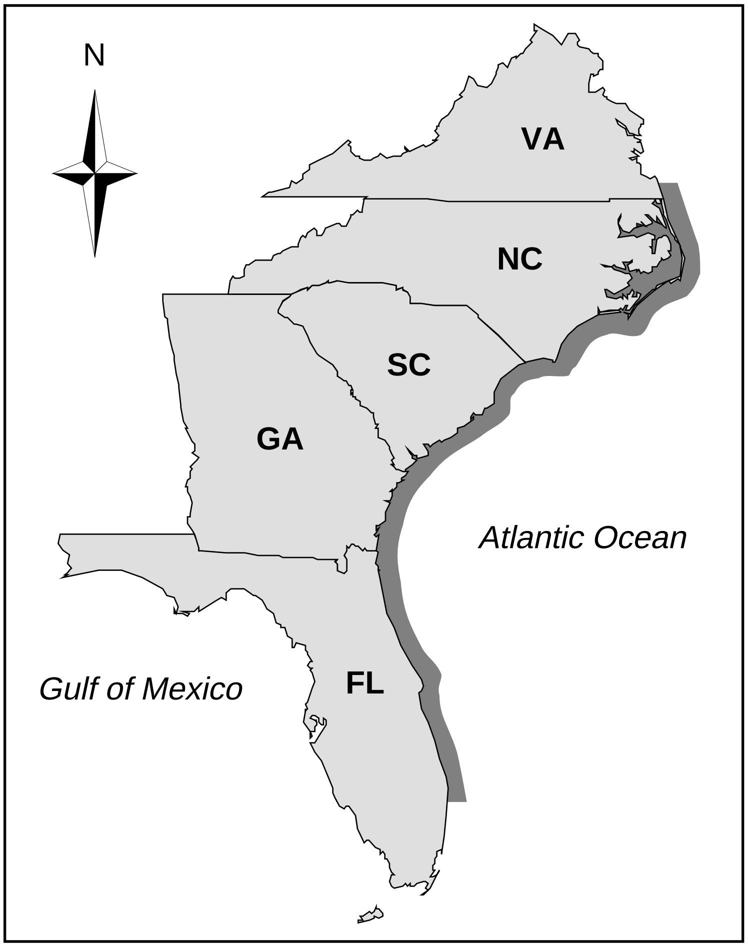
NOAA Technical Memorandum NOS ORCA 97

ENVIRONMENTAL QUALITY OF ESTUARIES OF THE CAROLINIAN PROVINCE: 1994

Annual Statistical Summary for the 1994 EMAP-Estuaries Demonstration Project in the Carolinian Province



July 1996

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

DEPARTMENT OF COMMERCE UNITED STATES OF AMERICA

National Ocean Service
Office of Ocean Resources Conservation and Assessment
Coastal Monitoring and Bioeffects Assessment Division

NOAA Technical Memorandum NOS ORCA 97

Environmental Quality of Estuaries of the Carolinian Province: 1994

(Annual Statistical Summary for the 1994 EMAP-Estuaries Demonstration Project in the Carolinian Province)

Jeffrey L. Hyland[1], Timothy J. Herrlinger[2], Timothy R. Snoots[3], Amy H. Ringwood[3],
Robert F. Van Dolah[3], Courtney T. Hackney[4], Gary A. Nelson[5], Jeffrey S. Rosen[6],
and Steven A. Kokkinakis[7]

[1] NOAA/NOS/ORCA/CMBAD, Charleston, SC
[2] Grice Marine Biological Laboratory, University of Charleston, SC
[3] SC Department of Natural Resources, Marine Resources Research Institute, Charleston, SC
[4] University of North Carolina-Wilmington, Wilmington, NC
[5] FL Dept. of Environmental Protection, FL Marine Research Institute, St. Petersburg, FL
[6] Technology Planning and Management Corp., Scituate, MA
[7] NOAA/NOS/ORCA/CMBAD, Silver Spring, MD

Charleston, South Carolina
July 1996

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Michael Kantor Secretary	D. James Baker Under Secretary	W. Stanley Wilson Assistant Administrator

Coastal Monitoring and Bioeffects Assessment Division
Office of Ocean Resources Conservation and Assessment
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Notice

PREFACE

This document is the first annual statistical summary for the Carolinian Province estuaries component of the nationwide Environmental Monitoring and Assessment Program (EMAP). EMAP-Estuaries in the Carolinian Province is jointly sponsored by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (EPA). The program is being administered through the NOAA Carolinian Province Office in Charleston, South Carolina and implemented through partnerships with a combination of federal and state agencies, universities, and the private sector.

The appropriate citation for this report is:

Hyland, J. L., T. J. Herrlinger, T. R. Snoots, A. H. Ringwood, R. F. Van Dolah, C. T. Hackney, G. A. Nelson, J. S. Rosen, and S. A. Kokkinakis. 1996. Environmental quality of estuaries of the Carolinian Province: 1994. Annual statistical summary for the 1994 EMAP-Estuaries Demonstration Project in the Carolinian Province. NOAA Technical Memorandum NOS ORCA 97. NOAA/NOS, Office of Ocean Resources Conservation and Assessment, Silver Spring, MD. 102 p.

DISCLAIMER

This report provides a summary of ecological conditions of estuaries of the Carolinian Province based on data collected during a single sampling period (June 30 – August 31 1994) in accordance with the sampling design and protocols established for the nationwide Environmental Monitoring and Assessment Program (EMAP). The EMAP-Estuaries scientific design incorporates a broad-based sampling scale in which a large regionally extensive population of estuaries is sampled each year. Each estuary is usually represented by a single randomly selected station. This design is intended to support probability-based estimates of the percent area of degraded vs. nondegraded estuaries across the region (or smaller subpopulations of estuaries). However, the design is limited in its ability to support detailed characterizations of pollutant distributions and sources within individual estuarine systems. Such assessments would require finer-scale sampling designs applied in the particular areas of concern. Furthermore, because the data presented here represent only the first year of sampling, it is not possible at this point in the program to report on temporal changes or trends. Collection of data over several years should provide an answer to the question of whether the conditions of the estuarine resources within the region are getting better or worse with time. Moreover, the statistical power to detect such changes should be enhanced as measurements from multiple years of sampling are included in the database. Such limitations of the present data must be recognized should the information be used for policy, regulatory, or legislative purposes.

ACKNOWLEDGMENTS

EMAP-Estuaries in the Carolinian Province is jointly sponsored by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (EPA). EPA funds were provided through Interagency Agreement #DW13936394-01 from EPA's Office of Research and Development. NOAA funds were provided by the National Ocean Service from the Coastal Monitoring and Bioeffects Assessment Division (CMBAD), of the Office of Ocean Resources Conservation and Assessment (ORCA), and from the Coastal Services Center in Charleston, SC.

Scientific support for this program has been provided through partnerships with a combination of universities, state agencies, and private institutions. The following organizations provided a full range of sampling, analytical, and interpretive support in each of their respective subregions through individual cooperative agreements with NOAA: University of North Carolina-Wilmington (UNC-W) for work in the southern Virginia and North Carolina subregion; South Carolina Department of Natural Resources/Marine Resources Research Institute (SCDNR/MRRI) for work in the South Carolina and Georgia subregion; and the Florida Department of Environmental Protection/Florida Marine Research Institute (FDEP/FMRI) for work in the Florida subregion. Other research organizations provided additional scientific support through subcontracts with these lead institutions. For example, *Ampelisca abdita* and Microtox® sediment toxicity tests were performed by Science Applications International Corporation (SAIC) and the Citadel, respectively, both under subcontracts with SCDNR/MRRI.

Province-wide information management and data-analysis support was provided by SCDNR/MRRI, the University of Charleston South Carolina/Grice Marine Biological Laboratory (UCSC/GMBL), and the company Technology Planning and Management Corporation (TPMC). Analysis of chemical contaminants in samples from all stations throughout the province was performed by the Geochemical and Environmental Research Group of Texas A&M University (TAMU/GERG).

EMAP-Estuaries in the Carolinian Province is a comprehensive, interdisciplinary, and regionally extensive monitoring program that has required the input of literally hundreds of individuals working together to complete the effort represented in this report. The dedication and cooperation of all of these individuals are greatly appreciated. While the success of the program has been due to the combined efforts of all of these individuals, special recognition is extended to the following participants (listed in alphabetical order):

Citadel

Philippe Ross

Clemson University

Marie G. DeLorenzo
Teresa Wilson

Florida Department of Environmental Protection

Doug Adams
Kim Amendola
David Camp
David Cook
Bob Heagey
Jan Landsberg
James McKenna
Gil McRae
Craig Norwicki
Richard Paperno
Tom Perkins
Derek Tremain
Mike Wessel

Hydrolab Corporation

Brian Wisehart

National Biological Service

Virginia Engle
Thomas Heitmuller
Ziad Malaeb

NC State University/ College of Veterinary Medicine

Edward Noga

NOAA

Gunnar Lauenstein
Camille Mageau
Charles Parker
Andrew Robertson

S.C. Department of Natural Resources

Marianne Armstrong-Taylor
Greg Gilbert
David Goldman
Fred Holland
John Jones
Marty Levinson
Paulette Powers
George Steele

Science Applications International Corporation

Corneilia Mueller
John Scott
Glen Thursby

Texas A&M University

Paul Boothe
James Brooks
Guy Denoux
Terry Wade

University of Georgia

Steve Rathbun

University of North Carolina-Wilmington

Martin Posey
Steve Ross
Mary Smith
Kevin Stokesbury
Tracy Wheeler

University of Charleston S.C., Grice Marine Biological Laboratory

Rick Brusca
Charles Keppler
Mike Wert

U.S. EPA (and Contract Organizations)

Matt Adams
(Johnson Controls World Services)
Harry Buffum
(Signal Corporation)
Jack Fournie
Steve Hale
Linda Harwell
(Johnson Controls World Services)
Daryl Keith
John Macauley
Brian Melzian
John Paul
Miriam Rodon-Naveira
Kevin Summers

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

A study was conducted in the Carolinian Province to identify the estuarine resources of this region and assess their condition based on a variety of synoptically measured indicators of environmental quality. The Carolinian Province, one of 12 coastal regions established under the nationwide Environmental Monitoring and Assessment Program (EMAP), extends from Cape Henry, Virginia through St. Lucie Inlet, Florida. Indicators used in this study included measures of: (1) general habitat condition (depth, physical properties of water, sediment grain-size and organic carbon content), (2) pollution exposure (sediment contaminants, sediment toxicity, low dissolved oxygen conditions), (3) biotic conditions (diversity and abundances of macroinfaunal and demersal species, pathologies in demersal biota), and (4) aesthetic quality (presence of anthropogenic debris, visible oil, noxious sediment odor, and water clarity). A stratified random sampling approach was incorporated to support probability-based estimates of the areal extent of degraded vs. undegraded resources.

Estuaries were stratified into three classes based on physical dimensions: large estuaries, small estuaries, and large tidal rivers. This classification scheme resulted in the identification of 200 estuaries with an overall estimated surface area of 11,622 km^2. There were three large estuaries, three large tidal rivers, and 194 small estuaries. A total of 84 base stations and 13 supplemental stations were sampled from June 30 – August 31, 1994. Base stations were randomly selected sites that formed the core of the probability-based monitoring design. By estuarine class, base stations included 20 in large estuaries, 47 in small estuaries, and 17 in large tidal rivers. By subregion, there were 46 stations in southern Virginia – North Carolina, 20 in South Carolina – Georgia, and 18 in Florida. Supplemental stations in suspected contaminated areas provided sites for field validation of additional ecological indicators developed during the study.

Over half (54%) of the surface area of these estuaries showed no major evidence of environmental degradation based on any of the measured biotic, exposure, or aesthetic indicators. Twenty percent of the province, represented by 17 stations, exhibited adverse biological conditions linked to significant pollution exposure (significant sediment toxicity, high sediment contamination in excess of reported bioeffect guidelines, or low dissolved oxygen concentrations in bottom waters). The majority (11) of these sites were in North Carolina. Most were characterized by degraded infaunal assemblages accompanied by high sediment contamination and/or significant sediment toxicity based on Microtox® assays. Biotic indicators based on demersal species variables were not as effective as infaunal variables in discriminating between undegraded and degraded stations (classified on the basis of exposure indicators). Additional localized impacts not accounted for in the above estimate of degraded estuaries were detected at nonrandom supplemental sites near potential contaminant sources.

A strength of the EMAP-Estuaries probability-based sampling design is its ability to support unbiased estimates of ecological condition with known confidence. Further sampling in the Carolinian Province should improve the accuracy of these estimates and provide a basis for assessing how the overall quality of these estuaries is changing with time.

1. INTRODUCTION

1.1 Background and Purpose of Study

This study was conducted as part of the estuaries component of the Environmental Monitoring and Assessment Program (EMAP-E). EMAP, initiated by the Environmental Protection Agency (EPA), is a nationwide federal program aimed at monitoring the environmental health of a variety of coastal and terrestrial ecosystems. The estuaries portion of EMAP is conducted jointly by EPA and the National Oceanic and Atmospheric Administration (NOAA) and is designed to provide a quantitative assessment of the regional extent of potential environmental problems in the nation's estuaries by measuring status and change in selected ecological indicators. A detailed program plan for EMAP-E and related efforts in other near-coastal environments is described by Holland (1990). The integrated approach to monitoring these coastal resources fulfills a key directive under the 1992 National Coastal Monitoring Act (Sec. 501 *Et Seq*, 33 U.S.C. 2801) for NOAA, EPA and other federal agencies to establish a comprehensive national program for consistent monitoring of the nation's coastal environments and ecosystems.

In 1993, NOAA and EPA formalized an agreement to initiate a joint monitoring program in the Carolinian Province. The Carolinian Province, which is one of 12 EMAP-E regions, extends from Cape Henry, Virginia through the southern end of the Indian River Lagoon along the east coast of Florida (Figure 1-1). The estuarine resources of this region are diverse and extensive, covering an estimated 11,622 km^2. There is an increasing need for effective management of these resources given predicted influxes of people and businesses to southeastern coastal states over the next few decades and the ensuing pressures on the coastal zone of this region. Culliton et al. (1990) estimated that the coastal population of the southeastern United States will have increased by 181% (the largest in the country) from 1960 to 2010. The Carolinian monitoring program is intended to provide valuable information on the overall health of southeastern estuaries in addition to a reliable baseline for evaluating how conditions of these resources are changing with time. The program also provides an opportunity to refine methods for conducting future monitoring and assessment studies in this and other regions.

An initial pilot study was conducted in the Carolinian Province in 1993 to collect background information on ranges of environmental variables and to determine appropriate indicators of environmental quality to include in subsequent monitoring efforts. Results of the pilot study are summarized by Ringwood et al. (1995a). A full province-wide monitoring effort began in 1994. This effort incorporates approaches suggested in the pilot study but is based primarily on the overall EMAP-E sampling design and protocols to ensure data comparability with other provinces. Thus far, two years of field sampling have been completed. The following report provides a summary of ecological conditions of estuaries of the Carolinian Province based on data collected during the first monitoring season (summer 1994).

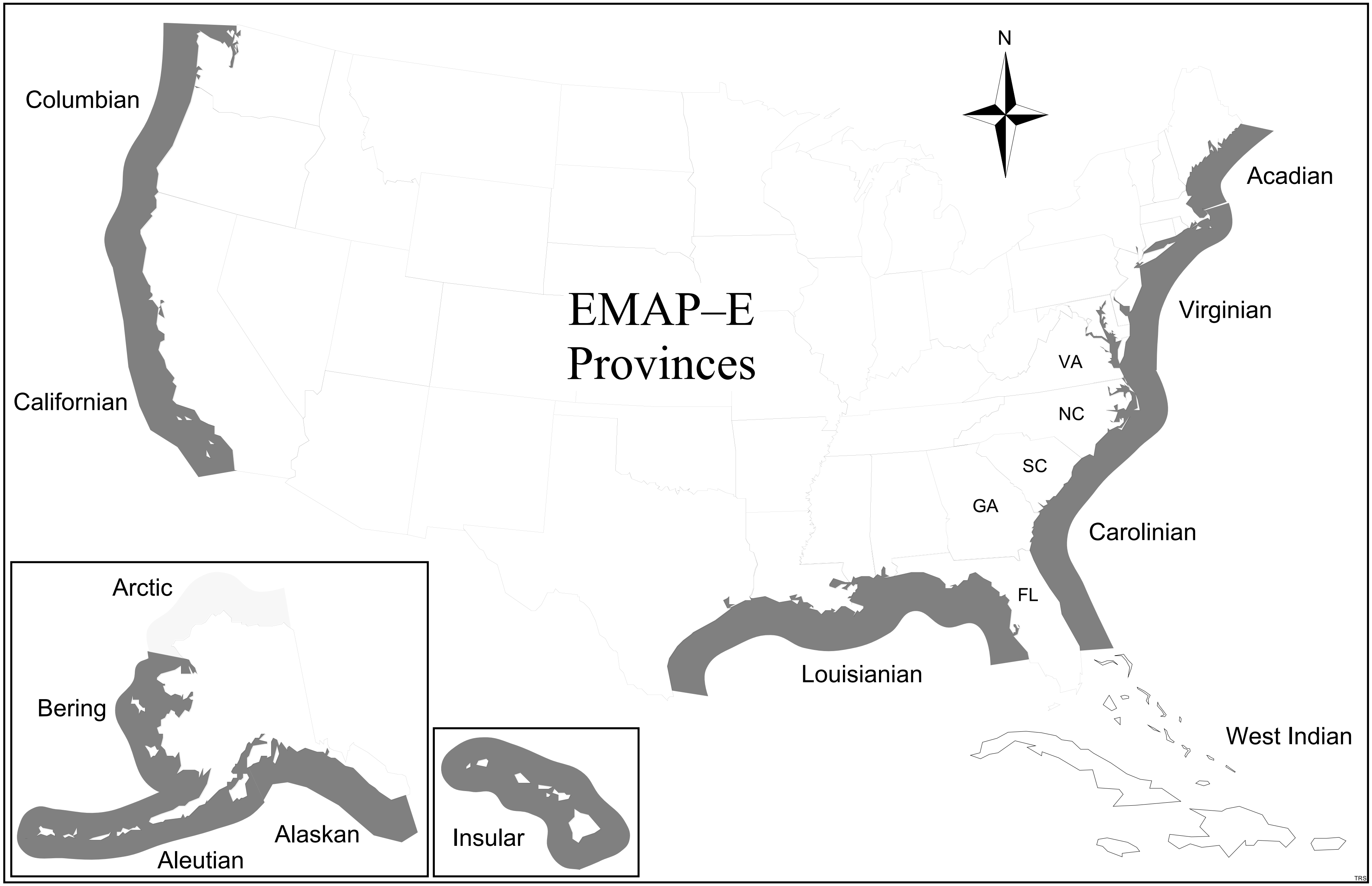


Figure 1-1. EMAP-E provinces

1.2 Objectives

The objectives of this program are to:

1. Assess the conditions of estuarine resources of the Carolinian Province based on a variety of synoptically measured indicators of environmental quality;
2. Establish a baseline for evaluating how the conditions of these resources are changing with time; and
3. Develop and validate improved methods for use in future coastal monitoring and assessment efforts.

These objectives are being addressed using a probability-based sampling design, under which a large regionally extensive population of estuaries, each represented by one or more randomly selected stations, is sampled from year to year. This design makes it possible to produce unbiased estimates of the percent area of degraded vs. nondegraded estuaries, based on a series of synoptically measured indicators of environmental quality. With such capability, the above objectives may be addressed by asking the following kinds of related assessment questions:

- What proportion of estuarine bottom waters in the Carolinian Province experiences hypoxia?
- What proportion of estuarine sediments in the Carolinian Province contains concentrations of anthropogenic chemical contaminants above reported bioeffect levels?
- What proportion of estuaries in the Carolinian Province contains sediments that are toxic to standard test populations of marine organisms?
- What proportion of estuarine sediments in the Carolinian Province has a benthic community structure indicative of polluted environments?
- What proportion of estuaries in the Carolinian Province has demersal fish and invertebrate community structure indicative of polluted environments?
- What is the incidence of gross external pathologies among demersal fish and invertebrate species in the Carolinian Province?
- What is the incidence of chemical contaminant loading in the tissues of commercially and recreationally important fishes and invertebrates in the Carolinian Province (Yr 2 only)?
- What proportion of Carolinian Province estuaries is aesthetically degraded (e.g., contains anthropogenic marine debris, oil sheens, or sediments with noxious odors)?
- Are there linkages between degraded biological conditions of these estuaries and exposure to pollutants and other anthropogenic factors?
- How do indicators of environmental quality for southeastern estuaries compare to those of other regions?

Methods used to answer these kinds of questions are described in Section 2.0 of this report. Section 3.0 presents results for each of the various types of indicators. Conclusions are given in Section 4.0.

2. METHODS

2.1 Sampling and Statistical Design

An overall goal of EMAP is to make statistically unbiased estimates of ecological condition with known confidence. To meet this goal, a probabilistic sampling framework consisting of randomly selected sites was established. Under this design, each sampling point is a statistically valid probability sample and considered to be representative of the estuary from which it was selected. As a result, percentages of estuarine area throughout the province with indicator values above or below suggested environmental guidelines can be estimated based on the conditions observed at individual sampling points. Statistical confidence intervals around these estimates also can be calculated. Moreover, these estimates can be combined with those for other regions that were sampled in a consistent manner to yield national estimates of estuarine condition. The following section describes how stations were selected using this probabilistic sampling design. Supplemental sites, selected nonrandomly in suspected polluted areas, were included in the survey and are discussed below as well.

Sampling sites in 1994 consisted of 84 base stations and 13 supplemental stations (Table 2-1). Base stations were randomly selected sites that formed the core of the probability-based monitoring design. Data collected from these sites were used to produce unbiased estimates of estuarine condition throughout the province based on the various synoptically measured indicators of environmental quality. The province-wide distribution of base sites is shown in Figure 2-1. Supplemental stations were sites selected non-randomly in areas for which there was some prior knowledge of the ambient environmental conditions. These sites, which usually were places with histories of sediment contamination or low-oxygen conditions, were used to test the discriminatory power of various ecological indicators included in the program.

As in other EMAP-E provinces (Strobel et al. 1994, Summers et al. 1993b), the sampling design for base sites in the Carolinian Province was stratified based foremost on physical dimensions of an estuary. Estuaries were divided into three classes: large estuaries (area >260 km^2 and length/width aspect ratio <20), small estuaries (area 2.6–260 km^2), and large tidal rivers (tidally influenced portion of a river with detectable tides >2.5 cm, area >260 km^2 and length/width aspect ratio >20). This classification scheme resulted in the identification of 200 estuaries with an overall surface area of 11,622 km^2 (Table 2-2). The total is comprised of three large estuaries, three large tidal rivers, and 194 small estuaries with corresponding subpopulation areas of 5,581 km^2, 1,134 km^2, and 4,907 km^2, respectively. Currituck, Albemarle, and Pamlico Sounds — all in North Carolina — comprise the three large estuaries. The three large tidal rivers are the Neuse and Pamlico Rivers in North Carolina and the Indian River in Florida. Small estuaries that were sampled in 1994 (47 of the total 194) are listed in Table 2-1.

Stratification of the overall sampling area into classes of estuaries with similar attributes is necessary in order to minimize within-class sampling variability. Also, it is not feasible to sample all of the different types of estuaries that exist within a broad geographic region at the same spatial scale. Stratification by physical dimensions of an estuary was adopted because:

TABLE 2-1. Carolinian Province summer 1994 sampling sites with target station coordinates. In the EMAP station number, RR = Large Tidal River, RP = Large Tidal River Replicate, SR = Small Estuary, and LR = Large Estuary.

CPO Sta. No.	EMAP Sta. No.	State	Estuary	Latitude	Longitude	Area (km^2)
Base Sites						
CP94001	CA94RR09	FL	Indian R. Lagoon	27°12.07'	80°10.55'	34.1
CP94002	CA94SR50	FL	St. Lucie River	27°12.82'	80°13.19'	25.1
CP94003	CA94RR10	FL	Indian R. Lagoon	27°24.30'	80°17.29'	33.70
CP94004	CA94RR11	FL	Indian R. Lagoon	27°32.10'	80°19.80'	33.3
CP94005	CA94RR12	FL	Indian R. Lagoon	27°40.71'	80°23.16'	32.9
CP94006	CA94RR13	FL	Indian R. Lagoon	27°53.83'	80°30.18'	32.6
CP94007	CA94RP14	FL	Indian R. Lagoon	27°55.03'	80°30.41'	Rep.
CP94008	CA94RR14	FL	Indian R. Lagoon	27°59.70'	80°33.15'	36.3
CP94009	CA94RR15	FL	Indian R. Lagoon	28°09.64'	80°37.12'	40.4
CP94010	CA94RR16	FL	Indian R. Lagoon	28°15.40'	80°40.50'	37.7
CP94011	CA94RR17	FL	Indian R. Lagoon	28°30.15'	80°44.86'	37.4
CP94012	CA94RP18	FL	Indian R. Lagoon	28°42.77'	80°47.63'	Rep.
CP94013	CA94RR18	FL	Indian R. Lagoon	28°43.31'	80°48.18'	44.4
CP94014	CA94SR49	FL	Mosquito Lagoon	28°51.11'	80°47.46'	105.8
CP94015	CA94SR47	FL	Guana River	30°02.17'	81°19.90'	5.7
CP94016	CA94SR46	FL	Julington Creek	30°08.02'	81°37.53'	3.1
CP94017	CA94SR45	FL	Trout River	30°23.85'	81°38.72'	6.2
CP94018	CA94SR44	FL	Nassau Sound	30°30.93'	81°26.61'	9.3
CP94019	CA94SR43	GA	St. Marys River	30°42.64'	81°28.22'	12.6
CP94020	CA94SR42	GA	St. Andrews Snd	30°58.90'	81°25.67'	29.8
CP94021	CA94SR41	GA	St. Simons Snd	31°06.39'	81°27.08'	16.3
CP94022	CA94SR40	GA	Doboy Sound	31°23.44'	81°17.58'	41.1
CP94023	CA94SR39	GA	Sapelo Sound	31°32.82'	81°11.39'	27.0
CP94024	CA94SR38	GA	St. Catherines Snd	31°43.29'	81°09.83'	18.9
CP94025	CA94SR37	GA	Ossabaw Sound	31°51.71'	81°02.34'	36.4
CP94026	CA94SR36	GA	Wassaw Sound	31°55.81'	80°58.08'	31.2
CP94027	CA94SR35	SC	Wright River	32°04.18'	80°55.11'	4.6
CP94028	CA94SR22	NC	Lockwoods Folly R.	33°55.81'	78°13.05'	4.6
CP94029	CA94SR21	NC	Topsail Sound	34°22.79'	77°37.09'	9.2
CP94030	CA94SR20	NC	Alligator Bay	34°30.33'	77°24.42'	5.8
CP94031	CA94SR19	NC	Queens Creek	34°40.15'	77°09.09'	3.5
CP94032	CA94SR18	NC	Back Sound	34°41.01'	76°33.39'	50.8
CP94033	CA94SR17	NC	Core Sound	34°46.39'	76°27.19'	222.5
CP94034	CA94RR04	NC	Neuse River	34°58.37'	76°41.77'	144.3
CP94035	CA94SR16	NC	West Bay	35°00.34'	76°24.47'	93.7
CP94036	CA94RR03	NC	Neuse River	35°04.38'	76°33.08'	268.1
CP94037	CA94LR10	NC	Pamlico Sound	35°05.00'	76°11.38'	280.0
CP94038	CA94SR14	NC	Broad Creek	35°05.74'	76°36.00'	7.0
CP94039	CA94LR11	NC	Pamlico Sound	35°07.19'	76°01.68'	280.0

TABLE 2-1. (Continued).

CPO Sta. No.	EMAP Sta. No.	State	Estuary	Latitude	Longitude	Area (km^2)
Base Sites (Continued)						
CP94040	CA94LR12	NC	Pamlico Sound	35º08.41'	76º28.21'	280.0
CP94041	CA94LR13	NC	Pamlico Sound	35º09.05'	76º13.21'	280.0
CP94042	CA94LR14	NC	Pamlico Sound	35º09.60'	75º59.06'	280.0
CP94043	CA94SR13	NC	Jones Bay	35º13.85'	76º33.62'	13.9
CP94044	CA94LR15	NC	Pamlico Bay	35º15.42'	75º45.12'	280.0
CP94045	CA94LR16	NC	Pamlico Sound	35º18.34'	75º34.03'	280.0
CP94046	CA94SR08	NC	West Bluff Bay	35º20.56'	76º10.53'	5.0
CP94047	CA94SR12	NC	South Creek	35º21.27'	76º41.62'	14.9
CP94048	CA94RR01	NC	Pamlico River	35º21.44'	76º28.64'	208.7
CP94049	CA94SR09	NC	Swanquarter Bay	35º22.04'	76º20.49'	20.1
CP94050	CA94LR17	NC	Pamlico Sound	35º22.73'	75º52.56'	280.0
CP94051	CA94RP02	NC	Pamlico River	35º23.77'	76º40.48'	Rep.
CP94052	CA94RR02	NC	Pamlico River	35º23.85'	76º41.54'	150.1
CP94053	CA94SR11	NC	Bath Creek	35º27.45'	76º49.03'	4.2
CP94054	CA94SR10	NC	Slade Creek	35º28.54'	76º32.32'	5.8
CP94055	CA94LR18	NC	Pamlico Sound	35º32.46'	75º42.96'	280.0
CP94056	CA94LR19	NC	Pamlico Sound	35º33.45'	75º34.75'	280.0
CP94057	CA94SR07	NC	Long Shoal River	35º34.78'	75º51.00'	21.4
CP94058	CA94LR20	NC	Pamlico Sound	35º39.40'	75º36.14'	280.0
CP94059	CA94LR21	NC	Pamlico Sound	35º43.10'	75º33.82'	280.0
CP94060	CA94SR06	NC	Croatan Sound	35º51.43'	75º40.07'	88.0
CP94061	CA94SR05	NC	Bull Bay	35º57.67'	76º21.12'	38.7
CP94062	CA94LR05	NC	Albemarle Sound	35º59.46'	76º31.35'	280.0
CP94063	CA94LR06	NC	Albemarle Sound	36º00.36'	76º32.15'	280.0
CP94064	CA94LR07	NC	Albemarle Sound	36º01.19'	75º55.57'	280.0
CP94065	CA94SR04	NC	Edenton Bay	36º02.72'	76º37.14'	10.2
CP94066	CA94LR08	NC	Albemarle Sound	36º03.15'	76º18.53'	280.0
CP94067	CA94SR03	NC	Yeopim River	36º05.01'	76º27.33'	8.5
CP94068	CA94LR01	NC	Currituck Sound	36º05.90'	75º46.78'	280.0
CP94069	CA94LR09	NC	Albemarle Sound	36º07.29'	75º56.31'	280.0
CP94070	CA94LR02	NC	Currituck Sound	36º08.68'	75º44.86'	280.0
CP94071	CA94LR03	NC	Currituck Sound	36º23.15'	75º51.30'	280.0
CP94072	CA94SR02	NC	Northwest River	36º30.86'	76º02.46'	8.8
CP94073	CA94SR34	SC	Calibogue Sound	32º10.22'	80º47.74'	27.7
CP94074	CA94SR32	SC	Trenchards Inlet	32º16.78'	80º35.60'	11.9
CP94075	CA94SR33	SC	Chechessee River	32º17.11'	80º44.94'	28.3
CP94076	CA94SR30	SC	St Pierre Creek	32º32.36'	80º20.98'	3.5
CP94077	CA94SR31	SC	Combahee River	32º33.55'	80º32.83'	17.4
CP94078	CA94SR29	SC	Bohicket Creek	32º36.86'	80º09.98'	6.9
CP94079	CA94SR27	SC	Charleston Harbor	32º45.87'	79º53.20'	25.9

TABLE 2-1. (Continued).

CPO Sta. No.	EMAP Sta. No.	State	Estuary	Latitude	Longitude	Area (km^2)
Base Sites (Continued)						
CP94080	CA94SR26	SC	Dewees Creek	32º49.68'	79º44.32'	20.5
CP94081	CA94SR25	SC	Bulls Bay	32º59.58'	79º33.56'	70.6
CP94082	CA94SR24	SC	Sampit River	33º21.51'	79º17.51'	5.8
CP94083	CA94SR23	SC	Little River	33º51.30'	78º33.92'	4.4
CP94084	CA94SR01	VA	Indian River	36º43.43'	76º11.26'	10.8
Supplemental Sites						
CP94JAC	NA	FL	Jacksonville	30º22.97'	81º26.99'	NA
CP94CF_	NA	NC	Cape Fear River	35º07.45'	77º55.64'	NA
CP94ES4	NA	NC	Currituck Banks	36º23.59'	75º50.94'	NA
CP94MI_	NA	NC	Masonboro Island	34º09.32'	77º50.97'	NA
CP94RC_	NA	NC	Rachel Carson	34º42.19'	76º37.27'	NA
CP94ZI_	NA	NC	Zeke's Island	33º57.18'	77º56.27'	NA
CP94DSL	NA	SC	Diesel Creek	32º48.95'	79º57.75'	NA
CP94KOP	NA	SC	Kopper's Site	32º49.12'	79º57.83'	NA
CP94LTH	NA	SC	Lighthouse Creek	32º42.15'	79º55.22'	NA
CP94NMK	NA	SC	Newmarket Creek	32º48.41'	79º56.11'	NA
CP94NOI	NA	SC	Noisette Creek	32º52.33'	79º58.28'	NA
CP94PLM	NA	SC	Plum Island	32º45.78'	79º56.86'	NA
CP94SPY	NA	SC	Shipyard Creek	32º50.37'	79º56.67'	NA
Surface Area Totals (km^2)						
Large Estuaries:			5581.1			
Large Tidal Rivers:			1134.0			
Small Estuaries (all yrs.):			4907.0			
Small Estuaries (1994):			1243.4			
Total Carolinian Province:			11,622.1			

TABLE 2-2. Estuarine resources of the Carolinian Province.

	Province	Large [a]	Small [b]	Tidal [c]
Number of Estuaries	200	3	194	3
Area Represented (km^2)	11,622.1	5,581.1	4,907	1,134
Number of Stations Sampled (1994)	84	20	47	17

[a] Large Estuaries = Area > 260 km^2 and length/width aspect ratio < 20

[b] Small Estuaries = Area 2.6 – 260 km^2

[c] Large Tidal Rivers = Area > 260 km^2 and length/width > 20

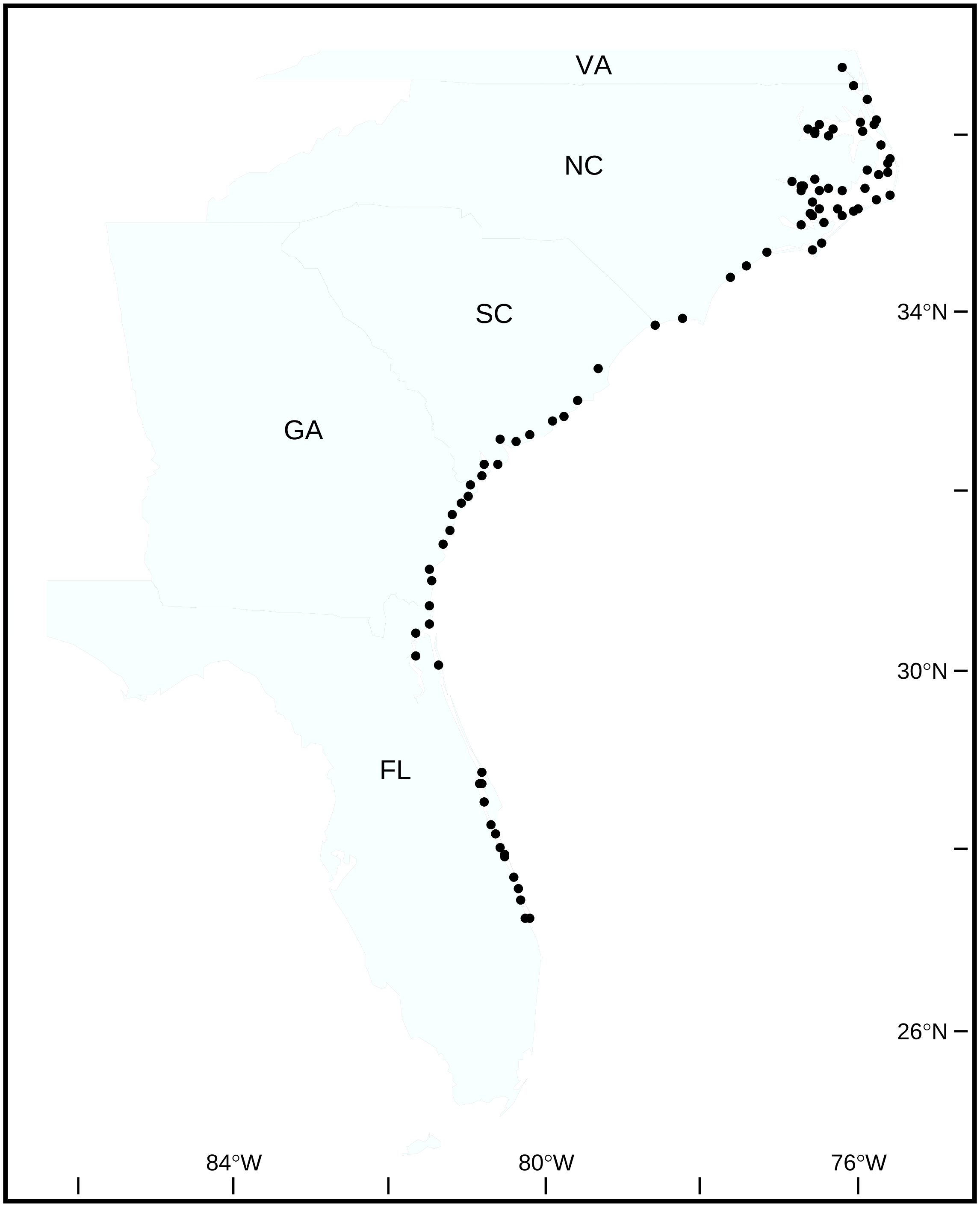


FIGURE 2-1. 1994 Carolinian Province sampling sites.

(1) such attributes usually show minimal change over extended periods; (2) alternative classification variables such as salinity, sediment type, depth, and extent of pollutant loadings would result in the definition of classes for which areal extents could vary widely from year to year; (3) data for physically based classes can be aggregated into geographic units that are meaningful from a regulatory or general-interest perspective; and (4) estuarine boundaries can be delineated more readily and accurately from maps or charts of the physical dimensions of coastal areas than from maps of sediment or water-column characteristics.

Base sites in large estuaries were selected using a stratified random sampling design, with double randomization, similar to the approach used in the EMAP Louisianian Province (Summers et al. 1993b, Rathbun 1994). A triangular lattice was placed over the study region and the resulting grid shifted randomly thus producing the first randomization. A tessellation of the grid cells was performed next to partition the province into a series of contiguous hexagonal quadrats each with a surface area of 280 km^2. A station was then selected randomly from each of the hexagons coinciding with large estuaries, thus producing the second randomization. As a result of this process, 20 stations were established in large estuaries in 1994: 12 in Pamlico Sound, five in Albemarle Sound, and three in Currituck Sound (Table 2-1).

Under this design, a new station location is to be selected randomly within each large estuary hexagon for each of the following three years. Stations sampled in any given year also are intended to be resampled every four years thereafter to facilitate unbiased estimates of temporal trends. Unbiased design-based estimates of the variances of environmental parameters can be computed without having to resample a subset of the same sites every year, due to the double randomization of both the position of hexagons and location of sites within hexagons (Rathbun 1994).

Base sites in large tidal rivers were selected using a stratified random sampling design in which the strata were represented by a series of river segments. This “spine and rib” approach, similar to the one used in the EMAP Louisianian Province (Summers et al. 1993b), is basically the linear analog of the sampling grid for large estuaries. Segments of equal length (25 km) were established within the tidally influenced estuarine portions of the rivers (river mouths inland to salinities of ~ 0.5 ‰). Because the Indian River (a bar-built estuary with several inlets along its axis) is tidally influenced throughout its length, ten segments were established along this 250-km large tidal river. For the Neuse and Pamlico Rivers, two segments were established between the mouth of each river and the inland boundary of saltwater influence. A minimum of one sampling station was then selected randomly within each segment of each river. In 1994, three river segments (one in the Pamlico River and two in the Indian River) were also replicated to provide estimates of within-segment spatial variability. As a result of this process, 17 stations were established in large tidal rivers in 1994: 12 in the Indian River, three in the Pamlico River, and two in the Neuse River (Table 2-1).

Under this design, a new station location is to be selected randomly within each river segment during each of the subsequent three years. As with the design for large estuaries, the above pattern of sampling should then be repeated every four years to facilitate unbiased estimates of temporal trends. In addition, unlike the design for large estuaries, a subset of the large tidal river stations is to be resampled annually to provide unbiased design-based estimates of the variances of environmental parameters.

A stratified random sampling design with double randomization was used to select base sites within small estuaries. Under this design, a list frame of all 194 small estuaries was constructed with the individual estuaries ordered from north to south. The first randomization was obtained by selecting a random starting point among the estuaries. Beginning with that point, the estuaries were partitioned into spatial strata each composed of four neighboring small estuaries. This process continued until all estuaries on the list frame were partitioned. One estuary was then chosen at random from each group of four, thus producing the second randomization. Based on this process, 47 small estuaries, each represented by a single randomly selected sampling site, were chosen for the summer 1994 sampling effort (Table 2-1).

In each of the subsequent three years, a new small estuary is to be chosen at random from the remaining unsampled estuaries comprising each group of four. As with the designs for the other two estuarine classes, the same stations in any given year also are intended to be resampled every four years to facilitate unbiased estimates of temporal trends. This sampling design for small estuaries is similar to the one used in the EMAP Louisianian Province, except that in the latter case the starting position for grouping estuaries was not randomized. The double randomization incorporated into the design for the Carolinian Province makes it possible to produce unbiased estimates of the variances of environmental parameters without having to resample a subset of the sites annually.

The data discussed in this report are based on samples collected June 30 – August 31, 1994. This time-frame was selected to coincide as much as possible with the index sampling period used in other EMAP-E provinces (typically between July 1 and September 30) and within which estuarine responses to potential anthropogenic and natural stresses are presumed to be the most pronounced.

2.2 Environmental Indicators

A standard series of environmental parameters was measured at each of the base stations to provide a consistent set of synoptic data for making province-wide estimates of estuarine condition. These “core” environmental indicators included measures of general habitat conditions, pollutant exposure, biotic integrity, and aesthetic quality (Table 2-3). Habitat indicators describe the physical and chemical conditions of sample sites, and provide basic information about the overall environmental setting. Exposure indicators provide measures of the types and amounts of pollutants, or other adverse conditions, that could be harmful to resident biota or human health. Biotic condition indicators provide measures of the status of biological resources in response to the surrounding environmental conditions. Aesthetic indicators provide additional measures of environmental quality from a human perceptual perspective. There is a fair amount of overlap among these various indicator categories. For example, some aesthetic indicators (presence of oil sheens, noxious sediment odors, and highly turbid waters) could also reflect adverse exposure conditions. Another example is dissolved oxygen (DO), listed as an exposure indicator because of the potential adverse biological effects of low oxygen concentrations, but which also is clearly a measure of general habitat conditions. These various core environmental parameters included ones used in other EMAP-E provinces (Strobel et al. 1994, Summers et al. 1993b) to support regional comparisons and to provide a means for producing combined nationwide estimates of estuarine condition.

In addition to making the standard EMAP-E measurements, an emphasis was placed on developing and validating other complementary methods to aid in evaluating the quality of southeastern estuaries. Such indicators that are under development in the Carolinian Province are listed in Table 2-4. They include sediment bioassays with alternative test species, such as the amphipod *Ampelisca verrilli* as an alternative to *A. abdita* in standard 10-day solid-phase toxicity tests; assays with additional sublethal biological endpoints, such as effects on feeding, growth and fertilization success in key estuarine organisms; additional indices of environmental quality for tidal marshes and estuarine fish assemblages; and the incorporation of additional exposure

TABLE 2-3. Core environmental indicators for the Carolinian Province.

Habitat Indicators

- Water depth
- Water temperature
- Salinity
- Density stratification of water column
- Dissolved oxygen concentrations
- pH
- Percent silt-clay content of sediments
- Percent Total Organic Carbon (TOC) in sediments
- Sediment acid-volatile sulfides (Yr 2 only)

Exposure Indicators

- Low dissolved oxygen conditions
- Sediment contaminants (16 inorganic metals, 4 butyltins, 28 aliphatic hydrocarbons, 45 polynuclear aromatic hydrocarbons, 21 polycyclic chlorinated biphenyls, 24 pesticides)
- Contaminants in fishes and invertebrates (Yr 2 only)
- Sediment toxicity (*Ampelisca abdita* solid-phase, acute-toxicity test, Microtox® solid-phase, sublethal toxicity test)

Biotic Condition Indicators

- Infaunal species composition
- Infaunal species richness and diversity
- Infaunal abundance
- Demersal species composition (fishes and invertebrates)
- Number of demersal species
- Demersal species abundance
- Demersal species lengths
- External pathological abnormalities in demersal biota
- Benthic infaunal index

Aesthetic Indicators

- Water clarity (secchi depths)
- Anthropogenic debris (sea surface and in trawls)
- Noxious sediment odors (sulfides, petroleum)
- Oil sheens (sea surface and bottom sediments)

TABLE 2-4. Environmental indicators under development in the Carolinian Province.

Biotic Condition Indicators

- Benthic index of environmental quality for tidal marshes (incorporating attributes that reflect responses to pollutant stress independent of natural variations in salinity and elevation)
- Index of environmental quality based on changes in fish parasite assemblages

Exposure Indicators

- 10-day acute-toxicity sediment bioassay with alternative amphipod species, *Ampelisca verrilli*
- 1-week sublethal bioassay for testing effects of sediment exposure on growth of juvenile clams *Mercenaria mercenaria*
- 96-hour sublethal bioassay for testing effects of sediment exposure on feeding rates of *Ampelisca verrilli*
- 1-hour sublethal bioassay using gametes of oysters *Crassostrea virginica* and clams *Mercenaria mercenaria* for testing effects of sediment exposure on fertilization success
- Sediment porewater ammonia and hydrogen sulfide concentrations

indicators, such as porewater ammonia and hydrogen sulfide concentrations, to help in the interpretation of sediment toxicity results. Most of these indicators are being developed with samples collected from nonrandom supplemental sites (see Table 2-1). While some of the data from these "developmental" indicators (e.g., porewater ammonia data) are used in the present report to help in interpreting conditions at base sites, discussions of their sensitivity and overall utility as monitoring tools will be presented in subsequent publications.

2.3 Procedures for Measuring Indicators

2.3.1 Habitat Indicators

2.3.1.1 Water Quality Parameters

Salinity (‰), pH, temperature (°C), dissolved oxygen (DO, mg/L), and water depth (m) were recorded electronically with a "Datasonde 3" (DS3) multiprobe data logger manufactured by

Hydrolab Corporation. Both instantaneous and continuous records were made of these variables at each of the base stations. The instantaneous measurements were taken along surface-to-bottom depth profiles, at 1-m intervals for water depths >3 m, and at 0.5-m intervals for depths <3 m. Data were recorded on downcasts and upcasts. The continuous measurements were made from a single near-bottom depth at 30-min intervals over a minimum 24-h period. To make these latter measurements, the DS3 unit was placed inside a protective PVC sleeve, outfitted with a pinger, and deployed using either a mooring in the case of deep sites (>3 m), or a stationary pole for shallower sites (<3 m). Bottom depth also was recorded at each station with the boat's fathometer.

Quality control procedures for water quality measurements included pre-deployment calibration of the Datasonde sensors against standards, and pre- and post-deployment precision checks based on side-by-side comparisons with other calibrated instruments. Maximum acceptable differences for these various quality control steps are summarized in Table 2-5. Range checks also were performed on all downloaded data to identify unacceptable or suspect values (outside expected environmental ranges). Range-check guidelines that were used are summarized by variable in Table 2-6.

2.3.1.2 Sediment Characteristics

Percent water content of sediments, percent silt-clay, and percent total organic carbon (TOC) were measured at each station from subsamples of composited surface sediment (upper 2 cm) collected with a 0.04-m^2 Young grab sampler. Subsamples for these sediment characteristics were obtained from the same composite source used for the analysis of contaminants and toxicity testing (see next section). Multiple grabs (~ 8–10) were taken at each station to produce enough composited surface sediment (~ 4–4.5 L) to support all of the various kinds of sediment analyses (including toxicity testing and contaminant analysis). A 300 mL subsample of the composite was obtained for the analysis of percent water and percent silt-clay, and a 50-mL subsample was obtained for the analysis of percent TOC.

TABLE 2-5. Quality control tolerance ranges for Datasonde instrument calibrations and field measurements.

Frequency of Check	Parameter	Checked Against	Max. Acceptable Difference
Pre-survey Calibration	Temperature	Thermometer	± 1 °C
	Salinity	Standard seawater	± 0.2 ‰
	DO	Manufacturer's setting	± 0.3 mg/L
	% Sat. DO	Manufacturer's setting	± 2.5 % (100 – 105% range)
	pH	pH buffer solution	± 0.1 pH units
Pre-Deployment Field Comparison	Temperature	Deployed vs. Back-up Datasondes	± 1 °C
	Salinity	Deployed vs. Back-up Datasondes	± 1 ‰
	DO	Deployed vs. Back-up Datasondes	± 0.3 mg/L
	pH	Deployed vs. Back-up Datasondes	± 0.3 pH units
Post-Deployment Field Comparison	Temperature	Deployed vs. Back-up Datasondes	± 1 °C
	Salinity	Deployed vs. Back-up Datasondes	± 1 ‰
	DO	Deployed vs. Back-up Datasondes	± 0.5 mg/L
	pH	Deployed vs. Back-up Datasondes	± 0.5 pH units

TABLE 2-6. Range-check guidelines for water quality variables.

Variable	Range
Temperature (°C)	19.0 – 33.0
Salinity (‰)	0.5 – 36.0
pH	5.0 – 9.0
Dissolved oxygen (mg/L)	0.3 – 12.0
Depth (m)	0.2 – 15.0

Procedures for analyzing sediment characteristics were based on the general protocols provided in the EMAP-E Laboratory Methods Manual (USEPA 1993, 1994a). Percent water was calculated as a loss in the weight of the sample after drying (60 °C) and correcting for salt content. For percent silt-clay, sediment samples were first dispersed with sodium hexametaphosphate and then sieved through a 63-μ screen. Coarser sediments retained on the screen were dried (60 °C) and weighed. A 40-mL subsample of the filtrate also was dried (60 °C) and used to estimate the percent silt-clay relative to the total sample weight. Approximately 10% of each batch of samples analyzed by the same technician were re-analyzed as a quality control check for the analysis of percent water and percent silt-clay. Measurement differences could not exceed 10%.

Measurements of TOC were obtained from ~ 5–10 mg samples of dried sediment that were acidified (with 1M H_3PO_4) to remove carbonates, sonicated, and filtered. Filters containing the sediment were dried and combusted (Salonen 1979) on either a CHN or elemental analyzer to determine TOC concentration (expressed as percent TOC per gram of dried sediment). Portions of the TOC samples, one for each batch of 25 or fewer samples, were run in duplicate as tests of analytical precision. Measurement differences could not exceed 20%. Quality control procedures for TOC also included the analysis of acetanalide standards and certified reference sediments (e.g., BCSS-1 marine sediment from NRC).

2.3.2 Exposure Indicators

2.3.2.1 Dissolved Oxygen

Dissolved oxygen (DO) was measured at each of the base sites with Hydrolab DS3 data loggers as described above in Section 2.3.1. Data from both instantaneous depth profiles and continuous near-bottom records were obtained at each station where possible.

2.3.2.2 Sediment Contaminants

Organic and metal contaminants were measured in subsamples of composited surface sediment (upper 2 cm) from multiple benthic grabs collected at each of the base sites and selected supplemental sites. These subsamples were taken from the same sediment composite used for toxicity testing and the analysis of other physical/chemical characteristics (see Section 2.3.1.2). At each station, ~ 300 mL of the composited sediment were collected each for the analysis of organics and metals. Stations were represented usually by unreplicated samples, with the exception of duplicates that were run at ~ 10% of the stations as part of the quality control program (see below). All contaminant analyses were performed at Texas A&M University.

A total of 16 inorganic metals, 4 butyltins, 28 aliphatic hydrocarbons, 45 polynuclear aromatic hydrocarbons (PAHs), 21 polycyclic chlorinated biphenyls (PCBs), and 24 pesticides were measured at each of the stations. Table 2-7 summarizes the measurement units, detection limits, analytical methods, and protocol references for each of these analyte groups.

Quality control procedures for the analysis of sediment contaminants consisted of: (1) participation in a series of intercalibration exercises (minimum of two intercalibrations per year for metals and three intercalibrations per year for organics); (2) continuous checks on analytical precision and accuracy from the analysis of Standard Reference Materials (SRMs) with each batch of samples; (3) initial and ongoing

TABLE 2-7. Summary of analytical methods for the analysis of contaminants in sediments.

Analyte	Units (dry wgt.)	Min. Detection Limits [a]	Method [b]	Reference
Si	µg/g	10,000	FAA	Taylor and Presley 1993
Al	µg/g	1500	FAA	Taylor and Presley 1993
Fe	µg/g	500	INAA	Taylor and Presley 1993
Cr	µg/g	5.0	INAA	Taylor and Presley 1993
Zn	µg/g	2.0	FAA	Taylor and Presley 1993
Mn	µg/g	1.0	FAA	Taylor and Presley 1993
Cu	µg/g	5.0	GFAA	Taylor and Presley 1993
As	µg/g	1.5	INAA	Taylor and Presley 1993
Ni	µg/g	1.0	GFAA	Taylor and Presley 1993
Pb	µg/g	1.0	GFAA	Taylor and Presley 1993
Sb	µg/g	0.2	INAA	Taylor and Presley 1993
Se	µg/g	0.1	INAA	Taylor and Presley 1993
Sn	µg/g	0.1	GFAA	Taylor and Presley 1993
Cd	µg/g	0.05	GFAA	Taylor and Presley 1993
Ag	µg/g	0.01	GFAA	Taylor and Presley 1993
Hg	µg/g	0.01	CVAA	Taylor and Presley 1993
Butyltins (mono-, di-, tri-, tetra-)	ng Sn/g	1.0	GC/FPD	Wade et al. 1990
PAHs (44 parent compounds & alkylated homologues, Tot. PAHs)	ng/g	5.0	GC/MS-SIM	Wade et al. 1993
Aliphatics (C10–C34 alkanes, Tot. Alk., pristane, phytane)	ng/g	25	GC/FID	Wade et al. 1994
Pesticides [DDD (2,4′& 4, 4′), DDE (2,4′ & 4,4′), DDT(2,4′ & 4,4′), Total DDD/DDE/DDT, aldrin, chlordane (alpha-, gamma-, oxy-), dieldrin, heptachlor, heptachlor epoxide, hexachlorobenzene, BHC (alpha-, beta-, gamma-, delta-), mirex, trans- & cis-nonachlor, endrin, endosulfan, toxaphene]	ng/g	0.1	GC/ECD	Wade et al. 1993
PCBs (Congener Nos. 8, 18, 28, 44, 52, 66, 77/110, 101, 105, 188/108/149, 126, 128, 138, 153, 170, 180, 187/182/159, 195, 206, 209, Tot. PCB s)	ng/g	0.1	GC/ECD	Wade et al. 1993

[a] Based on sample size of 0.2 g for metals and 15 g for organics.

[b] GC/ECD = Gas Chromatography/Electron Capture Detection; GC/MS-SIM = GC/Mass Spectroscopy - Selective Ion Monitoring Mode; GC/FID = GC/Flame Ionization Detection; FAA = Flame Atomic Absorption; GC/FPD = GC/Flame Photo Detection; INAA = Instrumental Neutron Activation Analysis.

instrument calibration checks (ongoing checks performed minimally at the middle and end of each sample batch); (4) analysis of laboratory reagent blanks (one with each sample batch); (5) analysis of laboratory fortified sample matrix spikes and laboratory fortified sample matrix duplicates; (6) analysis of sample duplicates in ~ 10% of the samples (9 field sediment duplicates, 5 lab duplicates from splits of 5 of the 9 field duplicates); and (7) analysis of internal surrogate and injection standards with each sample. With respect to the analysis of SRMs, if analytical results deviated by more than ± 20% from the certified values for metals, or by more than ± 30% for the organics in the SRM, then a re-analysis of those samples was required. These procedures are consistent with the general quality control requirements of both EMAP-E (Heitmuller and Valente 1993, see Table 5-4 therein) and the NOAA National Status and Trends Program (Lauenstein and Cantillo 1993).

2.3.2.3 Amphipod Toxicity

The 10-day, solid-phase toxicity test with the marine amphipod *Ampelisca abdita* was one of two standard assays used to evaluate potential toxicity of sediments from base sites and selected supplemental sites. Procedures followed the general guidelines provided in ASTM Protocol E1367-90 (ASTM 1991) and the EMAP-E Laboratory Methods Manual (USEPA 1994a). This is an acute toxicity test which measures the effect of sediment exposure on amphipod survival under static conditions. Approximately 3–3.5 L of surface sediments (composite of upper 2 cm from multiple grabs) were collected from the sampling sites and stored in 3.7-L polyethylene jars at 4 °C in the dark until testing. Tests were conducted with subsamples of the same sediment on which the analysis of contaminants and other sediment characteristics was performed. All sediment samples were tested within 30 days of collection as recommended in the EMAP-E protocol.

Amphipods were collected from tidal flats in the Pettaquamscutt River, Rhode Island, and transported to the laboratory (SAIC in Narragansett, RI or SCDNR/MRRI in Charleston, S.C.) where they were acclimated for 2–6 days prior to testing. During the acclimation period, the amphipods were fed the diatom *Phaeodactylum tricornutum*. Healthy juvenile amphipods of approximately the same size (0.5–1.0 mm) were used to initiate tests.

The general health of each batch of amphipods was evaluated in a reference toxicity test (i.e., “positive control”). These tests were run for 96 h in a dilution series with seawater (no sediment phase) and the reference toxicant sodium dodecyl sulfate (SDS). LC_{50} values were computed for comparison with other reported toxicity ranges for this same reference toxicant and test species. The animals were not used in definitive tests with field samples unless acceptable reference toxicant results were obtained. Mean LC_{50} values ranged from 5.16–11.22 mg/L for tests run by SAIC and from 3.71–6.82 mg/L for SCDNR/MRRI.

Treatments for the definitive tests with field samples consisted of a single concentration of each sediment sample (100% sediment) and a negative control [i.e., sediment from the Control Long Island Sound (CLIS) reference station for the U.S. Army Corps of Engineers, New England Division]. A negative control was run with each batch of field samples (which ranged from 5–20 samples per batch). The tests were conducted under static conditions at a temperature of 20 ± 1 °C and salinity range of 25–35 ‰ (25–32 ‰ for SAIC, and 30–35 ‰ for SCDNR/MRRI). Twenty amphipods were randomly distributed to each of five replicates per each treatment including the control. Amphipods were not fed during the tests.

The negative controls provided a basis of comparison for determining statistical differences in survival in the field sediments. In addition, control survival provided a measure of the acceptability of final test results. Test results were considered valid if mean control survival (among the 5 replicates) was ≥85% and survival in any single control chamber was ≥80%. Mean control survival ranged from 87–98% throughout the various tests.

One-liter glass containers with covers were used as test chambers. Each chamber was filled with 200 mL of sediment and 600–800 mL of filtered seawater. The sediment was press-sieved, through either a 1.0-mm screen for control samples or a 2.0-mm screen for field samples, to remove ambient fauna prior to placing it in a chamber. Light was held constant during the 10-day test to inhibit amphipod emergence from the sediment, thus maximizing exposure to the test sediment. Air was supplied using oil-free pumps and glass pipettes inserted into the test chambers. Water tables with recirculating chiller pumps were used to maintain constant temperatures (20 ± 1 °C). Daily recordings were made of temperature and the number of dead vs. living animals. On two separate days, near the beginning and end of the 10-day exposure, two of the five replicate chambers for each treatment were selected randomly and measured for salinity, dissolved oxygen, pH, and total ammonia in the overlying water.

At the conclusion of a test, the sediment from each chamber was sieved through a 0.5-mm screen to remove amphipods. The number of animals dead, alive, or missing was recorded. Sediments with >10% missing animals were re-examined under a dissecting microscope to ensure that no living specimens had been missed. Amphipods still unaccounted for were considered to have died and decomposed in the sediment.

Differences between survival of amphipods in field versus control samples were evaluated, in most cases, by *t*-tests run on untransformed percentage data. In some cases, where the data did not meet assumptions of normality or equality of variances, a Mann-Whitney *U* test was used. Samples were considered to be significantly toxic if mean survival in comparison to the control was ≤80% and statistically different at $\alpha \leq 0.05$.

A variety of quality control procedures were incorporated to assure acceptability of amphipod test results and comparability of the data with other studies. As described above, these provisions included the use of standard ASTM and EMAP protocols, positive controls run with a reference toxicant, negative “performance” controls run with reference sediment from the amphipod collection site, and routine monitoring of water quality variables to identify any departures from optimum tolerance ranges. In addition, an inter-laboratory comparison of results using the *A. abdita* assay was performed by the two participating testing facilities (SAIC and SCDNR/MRRI). Samples from two of the base sites were tested by each facility. Results were highly comparable: mean survival in field samples relative to controls was 96% for both samples by one lab, and 98–100% by the other lab.

2.3.2.4 Microtox® Toxicity

A second bioassay used to measure potential sediment toxicity at all base sites (and selected supplemental sites) was the Microtox® solid-phase test with the photoluminescent bacterium *Vibrio fischeri* (formerly *Photobacterium phosphoreum*). This assay provides a sublethal measure of toxicity based on attenuation of light production by the bacterial cells due to exposure to the sediment sample (Bulich 1979, Ross et al. 1991, Microbics 1992 a and b). Microtox® has not been used in other EMAP-E provinces, but its recent application in other coastal assessment programs suggested that it might be a useful tool to consider for the Carolinian Province. Small sample sizes (a 100 mL subsample of the composited surface sediment from each station) and a short processing time (20-min exposures) provide clear logistical advantages. Results of the Carolinian Province Pilot Study (Ringwood et al. 1995a) also suggested that this test was more powerful in its ability to discriminate between degraded and reference sites than the amphipod toxicity test.

Tests were conducted following the general protocol provided by Microbics Corporation (1992a, b) in addition to data-interpretation guidelines developed by Dr. Philippe Ross of the Citadel, South Carolina (see Appendix B of the Carolinian Province Demonstration Plan, Hyland et al. 1994). All tests were conducted in duplicate within the recommended 10-day holding period. A 0.3 g aliquot of sediment was used to make a dilution series ranging from 0.01–10% sediment in a 2% saline diluent. A reagent solution containing the bacteria was then added to each sediment suspension. After a 20-min incubation period, a column filter was used to separate the liquid phase and bacterial cells from the sediment. Post-exposure light output in each of the filtrates was measured on a Microtox® Model 500 Analyzer. A log-linear regression model was used to determine an EC_{50} — the sediment concentration that reduced light production by 50% relative to a control (nontoxic reagent blank). EC_{50} values were corrected for percent water content and reported as dry-weight concentrations.

Assays were run with the reference toxicant phenol with each new batch of bacteria. These tests provided measures of the general quality of the bacterial populations, as well as the ability of the laboratory to produce results consistent with the expected phenol toxicity range (Microtox® EC_{50} values typically between 13–26 mg/L). Use of the standard Microtox® equipment and protocol helped to assure data comparability with results of other Microtox® studies.

2.3.2.5 Porewater Ammonia

Concentrations of ammonia in porewater were measured from each of the sediment samples used in the amphipod toxicity tests. Prior to initiating a test, a porewater sample was extracted from the sediment sample either by centrifuging or using a vacuum extraction method described by Winger and Lasier (1991). Total ammonia concentrations were determined spectrophotometrically using the salicylate method described by Bower and Holm-Hansen (1980). Unionized ammonia, the form usually considered the most toxic to aquatic fauna (USEPA 1989), was calculated based on the total ammonia concentration and the corresponding salinity, pH, and temperature of the sample (Whitfield 1978, Hampton 1977). Porewater ammonia concentrations were used to help interpret sediment toxicity results.

2.3.3 Biotic Condition Indicators

2.3.3.1 Benthic Infaunal Indicators

Four replicate bottom grabs were collected from each station with a 0.04-m^2 Young grab sampler. Care was taken to avoid grabs that were partially filled, slumped or canted to one side, clogged with excessive amounts of shelly substrates, or overfilled to the point that sediment was being pushed through the top of the grab. Contents of the grabs were live-sieved in the field with a 0.5-mm mesh screen. Material retained on the screen was placed in plastic containers, fixed in 10% buffered formalin with rose bengal (to facilitate subsequent sorting), and transferred to the laboratory for further processing. Samples from Virginia and North Carolina sites were processed by the University of North Carolina-Wilmington, samples from South Carolina and Georgia sites were processed by SCDNR/MRRI, and samples from Florida sites were processed by FDEP/FMRI. Further details on infaunal sampling procedures are provided in the Carolinian Province Field Operations Manual (Kokkinakis et al. 1994).

Once samples were received in the laboratory, they were transferred from formalin to 70% alcohol. Two of the four samples from each station were further processed to characterize the infaunal assemblages and the remaining two samples were archived (for possible future analysis). Samples were processed based on currently accepted practices in benthic ecology (e.g., Holme and McIntyre 1971) and on specific protocols described in the EMAP-E Lab Methods Manual (USEPA 1994a). Animals were sorted from sample debris under a dissecting microscope. Sorted specimens were identified to the lowest possible taxon, i.e. the species level wherever possible. As species were identified, and the number of individuals per each species recorded, they were placed back in 70% alcohol and archived permanently by species. The data were used to compute numbers of species and individuals; the Shannon information function, H′ (Shannon and Weaver 1949); densities of dominant species; and percent abundance of key taxonomic or other functional groups (e.g., % pollution tolerant vs. sensitive species). Base 2 logarithms were used to calculate H′.

Several steps were taken to assure data quality and comparability. Each technician responsible for sorting samples needed to demonstrate initial proficiency by removing ≥95% of the animals in each of five consecutive samples. Tests of ongoing sorting proficiency were performed by resorting 10% of the samples and checking to see that ≥95% of the animals in each sample had been removed by the original sorter. Species identifications were performed by skilled taxonomists using standard taxonomic keys and reference collections. To catch potential misidentifications, a minimum of 10% of the samples was checked by independent qualified taxonomists. Data corrections were incorporated as necessary. Lastly, species lists from the three participating taxonomy laboratories were carefully cross-checked in the process of merging the information into a common province-wide benthic data base.

2.3.3.2 Benthic Infaunal Index

The health of benthic communities has been characterized traditionally by individual measures of abundance, biomass, diversity, and the relative abundances of key species or functional groups. These variables have been used in numerous studies to document biological responses to contaminant exposure, organic over-enrichment, hypoxia events, and various other habitat changes. Prior EMAP-E monitoring efforts have demonstrated that combining multiple benthic attributes into a single index can provide an additional powerful tool for distinguishing between environmentally degraded and undegraded areas (Weisberg et al. 1992; Summers et al. 1993a, b). The EMAP-E index, in summary, is a combined discriminant score derived from a linear combination of variables that maximizes the ability to separate degraded from undegraded sites based on the multivariate techniques of stepwise and canonical discriminant analysis.

A similar benthic index is being developed with the Carolinian Province data. However, results are not yet available due to additional analyses required to partition out the combined influences of several natural abiotic factors (salinity, silt-clay, TOC, and latitude) that have been found to have strong associations with the various infaunal variables. Different ways of treating the data to minimize the sensitivity of the index to such sources of variation are being examined. Options being considered include the derivation of separate benthic indices for different environmental regimes. Once the best methods for partitioning out these sources of variability have been identified and applied, construction of the index will proceed following the discriminant analysis approach of EMAP-E or an appropriate alternative. Results will be presented in the next annual statistical summary (for the 1995 index period) and other relevant publications.

2.3.3.3 Demersal Species Indicators

Fishes and invertebrates (mostly squid, shrimp, and crabs) were collected at each station with a 4.9-m otter trawl (2.5 cm mesh wings and cod end) towed against the tidal currents. Tow duration was 10 min wherever possible and tow speed was 2–3 kts. Two tows were conducted at each station. Fishes and invertebrates captured in the trawls were carefully removed, sorted and identified to the lowest possible taxon (usually to species), enumerated, measured for length to the nearest mm, and examined for the presence of external pathological disorders. In cases where a species was caught in excessive numbers, a minimum subsample of 30 individuals was measured for length. Specimens were examined for the following types of pathological disorders: lumps due to internal growths, external growths or tumors, ulcers, fin erosion, shell disease in blue crabs, and cotton disease in shrimp. Specimens with pathologies were preserved in the field (Dietrich's solution for fishes and freezing for crustaceans) and transferred to independent specialists for confirmation (fishes: Dr. J. Fournie, EPA-Gulf Breeze, FL; crustaceans: Dr. E. Noga, NC State University).

Several quality control measures were incorporated. To help assure that the biota were identified accurately, all field crews had at least one member on board familiar with the species that were likely to be caught in bottom trawls. In addition, species identifications were validated in the laboratory by examination of voucher specimens collected for each species encountered in the field. The quality of pathology data was checked as well. Subsamples of apparently non-diseased animals (~ 10 individuals of each of 5 target species at 10% of the stations) also were collected and examined by the pathology specialists to evaluate the potential error rate of the field crews with respect to missing abnormalities that may have been present (i.e., false negatives). Database entries for all trawl measurements were checked against the original field-recorded measurements (field sheets) and any inconsistencies were corrected.

2.3.4 Aesthetic Indicators

Four additional indicators provided measures of environmental quality important from a human aesthetic perspective. These indicators were presence of marine anthropogenic debris (observed either on the sea surface or in bottom trawls), presence of oil (observed either on the sea surface or in bottom sediments), noxious sediment odors (smell of sulfur, oil, or sewage in bottom sediments), and water clarity. A secchi disk was used to measure water clarity.

2.4 QA / QC

As described in the above sections on methods, a variety of quality control measures were incorporated to assure data reliability and comparability. Such provisions included rigorous staff training, the use of standard EMAP and other published protocols, routine instrument calibrations, measures of analytical accuracy and precision (e.g., analysis of standard reference materials, spiked samples, and field and laboratory replicates), measures of the quality of test organisms and overall data acceptability in sediment bioassays (e.g., use of positive and negative controls), range checks on the various types of data, cross-checks between original data sheets (field or lab) and the various computer-entered data sets, and participation in intercalibration exercises. Additional quality assurance elements for this program included an initial program-wide training workshop on all sampling and analysis requirements, program-wide audits of field and laboratory operations, documentation of chain-of-custody, and maintaining open lines of communication and information exchange. A full description of the quality assurance program is provided in Kokkinakis et al. (1994).

2.5 Data Analysis

The principal approach used to analyze the various indicator data was the application of cumulative distribution functions (CDFs). This same approach has been used by other EMAP-E provinces (Strobel et al. 1994, Summers et al. 1993b). The CDFs describe the full distribution of indicator values in relation to their areal extent across the province or a subcomponent of particular interest (e.g., geographic subregion or estuarine class). Approximate 95% confidence intervals for the CDFs also were computed based on estimates of variance.

CDFs and associated variances were estimated using statistical formulas appropriate for the type of estuarine class and corresponding sampling design. The CDF estimate for small estuaries, treated as discrete resources, was based on the following equation from Cochran (1977):

$$\hat{P}_{Sx} = \frac{\sum_{i=1}^{n} A_i \bar{y}_i}{\sum_{i=1}^{n} A_i}$$

where,

$\hat{P}_{Sx}$ = CDF estimate for value x

$\bar{y}_i = \frac{1}{m_i}\sum_{j=1}^{m_i} y_{ij}$

m_i = number of samples at small system i

$y_{ij} = \begin{cases} 1 \text{ if response is less than or equal to } x \\ 0 \text{ otherwise} \end{cases}$

A_i = area of small system i

n = number of small systems sampled.

Because small estuaries sampled in 1994 represented a subset of the total number of small estuaries present in the province, the following modification of the formula given in Cochran (1977) was used to estimate variance (mean squared error, MSE):

$$MSE(\hat{P}_{Sx}) = \frac{\frac{N^2}{n}(1-f_1)\frac{\sum_{i=1}^{n} A_i^2(\bar{y}_i - \hat{P}_{Sx})^2}{n-1} + \frac{N}{n^*}\sum_{i=1}^{n^*}\frac{A_i^2 S_{2i}^2}{m_i}}{A^2}$$

where,

N = number of small estuaries in the province (194)

$f_1 = \frac{n}{N}$

n^* = number of small estuaries with replicate samples

$S_{2i}^2 = \frac{\sum_{j=1}^{m_i}(y_{ij} - \bar{y}_i)^2}{m_i - 1}$

A = the total area of small estuaries in the province (4907 km^2).

Estimates of CDFs for large tidal rivers, which were treated as extensive continuous resources, were obtained by applying the following Horvitz-Thompson estimator (Cochran 1977) using selection probabilities inversely related to station area:

$$\hat{P}_{Tx} = \frac{1}{A}\sum_{i=1}^{n}\frac{y_i}{\pi_i}$$

where,

$\hat{P}_{Tx}$ = Estimate CDF at value x

$y_i = \begin{cases} 1 \text{ if response is less than or equal to } x \\ 0 \text{ otherwise} \end{cases}$

π_i = inclusion probability for station i ($1/$area)

A = total area of sampled tidal rivers (1134 km^2)

n = number of stations sampled.

To produce unbiased estimates of variance, joint event probabilities π_{ij} must be non-zero. The variance for the CDF estimates was obtained by applying the Yates-Grundy estimate of variance (Cochran 1977) and using approximate joint event probabilities (Stevens et al. 1991), as follows:

$$\widehat{\mathrm{var}}(\hat{P}_{Tx}) = \frac{1}{A^2}\sum_{i=1}^{n}\sum_{j>i}^{n}\left(\frac{\pi_i\pi_j - \pi_{ij}}{\pi_{ij}}\right)\left(\frac{y_i}{\pi_i} - \frac{y_j}{\pi_j}\right)^2$$

where,

π_{ij} = probability that sites i and j are selected for sampling

$\pi_{ij} = \frac{2(n-1)\pi_i\pi_j}{2n - \pi_i - \pi_j}$.

Formulas used to estimate CDFs and corresponding variances for large estuaries were the same as those presented above for large tidal rivers. Areas for all base stations in large estuaries were 280 km^2 (the size of hexagonal grid cell). The total area of sampled large estuaries was 5581.1 km^2.

Estimates of the CDFs across strata were computed as weighted averages of the relevant station class CDFs, as follows:

$$\hat{P}_x = W_s\hat{P}_{Sx} + W_T\hat{P}_{Tx} + W_L\hat{P}_{Lx}$$

where,

W_S = relative area of small estuaries
W_T = relative area of large tidal rivers
W_L = relative area of large estuaries.

The above variance estimates were used to calculate approximate 95% confidence intervals based on the formula:

$$\hat{P}_x \pm 1.96\sqrt{MSE(\hat{P}_x)}$$

In order to produce these confidence intervals it was assumed that the CDF estimates were distributed normally.

One way of presenting the CDF data was to produce plots with indicator values on the x-axis and the cumulative percentage of estuarine area on the y-axis. A CDF plot provides a direct means of assessing the range in indicator values across the province and portions of estuaries characterized by the individual values. In addition, the proportion of estuarine resources with indicator values above or below specific environmental guidelines (breakpoint values) can be determined directly from these plots. This can be a very useful management tool. For example, a CDF for dissolved oxygen (DO) could be used to determine the percent of estuarine bottom waters within the province that had DO concentrations below the general water quality standard of 5 mg/L adopted by many states.

Information from the CDFs also was presented as bar graphs to show percentages of estuaries with indicator values above or below specific guideline values. Wherever possible, published guidelines were used for this purpose. For example, sediment quality guidelines for chemical contaminants were based on the Effects Range Low (ER-L) and Effects Range Median (ER-M) values of Long et al. (1995, Long and Morgan 1990) or the comparable Threshold Effects Level (TEL) and Probable Effect Level (PEL) values of MacDonald (1994). Conditions were evaluated in relation to other more subjective criteria for some indicator variables (e.g., water clarity and most biotic condition indicators).

Correlation analysis also was conducted to examine the strength and direction of association between biotic condition indicators and various measures of exposure and habitat conditions. Data transformations were made to establish conditions of normality wherever possible. Pearson's product-moment correlation coefficient, r, and Spearman's correlation coefficient, r_s, were used for the analysis of normal and non-normal data, respectively, based on procedures provided in SAS (1989).

2.6 Unsamplable Area

One small estuarine site (Station 15, Guana River, FL) could not be sampled due to its shallow depth and inaccessibility. This site represented 0.2% of the area of the province. Another site in a small estuary (Station 28, Lockwoods Folly River, NC) could not be sampled for sediment-related variables due to extensive oyster reefs in the area. This site also represented 0.2% of the total area of the province. Dense algae and other bottom obstructions prevented successful trawling at three stations (Stations 12 in Indian River, FL; 14 in Mosquito Lagoon, FL; and 65 in Edenton Bay, NC). All core environmental indicators were measured at remaining base stations. However, the continuous DS3 records of water-quality variables from 28 stations were either never retrieved, due to instrument losses in the field, or not used due to their questionable variability based on QC analysis of the data. Water quality data for these sites are represented solely by the instantaneous DS3 measurements.

3. INDICATOR RESULTS

3.1 Habitat Indicators

3.1.1 Water Depth and Tidal Range

Figure 3.1-1 shows the distribution of bottom depth in relation to the cumulative percent area of Carolinian Province estuaries. Because of the large tidal ranges that occur at many of these sites (discussed below), all depths were standardized to mean lower low water (MLLW) based on tidal prediction data from the nearest NOAA harmonic stations (Nautical Software 1995). MLLW-corrected depths ranged from 0–11.5 m. Most of the estuaries had fairly shallow depths: 62% had depths <4 m and 91% had depths <6.0 m. About 16% of the area of the province was represented by depths <1 m, though all of these sites had at least 0.5 m of water at the time of sampling. The shallowest sites occurred in large tidal rivers (mean depth of 2.5 m and range of 0.1–5.5 m, Table 3-1). Though mean and median depths were greatest in large estuarine systems, the deepest site was in a small estuary.

The maximum daily tidal range at a station varied from 0.1–2.9 m across the province (Fig. 3.1-2). At most stations these fluctuations were <1 m over a minimum 12-h period. However, about 10% of the province was characterized by relatively large tides in excess of 2 m. These fluctuations were the most pronounced in the SC/GA portion of the province, where 62% of the area of these estuaries had tides >2 m (Fig. 3.1-3A). There were no obvious differences in tidal ranges in relation to estuarine class (Fig. 3.1-3B).

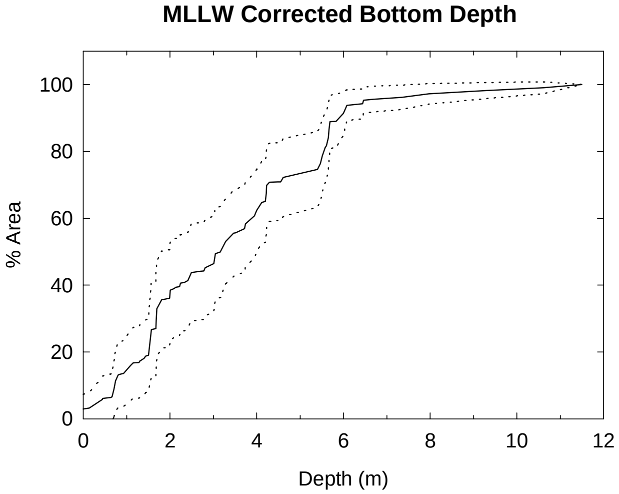


FIGURE 3.1-1. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. bottom depths converted to mean lower low water (MLLW). Data are from instantaneous water-column profiles.

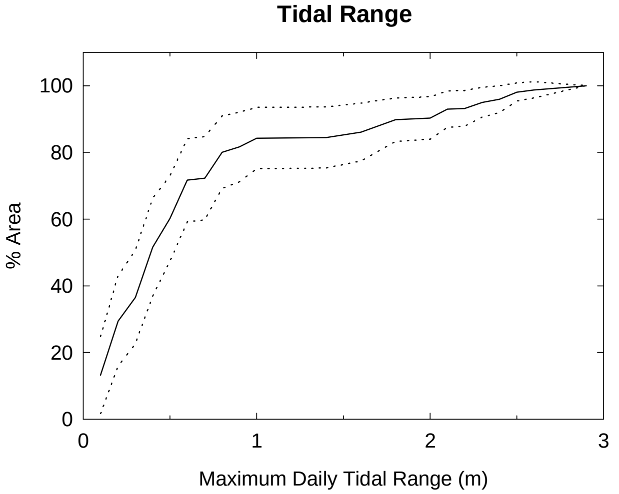


FIGURE 3.1-2 Percent area (and 95% C.I.) of Carolinian Province estuaries vs. maximum daily tidal range (max.–min. water depths recorded over min. 12-h period at a station).

TABLE 3.1. Mean, median and range (min. – max.) by estuarine class for observations of depth, dissolved oxygen, salinity, temperature, and pH of bottom waters.[a]

		Estuarine Class			
Parameter	Statistic	All	Large	Small	Tidal
Depth [b] (m)	mean	3.2	3.6	3.3	2.5
	median	2.5	4.0	2.4	1.5
	range	(0.0–11.5)	(0.4–6.1)	(0.0–11.5)	(0.1–5.5)
Dissolved Oxygen (mg/L)	mean	6.0	7.3	5.5	5.9
	median	6.3	7.3	5.7	6.7
	range	(1.2–12.5)	(5.0–12.5)	(1.2–9.0)	(1.5–7.8)
Salinity (‰)	mean	22.1	18.0	23.3	23.7
	median	25.1	22.7	26.5	24.3
	range	(0.2–39.1)	(1.6–37.4)	(0.2–39.1)	(20.2–30.8)
Temperature (°C)	mean	27.9	26.4	28.1	29.0
	median	27.9	27.3	27.9	28.6
	range	(19.6–33.0)	(19.6–29.2)	(26.1–31.3)	(26.6–33.0)
pH	mean	7.8	7.9	7.7	7.9
	median	7.9	7.9	7.7	7.9
	range	(6.7–8.4)	(7.3–8.4)	(6.7–8.4)	(7.3–8.4)

[a] Based on instantaneous profile data at maximum recorded depth.

[b] Bottom depths based on instantaneous profile depths corrected to Mean Lower Low Water.

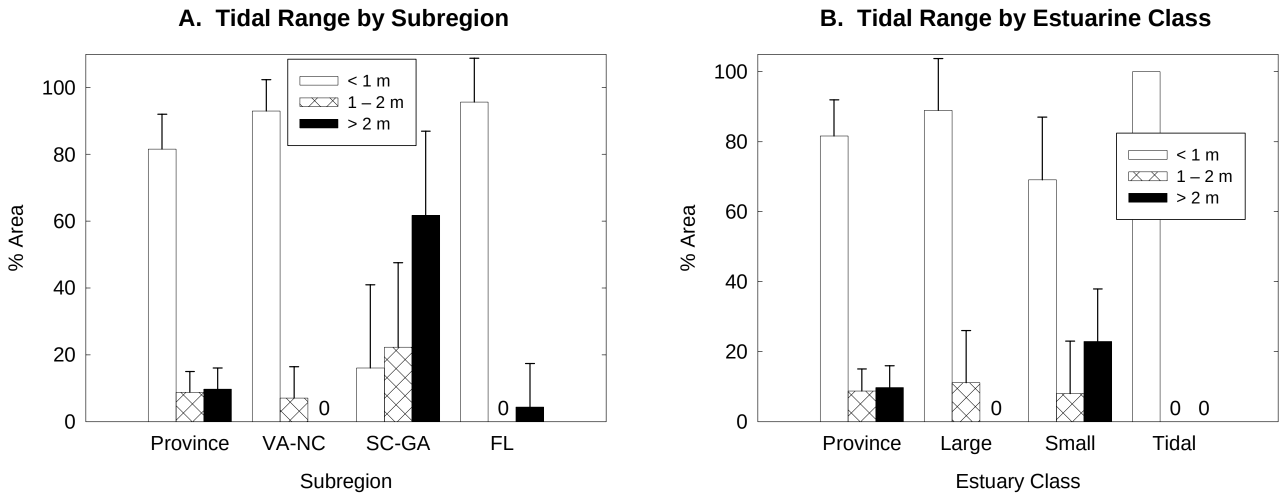


FIGURE 3.1-3. Comparison by subregion (A) and estuarine class (B) of the percent area (and 95% C.I.) of Carolinian Province estuaries with small (<1 m), moderate (1–2 m), or large (>2 m) maximum daily tidal ranges (max. – min. water depths recorded over min. 12-h period at a station).

3.1.2 Salinity

Bottom salinities ranged from 0.2–39.1 ‰ across the province (Fig. 3.1-4, Table 3-1). Based on the Venice salinity classification system (Carriker 1967), 18% of these estuarine waters were oligohaline (<5 ‰), 9% were mesohaline (5–18 ‰), 52% were polyhaline (>18–30 ‰), and 22% were euhaline ("marine," >30 ‰) (Fig. 3.1-5). Large tidal rivers consisted almost exclusively of polyhaline waters, small estuaries consisted mostly of a mix of polyhaline and euhaline waters, and large estuaries consisted mostly of oligohaline and polyhaline waters.

3.1.3 Water Temperature

Temperature ranged from 19.6–33.0 °C in bottom waters across the province (Fig. 3.1-6, Table 3-1). A large percentage of the province (67%) was characterized by temperatures within a narrow range of 27–29 °C. Median temperatures showed little variation in relation to estuarine class, though mean temperature was slightly lower in the deeper, large estuaries than in the other two estuarine classes (Table 3-1). These temperatures are representative of the sampling period from June 30 – August 31, 1994.

3.1.4 pH

The pH of bottom waters ranged from 6.7–8.4 in estuaries throughout the province (Fig. 3.1-7, Table 3-1). Most of the province (86%) was characterized by pH within a very narrow range of 7.5–8.0. Mean and median pH values showed little variation in relation to estuarine class (Table 3-1).

3.1.5 Percent Silt-Clay and TOC

Sediment characteristics such as grain size and organic content can have significant effects on the distribution of benthic species and on the concentrations and bioavailability of sediment associated contaminants. Higher percentages of sand, for example, may provide a greater number

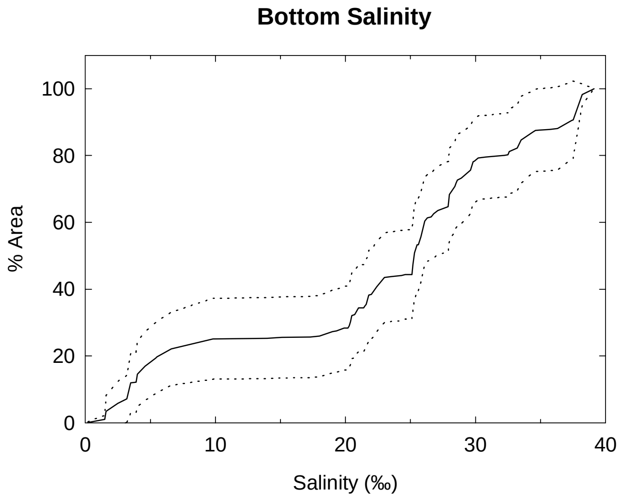


FIGURE 3.1-4. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. salinity of bottom waters. Data are from instantaneous water-column profiles.

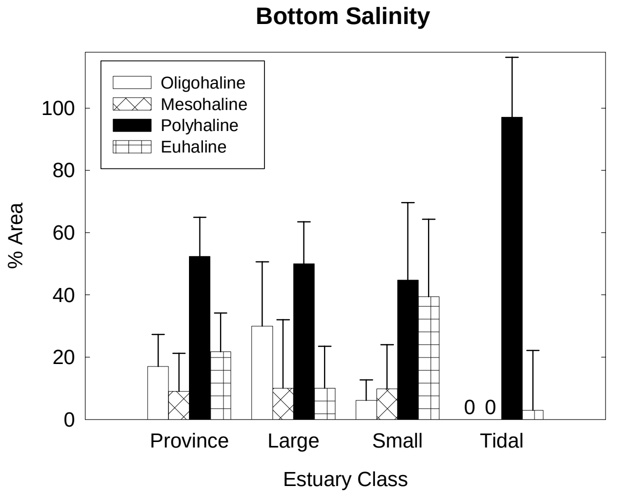


FIGURE 3.1-5. Percent area (and 95 % C.I.) of Carolinian Province estuaries with oligohaline (<5 ‰), mesohaline (5–18 ‰), polyhaline (>18–30 ‰), or euhaline (>30 ‰) salinity ranges in bottom waters. Data are from instantaneous water-column profiles.

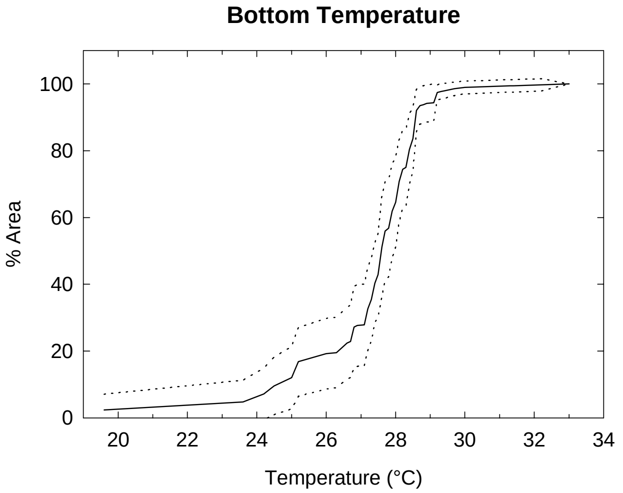


FIGURE 3.1-6. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. temperature of bottom waters. Data are from instantaneous water-column profiles.

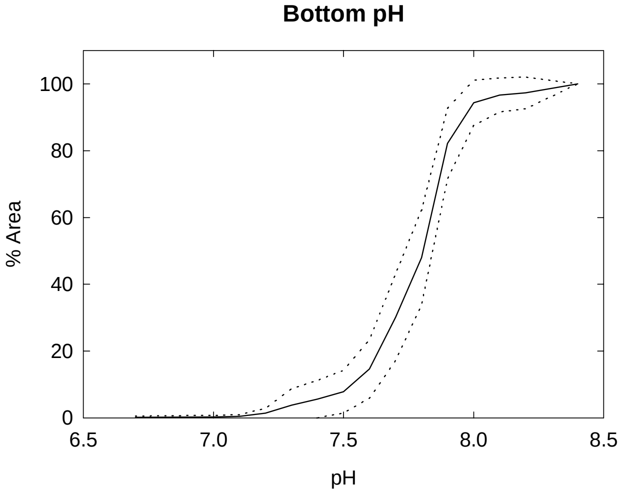


FIGURE 3.1-7. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. pH of bottom waters. Data are from instantaneous water-column profiles.

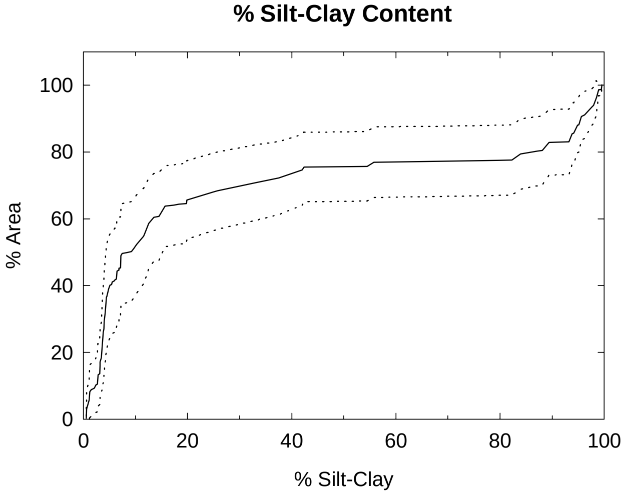


FIGURE 3.1-8. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. percent silt-clay of sediments.

of microhabitats for interstitial species to exist and could increase sediment permeability allowing greater exchange of oxygen and nutrients at depth in the sediment (Hyland et al. 1991, Weston 1988). Grain size and organic content of sediments also are known to be strongly correlated with one another. Finer substrates tend to have a proportionally greater organic content than coarser sediments due to a higher surface-to-volume ratio of the sediment particles. There are logical functional links between benthic organisms and the presence of sediment organic matter as potential food sources. However, the higher surface-to-volume ratio of muds may also provide a greater surface area for sorption of chemical contaminants.

The percent silt-clay content of sediments ranged from 0.6–99.6% (Fig. 3.1-8). About 66% of the province was comprised of sands (<20% silt-clay), about 12% was comprised of intermediate muddy sands (20–80% silt-clay), and about 22% was comprised of muds (>80% silt-clay) (Fig. 3.1-9). The predominance of sandy substrates was characteristic of both large and small estuaries, while large tidal rivers were dominated by muds.

Percent TOC ranged from <0.01% (detection limit) to 4.9% (Fig. 3.1-10). Low to normal TOC levels (<1%, *sensu* Summers et al. 1993b) occurred in 67% of the province sediments. Higher levels (>2%), suggestive of organic enrichment either from natural or anthropogenic inputs, occurred in 20% of the province. Such organically enriched substrates dominated estuaries within the large tidal river class (Fig. 3.1-11).

Relationships between the silt-clay and TOC content of sediments and various biological, toxicological, and chemical variables are discussed below.

3.1.6 Density Stratification

Density stratification of the water column was measured as $\Delta\sigma_t$, the σ_t difference between surface and bottom waters, where σ_t is the density of a parcel of water with a given salinity and temperature relative to atmospheric pressure. Sigma-t is a commonly used measure of seawater density and can be computed from standard σ_t tables based on the observed salinity and temperature of the sample (e.g., Knauss 1978).

Stratification of the water column is an important factor to consider because, if large enough, it can restrict the normal mixing of bottom and oxygen-rich surface waters, allowing the bottom layer to become hypoxic or anoxic. Stratification also may create conditions favorable for phytoplankton growth in the surface layer (e.g., higher concentrations of nutrients) which could lead to subsequent increases in detrital loading and biological oxygen demand in the bottom layer.

The CDF for $\Delta\sigma_t$ (Fig. 3.1-12) included values ranging from – 0.8 to 12.2. The majority of these estuarine waters (76%) had $\Delta\sigma_t$ values between – 1 to 1 units, indicating relatively unstratified, well-mixed conditions. Fourteen percent showed significant stratification (defined here as $| \Delta\sigma_t | > 2$). These more stratified waters were the most pronounced in large tidal rivers and the least pronounced in large estuaries (Fig. 3.1-13). Similarly small percentages of stratified estuarine waters were observed both in the

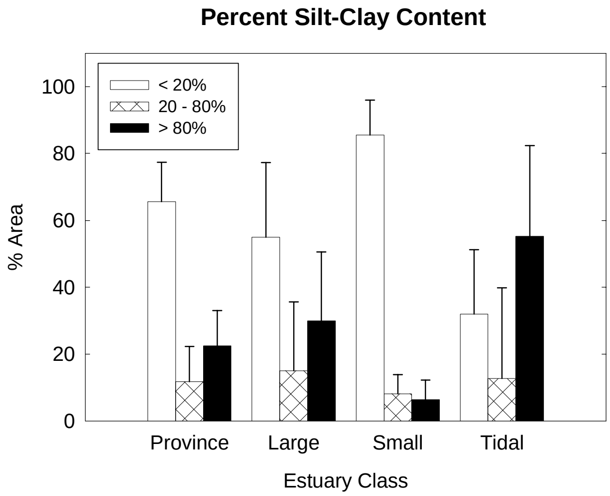


FIGURE 3.1-9. Percent area (and 95% C.I.) of Carolinian Province estuaries with low (<20%), moderate (20–80%), or high (>80%) silt-clay content of sediments.

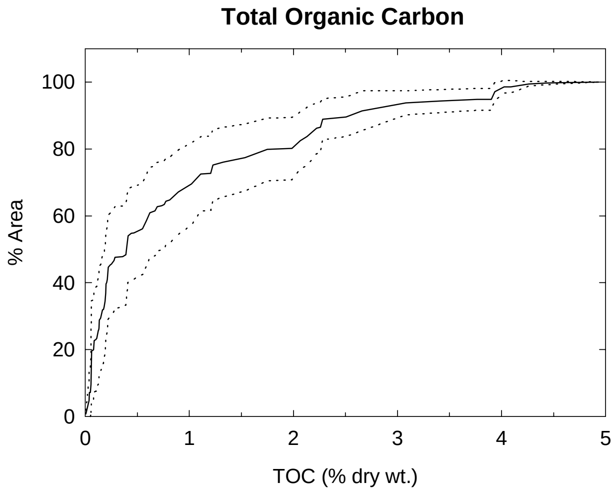


FIGURE 3.1-10. Percent area (and 95% C.I.) of Carolinian Province Estuaries vs. mean total organic carbon (TOC) in sediments.

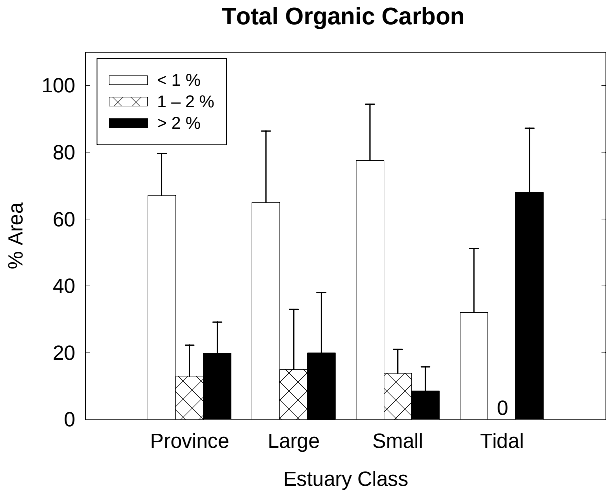


FIGURE 3.1-11. Percent area (and 95% C.I.) of Carolinian Province estuaries with low to normal (<1%), moderate (1–2%), or high (>2%) percentages of total organic carbon (TOC) in sediments.

Virginia Province (13% for 1990 – 1993, Strobel et al. 1995) and Louisianian Province (15% in 1991, Summers et al. 1993b; and 4% in 1992, Macauley et al. 1994).

Density patterns in relation to dissolved oxygen concentrations are discussed below in Section 3.2.1.

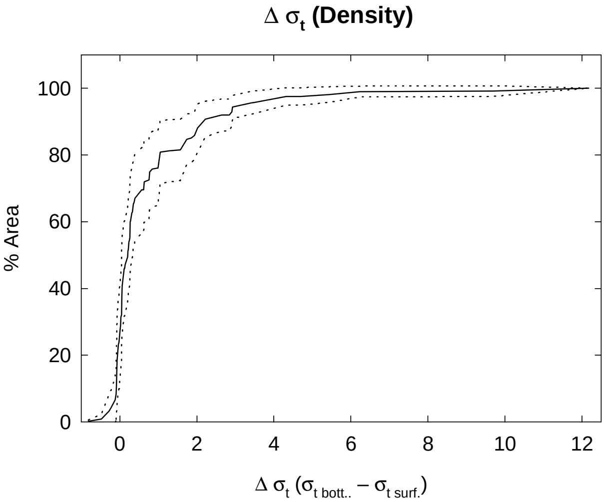


FIGURE 3.1-12. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. $\Delta\sigma_t$ (sigma-t density difference between bottom and surface waters).

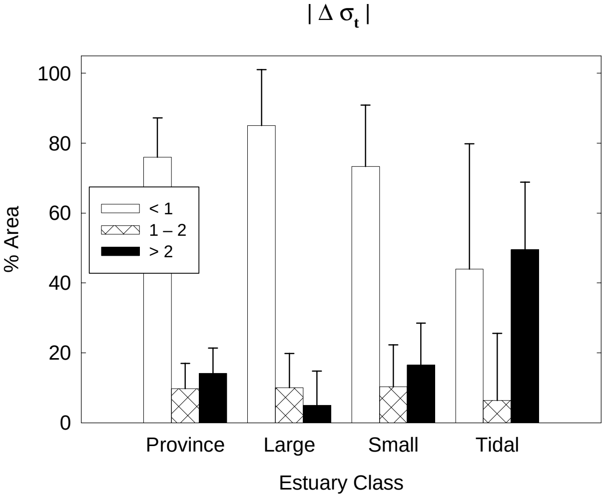


FIGURE 3.1-13. Percent area (and 95% C.I.) of Carolinian Province estuaries with low (<1), moderate (1–2), or high (>2) degrees of stratification (| $\Delta\sigma_t$ |).

3.2 Exposure Indicators

3.2.1 Dissolved Oxygen (Instantaneous)

Dissolved oxygen (DO) is treated as an exposure indicator because of the potential adverse biological consequences of low-oxygen conditions. Anoxic and severe hypoxic conditions can cause significant mortality in aquatic populations even over brief exposure periods. High benthic mortalities following periods of anoxia have been noted in the New York Bight (Falkowski et al. 1990, Swanson and Sindermann 1979) and Chesapeake Bay (Seliger et al. 1985). DO concentrations less than 0.21 mg/L have been shown to be lethal to a variety of benthic invertebrates in short-term laboratory exposures (Theede 1973). Extended exposure to less severe hypoxic conditions also can lead to longer-term chronic effects on survival. Hyland et al. (1991) found reduced numbers of benthic species and abundances off the coast of southern California at sites where DO concentrations were below ~ 2 mg/L. Rhoads et al. (1971) also noted that the diversity of benthic invertebrates in several oxygen-deficient marine basins drops markedly as oxygen falls below 1.43 mg/L. Many states have set water quality standards for DO at 5.0 mg/L.

DO concentrations in the Carolinian Province, based on instantaneous daylight measurements, ranged from 5.1–10.4 mg/L in surface waters (Fig. 3.2-1A) and from 1.2–12.5 mg/L in bottom waters (Fig. 3.2-1B, Table 3-1). Though surface DO concentrations were above the general water quality standard of 5 mg/L at all base stations, bottom DO concentrations were below this level in 12% of the province including sites in all estuarine classes (Fig. 3.2-2A) and subregions (Fig.

3.2-2B). A similar percentage of estuaries with DO concentrations <5 mg/L (i.e., 15%) was reported for the Louisianian Province (Summers et al. 1993b, for the 1991 index period). DO concentrations <2 mg/L (based on the instantaneous records) were rare, found only in 2.5% of the province. The large tidal river class consisted of the highest proportion of estuaries (17%) with bottom DO concentrations below this lower criterion. None of the sites in the large estuary class or the SC/GA portion of the province had instantaneous DO concentrations <2 mg/L.

In most places, DO concentrations in surface and bottom waters were similar, reflecting the absence of significant water-column stratification at the time of sampling. As was discussed above (Section 3.1.6), highly stratified waters appeared in a fairly small percentage (14%) of these estuaries. Though not shown here, the results of regression analysis revealed no significant variation (tested at $\alpha = 0.05$) in bottom DO concentrations, or surface-to-bottom differences in DO, as a function of density stratification ($r^2 = 0.14$ for $\Delta\sigma_t$ vs. bottom DO, and for $\Delta\sigma_t$ vs. ΔDO). Small surface-to-bottom differences in DO of <1 mg/L were observed in 79% of the province (Fig. 3.2-3). Larger differences in excess of 1 mg/L were the most pronounced in large tidal rivers (Fig. 3.2-4).

A summary of the DO data by station, both from instantaneous and continuous records, is presented in Appendix A along with other water quality data.

3.2.2 Dissolved Oxygen (Continuous)

The continuous measurements provided a more complete record of DO conditions within an estuary including potential diurnal and tidal variations. Minimum near-bottom DO concentrations based on these records ranged from 0.07–7.7 mg/L (Fig. 3.2-5) which included values at two stations (replicate sites in the Pamlico River) below the range of daytime instantaneous measurements (1.2–12.5 mg/L, Fig. 3.2-1B). These two cases were both recorded during the day, thus the lower range in continuous relative to instantaneous measurements was not due to day-night differences. Estimates of the percentage of estuarine waters with bottom DO concentrations below potential bioeffect criteria were about the same for the two measurement approaches: 15% had DO <5 mg/L based on continuous records and 12% had DO concentrations <5 mg/L based on instantaneous records. Similarly, 4% had DO <2 mg/L based on continuous records and 2.5% had DO concentrations <2 mg/L based on instantaneous records. Low-oxygen conditions were again the most pronounced in large tidal rivers (Fig. 3.2-6).

Sites were classified as degraded with respect to DO based on a combination of the following three criteria: DO <0.3 mg/L at any time (to represent short-term exposure to severe hypoxic conditions), DO <2.0 mg/L for more than 20% of the measurement period, or DO <5.0 mg/L throughout the measurement period (to represent extended exposure to higher chronic effect levels). Only three sites (replicate Stations 51 and 52 in the Pamlico River, NC; and Station 77 in the Combahee River, SC) were classified as degraded based on these criteria. These three sites represented 5% of the total province area (Table 3.2-1).

A wide range of DO patterns occurred in these estuaries. In some places, DO followed cyclical patterns consisting of both diurnal and tidal components. An example is provided by Station 83, in Little River, SC, where the highest DO concentrations were recorded at late afternoon to early evening during high tide (Fig. 3.2-7A). In contrast, Station 47 in South Creek, NC showed a DO pattern that consisted of large day-night variations without any significant tidal influences (Fig. 3.2-7B). The contribution of the tidal component to variations in DO was the most pronounced in the SC/GA portion of the province, which is consistent with the greater tidal ranges observed in these estuaries relative to those in NC and FL (Section 3.1.1).

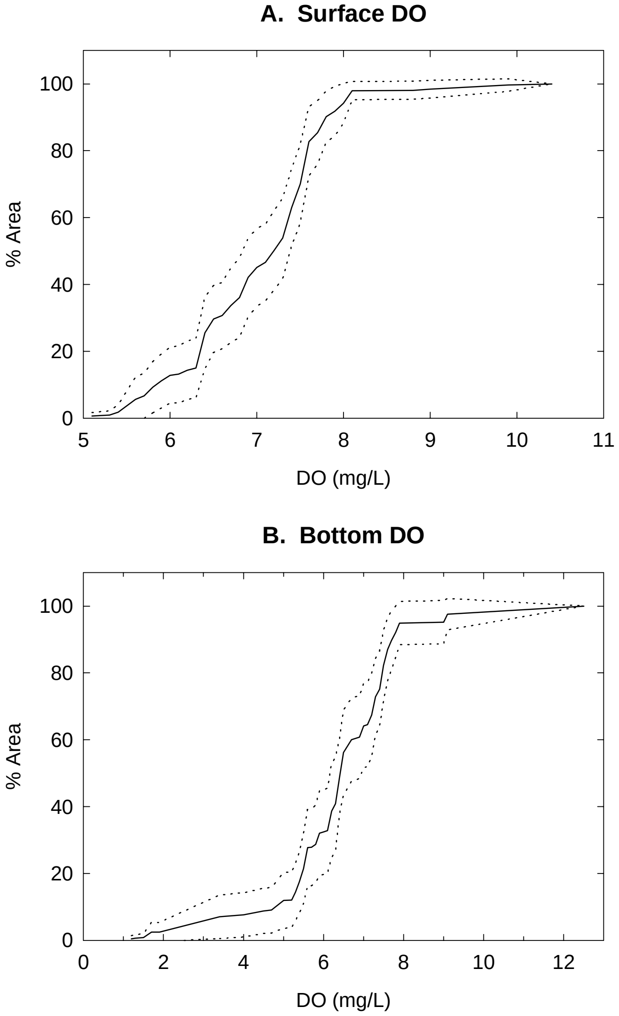


FIGURE 3.2-1. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. dissolved oxygen concentration in surface waters (A), and bottom waters (B) based on instantaneous water-column profiles.

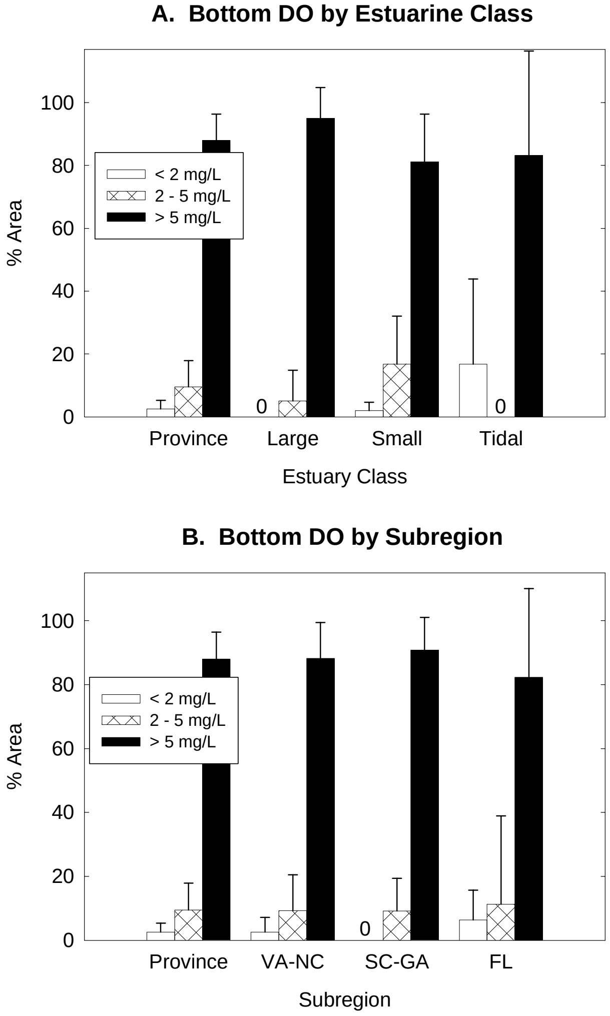


FIGURE 3.2-2. Comparison by estuarine class (A) and subregion (B) of the percent area (and 95% C.I.) of Carolinian Province estuaries with low (<2 mg/L), moderate (2–5 mg/L), or high (>5 mg/L) dissolved oxygen concentrations in bottom waters. Data are from instantaneous water-column profiles.

TABLE 3.2-1. Percent area (and 95% C.I.) of Carolinian Province estuaries with significantly low dissolved oxygen (DO) concentrations: <0.3 mg/L at any time, or <2.0 mg/L for more than 20% of the measurement period, or <5.0 mg/L at all times throughout the measurement period. Data are from continuous near-bottom observations.

Estuary Class	Number of Stations	% Area ± 95 % C.I.
Province	3 [a]	5 ± 7
Large	0	0
Small	1	2 ± 4
Tidal Rivers	2 [a]	42 ± 70

[a] Station CP94052 and its replicate site CP94051 in the Pamlico River are both included in the number of stations reported.

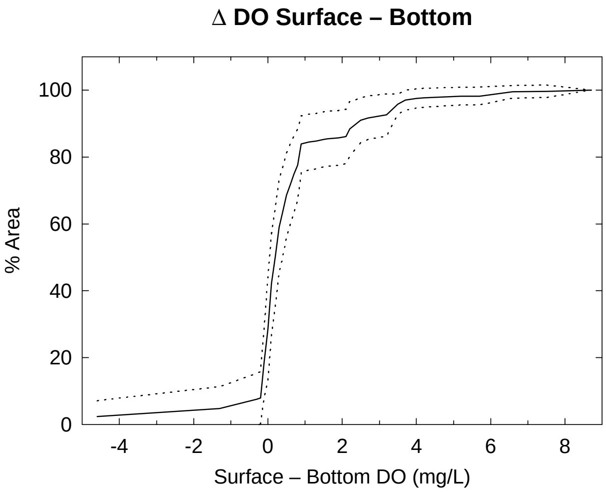


FIGURE 3.2-3. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. dissolved oxygen (DO) concentration differences between surface and bottom waters. Data are from instantaneous water-column profiles.

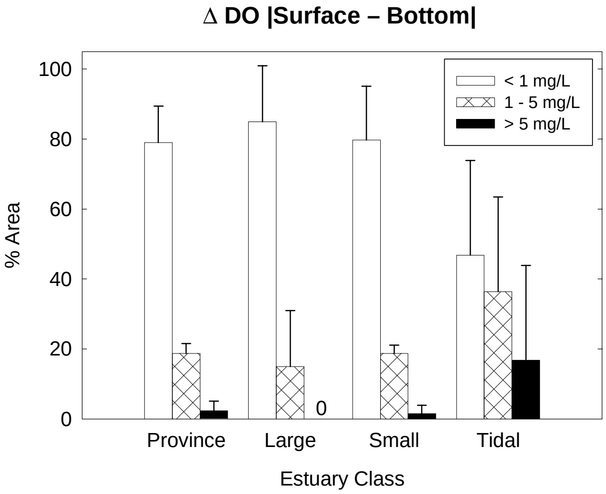


FIGURE 3.2-4. Percent area (and 95% C.I.) of Carolinian Province estuaries with low (<1 mg/L), moderate (1–5 mg/L), or high (>5 mg/L) differences in dissolved oxygen concentrations between surface and bottom waters ($|DO_{sur.} – DO_{bot.}|$). Data are from instantaneous water-column profiles.

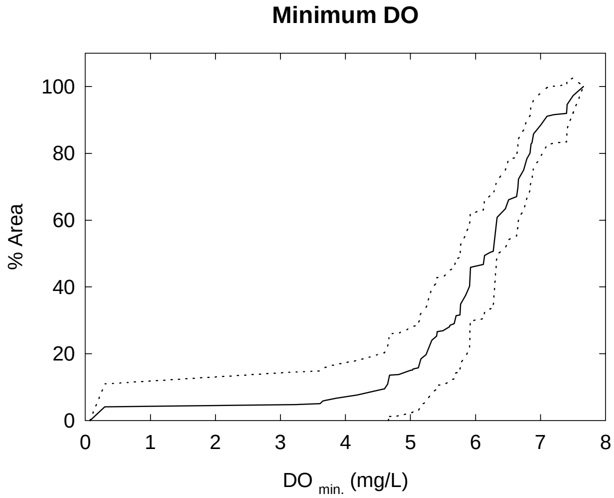


FIGURE 3.2-5. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. minimum near-bottom dissolved oxygen (DO) concentrations observed during continuous water-quality sampling.

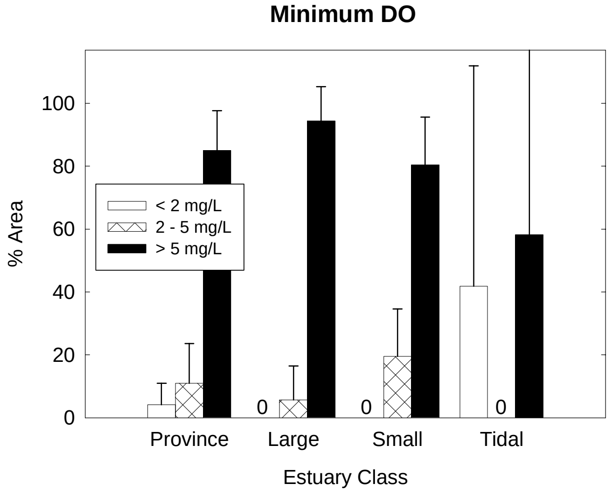


FIGURE 3.2-6. Percent area (and 95% C.I.) of Carolinian Province estuaries with low (<2 mg/L), moderate (2–5 mg/L), or high (>5 mg/L) minimum dissolved oxygen (DO) concentrations in bottom waters. Data are from continuous near-bottom observations.

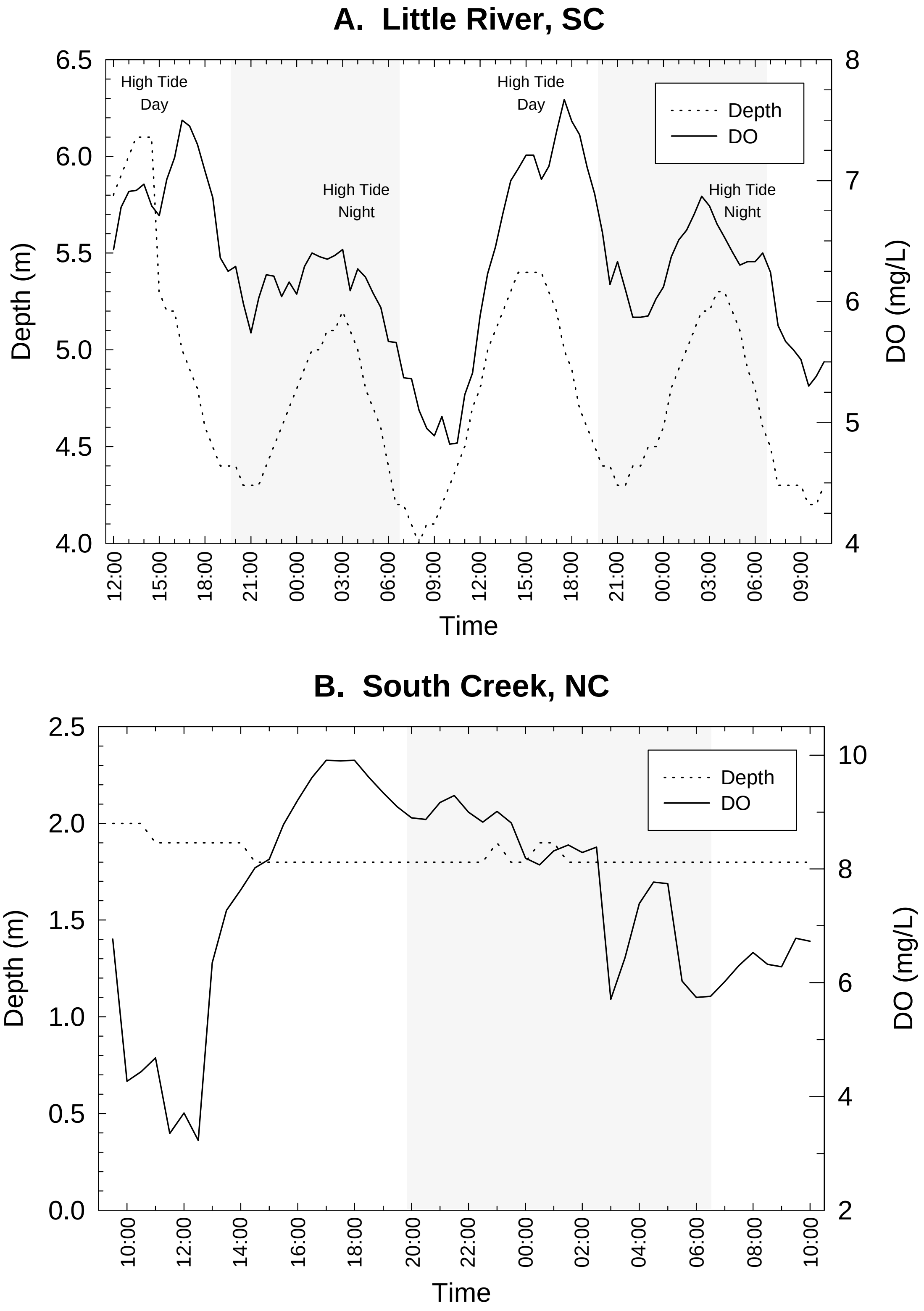


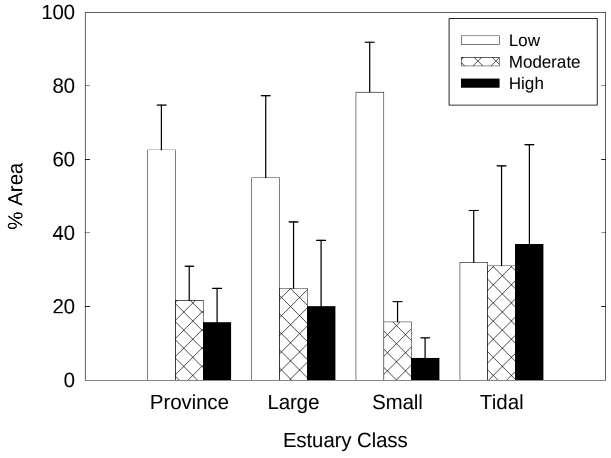
FIGURE 3.2-7. Time series plots of dissolved oxygen and depth at (A) Station 83 in Little River, SC on August 29–31, 1994 and (B) Station 47 in South Creek, NC on August 16–17, 1994. Time from sunset to sunrise is shaded. Data are from continuous, near-bottom datasonde observations.

3.2.3 Sediment Contaminants

Concentrations of sediment hydrocarbons, PCBs and pesticides, and metals are listed by station in Appendices B, C, and D respectively. Contaminants that were present in excess of concentrations known to cause adverse effects on marine biota have been highlighted. Such bioeffect exceedances were based primarily on the Effects Range-Low (ER-L) and Effects Range-Median (ER-M) guidelines of Long et al. (1995, Long and Morgan 1990) or the comparable Threshold Effects Level (TEL) and Probable Effects Level (PEL) guidelines of MacDonald (1994). ER-M and PEL values both represent higher-end probable effect levels above which adverse effects on a wide variety of benthic organisms are expected to occur. ER-L and TEL values represent lower threshold levels below which bioeffects are rarely expected. A summary of the number of sites, and corresponding percent area of the province, that had contaminants in excess of these bioeffect guidelines is presented in Table 3.2-2. The range in concentrations observed among the various sites, along with the median and mean concentration, is included for each of the contaminants.

The majority of the province (63%) showed low levels of sediment contamination with all of the measured contaminants falling below corresponding threshold ER-L or TEL bioeffect guidelines (Fig. 3.2-8). Sixteen percent of the province showed significant sediment contamination defined by the presence of three or more contaminants in excess of the lower ER-L/TEL values, or one or more contaminants in excess of the higher ER-M/PEL values. The large tidal river class contained the highest proportion of contaminated sediments (Fig. 3.2-8A) due to contributions of the Neuse River (Station 36) and Pamlico River (Stations 51 and 52). High sediment contamination was rare in SC/GA estuaries (Fig. 3.2-8B).

A. Sediment Contamination by Estuarine Class



B. Sediment Contamination by Subregion

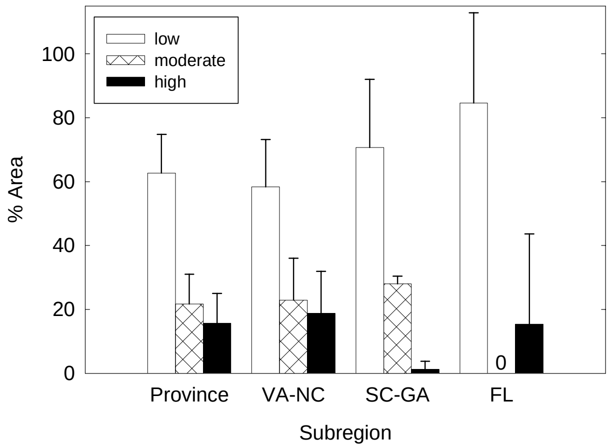


FIGURE 3.2-8. Comparison by estuarine class (A) and subregion (B) of the percent area (and 95% C.I.) of Carolinian Province estuaries with low (no ER-L or TEL exceedances), moderate (1–2 ER-L or TEL exceedances), or high (≥3 ER-L or TEL exceedances, or ≥1 ER-M or PEL exceedance) levels of sediment contamination.

TABLE 3.2-2. Summary of contaminant concentrations (ng/g) and sediment quality guideline exceedances at EMAP base sites in the Carolinian Province during summer 1994. ER-L and ER-M values are from Long et al. (1995) and Long and Morgan (1990); TEL and PEL values are from MacDonald (1994). Areal percentages include ± 95 % confidence intervals.

	Median	Mean	Range	ER-L / TEL		ER-M / PEL	
Contaminant	Conc.	Conc.	(Min – Max)	No. Sites	% Area	No. Sites	% Area
Metals (µg/g)							
Antimony	0.2	0.4	0.0 – 3.4	4	3 ± 3	0	0
Arsenic	2.9	4.3	0.0 – 20.5	13	20 ± 10	0	0
Cadmium	0.1	0.1	0.0 – 1.1	0	0	0	0
Chromium	25.2	37.0	3.8 – 130.9	8	12 ± 8	0	0
Copper	2.4	7.3	0.5 – 36.3	1	< 1 ± < 1	0	0
Lead	8.3	13.6	1.8 – 52.7	2	3 ± 5	0	0
Mercury	< 0.1	< 0.1	0.0 – 0.3	5	8 ± 8	0	0
Nickel	3.8	8.6	0.5 – 34.3	14	19 ± 10	0	0
Silver	< 0.1	0.1	0.0 – 0.4	0	0	0	0
Zinc	23.3	46.0	< 0.1 – 182.8	3	5 ± 6	0	0
PAHs (ng/g)							
Acenaphthene	0.2	1.1	< 0.1 – 33.6	1	< 1 ± < 1	0	0
Acenaphthylene	0.2	3.1	< 0.1 – 74.2	1	< 1 ± < 1	0	0
Anthracene	0.5	5.5	< 0.1 – 136.4	1	< 1 ± < 1	0	0
Benzo[a]anthracene	1.1	22.0	< 0.1 – 426.9	2	3 ± 5	0	0
Benzo[a]pyrene	1.4	22.6	< 0.1 – 431.3	1	< 1 ± < 1	0	0
Chrysene	1.5	25.1	< 0.1 – 469.9	1	< 1 ± < 1	0	0
Dibenz[a,h]anthracene	0.3	3.7	< 0.1 – 79.8	1	< 1 ± < 1	0	0
Fluoranthene	2.8	40.5	< 0.1 – 802.1	2	3 ± 5	0	0
Fluorene	0.3	2.0	< 0.1 – 46.3	1	< 1 ± < 1	0	0
2-Methylnaphthalene	0.6	2.6	0.1 – 56.1	0	0	0	0
Naphthalene	1.4	6.0	< 0.1 – 167.0	1	< 1 ± < 1	0	0
Phenanthrene	1.3	10.6	< 0.1 – 263.1	1	< 1 ± < 1	0	0
Pyrene	2.5	42.2	0.1 – 867.7	1	< 1 ± < 1	0	0
Total PAHs [a]	36.1	436.4	1.7 –9179.2	2	3 ± 5	0	0
PCBs (ng/g)							
Total PCBs	3.7	17.5	2.4 – 311.5	8	5 ± 5	3	3 ± 5
Pesticides (ng/g)							
Chlordane [b]	0.0	0.2	0.0 – 5.2	1	< 1 ± < 1	1	< 1 ± < 1
4,4'-DDD (p,p'-DDD)	< 0.1	0.4	0.0 – 6.6	8	8 ± 8	0	0
4,4'-DDE (p,p'-DDE)	< 0.1	0.7	0.0 – 10.1	8	8 ± 7	0	0
4,4'-DDT (p,p'-DDT)	0.0	0.1	0.0 – 3.6	3	1 ± 1	0	0
Dieldrin	0.0	0.1	0.0 – 1.4	18	23 ± 10	0	0
Endrin	0.0	< 0.1	0.0 – 0.3	1	< 1 ± 1	0	0
Lindane [c]	0.0	< 0.1	0.0 – 0.8	2	1 ± 2	0	0
Total DDT [d]	0.1	1.3	0.0 – 18.8	17	14 ± 9	0	0

[a] without Perylene

[b] alpha-, gamma-, and oxychlordane

[c] gamma BHC

[d] all six DDD, DDE, and DDT congeners

Contaminants that appeared to be the most prevalent in the Carolinian Province are antimony, arsenic, chromium, mercury, nickel, zinc, total PCBs, total chlordane, DDT and derivatives, and dieldrin (Table 3.2-2). These contaminants were found either at concentrations in excess of ER-M/PEL values in at least one estuary (e.g., chlordane and total PCBs) or at concentrations in excess of the lower ER-L/TEL values in three or more estuaries (remaining ones). PCB contamination was the most pronounced. Total PCBs were found at three stations in excess of the ER-M value of 180 ng/g and at eight stations in excess of the ER-L value of 22.7 ng/g.

Comprehensive bioeffect guidelines, such as ER-L/TEL and ER-M/PEL values, do not exist for all of the chemical contaminants that were measured in this study. The above estimates of uncontaminated vs. contaminated sediments do not account for such contaminants, even though they may have been present at concentrations well above detection limits at many of the sites. A very good example is tributyltin (TBT), a compound found in antifouling paints. Though known to be highly toxic in the water column (Carr et al. 1987, U.S. EPA 1988), there are limited data on its toxicity in sediments. The EMAP-E program in the Louisianian Province used a criterion of >5 ppb (expressed as ng Sn/ g dry wt. sediment) to flag concentrations in a potential toxicity range (Macauley et al. 1994). Twenty three percent of the estuarine area of the Carolinian Province had TBT concentrations above this level (Fig. 3.2-9). In comparison, only 7% of the Louisianian Province estuaries had TBT concentrations above 5 ng/g. This result suggests that TBT is present in a number of places in the Carolinian Province at concentrations that could be causing or contributing to adverse biological effects. However, because the bioeffect range for TBT in sediments is not clearly defined as yet, these data were not included in the above CDF estimates of contaminated vs. uncontaminated estuaries.

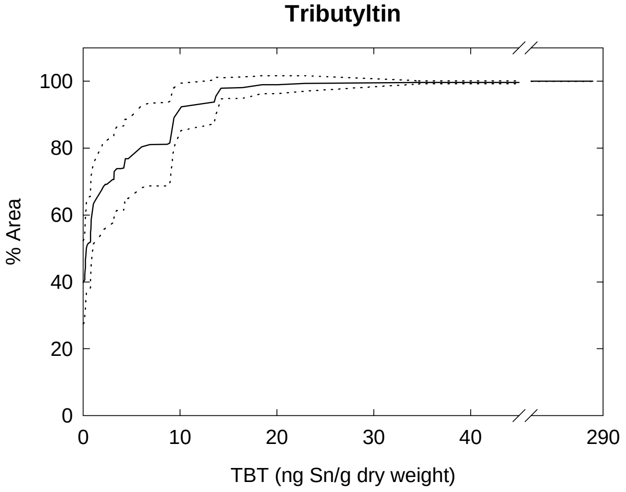


FIGURE 3.2-9. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. tributyltin (TBT) concentrations in sediments.

Concentrations of TBT in the Carolinian Province ranged from below detection limits to 289 ng/g (Fig. 3.2-9). The five highest concentrations, ranging from 20.1–289 ng/g, were found in Florida at two small estuarine sites (Station 16 in Julington Creek and Station 17 in the Trout River) and at three Indian River Lagoon sites (Stations 10, 12, and 13). The Julington Creek and Trout River sites are both in the immediate vicinity of naval facilities. High TBT concentrations in the Indian River appear to reflect the many years of intensive year-round recreational and commercial boating activities in these estuaries. Boat ramps and marinas are near all three of the contaminated Indian River sites.

Total alkanes comprise another contaminant group with an uncertain bioeffect range in sediments. Sediment quality guidelines, such as ER-L/ER-M and TEL/PEL values, have not been established for total alkanes. Macauley et al. (1994) used a criterion of >7000 ng/g to flag concentrations within a potential toxicity range for estuaries of the Louisianian Province. Less than 1% of the Carolinian Province had total alkane concentrations above this level (CDF not shown). This small portion of affected area was limited to the small estuarine class. As with TBT, the total alkane data were not included in the above CDF estimates of degraded vs. undegraded estuaries.

The broad-scale probabilistic sampling framework of EMAP-E was not designed to support detailed characterizations of pollutant distributions and sources within individual estuarine systems. Typically, a single randomly selected station represented an entire estuary. Thus, some estuaries classified as undegraded may include additional contaminated portions outside of the immediate vicinity of randomly selected sites. Such impacts were clearly detected in this study at nonrandom sites near potential contaminant sources. For example, significant chromium contamination was observed in sediments at Shipyard Creek, a supplemental site in Charleston Harbor, SC. The chromium concentration at this site (CP94SPY) was 1,911 μg/g (Appendix D), which exceeds the ER-M value for chromium (Long et al. 1995) by more than a factor of five and is much greater than concentrations considered to be "high" in national and worldwide chromium databases (Cantillo and O'Connor 1992).

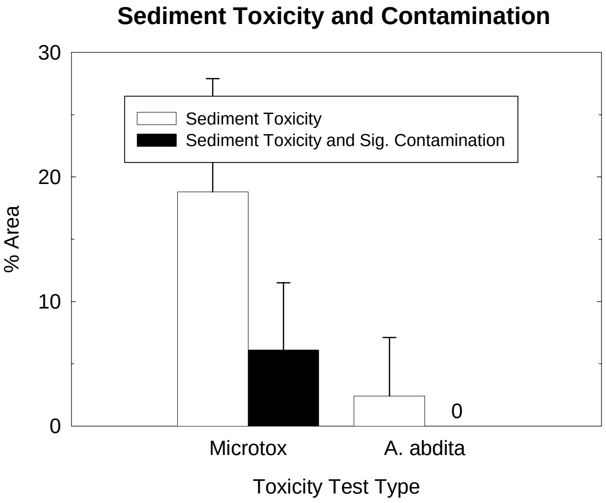


FIGURE 3.2-10. Percent area (and 95% C.I.) of Carolinian Province estuaries with sediment contamination in combination with significant toxicity test results. Significant *Ampelisca abdita* (amphipod) toxicity = mortality relative to control ≥20% and significant at α = 0.05. Sig. Microtox® = EC_{50} ≤0.2% if silt clay content of sediment ≥20%, or EC_{50} ≤0.5 if silt-clay content <20%. Significant contamination = ≥ 3 ER-L / TEL exceedances, or ≥1 ER-M / PEL exceedance.

3.2.4 Sediment Toxicity

Only one of the 84 base stations — Station 63 in the Albemarle Sound, NC — showed significant toxicity based on the *Ampelisca abdita* assay (Fig. 3.2-10 and Appendix E). A sample was regarded as being toxic if percent survival in the test sediment was statistically different from the corresponding control survival (tested at α = 0.05) and ≤80% of control survival. The toxicity observed at Station 63 represented only 2% of the area of the province. In comparison, about 10% of the estuaries in both the Louisianian Province (Macauley et al. 1994) and the Virginian Province (Strobel et al. 1995) were reported to contain toxic sediments based on this assay; samples were collected during the summer 1992 in both cases.

The *A. abdita* assay did not appear to be a very sensitive tool for detecting degraded sediment conditions. There were no significant correlations between amphipod survival and any of the sediment contaminants (Table 3.2-3). Several stations where there was no evidence of *A. abdita* toxicity contained highly contaminated sediments (Appendix E). Moreover, the single toxicity occurrence at Station 63 was not accompanied by any evidence of chemical contamination (Fig. 3.2-10, Appendix E). All contaminants at this site were below corresponding ER-L or TEL bioeffect guidelines. A high unionized ammonia concentration of 510 μg/L in sediment porewater may have contributed to the toxicity of this sample (Appendix E). The USEPA (1989) established water quality criteria for unionized ammonia in marine systems based on a chronic value of 40 μg/L and an acute value of 500 μg/L. The No Observable Effect Concentration (NOEC) for unionized ammonia and *Ampelisca abdita* is 400 μg/L (USEPA 1994b).

In addition to having exhibited low sensitivity to contaminant associated toxicity, *Ampelisca abdita* did not appear to be very representative of southeastern estuaries based on the present sampling. For example, this species accounted for only 0.5% of the total infaunal abundance in

Carolinian Province samples, and occurred in about half as many samples as the congener amphipods *A. verrilli* and *A. vadorum*. As noted in the methods section, an alternative assay using *A. verrilli* is being developed and evaluated as part of the present study.

Eighteen core stations, representing 19% of the area of the province, showed significant Microtox® toxicity (Fig. 3.2-10, Appendix F). Results were expressed as EC_{50} values — the sediment concentration causing a 50% reduction in light production by photoluminescent bacteria *Vibrio fischeri*. Because of the strong inverse relationship between Microtox® EC_{50} values and percent silt-clay content (Table 3.2-3), evaluation criteria were established for two separate silt-clay classes. Sediments with ≥20% silt-clays (muddy sands to muds) were classified as being toxic if EC_{50} values were ≤0.2%; sediments with <20% silt-clays (sands) were classified as being toxic if EC_{50} values were ≤0.5%. Lower EC_{50} values in muddier sediments are believed to be caused by physical adsorption of the bacteria to the sediment particles. Ringwood et al. (1995b) demonstrated this effect by conducting Microtox® assays in artificial sediment mixtures of pure sand and kaolin clay and evaluating the EC_{50} values as a function of the finer-particle content.

EC_{50} values showed strong negative correlations with several contaminants: DDD, dieldrin, chlordane, and total PCBs (Table 3.2-3). However, only six of the 18 base sites that had toxic sediments based on the Microtox® assay also had high levels of contaminants (Appendix F). These sites represented only 6% of the area of the province (Fig. 3.2-10). False positives (the 12

Table 3.2-3. Results of Spearman rank-order correlations (r_s) between toxicity indicators and various habitat and exposure indicators. All contaminant variables were normalized to percent silt-clay before analysis (Concentration / % silt-clay). S = significant correlation at Dunn-Sidák adjusted significance level of $\alpha' = 0.0030$ (to control for experiment-wise error rate), based on unadjusted $\alpha = 0.05$ and k = 17 comparisons; NS = not significant.

	Microtox® EC_{50} (% sediment dilution)			*Ampelisca abdita* Survival (% relative to control)		
Measure	r_s	$P > \lvert r_s \rvert$	Result	r_s	$P > \lvert r_s \rvert$	Result
Porewater Ammonia	-0.04	0.7541	NS	-0.00	0.9925	NS
% Silt-Clay Content	-0.72	0.0001	S	0.31	0.0044	NS
Total Organic Carbon	-0.65	0.0001	S	0.40	0.0002	S
Arsenic	0.29	0.0084	NS	0.02	0.8692	NS
Chromium	0.67	0.0001	S	-0.23	0.0357	NS
Nickel	0.50	0.0001	S	-0.08	0.4695	NS
Antimony	-0.15	0.1743	NS	0.32	0.0038	NS
Zinc	0.66	0.0001	S	-0.21	0.0650	NS
Mercury	-0.19	0.0796	NS	-0.11	0.3181	NS
Tributyltin	-0.18	0.0983	NS	-0.06	0.5983	NS
4,4’-DDD	-0.33	0.0026	S	0.20	0.0744	NS
4,4’-DDE	-0.27	0.0139	NS	0.20	0.0751	NS
4,4’-DDT	-0.25	0.0235	NS	-0.01	0.9500	NS
Total DDT	-0.25	0.0211	NS	0.18	0.0987	NS
Dieldrin	-0.38	0.0004	S	-0.013	0.9099	NS
Chlordane	-0.34	0.0017	S	0.08	0.4953	NS
Total PCBs	0.53	0.0001	S	-0.28	0.0124	NS

cases of high toxicity and low contamination) may be attributable in part to high unionized ammonia levels. Though province-wide concentrations of unionized ammonia nitrogen (UAN) overall showed no significant correlation with EC_{50} values (Table 3.2-3), 10 of the 12 Microtox® false positives were associated with sediments containing UAN at relatively high levels above 100 µg/L (Appendix F). As noted above, Microtox® responses also may be influenced by physical effects of the sediment particles.

3.3 Biotic Condition Indicators

3.3.1 Infaunal Species Richness and Diversity

One of the most common attributes used to describe faunal communities is diversity — the numbers and relative proportions of species present. Diversity measures have been used for many years as tools for assessing ecological impacts of water pollution (Wilhm and Dorris 1968, Boesch 1977). Such an application has been very popular in investigations of benthic communities. Reductions in benthic species diversity have been documented for a variety of pollution incidents, including oil spills (Sanders et al. 1980), sewage inputs (Anger 1975), discharges of paper-mill wastes (Pearson and Rosenberg 1978), and numerous other examples. Although patterns in benthic species diversity are influenced by a variety of natural environmental factors (e.g., latitudinal gradients, salinity, sediment particle size and organic content, food availability, biological interactions), certain characteristics of these biota render them very appropriate for use in pollution studies. For example, benthic fauna live in close association with bottom substrates where chemical contaminants and organic pollutants tend to accumulate, and where low-oxygen conditions are typically the most severe. Moreover, because most benthic organisms have limited mobility, it can be very difficult for them to avoid exposure to pollutants and other adverse conditions in their immediate surroundings.

One of the simplest measures of diversity is species richness, expressed in this study as the number of species present in a sample. Values of the mean number of species per grab (0.04 m^2) ranged from 0–75 (Fig. 3.3-1, Appendix G). The CDF included “low” numbers (defined here as ≤3) in 10% of the province, “moderate” numbers (>3 to <7) in 13%, and “high” numbers (≥7) in 77%.

Species richness was significantly correlated with latitude, bottom salinity, and silt-clay and TOC content of sediment (Table 3.3-1). Because of the potential influence of these natural factors on species richness, caution must be used in attempting to attribute low species numbers solely to anthropogenic stress. However, Fig. 3.3-2 shows that stations with ≤3 species per grab were always at sites that were classified as degraded based on the various exposure variables (i.e., significant sediment contamination, low DO, and/or significant sediment toxicity). Also, high numbers of species (≥7 per grab), though found at “degraded” sites, occurred in a much larger proportion of the undegraded sites. None of the degraded sites that contained high numbers of benthic species were associated with high contaminant levels or low-oxygen conditions; they were all classified as degraded based only on Microtox® toxicity hits. The difference between mean numbers of species per grab at degraded and undegraded sites was highly significant (P = 0.0001) based on the Wilcoxon rank-sum test (Table 3.3-2).

Low species richness was the most pronounced in large tidal rivers where 55% of these estuarine habitats had ≤3 species per grab (Fig. 3.3-3A). As noted above, sediment contamination also was the most pronounced in this estuarine class. Low species richness was observed in similar proportions in VA/NC and FL estuaries (11% and 14% respectively) and was not observed at any of the SC/GA sites (Fig. 3.3-3B).

TABLE 3.3-1. Results of Spearman rank-order correlations (r_s) between infaunal species indicators and various habitat and exposure indicators. All contaminant variables were normalized to percent silt-clay before analysis (Concentration / % silt-clay). S = significant correlation at Dunn-Sidák adjusted significance level of $\alpha' = 0.0024$ (to control for experiment-wise error rate), based on unadjusted $\alpha = 0.05$ and k = 21 comparisons; NS = not significant.

Habitat / Exposure Indicator	Mean Abundance per Station			Mean Richness Per Station			Mean H′ Per Station		
	r_s	$P > \lvert r_s \rvert$	Result	r_s	$P > \lvert r_s \rvert$	Result	r_s	$P > \lvert r_s \rvert$	Result
Bottom Salinity	0.38	0.0004	S	0.62	0.0001	S	0.60	0.0001	S
Bottom D.O.	0.04	0.7279	NS	0.17	0.1261	NS	0.23	0.0400	NS
Station Latitude	-0.37	0.0007	S	-0.56	0.0001	S	-0.49	0.0001	S
% Silt-Clay Content	-0.37	0.0006	S	-0.56	0.0001	S	-0.52	0.0001	S
Total Organic Carbon	-0.39	0.0003	S	-0.60	0.0001	S	-0.58	0.0001	S
Microtox® EC_{50}	0.18	0.1073	NS	0.23	0.0347	NS	0.24	0.0293	NS
Ampelisca Survival	-0.12	0.2785	NS	-0.16	0.1646	NS	-0.11	0.3254	NS
Arsenic	0.18	0.0965	NS	0.36	0.0009	S	0.33	0.0025	NS
Chromium	0.32	0.0035	NS	0.50	0.0001	S	0.47	0.0001	S
Nickel	0.18	0.1064	NS	0.32	0.0035	NS	0.29	0.0080	NS
Antimony	0.01	0.9116	NS	-0.07	0.5458	NS	-0.10	0.3377	NS
Zinc	0.24	0.0322	NS	0.40	0.0002	S	0.37	0.0006	S
Mercury	0.09	0.4424	NS	0.04	0.6904	NS	-0.02	0.8896	NS
Tributyltin	0.05	0.6311	NS	0.17	0.1272	NS	0.19	0.0856	NS
4,4’-DDD	-0.32	0.0034	NS	-0.61	0.0001	S	-0.60	0.0001	S
4,4’-DDE	-0.31	0.0040	NS	-0.60	0.0001	S	-0.63	0.0001	S
4,4’-DDT	-0.18	0.1121	NS	-0.33	0.0028	NS	-0.29	0.0079	NS
Total DDT	-0.27	0.0149	NS	-0.55	0.0001	S	-0.57	0.0001	S
Dieldrin	-0.40	0.0002	S	-0.51	0.0001	S	-0.45	0.0001	S
Chlordane	-0.43	0.0001	S	-0.48	0.0001	S	-0.39	0.0003	S
Total PCBs	0.22	0.0475	NS	0.29	0.0082	NS	0.24	0.0277	NS

TABLE 3.3-2. Comparison of infaunal species richness, diversity, total faunal abundance, and abundances of dominant taxa at undegraded vs. degraded sites in the Carolinian Province. Means and results of Wilcoxon rank-sum tests for differences between undegraded and degraded sites are given. $N_{undegraded} = 52$, $N_{degraded} = 30$. N.S. = Not significant, S = Significant at $\alpha = 0.05$.

Taxa	Undegraded Stations	Degraded Stations	Z	$P > \lvert Z \rvert$	Result
Oligochaeta	22.8	18.7	-0.33	0.7409	NS
Mediomastus spp.	21.6	18.2	-1.88	0.0605	NS
Acteocina canaliculata	10.4	1.4	-3.12	0.0018	S
Mulinea lateralis	4.7	9.3	-1.80	0.0715	NS
Streblospio benedicti	7.5	3.8	-0.18	0.8537	NS
Overall Assemblage	**Undegraded Stations**	**Degraded Stations**	Z	$P > \lvert Z \rvert$	**Result**
Mean Richness	22.3	12.4	-4.26	0.0001	S
Mean Abundance	201.1	126.4	-3.37	0.0007	S
Mean H′ Diversity	3.0	1.8	-4.02	0.0001	S

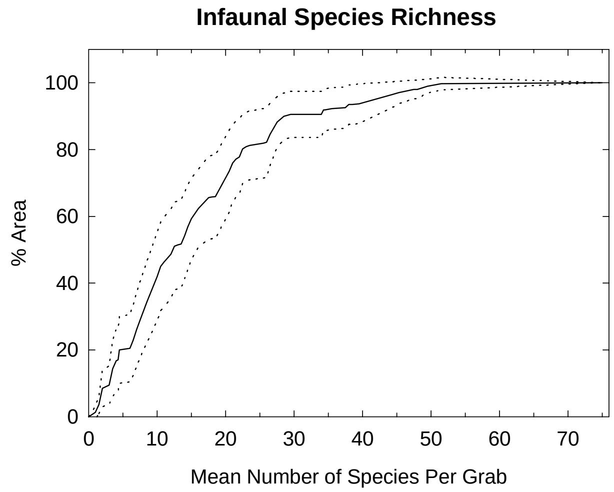


FIGURE 3.3-1. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. mean number of infaunal species per grab (0.04 m^2).

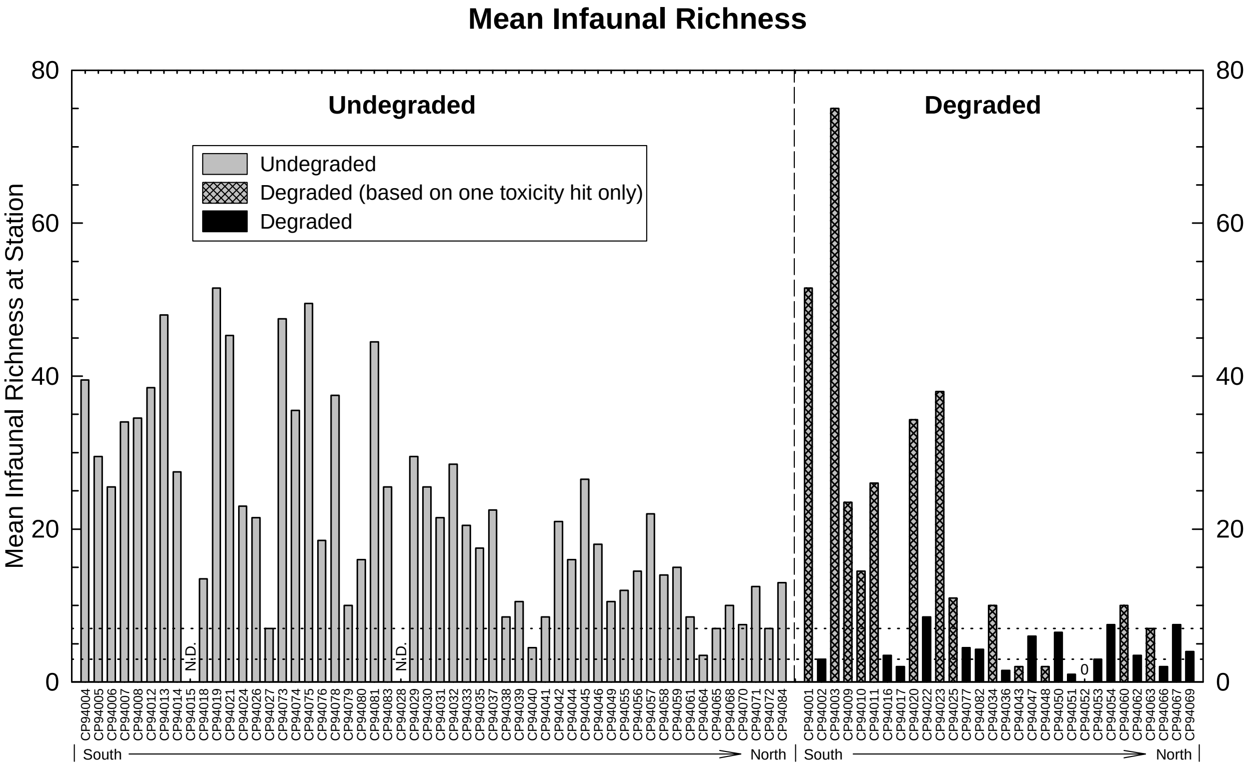


FIGURE 3.3-2. Mean infaunal richness by station, with stations grouped into degraded and undegraded categories based on contaminant levels, DO conditions, and toxicity testing results. Dotted reference lines are included to indicate low (≤3), moderate (>3 to <7), and high (≥7) mean infaunal richness values. N.D. = No data.

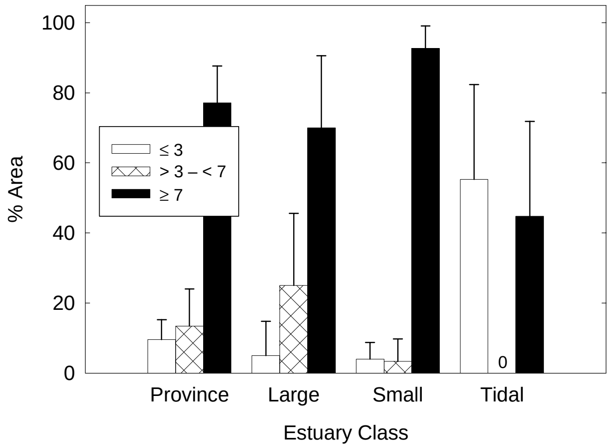
Another measure of diversity used in this study was the Shannon information function, H′ (Shannon and Weaver 1949). This index provides a combined measure of both species richness and the distribution of abundance among species. H′ (derived using base 2 logarithms) ranged from 0–4.8 (Appendix G, Fig. 3.3-4). The CDF included “low” numbers (defined here as ≤1) in 12% of the province, “moderate” numbers (>1 to <3) in 50%, and “high” numbers (≥3) in 38%.

As with species richness, H′ was significantly correlated with latitude, bottom salinity, and the silt-clay and TOC content of sediment (Table 3.3-1). Thus, the potential influence of these and possibly other unmeasured natural factors must be considered when attempting to associate low diversity values with anthropogenic stress. However, Fig. 3.3-5 shows that all but one of the base stations having H′ values ≤1 corresponded with sites also classified as degraded based on the various exposure indicators. The difference between mean H′ per grab at degraded and undegraded sites was highly significant (*P* = 0.0001) based on the Wilcoxon rank-sum test (Table 3.3-2).

Similar to species richness patterns, low H′ was the most pronounced in large tidal rivers (Fig. 3.3-6A). By subregion (Fig. 3.3-6B), low H′ was the most pronounced in the VA/NC portion of the province, occurring only rarely in SC/GA and FL estuaries. This latter result could be due in part to the natural trend of lower H′ values at more northern latitudes (Table 3.3-1); however, as noted above, all but one of the NC sites with low H′ were accompanied by additional evidence of environmental degradation based on exposure indicators.

Species richness and H′ diversity showed significant (or marginally significant) negative correlations with total DDT, DDD, DDE, dieldrin, and total chlordane (Table 3.3-1). There also

A. Infaunal Richness by Estuarine Class



B. Infaunal Richness by Subregion

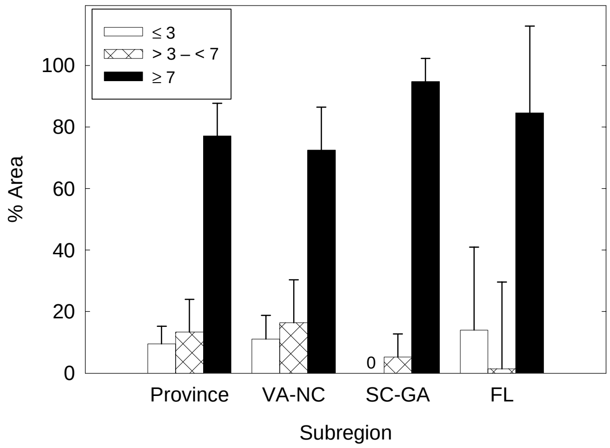


FIGURE 3.3-3. Comparison by estuarine class (A) and subregion (B) of the percent area (and 95% C.I.) of Carolinian Province Estuaries with low (≤3), moderate (>3 to <7), or high (≥7) mean infaunal richness per grab.

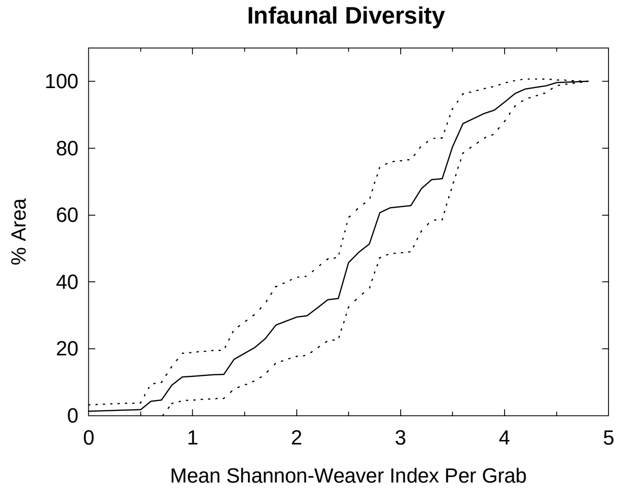


FIGURE 3.3-4. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. mean Shannon-Weaver Index (H′) per grab.

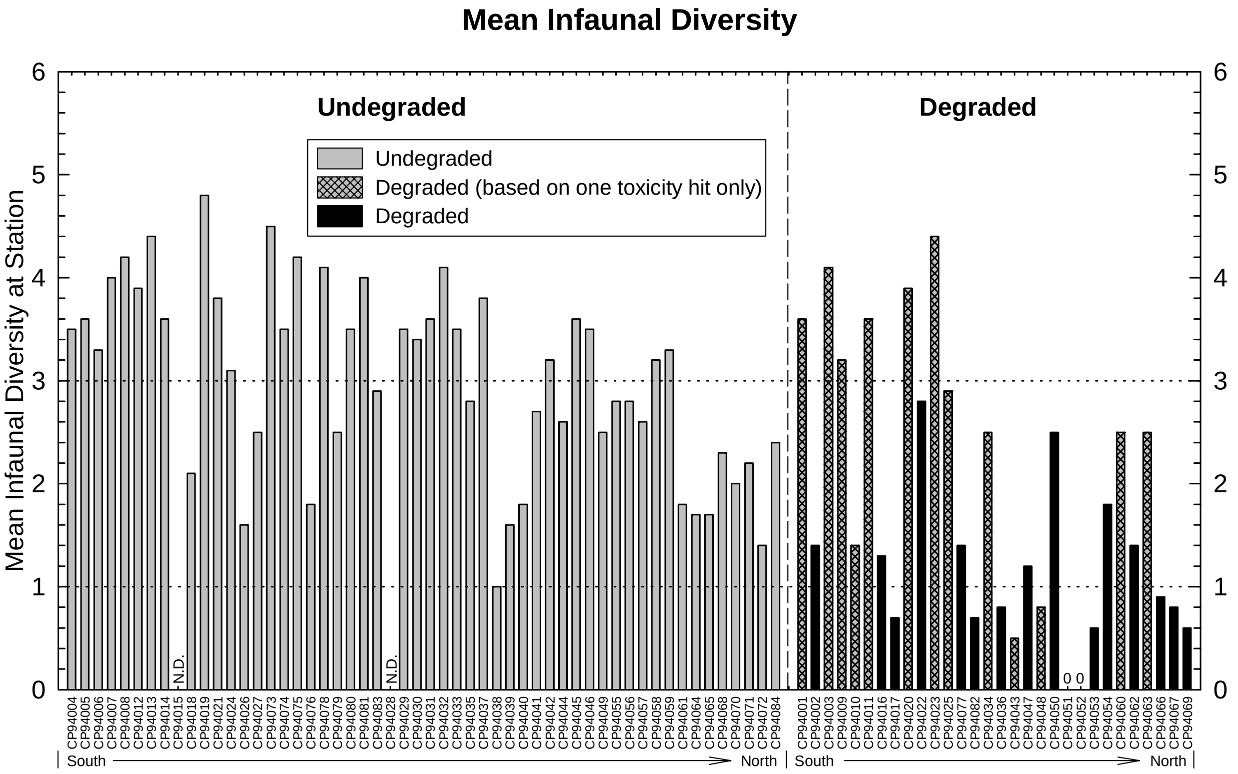


FIGURE 3.3-5. Mean infaunal diversity (H′) by station, with stations grouped into degraded and undegraded categories based on contaminant levels, DO conditions, and toxicity testing results. Dotted reference lines are included to indicate low (≤1), moderate (>1 to <3), and high (≥3) mean infaunal diversity values. N.D. = No data.

were significant positive correlations of species richness and/or H′ with arsenic, chromium, and zinc though the direction of these associations is difficult to interpret. Neither of these infaunal diversity measures were significantly correlated with dissolved oxygen or sediment toxicity.

3.3.2 Infaunal Abundance and Taxonomic Composition

Total faunal abundance is another attribute commonly used to characterize benthic communities. Abundance (mean number of individuals per grab) ranged from 0–998 (Appendix G, Fig. 3.3-7). The CDF included “low” values (defined here as ≤25) in 22% of the province, “moderate” values (>25 to <50) in 7%, and “high” values (≥50) in 71%.

As with diversity, abundance was significantly correlated with latitude, bottom salinity, and the silt-clay and TOC content of sediment (Table 3.3-1). Thus, the potential influence of these and possibly other unmeasured natural factors must be considered when attempting to associate low diversity values with anthropogenic stress. However, Fig. 3.3-8 shows that stations that had low abundance based on the above criteria usually corresponded with sites that were classified as degraded based on the various exposure indicators. For example, 13 of the 30 “degraded” stations had low infaunal abundance, while only 3 of the 52 “undegraded” sites (excluding two unsamplable sites) had low abundance. Moreover, high abundance (≥50 per grab), though found at both degraded and undegraded sites, occurred at a much larger proportion of the undegraded sites. The difference between mean abundance per grab at degraded and undegraded sites was highly significant (*P* = 0.0007) based on the Wilcoxon rank-sum test (Table 3.3-2).

Similar to the species diversity patterns, low infaunal abundance was the most pronounced in large tidal rivers (Fig. 3.3-9A). Low abundances

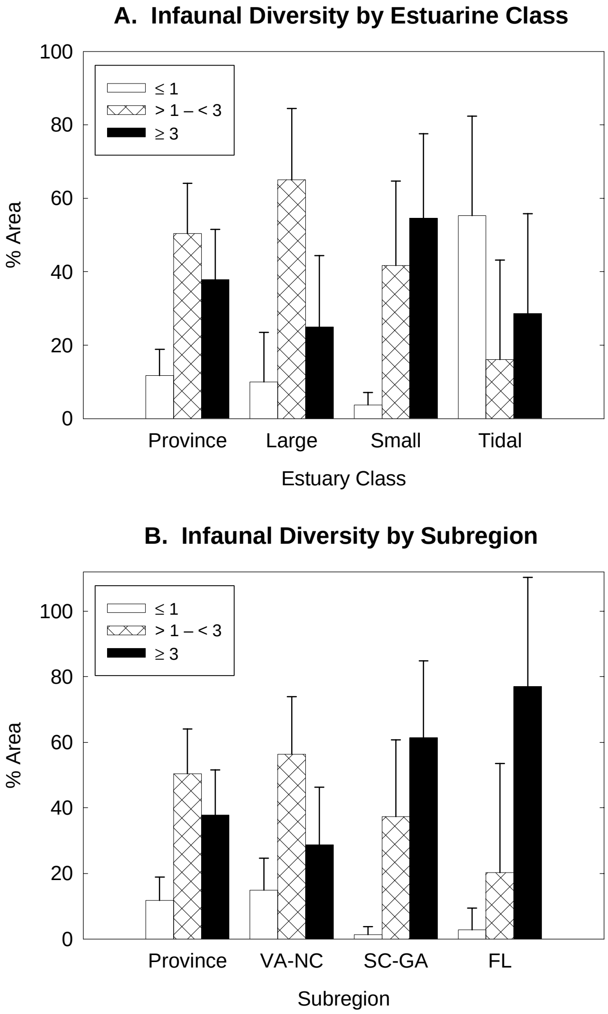


Figure 3.3-6. Comparison by estuarine class (A) and subregion (B) of the percent area (and 95% C.I.) of Carolinian Province Estuaries with low (≤1), moderate (>1 to <3), or high (≥3) mean Shannon-Weaver Index per grab.

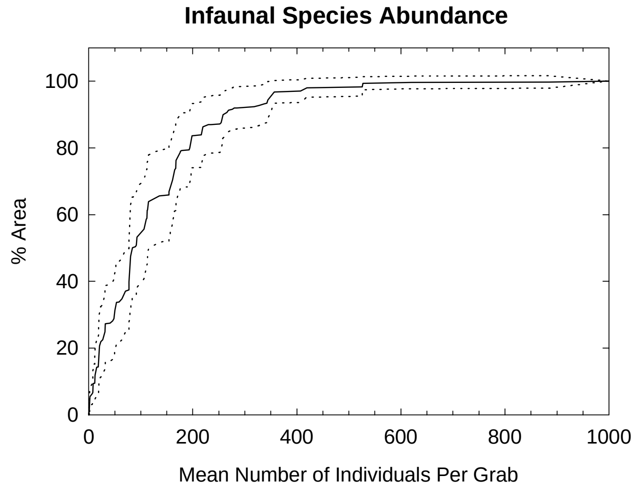


FIGURE 3.3-7. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. mean infaunal species abundance per grab.

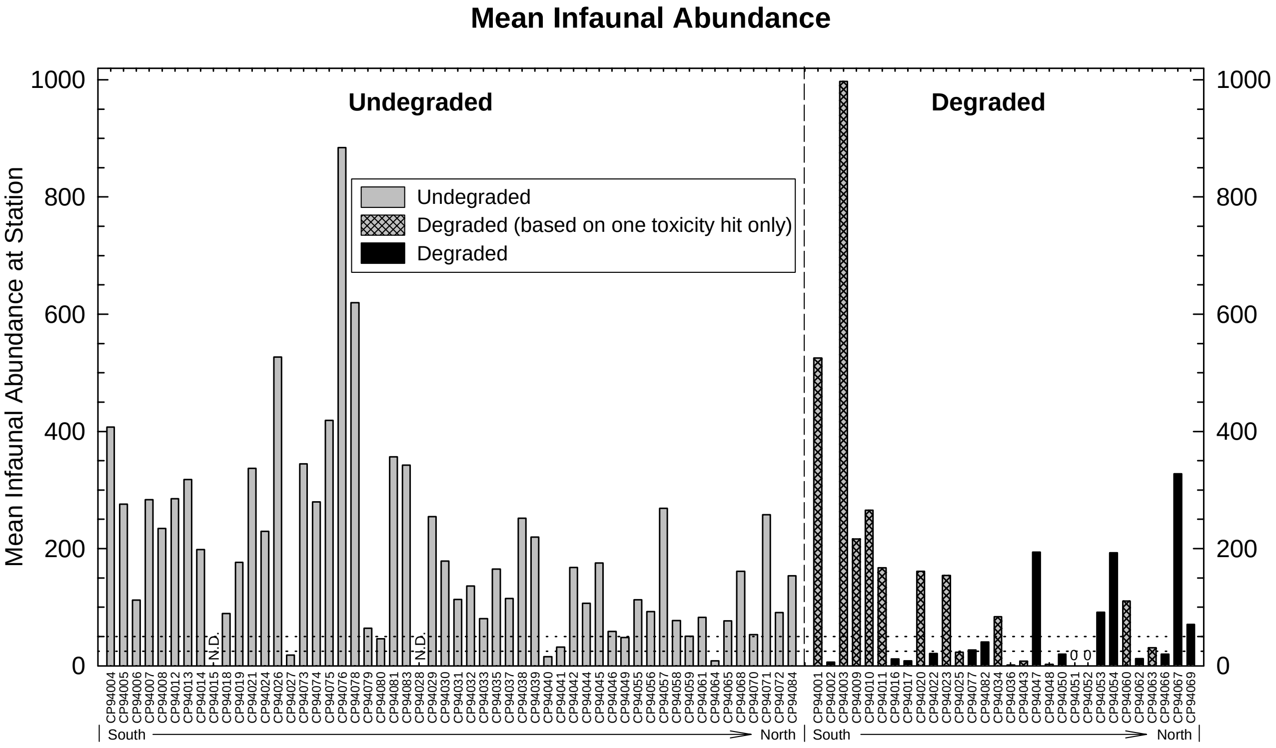


FIGURE 3.3-8. Mean infaunal abundance by station, with stations grouped into degraded and undegraded categories based on contaminant levels, DO conditions, and toxicity testing results. Dotted reference lines are included to indicate low (≤25), moderate (>25 to <50), and high (≥50) values of mean infaunal abundance. N.D. = No data.

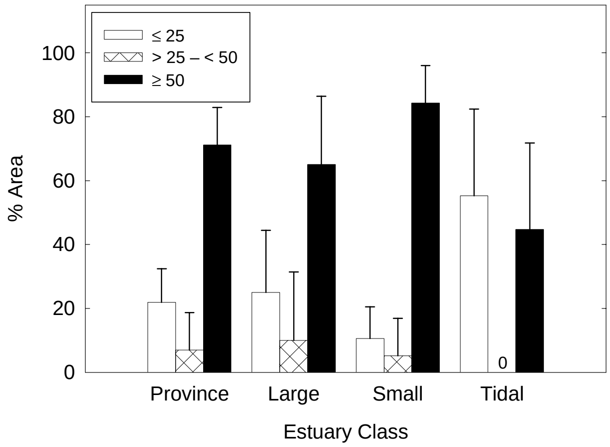
were observed in similarly small proportions (15–24%) among the three subregions (Fig. 3.3-9B).

Infaunal abundance was significantly correlated with dieldrin and total chlordane (Table 3.3-1). These same two contaminants also showed significant correlations with species richness and H′ diversity. As with the diversity measures, infaunal abundance was not significantly correlated with dissolved oxygen or sediment toxicity.

A total of 29,238 infaunal organisms, representing 505 taxa (most identified to the species level), were encountered among the 163 grabs (0.04 m^2 each) collected at base stations throughout the province. Annelids (polychaetes and tubificid oligochaetes) comprised the majority of these taxa by both abundance (63%) and species richness (51%) (Table 3.3-3). Arthropods (mostly peracarid crustaceans and chironomid insect larvae) and mollusks (gastropods and bivalves) were the next most important groups, found in similar proportions with respect to both abundance and numbers of species. The relative proportions of these broad taxonomic groups were fairly consistent across the three estuarine classes.

Table 3.3-4 summarizes the five most abundant taxa by estuarine class and subregion. Province-wide dominants (in decreasing order of abundance) were oligochaetes, the polychaete *Mediomastus* spp., the gastropod *Acteocina canaliculata*, the bivalve *Mulinia lateralis*, and the polychaete *Streblospio benedicti*. Dominance patterns showed distinct shifts among the various estuarine classes and subregions. For example, only one dominant (*Mediomastus* spp.) was common to all three subregions. However, three of the five taxa that were listed as province-wide dominants (*Mediomastus*, *Mulinia*, and *Acteocina*) also appeared as dominants in the northern-most and southern-most subregions. Thus, there was some similarity in species composition

A. Infaunal Abundance by Estuarine Class



B. Infaunal Abundance by Subregion

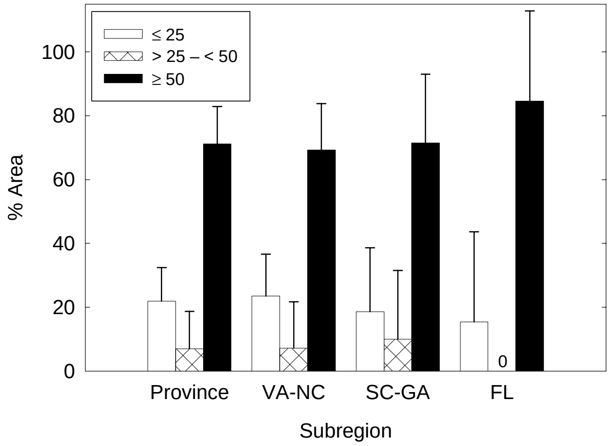


FIGURE 3.3-9. Comparison by estuarine class (A) and subregion (B) of the percent area (and 95% C.I.) of Carolinian Province estuaries with low (≤25), moderate (>25 to <50), or high (≥50) mean infaunal abundance per grab.

TABLE 3.3-3. Relative percent composition of major taxonomic groups by estuarine class.

	Percent Abundance			
Estuarine Class	Annelida	Arthropoda	Mollusca	Other
All	63.0	13.9	15.5	7.5
Large	42.0	21.8	29.0	7.3
Small	69.4	12.8	11.1	6.6
Tidal	58.9	12.7	18.9	9.5
	Percent Species			
Estuarine Class	Annelida	Arthropoda	Mollusca	Other
All	50.74	17.69	19.18	12.39
Large	46.24	21.90	21.90	9.96
Small	54.48	17.09	17.58	10.85
Tidal	45.55	16.83	21.01	16.61

between northern and southern portions of the province, although (as discussed above) diversity and abundance patterns were strongly correlated with latitude.

Three of the five province-wide dominants (*Acteocina canaliculata*, *Mediomastus* spp., and *Mulinia lateralis*) exhibited significant to near-significant differences in abundances between degraded and undegraded sites (Table 3.3-2). Abundances of *A. canaliculata* and *Mediomastus* spp. were higher at undegraded sites, which may be a reflection of their sensitivity to pollution stress (Hyland et al. 1985). In contrast, *M. lateralis* had higher abundances at degraded sites which is consistent with occasional reports on its resistance to pollution stress (Hyland et al. 1985) and population success in response to disturbance (Boesch 1974). Oligochaetes and the polychaete *Streblospio benedicti,* both of which showed no significant differences between degraded and undegraded areas, also are regarded as pollution-resistant species (Pearson and Rosenberg 1978, Hyland et al. 1985).

3.3.3 Number of Demersal Species

A total of 98 demersal species were sampled from 158 trawls conducted in the Carolinian Province. The mean number of species per trawl at a station ranged from 0.5–17.5 (Fig. 3.3-10, Appendix G). Seventy-nine percent of the area of the province had a mean of four or more species per trawl. Only 6% of the area of the province, represented by four stations, exhibited low mean species richness (defined here as ≤2 species/trawl). Three of these stations were classified as degraded based on various exposure indicators (Fig. 3.3-11). Stations where low species richness occurred were all in large tidal rivers or large estuaries of North Carolina (Fig. 3.3-12). High numbers of species occurred in similar proportions among various estuarine classes and subregions.

Overall, there was no significant difference in mean demersal richness between degraded and undegraded sites (Fig. 3.3-11 and Table 3.3-5). The criteria used to group stations into these two classes were based primarily on sediment exposure indicators. The lack of a strong linkage between adverse sediment conditions and demersal species richness is not surprising since most of the dominant species (Table 3.3-7) do not have direct contact with bottom sediments for extended periods. Furthermore, because most fishes caught in trawls were juveniles, they may not have undergone a characteristic ontogenetic shift from a planktivorous (nektonic) diet to a

TABLE 3.3-4. Abundances of dominant infaunal species (listed in decreasing order of abundance) and all infauna by estuarine class (A), and subregion (B). Mean abundance per grab (0.04 m^2) and range (minimum – maximum) over all grabs are given.

A. Province		Large		Small		Tidal	
Taxa	Abundance	Taxa	Abundance	Taxa	Abundance	Taxa	Abundance
Unidentified Oligochaete	21.3 (0 – 384)	*Acteocina canaliculata* Gastropod	10.0 (0 – 49)	Unidentified Oligochaete	35.6 (0 – 384)	*Mediomastus* spp. Polychaete	23.7 (0 – 55)
Mediomastus spp. Polychaete	20.4 (0 – 202)	*Acanthohaustorius millsi* Amphipod	9.7 (0 – 140)	*Mediomastus* spp. Polychaete	24.6 (0 – 202)	*Mulinia lateralis* Bivalve	16.9 (0 – 198)
Acteocina canaliculata Gastropod	7.1 (0 – 144)	Unidentified Oligochaete	9.4 (0 – 130)	*Sphaerosyllis perkinsi* Polychaete	9.2 (0 – 411)	*Acteocina canaliculata* Gastropod	15.7 (0 – 144)
Mulinia lateralis Bivalve	6.4 (0 – 198)	*Mediomastus* spp. Polychaete	8.0 (0 – 64)	*Tharyx killariensis* Polychaete	8.6 (0 – 325)	*Fabricinuda trilobata* Polychaete	15.4 (0 – 216)
Streblospio benedicti Polychaete	6.1 (0 – 57)	*Marenzellaria viridis* Polychaete	7.2 (0 – 61)	*Streblospio benedicti* Polychaete	7.8 (0 – 57)	*Exogone dispar* Polychaete	14.4 (0 – 239)
All Fauna (505 spp. from 163 grabs)	61.3 (0 – 440)	All Fauna	44.2 (4 – 191)	All Fauna	85.8 (0.5 – 814)	All Fauna	86.0 (0 – 522)

B. VA – NC		SC – GA		FL	
Taxa	Abundance	Taxa	Abundance	Taxa	Abundance
Mediomastus spp. Polychaete	21.7 (0 – 202)	Unidentified Oligochaete	49.4 (0.2 – 384)	*Mediomastus* spp. Polychaete	21.8 (0 – 55)
Unidentified Oligochaete	17.8 (0 – 288)	*Sphaerosyllis perkinsi* Polychaete	20.7 (0 – 411)	*Mulinia lateralis* Bivalve	16.4 (0 – 198)
Acteocina canaliculata Gastropod	6.7 (0 – 49)	*Tharyx killariensis* Polychaete	19.4 (0 – 325)	*Fabricinuda trilobata* Polychaete	16.1 (0 – 216)
Mulinia lateralis Bivalve	5.4 (0 – 66)	*Mediomastus* spp. Polychaete	16.2 (0 – 88)	*Acteocina canaliculata* Gastropod	15.7 (0 – 144)
Acanthohaustorius millsi Amphipod	4.9 (0 – 140)	*Sabellaria vulgaris* Polychaete	12.2 (0 – 125)	*Exogone dispar* Polychaete	14.4 (0 – 239)
All Fauna	56.5 (0 – 288)	All Fauna	117.9 (1 – 802)	All Fauna	84.5 (0 – 522)

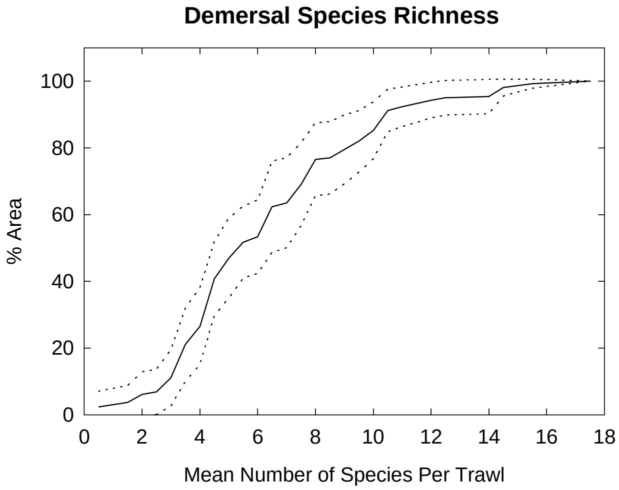


FIGURE 3.3-10. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. mean number of demersal species per trawl.

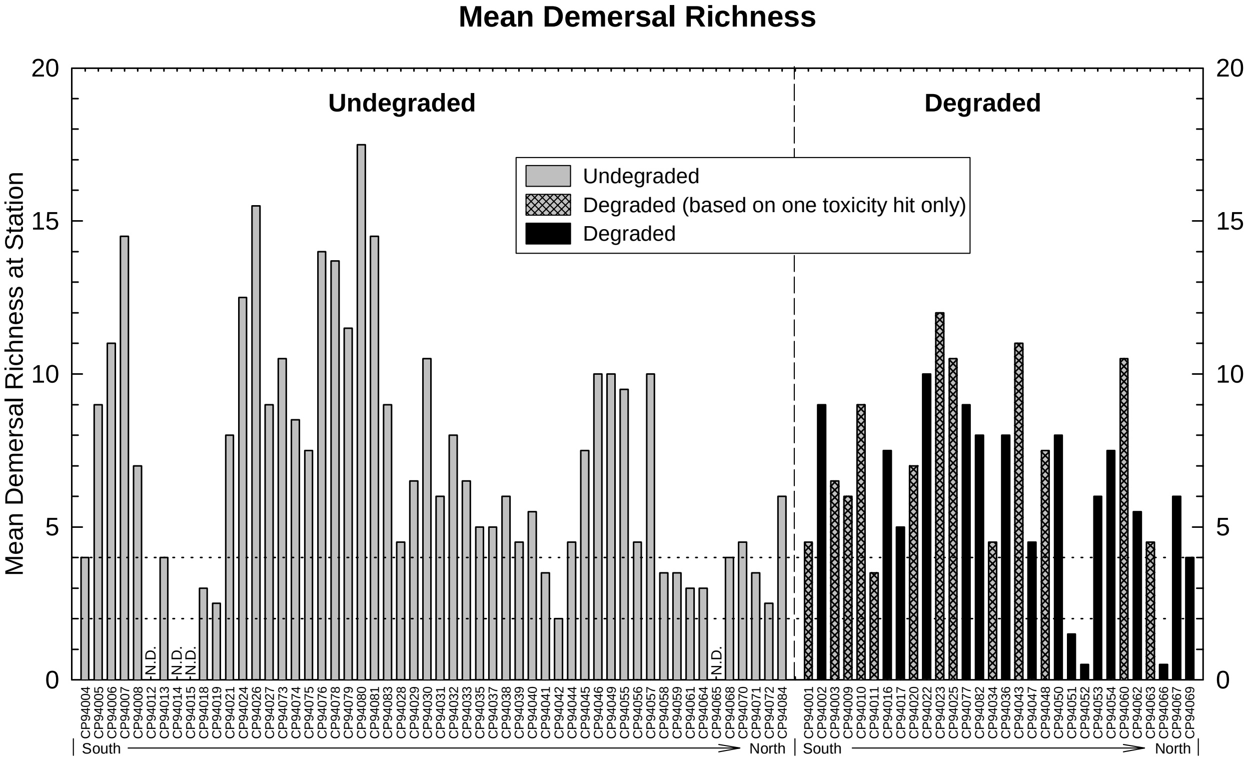


FIGURE 3.3-11. Mean number of demersal species per trawl by station, with stations grouped into degraded and undegraded categories based on contaminant levels, DO conditions, and toxicity testing results. Dotted reference lines are included to indicate low (≤2), moderate (>2 to <4), and high (≥4) values of mean demersal species richness. N.D. = No data.

TABLE 3.3-5. Comparison of demersal species richness and abundance at undegraded vs. degraded sites in the Carolinian Province. Means and results of Wilcoxon rank-sum tests for differences between undegraded and degraded sites are reported. $N_{undegraded} = 50$, $N_{degraded} = 30$. N.S. = Not significant, S = Significant at $\alpha = 0.05$.

Overall Assemblage	Undegraded Stations	Degraded Stations	*Z*	*P* > | *Z* |	Result
Mean Richness	7.4	6.6	-0.33	0.7425	NS
Mean Abundance	85.1	70.4	0.02	0.9802	NS

TABLE 3.3-6. Results of Spearman rank-order correlations (r_s) between demersal species indicators and various habitat and exposure indicators. S = significant correlation at Dunn-Sidák adjusted significance level of $\alpha' = 0.0170$ (to control for experiment-wise error rate), based on unadjusted $\alpha = 0.05$ and k = 3 comparisons; NS = not significant.

	Mean Richness per Trawl			Mean Abundance Per Trawl			Mean Number of Pathologies Per Trawl		
Habitat Measure	r_s	$P > \|r_s\|$	Result	r_s	$P > \|r_s\|$	Result	r_s	$P > \|r_s\|$	Result
Bottom Salinity	0.23	0.0433	NS	0.08	0.4758	NS	-0.07	0.5198	NS
Bottom D.O.	-0.31	0.0053	S	-0.18	0.1044	NS	-0.01	0.9503	NS
Station Latitude	-0.38	0.0006	S	-0.18	0.1173	NS	0.02	0.8553	NS

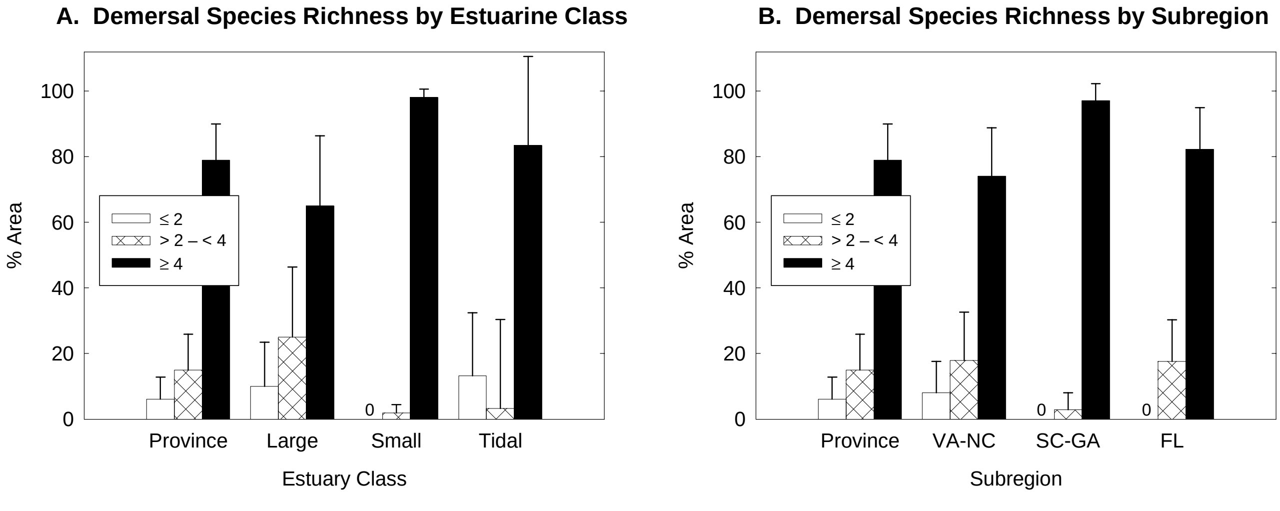


FIGURE 3.3-12. Comparison by estuarine class (A) and subregion (B) of the percent area (and 95% C.I.) of Carolinian Province estuaries with low (≤2), moderate (>2 to <4), or high (≥4) values of mean demersal species richness per trawl.

more benthic feeding mode exhibited by adults. Such organisms would not have been exposed to pollutants via contaminated benthic prey.

Significant negative correlations (r_s) were observed between mean species richness and both bottom DO and station latitude (Table 3.3-6). However, regression analysis revealed that these trends were very weak due to high variability in the data. The r^2 values for species richness as linear functions of DO and latitude were only 0.0081 and 0.0732 respectively. Although a trend of increasing species numbers with decreasing DO was implied from the correlation analysis, actually the full range of species richness values (0.5–17.5 per trawl) occurred within a fairly normal range of DO (5–8 mg/L, graph not shown). Furthermore, the apparent trend of increasing species numbers with decreasing latitude was not consistent across the entire province (Fig. 3.3-13). The regression analysis showed a curvilinear relationship due to higher species numbers in the central portion of the province. This source of variability remains unexplained.

3.3.4 Demersal Abundance

A total of 12,699 demersal organisms were sampled from 158 trawls conducted in the Carolinian Province. The mean number of demersal individuals per trawl at a station ranged from 0.5–438.5 (Fig. 3.3-14, Appendix G). Only 7% of the area of the province displayed low mean demersal abundance (defined here as ≤5 individuals/trawl). Fifty-six percent of the province had a mean abundance of at least 25 individuals per trawl. Low demersal abundance was the least pronounced in small estuaries and the SC-GA subregion (Fig. 3.3-15).

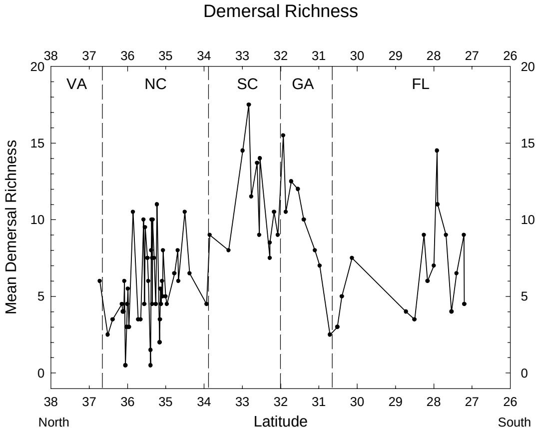


FIGURE 3.3-13. Relationship between mean demersal richness and station latitude.

Low demersal abundance was found in similar proportions in both degraded and undegraded areas of the province (Fig. 3.3-16), suggesting that this parameter was not a good discriminator between degraded versus undegraded stations. There was no significant difference in mean abundance per trawl between undegraded and degraded stations (Table 3.3-5). No significant correlations were observed between mean demersal abundance and salinity, bottom DO, or station latitude (Table 3.3-6).

Over the entire province, trawls were numerically dominated by Atlantic croaker, spot, star drum, pinfish, and brown shrimp (Table 3.3-7). Three of these five dominants (Atlantic croaker, spot, brown shrimp) are harvested commercially and/or recreationally. Other dominants associated with individual estuarine classes and subregions (e.g., blue crab, white shrimp, weakfish, southern kingfish) are also of commercial or recreational fishing value.

3.3.5 Pathological Disorders in Demersal Biota

A total of 13,304 demersal fishes, crabs, and shrimp were caught in otter trawls and examined externally for obvious signs of pathological disorders. Only 26 pathologies, representing 0.2% of the sample population, were noted (Table 3.3-8). They were recorded from 19 stations representing 17% of the area of the province. Only two stations (CP94024 and CP94053), representing <1% of the area of the province, produced

TABLE 3.3-7. Abundances of dominant demersal species (listed in decreasing order of abundance) and all demersal biota by estuarine class (A), and subregion (B). Mean abundance per trawl and range (minimum – maximum) over all trawls are given.

A.

Province		Large		Small		Tidal	
Species	Abundance	Species	Abundance	Species	Abundance	Species	Abundance
Atlantic Croaker *Micropogonias undulatus*	18.7 (0 – 337)	Atlantic Croaker *Micropogonias undulatus*	32.2 (0 – 337)	Atlantic Croaker *Micropogonias undulatus*	16.4 (0 – 104)	Silver Perch *Bairdiella chrysoura*	15.5 (0 – 146)
Spot *Leiostomus xanthurus*	10.9 (0 – 168)	Spot *Leiostomus xanthurus*	7.0 (0 – 36)	Star Drum *Stellifer lanceolatus*	13.8 (0 – 205)	Spot *Leiostomus xanthurus*	9.0 (0 – 73)
Star Drum *Stellifer lanceolatus*	7.6 (0 – 205)	Pinfish *Lagodon rhomboides*	4.0 (0 – 73)	Spot *Leiostomus xanthurus*	13.3 (0 – 168)	Atlantic Croaker *Micropogonias undulatus*	8.3 (0 – 102)
Pinfish *Lagodon rhomboides*	5.0 (0 – 84)	Blue Crab *Callinectes sapidus*	2.5 (0 – 19)	White Shrimp *Penaeus setiferus*	8.5 (0 – 133)	Pigfish *Orthopristis chrysoptera*	5.6 (0 – 64)
Brown Shrimp *Penaeus aztecus*	4.7 (0 – 82)	Hogchoaker *Trinectes maculatus*	2.2 (0 – 42)	Brown Shrimp *Penaeus aztecus*	7.8 (0 – 82)	Weakfish *Cynoscion regalis*	3.0 (0 – 34)
All Fauna (98 spp. from 158 trawls)	46.3 (0 – 363)	All Fauna	47.9 (0 – 406)	All Fauna	58.9 (0 – 248)	All Fauna	40.1 (0 – 208)

B.

VA – NC		SC – GA		FL	
Species	Abundance	Species	Abundance	Species	Abundance
Atlantic Croaker *Micropogonias undulatus*	27.2 (0 – 337)	Star Drum *Stellifer lanceolatus*	30.4 (0 – 205)	Silver Perch *Bairdiella chrysoura*	16.6 (0 – 146)
Spot *Leiostomus xanthurus*	11.8 (0 – 73)	White Shrimp *Penaeus setiferus*	18.2 (0 – 133)	Pigfish *Orthopristis chrysoptera*	6.0 (0 – 64)
Pinfish *Lagodon rhomboides*	7.7 (0 – 84)	Spot *Leiostomus xanthurus*	16.7 (0 – 168)	Blue Crab *Callinectes sapidus*	4.2 (0 – 19)
Brown Shrimp *Penaeus aztecus*	7.0 (0 – 82)	Atlantic Croaker *Micropogonias undulatus*	12.4 (0 – 60)	Silver Jenny *Eucinostomus gula*	3.0 (0 – 28)
Blue Crab *Callinectes sapidus*	4.9 (0 – 34)	Hogchoaker *Trinectes maculatus*	7.0 (0 – 64)	Southern Kingfish *Menticirrhus americanus*	3.0 (0 – 40)
All Fauna	57.5 (0 – 382)	All Fauna	84.7 (0 – 246)	All Fauna	31.0 (0 – 155)

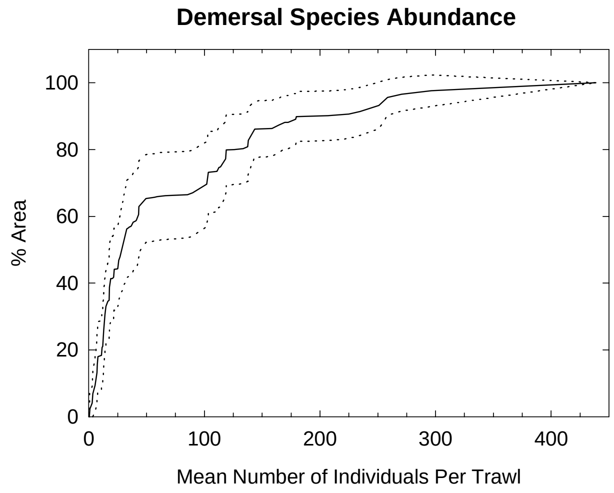


FIGURE 3.3-14. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. mean demersal abundance per trawl.

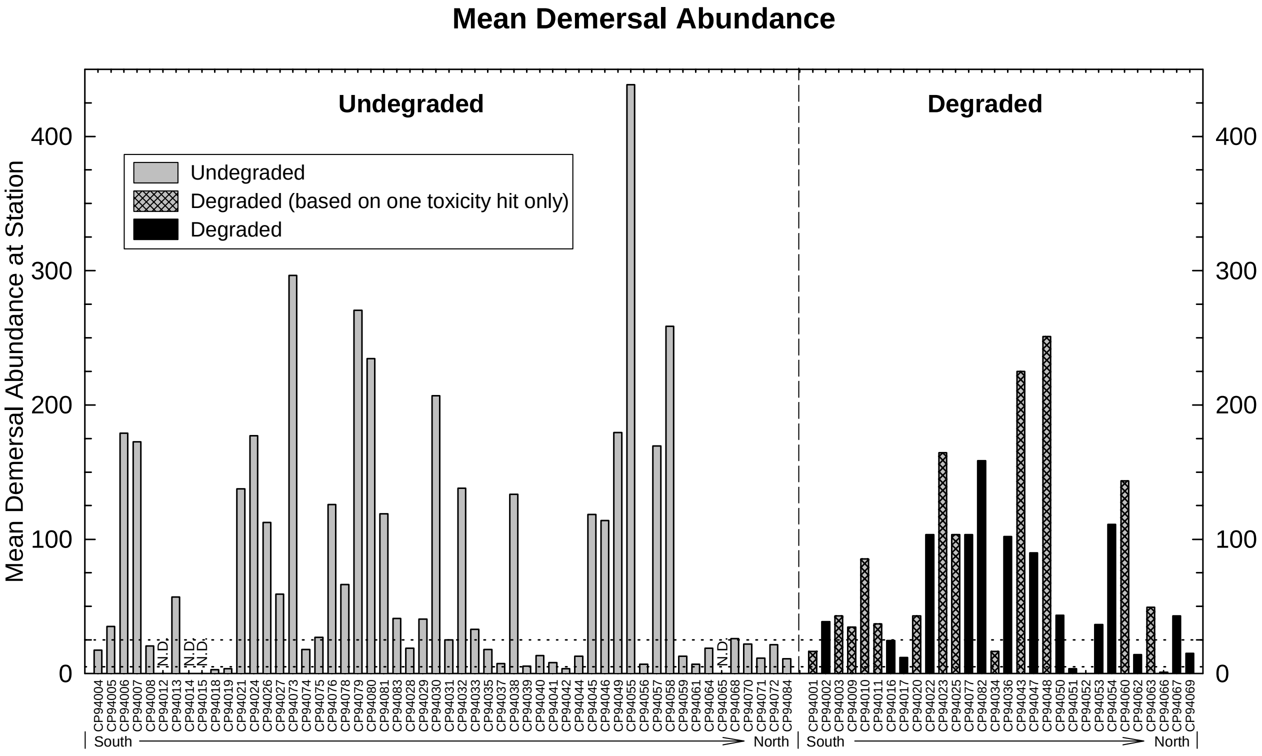


FIGURE 3.3-16. Demersal species abundance (mean number of individuals per trawl) by station, with stations grouped into degraded and undegraded categories based on contaminant levels, DO conditions, and toxicity testing results. Dotted reference lines are included to indicate low (≤5), moderate (>5 to <25), and high (≥25) values of mean demersal abundance per trawl. N.D. = No data.

relatively high mean numbers of pathologies per trawl, defined here as >1 (Fig. 3.3-17). However, of these stations, both in small estuaries, only one (CP94053) coincided with areas that showed additional signs of environmental degradation based on various exposure indicators (Fig. 3.3-18). The remaining 17 stations that produced moderate numbers of mean pathologies per trawl (0.5–1) were distributed over both degraded and undegraded areas in similar proportions and thus included cases that did not appear to be associated with anthropogenic sources of stress. There were no significant correlations (tested at α = 0.05) between mean number of pathologies per trawl and bottom salinity, bottom DO, or station latitude (Table 3.3-6).

Pathological disorders in fishes (lumps due to internal growths, external growths, ulcers, and fin erosion) were observed at 12 stations representing 12% of the area of the province (Table 3.3-8). The affected specimens (16) represented 0.14% of the sampled fish population. By species (Table 3.3-9), the highest percentage of pathologies was noted in Atlantic menhaden (18.2% of the menhaden examined). Pathologies were also observed in white catfish (9.5%), silver jenny (2.2%), silver perch (0.2%), Atlantic croaker (0.2%), and spot (0.1%). Fin erosion was the most prevalent type of fish pathology, followed by ulcers, external growths, and lumps (none observed). Five of the stations where fish pathologies were observed (CP94048, CP94053, CP94054, CP94062, and CP94067) were in areas

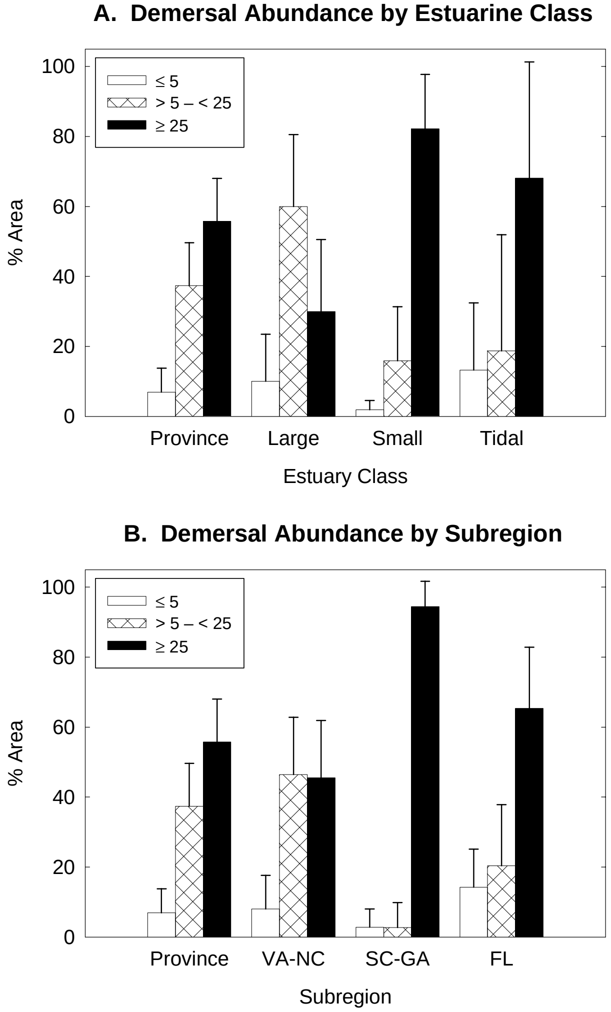


FIGURE 3.3-15. Comparison by estuarine class (A) and subregion (B) of the percent area (and 95% C.I.) of Carolinian Province estuaries with low (≤5), moderate (>5 to <25), or high (≥25) values of mean demersal abundance per trawl.

TABLE 3.3-8. Summary of the occurrences of pathologies in demersal biota of the Carolinian Province.

Pathology Type	Number of Pathologies	Number of Biota Examined	% of Biota Examined	Number of Stations	% Area ± 95 % C.I.
Fish Pathologies	16	10,483	0.14	12	12 ± 8
Shrimp Cotton Disease	9	1,603	0.56	6	5 ± 4
Crab Shell Disease	1	613	0.16	1	1 ± 2
All Pathologies	26	13,304	0.20	19	17 ± 9

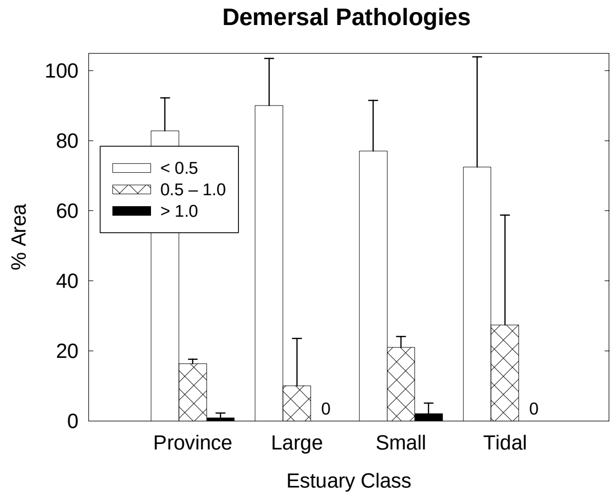


FIGURE 3.3-17. Percent area (and 95% C.I.) of Carolinian Province estuaries with low (<0.5), moderate (0.5 to 1.0), and high (>1.0) mean numbers of demersal pathologies per trawl.

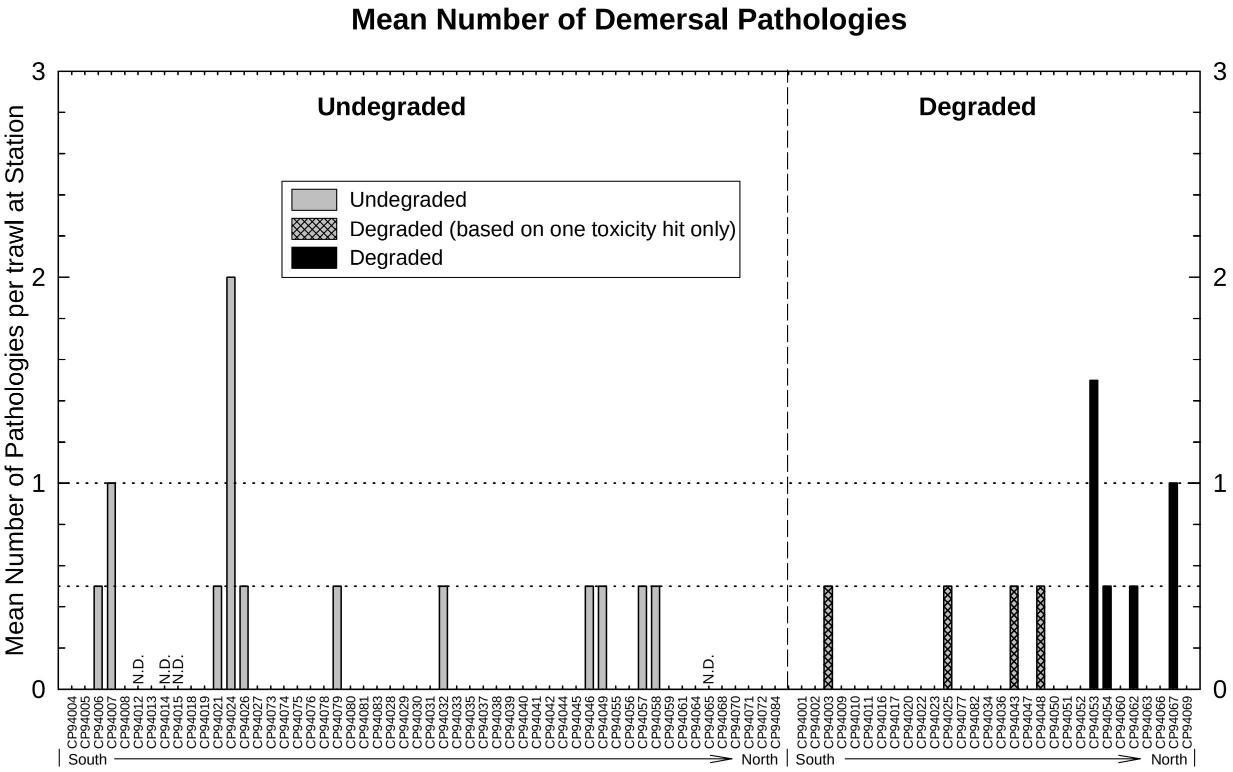


FIGURE 3.3-18. Mean number of demersal pathologies per trawl by station, with stations grouped into degraded and undegraded categories based on contaminant levels, DO conditions, and toxicity testing results. Dotted reference lines are included to indicate low (<0.5), moderate (0.5 to 1.0), and high (>1.0) mean numbers of demersal pathologies per trawl. N.D. = No data.

TABLE 3.3-9. Breakdown by species of the occurrences of pathologies in demersal biota.

Taxon	Number of Pathologies	Number Examined	% of Taxon Examined	% of All Biota Examined [a]	Pathology Type [b]	States and Stations Where Observed	
Fishes							
Atlantic Croaker (*Micropogonias undulatus*)	5	3079	0.2	0.04	4 FE, 1 UL	NC	(32, 46, 48, 49,58)
Spot (*Leiostomus xanthurus*)	2	1791	0.1	0.02	1 FE, 1 UL	NC	(57, 67)
Silver Perch (*Bairdiella chrysoura*)	1	495	0.2	0.01	1 FE	FL	(6)
Silver Jenny (*Eucinostomus gula*)	2	89	2.2	0.02	2 FE	FL	(7)
Atlantic Menhaden (*Brevoortia tyrannus*)	4	22	18.2	0.03	3 FE, 1 UL	NC	(53, 54)
White Catfish (*Ameiurus catus*)	2	21	9.5	0.02	1 FE, 1 GR	NC	(62, 67)
Crustaceans							
Blue Crab (*Callinectes sapidus*)	1	613	0.2	0.01	1 SD	SC	(79)
White Shrimp (*Penaeus setiferus*)	6	760	0.8	0.04	6 CD	GA	(21, 24, 26)
Brown Shrimp (*Penaeus aztecus*)	1	795	0.1	0.01	1 CD	NC	(43)
Pink Shrimp (*Penaeus duorarum*)	1	15	6.7	0.01	1 CD	GA	(25)
Unidentified Shrimp (*Penaeus* sp.)	1	33	3.0	0.01	1 CD	FL	(3)

[a] Total number of trawl biota examined = 13,304

[b] FE = fin erosion, UL = ulcer, GR = growth, CD = cotton disease, SD = shell disease

that showed additional signs of environmental degradation based on exposure indicators (Fig. 3.3-18).

Shrimp "cotton disease" was noted at six stations representing 5% of the area of the province (Table 3.3-8). The diseased specimens represented 0.56% of the sampled shrimp population. Although cotton disease was more common in white shrimp (*Penaeus setiferus*), it was observed in other penaeid shrimp as well (Table 3.3-9). Three of the six stations where this condition was recorded (CP94003, CP94025, and CP94043) showed other signs of environmental degradation based on exposure indicators (Fig. 3.3-18). The cause of cotton disease (also called milk disease) is believed to be microsporidian parasites (Johnson 1989). High occurrences of cotton disease could have a negative effect on commercial fisheries due to a decline in the marketability of the diseased shrimp. Also, an absence of eggs has been noted in female shrimp infected with cotton disease (Johnson 1989). Thus, the disease could cause long-term reductions in shrimp populations.

Only one station (CP94079), a degraded site in Charleston Harbor, showed an incidence of shell disease in the blue crab *Callinectes sapidus* (Tables 3.3-8 and 3.3-9). A single diseased crab was found at this station, which represented 0.2% of the area of the province. Crab shell disease can occur as rust-like spots on the carapace and appendages, large ulcers, or losses of portions of the body. Though the etiology is uncertain, a number of pathogens (fungi and chitinoclastic bacteria of the genera *Vibrio* and *Pseudomonas*) have been reported from lesions (Johnson 1989). Increased incidences of shell disease have been reported from polluted environments (Young and Pearce 1975) and there is some evidence of effects on immunological function in crabs from such areas (Noga et al. 1990). During the 1993 Carolinian Province pilot study (Ringwood et al. 1995a), 11 diseased crabs (from a total sample of 270 crabs) were found at four of the 24 stations sampled. All four of these stations were in polluted areas.

3.4 Aesthetic Indicators

The presence of anthropogenic debris ("trash") in surface and bottom waters provides an obvious sign of human impacts. Though floating trash was observed in <1% of the surface waters of the province, bottom debris was found in about 10% of these estuaries (Fig. 3.4-1). In comparison, bottom debris was reported in 16% of Louisianian Province estuaries (Summers et al. 1993b, for 1991 index period) and in 20% of Virginian Province estuaries (Strobel et al. 1995, for overall 1990 – 1993 index period). Two other indicators of human activity were the presence of oil and noxious sediment odor (i.e., smell of sewage, oil, or H_2S). Oil was observed only in 2% of the bottom sediments of the province and in none of the surface waters (Fig. 3.4-2). Noxious odors were detectable in 14% of the province sediments (Fig. 3.4-3). Bottom debris, oily sediments, and noxious sediment odors were the most pronounced in large tidal rivers and the least pronounced in large estuaries. Such a pattern is logical given the higher intensity of industry, human settlement, and recreational activities in the vicinity of large tidal rivers and small estuarine systems.

Secchi-disk readings were taken at each station as a measure of water clarity. Secchi depths ranged from 0.4–2.1 m (Fig. 3.4-4). A secchi depth <0.5 m was used as a criterion to characterize low water clarity (*sensu* Summers et al. 1993b) reflecting, for example, the inability of a person to see his hand in front of his face. Only 1% of the Carolinian Province estuaries had low water clarity (poor visibility) based on this criterion. In contrast, Summers et al. (1993b) found a much higher percentage (24%) of Louisianian estuaries with secchi depths <0.5 m. Fifty-six percent of the Carolinian Province estuaries had intermediate water clarity (secchi depths of 0.5–1.0 m) and 43% had relatively high water clarity (secchi depths >1.0 m). Similar proportions were observed among the various estuarine classes (Fig. 3.4-5).

Turbid waters are often interpreted as a sign of poor environmental quality caused by factors such as nutrient over-enrichment. However, it must be understood that turbid waters also are a natural characteristic of estuaries due to factors such as high primary productivity, large tidal ranges, and high detrital and sediment loadings. Thus, the secchi-disk data must be interpreted with caution.

3.5 Environmental Conditions Based on Combinations of Exposure, Aesthetic, and Biological Response Indicators

Degraded infaunal assemblages were more closely coupled with sediment contamination than with any of the other indicators of exposure or aesthetic quality (Table 3.4-1A). Low infaunal diversity (H′), richness, and abundance were accompanied by significant sediment contamination in 9%, 7%, and 12% of the area of the province, respectively. Of the remaining exposure indicators, sediment toxicity based on the Microtox® assay showed the next highest amount of areal overlap with low values of these benthic variables. Noxious sediment odor was the aesthetic indicator most coupled with evidence of degraded infaunal assemblages.

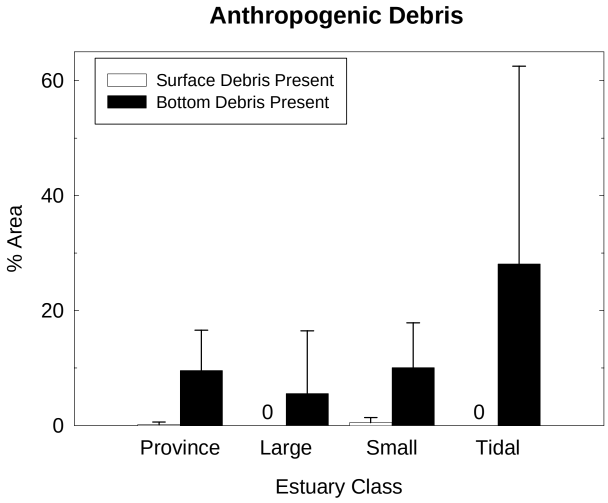


FIGURE 3.4-1. Percent area (and 95% C.I.) of Carolinian Province estuaries with anthropogenic debris present in surface waters or on the bottom.

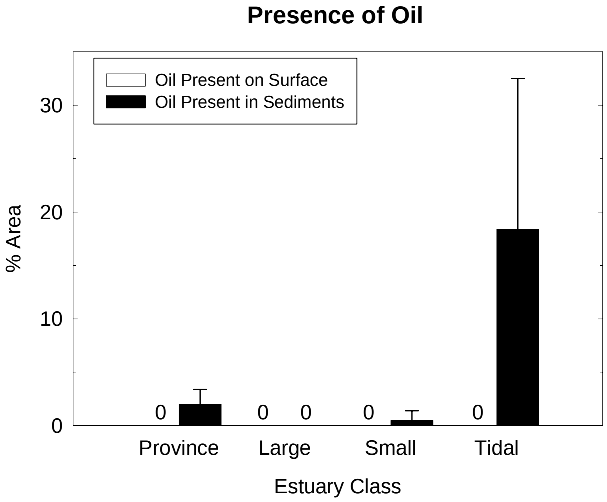


FIGURE 3.4-2. Percent area (and 95% C.I.) of Carolinian Province estuaries with oil detected (by smell or sight) in surface waters or in bottom sediments.

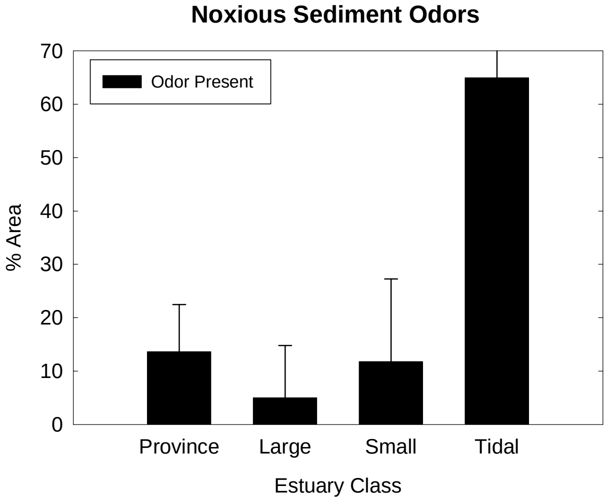


FIGURE 3.4-3. Percent area (and 95% C.I.) of Carolinian Province estuaries with noxious sediment odors (sulfur, oily, or sewage smell).

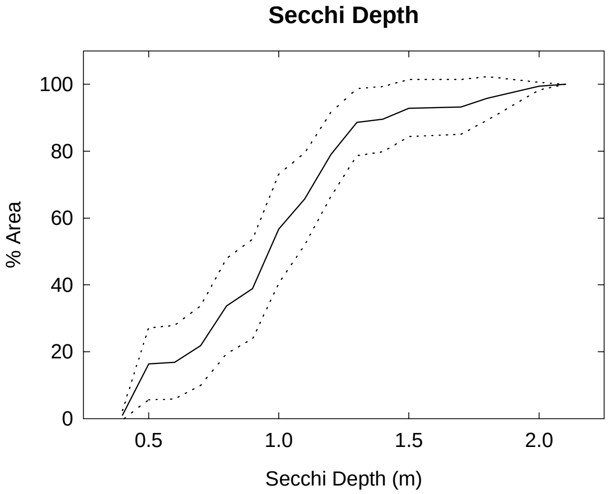


FIGURE 3.4-4. Percent area (and 95% C.I.) of Carolinian Province estuaries vs. secchi depths (m). Calculations are based on stations with bottom depths >0.5 m (N = 77).

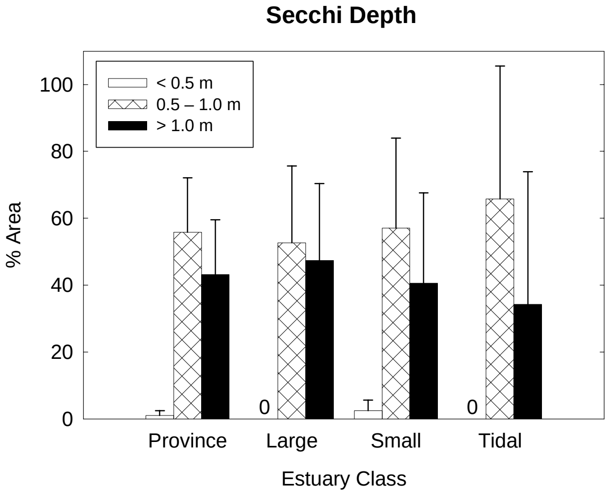


FIGURE 3.4-5. Percent area (and 95% C.I.) of Carolinian Province estuaries with low (<0.5 m), moderate (0.5 to 1.0 m), or high (>1.0 m) secchi depths. Calculations are based on stations with bottom depths >0.5 m (N = 77).

Low demersal species richness and abundance were observed in only 6% and 7% of the area of the province respectively (Table 3.4-1A). In the few places where these conditions occurred, they usually were accompanied by low DO and/or high sediment contamination. Sediment contamination also was observed at one of the two sites where a high number of pathologies in demersal biota were recorded. Noxious sediment odor was the only aesthetic indicator observed at sites where there also was evidence of degraded demersal assemblages.

Over half (54%) of the Carolinian Province showed no major evidence of environmental degradation based on any of the measured biotic, exposure, and aesthetic variables (Table 3.4-1B). Degraded conditions based on exposure and aesthetic indicators, independent of biotic conditions, were observed in about 40% of the province. Of these areas, about 31% were represented by potentially harmful levels of one or more of the various exposure indicators. Adverse biological conditions, independent of exposure or aesthetic variables, were observed in about 29% of the province.

Twenty percent of the area of the province, represented by 17 of the 84 base stations, exhibited adverse biological conditions coupled with evidence of pollution exposure (significant sediment toxicity, high sediment contamination in excess of bioeffect guidelines, or low DO concentrations in bottom waters). These 17 stations are listed in Table 3.4-2. The majority (11) of these sites were in North Carolina. Most were characterized by degraded infaunal assemblages accompanied by high sediment contamination and/or significant sediment toxicity based on the Microtox® assay.

TABLE 3.4–1. Summary of the overall condition of Carolinian Province estuaries based on various combinations of exposure, aesthetic and biotic condition indicators. Percent area (and number of stations) are given.

A.		Exposure and Aesthetic Indicators							
Biotic Condition Indicators		Low DO [a] (5%, N=3)	Sig. Sediment Contamination [b] (16%, N=15)	Sig. Amphipod Toxicity [c] (2%, N=1)	Sig. Microtox Toxicity [d] (19%, N=18)	Low Water Clarity [e] (1%, N=3)	Noxious Sediment Odor (14%, N=13)	Oily Sediments (2%, N=2)	Anthropo-genic Debris Present (9%, N=16)
Low Infaunal Diversity [f]	(12%, N=12)	4 (2)	9 (9)	0 (0)	7 (6)	< 1 (1)	6 (7)	2 (2)	1 (3)
Low Infaunal Richness [g]	(9%, N=9)	4 (2)	7 (7)	0 (0)	5 (4)	0 (0)	6 (7)	2 (1)	1 (2)
Low Infaunal Abundance [h]	(22%, N=16)	4 (2)	12 (9)	0 (0)	8 (6)	0 (0)	8 (7)	2 (1)	1 (3)
Low Demersal Richness [i]	(6%, N=4)	4 (2)	4 (3)	0 (0)	0 (0)	0 (0)	1 (2)	0 (0)	0 (0)
Low Demersal Abundance [j]	(7%, N=6)	4 (2)	4 (3)	0 (0)	0 (0)	0 (0)	1 (2)	0 (0)	0 (0)
High Demersal Pathologies [k]	(1%, N=2)	0 (0)	< 1 (1)	0 (0)	0 (0)	0 (0)	< 1 (1)	0 (0)	0 (0)

B.	Undegraded	Degraded
Condition based on DO [a], contaminant [b], and toxicity [c,d] exposure indicators (independent of biotic indicators)	69 (53)	31 (30)
Condition based on all exposure and aesthetic indicators (independent of biotic indicators)	60 (45)	40 (38)
Condition based on biotic indicators [f,g,h,i,j,k] (independent of exposure or aesthetic indicators)	71 (58)	29 (25)
Condition based on all indicators (biotic, exposure, and aesthetic)	54 (38)	46 (45)
Condition based on ≥ 1 Sig. biotic indicator [f,g,h,i,j,k] and ≥ 1 Sig. exposure indicator [a,b,c,d]	80 (66)	20 (17)

[a] Low near-bottom DO (one or more observations < 0.3 mg/L, or ≥ 20 % of the observations < 2.0 mg/L, or all observations < 5.0 mg/L).

[b] ≥ 3 ER-L or TEL contaminant exceedances, or ≥ 1 ER-M or PEL exceedance.

[c] Percent survival difference relative to control > 20 %, and significant at P = 0.05.

[d] Significant Microtox® toxicity = Water corrected $EC_{50} \leq 0.2$ % if silt-clay content of sediment ≥ 20 %, or $EC_{50} \leq 0.5$ % if silt-clay content < 20 %.

[e] Secchi depth < 0.5 m (of only those observations with depths > 0.5 m)

[f] Mean diversity per grab ≤ 1.

[g] Mean richness per grab ≤ 3.

[h] Mean abundance per grab ≤ 25.

[i] Mean richness per trawl ≤ 2.

[j] Mean abundance per trawl ≤ 5.

[k] Mean number of pathologies per trawl > 1.

TABLE 3.4-2. Stations sampled in the Carolinian Province in 1994 that exhibited evidence of degraded biological conditions accompanied by significant pollution exposure.

Station	Estuary Type	Location	Adverse Condition [a]
CP94002	Small Estuary	St. Lucie River, FL	INF, CON, MTX
CP94016	Small Estuary	Julington Creek, FL	INF, CON
CP94017	Small Estuary	Trout River, FL	INF, CON
CP94022	Small Estuary	Doboy Sound, GA	INF, MTX
CP94025	Small Estuary	Ossabaw Sound, GA	INF, MTX
CP94036	Large Tidal River	Neuse River, NC	INF, CON, MTX
CP94043	Small Estuary	Jones Bay, NC	INF, MTX
CP94048	Large Tidal River	Pamlico River, NC	INF, MTX
CP94050	Large Estuary	Pamlico Sound, NC	INF, CON
CP94051	Large Tidal River (Rep.)	Pamlico River, NC	INF, DEM, CON, DO
CP94052	Large Tidal River	Pamlico River, NC	INF, DEM, CON, DO
CP94053	Small Estuary	Bath Creek, NC	INF, PATH, CON
CP94062	Large Estuary	Albemarle Sound, NC	INF, CON
CP94066	Large Estuary	Albemarle Sound, NC	INF, DEM, CON
CP94067	Small Estuary	Yeopim River, NC	INF, MTX, CON
CP94069	Large Estuary	Albemarle Sound, NC	INF, MTX, CON
CP94082	Small Estuary	Sampit River, SC	INF, CON, MTX

[a] CON = High sediment contamination.
DEM = Low values of demersal species abundance or diversity.
DO = Low dissolved oxygen.
INF = Low values of infaunal species abundance or diversity.
PATH = High incidence of pathologies in demersal biota.
MTX = Sig. sediment toxicity based on Microtox® assay.

4. SUMMARY

1. The Carolinian Province, one of 12 national EMAP-Estuaries regions, extends from Cape Henry Virginia through the southern end of the Indian River Lagoon along the east coast of Florida.

2. A study was conducted to identify the estuarine resources of this region and assess their condition based on a variety of synoptically measured indicators of environmental quality. A stratified random sampling approach was incorporated to support probability-based estimates of the aerial extent of degraded vs. undegraded resources.

3. Estuaries were stratified into three classes based on physical dimensions: large estuaries (area >260 km^2 and length/width <20), small estuaries (2.6–260 km^2), and large tidal rivers (tidally influenced portion of a river with detectable tides >2.5 cm, area >260 km^2, and length/width >20). This classification scheme resulted in the identification of 200 estuaries with an overall surface area of 11,622 km^2. The total was comprised of three large estuaries, three large tidal rivers, and 194 small estuaries with corresponding subpopulation areas of 5581.1 km^2, 1134 km^2, and 4907 km^2 respectively.

4. A total of 84 base stations and 13 supplemental stations were sampled from June 30 – August 31, 1994. Base stations were randomly selected sites that formed the core of the probability-based monitoring design. By estuarine class, the base stations included 20 in large estuaries, 47 in small estuaries, and 17 in large tidal rivers. By subregion, there were 46 stations in southern Virginia – North Carolina (VA/NC), 20 in South Carolina – Georgia (SC/GA), and 18 in Florida (FL).

5. Large tidal ranges in excess of 2 m were observed in 10% of the province. Such conditions were the most characteristic in the SC/GA portion of the province, where 62% of these estuaries had tidal ranges of this magnitude.

6. Most estuaries (52%) were within the polyhaline salinity zone (>18–30 ‰). The lowest salinities were found in large estuaries in NC.

7. High density stratification (defined in this study as σ_t differences between surface and bottom waters >2) represented a relatively small percentage of the province (14%). Stratified waters were the most pronounced in large tidal rivers by estuarine class, and in SC/GA by subregion.

8. Most of the bottom substrates of the Carolinian Province (66%) were composed of sands (low silt-clay content <20%). Low silt-clay content was the most pronounced in small estuaries and in the SC/GA and FL portions of the province.

9. Bottom substrates in 20% of the province had relatively high levels of TOC (>2%). High TOC was the most pronounced in large tidal rivers and in the VA/NC subregion. High TOC occurred in a very small percentage (1%) of SC/GA estuaries.

10. Surface DO concentrations, based on instantaneous daylight measurements, were observed above the common state water quality standard of 5 mg/L at all base stations. Bottom DO concentrations based on instantaneous measurements were below this level in 12% of the province including sites in all estuarine classes and subregions. DO concentrations <2 mg/L were rare, found only in 2% of the province. The large tidal river class contained the highest proportion of estuaries (17%) with bottom DO concentrations below this lower criterion. None of the base stations in the SC/GA portion of the province had instantaneous DO concentrations <2 mg/L.

11. A combination of the following three criteria (based on data from continuous water-quality observations) was used to classify sites as degraded with respect to DO: DO <0.3 mg/L at any time during the measurement period (to represent short-term exposure to severe hypoxic conditions), DO <2 mg/L for more than 20% of the measurement period, or DO <5.0 mg/L throughout the entire measurement period (to represent extended exposure to higher chronic effect levels). Only three sites (replicate Stations 51 and 52 in the Pamlico River, NC; and Station 77 in the Combahee River, SC), representing 5% of the area of the province, were classified as degraded based on these criteria. Both estuaries also showed evidence of degraded infaunal assemblages. The Pamlico River sites showed additional evidence of degraded demersal assemblages.

12. Carolinian Province estuaries exhibited a wide range of DO patterns. In some places, DO followed cyclical patterns consisting of both diurnal and tidal components (with lowest DO concentrations occurring at late night to early morning during low tide). In other places, DO followed a pattern consisting of large day-night variations without any significant tidal influences. The contribution of the tidal component to variations in DO was the most pronounced in SC/GA estuaries, due to the large tidal ranges observed in this portion of the province.

13. The majority of the province (63%) showed low levels of sediment contamination, with all of the measured contaminants at those sites falling below corresponding threshold ER-L or TEL bioeffect guidelines. Sixteen percent of the province showed significant sediment contamination defined by the presence of three or more contaminants in excess of the lower ER-L/TEL values, or one or more contaminants in excess of the higher ER-M/PEL values. High sediment contamination was the most pronounced in large tidal rivers, primarily due to contributions from sites in the Neuse and Pamlico Rivers in NC.

14. Contaminants that appeared to be the most prevalent in the Carolinian Province were antimony, arsenic, chromium, mercury, nickel, zinc, total PCBs, total chlordane, DDT and derivatives, and dieldrin. These contaminants were found either at concentrations in excess of ER-M/PEL values in at least one estuary (e.g., chlordane and total PCBs) or at concentrations in excess of the lower ER-L/TEL values in three or more estuaries (remaining ones). PCB contamination was the most pronounced. Total PCBs were found at three stations in excess of the ER-M value of 180 ng/g and at eight stations in excess of the ER-L value of 22.7 ng/g.

15. In addition, tributyltin (TBT), a component of antifouling paints, was observed in 23% of the province at concentrations above 5 ppb – a level used by the EMAP-Estuaries program in the Louisianian Province to flag concentrations in a potential toxicity range (Macauley et al. 1994). This result suggested that TBT was present in a number of places in the Carolinian Province at concentrations that could be contributing to adverse biological effects. However, because the bioeffect range for TBT in sediments is not clearly defined as yet, TBT data were not included in estimates of contaminated vs. uncontaminated estuaries based on bioeffect guideline exceedances. Estimates of the areal extent of contaminated sediments could change significantly if TBT, and other contaminants with unclear sediment bioeffect ranges, were included in the computations.

16. The five highest TBT concentrations, ranging from 20.1–289 ng Sn/g, occurred in FL at two small estuarine sites (Station 16 in Julington Creek and Station 17 in the Trout River) and at three Indian River Lagoon sites (Stations 10, 12, and 13). The Julington Creek and Trout River sites are both in the immediate vicinity of naval facilities. High TBT concentrations in the Indian River appear to reflect the many years of intensive year-round recreational and commercial boating activities in these estuaries. Boat ramps and marinas are near all three of the contaminated Indian River sites.

17. The broad-scale probabilistic sampling framework of EMAP-E was not designed to support detailed characterizations of pollutant distributions and sources within individual estuarine systems. Thus, some estuaries classified as undegraded may include additional contaminated portions outside of the immediate vicinity of randomly selected sites. Such impacts were clearly detected at nonrandom supplemental sites near potential contaminant sources. For example, significant chromium contamination was observed in sediments at Shipyard Creek (CP94SPY), a supplemental site in Charleston Harbor, SC. The chromium concentration at this site (1,911 µg/g) exceeds the ER-M value for chromium (Long et al. 1995) by more than a factor of five and is much greater than concentrations considered to be "high" in national and worldwide chromium databases (Cantillo and O'Connor 1992).

18. Significant *Ampelisca abdita* toxicity (mortality relative to control ≥ 20% and statistically significant when tested at $\alpha = 0.05$) occurred at only one site (Station 63 in Albemarle Sound) representing 2% of the area of the province. This single toxicity response was not accompanied by any additional evidence of sediment contamination or adverse biological conditions. A similar test with the congener amphipod *Ampelisca verrilli*, which was developed in this study and used during the subsequent 1995 sampling effort, may provide a more sensitive alternative for southeastern estuaries.

19. Sediment toxicity based on the Microtox® assay was observed at 18 sites representing 19% of the area of the province. Half of these sites were accompanied by additional evidence of degraded infaunal assemblages. Five of the sites were in areas of significant sediment contamination.

20. A total of 29,238 macroinfaunal organisms (>0.5 mm), representing 505 different taxa, were identified from 163 grabs (0.04 m^2 each) collected at base stations throughout the province. Mean species richness, diversity (H′), and abundance per grab ranged from 0–75, 0–4.8, and 0–998, respectively.

21. Infaunal species richness, H′, and abundance all showed significant positive correlations with salinity and significant negative correlations with latitude, percent silt-clay, and percent TOC.

22. Annelids (polychaetes and tubificid oligochaetes) comprised the majority of infaunal taxa by both abundance (63%) and numbers of species (51%). Arthropods (mostly peracarid crustaceans and chironomid insect larvae) and mollusks (gastropods and bivalves) were the next most important groups, found in similar proportions with respect to both abundance and numbers of species.

23. The five most abundant infaunal taxa province-wide (in decreasing order of abundance) were oligochaetes, the polychaete *Mediomastus* spp., the gastropod *Acteocina canaliculata*, the bivalve *Mulinia lateralis,* and the polychaete *Streblospio benedicti*. There were distinct shifts in the dominance patterns among the various estuarine classes and subregions. For example, only one taxon (*Mediomastus* spp.) was ranked as a dominant in all three subregions. However, three of these five taxa (*Mediomastus*, *Mulinia*, and *Acteocina*) appeared as dominants in the northern-most and southern-most subregions. Thus, there was some similarity in species composition between northern and southern portions of the province, although infaunal diversity and abundance patterns were strongly correlated with latitude.

24. A total of 12,699 demersal organisms, representing 98 different taxa, were identified from 158 trawls (4.9-m otter trawls with 2.5-cm mesh) conducted throughout the Carolinian Province. Mean number of species and abundance per trawl ranged from 0.5–17.5 and 0.5–438.5, respectively.

25. Over the entire province, trawls were numerically dominated by Atlantic croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), star drum (*Stellifer lanceolatus*), pinfish (*Lagodon rhomboides*), and brown shrimp (*Penaeus aztecus*). Dominance patterns showed distinct shifts among the three subregions. In VA/NC, the dominants (in decreasing order of abundance) were Atlantic croaker, spot, pinfish, brown shrimp, and blue crab (*Callinectes sapidus*). In SC/GA, they were star drum, white shrimp (*Penaeus setiferus*), spot, Atlantic croaker, and hogchoaker (*Trinectes maculatus*). In FL, they were silver perch (*Bairdiella chrysoura*), pigfish (*Orthopristis chrysoptera*), blue crab, silver jenny (*Eucinostomus gula*), and southern kingfish (*Menticirrhus americanus*).

26. Four aesthetic indicators were monitored: presence of anthropogenic debris (sea surface and in bottom trawls), presence of oil (sea surface and in bottom sediments), noxious sediment odor (smell of sulfur, oil, or sewage in bottom sediments), and water clarity (secchi depths). Anthropogenic debris was observed in <1% of the surface waters and in about 10% of the bottom waters. Oil was observed only in 2% of the bottom sediments and in none of the surface waters. Noxious odors were detectable in 14% of the province

sediments. Low water clarity, represented by secchi depths <0.5 m, was observed in only 1% of the area of the province.

27. Thirty-one percent of the area of the province was represented by potentially harmful levels of one or more of the various exposure indicators (significant sediment toxicity, sediment contamination in excess of bioeffect guidelines, or low DO concentrations in bottom waters). High sediment contamination and toxicity based on the Microtox® assay accounted for the majority of these cases. Twenty-nine percent of the area of the province showed some sign of biological degradation based on at least one variable that was within a range suggestive of adverse conditions. Low infaunal species richness, diversity (H′), and abundance accounted for the majority of these cases.

28. Over half (54%) of the Carolinian Province showed no major evidence of environmental degradation based on any of the measured biotic, exposure, or aesthetic variables. Twenty percent of the province, represented by 17 stations, exhibited adverse biological conditions linked to significant pollution exposure. The majority (11) of these sites were in North Carolina. Most of these sites were characterized by degraded infaunal assemblages accompanied by high sediment contamination and/or significant sediment toxicity based on the Microtox® assay.

29. Biotic indicators based on demersal species parameters did not function as effectively as infaunal indicators in discriminating between undegraded and degraded stations.

30. A strength of the EMAP-E probability-based sampling design is its ability to support unbiased estimates of ecological condition with known confidence. Further sampling in the Carolinian Province should improve the accuracy of these estimates and provide a basis for assessing temporal trends. An important question to address in future studies is how the overall quality of these estuaries is changing with time.

Table 4-1 summarizes the general characteristics of the Carolinian Province and the areal extent of selected indicators within specific ranges of interest.

TABLE 4–1. Summary of the general characteristics of the Carolinian Province and the percent area (with 95 % Confidence Intervals) exhibiting the designated levels of selected indicators.

		Estuarine Class			Subregion		
Indicators and Characteristics	Province	Large	Small	Tidal	VA-NC	SC-GA	FL
General Characteristics							
Size (km^2)	11,622.1	5581.1	4907	1134	8834.9	1688.2	1099
No. of Estuaries	200	3	194	3	90	79	25
Base Stations Sampled in 1994	84	20	47	17	46	20	18
Habitat Indicators							
Tidal Range > 2 m	10 ± 6	0	23 ± 15	0	0	62 ± 25	4 ± 13
Salinity (Bottom Waters)							
• Oligohaline (< 5 ‰)	17 ± 10	30 ± 21	6 ± 6	0	22 ± 14	1 ± 2	1 ± 3
• Mesohaline (5–18 ‰)	9 ± 12	10 ± 22	10 ± 14	0	11 ± 16	0	3 ± 8
• Polyhaline (>18–30 ‰)	52 ± 13	50 ± 14	45 ± 25	97 ± 19	48 ± 15	57 ± 25	89 ± 12
• Euhaline (> 30 ‰)	22 ± 12	10 ± 14	39 ± 25	3 ± 19	19 ± 15	41 ± 25	7 ± 12
Significant Water Stratification, $\lvert\Delta\sigma_t\rvert > 2$	14 ± 7	5 ± 10	16 ± 12	50 ± 19	10 ± 8	36 ± 23	11 ± 24
Silt-Clay Content							
• Silt-clay < 20 %	66 ± 12	55 ± 22	86 ± 10	32 ± 19	60 ± 14	83 ± 18	84 ± 28
• Silt-clay > 80 %	22 ± 10	30 ± 21	6 ± 6	55 ± 27	28 ± 14	1 ± 2	15 ± 28
Total Organic Carbon (TOC) > 2 %	20 ± 9	20 ± 18	9 ± 7	68 ± 19	24 ± 12	1 ± 2	14 ± 36
Exposure Indicators							
Low DO (Bottom Waters)							
• DO < 5 mg/L (Instantaneous)	12 ± 8	5 ± 10	19 ± 15	17 ± 27	12 ± 11	9 ± 10	18 ± 28
• DO < 2 mg/L (Instantaneous)	2 ± 3	0	2 ± 3	17 ± 27	2 ± 5	0	6 ± 9
• Significant low DO (Chronic and Acute) [a]	5 ± 7	0	2 ± 4	42 ± 70	4 ± 6	5 ± 9	0
Sediment Toxicity							
• Significant Amphipod Toxicity [b]	2 ± 5	5 ± 10	0	0	3 ± 6	0	0
• Significant Microtox® Toxicity [c]	19 ± 9	5 ± 10	22 ± 17	71 ± 31	15 ± 11	32 ± 23	28 ± 26

TABLE 4–1. (Continued).

		Estuarine Class			Subregion		
Indicators and Characteristics	Province	Large	Small	Tidal	VA-NC	SC-GA	FL
Exposure Indicators (Continued)							
Sediment Contamination							
• ≥ 1 ER-L/TEL Exceedance	37 ± 12	45 ± 22	22 ± 13	68 ± 14	42 ± 15	29 ± 21	15 ± 28
• ≥ 1 ER-M/PEL Exceedance	3 ± 5	5 ± 10	1 ± 1	0	3 ± 6	0	4 ± 8
• ≥ 3 ER-L/TEL or ≥ 1 ER-M/PEL Exceedance	16 ± 9	20 ± 18	6 ± 6	37 ± 27	19 ± 13	1 ± 2	15 ± 28
• Total Alkanes ≥ 7000 ng/g	< 1	0	2 ± 2	0	< 1	1 ± 2	4 ± 8
• Tributyltin > 5 ng/g	23 ± 12	5 ± 10	47 ± 25	11 ± 27	19 ± 12	15 ± 17	74 ± 13
Biotic Condition Indicators							
Infauna							
• Mean Species Richness/Grab ≤ 3	9 ± 6	5 ± 10	4 ± 5	55 ± 27	11 ± 8	0	14 ± 27
• Mean Abundance/Grab ≤ 25	22 ± 11	25 ± 20	11 ± 10	55 ± 27	24 ± 13	19 ± 20	15 ± 28
• Mean H′(Diversity)/Grab ≤ 1	12 ± 7	10 ± 13	4 ± 3	55 ± 27	15 ± 10	1 ± 2	3 ± 7
Demersal Biota							
• Mean Species Richness/Trawl ≤ 2	6 ± 7	10 ± 13	0	13 ± 19	8 ± 10	0	0
• Mean Abundance/Trawl ≤ 5	7 ± 7	10 ± 13	2 ± 3	13 ± 19	8 ± 10	3 ± 5	14 ± 11
• Mean # Pathologies/Trawl > 1	1 ± 1	0	2 ± 3	0	< 1	4 ± 8	0
Aesthetic Indicators							
Anthropogenic Marine Debris Present							
• At Sea Surface	< 1	0	< 1	0	0	1 ± 2	0
• On Bottom	10 ± 7	6 ± 11	10 ± 8	28 ± 34	7 ± 9	14 ± 15	30 ± 13
Secchi depth < 0.5 m	1 ± 1	0	2 ± 3	0	< 1	5 ± 8	0
Noxious Sediment Odors Present	14 ± 9	5 ± 10	12 ± 16	65 ± 37	12 ± 8	0	60 ± 31
Oil Present							
• At Sea Surface	0	0	0	0	0	0	0
• In Sediments	2 ± 1	0	< 1	18 ± 14	2 ± 4	1 ± 2	0

[a] DO < 2 mg/L for > 20% of continuous datasonde record, or DO < 5 mg/L throughout entire continuous record, or DO < 0.3 mg/L at any time during continuous record.

[b] Mortality relative to control ≥ 20 % and significant at $\alpha = 0.05$.

[c] $EC_{50} \leq 0.2$ if silt-clay ≥ 20 %, or $EC_{50} \leq 0.5$ % if silt-clay < 20 %.

5. REFERENCES

American Society for Testing and Materials (ASTM). 1991. Guide for conducting 10-day static sediment toxicity tests with marine and estuarine amphipods. ASTM Standard Methods Volume 11.04, Method Number E-1367-90. ASTM, Philadelphia, PA.

Anger, K. 1975. On the influence of sewage pollution on inshore benthic communities in the south of Kiel Bay: 2. Quantitative studies on community structure. Helgoländer wiss. Meeresunters., 27: 408–438.

Boesch, D.F. 1974. Diversity, stability and response to human disturbance in estuarine ecosystems. *In*: Proceedings of the First International Congress of Ecology, Centre for Agricultural Publishing and Documentation, Wageningen, The Netherlands, 109-114.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. EPA Grant No. R803599-01-1, ROAP/TASK No.21 BEI, U.S. EPA Corvallis Environmental Research Laboratory, Newport, OR.

Bower, C.E. and T. Holm-Hansen. 1980. A salicylate-hypochlorite method for determining ammonia in seawater. Can. J. Fish. Aquat. Sci., 37: 794–798.

Bulich, A.A. 1979. Use of luminescent bacteria for determining toxicity in aquatic environments. *In*: L. L. Marking and R. A. Kimerle (eds.), Aquatic Toxicology, pp. 98–106. ASTM STP 667. American Society for Testing and Materials, Philadelphia, PA.

Cantillo, A.Y. and T.P. O’Connor. 1992. Trace element contaminants in sediments from the NOAA National Status and Trends Programme compared to data from throughout the world. Chem. and Ecol., 7: 31-50.

Carr, R.S., J.L. Hyland, T. Purcell, L.J. Larson, and L.T. Brooke. 1987. Provisional aquatic life advisory concentrations for tributyltin. Paper presented at the Ocean’s ’87 Organotin Symposium, held in Halifax, Nova Scotia, Sept. 28–Oct. 1, 1987. Proceedings addendum.

Carriker, M.R. 1967. Ecology of estuarine benthic invertebrates: A perspective. *In*: G. Lauff (ed.), Estuaries, pp. 442–487. AAAS, Washington, D.C.

Cochran, W.G. 1977. Sampling techniques. 3rd edition. John Wiley, New York. 428 p.

Culliton, T.J., M.A. Warren, T.R. Goodspeed, D.G. Remer, C.M. Blackwell and J.J. McDonough III. 1990. 50 years of population change along the Nation's coast, 1960–2010. National Ocean Service, NOAA, U.S. Department of Commerce. Rockville, MD. 41 p.

Falkowski, P.G., T.S. Hopkins, and J.J. Walsh. 1980. An analysis of factors affecting oxygen depletion in the New York Bight. J. Mar. Res., 38: 479-506.

Hampton, B.L. 1977. Relationship between total ammonia and free ammonia in terrestrial and ocean waters. J. Cons. Int. Explor. Mer., 37: 117–122.

Heitmuller, P.T. and R. Valente. 1993. EMAP - Estuaries Louisianian Province - 1993 Quality Assurance Project Plan. U.S. EPA Environmental Research Laboratory, Gulf Breeze, FL.

Holland, A.F. (ed). 1990. Near coastal program plan for estuaries. EPA600/14-90/033. U.S. EPA Office of Research and Development, Narragansett, RI.

Holme, N.A. and A.D. McIntyre. 1971. Methods for the study of marine benthos. IBP Handbook No.16. Blackwell Scientific Publications, Oxford and Edinburgh. 334 p.

Hyland, J., E. Baptiste, J. Campbell, J. Kennedy, R. Kropp, and S. Williams. 1991. Macroinfaunal communities of the Santa Maria Basin on the California outer continental shelf and slope. Mar. Ecol. Prog. Ser., 78: 147–161.

Hyland, J.L., E.J. Hoffman, and D.K. Phelps. 1985. Differential responses of two nearshore infaunal assemblages to experimental petroleum additions. J. Mar. Res., 43: 365–394.

Hyland, J.L., C. Mageau, S. Kokkinakis, F.A. Holland, A. Ringwood, S. Rathbun, A. Robertson, and G.E. Gilbert. 1994. Demonstration plan for monitoring the estuarine waters of the Carolinian Province - 1994. November 1994. NOAA/NOS/ORCA, Silver Springs, MD.

Johnson, S.K. 1989. Handbook of shrimp diseases, Texas A & M Univ. Sea Grant Publ. TAMU-SG-90-601, 25 p.

Knauss, J.A. 1978. Introduction to physical oceanography. Prentice-Hall, Inc., Englewood Cliffs, N. J.

Kokkinakis, S.A., C. Mageau, and A. Robertson. 1994. Carolinian Demonstration Project - 1994 Quality Assurance Project Plan. June 1994. NOAA/NOS/ORCA, Silver Springs, MD.

Lauenstein, G.G. and A.Y. Cantillo (eds.). 1993. Sampling and analytical methods of the National Status and Trends Programs, National Benthic Surveillance and Mussel Watch Projects, 1984–1992. NOAA Technical Memorandum, NOS ORCA 71.

Long, E.R. and L. G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. NOAA Technical Memorandum NOS OMA 52. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Rockville, MD.

Long, E.R., D.D. MacDonald, S.L. Smith, and F. D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Envir. Man., 19: 81–97.

Macauley, J.M., J.K. Summers, P.T. Heitmuller, V.D. Engle, G.T. Brooks, M. Babikow, and A.M. Adams. 1994. Annual Statistical Summary: EMAP - Estuaries Louisiana Province - 1992. U.S. EPA Office of Research and Development, Environmental Research Laboratory, Gulf Breeze, FL. EPA/620/R-94/002.

MacDonald, D.D. 1994. Approach to the assessment of sediment quality in Florida coastal waters. Vols. I–IV. Florida Department of Environmental Regulation.

Microbics Corporation. 1992a. Microtox Manual (5 volume set). Carlsbad, CA.

Microbics Corporation. 1992b. Microtox Update Manual, 128 p. Carlsbad, CA.

Nautical Software, Inc. 1995. Tides and currents for Windows. Ver. 2.0 user's guide (2nd edition) and software. Nautical Software, Inc., Beaverton, OR.

Noga, E.J., D.W. Engel, and T.W. Arroll. 1990. Shell disease in blue crabs, *Callinectes sapidus*, from the Albemarle-Pamlico estuary. Albemarle-Pamlico Estuarine Study, Project No. 90–22. N.C. Dept. of Natural Resources and Community Development. 48 p.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev., 16, 229–311.

Rathbun, S.L. 1994. Design considerations for the Carolinian Province of EMAP - Estuaries. Final Report (May 1994) to S.C. Dept. Natural Resources, Marine Resources Research Institute. Dept. of Statistics, U. of Georgia, Athens, GA.

Rhoads, D.C. and J.W. Morse. 1971. Evolutionary and ecological significance of oxygen-deficent marine basins. Lethaia, 4: 413–428.

Ringwood, A.H., A.F. Holland, R. Kneib, and P. Ross. 1995a. EMAP/NS&T pilot studies in the Carolinian Province: Indicator testing and evaluation in southeastern estuaries. Final Report (May 1995) under Grant NA90AA-D-SG790 through S.C. Sea Grant College Program. S.C. Dept. of Natural Resources, Marine Resources Research Institute, Charleston, S.C.

Ringwood, A.H., R. Van Dolah, A.F. Holland, and M.G. Delorenzo. 1995b. Year one demonstration project studies conducted in the Carolinian Province by Marine Resources Research Institute: Results and summaries. Draft Annual Report (September 1995) under NOAA Cooperative Agreement No. NA470A0177. South Carolina Department of Natural Resources, Marine Resources Research Institute, Charleston, S.C.

Ross, P.E., L.C. Burnett, C. Kermode, and M. Timme. 1991. Miniaturizing a toxicity test battery for screening contaminated sediments. Can. Tec. Rep. Fish. Aquat. Sci., 1774: 331–335.

Salonen, K. 1979. A versatile method for the rapid and accurate determination of carbon by high temperature combustion. Limnol. Oceanogr., 24: 177–183.

Sanders, H.L., J.F. Grassle, G.R. Hampson, L.S. Morse, S. Garner-Price, and C.C. Jones. 1980. Anatomy of an oil spill: Long-term effects from the grounding of the barge Florida off West Falmouth, MA. J. Mar. Res., 38: 265–380.

SAS Institute, Inc. 1989. SAS/STAT user's guide. Ver. 6, 4th edition, Vols. I & II. SAS Institute, Inc., Cary, N.C.

Seliger, H.H., J.A. Boggs, and W.H. Biggley. 1985. Catastrophic anoxia in the Chesapeake Bay in 1984. Science, 228: 70–73.

Shannon, C.E. and W. Weaver. 1949. The mathematical theory of communication. Univ. of Illinois Press, Urbana. 117 p.

Stevens, D.L. Jr., A.R. Olsen, and D. White. 1991. Environmental monitoring and assessment program - integrated sampling design. Draft report. U.S. EPA Environmental Research Laboratory, Corvallis, OR.

Strobel, C.J., H.W. Buffum, S.J. Benyi, E.A. Petrocelli, D.R. Reifsteck, and D.J. Keith. 1995. Statistical summary: EMAP - Estuaries Virginian Province - 1990 to 1993. U.S. EPA National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, R.I. EPA/620/R-94/026.

Strobel, C.J., S.J. Benyi, D.J. Keith, H.W. Buffum, and E.A. Petrocelli. 1994. Statistical summary: EMAP - Estuaries Virginian Province - 1992. U.S. EPA Office of Research and Development, Environmental Research Laboratory, Narragansett, RI. EPA/620/R-94/019.

Summers, J.K., J.M. Macauley, V.D. Engle, G.T. Brooks, P.T. Heitmuller, and A.M. Adams. 1993a. Louisianian Province demonstration report: EMAP - Estuaries - 1991. U.S. EPA Office of Research and Development, Environmental Research Laboratory, Gulf Breeze, FL. EPA/600/R-93/xxx.

Summers, J.K., J.M. Macauley, P.T. Heitmuller, V.D. Engle, A.M. Adams, and G.T. Brooks. 1993b. Annual statistical summary: EMAP - Estuaries Louisianian Province - 1991. U.S. EPA Office of Research and Development, Environmental Research Laboratory, Gulf Breeze, FL. EPA/600/R-93/001.

Swanson, R.L. and C.J. Sindermann (eds.). 1979. Oxygen depletion and associated benthic mortalities in New York Bight. NOAA Prof. Pap. 11. 350 p.

Taylor, B.J. and B.J. Presley. 1993. GERG trace element quantification techniques. *In*: G.G. Lauenstein and A.Y. Cantillo (eds.). Sampling and analytical methods of the National Status and Trends Programs, National Benthic Surveillance and Mussel Watch Projects, 1984-1992. NOAA Technical Memorandum, NOS ORCA 71.

Theede, H. 1973. Comparative studies on the influence of oxygen deficiency and hydrogen sulfide on marine bottom invertebrates. Neth. J. Sea. Res., 7: 244–252.

U.S. EPA. 1988. Ambient water quality criteria for tributyltin - 1988. Draft. Criteria and Standards Division, Office of Water Regulations and Standards, U.S. EPA, Washington, D.C.

U.S. EPA. 1989. Ambient water quality criteria for ammonia (saltwater). Criteria and Standards Division, Office of Water Regulations and Standards, U.S. EPA, Washington, D.C. EPA 400/5-88-004.

U.S. EPA. 1993. Environmental Monitoring and Assessment Program. Laboratory methods manual - estuaries. Office of Research and Development, Environmental Monitoring and Systems Laboratory, Cincinnati, OH. EPA/600/4-91/024.

U.S. EPA. 1994a. Environmental Monitoring and Assessment Program (EMAP): Laboratory methods manual - estuaries, Volume 1: Biological and physical analyses. Office of Research and Development, Environmental Monitoring and Systems Laboratory, Cincinnati, OH. EPA/620/R-94/xxx.

U.S. EPA. 1994b. Methods for assessing the toxicity of sediment-associated contaminants with estuarine and marine amphipods. EPA 600/R-94/025. U.S. EPA Office of Research and Development, Narragansett, R.I.

Wade, T.L., J.M. Brooks, M.C. Kennicutt II, T.J. McDonald, J.L. Sericano, and T.J. Jackson. 1993. GERG trace organics contaminant analytical techniques. *In*: G.G. Lauenstein and A.Y. Cantillo (eds.). Sampling and analytical methods of the National Status and Trends Programs, National Benthic Surveillance and Mussel Watch Projects, 1984-1992. NOAA Technical Memorandum, NOS ORCA 71.

Wade, T.L., B. Garcia-Romero, and J.M. Brooks. 1990. Butyltin in sediments and bivalves from U.S. coastal areas. Chemosphere, 20: 647-662.

Wade, T.L., D.J. Velinsky, E. Reinharz, and C.E. Schekat. 1994. Tidal river sediments in the Washington, D.C. area. II. Distribution and sources of organic contaminants. Estuaries, 17: 321-333.

Weisberg, S.B., J.B. Frithsen, A.F. Holland, J.F. Paul, K.J. Scott, J.K. Summers, H.T. Wilson, R. Valente, D.G. Heimbuch, J. Gerritsen, S.C. Schimmel, and R.W. Latimer. 1992. EMAP-Estuaries Virginian Province 1990 demonstration project report. U.S. EPA Environmental Research Laboratory, Narragansett, R.I. EPA/600/R-92/100.

Weston, D.P. 1988. Macrobenthos-sediment relationships on the continental shelf off Cape Hatteras, North Carolina. Contin. Shelf Res., 8: 267–286.

Whitfield, M. 1978. The hydrolysis of ammonium ions in sea water - experimental confirmation of predicted constants at one atmosphere pressure. J. Mar. Biol. Assoc. U.K., 58: 781–787.

Wilhm, J.L. and T.C. Dorris. 1968. Biological parameters for water quality criteria. Bioscience, 18: 447–481.

Winger, P.V. and P.J. Lasier. 1991. A vacuum-operated pore-water extractor for estuarine and freshwater sediments. Arch. Environ. Contam. Toxicol., 21: 321–324.

Young, J.S. and J.B. Pearce. 1975. Shell disease in crabs and lobsters from New York Bight. Mar. Poll. Bull., 6: 101–105.

APPENDICES

APPENDIX A. Bottom depth, dissolved oxygen, salinity, temperature, and pH records by station for 1994 EMAP in the Carolinian Province. Median and range (minimum–maximum) are given.

	Bottom Depth (m)		Dissolved Oxygen (mg/L)		Salinity (‰)		Temperature (°C)		pH	
Station	Profile[a,b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]
CP94001	0.6	0.5	6.7	–	24.2	–	28.4	28.3	7.8	7.9
		(0.3–0.7)	(6.6–6.7)	–	(24.1–24.3)	–	(28.4–28.4)	(27.6–29.7)	(7.8–7.8)	(7.8–8.0)
CP94002	2.8	2.9	6.4	–	4.3	23.6	29.1	27.7	7.7	7.5
		(2.7–3.1)	(2.9–6.6)	–	(3.7–21.3)	(19.9–26.6)	(27.8–29.2)	(27.4–28.0)	(7.5–7.7)	(7.3–7.6)
CP94003	1.7	1.8	7.5	–	26.6	27.3	28.8	29.0	7.9	8.0
		(1.6–2.1)	(7.5–8.3)	–	(26.3–26.6)	(27.1–28.2)	(28.8–28.8)	(28.4–29.8)	(7.9–7.9)	(7.8–8.1)
CP94004	0.9	–	6.7	–	30.8	–	29.3	–	8.0	–
		–	(6.6–7.8)	–	(30.8–30.8)	–	(29.3–29.3)	–	(8.0–8.0)	–
CP94005	0.1	–	5.8	–	23.6	–	32.2	–	7.9	–
		–	(5.7–6.5)	–	(23.2–23.7)	–	(32.2–32.2)	–	(7.9–7.9)	–
CP94006	1.3	0.8	7.7	–	20.0	19.9	33.2	31.6	8.3	8.0
		(0.8–0.9)	(7.6–7.8)	–	(18.6–20.7)	(18.1–20.9)	(33.0–33.3)	(30.9–32.9)	(8.2–8.3)	(7.9–8.2)
CP94007	1.3	0.7	7.8	–	25.6	24.8	29.7	29.0	8.0	8.0
		(0.6–0.8)	(7.8–7.9)	–	(25.5–25.6)	(24.4–25.5)	(29.7–29.7)	(28.3–30.1)	(8.0–8.0)	(7.9–8.1)
CP94008	1.5	–	7.0	–	20.1	–	31.7	–	8.4	–
		–	(6.7–7.1)	–	(20.1–20.2)	–	(31.2–31.9)	–	(8.4–8.4)	–
CP94009	2.7	–	9.8	–	23.0	–	30.6	–	8.1	–
		–	(1.6–10.5)	–	(22.7–24.6)	–	(29.2–30.8)	–	(7.3–8.2)	–
CP94010	4.0	3.8	6.4	–	21.8	23.0	28.5	29.1	7.9	7.9
		(3.7–3.9)	(6.1–6.8)	–	(21.8–21.8)	(22.3–23.3)	(28.3–28.5)	(28.4–29.5)	(7.9–7.9)	(7.5–8.1)
CP94011	1.3	1.0	7.2	–	26.3	26.5	29.2	28.9	7.9	7.9
		(1.0–1.1)	(7.1–7.4)	–	(26.2–26.3)	(26.1–27.2)	(29.2–29.2)	(28.3–29.6)	(7.9–7.9)	(7.8–8.0)
CP94012	1.5	1.7	7.0	–	24.7	24.7	29.5	29.0	7.9	7.9
		(1.6–1.8)	(6.9–7.3)	–	(24.6–25.5)	(24.5–25.3)	(28.6–29.7)	(28.5–30.2)	(7.8–7.9)	(7.9–8.0)

[a] Bottom depths based on instantaneous profile depths corrected to Mean Lower Low Water.

[b] Instantaneous, surface-to-bottom depth profiles (taken at 1-m intervals for bottom depths > 3m; 0.5-m intervals for depths < 3m).

[c] Continuous, time-series measurements taken at 30-min. intervals typically over a 24-hr period at a single near-bottom depth.

APPENDIX A. (Continued).

Station	Bottom Depth (m)		Dissolved Oxygen (mg/L)		Salinity (‰)		Temperature (°C)		pH	
	Profile[a,b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]
CP94013	1.5	1.6	6.8	–	24.8	25.0	29.2	28.9	7.8	7.9
		(1.6–1.7)	(6.7–6.9)	–	(24.5–25.1)	(24.8–25.2)	(28.6–29.5)	(28.4–29.6)	(7.8–7.9)	(7.8–8.0)
CP94014	1.7	1.7	5.5	–	27.9	27.7	28.3	29.3	7.9	8.0
		(1.7–1.8)	(5.5–5.7)	–	(27.9–28.0)	(27.7–27.9)	(28.2–28.3)	(28.3–29.9)	(7.9–7.9)	(8.0–8.1)
CP94015	–	–	–	–	–	–	–	–	–	–
		–	–	–	–	–	–	–	–	–
CP94016	1.3	–	5.2	–	0.2	–	28.7	–	7.0	–
		–	(5.1–5.4)	–	(0.2–0.2)	–	(28.7–28.7)	–	(7.0–7.0)	–
CP94017	0.8	0.9	5.3	–	16.4	15.5	28.4	28.1	7.5	7.4
		(0.5–1.4)	(1.4–5.7)	–	(14.9–16.9)	(10.8–18.1)	(28.0–28.6)	(27.4–29.3)	(7.5–7.7)	(7.2–7.5)
CP94018	6.7	7.7	6.0	–	32.8	35.5	28.9	28.2	7.6	7.7
		(6.5–8.6)	(5.8–6.2)	–	(32.3–32.8)	(32.4–36.4)	(28.8–29.0)	(27.7–29.4)	(7.6–7.6)	(7.3–7.8)
CP94019	6.4	8.2	6.0	–	34.6	33.2	27.3	28.0	8.0	7.8
		(7.0–9.1)	(5.9–6.2)	–	(34.0–34.7)	(29.7–35.2)	(27.3–27.5)	(27.3–29.0)	(7.9–8.0)	(7.5–7.9)
CP94020	8.0	9.1	6.2	6.7	32.1	31.9	27.0	27.5	7.9	7.9
		(8.2–10.0)	(5.8–7.5)	(5.4–7.8)	(28.6–32.6)	(30.3–33.0)	(26.8–28.6)	(27.0–27.9)	(7.8–7.9)	(7.8–8.0)
CP94021	7.4	9.2	5.3	5.5	24.1	27.5	28.1	27.4	7.7	7.7
		(8.2–10.2)	(4.9–6.5)	(3.9–6.0)	(22.4–29.0)	(24.5–29.6)	(26.8–28.7)	(26.5–28.3)	(7.6–7.7)	(7.5–7.8)
CP94022	3.7	5.6	5.8	–	16.4	17.7	28.7	28.3	7.5	–
		(4.3–6.6)	(5.5–6.9)	–	(14.7–19.0)	(16.8–19.6)	(28.4–28.7)	(27.6–28.7)	(7.5–7.6)	–
CP94023	4.3	5.7	6.0	6.2	26.6	26.2	28.7	27.9	7.6	7.7
		(4.4–6.8)	(5.8–6.5)	(5.6–7.1)	(26.1–26.8)	(23.7–30.4)	(28.6–28.7)	(26.8–29.1)	(7.6–7.6)	(7.5–8.0)
CP94024	2.4	4.5	6.3	6.6	26.3	22.9	27.6	27.7	7.7	7.6
		(3.1–5.7)	(6.1–6.8)	(6.1–7.1)	(26.1–26.4)	(20.4–28.7)	(27.6–27.7)	(27.3–28.3)	(7.7–7.7)	(7.5–7.8)

[a] Bottom depths based on instantaneous profile depths corrected to Mean Lower Low Water.

[b] Instantaneous, surface-to-bottom depth profiles (taken at 1-m intervals for bottom depths > 3m; 0.5-m intervals for depths < 3m).

[c] Continuous, time-series measurements taken at 30-min. intervals typically over a 24-hr period at a single near-bottom depth.

APPENDIX A. (Continued).

	Bottom Depth (m)		Dissolved Oxygen (mg/L)		Salinity (‰)		Temperature (°C)		pH	
Station	Profile[a,b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]
CP94025	3.0	4.8	6.7	5.5	25.8	16.1	27.8	27.8	7.8	7.6
		(3.1–6.0)	(6.3–7.2)	(4.6–6.5)	(24.5–27.9)	(13.3–30.0)	(27.5–27.9)	(27.4–28.2)	(7.7–7.9)	(7.3–7.9)
CP94026	6.5	7.6	5.5	5.8	28.5	27.4	27.5	27.9	7.7	7.7
		(6.3–8.8)	(5.4–5.8)	(4.7–6.7)	(28.4–28.6)	(21.0–30.0)	(27.5–27.6)	(27.4–28.1)	(7.7–7.7)	(7.6–7.9)
CP94027	2.8	3.7	5.8	6.2	19.3	18.8	26.1	27.2	7.6	7.6
		(2.5–4.6)	(5.8–6.6)	(5.0–7.1)	(19.1–19.3)	(17.6–22.6)	(25.9–26.1)	(25.5–27.9)	(7.6–7.6)	(7.5–7.7)
CP94028	0.0	0.6	7.2	6.1	37.5	–	29.4	27.9	7.9	7.9
		(0.0–0.8)	(7.0–7.3)	(5.0–6.9)	(37.4–37.5)	–	(29.4–29.4)	(25.2–30.3)	(7.9–7.9)	(7.7–7.9)
CP94029	0.5	0.4	7.5	6.9	36.3	–	28.3	27.4	7.9	7.9
		(0.1–0.8)	(7.3–7.5)	(5.6–7.7)	(36.2–36.3)	–	(28.2–28.3)	(25.4–29.3)	(7.5–8.0)	(7.8–8.0)
CP94030	0.4	0.2	5.9	6.3	35.7	36.3	31.3	27.0	7.9	7.8
		(0.1–0.3)	(5.8–5.9)	(5.8–6.8)	(35.2–35.8)	(35.3–36.9)	(31.1–31.3)	(25.9–28.3)	(7.9–7.9)	(7.8–7.8)
CP94031	0.7	0.4	6.9	5.9	34.9	34.3	27.9	27.2	7.9	7.8
		(0.2–0.7)	(6.9–7.0)	(4.6–7.0)	(34.5–35.0)	(13.0–34.9)	(27.5–27.9)	(26.2–28.2)	(7.9–7.9)	(7.7–7.9)
CP94032	0.8	0.5	5.6	5.9	39.0	–	27.7	26.9	7.9	7.9
		(0.4–0.6)	(5.6–6.1)	(5.7–6.2)	(39.0–39.2)	–	(27.2–27.7)	(26.0–28.0)	(7.9–7.9)	(7.9–7.9)
CP94033	1.6	1.0	6.4	7.7	38.3	–	27.6	27.4	7.8	8.0
		(0.7–1.5)	(6.4–6.4)	(6.3–10.5)	(38.0–38.3)	–	(27.4–27.6)	(26.4–28.0)	(7.8–7.8)	(8.0–8.1)
CP94034	3.7	–	9.9	–	17.0	–	28.6	–	8.3	–
		–	(6.0–11.5)	–	(16.5–20.7)	–	(27.9–30.1)	–	(8.0–8.5)	–
CP94035	3.3	1.6	6.8	6.7	23.5	–	29.0	–	7.9	8.0
		(1.5–1.9)	(3.4–7.0)	(5.3–8.0)	(23.3–25.3)	–	(28.5–29.3)	–	(7.7–7.9)	(7.9–8.1)
CP94036	5.5	–	6.7	–	25.5	–	26.6	–	8.1	–
		–	(4.3–8.0)	–	(19.4–26.6)	–	(26.4–27.3)	–	(7.8–8.1)	–

[a] Bottom depths based on instantaneous profile depths corrected to Mean Lower Low Water.

[b] Instantaneous, surface-to-bottom depth profiles (taken at 1-m intervals for bottom depths > 3m; 0.5-m intervals for depths < 3m).

[c] Continuous, time-series measurements taken at 30-min. intervals typically over a 24-hr period at a single near-bottom depth.

APPENDIX A. (Continued).

Station	Bottom Depth (m)		Dissolved Oxygen (mg/L)		Salinity (‰)		Temperature (°C)		pH	
	Profile[a,b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]
CP94037	4.2	3.5	6.9	6.2	29.3	30.0	25.2	25.1	8.0	8.0
		(3.5–3.6)	(6.4–7.0)	(5.9–6.9)	(29.2–30.1)	(29.4–31.0)	(25.1–25.2)	(24.8–25.3)	(7.9–8.0)	(7.9–8.0)
CP94038	1.8	0.8	6.5	8.2	17.0	16.1	29.3	30.7	7.8	7.9
		(0.7–0.9)	(4.7–6.7)	(6.9–8.5)	(16.7–18.0)	(16.1–16.2)	(29.1–29.4)	(29.4–30.9)	(7.6–7.8)	(7.8–8.0)
CP94039	2.0	1.9	6.3	7.3	34.4	32.3	24.2	24.3	7.8	8.0
		(1.3–2.3)	(6.1–6.5)	(6.7–8.0)	(33.8–34.5)	(28.7–39.1)	(24.1–24.3)	(22.9–25.0)	(7.7–7.9)	(7.9–8.1)
CP94040	5.7	–	6.8	–	28.3	–	26.1	–	8.1	–
		–	(6.3–7.2)	–	(27.9–28.7)	–	(25.6–26.2)	–	(8.1–8.1)	–
CP94041	5.7	4.9	6.7	6.6	29.2	29.6	25.2	25.2	8.0	8.0
		(4.8–4.9)	(5.9–6.8)	(5.9–7.3)	(29.1–29.7)	(29.3–29.9)	(25.0–25.2)	(25.1–25.4)	(8.0–8.0)	(7.9–8.0)
CP94042	3.5	2.9	7.0	7.2	26.1	28.8	24.5	24.7	7.9	8.0
		(2.7–3.1)	(7.0–7.6)	(6.7–7.5)	(26.0–26.5)	(27.5–29.3)	(23.5–24.6)	(24.3–25.0)	(7.9–7.9)	(7.9–8.0)
CP94043	2.1	1.7	6.4	7.7	23.3	23.2	25.9	26.4	8.0	8.1
		(1.6–1.8)	(3.3–7.9)	(6.8–8.5)	(23.2–25.2)	(22.9–23.4)	(24.3–26.7)	(25.3–27.3)	(7.7–8.0)	(8.0–8.1)
CP94044	2.5	1.6	7.3	7.2	25.8	24.9	25.0	24.8	7.9	8.0
		(1.5–2.0)	(7.2–7.4)	(6.9–7.6)	(25.7–25.9)	(24.5–25.6)	(24.7–25.0)	(24.2–25.3)	(7.9–8.0)	(7.9–8.0)
CP94045	1.8	1.4	7.6	7.4	25.5	25.1	23.6	23.9	7.9	8.0
		(1.2–1.6)	(7.5–7.6)	(6.9–8.1)	(25.4–25.7)	(24.7–25.4)	(23.3–23.7)	(23.3–24.6)	(7.8–7.9)	(7.9–8.3)
CP94046	2.2	2.0	7.0	6.9	21.9	21.7	28.2	27.9	8.0	8.0
		(1.8–2.0)	(6.5–7.8)	(6.3–7.6)	(21.8–22.0)	(21.7–21.9)	(27.4–28.5)	(27.2–28.5)	(7.9–8.0)	(7.9–8.1)
CP94047	3.2	1.8	5.1	7.9	17.2	15.9	26.9	27.8	7.9	8.1
		(1.8–2.0)	(1.2–7.0)	(3.2–9.9)	(15.8–21.6)	(15.6–18.0)	(26.6–27.1)	(26.5–28.4)	(7.4–8.1)	(7.5–8.3)
CP94048	5.5	4.8	6.8	6.4	20.2	20.7	27.5	27.3	8.0	8.0
		(4.6–5.2)	(6.5–7.1)	(5.9–7.0)	(20.1–20.6)	(20.0–20.9)	(27.2–27.7)	(26.9–27.7)	(7.9–8.0)	(7.9–8.0)

[a] Bottom depths based on instantaneous profile depths corrected to Mean Lower Low Water.

[b] Instantaneous, surface-to-bottom depth profiles (taken at 1-m intervals for bottom depths > 3m; 0.5-m intervals for depths < 3m).

[c] Continuous, time-series measurements taken at 30-min. intervals typically over a 24-hr period at a single near-bottom depth.

APPENDIX A. (Continued).

	Bottom Depth (m)		Dissolved Oxygen (mg/L)		Salinity (‰)		Temperature (°C)		pH	
Station	Profile[a,b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]
CP94049	1.4	0.9	6.9	6.9	20.3	20.7	28.4	27.4	7.9	8.1
		(0.8–1.1)	(6.8–7.0)	(6.6–7.3)	(20.3–20.4)	(20.4–20.8)	(28.3–28.4)	(26.9–28.5)	(7.9–7.9)	(8.1–8.2)
CP94050	5.6	–	6.5	–	25.2	–	27.3	–	8.0	–
		–	(6.1–7.0)	–	(24.9–27.3)	–	(27.0–27.4)	–	(8.0–8.0)	–
CP94051	4.6	3.7	7.2	7.4	17.0	16.7	27.4	27.8	8.1	8.1
		(3.5–4.1)	(1.7–7.7)	(0.3–8.3)	(16.5–20.5)	(16.6–20.7)	(26.7–27.5)	(26.7–28.1)	(7.4–8.1)	(7.2–8.2)
CP94052	4.6	3.3	5.4	7.4	17.6	16.6	27.4	27.6	7.8	8.1
		(3.2–3.3)	(1.0–8.3)	(0.1–8.7)	(15.6–21.5)	(16.4–21.1)	(26.5–27.8)	(26.6–28.0)	(7.3–8.1)	(7.2–8.2)
CP94053	2.3	1.4	7.4	6.4	13.6	13.1	27.9	28.1	7.8	7.9
		(1.4–1.5)	(1.3–10.0)	(5.5–8.1)	(13.0–17.6)	(12.9–13.4)	(27.5–28.8)	(27.7–28.8)	(7.1–8.1)	(7.6–8.1)
CP94054	1.9	1.0	5.9	4.9	13.9	13.8	28.2	27.7	7.5	7.3
		(1.0–1.2)	(4.4–7.8)	(3.6–6.6)	(13.9–14.0)	(13.7–13.9)	(28.0–28.3)	(27.3–28.5)	(7.3–7.5)	(7.2–7.6)
CP94055	4.0	4.4	7.0	6.9	21.9	22.5	27.6	28.0	7.9	7.9
		(4.1–4.6)	(5.0–7.6)	(6.1–7.5)	(21.6–22.5)	(22.3–22.6)	(26.7–28.0)	(27.5–28.5)	(7.7–8.0)	(7.9–8.0)
CP94056	4.2	4.9	7.3	6.7	22.7	16.5	27.8	28.0	8.0	8.0
		(4.5–5.1)	(5.3–7.7)	(4.7–7.4)	(21.4–23.3)	(15.6–23.6)	(25.2–29.3)	(27.6–28.6)	(7.7–8.0)	(7.7–8.0)
CP94057	1.2	0.7	6.0	6.7	19.6	19.8	28.6	29.1	7.9	7.9
		(0.5–0.8)	(4.5–7.2)	(6.2–7.6)	(18.2–21.0)	(19.0–21.7)	(26.6–29.5)	(28.0–30.9)	(7.6–8.0)	(7.9–8.0)
CP94058	4.1	3.1	7.6	6.7	20.9	21.8	28.1	28.5	8.0	8.0
		(2.9–3.4)	(6.4–8.0)	(6.5–7.1)	(16.6–29.9)	(20.8–22.1)	(22.9–29.3)	(27.2–28.9)	(7.9–8.1)	(7.9–8.0)
CP94059	0.7	0.4	7.6	7.7	37.3	35.8	19.6	21.2	7.8	8.0
		(0.3–0.6)	(7.5–7.7)	(7.1–8.4)	(37.0–37.4)	(32.9–36.3)	(19.6–19.6)	(20.2–23.9)	(7.8–7.8)	(7.9–8.1)
CP94060	3.1	2.4	7.3	–	9.8	9.0	26.8	26.1	7.9	7.9
		(2.2–2.8)	(7.3–7.4)	–	(9.7–9.8)	(7.6–9.8)	(26.6–26.8)	(24.8–26.7)	(7.9–7.9)	(7.8–8.0)

[a] Bottom depths based on instantaneous profile depths corrected to Mean Lower Low Water.

[b] Instantaneous, surface-to-bottom depth profiles (taken at 1-m intervals for bottom depths > 3m; 0.5-m intervals for depths < 3m).

[c] Continuous, time-series measurements taken at 30-min. intervals typically over a 24-hr period at a single near-bottom depth.

APPENDIX A. (Continued).

	Bottom Depth (m)		Dissolved Oxygen (mg/L)		Salinity (‰)		Temperature (°C)		pH	
Station	Profile[a,b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]
CP94061	4.0	3.4 (2.6–3.5)	7.9 (7.4–8.1)	7.7 (6.8–8.5)	3.2 (2.7–3.2)	2.7 (2.5–3.2)	28.9 (28.6–29.4)	29.2 (28.8–29.9)	8.0 (7.9–8.1)	7.9 (7.7–8.3)
CP94062	6.0	5.4 (5.2–5.6)	10.6 (7.8–12.5)	5.7 (5.2–6.2)	1.6 (1.5–2.5)	2.5 (2.5–2.6)	28.6 (28.3–29.5)	28.4 (28.3–28.5)	7.6 (7.2–7.7)	7.1 (7.1–7.3)
CP94063	1.1	1.0 (0.8–1.0)	8.8 (7.6–9.1)	7.7 (6.5–9.2)	1.5 (1.0–1.6)	1.6 (1.4–2.1)	29.6 (29.0–31.6)	28.7 (28.2–30.9)	7.8 (7.7–8.0)	7.7 (7.3–8.2)
CP94064	5.7	4.2 (4.1–4.3)	7.5 (7.2–7.8)	7.6 (7.0–8.1)	4.0 (4.0–4.0)	4.0 (3.9–4.2)	28.0 (27.6–28.1)	28.2 (28.0–28.7)	7.7 (7.0–7.9)	7.6 (7.4–7.9)
CP94065	2.2	1.1 (1.0–1.3)	7.6 (7.1–8.1)	7.5 (7.2–8.3)	0.7 (0.7–0.7)	0.8 (0.8–0.8)	29.7 (29.4–30.0)	30.0 (29.4–31.5)	7.8 (7.8–8.3)	7.5 (7.4–7.8)
CP94066	6.1	5.0 (4.9–5.1)	7.7 (6.7–8.2)	7.2 (6.7–7.8)	3.4 (3.3–3.5)	3.4 (3.3–3.5)	29.0 (28.5–30.1)	28.9 (28.7–29.6)	7.9 (7.7–8.1)	7.7 (7.6–7.9)
CP94067	2.0	1.0 (0.9–1.6)	5.9 (5.5–7.2)	6.4 (5.1–8.8)	1.5 (1.4–1.5)	1.4 (1.3–1.5)	29.8 (29.6–30.3)	30.5 (29.9–31.5)	7.6 (7.5–8.1)	7.8 (7.3–8.9)
CP94068	1.7	0.6 (0.6–0.7)	7.6 (7.3–7.7)	7.8 (7.4–8.5)	5.4 (5.4–5.4)	5.6 (4.8–5.9)	27.4 (27.4–27.7)	28.3 (27.5–29.0)	7.9 (7.9–7.9)	8.0 (7.8–8.2)
CP94069	5.4	4.1 (4.1–4.3)	7.6 (7.3–7.8)	7.8 (7.5–8.4)	3.5 (3.4–3.5)	3.4 (3.1–3.6)	28.0 (27.8–29.2)	28.2 (27.8–28.8)	7.6 (7.6–7.7)	7.7 (7.5–8.0)
CP94070	0.4	0.2 (0.1–0.4)	7.7 (7.4–7.8)	8.2 (7.7–9.4)	6.5 (6.3–6.6)	6.4 (5.9–6.7)	28.2 (28.1–28.3)	29.2 (27.6–31.3)	7.9 (7.9–7.9)	8.0 (7.7–8.5)
CP94071	0.7	1.6 (0.2–2.0)	7.9 (7.8–7.9)	8.3 (6.8–9.3)	4.6 (4.6–4.6)	4.5 (4.3–4.6)	27.2 (27.2–27.2)	27.2 (26.0–28.1)	8.4 (8.4–8.4)	8.4 (7.7–8.6)
CP94072	1.4	1.0 (0.9–1.1)	9.0 (8.8–9.1)	8.7 (7.4–9.6)	1.5 (1.5–1.5)	1.5 (1.5–1.6)	28.3 (28.3–28.3)	28.0 (27.4–28.5)	8.4 (8.4–8.4)	8.2 (7.8–8.5)

[a] Bottom depths based on instantaneous profile depths corrected to Mean Lower Low Water.

[b] Instantaneous, surface-to-bottom depth profiles (taken at 1-m intervals for bottom depths > 3m; 0.5-m intervals for depths < 3m).

[c] Continuous, time-series measurements taken at 30-min. intervals typically over a 24-hr period at a single near-bottom depth.

APPENDIX A. (Continued).

	Bottom Depth (m)		Dissolved Oxygen (mg/L)		Salinity (‰)		Temperature (°C)		pH	
Station	Profile[a,b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]	Profile[b]	Time Series[c]
CP94073	11.5	13.4 (12.0–14.5)	5.5 (5.4–6.6)	5.9 (5.2–6.2)	27.1 (27.0–27.3)	27.6 (27.3–29.0)	27.7 (26.6–27.8)	27.9 (27.3–28.4)	7.7 (7.7–7.7)	7.7 (7.6–7.9)
CP94074	2.1	4.0 (2.8–5.1)	6.5 (6.2–6.5)	6.5 (5.7–7.5)	31.9 (30.2–32.0)	30.1 (28.2–31.7)	27.9 (27.8–27.9)	28.2 (27.0–29.1)	8.0 (8.0–8.0)	7.9 (7.9–8.0)
CP94075	9.3	11.3 (10.0–12.1)	7.1 (7.0–7.7)	5.8 (5.4–6.3)	30.2 (29.9–30.3)	30.1 (29.8–30.4)	28.4 (28.3–28.6)	28.4 (28.1–28.7)	7.7 (7.6–7.7)	7.8 (7.7–7.8)
CP94076	5.8	8.2 (6.9–9.4)	5.7 (5.4–5.8)	5.1 (3.7–6.1)	32.2 (31.8–32.2)	26.2 (24.4–33.4)	27.7 (27.7–28.0)	28.9 (27.8–29.9)	8.0 (7.9–8.0)	7.6 (7.3–8.0)
CP94077	5.6	7.0 (5.7–7.8)	4.0 (3.9–5.1)	4.2 (3.7–4.8)	21.4 (20.6–21.5)	20.8 (18.1–24.9)	27.9 (27.9–28.3)	28.7 (28.1–28.9)	7.2 (7.2–7.2)	7.1 (7.0–7.4)
CP94078	4.2	5.3 (4.1–6.3)	4.5 (4.2–5.3)	– –	29.9 (29.6–30.0)	28.7 (26.0–31.8)	27.7 (27.6–27.7)	27.9 (27.5–29.0)	7.7 (7.7–7.7)	7.5 (7.3–7.9)
CP94079	10.6	12.1 (11.3–12.9)	5.4 (5.2–6.7)	5.7 (5.0–6.2)	25.8 (20.3–28.6)	29.9 (28.3–31.9)	28.0 (27.2–28.2)	27.8 (27.4–28.0)	7.7 (7.6–7.7)	7.9 (7.8–8.0)
CP94080	2.2	3.8 (3.0–4.6)	5.6 (5.5–6.3)	5.8 (4.2–6.3)	33.4 (33.2–33.5)	31.8 (28.3–33.6)	27.9 (27.1–27.9)	27.9 (27.0–29.9)	7.9 (7.9–7.9)	7.9 (7.7–8.1)
CP94081	0.0	0.5 (0.1–0.7)	5.6 (5.5–5.9)	6.1 (5.8–6.7)	33.5 (33.4–33.6)	34.2 (33.6–34.5)	28.6 (28.2–28.7)	27.2 (26.2–29.6)	7.8 (7.8–7.8)	7.9 (7.8–7.9)
CP94082	3.5	4.1 (3.3–4.7)	5.4 (4.9–8.5)	– –	2.7 (1.1–3.9)	3.8 (2.8–6.3)	26.4 (26.3–27.6)	27.0 (26.5–27.5)	6.7 (6.7–6.7)	6.7 (6.6–6.9)
CP94083	4.5	4.8 (4.0–6.1)	6.5 (6.0–6.7)	6.3 (4.8–7.7)	32.2 (19.2–32.5)	30.0 (24.6–33.4)	27.1 (27.1–27.7)	27.8 (27.0–28.2)	7.9 (7.8–7.9)	7.9 (7.8–8.0)
CP94084	0.0	0.5 (0.5–0.6)	5.8 (5.5–8.3)	– –	5.3 (4.6–5.5)	4.5 (3.8–5.2)	30.0 (27.1–30.2)	30.4 (29.8–31.0)	7.2 (7.1–7.6)	6.8 (6.6–7.2)

[a] Bottom depths based on instantaneous profile depths corrected to Mean Lower Low Water.

[b] Instantaneous, surface-to-bottom depth profiles (taken at 1-m intervals for bottom depths > 3m; 0.5-m intervals for depths < 3m).

[c] Continuous, time-series measurements taken at 30-min. intervals typically over a 24-hr period at a single near-bottom depth.

APPENDIX B. Concentrations of aliphatic and aromatic hydrocarbons (ng/g dry wt) at EMAP sites in the Carolinian Province during summer 1994. Analytes in excess of reported bioeffect levels (listed at end for reference) are bolded.

Station	Acenaphthene	Acenaphthylene	Anthracene	Benzo[a]-anthracene	Benzo[a]-pyrene	Chrysene	Dibenz[a,h]-anthracene	Fluoranthene	Fluorene	2-Methyl-naphthalene	Naphthalene	Phenanthrene	Pyrene	Total Alkanes	Total PAHs w/o Perylene
CP94001	0.07	0.21	0.29	1.09	1.57	1.84	0.24	2.66	0.20	0.49	1.16	0.83	2.76	187.9	34.01
CP94002	1.02	7.20	12.59	37.95	55.33	62.08	8.70	84.31	2.31	3.13	7.65	16.39	84.95	2900.5	904.77
CP94003	0.20	0.16	0.21	0.38	0.62	0.74	0.11	1.36	0.19	0.46	0.87	0.73	1.17	184.2	18.02
CP94004	0.08	0.09	0.18	0.35	0.57	0.71	0.12	1.18	0.19	0.41	0.78	0.68	1.15	338.5	16.29
CP94005	0.15	0.20	0.36	1.36	2.35	2.92	0.44	4.12	0.21	0.44	1.00	1.28	3.75	313.9	44.19
CP94006	0.13	0.34	0.39	0.98	1.67	1.94	0.24	2.84	0.21	0.56	1.17	0.94	2.80	261.0	38.20
CP94007	0.06	0.11	0.26	0.29	0.41	0.63	0.05	0.86	0.14	0.59	1.36	0.77	0.86	120.1	13.95
CP94008	0.11	0.20	0.21	0.47	0.90	0.77	0.19	1.18	0.20	0.57	1.05	0.76	1.19	300.5	22.40
CP94009	0.38	0.97	1.84	9.90	10.02	16.49	1.36	20.91	0.73	1.03	1.64	4.17	17.67	340.4	191.32
CP94010	0.40	1.05	3.04	7.10	10.44	13.65	1.76	16.67	1.16	1.62	2.18	4.76	13.54	423.7	183.27
CP94011	0.16	0.09	0.15	0.13	0.21	0.23	0.05	0.49	0.16	0.53	0.77	0.39	0.42	82.8	9.35
CP94012	0.06	0.04	0.16	0.06	0.11	0.17	0.13	0.33	0.15	0.43	0.76	0.42	0.30	164.4	8.71
CP94013	0.05	0.02	0.14	0.07	0.11	0.17	0.03	0.33	0.18	0.38	0.76	0.47	0.42	143.1	7.33
CP94014	0.05	0.08	0.18	0.23	0.34	0.58	0.10	0.58	0.17	0.56	0.80	0.47	0.48	516.5	15.88
CP94015	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CP94016	8.55	21.49	35.40	110.96	108.80	115.91	24.80	227.15	15.66	17.08	37.23	51.03	325.88	**52558.9** [c]	3144.65
CP94017	**33.60** [a]	**74.19** [a]	**136.38** [a]	**386.06** [a]	**431.32** [a]	**469.92** [a]	**79.77** [a]	**802.09** [a]	**46.26** [a]	56.05	**167.01** [a]	**263.09** [a]	**867.73** [a]	**14362.4** [c]	**9179.22** [a]
CP94018	0.03	0.01	0.02	0.03	0.04	0.06	0.02	0.07	0.06	0.15	0.45	0.12	0.10	26.1	1.71
CP94019	0.15	0.19	0.47	0.52	0.42	0.61	0.04	1.55	0.23	0.59	1.89	0.92	1.25	218.4	25.10
CP94020	0.17	0.33	0.52	1.60	2.07	2.03	0.37	3.53	0.48	0.95	2.32	1.23	3.12	526.1	43.34

[a] In excess of ER-L.

[b] In excess of ER-M.

[c] In excess of potential sediment toxicity level for total alkanes.

APPENDIX B. (Continued).

Station	Acenaphthene	Acenaphthylene	Anthracene	Benzo[a]-anthracene	Benzo[a]-pyrene	Chrysene	Dibenz[a,h]-anthracene	Fluoranthene	Fluorene	2-Methyl]-naphthalene	Naphthalene	Phenanthrene	Pyrene	Total Alkanes	Total PAHs w/o Perylene
CP94021	0.18	0.63	1.65	5.31	3.98	6.17	0.47	4.86	0.44	0.61	1.37	1.97	4.36	296.5	69.68
CP94022	0.28	2.76	1.56	2.09	4.49	4.42	0.59	4.81	0.76	1.31	2.76	1.85	4.29	1322.0	95.42
CP94023	0.03	0.03	0.12	0.35	0.71	0.72	0.07	1.12	0.33	0.60	1.18	0.60	1.11	269.7	18.10
CP94024	0.07	0.18	0.17	0.52	0.51	0.85	0.11	3.79	0.21	0.45	1.12	0.71	2.66	287.2	20.10
CP94025	0.04	0.49	0.48	4.60	4.17	4.66	0.67	5.89	0.25	0.62	1.21	0.95	5.47	399.9	72.64
CP94026	0.07	0.07	0.13	0.41	0.51	0.52	0.07	0.85	0.23	0.49	1.05	0.53	0.78	123.5	12.67
CP94027	0.09	0.10	0.36	0.59	0.86	1.00	0.10	1.54	0.28	0.95	1.77	1.48	1.56	249.3	29.30
CP94028	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CP94029	0.05	0.05	0.18	0.13	0.11	0.35	0.03	0.46	0.13	0.38	0.91	0.36	0.35	120.0	7.50
CP94030	0.29	0.55	1.40	4.77	4.56	7.49	0.74	9.64	0.59	1.44	3.25	2.21	8.25	799.7	110.97
CP94031	0.08	0.12	0.35	0.99	1.17	1.78	0.23	2.82	0.18	0.54	0.99	0.88	2.26	467.4	32.15
CP94032	0.11	0.31	1.22	1.83	2.03	3.58	0.30	4.69	0.45	0.63	1.29	1.68	3.34	220.4	45.94
CP94033	0.03	0.03	0.21	0.18	0.27	0.28	0.03	0.49	0.19	0.37	0.78	0.33	0.30	101.3	8.27
CP94034	0.47	3.93	3.36	19.96	18.41	16.74	1.74	34.96	1.37	1.92	3.41	6.26	39.96	2131.5	390.01
CP94035	0.08	0.23	0.25	1.13	1.33	1.24	0.16	1.96	0.29	0.55	1.29	0.89	2.21	423.9	33.85
CP94036	1.04	4.56	3.83	22.48	27.26	23.38	2.38	42.22	2.65	3.13	7.16	11.20	49.09	3824.1	493.80
CP94037	0.08	0.08	0.10	0.26	0.25	0.28	0.03	0.51	0.19	0.51	0.61	0.63	0.58	128.7	9.42
CP94038	0.33	5.17	3.30	19.69	27.74	24.14	2.97	54.74	0.90	1.81	3.60	16.30	75.95	1240.4	494.07
CP94039	0.18	0.03	0.17	0.03	0.01	0.09	0.04	0.09	0.13	0.93	0.96	0.76	0.15	115.9	9.25
CP94040	0.53	2.56	2.55	9.61	12.75	12.75	1.69	23.46	1.37	3.35	7.35	10.17	29.20	1402.5	291.17
CP94041	0.37	2.47	2.01	11.80	16.09	16.62	2.25	24.59	0.96	2.40	3.75	8.76	30.29	1179.1	307.10

[a] In excess of ER-L.

[b] In excess of ER-M.

[c] In excess of potential sediment toxicity level for total alkanes.

Appendix B. (Continued).

Station	Acenaphthene	Acenaphthylene	Anthracene	Benzo[a]-anthracene	Benzo[a]-pyrene	Chrysene	Dibenz[a,h]-anthracene	Fluoranthene	Fluorene	2-Methyl]-naphthalene	Naphthalene	Phenanthrene	Pyrene	Total Alkanes	Total PAHs w/o Perylene
CP94042	0.03	0.06	0.12	0.04	0.08	0.21	0.05	0.31	0.31	0.70	1.84	0.65	0.23	116.2	9.70
CP94043	0.71	6.60	5.14	31.98	45.08	47.91	5.87	68.95	2.35	3.95	7.59	18.63	76.05	3273.8	800.33
CP94044	0.08	0.06	0.04	0.05	0.04	0.10	0.03	0.17	0.17	0.46	1.28	0.56	0.16	93.6	6.87
CP94045	0.21	0.10	0.27	0.24	0.42	0.58	0.17	0.91	0.48	1.98	4.99	1.37	0.87	372.9	40.05
CP94046	0.04	0.05	0.15	0.02	0.11	0.23	0.02	0.25	0.13	0.73	1.46	0.59	0.28	151.6	7.58
CP94047	1.04	2.92	2.65	20.40	23.32	23.77	2.41	45.25	1.85	3.51	6.10	10.94	42.55	3922.3	407.83
CP94048	0.42	2.61	2.22	8.28	10.46	7.65	1.79	21.34	2.00	3.41	6.25	6.90	22.77	3129.8	241.89
CP94049	0.02	0.03	0.18	0.07	0.07	0.08	0.03	0.22	0.21	0.63	1.91	0.94	0.24	151.5	10.86
CP94050	0.51	2.21	1.88	9.38	13.25	14.22	1.95	22.64	1.65	4.13	9.04	10.49	27.99	2455.2	298.74
CP94051	1.98	6.76	8.12	16.16	23.93	26.54	3.28	57.25	12.57	19.80	43.51	23.45	70.13	5646.6	826.91
CP94052	1.85	6.49	19.33	32.13	45.24	42.14	8.88	63.26	4.65	7.13	11.73	25.31	69.76	6485.9	842.65
CP94053	4.47	23.67	42.77	104.45	146.01	151.58	24.13	200.96	10.06	8.88	17.09	48.93	205.46	**16174.8** [c]	2360.19
CP94054	1.70	4.38	16.24	35.70	37.78	33.53	6.97	67.73	3.60	5.39	9.96	23.97	64.69	**8041.6** [c]	695.84
CP94055	0.48	3.61	6.60	20.00	21.64	19.50	3.13	36.49	1.63	1.26	3.05	12.89	41.57	2196.3	364.18
CP94056	0.18	0.07	2.45	0.50	0.45	0.63	0.04	1.81	0.39	0.45	1.13	1.15	1.56	179.9	19.27
CP94057	0.22	0.13	2.34	0.71	0.80	1.02	0.13	2.16	0.40	0.59	1.18	1.30	1.94	516.6	26.49
CP94058	0.15	0.12	2.05	0.54	0.49	0.79	0.11	1.54	0.34	0.32	0.83	1.00	1.13	166.5	21.32
CP94059	0.17	0.04	2.85	0.46	0.38	0.62	0.05	1.97	0.36	0.36	0.70	1.38	1.47	100.9	18.73
CP94060	0.44	1.25	4.00	5.38	6.98	8.09	1.06	16.05	1.24	1.16	2.70	8.24	18.05	3019.8	168.83
CP94061	0.22	0.14	2.08	1.21	1.13	1.03	0.27	2.68	0.26	0.31	0.77	1.31	2.31	207.2	26.46
CP94062	0.81	7.30	8.81	35.26	42.70	34.43	7.50	60.44	2.37	3.07	8.36	18.15	62.57	3029.7	716.22

[a] In excess of ER-L.

[b] In excess of ER-M.

[c] In excess of potential sediment toxicity level for total alkanes.

APPENDIX B. (Continued).

Station	Acenaphthene	Acenaphthylene	Anthracene	Benzo[a]-anthracene	Benzo[a]-pyrene	Chrysene	Dibenz[a,h]-anthracene	Fluoranthene	Fluorene	2-Methyl]-naphthalene	Naphthalene	Phenanthrene	Pyrene	Total Alkanes	Total PAHs w/o Perylene
CP94063	0.05	0.04	0.08	0.25	0.37	0.35	0.03	0.58	0.07	0.19	0.60	0.28	0.56	110.5	10.44
CP94064	0.16	0.60	0.52	2.58	3.29	3.70	0.66	5.09	0.57	0.96	2.16	2.16	5.06	2089.2	78.36
CP94065	0.21	6.70	5.98	87.21	83.62	77.60	12.57	80.87	1.19	1.31	7.26	6.79	80.64	811.1	882.95
CP94066	4.09	7.41	41.93	**426.95** [a]	243.91	372.32	39.85	**624.94** [a]	8.32	3.99	7.61	58.94	506.51	5948.5	**4549.38** [a]
CP94067	1.74	22.56	16.89	176.87	205.85	173.21	28.35	263.17	5.55	2.68	9.69	50.82	310.56	3983.8	2755.91
CP94068	0.03	0.04	0.16	0.11	0.18	0.19	0.02	0.32	0.12	0.19	0.75	0.34	0.29	341.0	6.98
CP94069	0.36	2.77	2.21	12.39	17.02	17.04	3.31	23.73	1.62	2.22	4.77	8.90	26.07	5084.9	325.51
CP94070	0.06	0.06	0.08	0.05	0.02	0.07	0.07	0.19	0.09	0.34	0.64	0.26	0.15	205.7	3.36
CP94071	0.14	0.13	0.50	1.05	1.12	1.27	0.22	3.12	0.72	0.73	1.47	1.69	2.19	1484.6	42.23
CP94072	0.45	4.25	6.27	41.54	47.49	44.14	5.84	79.70	2.78	2.14	5.61	20.82	78.36	6577.8	706.25
CP94073	0.03	0.04	0.59	0.28	0.21	0.73	0.08	0.68	0.11	0.32	0.71	0.28	0.43	197.2	11.23
CP94074	0.04	0.06	0.08	0.18	0.49	0.29	0.09	0.36	0.15	0.31	0.63	0.35	0.30	117.3	7.83
CP94075	0.06	0.04	0.15	0.18	0.26	0.23	0.08	0.39	0.10	0.34	0.90	0.34	0.32	123.0	6.31
CP94076	0.08	0.31	0.41	1.24	1.40	1.07	0.26	1.84	0.25	0.57	1.21	0.82	1.93	420.2	26.44
CP94077	0.07	0.07	0.13	0.20	0.17	0.18	0.05	0.53	0.13	0.34	1.29	0.34	0.53	139.5	6.66
CP94078	0.19	0.68	1.04	2.18	3.88	4.53	0.62	3.79	0.29	0.76	1.38	0.92	3.50	431.5	62.50
CP94079	1.16	3.42	7.98	15.62	17.14	18.34	2.84	30.45	1.99	1.74	3.71	7.58	26.43	1200.3	322.21
CP94080	0.10	0.27	0.40	0.89	1.02	0.90	0.27	1.65	0.14	0.77	1.64	0.70	1.44	217.1	24.27
CP94081	0.06	0.04	0.23	0.26	0.46	0.55	0.06	0.88	0.19	0.56	1.56	0.55	0.73	301.6	17.27
CP94082	11.93	5.51	19.35	60.32	46.33	106.83	7.86	118.70	13.88	11.67	23.15	65.90	101.95	**11365.5** [c]	1466.88
CP94083	0.18	0.07	0.25	0.87	0.89	1.09	0.24	1.54	0.14	0.26	0.85	0.76	1.43	86.2	15.10

[a] In excess of ER-L.

[b] In excess of ER-M.

[c] In excess of potential sediment toxicity level for total alkanes.

APPENDIX B. (Continued).

Station	Acenaphthene	Acenaphthylene	Anthracene	Benzo[a]-anthracene	Benzo[a]-pyrene	Chrysene	Dibenz[a,h]-anthracene	Fluoranthene	Fluorene	2-Methyl]-naphthalene	Naphthalene	Phenanthrene	Pyrene	Total Alkanes	Total PAHs w/o Perylene
CP94084	0.18	0.35	0.81	3.53	3.11	4.27	0.70	6.86	0.39	0.47	1.28	2.72	7.94	2836.3	91.18
CP94CF_	0.28	0.52	1.15	2.62	2.96	3.78	0.54	7.20	0.73	1.01	3.18	1.91	7.73	**107335.8** [c]	297.04
CP94DSL	**70.61** [a]	38.25	**139.32** [a]	**573.63** [a]	**617.89** [a]	**646.65** [a]	**74.74** [a]	**1302.79** [a]	**46.91** [a]	25.44	42.15	**649.78** [a]	**1454.24** [a]	4006.8	**10719.15** [a]
CP94ES4	0.25	0.25	0.47	0.45	0.36	0.54	0.17	1.57	0.59	1.26	2.32	1.59	1.22	1716.5	16.01
CP94JAC	0.15	0.10	0.33	0.78	0.69	0.91	0.09	1.87	0.18	0.28	0.98	0.62	2.61	81.8	18.97
CP94KOP	**169.01** [a]	**133.88** [a]	**2478.26** [b]	**1737.73** [b]	**1434.48** [a]	**2951.13** [b]	**201.75** [a]	**3857.43** [a]	**376.51** [a]	54.15	45.16	**1138.03** [a]	**3511.99** [b]	**10793.7** [c]	**32188.88** [a]
CP94LTH	0.28	0.16	0.33	0.19	0.24	0.30	0.27	0.75	0.12	0.69	1.24	0.93	0.66	111.0	8.82
CP94MI_	0.06	0.17	0.54	0.31	0.29	0.69	0.11	1.02	0.14	0.30	0.91	0.55	0.92	123.5	10.34
CP94NMK	**67.91** [a]	**84.42** [a]	**136.61** [a]	**681.80** [a]	**534.79** [a]	**894.98** [a]	59.12	**1681.33** [a]	**66.73** [a]	**96.77** [a]	101.87	**365.31** [a]	**1591.71** [a]	**14930.3** [c]	**14024.65** [a]
CP94PLM	1.19	2.55	3.48	12.95	15.92	13.49	1.86	19.90	0.93	2.39	4.64	4.69	24.11	1352.7	239.54
CP94RC_	0.11	0.08	0.08	0.27	0.14	0.15	0.23	1.07	0.40	0.95	1.16	0.53	0.76	69.0	8.68
CP94SPY	**36.15** [a]	**52.94** [a]	**109.67** [a]	224.02	220.10	263.20	27.85	546.17	**39.92** [a]	37.24	**174.75** [a]	**268.22** [a]	**696.39** [a]	3570.8	**8195.67** [a]
CP94ZI_	0.54	1.42	2.85	8.34	12.00	15.28	2.25	21.50	1.72	4.52	8.04	8.28	17.65	2777.7	300.45
Bioeffect Values:															
ER-L[d]	16	44	85.3	261	430	384	63.4	600	19	70	160	240	665	–	4022
ER-M [d]	500	640	1100	1600	1600	2800	260	5100	540	670	2100	1500	2600	–	44792
Total alkane potential toxicity level [e]														7000	

[a] In excess of ER-L.

[b] In excess of ER-M.

[c] In excess of potential sediment toxicity level for total alkanes.

[d] From Long et al. (1995).

[e] From Macauley et al. (1994).

APPENDIX C. Concentrations (ng/g dry wgt.) of PCBs and Pesticides at EMAP sites in the Carolinian Province during summer 1994. Analytes in excess of reported bioeffect levels (listed at the end for reference) are bolded. N.D. = Not detected.

Station	Total PCB	Dieldrin	Endrin	Total Chlordane	Total DDT	4,4′-DDD	4,4′-DDE	4.4′-DDT
CP94001	2.56	N.D.	N.D.	N.D.	0.02	N.D.	0.02	N.D.
CP94002	16.36	**0.28**[a]	N.D.	0.15	**4.09**[a]	0.83	**2.78**[a]	0.17
CP94003	3.66	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94004	2.47	N.D.	N.D.	N.D.	0.02	N.D.	0.02	N.D.
CP94005	6.86	N.D.	N.D.	N.D.	0.06	N.D.	0.06	N.D.
CP94006	2.60	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94007	3.73	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94008	4.00	N.D.	N.D.	N.D.	0.03	N.D.	N.D.	0.03
CP94009	5.72	N.D.	N.D.	N.D.	0.07	N.D.	0.07	N.D.
CP94010	8.17	N.D.	N.D.	N.D.	0.10	N.D.	0.10	N.D.
CP94011	5.10	N.D.	N.D.	N.D.	0.02	N.D.	N.D.	N.D.
CP94012	3.77	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94013	3.65	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94014	3.97	N.D.	N.D.	N.D.	0.04	N.D.	N.D.	0.04
CP94015	–	–	–	–	–	–	–	–
CP94016	**311.54**[b]	N.D.	N.D.	1.79	**10.68**[a]	**2.36**[a]	**6.03**[a]	0.87
CP94017	**282.83**[b]	**1.42**[a]	N.D.	**5.15**[b]	**17.64**[a]	**6.56**[a]	**8.48**[a]	0.36
CP94018	2.45	N.D.	N.D.	N.D.	< 0.01	N.D.	< 0.01	< 0.01
CP94019	2.93	N.D.	N.D.	0.01	0.02	N.D.	0.01	< 0.01
CP94020	5.37	< 0.01	N.D.	0.01	0.09	0.05	0.03	< 0.01
CP94021	**91.79**[a]	0.01	N.D.	0.04	0.13	0.05	0.03	0.01
CP94022	6.01	0.01	N.D.	0.04	0.22	0.08	0.09	N.D.
CP94023	2.64	N.D.	N.D.	N.D.	0.03	N.D.	0.02	N.D.
CP94024	2.67	< 0.01	N.D.	< 0.01	0.02	N.D.	0.01	N.D.
CP94025	3.55	< 0.01	N.D.	0.02	0.06	N.D.	0.02	0.01
CP94026	2.76	N.D.	N.D.	N.D.	0.02	N.D.	0.02	N.D.
CP94027	2.62	N.D.	N.D.	N.D.	0.01	N.D.	0.01	< 0.01
CP94028	–	–	–	–	–	–	–	–
CP94029	2.71	N.D.	N.D.	N.D.	0.01	N.D.	< 0.01	N.D.
CP94030	4.51	N.D.	N.D.	0.01	0.26	0.05	0.18	N.D.
CP94031	2.78	N.D.	N.D.	0.01	0.08	N.D.	0.07	< 0.01
CP94032	3.09	N.D.	N.D.	0.03	0.10	N.D.	0.02	0.03
CP94033	2.69	N.D.	N.D.	0.01	0.01	N.D.	< 0.01	N.D.
CP94034	6.71	**0.06**[a]	N.D.	0.46	0.94	0.29	0.53	0.02
CP94035	2.84	0.01	N.D.	< 0.01	0.09	0.04	0.04	N.D.
CP94036	11.17	**0.04**[a]	N.D.	0.75	**1.62**[a]	0.46	0.90	0.04
CP94037	2.88	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

---

[a] In excess of ER-L or TEL.

[b] In excess of ER-M or PEL.

APPENDIX C. (Continued).

Station	Total PCB	Dieldrin	Endrin	Total Chlordane	Total DDT	4,4′-DDD	4,4′-DDE	4.4′-DDT
CP94038	4.49	N.D.	N.D.	N.D.	**2.24** [a]	0.41	0.38	**1.37** [a]
CP94039	2.76	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94040	4.71	N.D.	N.D.	N.D.	0.58	0.20	0.36	N.D.
CP94041	5.22	0.02	N.D.	N.D.	0.27	0.11	0.15	N.D.
CP94042	2.53	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94043	5.82	N.D.	N.D.	N.D.	**1.58** [a]	0.49	0.85	N.D.
CP94044	2.64	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94045	2.60	N.D.	N.D.	0.01	0.03	0.02	0.01	N.D.
CP94046	2.62	N.D.	N.D.	N.D.	0.01	N.D.	0.01	N.D.
CP94047	12.87	N.D.	N.D.	0.09	**6.12** [a]	1.09	1.36	**3.60** [a]
CP94048	4.78	0.02	N.D.	0.09	0.84	0.28	0.54	N.D.
CP94049	2.79	< 0.01	N.D.	N.D.	0.01	N.D.	0.01	N.D.
CP94050	4.72	**0.02** [a]	N.D.	0.02	0.87	0.36	0.42	N.D.
CP94051	**47.86** [a]	**0.11** [a]	N.D.	0.26	**2.85** [a]	0.84	1.88	N.D.
CP94052	**29.24** [a]	N.D.	N.D.	0.16	**6.00** [a]	**1.51** [a]	**3.55** [a]	0.62
CP94053	**60.62** [a]	**1.44** [a]	N.D.	1.36	**18.81** [a]	**5.04** [a]	**10.14** [a]	**2.22** [a]
CP94054	20.68	**0.27** [a]	N.D.	0.07	**4.55** [a]	1.18	**3.04** [a]	0.21
CP94055	8.60	**0.10** [a]	N.D.	0.02	0.42	0.13	0.26	N.D.
CP94056	3.29	N.D.	N.D.	N.D.	0.02	N.D.	0.02	N.D.
CP94057	2.92	N.D.	N.D.	N.D.	0.06	0.02	0.03	N.D.
CP94058	3.20	N.D.	N.D.	N.D.	0.02	N.D.	0.02	N.D.
CP94059	3.13	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94060	5.07	N.D.	N.D.	0.02	0.45	0.15	0.20	0.10
CP94061	2.43	N.D.	N.D.	N.D.	0.07	0.03	0.04	N.D.
CP94062	17.20	**0.29** [a]	N.D.	0.47	**4.56** [a]	**1.66** [a]	**2.23** [a]	0.25
CP94063	2.66	N.D.	N.D.	0.02	0.06	0.03	0.03	N.D.
CP94064	3.97	**0.05** [a]	N.D.	0.07	0.71	0.27	0.32	0.09
CP94065	5.65	**0.07** [a]	N.D.	N.D.	0.56	0.23	0.27	0.03
CP94066	**190.81** [b]	**0.49** [a]	N.D.	0.44	**6.94** [a]	**2.90** [a]	**3.20** [a]	0.3
CP94067	**56.02** [a]	**0.19** [a]	**0.30** [a]	0.11	**4.05** [a]	**1.24** [a]	2.19	0.35
CP94068	2.96	N.D.	N.D.	0.02	0.03	N.D.	0.02	N.D.
CP94069	12.96	**0.16** [a]	N.D.	0.25	**3.16** [a]	**1.33** [a]	1.46	0.25
CP94070	2.55	N.D.	N.D.	N.D.	< 0.01	N.D.	< 0.01	N.D.
CP94071	2.80	N.D.	N.D.	N.D.	0.48	0.28	0.17	N.D.
CP94072	5.38	N.D.	N.D.	0.06	**2.34** [a]	1.22	0.95	N.D.
CP94073	2.82	N.D.	N.D.	N.D.	0.13	0.08	0.03	0.01
CP94074	2.61	N.D.	N.D.	N.D.	0.01	N.D.	0.01	N.D.
CP94075	2.95	N.D.	N.D.	N.D.	0.03	0.01	0.01	N.D.
CP94076	2.77	N.D.	N.D.	N.D.	0.08	0.03	0.05	N.D.

[a] In excess of ER-L or TEL.

[b] In excess of ER-M or PEL.

APPENDIX C. (Continued).

Station	Total PCB	Dieldrin	Endrin	Total Chlordane	Total DDT	4,4′-DDD	4,4′-DDE	4.4′-DDT
CP94077	2.55	N.D.	N.D.	< 0.01	0.01	< 0.01	0.01	N.D.
CP94078	6.58	N.D.	N.D.	N.D.	0.42	0.11	0.25	0.05
CP94079	5.98	**0.03**[a]	N.D.	0.20	0.57	0.20	0.20	0.08
CP94080	3.51	N.D.	N.D.	N.D.	0.03	0.01	0.01	N.D.
CP94081	3.67	N.D.	N.D.	0.01	0.05	0.02	0.02	N.D.
CP94082	20.52	**0.14**[a]	N.D.	0.53	**1.82**[a]	0.76	0.93	0.02
CP94083	2.57	N.D.	N.D.	N.D.	0.03	0.01	0.01	N.D.
CP94084	3.52	**0.04**[a]	N.D.	0.03	0.24	0.09	0.10	0.04
CP94CF_	5.19	**0.03**[a]	N.D.	0.11	0.36	0.14	0.09	0.04
CP94DSL	**112.41**[a]	**1.01**[a]	N.D.	**2.39**[a]	**5.45**[a]	**1.64**[a]	**2.78**[a]	N.D.
CP94ES4	3.92	N.D.	N.D.	N.D.	0.11	0.07	0.05	N.D.
CP94JAC	6.33	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94KOP	**68.04**[a]	**3.34**[a]	N.D.	**4.15**[a]	**6.31**[a]	**1.75**[a]	**2.71**[a]	0.26
CP94LTH	3.89	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94MI_	2.76	N.D.	N.D.	0.01	0.02	N.D.	0.01	N.D.
CP94NMK	**534.07**[b]	**6.02**[a]	N.D.	**22.95**[b]	**42.77**[a]	**22.29**[b]	**14.08**[a]	**3.46**[a]
CP94PLM	6.36	N.D.	N.D.	0.09	0.33	0.10	0.23	N.D.
CP94RC_	3.20	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CP94SPY	21.00	**0.12**[a]	N.D.	0.89	**9.30**[a]	**5.61**[a]	**2.93**[a]	0.04
CP94ZI_	4.82	< 0.01	N.D.	0.20	0.31	0.09	0.21	N.D.
Bioeffect Values:								
ER-L	22.7[c]	0.02[d]	0.02[d]	–	1.58[c]	–	2.2[c]	–
ER-M	180[c]	8[d]	45[d]	–	46.1[c]	–	27[c]	–
TEL	–	–	–	2.26[e]	–	1.22[e]	–	1.19[e]
PEL	–	–	–	4.79[e]	–	7.81[e]	–	4.77[e]

[a] In excess of ER-L or TEL.
[b] In excess of ER-M or PEL.
[c] From Long et al. 1995
[d] From Long and Morgan 1990
[e] From MacDonald 1994

Appendix D. Concentrations of inorganic metals (µg/g dry wgt.) and tributyltin (TBT, as ng Sn/g dry weight) at EMAP sites in the Carolinian Province during summer 1994. Analytes in excess of reported bioeffect values (listed at the end for reference) are bolded. N.D. = Not detectable.

Station	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Sb	TBT	Zn
CP94001	0.03	1.07	0.03	9.94	2.27	0.01	2.03	6.19	N.D.	0.38	10.73
CP94002	0.10	7.40	0.20	73.84	27.58	0.09	17.51	27.53	0.27	**18.49**[c]	80.29
CP94003	0.03	1.39	0.03	14.18	1.65	0.02	2.23	7.93	N.D.	0.71	12.15
CP94004	N.D.	1.28	0.04	12.74	2.71	N.D.	1.65	7.72	0.87	0.83	13.73
CP94005	0.04	1.04	0.06	16.67	4.14	0.02	1.77	8.22	N.D.	0.47	17.79
CP94006	0.02	1.06	0.04	12.80	2.99	0.02	1.88	7.39	N.D.	0.44	17.93
CP94007	0.02	N.D.	N.D.	6.14	0.86	N.D.	0.46	1.87	N.D.	3.89	6.67
CP94008	0.01	0.95	0.02	8.09	1.96	0.02	0.98	3.53	N.D.	4.66	10.79
CP94009	0.12	2.88	0.14	31.32	11.32	0.12	7.06	19.07	0.38	**8.93**[c]	42.24
CP94010	0.17	3.75	0.20	38.09	15.84	0.07	9.35	19.42	0.23	**34.65**[c]	56.42
CP94011	N.D.	N.D.	N.D.	4.95	1.62	0.01	0.70	2.58	N.D.	0.23	7.32
CP94012	0.03	N.D.	0.03	6.37	1.14	0.02	1.39	4.99	N.D.	**22.87**[c]	8.10
CP94013	0.02	N.D.	0.03	6.37	0.93	0.01	1.11	4.60	0.23	**20.10**[c]	8.00
CP94014	0.03	1.22	0.05	10.71	2.07	0.02	2.13	5.87	N.D.	**6.02**[c]	11.21
CP94015	–	–	–	–	–	–	–	–	–	–	–
CP94016	0.22	5.29	0.73	60.61	24.07	**0.23**[a]	19.85	35.65	1.99	**289.28**[c]	120.63
CP94017	0.38	**9.39**[a]	0.68	**83.99**[a]	**36.26**[a]	**0.21**[a]	**21.59**[a]	**52.66**[a]	0.60	**96.46**[c]	**182.78**[a]
CP94018	0.02	3.99	0.02	3.78	0.47	0.01	0.71	2.33	N.D.	2.23	10.43

[a] In excess of ER-L.

[b] In excess of ER-M.

[c] In excess of TBT potential sediment toxicity level.

APPENDIX D. (Continued).

Station	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Sb	TBT	Zn
CP94019	0.02	1.18	0.04	11.49	0.84	0.01	1.34	3.65	0.21	0.81	9.13
CP94020	0.03	4.96	0.09	28.93	4.10	0.02	5.58	8.42	N.D.	1.26	29.68
CP94021	0.03	4.27	0.11	19.29	2.30	0.02	3.54	7.06	0.30	0.27	18.66
CP94022	0.04	**9.10**[a]	0.11	47.45	6.84	0.03	8.77	12.39	0.29	**13.53**[c]	44.73
CP94023	0.01	2.87	0.13	22.63	2.20	0.01	3.60	7.10	N.D.	N.D.	22.05
CP94024	0.02	2.79	0.07	20.75	1.93	N.D.	2.96	7.10	N.D.	**6.86**[c]	18.52
CP94025	N.D.	4.05	0.12	17.00	2.42	0.01	3.75	6.33	N.D.	0.17	19.57
CP94026	0.02	7.80	0.27	10.35	1.24	0.01	2.06	5.56	N.D.	N.D.	14.44
CP94027	N.D.	3.74	0.05	24.95	2.46	0.02	4.40	8.54	N.D.	0.36	18.67
CP94028	–	–	–	–	–	–	–	–	–	–	–
CP94029	0.02	2.46	0.06	17.41	1.26	N.D.	1.18	4.07	N.D.	N.D.	12.86
CP94030	0.04	8.03	0.06	58.54	5.85	0.02	9.65	15.04	0.43	2.28	43.90
CP94031	0.02	2.69	0.07	14.76	1.50	N.D.	1.88	5.59	0.56	**8.66**[c]	15.36
CP94032	0.02	3.41	0.02	25.33	2.30	N.D.	4.23	10.24	0.21	**13.69**[c]	25.07
CP94033	0.01	1.27	N.D.	6.15	0.99	N.D.	1.07	3.63	N.D.	**9.36**[c]	9.72
CP94034	0.08	6.44	0.21	53.43	10.15	0.04	12.52	19.84	**2.14**[a]	2.11	65.86
CP94035	0.03	N.D.	0.03	36.20	2.04	0.01	3.07	10.34	N.D.	**10.12**[c]	20.22
CP94036	0.18	**12.38**[a]	0.49	**83.40**[a]	21.55	0.09	**23.54**[a]	32.76	1.26	0.34	123.32
CP94037	0.01	N.D.	N.D.	12.43	1.21	0.01	2.56	6.84	N.D.	4.34	16.80
CP94038	0.02	6.35	0.17	56.35	11.31	0.06	13.65	17.68	0.41	0.76	79.58
CP94039	N.D.	1.05	N.D.	6.42	0.68	0.01	1.14	4.06	1.01	N.D.	6.80

[a] In excess of ER-L.

[b] In excess of ER-M.

[c] In excess of TBT potential sediment toxicity level.

APPENDIX D. (Continued).

Station	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Sb	TBT	Zn
CP94040	0.07	**11.66**[a]	0.24	73.23	15.92	0.07	**21.66**[a]	28.28	0.45	0.80	99.77
CP94041	0.06	**9.17**[a]	0.09	59.88	9.14	0.04	16.68	22.16	0.34	N.D.	74.72
CP94042	0.02	1.23	0.02	21.66	1.22	N.D.	2.04	7.12	N.D.	N.D.	16.18
CP94043	0.07	7.57	0.35	74.07	14.22	0.08	20.71	26.79	0.49	0.79	123.56
CP94044	0.02	1.54	0.01	9.38	1.08	N.D.	2.24	5.36	N.D.	N.D.	15.21
CP94045	0.02	2.12	0.03	18.93	2.95	N.D.	5.03	8.24	0.21	0.77	25.17
CP94046	0.03	1.49	N.D.	28.62	1.19	N.D.	1.78	7.06	N.D.	N.D.	12.59
CP94047	0.14	7.76	1.12	**81.60**[a]	19.59	0.07	**21.72**[a]	30.44	0.63	0.77	127.64
CP94048	0.07	**8.46**[a]	0.20	75.73	11.96	0.05	**21.88**[a]	26.86	0.46	N.D.	102.00
CP94049	0.01	0.50	N.D.	12.91	1.23	0.01	1.24	5.77	**2.02**[a]	N.D.	12.41
CP94050	0.05	**14.69**[a]	0.07	68.01	12.09	0.06	**22.02**[a]	25.84	0.36	1.04	86.76
CP94051	0.14	**11.13**[a]	0.90	80.83	19.66	0.11	**25.70**[a]	28.61	0.78	3.18	124.10
CP94052	0.16	**9.55**[a]	0.99	**81.50**[a]	20.84	0.10	**26.04**[a]	27.49	0.57	2.44	120.79
CP94053	0.21	7.80	0.65	80.12	25.64	0.13	**23.39**[a]	40.97	1.14	3.04	135.05
CP94054	0.06	6.03	0.25	73.16	10.66	0.09	**22.05**[a]	25.92	0.49	4.20	106.29
CP94055	0.02	3.96	0.04	45.29	5.24	0.03	10.31	14.20	0.29	0.24	43.03
CP94056	0.04	2.57	N.D.	23.50	1.91	N.D.	3.87	7.30	0.20	N.D.	26.47
CP94057	0.04	1.19	N.D.	13.80	1.81	N.D.	2.66	6.51	0.26	0.14	16.17
CP94058	0.04	1.48	N.D.	16.45	1.70	N.D.	3.57	6.21	N.D.	N.D.	22.04
CP94059	0.03	1.94	0.03	**130.85**[a]	1.91	N.D.	5.55	9.05	N.D.	N.D.	65.81
CP94060	0.07	5.06	0.13	43.19	8.42	0.05	14.36	15.15	0.29	1.89	57.56

[a] In excess of ER-L.

[b] In excess of ER-M.

[c] In excess of TBT potential sediment toxicity level.

APPENDIX D. (Continued).

Station	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Sb	TBT	Zn
CP94061	0.02	N.D.	0.01	46.81	1.79	N.D.	2.68	8.02	N.D.	0.18	43.52
CP94062	0.16	**9.80**[a]	0.27	**97.18**[a]	33.05	**0.25**[a]	**34.34**[a]	39.13	0.91	**14.23**[c]	**175.01**[a]
CP94063	0.02	0.64	0.02	8.17	1.03	N.D.	1.13	4.80	N.D.	N.D.	11.17
CP94064	0.04	3.33	0.07	38.13	7.31	0.04	10.15	12.22	0.36	3.20	57.43
CP94065	0.03	N.D.	0.02	10.85	1.22	0.01	1.71	9.47	N.D.	N.D.	14.13
CP94066	0.13	**8.87**[a]	0.25	**96.34**[a]	32.87	**0.32**[a]	**32.84**[a]	39.06	0.94	N.D.	**154.96**[a]
CP94067	0.04	2.23	0.14	25.12	4.92	0.06	6.15	12.69	0.21	0.34	35.89
CP94068	0.02	0.80	0.02	8.83	1.43	N.D.	1.83	4.36	N.D.	N.D.	11.64
CP94069	0.08	7.42	0.19	78.84	22.32	**0.17**[a]	**27.66**[a]	**50.83**[a]	0.84	1.04	109.52
CP94070	0.03	1.52	0.03	43.89	1.05	0.01	2.10	3.27	N.D.	N.D.	12.02
CP94071	0.03	1.93	0.08	32.74	4.92	0.02	8.00	11.54	0.26	N.D.	38.06
CP94072	0.06	5.84	0.13	54.24	7.16	0.03	14.83	15.44	0.29	N.D.	61.54
CP94073	N.D.	4.02	0.14	35.15	1.36	0.02	2.01	5.48	N.D.	N.D.	16.67
CP94074	N.D.	2.11	0.03	24.09	1.20	N.D.	2.16	5.85	**2.60**[a]	N.D.	15.34
CP94075	N.D.	2.26	0.08	17.44	1.27	0.01	1.80	4.94	**3.36**[a]	N.D.	11.80
CP94076	0.01	4.58	0.03	20.79	2.12	0.01	3.13	5.11	N.D.	N.D.	17.92
CP94077	N.D.	1.44	N.D.	15.12	0.55	N.D.	0.50	1.84	0.33	N.D.	7.66
CP94078	0.01	5.45	0.03	35.65	5.87	0.02	7.30	10.42	0.21	0.16	35.64
CP94079	0.07	**11.21**[a]	0.13	53.26	12.06	0.02	13.81	16.17	1.45	3.47	61.60
CP94080	0.02	4.30	0.02	23.93	3.16	0.01	4.42	9.22	1.18	0.22	24.60
CP94081	0.01	8.08	N.D.	35.25	3.74	0.01	6.16	12.44	1.27	N.D.	34.70

[a] In excess of ER-L.

[b] In excess of ER-M.

[c] In excess of TBT potential sediment toxicity level.

APPENDIX D. (Continued).

Station	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Sb	TBT	Zn
CP94082	0.13	**20.49**[a]	0.11	**90.86**[a]	29.87	0.07	**30.45**[a]	27.15	1.01	**16.48**[c]	139.25
CP94083	N.D.	1.79	N.D.	15.00	0.61	N.D.	1.20	3.80	0.81	0.53	10.43
CP94084	0.04	2.00	0.04	41.14	6.87	0.03	9.72	16.55	N.D.	0.36	31.65
CP94CF_	0.03	5.65	0.05	42.75	7.14	0.02	9.11	10.77	0.35	**6.43**[c]	46.36
CP94DSL	0.44	**25.45**[a]	0.29	**132.65**[a]	**62.59**[a]	**0.15**[a]	**25.90**[a]	**87.65**[a]	1.34	**6.16**[c]	**187.51**[a]
CP94ES4	0.03	1.70	0.03	28.10	2.54	0.01	4.73	7.22	N.D.	N.D.	20.18
CP94JAC	0.03	0.89	0.04	5.33	0.82	N.D.	0.89	2.95	N.D.	**6.23**[c]	8.87
CP94KOP	0.22	**20.59**[a]	0.20	1**13.52**[a]	**44.35**[a]	0.10	**24.67**[a]	46.40	1.50	**25.70**[c]	**155.50**[a]
CP94LTH	0.02	2.81	0.01	12.92	0.62	N.D.	1.22	4.17	N.D.	1.27	8.55
CP94MI_	N.D.	2.06	0.03	10.65	0.87	N.D.	0.84	2.82	N.D.	0.59	8.73
CP94NMK	0.44	**19.24**[a]	0.91	**176.81**[a]	**76.30**[a]	**0.15**[a]	**22.42**[a]	**166.20**[a]	1.77	4.59	**274.47**[a]
CP94PLM	0.05	5.42	0.06	38.00	6.89	0.02	6.55	12.89	0.29	1.64	36.87
CP94RC_	0.01	1.14	0.01	19.46	0.69	0.01	0.85	3.00	N.D.	N.D.	6.89
CP94SPY	0.09	**10.40**[a]	0.30	**1911.05**[b]	26.79	0.09	18.13	23.37	0.72	**12.07**[c]	87.16
CP94ZI_	0.09	**16.47**[a]	0.11	71.43	14.11	0.06	15.89	21.34	0.52	N.D.	77.83
Bioeffect Values:											
ER-L	1.0 [d]	8.2 [d]	1.2 [d]	81 [d]	34 [d]	0.15 [d]	20.9 [d]	46.7 [d]	2.0 [e]	–	150 [d]
ER-M	3.7 [d]	70.0 [d]	9.6 [d]	370 [d]	270 [d]	0.71 [d]	51.6 [d]	218.0 [d]	25 [e]	–	410 [d]
TBT potential toxicity range	–	–	–	–	–	–	–	–	–	>5 [f]	–

[a] In excess of ER-L.

[b] In excess of ER-M.

[c] In excess of TBT potential sediment toxicity level.

[d] From Long et al. 1995

[e] From Long and Morgan 1990

[f] From Macauley 1994

APPENDIX E. Results of 10-day solid-phase toxicity tests with the amphipod *Ampelisca abdita*.

Station	Holding Times (Days)	Survival (%)	Control Survival (%)	Survival as a % of Control	Test Significance [a]	Bioeffect Exceedances [b]	Porewater UAN (µg/L) [c]
CP94001	14	91	96	95		0, 0	239
CP94002	14	94	96	98		3, 0	15
CP94003	13	87	96	91		0, 0	121
CP94004	13	93	96	96		0, 0	26
CP94005	20	84	87	97		0, 0	326
CP94006	22	91	92	99		0, 0	421
CP94007	13	87	96	91	*	0, 0	12
CP94008	22	91	92	99		0, 0	464
CP94009	21	93	87	107		0, 0	342
CP94010	27	93	93	100		0, 0	200
CP94011	27	90	93	97		0, 0	634
CP94012	26	89	93	96		0, 0	142
CP94013	26	93	93	100		0, 0	688
CP94014	26	85	93	91	*	0, 0	161
CP94015	–	–	–	–	–	–	–
CP94016	17	94	92	102		4, **1**	1029
CP94017	20	91	96	95		24, **2**	41
CP94018	18	86	96	90		0, 0	18
CP94019	18	89	96	93	*	0, 0	360
CP94020	22	93	92	101		0, 0	149
CP94021	–	–	–	–	–	1, 0	–
CP94022	27	94	93	101		1, 0	876
CP94023	29	90	93	97		0, 0	50
CP94024	26	92	93	99		0, 0	674
CP94025	12	98	96	102		0, 0	11
CP94026	29	92	95	97		0, 0	5
CP94027	12	94	96	98		0, 0	–
CP94028	–	–	–	–	–	–	–
CP94029	27	80	87	92	*	0, 0	260
CP94030	6	95	98	97		0, 0	68
CP94031	13	96	98	98		0, 0	302

[a] * = Sample results were statistically less than the negative control ($\alpha = 0.05$).
** = Sample results were statistically less than the negative control ($\alpha = 0.05$) and ≤ 80% of control survival.

[b] Number of contaminants present at concentrations in excess of ER-L / TEL values or ER-M / PEL values (bolded).

[c] Porewater concentrations of unionized ammonia nitrogen (UAN µg/L) are shown to reflect the possible influence of this factor on amphipod toxicity.

APPENDIX E. (Continued).

Station	Holding Times (Days)	Survival (%)	Control Survival (%)	% of Control	Test Significance [a]	Bioeffect Exceedances [b]	Porewater UAN (µg/L) [c]
CP94032	25	84	87	97		0, 0	285
CP94033	25	85	87	98		0, 0	361
CP94034	8	95	98	97		2, 0	140
CP94035	8	94	98	96		0, 0	103
CP94036	25	93	95	98		5, 0	16
CP94037	19	94	96	98		0, 0	4
CP94038	7	98	98	100		2, 0	46
CP94039	19	80	96	83	*	0, 0	404
CP94040	25	94	95	99		2, 0	12
CP94041	19	92	96	96		1, 0	132
CP94042	19	100	96	104		0, 0	174
CP94043	25	95	95	100		1, 0	218
CP94044	21	90	96	94	*	0, 0	5
CP94045	20	95	96	99		0, 0	0
CP94046	27	91	93	98		0, 0	307
CP94047	28	90	93	97		4, 0	562
CP94048	26	93	93	100		2, 0	69
CP94049	27	91	93	98		1, 0	74
CP94050	26	96	93	103		3, 0	28
CP94051	28	94	93	101		5, 0	6
CP94052	28	98	93	105		8, 0	1539
CP94053	28	91	93	98		8, 0	325
CP94054	29	95	95	100		4, 0	180
CP94055	23	95	92	103		1, 0	98
CP94056	17	96	92	104		0, 0	33
CP94057	23	95	92	103		0, 0	108
CP94058	18	91	92	99		0, 0	45
CP94059	17	83	92	90	*	1, 0	18
CP94060	19	97	92	105		0, 0	107
CP94061	19	79	92	86		0, 0	65
CP94062	20	87	92	95		9, 0	147
CP94063	20	73	92	79	**	0, 0	510

[a] * = Sample results were statistically less than the negative control ($\alpha = 0.05$).
** = Sample results were statistically less than the negative control ($\alpha = 0.05$) and ≤ 80% of control survival.

[b] Number of contaminants present at concentrations in excess of ER-L / TEL values or ER-M / PEL values (bolded).

[c] Porewater concentrations of unionized ammonia nitrogen (UAN µg/L) are shown to reflect the possible influence of this factor on amphipod toxicity.

APPENDIX E. (Continued).

Station	Holding Times (Days)	Survival (%)	Control Survival (%)	% of Control	Test Significance [a]	Bioeffect Exceedances [b]	Porewater UAN (µg/L) [c]
CP94064	10	97	98	99		1, 0	59
CP94065	19	84	92	91		1, 0	496
CP94066	19	92	92	100		12, **1**	198
CP94067	19	84	92	91	*	5, 0	61
CP94068	10	99	98	101		0, 0	0
CP94069	10	97	98	99		6, 0	30
CP94070	10	94	98	96		0, 0	94
CP94071	8	95	94	101		0, 0	64
CP94072	8	97	94	103		1, 0	12
CP94073	12	96	96	100		0, 0	–
CP94074	13	95	96	99		1, 0	767
CP94075	14	94	96	98		1, 0	268
CP94076	26	92	96	96		0, 0	–
CP94077	25	95	96	99		0, 0	–
CP94078	29	99	96	103		0, 0	–
CP94079	10	85	88	97		2, 0	–
CP94080	10	86	88	98		0, 0	–
CP94081	13	86	88	98		0, 0	–
CP94082	27	93	96	97		5, 0	–
CP94083	8	99	96	103		0, 0	–
CP94084	8	89	94	95		1, 0	50
CP94CF_	19	91	95	96		1, 0	88
CP94DSL	14	95	96	99		23, 0	–
CP94ES4	8	95	94	101		0, 0	113
CP94JAC	20	89	96	93	*	0, 0	18
CP94KOP	5	91	88	103		19, **4**	–
CP94LTH	11	93	96	97		0, 0	–
CP94MI_	27	91	87	105		0, 0	469
CP94NMK	14	86	96	90		23, **3**	–
CP94NOI	5	87	88	99		–	–
CP94PLM	12	94	96	98		0, 0	–
CP94RC_	25	66	87	76	**	0, 0	–
CP94SPY	5	90	88	102		13, **1**	–
CP94ZI_	28	91	87	105		1, 0	1246

[a] * = Sample results were statistically less than the negative control ($\alpha = 0.05$).
** = Sample results were statistically less than the negative control ($\alpha = 0.05$) and $\leq$ 80% of control survival.

[b] Number of contaminants present at concentrations in excess of ER-L / TEL values or ER-M / PEL values (bolded).

[c] Porewater concentrations of unionized ammonia nitrogen (UAN µg/L) are shown to reflect the possible influence of these factors on amphipod toxicity.

APPENDIX F. Results of Microtox® toxicity tests. EC_{50} values (corrected for water content of sediment) are listed by station in decreasing order of toxicity.

Station	Microtox® EC_{50} (%)	Test Significance [a]	Bioeffect Exceedances [b]	Silt-Clay (%) [c]	Porewater UAN (µg/L) [c]
CP94082	0.018	*	5, 0	93.24	–
CP94KOP	0.056	*	19, **4**	91.06	–
CP94022	0.065	*	1, 0	37.53	876
CP94ZI_	0.065	*	1, 0	64.64	1246
CP94DSL	0.068	*	23, 0	78.80	–
CP94NMK	0.073	*	23, **3**	67.89	–
CP94003	0.082	*	0, 0	9.20	121
CP94036	0.082	*	5, 0	98.51	16
CP94002	0.083	*	3, 0	87.20	15
CP94048	0.092	*	2, 0	83.96	69
CP94001	0.141	*	0, 0	8.40	239
CP94SPY	0.143	*	13, **1**	35.02	–
CP94069	0.152	*	6, 0	89.42	30
CP94034	0.162	*	2, 0	55.78	140
CP94025	0.167	*	0, 0	10.17	11
CP94010	0.172	*	0, 0	14.50	200
CP94043	0.178	*	1, 0	96.22	218
CP94020	0.263	*	0, 0	19.86	149
CP94023	0.316	*	0, 0	9.66	50
CP94030	0.346		0, 0	54.44	68
CP94067	0.360	*	5, 0	18.29	61
CP94016	0.367		4, **1**	82.30	1029
CP94040	0.390		2, 0	95.61	12
CP94PLM	0.416	*	0, 0	19.01	–
CP94009	0.420	*	0, 0	17.30	342
CP94064	0.423		1, 0	24.89	59
CP94050	0.426		3, 0	94.85	28
CP94011	0.442	*	0, 0	2.70	634
CP94017	0.446		24, **2**	88.10	41
CP94060	0.451	*	0, 0	15.64	107
CP94NOI	0.471		–, –	32.94	–
CP94052	0.472		8, 0	99.42	1539

[a] Significant Microtox® toxicity = $EC_{50} \leq 0.2$ % if silt-clay content of sediment ≥ 20 %, or $EC_{50} \leq 0.5$ % if silt-clay content < 20 %. * = Significant test.

[b] Number of contaminants present at concentrations in excess or ER-L / TEL values or ER-M / PEL values (bolded).

[c] Percent silt-clay and porewater concentrations of unionized ammonia nitrogen (UAN µg/L) are shown to reflect the possible influence of these factors on Microtox® toxicity.

APPENDIX F. (Continued).

Station	Microtox® EC_{50} (%)	Test Significance [a]	Bioeffect Exceedances [b]	Silt-Clay (%) [c]	Porewater UAN (µg/L) [c]
CP94062	0.472		9, 0	97.69	147
CP94079	0.476		2, 0	42.36	–
CP94053	0.506		8, 0	94.14	325
CP94066	0.541		12, **1**	98.92	198
CP94076	0.558		0, 0	7.14	–
CP94041	0.608		1, 0	93.84	132
CP94014	0.612		0, 0	7.20	161
CP94055	0.649		1, 0	33.01	98
CP94013	0.774		0, 0	2.50	688
CP94078	0.777		0, 0	19.77	–
CP94072	0.804		1, 0	79.60	12
CP94005	0.840		0, 0	5.90	326
CP94084	0.871		1, 0	25.76	50
CP94054	0.904		4, 0	95.12	180
CP94047	0.984		4, 0	97.97	562
CP94081	0.990		0, 0	11.53	–
CP94080	1.010		0, 0	11.73	–
CP94051	1.098		5, 0	99.59	6
CP94038	1.216		2, 0	68.14	46
CP94021	1.220		1, 0	6.82	–
CP94004	1.270		0, 0	6.80	26
CP94074	1.340		1, 0	6.06	767
CP94026	1.390		0, 0	3.21	5
CP94CF_	1.400		1, 0	39.72	88
CP94024	1.515		0, 0	7.39	674
CP94006	1.550		0, 0	5.40	421
CP94031	1.908		0, 0	4.47	302
CP94012	1.942		0, 0	3.20	142
CP94027	2.030		0, 0	6.31	–
CP94073	2.100		0, 0	3.92	–
CP94075	2.313		1, 0	5.12	268
CP94032	2.316		0, 0	13.51	285
CP94057	2.347		0, 0	5.55	108

[a] Significant Microtox® toxicity = $EC_{50} \leq 0.2$ % if silt-clay content of sediment ≥ 20 %, or $EC_{50} \leq 0.5$ % if silt-clay content < 20 %. * = Significant test.

[b] Number of contaminants present at concentrations in excess or ER-L / TEL values or ER-M / PEL values (bolded).

[c] Percent silt-clay and porewater concentrations of unionized ammonia nitrogen (UAN µg/L) are shown to reflect the possible influence of these factors on Microtox® toxicity.

APPENDIX F. (Continued).

Station	Microtox EC_{50} (%)	Test Significance [a]	Bioeffect Exceedances [b]	Silt-Clay (%) [c]	Porewater UAN (µg/L) [c]
CP94029	2.660		0, 0	0.56	260
CP94008	2.760		0, 0	3.10	464
CP94056	2.790		0, 0	0.60	33
CP94045	2.950		0, 0	6.42	0
CP94ES4	3.270		0, 0	8.03	113
CP94035	3.570		0, 0	12.56	103
CP94058	3.580		0, 0	2.78	45
CP94059	3.700		1, 0	1.12	18
CP94007	4.380		0, 0	1.60	12
CP94042	4.680		0, 0	4.87	174
CP94019	4.860		0, 0	2.10	360
CP94039	4.920		0, 0	4.44	404
CP94077	6.960		0, 0	2.41	–
CP94071	7.290		0, 0	42.03	64
CP94049	7.450		1, 0	1.49	74
CP94JAC	9.090		0, 0	1.70	18
CP94083	10.310		0, 0	2.44	–
CP94MI_	11.560		0, 0	2.49	469
CP94033	11.70		0, 0	3.82	361
CP94046	12.95		0, 0	2.68	307
CP94018	17.51		0, 0	0.60	18
CP94RC_	18.33		0, 0	2.37	–
CP94063	45.49		0, 0	4.16	510
CP94044	48.05		0, 0	1.18	5
CP94037	109.24		0, 0	4.29	4
CP94061	141.19		0, 0	3.44	65
CP94LTH	154.41		0, 0	1.52	–
CP94065	316.05		1, 0	1.12	496
CP94068	9392.66		0, 0	4.01	0
CP94070	202615.21		0, 0	3.17	94
CP94015	–		–, –	–	–
CP94028	–		–, –	–	–

[a] Significant Microtox toxicity = $EC_{50} \leq 0.2$ % if silt-clay content of sediment ≥ 20 %, or $EC_{50} \leq 0.5$ % if silt-clay content < 20 %. * = Significant test.

[b] Number of contaminants present at concentrations in excess or ER-L / TEL values or ER-M / PEL values (bolded).

[c] Percent silt-clay and porewater concentrations of unionized ammonia nitrogen (UAN µg/L) are shown to reflect the possible influence of these factors on Microtox toxicity.

Appendix G. A. Mean Shannon-Weaver diversity (H′), species richness, and abundance per infaunal grab. B. Mean species richness and abundance per demersal trawl.

	A. Infaunal Grabs			B. Demersal (Fish) Trawls	
Station	Mean H′ per Grab	Mean Richness per Grab	Mean Abundance per Grab	Mean Richness per Trawl	Mean Abundance per Trawl
CP94001	3.6	51.5	525.5	4.5	16.5
CP94002	1.4	3.0	6.5	9.0	38.5
CP94003	4.1	75.0	997.5	6.5	43.0
CP94004	3.5	39.5	407.0	4.0	17.5
CP94005	3.6	29.5	276.0	9.0	35.0
CP94006	3.3	25.5	112.0	11.0	179.0
CP94007	4.0	34.0	283.5	14.5	172.5
CP94008	4.2	34.5	234.5	7.0	20.5
CP94009	3.2	23.5	216.5	6.0	34.5
CP94010	1.4	14.5	265.5	9.0	85.5
CP94011	3.6	26.0	167.5	3.5	37.0
CP94012	3.9	38.5	285.0	–	–
CP94013	4.4	48.0	318.0	4.0	57.0
CP94014	3.6	27.5	198.5	–	–
CP94015	–	–	–	–	–
CP94016	1.3	3.5	11.5	7.5	24.5
CP94017	0.7	2.0	8.5	5.0	12.0
CP94018	2.1	13.5	89.5	3.0	3.0
CP94019	4.8	51.5	176.5	2.5	3.5
CP94020	3.9	34.3	161.0	7.0	43.0
CP94021	3.8	45.3	337.3	8.0	137.5
CP94022	2.8	8.5	21.0	10.0	103.5
CP94023	4.4	38.0	154.5	12.0	164.5
CP94024	3.1	23.0	229.5	12.5	177.0
CP94025	2.9	11.0	23.0	10.5	103.5
CP94026	1.6	21.5	527.0	15.5	112.5
CP94027	2.5	7.0	18.5	9.0	59.0
CP94028	–	–	–	4.5	19.0
CP94029	3.5	29.5	254.5	6.5	40.5
CP94030	3.4	25.5	179.0	10.5	207.0
CP94031	3.6	21.5	113.0	6.0	25.0
CP94032	4.1	28.5	136.0	8.0	138.0
CP94033	3.5	20.5	80.5	6.5	33.0
CP94034	2.5	10.0	84.0	4.5	16.5
CP94035	2.8	17.5	165.0	5.0	18.0
CP94036	0.8	1.5	1.5	8.0	102.0

Appendix G. (Continued).

	A. Infaunal Grabs			B. Demersal (Fish) Trawls	
Station	Mean H′ per Grab	Mean Richness per Grab	Mean Abundance per Grab	Mean Richness per Trawl	Mean Abundance per Trawl
CP94037	3.8	22.5	115.0	5.0	7.5
CP94038	1.0	8.5	252.0	6.0	133.5
CP94039	1.6	10.5	219.5	4.5	5.5
CP94040	1.8	4.5	15.5	5.5	13.5
CP94041	2.7	8.5	32.0	3.5	8.0
CP94042	3.2	21.0	168.0	2.0	3.5
CP94043	0.5	2.0	8.0	11.0	225.0
CP94044	2.6	16.0	106.5	4.5	13.0
CP94045	3.6	26.5	175.5	7.5	118.5
CP94046	3.5	18.0	58.5	10.0	114.0
CP94047	1.2	6.0	194.0	4.5	90.0
CP94048	0.8	2.0	2.5	7.5	251.0
CP94049	2.5	10.5	48.5	10.0	179.5
CP94050	2.5	6.5	20.0	8.0	43.5
CP94051	0.0	1.0	1.0	1.5	3.5
CP94052	0.0	0.0	0.0	0.5	0.5
CP94053	0.6	3.0	91.5	6.0	36.5
CP94054	1.8	7.5	193.0	7.5	111.0
CP94055	2.8	12.0	112.5	9.5	438.5
CP94056	2.8	14.5	92.5	4.5	7.0
CP94057	2.6	22.0	269.0	10.0	169.5
CP94058	3.2	14.0	77.5	3.5	258.5
CP94059	3.3	15.0	50.5	3.5	13.0
CP94060	2.5	10.0	110.5	10.5	143.5
CP94061	1.8	8.5	82.5	3.0	7.0
CP94062	1.4	3.5	12.0	5.5	14.0
CP94063	2.5	7.0	31.0	4.5	49.5
CP94064	1.7	3.5	8.5	3.0	19.0
CP94065	1.7	7.0	77.0	–	–
CP94066	0.9	2.0	20.0	0.5	1.0
CP94067	0.8	7.5	327.5	6.0	43.0
CP94068	2.3	10.0	161.0	4.0	26.0
CP94069	0.6	4.0	70.5	4.0	15.0
CP94070	2.0	7.5	53.5	4.5	22.0
CP94071	2.2	12.5	258.0	3.5	11.5
CP94072	1.4	7.0	91.0	2.5	21.5
CP94073	4.5	47.5	344.5	10.5	296.5

APPENDIX G. (Continued).

Station	A. Infaunal Grabs			B. Demersal (Fish) Trawls	
	Mean H′ per Grab	Mean Richness per Grab	Mean Abundance per Grab	Mean Richness per Trawl	Mean Abundance per Trawl
CP94074	3.5	35.5	279.5	8.5	18.0
CP94075	4.2	49.5	419.0	7.5	27.0
CP94076	1.8	18.5	884.5	14.0	126.0
CP94077	1.4	4.5	27.0	9.0	103.5
CP94078	4.1	37.5	619.5	13.7	66.3
CP94079	2.5	10.0	64.0	11.5	270.5
CP94080	3.5	16.0	46.0	17.5	234.5
CP94081	4.0	44.5	356.5	14.5	119.0
CP94082	0.7	4.3	40.8	8.0	158.5
CP94083	2.9	25.5	342.5	9.0	41.0
CP94084	2.4	13.0	154.0	6.0	11.0
CP94CF_	0.9	7.0	119.5	–	–
CP94DSL	1.5	4.3	15.5	–	–
CP94ES4	2.4	12.5	93.0	–	–
CP94JAC	1.7	4.0	6.5	–	–
CP94LTH	1.8	6.3	23.3	–	–
CP94MI_	2.8	15.0	58.0	–	–
CP94NMK	1.7	5.3	40.0	–	–
CP94PLM	2.7	13.5	81.0	–	–
CP94RC_	3.1	12.5	34.5	–	–
CP94ZI_	1.1	4.0	39.5	–	–