
Autolytus sp.	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
Listriella barnardi	A	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
Lumbrineridae	P	0	0	0	1	0	0	0	0	2	0	0	0	0	2	0	1	0	0
Molgula manhattensis	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	0	0

Appendix 5.1. Continued

Species	Taxon code	Broad Creek Stations intertidal 1	4	6	subtidal 1	2	3	4	5	6	Okatee River Stations intertidal 2	4	6	subtidal 1	2	3	4	5	6
Xanthidae	C	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	4	0
Capitellidae	A	0	0	0	0	0	2	0	0	3	0	0	0	0	0	0	0	0	0
Laeonereis culveri	P	2	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Leitoscoloplos robustus	P	0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Melita nitida	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	0
Sphaerosyllis piriferopsis	P	0	0	0	0	0	4	0	0	1	0	0	0	0	0	0	0	0	0
Arabella iricolor	P	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	1	0
Caprellidae	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
Corophium sp.	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
Cyathura polita	C	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0
Elasmopus levis	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0
Marphysa sanguinea	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0
Melitidae	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0
Paraonidae	P	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0
Sabellaria vulgaris	P	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Scoletoma sp.	P	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Unciola serrata	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0
Bateidae	A	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Corbula contracta	M	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Corophiidae	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0
Dorvilleidae	P	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Leptocheirus plumulosus	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Nassarius vibex	M	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0
Neomysis americana	C	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0
Nephtys bucera	P	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
Pinnixa sp.	C	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Poecilochaetus johnsoni	P	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Protohaustorius wigleyi	A	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
Sphaerosyllis aciculata	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Amphipoda	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0

Appendix 5.1. Continued

		Broad Creek Stations									Okatee River Stations								
		intertidal			subtidal						intertidal			subtidal					
Species	Taxon code	1	4	6	1	2	3	4	5	6	2	4	6	1	2	3	4	5	6
Campylaspis sp.	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Clymenella torquata	P	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Cyathura sp.	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Dipolydora sp.	P	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Eteone heteropoda	P	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
Eunicidae	P	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
Leucothoe spinicarpa	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Mediomastus ambiseta	P	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Melita dentata	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Panopeus herbstii	C	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Polydora caulleryi	P	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Sabellidae	P	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
Sabellinae	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Streblosoma hartmanae	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Synchelidium americanum	A	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Abra aequalis	M	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Acteocina canaliculata	M	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amastigos caperatus	P	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphinomidae	P	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Anthozoa	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Aoridae	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Aricidea suecica	P	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astyris lunata	M	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Biffarius biformis	C	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Brania clavata	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Callianassa sp.	C	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Campylaspis affinis	C	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Capitella jonesi	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Cerapus tubularis	A	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Corbiculidae	M	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 5.1. Continued

		Broad Creek Stations									Okatee River Stations								
	Taxon	intertidal			subtidal						intertidal			subtidal					
Species	code	1	4	6	1	2	3	4	5	6	2	4	6	1	2	3	4	5	6
Glycera dibranchiata	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Hemipholis elongata	T	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Jasmineira bilobata	P	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Laonice cirrata	P	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Lepidonotus sublevis	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Lysidice ninetta	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Monopylephorus irroratus	O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Mulinea lateralis	M	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Mysidacea	C	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Nassarius acutus	M	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Nassarius sp.	M	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Nephtys picta	P	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	O	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Orbiniidae	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Pagurus longicarpus	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Palaemonetes pugio	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Phyllodocidae	P	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Podarkeopsis sp.	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Podocerus sp.	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Polycirrus sp.	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Polydora quadrilobata	P	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Prionospio sp.	P	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Pseudeurythoe ambigua	P	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Pycnogonida	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Sabellaria sp.	P	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Schistomeringos sp.	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Schistomeringos rudolphi	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Scoloplos sp.	P	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Serpulidae	P	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Sphaerosyllis glandulata	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Appendix 5.1. Continued

Species	Taxon code	Broad Creek Stations									Okatee River Stations								
		intertidal			subtidal						intertidal			subtidal					
		1	4	6	1	2	3	4	5	6	2	4	6	1	2	3	4	5	6
Spiophanes bombyx	P	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Tubificoides heterochaetus	O	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Turbonilla interrupta	M	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Uca minax	C	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Upogebia affinis	C	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Appendix 5.2. Total abundance of each species in all tidal creek stations sampled. Figures represent total number/0.12 m2.(A=amphipod; P=polychaete; O=oligochaete; M=mollusk; C=other crustacean; T=other taxa)

	Abundance/m2	Percent Abundance	Frequency of Occurrence	Rank by Abundance
Broad - BBT1				
Monopylephorus rubroniveus	5921.1	89.5	80.0	1.0
Tubificoides brownae	279.1	4.2	30.0	2.0
Streblospio benedicti	119.6	1.8	30.0	3.0
Monopylephorus irroratus	79.7	1.2	20.0	4.0
Tubificidae	59.8	0.9	20.0	5.0
Fabricia sp.	39.9	0.6	10.0	6.5
Nemertinea	39.9	0.6	20.0	6.5
Ampharetidae	19.9	0.3	10.0	9.5
Eulalia sanguinea	19.9	0.3	10.0	9.5
Heteromastus filiformis	19.9	0.3	10.0	9.5
Nereis succinea	19.9	0.3	10.0	9.5
Num of Species = 11	**Tot Abund = 6618.9**			
Broad - BBT2				
Streblospio benedicti	1656.9	52.7	80.0	1.0
Monopylephorus rubroniveus	925.9	29.5	70.0	2.0
Tubificidae	170.6	5.4	30.0	3.0
Heteromastus filiformis	121.8	3.9	30.0	4.0
Edotea montosa	48.7	1.6	20.0	5.5
Nereis succinea	48.7	1.6	20.0	5.5
Aphealochaeta sp.	24.4	0.8	10.0	10.0
Corbiculidae	24.4	0.8	10.0	10.0
Fabricia sp.	24.4	0.8	10.0	10.0
Glycera americana	24.4	0.8	10.0	10.0
Nemertinea	24.4	0.8	10.0	10.0
Sphaerosyllis longicauda	24.4	0.8	10.0	10.0
Tubificoides brownae	24.4	0.8	10.0	10.0
Num of Species = 13	**Tot Abund = 3143.3**			
Broad - BBT3				
Streblospio benedicti	394.7	42.9	70.0	1.0
Monopylephorus rubroniveus	109.7	11.9	30.0	2.5
Heteromastus filiformis	109.7	11.9	40.0	2.5
Capitomastus aciculatus	65.8	7.1	30.0	4.5
Eteone heteropoda	65.8	7.1	20.0	4.5
Aphealochaeta sp.	21.9	2.4	10.0	9.5
Drilonereis longa	21.9	2.4	10.0	9.5
Fabricia sp.	21.9	2.4	10.0	9.5

Appendix 5.2. Continued

	Abundance/m2	Percent Abundance	Frequency of Occurrence	Rank by Abundance
Glycera americana	21.9	2.4	10.0	9.5
Mercenaria mercenaria	21.9	2.4	10.0	9.5
Nereis succinea	21.9	2.4	10.0	9.5
Tubificidae	21.9	2.4	10.0	9.5
Tubificoides brownae	21.9	2.4	10.0	9.5
Num of Species = 13	**Tot Abund = 921.1**			
Broad - BBT4				
Monopylephorus rubroniveus	1096.5	19.4	60.0	1.0
Streblospio benedicti	921.1	16.3	90.0	2.0
Capitomastus aciculatus	855.3	15.1	70.0	3.0
Heteromastus filiformis	701.8	12.4	80.0	4.0
Tubificidae	657.9	11.6	70.0	5.0
Nereis succinea	329.0	5.8	70.0	6.0
Capitella capitata	285.1	5.0	30.0	7.0
Fabricia sp.	263.2	4.7	40.0	8.0
Tubificoides brownae	241.2	4.3	30.0	9.0
Monopylephorus irroratus	219.3	3.9	60.0	10.0
Leitoscoloplos sp.	21.9	0.4	10.0	12.5
Marionina spartinae	21.9	0.4	10.0	12.5
Mediomastus californiensis	21.9	0.4	10.0	12.5
Polydora cornuta	21.9	0.4	10.0	12.5
Num of Species = 14	**Tot Abund = 5657.9**			
Broad - BBT5				
Monopylephorus rubroniveus	6228.1	78.0	100.0	1.0
Streblospio benedicti	657.9	8.2	60.0	2.5
Heteromastus filiformis	657.9	8.2	80.0	2.5
Tubificidae	109.7	1.4	30.0	4.0
Nereis succinea	87.7	1.1	20.0	5.0
Tubificoides brownae	43.9	0.5	20.0	6.0
Aphealochaeta sp.	21.9	0.3	10.0	11.0
Capitella capitata	21.9	0.3	10.0	11.0
Eteone heteropoda	21.9	0.3	10.0	11.0
Exogone dispar	21.9	0.3	10.0	11.0
Leitoscoloplos sp.	21.9	0.3	10.0	11.0
Marionina spartinae	21.9	0.3	10.0	11.0
Monopylephorus irroratus	21.9	0.3	10.0	11.0
Polydora cornuta	21.9	0.3	10.0	11.0
Sabellidae	21.9	0.3	10.0	11.0
Num of Species = 15	**Tot Abund = 7982.5**			

Appendix 5.2. Continued

	Abundance/m2	Percent Abundance	Frequency of Occurrence	Rank by Abundance
Broad - BBT6				
Heteromastus filiformis	285.1	28.3	40.0	1.5
Capitella capitata	285.1	28.3	40.0	1.5
Streblospio benedicti	153.5	15.2	30.0	3.0
Monopylephorus rubroniveus	131.6	13.0	50.0	4.0
Capitomastus aciculatus	43.9	4.3	20.0	6.0
Laeonereis culveri	43.9	4.3	20.0	6.0
Nereis succinea	43.9	4.3	20.0	6.0
Sabellidae	21.9	2.2	10.0	8.0
Num of Species = 8	**Tot Abund = 1008.8**			
Okatee - OBT1				
Monopylephorus rubroniveus	9495.7	74.8	100.0	1.0
Tubificoides heterochaetus	2763.2	21.8	80.0	2.0
Tubificidae	263.2	2.1	30.0	3.0
Capitella capitata	87.7	0.7	20.0	4.0
Nemertinea	43.9	0.3	20.0	5.0
Rhepoxynius epistomus	21.9	0.2	10.0	6.5
Streblospio benedicti	21.9	0.2	10.0	6.5
Num of Species = 7	**Tot Abund = 12697.5**			
Okatee - OBT2				
Tubificidae	1381.6	50.8	70.0	1.0
Streblospio benedicti	482.5	17.7	60.0	2.0
Monopylephorus rubroniveus	263.2	9.7	50.0	3.0
Nereis succinea	175.4	6.5	40.0	4.5
Tubificoides brownae	175.4	6.5	20.0	4.5
Nemertinea	131.6	4.8	50.0	6.0
Heteromastus filiformis	65.8	2.4	20.0	7.0
Corbiculidae	21.9	0.8	10.0	8.5
Edotea montosa	21.9	0.8	10.0	8.5
Num of Species = 9	**Tot Abund = 2719.3**			
Okatee - OBT3				
Tubificidae	636.0	27.9	50.0	1.0
Tubificoides brownae	526.3	23.1	10.0	2.0
Monopylephorus rubroniveus	416.7	18.3	30.0	3.0
Streblospio benedicti	241.2	10.6	30.0	4.0
Heteromastus filiformis	219.3	9.6	40.0	5.0
Nemertinea	87.7	3.8	30.0	6.0

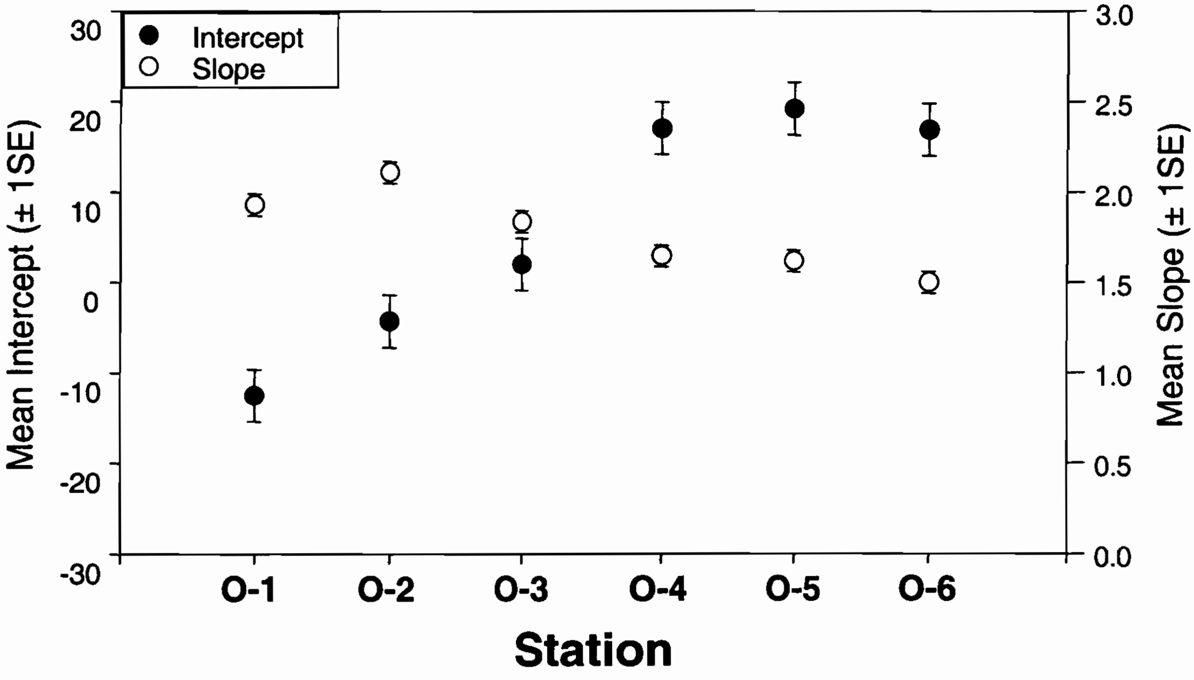
Appendix 5.2. Continued

	Abundance/m2	Percent Abundance	Frequency of Occurrence	Rank by Abundance
Cyathura polita	43.9	1.9	10.0	7.5
Nereis succinea	43.9	1.9	10.0	7.5
Capitella capitata	21.9	1.0	10.0	10.0
Fabricia sp.	21.9	1.0	10.0	10.0
Laeonereis culveri	21.9	1.0	10.0	10.0
Num of Species = 11	**Tot Abund = 2280.7**			
Okatee - OBT4				
Nereis succinea	789.5	45.6	60.0	1.0
Cyathura polita	438.6	25.3	70.0	2.0
Monopylephorus rubroniveus	285.1	16.5	20.0	3.0
Tubificidae	87.7	5.1	20.0	4.0
Streblospio benedicti	65.8	3.8	10.0	5.0
Tubificoides wasselli	43.9	2.5	10.0	6.0
Capitella capitata	21.9	1.3	10.0	7.0
Num of Species = 7	**Tot Abund = 1732.5**			
Okatee - OBT5				
Monopylephorus rubroniveus	1644.7	32.9	70.0	1.0
Nereis succinea	1118.4	22.4	100.0	2.0
Tubificidae	526.3	10.5	50.0	3.0
Fabricia sp.	372.8	7.5	30.0	4.5
Streblospio benedicti	372.8	7.5	30.0	4.5
Monopylephorus irroratus	241.2	4.8	30.0	6.5
Leitoscoloplos sp.	241.2	4.8	30.0	6.5
Tubificoides brownae	109.7	2.2	40.0	8.0
Capitomastus aciculatus	87.7	1.8	20.0	9.0
Capitella capitata	65.8	1.3	10.0	10.5
Nemertinea	65.8	1.3	20.0	10.5
Cyathura polita	43.9	0.9	10.0	12.5
Marionina spartinae	43.9	0.9	10.0	12.5
Hesionidae	21.9	0.4	10.0	15.0
Leptochelia rapax	21.9	0.4	10.0	15.0
Polydora cornuta	21.9	0.4	10.0	15.0
Num of Species = 16	**Tot Abund = 5000.0**			
Okatee - OBT6				
Colembolla	1535.1	47.3	20.0	1.0
Nereis succinea	745.6	23.0	70.0	2.0
Monopylephorus rubroniveus	329.0	10.1	60.0	3.0

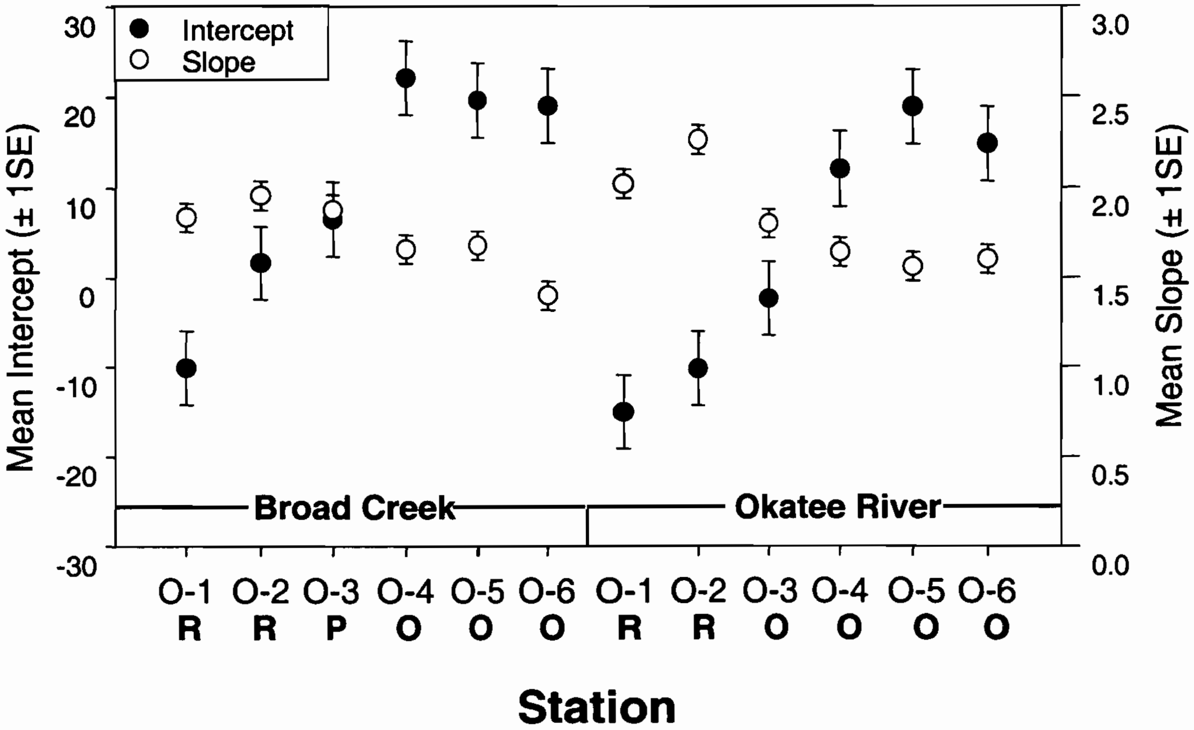
Appendix 5.2. Continued

	Abundance/m2	Percent Abundance	Frequency of Occurrence	Rank by Abundance
Cyathura polita	241.2	7.4	20.0	4.5
Tubificidae	241.2	7.4	40.0	4.5
Tubificoides wasselli	65.8	2.0	10.0	6.0
Tubificoides brownae	43.9	1.4	10.0	7.0
Capitella capitata	21.9	0.7	10.0	8.5
Streblospio benedicti	21.9	0.7	10.0	8.5
Num of Species = 9	**Tot Abund = 3245.6**			

Mean Slope and Intercept Values



Appendix 5.3a. Mean slope and intercept values for oyster size frequency curves at stations 1-6, Broad Creek and Okatee River data combined (n = 10).



Appendix 5.3b. Mean intercept and slope values for oyster size frequency curves at stations 1 - 6 in each drainage system (n = 5). R = restricted; P = prohibited; O = open.

Appendix 5.4. Dermo and MSX results from Broad Creek and Okatee River (n = 25 oysters/station).

Stations		Dermo Intensity	Dermo Prevalence	Mean Height (mm)	MSX Prevalence	MSX Intensity (H-M-L-R)
Broad Creek						
O-1	(Restricted)	1.84	100%	64	12%	0-1-1-1
O-2	(Restricted)	1.24	92%	66	12%	1-1-0-1
O-3	(Prohibited)	2.04	100%	57	4%	0-0-0-1
O-4	(Open)	2	100%	63	33%	2-1-4-1
O-5	(Open)	0.76	36%	66	21%	0-2-1-2
O-6	(Open)	2.08	84%	88	8%	0-0-2-0
Grand Mean		**1.66**	**85%**	**67**	**15%**	**3-5-8-6**
Okatee River						
O-1	(Restricted)	1.84	92%	68	4%	0-1-0-0
O-2	(Restricted)	2.28	96%	60	4%	0-1-0-0
O-3	(Open)	1.56	84%	72	12%	1-0-2-0
O-4	(Open)	1.4	88%	73	4%	0-0-1-0
O-5	(Open)	1.72	96%	74	4%	0-1-0-0
O-6	(Open)	1.48	92%	69	8%	0-0-0-2
Grand Mean		**1.71**	**91%**	**69**	**6%**	**1-3-3-2**

Appendix 5.5. Mean infection intensity and prevalence of the 52 stations sampled for *Perkinsus marinus* (Dermo) and *Haplosporidium neloni* (MSX) during August through October 1996. Stations are listed by counties.

Station Name	County	Dermo Infection Intensity	Dermo Prevalence	MSX Prevalence
Main Creek	Horry	2.48	88%	0%
Weston Creek	Georgetown	2.29	75%	0%
Clambank Creek	Georgetown	2.88	96%	0%
North Jones Creek	Georgetown	0.52	28%	0%
Casino Creek	Charleston	2.16	92%	12%
Mathew's Cut	Charleston	1.36	64%	32%
Horsehead Creek	Charleston	2.16	68%	8%
Nellie Creek	Charleston	1.48	76%	4%
Sandy Point Creek	Charleston	2.24	72%	4%
Five Fathom Creek	Charleston	2.04	76%	16%
Key Inlet	Charleston	1.88	68%	12%
Graham Creek	Charleston	1.92	80%	0%
Vanderhorst Creek	Charleston	1.52	76%	0%
Bull Creek	Charleston	0.6	32%	4%
Skipper Munn's	Charleston	1.92	80%	8%
Sewee Bay	Charleston	2.88	100%	0%
Clausen Creek	Charleston	1.32	60%	0%
Copahee Sound	Charleston	1.4	68%	0%
Capers Creek	Charleston	1.6	76%	8%
Swinton Creek	Charleston	1.56	100%	4%
Conch Creek	Charleston	0.92	84%	8%
Church Creek	Charleston	2.2	88%	0%
Clark Sound	Charleston	2	100%	4%
Folly River, North	Charleston	1.84	76%	12%
Cut Off Reach	Charleston	2.88	100%	12%
Folly Creek, Crosby's	Charleston	2.64	92%	8%
Kiawah River	Charleston	1.6	56%	0%
Bass Creek	Charleston	1.8	80%	4%
Capt. Sam's Inlet	Charleston	2.16	84%	4%
Russel Creek	Charleston	1.32	64%	8%
Leadenwah Creek	Charleston	1.29	68%	0%
Bohicket Creek	Charleston	2	76%	8%
Ocella Creek	Charleston	0.68	44%	0%
Big Bay Creek	Charleston	2	68%	12%
Two Sisters Creek	Colleton	1.48	92%	12%
North Fish Creek	Colleton	1.56	68%	12%
South Fish Creek	Colleton	1.72	72%	4%
Lucy Point Creek	Beaufort	0.28	20%	0%
Dataw Island	Beaufort	1.2	56%	0%
Johnson Creek	Beaufort	1.04	84%	0%
Capers Ck/Distant Is.	Beaufort	1.16	48%	0%
Battery Creek	Beaufort	0.72	44%	0%
Chechessee River	Beaufort	0.6	28%	0%
Colleton River	Beaufort	1	52%	4%

Appendix 5.5. Continued

Station Name	County	Dermo Infection Intensity	Dermo Prevalence	MSX Prevalence
Fripp Inlet	Beaufort	1.88	100%	0%
Club Bridge Creek	Beaufort	1.68	92%	0%
Station Creek	Beaufort	1.4	64%	0%
Mackay Creek	Beaufort	2.48	96%	0%
Jarvis Creek	Beaufort	2.4	92%	8%
Bull Creek	Beaufort	2.12	96%	8%
Old House Creek	Beaufort	2.56	100%	4%
Broad Creek	Beaufort	2.12	84%	0%

100% positive for Dermo
54% (or 28) positive for MSX

Appendix 5.6. Summary of biomarker analyses conducted with native adult oysters. The data are expressed as mean (standard deviation). Sample sizes are: glutathione (n=10), % lysosomal destabilization (n=15), lipid peroxidation (n=10).

Station	Glutathione (nM/g wet weight)	% Lysosomal Destabilization	Lipid Peroxidation MDA (nM/g wet weight)	Comparable Sediment Contaminant Site
Okatee River				
O-1	766.75 (205.09)	31.70 (6.89)	394.67 (148.65)	R-1
O-2	797.69 (130.94)	37.18 (6.73)	404.00 (131.00)	R-2
O-3	677.75 (158.49)	27.29 (6.91)	712.00 (151.61)[a]	R-3
O-4	680.34 (160.77)	33.88 (6.48)	363.67 (63.59)	R-4
O-5	693.26 (92.73)	32.01 (10.19)	433.67 (102.47)	R-5
O-6	609.28 (147.44)[a]	31.98 (8.98)	489.33 (86.02)	R-6,I-6
Broad Creek				
O-1	883.18 (188.73)	33.01 (8.81)	729.33 (160.08)[a]	R-1,I-1
O-2	754.09 (81.32)	41.93 (7.60)[a]	768.67 (216.89)[a]	R-2
O-3	644.16 (110.97)[a]	36.68 (10.83)	754.67 (101.30)[a]	R-3
O-4	671.11 (183.02)[a]	36.99 (8.76)	490.33 (99.94)	I-4,T-4
O-5	852.55 (129.49)	33.62 (6.10)	597.82 (121.94)[a]	R-5
O-6	778.94 (111.86)	35.36 (10.95)	496.36 (166.19)	R-6

Criteria: Lysosomal > 30%; GSH < 400; LPx > 700

[a] Significantly different from minimum value (lysosomomal destabilization and lipid peroxidation) or maximum value (glutathione). One Way Anova using Student-Newman-Keuls to identify different sites ($p<0.05$).

Appendix 5.7. Summary of oyster tissue contaminant samples collected from Broad Creek and the Okatee River. K = Actual value known to be less than value given. All metals and PAH data are in mg/kg Tissue Wet Weight. All PCBs and Pesticides data are in µg/kg Tissue Wet Weight.

River	Station	Date	ALUMINUM	ARSENIC	CADMIUM	CHROMIUM	COPPER	LEAD	MANGANESE	MERCURY	NICKEL	SILVER	TIN	ZINC
Broad	O-1	8/26/97	25	2 K	0.2 K	0.2 K	16	1 K	3.3	0.25 K	0.4 K	0.6 K	10 K	370
Broad	O-2	8/26/97	32	2 K	0.2 K	0.2 K	23	1 K	4	0.25 K	0.4 K	0.6 K	10 K	340
Broad	O-3	8/26/97	42	2 K	0.2	0.2 K	27	1 K	4.6	0.25 K	0.4 K	0.6 K	10 K	350
Broad	O-4	8/27/97	27	2 K	0.2	0.2 K	16	1 K	3.2	0.25 K	0.4 K	0.6 K	10 K	270
Broad	O-5	8/27/97	34	2.4	0.2	0.2 K	15	1 K	3.8	0.25 K	0.4 K	0.6 K	10 K	280
Broad	O-6	8/27/97	20	2.2	0.3	0.2 K	6.5	1 K	3.2	0.25 K	0.4 K	0.6 K	10 K	140
Okatee	O-1	9/10/97	45	2 K	0.4	0.2 K	10	1 K	4.5	0.25 K	0.4 K	0.6 K	10 K	660
Okatee	O-2	9/10/97	50	2 K	0.3	0.2 K	12	1 K	4.5	0.25 K	0.4 K	0.6 K	10 K	460
Okatee	O-3	9/10/97	56	2 K	0.4	0.2 K	12	1 K	3.8	0.25 K	0.4 K	0.6 K	10 K	400
Okatee	O-4	9/11/97	40	2 K	0.4	0.2 K	12	1 K	3.7	0.25 K	0.4 K	0.6 K	10 K	380
Okatee	O-5	9/11/97	13	2 K	0.2	0.2 K	7.4	1 K	3	0.25 K	0.4 K	0.6 K	10 K	230
Okatee	O-6	9/11/97	35	2 K	0.5	0.2 K	16	1 K	4.6	0.25 K	0.4 K	0.6 K	10 K	410

Appendix 5.7. Continued

River	Station	Date	ACENAPTHYLENE	ACENAPTHENE	ANTHRACENE	BENZO(B) FLUORANTHENE	BENZO(K) FLUORANTHENE	BENZO(A) PYRENE	CHRYSENE	FLUORANTHENE	FLUORENE	NAPHTHALENE	PHENANTHRENE	PYRENE
Broad	O-1	8/26/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Broad	O-2	8/26/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Broad	O-3	8/26/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Broad	O-4	8/27/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Broad	O-5	8/27/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Broad	O-6	8/27/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Okatee	O-1	9/10/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Okatee	O-2	9/10/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Okatee	O-3	9/10/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Okatee	O-4	9/11/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Okatee	O-5	9/11/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K
Okatee	O-6	9/11/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K

Appendix 5.7. Continued

River	Station	Date	BENZO(A) ANTHRACENE	DIBENZO(A,H) ANTHRACENE	2-METHYL NAPHTHALENE	BENZO (GHI) PERYLENE	PCB-1221	PCB-1232	PCB-1248	PCB-1260	PCB-1016	PCB-1242	PCB-1254	ALPHA-BHC
Broad	O-1	8/26/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K
Broad	O-2	8/26/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K
Broad	O-3	8/26/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K
Broad	O-4	8/27/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K
Broad	O-5	8/27/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K
Broad	O-6	8/27/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K
Okatee	O-1	9/10/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K
Okatee	O-2	9/10/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K
Okatee	O-3	9/10/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K
Okatee	O-4	9/11/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K
Okatee	O-5	9/11/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K
Okatee	O-6	9/11/97	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.05 K	0.005 K

Appendix 5.7. Continued

River	Station	Date	P,P'DDT	P,P'DDD	P,P'DDE	ALDRIN	ENDOSULFAN SULFATE	BETA ENDOSULFAN	ALPHA ENDOSULFAN	ENDRIN ALDEHYDE	CHLORDANE	DIELDRIN	ENDRIN	TOXPHENE
Broad	O-1	8/26/97	0.005	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K
Broad	O-2	8/26/97	0.005 K	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K
Broad	O-3	8/26/97	0.005 K	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K
Broad	O-4	8/27/97	0.005 K	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K
Broad	O-5	8/27/97	0.005 K	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K
Broad	O-6	8/27/97	0.005 K	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K
Okatee	O-1	9/10/97	0.005 K	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K
Okatee	O-2	9/10/97	0.005 K	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K
Okatee	O-3	9/10/97	0.005 K	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K
Okatee	O-4	9/11/97	0.005 K	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K
Okatee	O-5	9/11/97	0.005 K	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K
Okatee	O-6	9/11/97	0.005 K	0.005 K	0.005 K	5 K	0.005 K	0.005 K	0.005 K	0.005 K	25 K	5 K	5 K	125 K

Appendix 5.7. Continued

River	Station	Date	HEPTACHLOR	HEPTACHLOR EPOXIDE	LINDANE	DIAZINON	DURSBAN	BETA-BHC	DELTA-BHC	PERCENT FAT	NO.INDV.
Broad	O-1	8/26/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.5	52
Broad	O-2	8/26/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.5	52
Broad	O-3	8/26/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.6	67
Broad	O-4	8/27/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.6	67
Broad	O-5	8/27/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.6	92
Broad	O-6	8/27/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.9	92
Okatee	O-1	9/10/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.5	61
Okatee	O-2	9/10/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.6	61
Okatee	O-3	9/10/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.6	79
Okatee	O-4	9/11/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.6	79
Okatee	O-5	9/11/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.4	75
Okatee	O-6	9/11/97	5 K	5 K	5 K	0.005 K	0.005 K	5 K	5 K	0.7	75

Appendix 5.8. Summary of number of mussels and wet biomass (primarily *Geukensia demissa* and *Brachidontes exustus*) in each of the 60 samples and summed for each of the 12 Broad and Okatee Stations.

Site	Station	Replicate	Total Number of Mussels	Total Wet Biomass (g)
Broad	O-1	1	6	1.4854
Broad	O-1	2	0	0
Broad	O-1	3	1	0.161
Broad	O-1	4	0	0
Broad	O-1	5	1	0.207
Broad	O-1	totals	8	1.8534
Broad	O-2	1	4	0.4069
Broad	O-2	2	1	0.26
Broad	O-2	3	28	7.795
Broad	O-2	4	3	0.8736
Broad	O-2	5	17	8.696
Broad	O-2	totals	53	18.0309
Broad	O-3	1	13	4.3292
Broad	O-3	2	10	3.124
Broad	O-3	3	0	0
Broad	O-3	4	0	0
Broad	O-3	5	27	11.702
Broad	O-3	totals	50	19.1552
Broad	O-4	1	40	8.792
Broad	O-4	2	56	9.9536
Broad	O-4	3	35	6.635
Broad	O-4	4	43	8.34
Broad	O-4	5	65	11.95
Broad	O-4	totals	239	45.6706
Broad	O-5	1	64	16.708
Broad	O-5	2	48	9.2026
Broad	O-5	3	10	2.104
Broad	O-5	4	80	18.5659
Broad	O-5	5	49	11.132
Broad	O-5	totals	251	57.7125
Broad	O-6	1	133	27.304
Broad	O-6	2	120	67.51
Broad	O-6	3	148	34.3256
Broad	O-6	4	78	39.03
Broad	O-6	5	228	45.6805
Broad	O-6	totals	707	213.8501
Okatee	O-1	1	2	0.6991
Okatee	O-1	2	0	0
Okatee	O-1	3	0	0
Okatee	O-1	4	0	0
Okatee	O-1	5	1	0.5293
Okatee	O-1	totals	3	1.2281
Okatee	O-2	1	3	2.6087
Okatee	O-2	2	5	2.7145
Okatee	O-2	3	0	0

Appendix 5.8. Continued

Site	Station	Replicate	Total Number of Mussels	Total Wet Biomass (g)
Okatee	O-2	4	4	0.65
Okatee	O-2	5	2	3.4156
Okatee	O-2	totals	14	9.3888
Okatee	O-3	1	1	0.1233
Okatee	O-3	2	0	0
Okatee	O-3	3	3	0.8341
Okatee	O-3	4	2	2.8422
Okatee	O-3	5	4	2.5616
Okatee	O-3	totals	10	6.3612
Okatee	O-4	1	0	0
Okatee	O-4	2	0	0
Okatee	O-4	3	0	0
Okatee	O-4	4	0	0
Okatee	O-4	5	6	5.6777
Okatee	O-4	totals	6	5.6777
Okatee	O-5	1	1	0.0634
Okatee	O-5	2	0	0
Okatee	O-5	3	5	5.8278
Okatee	O-5	4	2	0.479
Okatee	O-5	5	5	5.6733
Okatee	O-5	totals	13	12.0435
Okatee	O-6	1	0	0
Okatee	O-6	2	0	0
Okatee	O-6	3	0	0
Okatee	O-6	4	0	0
Okatee	O-6	5	0	0
Okatee	O-6	totals	0	0

Appendix 5.9. Summary of *Fundulus heteroclitus* population metric data.

		Broad Creek					**Okatee River**					
Metric	Stat	T-1	T-2	T-3	T-4	T-5	T-1	T-2	T-3	T-4	T-5	T-6
Condition Index	avg	2.46	2.41	2.38	2.32	2.58	2.36	2.27	2.30	2.28	2.35	2.39
	std	0.27	0.20	0.22	0.24	0.21	0.24	0.15	0.17	0.17	0.31	0.21
	min	1.30	1.88	1.39	1.77	2.06	1.77	1.93	1.76	1.71	1.70	1.79
	max	3.70	3.22	3.37	2.91	3.19	2.96	2.80	2.75	2.64	3.95	2.82
Total Length	avg	59.43	52.55	51.52	62.87	66.01	49.96	47.09	45.92	43.27	57.32	44.56
	std	12.88	11.66	11.63	12.96	13.09	8.55	4.47	6.46	6.87	13.81	6.18
	min	38	34	37	37	41	37	36	36	23	39	27
	max	92	80	96	92	103	74	56	77	58	99	56
Standard Length	avg	48.55	42.87	41.97	51.02	54.23	41.06	38.00	36.98	34.86	46.09	36.17
	std	10.60	9.64	9.62	10.93	10.95	7.63	3.73	5.26	5.80	11.16	5.02
	min	31	27	30	31	33	29	29	29	17	32	21
	max	78	67	79	74	87	68	45	63	47	82	46
Weight	avg	3.28	2.25	2.14	3.60	4.71	1.82	1.28	1.25	1.05	2.84	1.21
	std	2.27	1.72	2.02	2.49	2.97	1.19	0.37	0.75	0.46	2.89	0.50
	min	0.65	0.53	0.6	0.66	0.9	0.59	0.51	0.55	0.1	0.73	0.2
	max	11.79	8.46	14.62	11.32	18.07	5.73	2.05	6.58	2.6	14.46	2.66
Abnormalities	number	1	0	2	5	2	2	0	6	0	3	0
	% abnormal	0.8	0.0	0.7	4.5	1.1	3.9	0.0	3.4	0.0	6.4	0.0
Sex Ratio	M : F	49:77	99:129	118:163	50:60	96:90	10:41	23:29	39:135	14:26	18:29	22:31
Immatures	number	2	1	0	2	0	0	4	4	4	0	1
	Number	128	229	281	112	186	51	56	178	44	47	54
	m	49	99.0	118	50	96	10	23	39	14	18	22
	f	77	129.0	163	60	90	41	29	135	26	29	31
	I	2	1.0	0	2	0	0	4	4	4	0	1
	total	128	229	281	112	186	51	56	178	44	47	54
	% female	60.2	56.3	58.0	53.6	48.4	80.4	51.8	75.8	59.1	61.7	57.4

Appendix 5.10. Okatee River and Broad Creek statistical comparisons for grass shrimp (α = 0.05 for all tests)

DATA TYPE	COMPARISONS	PARAMETER	NORMALITY	(p value)	TEST	RESULT	(p value)	MULTIPLE COMPAR. TEST	PAIRWISE COMP.
Grouped	System-wide (Okatee vs. Broad)	**Abundance**	**failed**	**<0.0001**	**Mann-Wh.**	**sign. diff.**	**0.032**		**Broad > Okatee**
		Biomass	**failed**	**<0.0001**	**Mann-Wh.**	**sign. diff.**	**0.029**		**Broad > Okatee**
		% Gravid Female	failed	<0.0001	Mann-Wh.	no sign. diff.	0.287		
		Larval	failed	<0.0001	Mann-Wh.	no sign. diff.	0.799		
		Average Size	failed	0.0078	Mann-Wh.	no sign. diff.	0.560		
	Between Habitats (within Okatee)	Abundance	failed	<0.0001	Kruskal-Wallis	no sign. diff.	0.823		
		Biomass	failed	0.0036	Kruskal-Wallis	no sign. diff.	0.831		
		% Gravid Female	failed	0.029	Kruskal-Wallis	no sign. diff.	0.359		
		Larval	failed	<0.0001	Kruskal-Wallis	no sign. diff.	0.235		
		Average Size	failed	0.0134	Kruskal-Wallis	no sign. diff.	0.217		
	Between Habitats (within Broad)	Abundance	failed	<0.0001	Kruskal-Wallis	no sign. diff.	0.270		
		Biomass	passed	0.0541	1 way ANOVA	no sign. diff.	0.282		
		% Gravid Female	passed	0.0611	1 way ANOVA	no sign. diff.	0.542		
		Larval	**failed**	**0.0205**	**Kruskal-Wallis**	**sign. diff.**	**0.008**	Dunn's	River > Tidal
		Average Size	passed	0.2106	1 way ANOVA	no sign. diff.	0.631		
	Tidal Data (Okatee vs Broad)	Abundance	failed	0.0022	Mann-Wh.	no sign. diff.	0.174		
		Biomass	* passed	0.1883	Mann-Wh.	no sign. diff.	0.137		
		% Gravid Female	failed	0.0106	Mann-Wh.	no sign. diff.	0.216		
		Larval	failed	<0.0001	Mann-Wh.	no sign. diff.	0.428		
		Average Size	failed	0.0013	Mann-Wh.	no sign. diff.	1.000		
	River Data (Okatee vs Broad)	Abundance	failed	<0.0001	Mann-Wh.	no sign. diff.	0.373		
		Biomass	failed	0.001	Mann-Wh.	no sign. diff.	0.468		
		% Gravid Female	**failed**	**0.0023**	**Mann-Wh.**	**sign. diff.**	**0.035**		**Broad > Okatee**
		Larval	failed	<0.0001	Mann-Wh.	no sign. diff.	0.200		
		Average Size	* passed	0.385	Mann-Wh.	no sign. diff.	0.718		
	Intertidal Data (Okatee vs Broad)	Abundance	failed	0.0486	Mann-Wh.	no sign. diff.	0.480		
		Biomass	passed	0.3483	t-test	no sign. diff.	0.408		
		% Gravid Female	passed	0.1209	t-test	no sign. diff.	0.683		
		Larval	passed	0.2446	t-test	no sign. diff.	0.179		
		Average Size	passed	0.084	t-test	no sign. diff.	0.744		

* The Normality Test passed with p>0.05, but the Equal Variance Test failed. Therefore, a nonparametric test was used.

Appendix 5.10. Continued

DATA TYPE	COMPARISONS	PARAMETER	NORMALITY	(p value)	TEST	RESULT	(p value)	MULTIPLE COMPAR. TEST	PAIRWISE COMP.
Ungrouped (site vs site)	System-Wide Okatee vs Broad)	**Abundance**	**failed**	**<0.0001**	**Kruskal-Wallis**	**sign. diff.**	**0.0001**	**Dunn's**	**none**
	Tidal (all pairwise)	**Abundance**	**failed**	**0.0031**	**Kruskal-Wallis**	**sign. diff.**	**0.027**	**Dunn's**	**BGT5 > OGT4**
		Biomass	**passed**	**0.1558**	**1 way ANOVA**	**sign. diff.**	**<0.0001**	**Stud.-New.-Keuls**	**see Chart #2**
		% Gravid Female	passed	0.1244	1 way ANOVA	no sign. diff.	0.812		
		Larval	passed	0.615	1 way ANOVA	no sign. diff.	0.491		
		Average Size	**failed**	**<0.0001**	**Kruskal-Wallis**	**sign. diff.**	**0.039**	**Dunn's**	**none**
	River (all pairwise)	**Abundance**	**failed**	**<0.0001**	**Kruskal-Wallis**	**sign. diff.**	**0.004**	**Dunn's**	**none**
		Biomass	**passed**	**0.233**	**1 way ANOVA**	**sign. diff.**	**<0.0001**	**Stud.-New.-Keuls**	**see Chart #2**
		% Gravid Female	**failed**	**0.0197**	**Kruskal-Wallis**	**sign. diff.**	**0.242**	**Dunn's**	**none**
		Larval	**failed**	**0.0019**	**Kruskal-Wallis**	**sign. diff.**	**0.004**	**Dunn's**	**none**
		Average Size	passed	0.3219	1 way ANOVA	no sign. diff.			
	Intertidal (all pairwise)	**Abundance**	**failed**	**0.0394**	**Kruskal-Wallis**	**sign. diff.**	**0.035**	**Dunn's**	**none**
		Biomass	**passed**	**0.362**	**1 way ANOVA**	**sign. diff.**	**0.003**	**Stud.-New.-Keuls**	**see Chart #2**
		% Gravid Female	failed	0.0029	Kruskal-Wallis	no sign. diff.	0.221		
		Larval	**failed**	**<0.0001**	**Kruskal-Wallis**	**sign. diff.**	**0.026**	**Dunn's**	**none**
		Average Size	failed	<0.0001	Kruskal-Wallis	no. sign. diff.			
GROUPED PAIRED BY SITE		Abundance			Mann-Whitney				BGT5 > OGT5
		Biomass			Mann-Whitney				BGT5 > OGT5
		Size			Mann-Whitney				OGT1 > BGT1
		Size			Mann-Whitney				OGT5 > BGT5
		Eggs per Female			Mann-Whitney				OGR1 > BGR1
		Eggs per Female			Mann-Whitney				OGR2 > BGR2
		Eggs per Female			Mann-Whitney				OGI1 > BGI1
		Larval Abundance			Mann-Whitney				BGR4 > OGR4
		Larval Abundance			Mann-Whitney				OGR2 > BGR2
		Larval Abundance			Mann-Whitney				OGR3 > BGR3
Contaminated vs Uncontaminated Sites (grouped data)		Abundance	failed	<0.0001	Kruskal-Wallis	no sign. diff.	0.099		
		Biomass	failed	<0.0001	Kruskal-Wallis	no sign. diff.	0.160		
		% Gravid Female	failed	0.0008	Kruskal-Wallis	no sign. diff.	0.516		
		Larval	**failed**	**<0.0001**	**Kruskal-Wallis**	**sign. diff.**	**0.044**	**Dunn's**	**see Chart #2**
		Average Size	failed	0.0019	Kruskal-Wallis	no sign. diff.	0.102		