Muskrat Populations in Virginia's Elizabeth River:

Influence of Environmental Contaminants

by

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(ABSTRACT)

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The influence of environmental contaminants on the muskrat population inhabiting the contaminated lower region of the Elizabeth River was studied through an analysis of contaminant burdens, physiological characteristics, and population dynamics in comparison to those of muskrat populations from a less contaminated region of the Elizabeth River (upper region) and a nearby uncontaminated river (Nansemond River). A total of 76 muskrats was collected for contaminant analysis during December 1986 - January 1987 and December 1987 - February 1988. Twenty-two of 35 carcasses analyzed for polynuclear aromatic hydrocarbons (PAHs) had detectable levels of from 1 to 6 PAH compounds. Only three muskrats from the lower region and one from the upper region of the Elizabeth River had PAH concentrations greater than 0.03 ppm dry wt (lower limit of detection). Liver DNA adduct levels were not significantly different between muskrats collected from the lower region of the Elizabeth River and muskrats collected from the Nansemond River. However, liver microsomal enzyme activity was greater in lower region Elizabeth River muskrats than in upper region Elizabeth River or Nansemond River muskrats, as indicated by significantly reduced pentobarbital sleeping times. The mean concentration of 14 PAH compounds detected in surface sediments from the lower region of the Elizabeth River (N = 10) was significantly greater

than the mean concentration detected in surface sediments collected from the upper region of the Elizabeth River (N = 5) or Nansemond River (N = 5).

Of 22 organochlorine compounds analyzed in 35 muskrat carcasses, dieldrin was detected in one carcass (0.25 ppm) from the lower region of the Elizabeth River, polychlorinated biphenyls were detected in two carcasses (0.66 ppm and 0.45 ppm) from the upper region of the Elizabeth River, and p,p′-DDE was detected in two carcasses (0.03 ppm each) from the upper region of the Elizabeth River and one carcass (0.03 ppm) from the Nansemond River. p,p′DDE was detected in 5 of 10 sediment samples from the lower region and 2 of 5 sediment samples from the upper region of the Elizabeth River. p,p′-DDD was detected in 3 of 10 sediment samples from the lower region of the Elizabeth River.

Twenty-seven of 33 metals analyzed were detected in muskrat kidneys and 9 of these were significantly different among the three study regions. Mean aluminum (13.19 ppm), cadmium (3.08 ppm), copper (12.85 ppm), nickel (0.50 ppm), and zinc (88.38 ppm) concentrations were greatest in lower region Elizabeth River muskrat kidneys. Mean cadmium (1.07 ppm), chromium (43.4 ppm), lead (104 ppm), tungsten (38.1 ppm), and mercury (0.50 ppm) concentrations were significantly greater in lower Elizabeth River sediment samples.

Density estimates based on shore length for the lower and upper regions of the Elizabeth River were 0.86 muskrats/100 m of shore and 1.1 muskrats/100 m of shore, respectively in 1987. Seventy-five female muskrats had a total of 637 placental scars ($\bar{x}$ = 8.49) ranging from 1 - 20. The number of placental scars per female did not differ significantly among regions. Twelve pregnant muskrats had a total of 54 fetuses ($\bar{x}$ = 4.5, range = 3 - 6). Average number of litters per year was estimated to be 1.89 with births occurring primarily from April - May and in September.

Results indicated that the environmental contaminants found in the lower region of the Elizabeth River have minimal influence on the muskrats from this region. Body and spleen weights were reduced but reproduction was not affected, and the muskrat density in this region appears to be stable and similar to the density in a less contaminated area. Immunological function may be depressed.

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INTRODUCTION

On April 22, 1990, the world will pay tribute to our environment with an Earth Day celebration, 20 years after the first such celebration. On that day, world attention will be focused on the environment with heightened awareness of our responsibility to ensure a quality environment for future generations. Industrial growth and development and the continued increase in the human population have stressed the environment and challenged scientists to develop new methods to detect, analyze, and remedy detrimental effects. With the increased environmental awareness that was sparked in 1963 by Rachel Carson's book *Silent Spring*, has come many advances in environmental science. To keep abreast of the very complex environmental changes resulting from the release of products and by-products of an increasing human population, environmental toxicologists are continually working to develop new technology for detection and analysis of these products and their potential toxic effects on living systems. With the complex changes that are occurring in our environment, simple detection of contaminant residue concentrations are no longer sufficient. There is a need for new methods that will quantify minute concentrations of contaminants and detect or predict detrimental effects prior to overt toxic responses. Researchers are currently trying to find reliable and sensitive techniques that will indicate exposure to low levels of contaminants prior to the advent of irreversible or detrimental changes in exposed organisms. Much of this research has previously involved laboratory studies,

although shifts to studies in natural systems have begun. Because of the many variables and increased complexity of natural systems, this shift is more like a "quantum leap". Aldo Leopold (1949) wrote in *A Sand County Almanac* "The ordinary citizen today assumes that science knows what makes the community clock tick; the scientist is equally sure he does not". His words are as relevant today as they were 40 years ago. The current study was designed to test the hypothesis that muskrats living in the Southern Branch of the Elizabeth River have accumulated elevated body burdens of environmental contaminants and that they do show related toxicological lesions. This study is a small segment of the research that will be needed before the effects of exposure to environmental contaminants will be understood.

OBJECTIVES

The specific objectives were as follows:

1. To determine tissue concentrations of selected environmental contaminants (heavy metals, organochlorines, and polynuclear aromatic hydrocarbons) in muskrats inhabiting the Southern Branch of the Elizabeth River.

2. To determine the effects of these contaminants on reproduction, body condition, and population dynamics of muskrats inhabiting the Southern Branch of the Elizabeth River.

3. To determine the usefulness and sensitivity of muskrats as monitors of local environmental pollution in marsh and riverine ecosystems.

STUDY AREA

The Elizabeth River is located in southeastern Virginia and is a major tributary emptying into the James River near its confluence with the Chesapeake Bay (Figure 1). A line drawn from Craney Island to Sewells Point delineates the mouth of the Elizabeth River which extends approximately 30 km to the Great Bridge locks, which serve as a navigational passage way for the "Virginia cut" of the intercoastal waterway. The river itself is divided into a main branch with 4 major tributaries: the Lafayette River, and the Eastern, Western, and Southern branches. The Elizabeth River serves as the drainage basin for approximately 777 km^2 of highly urbanized and industrialized land (Cerco and Kuo 1981). The river is under tidal influence with mean low and high water fluctuation of approximately 0.85 m. It receives fresh water by drainage from the Dismal Swamp through the Dismal Swamp Canal locks located at Deep Creek, the intercoastal water way connection to the North Landing River at Great Bridge, and from storm runoff. The drainage basin has a very low topographic relief, approximately 6.1 m, resulting in little net water movement (Neilson and Sturm 1978, Cerco and Kuo 1981).

The Elizabeth River system has a long history of development that began in the 1600's (VSWCB 1983, Nichols and Howard-Strobel 1986). Because it offered a protected port and was strategically located, this area began to develop as a significant trade, transport, and military center. Three metropolitan areas eventually developed surrounding the river. Norfolk, the oldest, became a town in 1680 and a city in 1845. Portsmouth became a parish in 1761 and a city in 1885, and Chesapeake eventually became a city in 1963 (Butt 1971). The human population in this area also showed a steady increase with a current population estimate of approximately 550,000 (VSWCB 1983).

Industrial development began with the agriculture and lumber trades and a naval shipyard, which was established in 1801. Eventually, commercial shipping, ship building, and railroads became established along the Elizabeth River and surrounding areas. Population and industrial

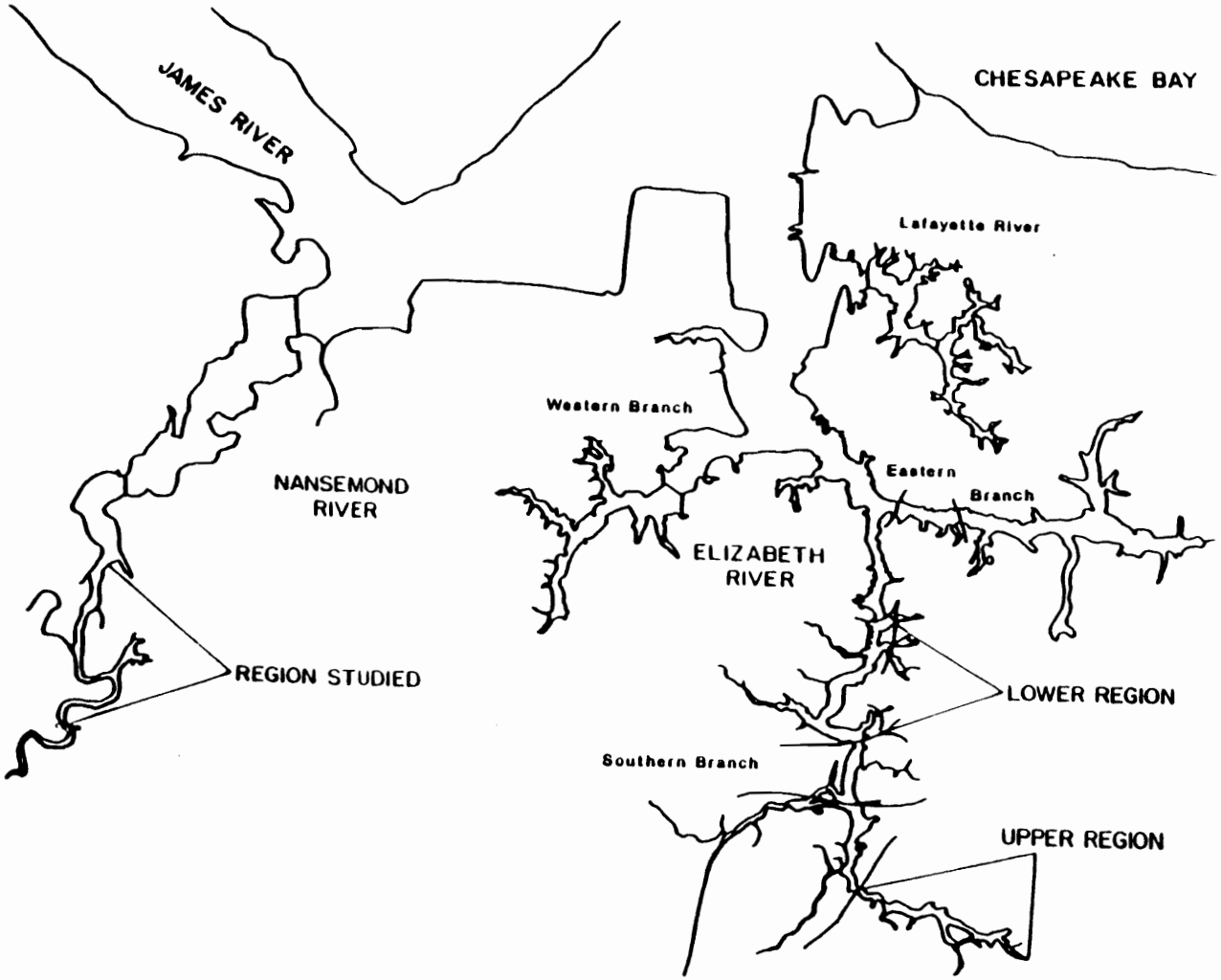

Figure 1 Regions in the Elizabeth and Nansemond Rivers, Virginia where muskrats were trapped and surface sediment samples were collected.

growths were especially large during the first and second world wars due to increased military and industrial needs (VSWCB 1983).

Along with the increased human and industrial expansion there has been a concomitant decrease in both the physical and chemical qualities of the river environment. Forty-six industries discharge industrial waste along with seven domestic discharges and a variety of nonpoint source discharges such as street runoff and recreational and commercial boat discharge. All of these have resulted in the degradation of water quality (Neilson and Sturm 1978, VSWCB 1983, 1984).

In addition to discharges into the river, dredging operations over the last 100 years have changed the river environment considerably. From 1880-1896, the Elizabeth River channel was deepened to 7.6 m. The main and southern branch channels of the river have been deepened since that time. The channel in the main branch is currently maintained at a 12.2 m depth and channel depths in the southern branch decrease from 10.7 m to 3.7 m as one moves up river (Nichols and Howard-Strobel 1986). Originally, dredge material was dumped near sites where the dredging operations occurred (in deep holes and along the river banks). Later (1893-1951), open water dumping occurred with dredge material being dumped at several locations in the lower Chesapeake Bay. Finally, from 1954-1957, the Corps of Engineers constructed a 10.36 km^2 enclosure north of Craney Island at the mouth of the Elizabeth River where most of the dredge material is currently being disposed. In addition to dumping, dredge material has been used over the years for landfill by surrounding communities. It is estimated that during this 100 years of dredging, 168 million m^3 of dredge material has been produced, and that disposal of this dredge material along the river has resulted in approximately 27% loss of the original river area (Nichols and Howard-Strobel 1986).

The main branch of the river is highly industrialized with ship building facilities and various ship loading and unloading facilities belonging to oil and coal companies and to the US Navy. The Lafayette River tributary is mainly urbanized in the upper reaches with some industries in the lower reaches. Numerous marinas and boating facilities also are present. The western branch of the river is an expanding urban area with marinas and recreational boating areas. The mouth of the eastern branch is industrialized and becomes progressively more urban (residential) towards the upper

reaches. The southern branch, which is a direct continuance of the main branch and is part of the intercoastal waterway, is highly industrialized at its lower reach and becomes urban and rural in its upper reach. Portions of the shoreline of the upper reach of the southern branch are composed of wooded and marsh habitat. Drainage from the Dismal Swamp by way of the Dismal Swamp Canal and the intercoastal waterway at Great Bridge serves as the headwaters for the Elizabeth River and empties into the southern branch (Neilson and Sturm 1978, Cerco and Kuo 1981, VSWCB 1983).

The Nansemond River is located approximately 12 km West of the the Elizabeth River and served as a reference river for this study. The Nansemond River is approximately 29 km in length and is mostly surrounded by forested and agricultural lands. This river has one major branch, the Western Branch, that receives overflow from the Western Branch Reservoir. The upper end of the river receives overflow from Lake Meade and flows through the City of Suffolk. Due to its proximate location and tidal similarity to the Elizabeth River and the lack of industrial development, the Nansemond provides a "natural" reference location for contaminant and biological studies of the Elizabeth River.

THE MUSKRAT

> There is an old Indian legend which tells that the Muskrat rendered great service to Nanabojou during the Flood. So the Sun-god said: "You may have any part of the country to live in that you please." The Muskrat took the deep blue lakes.
>
> But next day, he came back, and said: "I made a mistake; I want the grassy banks where there is something green to eat." These were given him.
>
> The next day, he was back to say that he was again mistaken, as the banks offered no chance to swim, and he wanted the deep water again.
>
> Nanabojou replied: "One day you want land; the next day, water. You don't know your own mind, so I will decide. Henceforth, you shall live in the Between-land of the marsh--neither land nor water--where there is long green grass to eat, and water deep enough to swim in." And so it has been ever since.
>
> Ernest Thompson Seton
> Lives of Game Animals 1928

Although several studies of the Elizabeth River have attempted to elucidate the effects of contaminants on aquatic life (Hargis et al. 1984, Huggett et al. 1987), no major studies have been conducted on contaminant influences on the mammalian fauna of this area. The muskrat is a common and valuable semiaquatic fur bearing mammal in the taxonomic Order Rodentia and Family Arvicolidae (Honacki et al. 1982). It is the only mammal with a close association with river environments that is known to inhabit all three study regions.

TRAPPING LOCATIONS

To facilitate trapping efforts and for comparative purposes, the Southern Branch of the Elizabeth River was divided into 2 regions. The lower region extended from the Jordan Bridge (State Route 337) up river to the Gilmerton Bridge (State Route 460) and the upper region extended from the Dominion Boulevard Bridge (State Route 104) up river to the intercoastal waterway locks at Great Bridge (Figure 1).

Aerial photographs from the U.S. Geological Survey were used to determine the number of hectares of marsh within each region studied. U.S. Fish and Wildlife Service National Wetlands Inventory maps, and marsh inventory maps prepared by the Virginia Institute of Marine Science were used to determine the percent coverage by major vegetation types in marshes where muskrats were trapped.

The lower region had 13,290 m of shore length and 6.15 ha of marsh associated with the main channel. The study area extended approximately 100 m up 4 tributaries entering this region. This reach of the river was divided into 8 trapping sections. These include 2 sections located at the mouth of Paradise Creek and Saint Julian's Creek considered suitable muskrat habitat, 2 sections

along the main channel of the river considered marginal muskrat habitat, and 4 sections along the main channel of the river considered to be poor muskrat habitat, although some muskrats were captured in these sections. The poor sections were characterized by sandy beaches with little or no vegetative cover. These 8 sections were the only areas within the lower region of the river where muskrat signs were seen and muskrats were subsequently trapped.

The upper region consisted of 9,209 m of shore length and 50.01 ha of marsh associated with the main channel. One major tributary, Bells Mill Creek, enters this region of the river. Unlike the lower region, the shore line in the upper region is mostly wooded with fringe marsh (shore line marsh extending only a few meters inland) and large tidal marshes up to 11.2 ha in size. Suitable muskrat habitat was found at several locations along this reach of the Elizabeth River, and there was few data indicating contamination of this environment.

The upper region of the Elizabeth River was divided into 300 m sections of river length to provide manageable areas for searching and trapping. This resulted in 28 sections, each of which was searched for signs of muskrat activity. Thirteen of the 28 sections were considered to provide suitable muskrat habitat and were the only sections where muskrat signs were seen and muskrats were captured.

The Nansemond River study area extended from a point 600 m north of Mintonville Point up river to Thompson Landing (Figure 1), encompassing 11,640 m of shore length and 274 ha of marsh. It was similar to the upper and lower regions of the Elizabeth River in tidal range and water salinity. The shore line was mostly wooded and associated with large expanses of tidal marsh. This region also was divided into 300 m sections of river length. The resulting 29 sections were all considered to provide suitable muskrat habitat. References to the Nansemond River will imply this region unless otherwise stated.

All sections of each region were searched for signs of muskrats and subjectively classified as good, marginal, or poor habitat. All sections with visible signs of muskrats were trapped. In addition, sections classified as good, marginal, or poor with no signs of muskrats were trapped. Suitability classifications were subjectively determined using vegetative cover, food availability, slope, soil texture, distance to low water, and water level.

All marshes where muskrats were trapped had a National Wetlands Inventory classification of E2EMP (estuarine, intertidal, emergent wetland, irregularly flooded) (Cowardin et al. 1979). *Spartina sp.* (*Spartina alterniflora* and/or *Spartina cynosuroides*) were the dominant vegetation type (75% of total vegetative cover) while olney threesquare (*Scirpus olneyi*), reed grass (*Phragmites australis*), and/or black needlerush (*Juncus roemerianus*) made up 5 - 10% of the total marsh vegetation in all three regions.

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CHAPTER 1: ENVIRONMENTAL CONTAMINANTS

INTRODUCTION

Chemical contamination of the Elizabeth River reflects the human population growth and industrial development that this region has experienced over the past 300 years. Numerous studies of the river sediment, water, and aquatic life have indicated high concentrations of environmental pollutants compared to nearby reference areas (VSWCB 1983, 1984). Among these toxic substances, polynuclear aromatic hydrocarbons, polychlorinated biphenyls, and heavy metals have become a major concern with especially high concentrations reported in the Southern Branch of the river (VSWCB 1983, 1984, Hargis et al. 1984, Bieri et al. 1986, Huggett et al. 1986).

Although muskrats are not located at the top trophic levels where one would expect bioaccumulating pollutant concentrations to be highest, they are relatively sedentary, abundant, widely distributed, have a close association with aquatic habitats, and have been shown to accumulate environmental contaminants (Everett and Anthony 1976, Erickson 1977, Sheffy 1977, McCabe 1982, Perry 1982, Erickson and Lindzey 1983). These characteristics are desirable for species used as indicators of environmental contamination. Based on the high concentrations of bioaccumulating environmental pollutants found in the Southern Branch of the Elizabeth River, one could hypothesize that a semiaquatic mammal such as the muskrat that inhabits this area would reflect these environmental conditions through elevated body burdens and toxicological lesions. This chapter deals with an analysis of environmental contaminants found in surface sediments and muskrats from the lower region of the Elizabeth River compared to those found in the upper region of the Elizabeth River and in the Nansemond River.

Polynuclear Aromatic Hydrocarbons

Polynuclear aromatic hydrocarbons (PAHs) consist of two or more fused benzene rings in various arrangements. There are hundreds of PAH compounds found in air, water, and soil resulting mainly from high temperature conversion of organic materials. At high temperature, the carbon, hydrogen and CH radicals of organic substances are released and these free radicals are able to polymerize resulting in the formation of the polynuclear aromatic hydrocarbons. During prehistoric times this phenomena resulted from naturally occurring fires; today they largely result from coal and refuse burning, coke production, automobile exhaust and various forms of industrial waste. Conversion of organics to PAHs can also occur at lower temperatures (100-150^{0}C) but at a slower rate (Zobell 1971, Baum 1978, Zedeck 1980).

Once PAHs have formed they can be transported over a large area through atmospheric drift and precipitation and/or terrestrial runoff, resulting in widespread distribution. The United States emits approximately 812.7 metric tons of benzo(a)pyrene, a potent carcinogenic PAH, into the atmosphere every year (Baum 1978, Zedeck 1980). Eighty percent comes from coal burning, whereas forest and agricultural refuse burning account for about 1% (Baum 1978). Concentrations of PAHs vary with location, being higher near producing sources and also varying from winter to summer as heating fuel use changes (Bridbord et al. 1976, Sawicki 1976, Baum 1978).

PAHs in the air, water, and soil can be incorporated into plant tissues. PAHs can be absorbed by plant roots and translocated to other plant parts. Some plants absorb PAHs deposited on their leaves and some synthesize various PAHs (Zobell 1971, Baum 1978). PAHs also can be found in animal tissue. They enter animal species by absorbtion through the skin, by inhalation, and by oral intake. Levels in human food items have varied depending upon location and also in the manner in which the food was prepared (i.e. distance from heat and time exposed) (IARC 1973). Levels in cooked beef and pork have been found to be higher than in uncooked samples. Up to 2 μg benzo(a)pyrene per kg have been found in smoked fish along with approximately 100 other PAHs (IARC 1973). PAHs can induce cancer in animals, with demonstrated effects in a

variety of organs (Zedeck 1980). Numerous studies (mainly with mice and rats) have been undertaken to elucidate the metabolic and carcinogenic effects of PAHs. Bingham and Falk (1969) applied a 1% solution of benz(a)anthracene in toluene 3 times a week to a shaved area of mouse skin with 8 of 29 mice developing tumors. When the solvent was changed to dodecane, 17 of 22 mice developed tumors. Other studies have shown that benzo(a)pyrene and dibenz(a,h)anthracene were more potent carcinogens than benz(a)anthracene. A 0.05% benzo(a)pyrene solution produced skin tumors in 100% of the exposed mice within 3 months of exposure compared to one year required for benz(a)anthracene. Dibenz(a,h)anthracene in a 0.2% acetone benzene solution resulted in skin tumors in 80% of the mice exposed twice weekly. The tumors reported were mostly papillomas and carcinomas (Lijinsky et al. 1965).

The potential for development of tumors through respiratory exposure was demonstrated by Sellakumar et al. (1977). They intratracheally exposed hamsters to 7H-dibenzo(c,g)carbazole, a PAH found in tobacco tar, with 72% of the hamsters developing respiratory tract tumors.

The effects of orally administered PAH also have been extensively studied. Neal and Rigdon (1967) reported that 50-250 ppm benzo(a)pyrene in the diets of mice produced stomach cancers in more than 70% of the mice fed the diet for 30 days. Mammary carcinomas also have resulted in mice exposed to a single oral dose (2 - 100 mg) of 7,12-dimethylbenz(a)anthracene or 3-methylcholanthracene, with most tumors appearing within 60 days of exposure (Huggins et al. 1961, Huggins and Yang 1962).

The carcinogenic effects usually are evident in fatty tissues such as mammary glands and adrenals, where PAH metabolites may remain for long periods of time (Zedeck 1980). Daniel et al. (1967) gave oral doses of ^{14}C and ^{3}H labeled 3-methylcholanthrene, 7,12-dimethylbenz(a)anthracene, dibenz(a,h)anthracene and dibenz(a,c)anthracene to rats. Radioactive materials were detected in gastro-intestinal lymph, bile, and urine in as early as one hour. Ten percent of the administered dose remained within the body tissues at 24 hours post dose. At 3-4 days after treatment, radioactive materials were found in the adrenals, fat, mesenteric lymph nodes, and ovaries, and in the milk of lactating rats at 7 days after treatment. Several months after treatment radioactive material could still be detected in exposed rats. Other experiments with

labeled 3-methylcholanthrene and 3,4-benzpyrene in the diets of lactating rats, rabbits, and sheep showed 0.19%, 0.003%, and 0.01% excretion in milk after 4 hrs., 24 hrs., and 7 days respectively (West and Horton 1976).

Transplacental studies have indicated that embryotoxic and carcinogenic effects can be found in rats treated with PAHs or their derivatives. Currie et al. (1970) found increased absorption and abnormal fetuses in rats treated with 7,12-dimethylbenz(a)anthracene or its 7-hydroxymethyl derivative. Tumors of the nervous system, kidneys and mammary glands also have been shown to develop in the offspring of rats treated intraperitoneally or orally with 7,12-dimethylbenz(a)anthracene while pregnant (Rice et al. 1978).

It is apparent from the available literature that PAHs can enter the animal body by either the oral, respiratory, or epidermal route. Orally assimilated PAHs pass from the intestinal lymph to the blood and concentrate in the liver and kidneys where they are metabolized and rapidly excreted in bile and urine. Small amounts may be retained by fatty tissues for longer periods of time. Although chemically stable, *in vivo* PAHs can undergo a wide variety of metabolic transformations catalyzed by the microsomal mixed-function oxidases. These are mainly hydroxylations and conjugations of the hydroxyl groups with glucuronic acid and sulphate. The majority of the hydroxylation reactions are probably preceded by an epoxide intermediate. In the case of benzo(a)pyrene, the ultimate carcinogen is an epoxide of the 7,8-dihydrodiol metabolite where the epoxide is in the 9,10 position adjacent to the "bay region". This 7,8-diol-9,10-epoxide metabolite can cause a physiological change through covalent bonding with nucleic acids (DNA) (Timbrell 1982). It addition to the liver and kidney, PAHs may be metabolized by the adrenals, testes, lung, and skin (Waterfall and Sims 1973, Sims and Grover 1974, Zedeck 1980).

The actual effects of the PAH metabolites on cells appears to result from the action of the PAH compounds during the DNA replicating phase of the cell's life cycle (Zedeck 1980). Proliferating cells in certain tissues (bone marrow, spleen, thymus, gonads, and intestinal epithelium) appear to be particularly sensitive to the effects of PAHs (Murad et al. 1973, Philips et al. 1973).

Polychlorinated Biphenyls

Another group of chemical compounds, the polychlorinated biphenyls (PCB's), also are of concern in the Elizabeth River system. PCB's were first synthesized in 1881 but were not commercially produced in the United States until 1929 (Swain 1983). The synthesis of PCB's is accomplished by the progressive chlorination of biphenyl molecules in the presence of a suitable catalyst (WHO 1976, Swain 1983). During this process 1 - 10 hydrogen atoms on the biphenyl are replaced by chlorine atoms with the possibility of 209 different compounds being produced. In actuality, only about half of these compounds are ever realized (Mathews and Tuey 1980, Swain 1983).

PCB's are manufactured under various trade names by different countries: Aroclor (USA), Phenochlor (France), Clophen (Federal Republic of Germany), Kanechlor (Japan), Fenchlor (Italy), Delor (Czechoslovakia), and Sovol (USSR) (WHO 1976, Swain 1983). Each manufacturer uses their own system to identify the chlorinated compounds. In the United States, Aroclor was manufactured by the Monsanto Company until it stopped production in 1977. Monsanto identified these compounds by a four digit number (Nisbet and Sarofim 1972, WHO 1976). The first two digits are generally a 12, which indicates a biphenyl and the last two digits indicate the percentage by weight of chlorine in the compound. For example, Aroclor 1260 would indicate a biphenyl with 60% chlorine by weight. During the manufacture of PCB compounds, different isomers (molecules with different percentages of chlorine), may occur simultaneously (Webb and McCall 1972, Willis and Addison 1972). Other manufacturers use the average number of chlorine atoms that have been substituted as the product code. Therefore, Clophen A60 and Phenochlor DP6 would indicate biphenyl compounds with a mean of 6 chlorine atoms per molecule (WHO 1976).

The attractiveness of PCB compounds to industry resulted from their high dielectric constant, chemical stability, resistance to heat, nonflammability, and low vapor pressure. Because of these characteristics PCBs have been used extensively as fluids in electrical transformers and capacitors, as heat transfer substances, as plasticizers, in hydraulic fluids, lubricating oils, and in paints and

carbonless copy paper. Because of their chemical properties, PCBs are relatively stable in the environment with a half life estimated between 8 and 15 years (WHO 1976, Swain 1983).

The toxicological problems with PCBs result from their release into the environment. From 1929 to 1971, it has been estimated that 0.5 million tons of PCBs were produced in North America and that world production during that time period was probably one million tons (WHO 1976). Nisbet and Sarofim (1972) estimated that in 1970, 33,000 tons of PCBs were manufactured in the United States with 36% being used in capacitors, 20% in transformers, 30% as plasticizers, 12% in hydraulic fluids and lubricants, and 1.5% as heat transfer liquids. They also estimated that 52.5% of the annual production enters the environment as disposal in dumps and landfills, 13% as leaks and disposal of industrial fluids, 9% by incineration, and 4.5% by vaporization from plasticizers. PCBs can therefore enter the environment by way of the atmosphere, soil, or water.

Atmospheric release results from incineration of PCB compounds in industrial and municipal landfills and by vaporization from plasticizers (WHO 1976). The atmosphere does not serve as a major reservoir for PCBs but rather a transport medium or input pathway for PCBs into aquatic and terrestrial systems (NAS 1979, Eisenreich et al. 1981, MacKay and Yuen 1981).

The disposal of transformers containing PCBs and other PCB containing substances into landfills and dumps along with atmospheric deposition offers the opportunity for PCB compounds to enter the environment by way of the soil. PCBs tend to bind with particulate matter, which explains high levels reported in soils and sediments (Holden 1970, Nimmo et al. 1971, WHO 1976, Eisenreich et al. 1979, Eisenreich et al. 1981, Swain 1983). Under experimental conditions Tucker et al. (1975) found that higher chlorinated PCBs were not leached from soil by percolating water and that lower chlorinated PCBs were leached slowly. PCBs also can be removed from the soil by volatilization and by biotransformation (Iwata et al. 1973, Haque et al. 1974).

Atmospheric deposition and industrial and municipal waste water discharge are major sources of PCB input into aquatic systems. PCBs entering water can bind to particulate matter and settle to the bottom as sediment. The sediment and water column of oceans, lakes, and rivers appear to be the major reservoir for PCBs in the environment (WHO 1976, NAS 1979, Eisenreich et al. 1981. MacKay and Yuen 1981).

Once in the environment, PCB compounds become available for accumulation in biotic systems. Experimental evidence indicates that PCBs are incorporated into animal tissues by absorption, inhalation, and ingestion (Vos and Beems 1971, Albro and Fishbein 1972, Melvas and Brandt 1973, Berlin et al. 1975).

Rats inhaling Aroclor 1254 vapors for 5 days a week over several weeks at concentrations ranging from 1.5 - 8.0 mg/m^3 exhibited enlarged livers (Treon et al. 1956). Vos and Beems (1971) applied Clophen A60, Phenochlor DP6, and Aroclor 1260 daily, 5 times a week for 38 days to rabbit skin at a dose of 118 mg/ 50 cm^2. Deaths occurred within the Clophen and Phenochlor treated group and kidney and liver lesions were noted in all groups.

Radioactive trace substances have been used to study the effects of oral intake of PCBs. Radioactively labelled 2,5,2′,4′,5′-pentachlorobiphenyl given as a single oral dose (15 mg/kg) to mice was rapidly taken up by the blood and distributed to the liver, kidneys, lungs, and adrenals. Within 4 - 24 hrs. body fat levels increased to their maximum burden while levels in most other tissues decreased. Radioactive material was also noted to appear rapidly in the bile and to be excreted in the feces (Berlin et al. 1975). Grant et al. (1971) reported PCB fat, liver, and brain concentrations of 996, 116, and 40 mg/kg respectively in rats four days following an oral dose of Aroclor 1254 at 500 mg/kg. Rats chronically exposed for 8 months to Aroclor 1254 in their diets at 0.2, 20, and 100 mg/kg eventually reached steady state tissue concentrations that were dose dependent. Those exposed to the 100 mg/kg diet had liver, brain, and fat PCB concentrations of 16, 3.4, and 32,0 mg/kg respectively (Grant et al. 1974).

Several other toxicological effects have been reported in mammals exposed to PCBs. Keplinger et al. (1971) gave diets containing 100 mg/kg Aroclor 1242 and 1254 to rats for 18 months and noted increased liver weights and reduced survival in litters. Other experiments by Kimbrough et al. (1972) reported no mortality in male rats but 8 of 10 female rats died when fed diets of 1 g/kg Aroclor 1260 for 8 months. The livers of exposed rats also showed dose dependent increases in weight, enlargement with orange fluorescence, enlarged hepatic cells vacuolated with lipid inclusions, increased smooth endoplasmic reticulum, and adenofibrosis. Bickers et al. (1972) and Ecobichon and Comeau (1974) also have reported enlarged livers and increased smooth

endoplasmic reticulum and have related these lesions to induction of microsomal mixed function oxidases. These phenomena were more evident in experiments involving higher chlorinated PCBs. The biphenyls with greater concentrations of chlorine also were shown by Johnstone et al. (1974) to cause a greater degree of enzyme induction. Induction of placenta and fetus microsomal enzyme activity also has been demonstrated in rats given PCBs during pregnancy and in livers of young rats that suckled mothers on a diet containing PCBs (Alvares and Kappas 1975).

An increase in hepatic microsomal enzyme activity also has occurred in rats resulting from the mobilization of PCBs stored in fat tissues under stress conditions (e.g. food deprivation and exposure to cold) (WHO 1976). Hepatic porphyria has also been induced in rats receiving oral doses of Aroclor 1242 and 1254 at 100 mg/kg of body weight for 21 days with high hepatic and urinary levels of uroporphyrin reported (Goldstein et al. 1974, Iverson et al. 1975). Induction of δ- aminolevulinic acid synthetase and inhibition of uroporphyrinogen decarboxylase also have been reported in cultures of chick embryo liver cells exposed to PCBs (Kawaniski et al. 1981).

PCB compounds also have been shown to have effects on immunosuppression. Guinea pigs fed diets containing 50 mg/kg of Clophen A60 or Aroclor 1260 showed lower antitoxin titer and lower antitoxin producing cells compared to controls when exposed to tetanus toxoid (Vos and de Roij 1972, Vos and van Driel-Grootenhuis 1972).

The effects of PCB's on reproduction also have been studied extensively. The reproductive effects on birds, fish, and mammals have been reported along with teratogenic effects (Jensen et al. 1969, Aulerich et al. 1971, Keplinger et al. 1971, Ringer et al. 1972, Cecil et al. 1975, Allen 1975). Keplinger et al. (1971) reported decreased survival in newborn rats fed diets of Aroclor 1242 and 1254 at 100 mg/kg, but no effects from Aroclor 1260 at that concentration. Other studies also have shown a decrease in pup survival along with an increase in the length of the estrous cycle and reduced frequency of ova implantation (Orberg and Kihlstrom 1973, Linder et al. 1974).

Feeding experiments with PCBs have also produced neoplastic lesions in liver tissue (Ito et al. 1973, Kimbrough and Linder 1974, Kimbrough et al. 1975). Kimbrough and Linder (1974) fed Aroclor 1254 at 300 mg/kg for 6 and 11 months to mice and noted hepatomas (neoplastic or

hyperplastic nodules) in 9 of 22 mice on the 11 month diet and 1 of 24 mice on the 6 month diet. Adenofibrosis was also reported in the livers of all 22 mice on the 11 month diet.

Kimbrough et al. (1975) reported hepatocellular carcinomas in 26 of 184 rats and neoplastic nodules in the liver of 144 of 184 rats on diets containing 100 mg/kg Aroclor 1260. They also reported finding no tumorous lesions in other organs.

The highest levels of PCBs reported from the Chesapeake Bay area have come from sediments of the Elizabeth River with values ranging from trace to 2 ppm. These consisted mainly of Aroclor 1242 and 1254 (Munson and Huggett 1972). STORET retrieval data indicates fish PCB levels of 0.725 mg/kg from the Eastern Branch of the Elizabeth River and 0.370 mg/kg from the Southern Branch (STORET is a storage and retrieval data base maintained by the Environmental Protection Agency, Research Triangle Park, North Carolina). Bieri et al. (1986) also reported identifying PCBs from 2 soil samples collected from the Southern Branch of the Elizabeth River but no quantitative data was given.

Heavy Metals

The third group of pollutants that have been found to be of some concern in the Elizabeth River are the heavy metals. Heavy metals are considered to be those metals beyond calcium in the periodic chart of elements. Several of these metals are normally a part of an organism's diet and are essential for proper body functioning. The natural occurrence of small quantities of other metals as part of the organisms physical environment often results in their incorporation into the biotic system in trace amounts (< 0.01% of the weight of organism) (Venugopal and Luckey 1975).

Trace amounts of the heavy metals normally are not toxic to an organism; however, environmental conditions, physical condition, age, sex, species, stress, and relationships between various metals may have an influence on toxicity. Heavy metals are considered toxic in mammals

when they cause growth retardation, decreased mental capability, reproductive changes, pathological tissue lesions, or mortality (Venugopal and Luckey 1975, Luckey and Venugopal 1979). Luckey and Venugopal (1977) gave an arbitrary toxicity classification for metals based on oral LD-50s as follows: < 1 mg/kg body weight = supertoxic, 1 - 5 mg/kg body weight = extremely toxic, 5 - 50 mg/kg body weight = highly toxic, 50 - 500 mg/kg body weight = moderately toxic, 500 - 5000 mg/kg body weight = slightly toxic, and 5000 - 15000 mg/kg body weight = practically nontoxic.

Heavy metals have certain chemical and physical properties that are of biological significance. Metal ions are electropositive and have an affinity for amino, imino, and sulfhydryl groups. The solubility of metal salts also influences their absorption into biological systems. Generally, the more soluble the metal salts, the more potentially toxic they become (Venugopal and Luckey 1975).

The activation and stabilization of enzymes often involves the binding of metals at active sites. Therefore, the protein-metal interactions play a significant role within biological systems. These interactions may be governed by specific side chain groups on the proteins and by competition between metal ions and proteins for electrons. Two other areas where metals play an important biological role and where toxic effects may be evident are in nucleic acid-metal interaction and membrane-metal interaction. Depending on their relative affinity, heavy metals generally bind to active sites of nucleic acids (phosphate groups, nitrogenous bases, and ribohydroxyl groups). This metal binding usually stabilizes the structure of the nucleic acid and some metals may promote the reversible unwinding and rewinding of the multiple stranded helix structure (Venugopal and Luckey 1975).

The toxicity of heavy metals also is influenced by the route of entry into an organism. Oral ingestion of heavy metals in the diet of mammals is probably the most significant route of entry. The concentration, electrogradients present, and degree of hydration of the ions are important factors in the passage of metals across the gastrointestinal membrane surface (Luckey and Venugopal 1977).

Heavy metals that are of concern to biological systems and have been reported from the Elizabeth River are cadmium, copper, lead, mercury, nickel, and zinc (VSWCB 1983, VSWCB

1984). Cadmium is not an essential element and its absorption via the digestive tract is relatively low. Ingested cadmium tends to accumulate in the liver, kidneys, and reproductive organs. High dietary levels of cadmium fed to mice (120 mg/week) resulted in depressed growth and reduced protein and fat digestion and absorption (Weber and Reid 1969, Venugopal and Luckey 1975). Kidney lesions resulting from cadmium toxicity include increase in size and number of lysosomes and mitochondrial swellings in proportion to the cadmium concentration (Nishizumi 1972). Nephropathy also results from proximal renal tubular damage (membranes) causing inefficient resorption of glomerular filtrate that is characterized by increased proteinurea, primarily low molecular weight serum proteins, and increased cadmium in the urine (Goyer 1986). Decreased spermatogenesis and testicular necrosis resulting from ischemia also have been reported (Venugopal and Luckey 1975). Cadmium competes with the essential metal zinc, displacing it from enzymes such as alkaline phosphatase. Cadmium also exhibits its toxic effects by inhibiting ATPases of myosin and of pulmonary alveolar macrophage cells and cell membranes (Cross et al. 1970, Venugopal and Luckey 1975).

Copper is an essential metal component of a number of enzymes such as phenol oxidases and cytochrome oxidases. Copper is absorbed by the stomach and intestines, and the rate of absorption is influenced by its concentration and the presence of other metal ions. Metabolism occurs in the liver, which also serves as the storage site for excess copper (van Campen 1971, Venugopal and Luckey 1975).

Rats fed a diet containing > 500 ppm copper resulted in blood quantities which could not be sequestered by erythrocytes, resulting in the release of copper into the blood serum which caused hemolysis. Pigs fed diets containing 600 - 700 ppm copper showed signs indicative of general tissue damage (Venugopal and Luckey 1975).

The toxic effects of mercury have been well documented in large scale exposures to humans and animals (Borg et al. 1969, Berlin 1979, Fimreite 1979). The divalent ionic form of mercury (Hg^{2+}) and the organic mercurials (especially methymercury) both are highly toxic to wildlife due to their lipid solubility and membrane permeability. The route of entrance into mammalian

systems is either by ingestion, inhalation, or through the skin. Tissue retention by the liver, kidneys, and brain is fairly high (Venugopal and Luckey 1975).

The permeability of membranes is affected by the binding of Hg^{2+} ions to thiol and phosphate ligands (Clarkson and Megos 1966). Divalent mercury ions complexing with phosphate ligands blocking the permeability of glucose in erythrocytes, increases passive alkali ion permeability, enters the cell and is accumulated. High concentrations can cause agglutination and hemolysis of erythrocytes. Induced diuresis resulting from permeability changes in the proximal tubular cells to sodium ions and inhibited cholinesterase activities also have been reported as toxic effects of mercuric ions (Venugopal and Luckey 1975). Verity and Brown (1970) reported decreases in lysosomal enzyme activity and mitochondrial cytochrome activity in kidneys after exposure to the mercuric ion.

Lead, like cadmium, shows relatively low absorption by the gastrointestinal tract; however, inhalation results in accumulation in the lungs with eventual dispersal to bone and soft tissues. The deposition of lead and its potential mobilization from bone are due to its metabolism being similar to that of calcium. The toxic effects of inorganic lead may not normally be manifest unless its mobilization from bone occurs. This usually will result from metabolic disturbances that would cause calcium mobilization resulting in osteolysis (Chisolm 1971). The inhalation of tetraethyl lead is a primary cause of organic lead poisoning. Tetraethyl lead is readily absorbed in the respiratory and gastrointestinal tracts and through the skin. Because of the affinity of organic lead for the lipids of nervous tissues, metabolism of tetraethyl lead results in organic lead accumulations in the brain (Browning 1969, Vengopal and Luckey 1975). Chronic exposure experiments with rats and mice (25 ppm soluble lead salts in diet) resulted in decreased longevity and impaired reproductive capacity (Schroeder and Mitchner 1971). Degeneration of seminiferous tubules and decrease in spermatozoa have been reported in avian species treated with lead shot (Veit et al. 1983). Lead exposure also can cause erythropoietic cells of bone marrow to undergo morphological changes that result in the production of abnormal erythrocytes. These abnormal erythrocytes have nuclear abnormalities, variation in cell size, and inadequate hemoglobin. Lead also affects erythrocytes by inhibition of Δ aminolevulinic acid dehydratase and ferrochelatase, two important enzymes in heme

synthesis (Moore et al. 1980, Waldron 1980). Structural damage to kidney mitochondria and the proximal renal tubules also has been reported from rats with blood lead concentrations of 150 ug/100 ml (Goyer 1968). Decreased resorption of glucose and amino acids by the kidney tubular cells is thought to be associated with the effects of lead on the active sodium transport mechanisms within these cells (Sandstead et al. 1970, Choie and Richter 1980). Mitochondrial respiration also is markedly inhibited by exposure to lead (Bull 1980).

Nickel is considered to be an essential metal for several species of animals, and studies have indicated that large doses of nickel compounds can be tolerated (Norseth and Piscator 1979). Animal experiments have indicated that 90% of ingested nickel is recovered in the feces with small amounts being absorbed and accumulated in the kidneys, liver, and lungs (NAS 1975, Norseth and Piscator 1979). Schroeder et al. (1974) found no effects in mice and rats exposed to 5 mg Ni/l in drinking water throughout their lifetime. However, this dose given in drinking water for 3 generations resulted in increased mortality among the newborns and an increase in the number of runts in all 3 generations (Schroeder and Mitchner 1971).

Zinc is an essential metal necessary for the functioning of various enzymes. The absorption of ingested zinc varies from 10 - 90% depending on several factors including body weight, current zinc status, and interfering substances (Elinder and Piscator 1979). Absorbed zinc concentrates in the prostate, bone, muscle, liver, and kidneys (Ansari et al. 1975, NRC 1978). Aughey et al. (1977) found hypertrophy of the adrenal cortex and of the pancreatic islets in mice given 500 mg Zn/l in drinking water. Pigs fed *ad libitum* diets containing $>0.1\%$ zinc carbonate for more than one month had symptoms of zinc toxicosis. Toxic symptoms were characterized by depressed rate of gain and food intake along with arthritis, lameness, and inflammation of the gastrointestinal tract (Brink et al. 1959). Kumar (1976) has reported increased fetal resorptions in rats given daily doses of 150 mg Zn/kg.

MATERIALS AND METHODS

Seventy-six muskrats were live trapping for contaminant study during December 1986 - January 1987 and December 1987 - February 1988. These muskrats were transported to a research trailer for sleeping time analysis and then killed for further data collection (see below).

At the research trailer, muskrats were transferred to a handling funnel, weighed, and given a 37 mg/kg i.m. dose of sodium pentobarbital (Nembutal, Lundy 1931). Sleeping time was recorded as an index of hepatic microsomal enzyme activity. Upon awakening muskrats were euthanized with a second i.m. injection of pentobarbital (1 ml, 60 mg), and standard measurements (weight, total length, tail length, hindfoot length, and ear length) were recorded. A longitudinal incision was made from the sternum to the urethral opening and blood samples were collected in vacutainers from the inferior vena cava (see Chapter 2).

Muskrats were necropsied and the liver and kidneys were towel dried and weighed. Sections of liver (approximately 2 g) were collected and kept at -20^0 C for DNA adduct analysis using ^{32}P-postlabeling procedures. Methods used in ^{32}P-postlabeling of DNA adducts are similar to those used by Gupta 1985, Dunn 1986, and Reddy and Randerath (1986) and are included in Appendix A. Sections of the liver and kidneys were placed in formalin for histological study and the remaining kidney tissues were placed in glass jars and subsequently sent to the Environmental Trace Substances Research Center (ETSRC), Columbia, Missouri for heavy metal analysis. Methods used by ETSRC for metal analysis are included in Appendix B. The muskrats were then frozen and transported to the laboratory.

Because DNA adducts were expected in muskrat liver samples, negative results obtained from ^{32}P-Postlabeling analysis of 8 liver samples lead me to suspect an error in methods. DNA adducts were detected in positive controls (known to contain DNA adducts) that were simultaneously analyzed with muskrat liver samples. Two liver samples and a sample that contained hydrolyzed DNA isolated from liver by me, were sent to an independent laboratory (College of Pharmacy, Rutgers University, Piscataway, New Jersey) for ^{32}P-Postlabeling analysis. Results from this

laboratory also were negative, confirming my results. Because positive results were obtained from controls and my results were confirmed by an independent laboratory, initial handling methods were suspected to have caused the negative results and not ^{32}P-Postlabeling procedures. An additional 15 muskrats (10 from the lower region of the Elizabeth River and 5 from the Nansemond River) were captured in May and June 1989 and sections of their livers were immediately placed in liquid nitrogen (-80^{0}C). In addition, two muskrats were collected and orally dosed using a pediatric feeding catheter (Foley Catheter 8Fr., Kendall Health Care Products, Mansfield, Maine) with 10 mg benzo(a)pyrene in 1 ml corn oil followed by a second 1 ml of corn oil to rinse the catheter. A third muskrat was similarly dosed with 2 ml of corn oil only. Food was withheld from dosed muskrats for 12 hr prior to dosing and 0.5 ml of pentobarbital was used as an anesthetic. Twenty-four hours after dosing, these muskrats were euthanized with pentobarbital and sections of liver tissue collected and immediately placed in liquid nitrogen. These 18 liver samples were sent to the Environmental Carcinogenesis Unit (ECU), British Columbia Cancer Research Center, British Columbia, Canada for ^{32}P-Postlabeling analysis.

In the laboratory, muskrats were thawed and the spleens, adrenals and reproductive tracts were removed. Carcasses of 35 muskrats (24 from the lower region and 6 from the upper region of the Elizabeth River and 5 from the Nansemond River) minus the heads, reproductive tracts, digestive tracts, adrenals, and organ tissues used for histological or heavy metal analysis were sent to the Mississippi State Chemistry Laboratory (MSCL), Mississippi State, Mississippi for organochlorine and PAH analysis. Methods used for the analysis of OC and PAH compounds are included in the Appendix C.

Forty surface sediment samples (top 1 - 3 cm) were collected in glass jars from the three regions (20 from the lower region of the Elizabeth River and 10 each from the upper region of the Elizabeth River and Nansemond River; Figure 2). Sediment collection sites were locationed in areas where muskrats had been trapped for contaminant analysis. Half of the sediment samples from each region were sent to the Mississippi State Chemistry Laboratory for OC and PAH analyses and half were sent to the Environmental Trace Substances Research Center for heavy metal analyses.

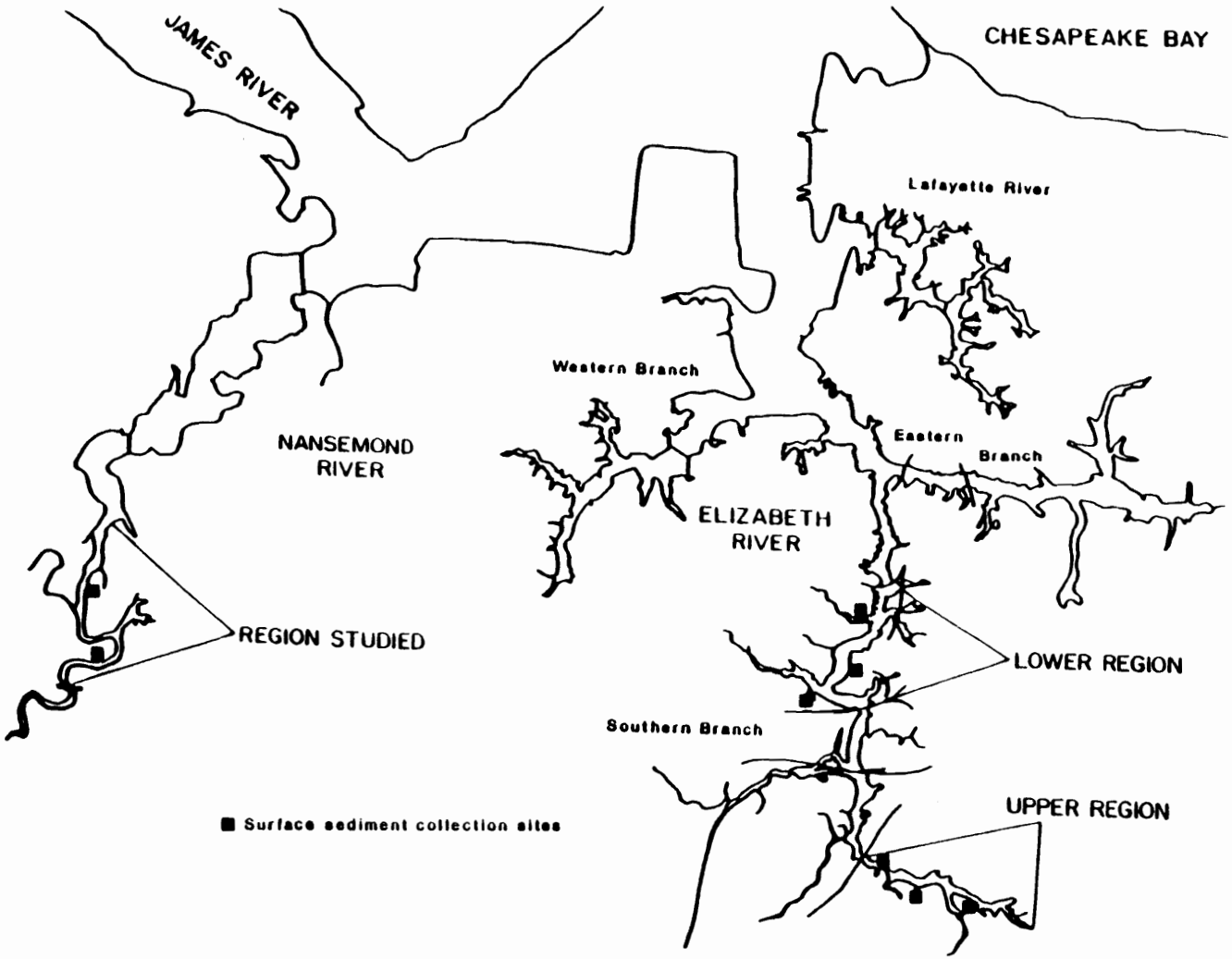

Figure 2. Locations in the Elizabeth and Nansemond Rivers where surface sediment samples were collected.

SAS computer software (SAS Institute Inc., 1985) was used for statistical analysis. All variables were checked for normal distributions using PROC UNIVARIATE (Shapiro-Wilk's) procedures. Means of variables that exhibited a normal distribution were compared among regions using ANOVA (General Linear Model (GLM)) procedures. Duncan's and Bonferroni's multiple comparison tests were used to separate means of variables found to be significantly different ($\alpha = 0.05$) by the ANOVA. Variables that did not exhibit normal distributions were either transformed and compared using ANOVA procedures (if transformations resulted in normal distributions) or compared among regions using Wilcoxon or Kruskal-Wallis nonparametric analysis (PROC NPAR1WAY). All ANOVA procedures (when appropriate) included analysis of main effects for location, sex, and age and all interactions of these variables. Correlations between variables were obtained using Pearson's procedures (PROC CORR). If normality or interactions are not mentioned it should be assumed that the distributions were normal and/or that the statistical results were nonsignificant.

RESULTS

A total of 76 muskrats was collected for contaminant analysis (10 during 1986-87 and 66 during 1987-88). Pentobarbital sleeping time was recorded for 63 muskrats (20 from the lower region and 19 from the upper region of the Elizabeth River and 24 from the Nansemond River). Thirty-five carcasses were sent to the Mississippi State Chemistry Laboratory for analysis of 22 OC and 14 PAH compounds and 76 pairs of kidneys were sent to the ETSL for analysis of 33 heavy metals.

Polynuclear Aromatic Hydrocarbons

Twenty-two of 35 carcasses (63%) had detectable concentrations of PAH's (Table 1). Six different PAH compounds were detected in muskrats from the lower region of the Elizabeth River, 3 in muskrats from the upper region of the Elizabeth River, and 4 in muskrats from the Nansemond River. Naphthalene was detected in the greatest number of muskrats (46%) followed by phenanthrene (29%), anthracene (14%), fluorene (6%), pyrene (6%), and chrysene (6%). Fourteen of 24 muskrats from the lower region of the Elizabeth River, 4 of 6 from the upper region of the Elizabeth River, and 4 of 5 from the Nansemond River had detectable concentrations of at least one PAH compound (Table 2). Only three muskrats from the lower region and one from the upper region of the Elizabeth River had concentrations greater than 0.03 ppm. The small number of samples with detectable PAH's and the low levels detected preclude the use of meaningful statistical analysis. Because PAHs are metabolized by the liver, the low concentrations were expected.

DNA adducts were detected in 18 of 18 muskrat liver samples analyzed at ECU (Table 3). Mean nmoles DNA adducts/mole normal nucleotide was not significantly different ($P = 0.326$) between samples collected from the lower region of the Elizabeth River and Nansemond River. The greatest (236 nmoles/mole) and least (15 nmoles/mole) concentrations were detected in Nansemond River muskrats. The greatest concentration was more than twice the next greatest concentration. If the sample with the greatest concentration is eliminated from analysis, the mean number of nmoles/mole for the Nansemond River (51.5) is similar to the mean value calculated for the Elizabeth River samples (49.2). Autoradiograms of polyethyleneimine-cellulose thin-layer chromatograms of representative samples are shown in Figure 3. The concentration of DNA adducts detected in two muskrats dosed with 10 mg benzo(a)pyrene both were above the mean detected in lower Elizabeth River or Nansemond River muskrats and well above the concentration detected in the muskrat dosed with corn oil only. Autoradiography results also show two distinct spots (Figure 4, lower left) in the benzo(a)pyrene dosed muskrats that are not present in the

Table 1. Concentrations of Polynuclear Aromatic Hydrocarbons (ppm dry wt.) detected[1] in 22 of 35 muskrats from the Elizabeth and Nansemond Rivers, Va. 1986 - 1988.

Location and Muskrat No.	Polynuclear Aromatic Hydrocarbon					
	Naphthalene	Fluorene	Phenanthrene	Anthracene	Pyrene	Chrysene
Elizabeth River						
Lower Region						
861	ND[2]	ND	ND	0.03	ND	ND
862	0.03	ND	ND	ND	ND	ND
863	ND	ND	0.03	ND	ND	ND
511	ND	ND	0.03	ND	ND	ND
526	0.06	ND	0.15	ND	ND	ND
562	0.04	ND	ND	ND	0.04	ND
563	0.03	ND	ND	ND	ND	0.03
560	0.03	ND	0.03	ND	ND	ND
552	0.03	ND	ND	ND	ND	ND
580	ND	ND	ND	ND	ND	0.03
908	0.07	0.07	0.07	ND	ND	ND
565	0.03	0.03	0.03	0.03	ND	ND
253	0.03	ND	ND	ND	ND	ND
554	0.03	ND	0.03	ND	ND	ND
Upper Region						
294	0.03	ND	ND	ND	ND	ND
549	ND	ND	ND	0.03	ND	ND
708	0.03	ND	0.11	ND	ND	ND
712	0.03	ND	0.03	ND	ND	ND
Nansemond River						
566	0.03	ND	0.03	ND	0.03	ND
579	0.03	ND	ND	0.03	ND	ND
593	ND	ND	ND	0.03	ND	ND
725	0.03	ND	ND	ND	ND	ND

[1]Lower limit of detection was 0.03 ppm, no fluoranthrene, 1,2-benzanthracene, benzo(b)fluoranthrene, benzo(k)fluoranthrene, benzo(e)pyrene, benzo(a)pyrene, 1,2,5,6-dibenzanthracene, or benzo(g,h,i)perylene was detected.
[2]None detected.

Table 2. Polynuclear Aromatic Hydrocarbons detected[1] (ppm dry wt) in muskrats from the Elizabeth and Nansemond Rivers, Va. 1986 - 1988.

	Elizabeth River					
	Lower Region		Upper Region		Nansemond River	
Polynuclear Aromatic Hydrocarbon	Muskrats with Detectable levels	PPM	Muskrats with Detectable levels	PPM	Muskrats with Detectable levels	PPM
Naphthalene	10 of 24	0.07 (N = 1) 0.06 (N = 1) 0.04 (N = 1) 0.03 (N = 7)	3 of 6	0.03 (N = 3)	3 of 5	0.03 (N = 3)
Fluorene	2 of 24	0.07 (N = 1) 0.03 (N = 1)	0 of 6	ND[2]	0 of 5	ND
Phenanthrene	6 of 24	0.15 (N = 1) 0.07 (N = 1) 0.03 (N = 4)	3 of 6	0.11 (N = 1) 0.03 (N = 2)	1 of 5	0.03 (N = 1)
Anthracene	2 of 24	0.03 (N = 2)	1 of 6	0.03 (N = 1)	2 of 5	0.03 (N = 2)
Pyrene	2 of 24	0.04 (N = 1) 0.03 (N = 1)	0 of 6	ND	1 of 5	0.03 (N = 1)
Chrysene	2 of 24	0.03 (N = 2)	0 of 6	ND	0 of 5	ND

[1]Lower limit of detection was 0.03 ppm, no fluoranthrene, 1,2-benzanthracene, benzo(b)fluoranthrene, benzo(k)fluoranthrene, benzo(e)pyrene, benzo(a)pyrene, 1,2,5,6-dibenzanthracene, or benzo(g,h,i)perylene was detected.
[2]None detected.

autoradiogram of the muskrat dosed with corn oil only. The upper and left-most spot corresponds to spots that have been seen in tissue culture cells treated with benzo(a)pyrene (Dr. Bruce Dunn, ECU, personal comunication).

Mean pentobarbital sleeping time was significantly less ($P = 0.025$) in lower region Elizabeth River muskrats ($\bar{x} \pm SE = 38.6 \pm 6.9$ min) than in upper region Elizabeth River (60.1 ± 7.7) or Nansemond River (63.1 ± 4.0) muskrats. There were no differences due to sex or age.

All 14 PAH compounds analyzed were detected in surface sediments (Table 4). Fluoranthrene, pyrene, benzo(b)fluoranthrene, benzo(a)pyrene, and benzo(g,h,i)perylene were detected in 100% of the sediment samples. 1,2-benzanthracene, chrysene, benzo(k)fluoranthrene, benzo(e)pyrene, and 1,2,5,6-dibenzanthracene were detected in $> 80\%$ of the sediment samples. All 14 PAHs were detected in surface sediments collected from the lower and upper regions of the Elizabeth River. Naphthalene, phenanthrene, and anthracene were not detected in Nansemond River sediment samples. Mean concentrations detected in sediment samples were greater ($P < 0.05$) in the lower region of the Elizabeth River than in the upper region of the Elizabeth River or Nansemond River (Table 5). Four sediment samples collected from the same section of the lower region of the Elizabeth River (4, 5, 6, 7; Table 4, Figure 5) had PAH concentrations as much as 29,000 times greater than concentrations detected in other samples. If these four samples are eliminated from analysis (i.e. only six samples from the lower region of the Elizabeth River are used in the analysis) a significant difference ($P < 0.12$) still remains among regions (Table 6). Mean sediment PAH concentrations in the lower region of the Elizabeth River (excluding the 4 samples with extremely high concentrations) were 2 - 53 times greater than mean sediment concentrations in the other two regions. Mean sediment PAH concentrations were lowest in the Nansemond River. Significant ($P < 0.001$) and high ($r \geq 0.88$) Pearson's correlation coefficients existed between the 14 PAH compounds detected in sediment samples (Table 7).

Table 3. DNA adduct levels detected in 18 muskrats from the Elizabeth and Nansemond Rivers, Virginia using ^{32}P-Postlabeling methods.

Location	Muskrat Number	Sex	Age	Adduct level nmole/mole Normal nucleotide
Elizabeth River	694	male	adult	115
Lower region	683	male	adult	73
	854	male	adult	54
	685	female	adult	50
	613	male	adult	45
	696	female	adult	41
	682	male	adult	37
	697	female	adult	31
	690	male	adult	23
	686	male	adult	23
$\bar{x} \pm$ SE				49.2 ± 8.73
Nansemond River	671	male	adult	236
	680	male	adult	71
	692	male	adult	66
	672	female	adult	54
	674	male	adult	15
$\bar{x} \pm$ SE				88.4 ± 38.18
Controls[1]	668	male	adult	219
	670	female	adult	97
	669	male	adult	37

[1] Muskrats 668 and 670 were dosed with 10 mg benzo(a)pyrene in corn oil, muskrat 669 was dosed with corn oil only.

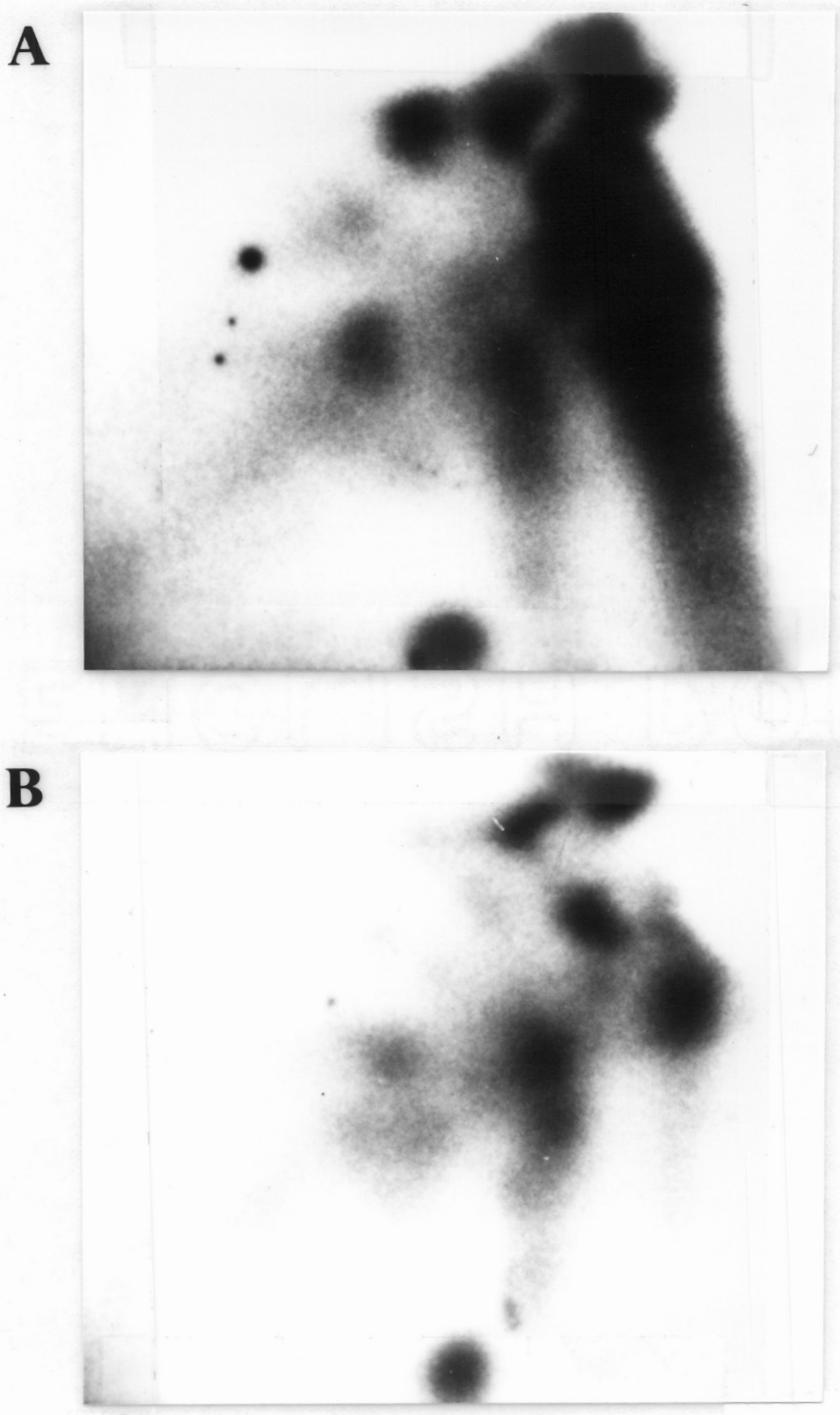

Figure 3. Autoradiograms of polyethyleneimine-cellulose thin layer chromatograms of liver samples from muskrats collected from the Nansemond River (A) (236 nmoles DNA adducts/mole of normal nucleotide) and Elizabeth River (B) (115 nmoles DNA adducts/mole of normal nucleotide) that were analyzed by ^{32}P-Postlabeling methods.

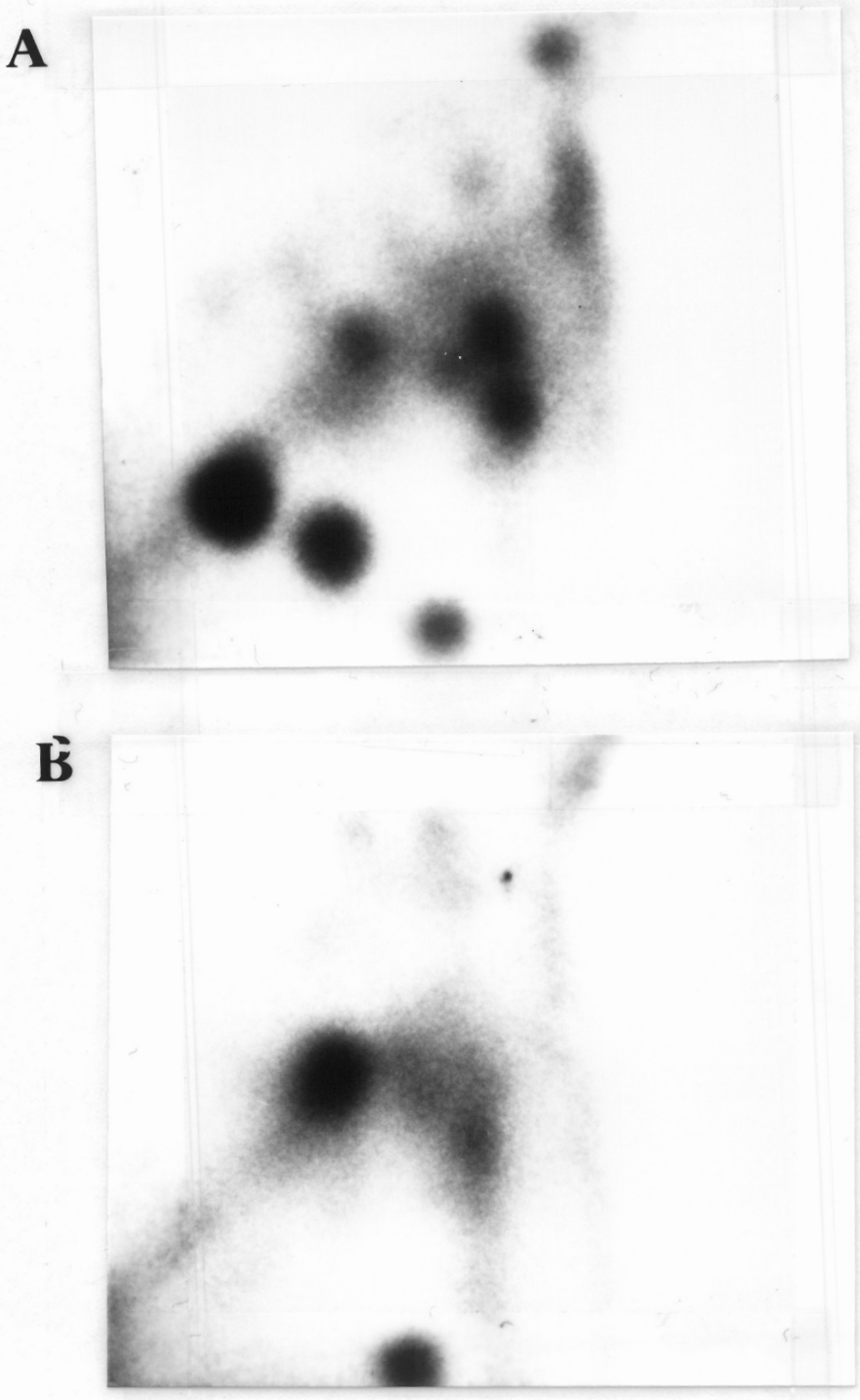

Figure 4. Autoradiograms of polyethyleneimine-cellulose thin layer chromatograms of benzo(a)pyrene treated (10 mg orally, A) and control (B) muskrat liver samples analyzed by ^{32}P-Postlabeling methods.

Table 4. Polynuclear Aromatic Hydrocarbons detected[1] (ppm dry wt) in surface sediment samples from the Elizabeth and Nansemond Rivers, Va. 1988.

	Elizabeth River															Nansemond River				
	Lower region										Upper region									
PAH	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5
Naphthalene	0.00	0.04	0.05	3.5	0.7	11.8	1.0	0.15	0.02	0.14	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluorene	0.00	0.04	0.05	16.1	4.4	39.5	4.8	0.07	0.02	0.11	0.03	0.03	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
Phenanthrene	0.02	0.12	0.18	63.2	35.2	102.6	30.8	0.22	0.06	0.25	0.06	0.11	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Anthracene	0.16	0.30	1.48	136.8	26.4	213.2	30.8	0.48	0.06	0.33	0.10	0.38	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Fluoranthrene	0.20	2.64	2.03	631.6	208.8	763.2	250.0	1.26	0.21	1.51	0.48	0.41	1.31	0.12	0.14	0.14	0.09	0.06	0.09	0.06
Pyrene	0.28	1.92	1.79	526.3	169.2	710.5	211.5	1.63	0.17	2.16	0.35	0.27	0.77	0.09	0.14	0.14	0.05	0.13	0.05	0.10
1,2-benzanthracene	0.13	0.88	0.99	358.9	92.3	447.4	150.0	0.63	0.17	1.37	0.10	0.11	0.62	0.00	0.07	0.00	0.00	0.06	0.05	0.05
Chrysene	0.15	1.44	2.86	491.2	74.7	500.0	111.5	1.19	0.27	2.71	0.22	0.05	1.15	0.15	0.27	0.00	0.00	0.00	0.14	0.15
Benzo(b)fluoranthrene	0.15	1.36	2.29	168.4	50.6	202.6	61.5	1.37	0.32	3.56	0.44	0.27	0.38	0.06	0.17	0.07	0.05	0.06	0.05	0.06
Benzo(k)fluoranthrene	0.05	0.52	0.65	80.7	30.8	76.3	26.9	0.52	0.11	0.38	0.13	0.08	0.15	0.03	0.03	0.00	0.00	0.00	0.00	0.05
Benzo(e)pyrene	0.10	0.52	2.03	340.4	70.3	421.1	136.5	1.59	0.23	2.11	0.29	0.22	0.54	0.03	0.14	0.07	0.05	0.13	0.09	0.00
Benzo(a)pyrene	0.13	1.04	1.32	266.7	72.5	289.5	94.2	1.22	0.24	3.01	0.38	0.16	0.38	0.06	0.14	0.07	0.05	0.06	0.05	0.05
1,2,5,6-dibenzanthracene	0.02	0.20	0.16	129.8	33.0	139.5	44.2	0.09	0.05	1.84	0.10	0.03	0.08	0.03	0.03	0.07	0.00	0.00	0.00	0.00
Benzo(g,h,i)perylene	0.11	0.64	0.83	200.0	92.3	315.8	73.1	0.78	0.18	3.56	0.25	0.03	0.35	0.06	0.03	0.07	0.05	0.45	0.05	0.05

[1]Lower limit of detection was 0.03 ppm.

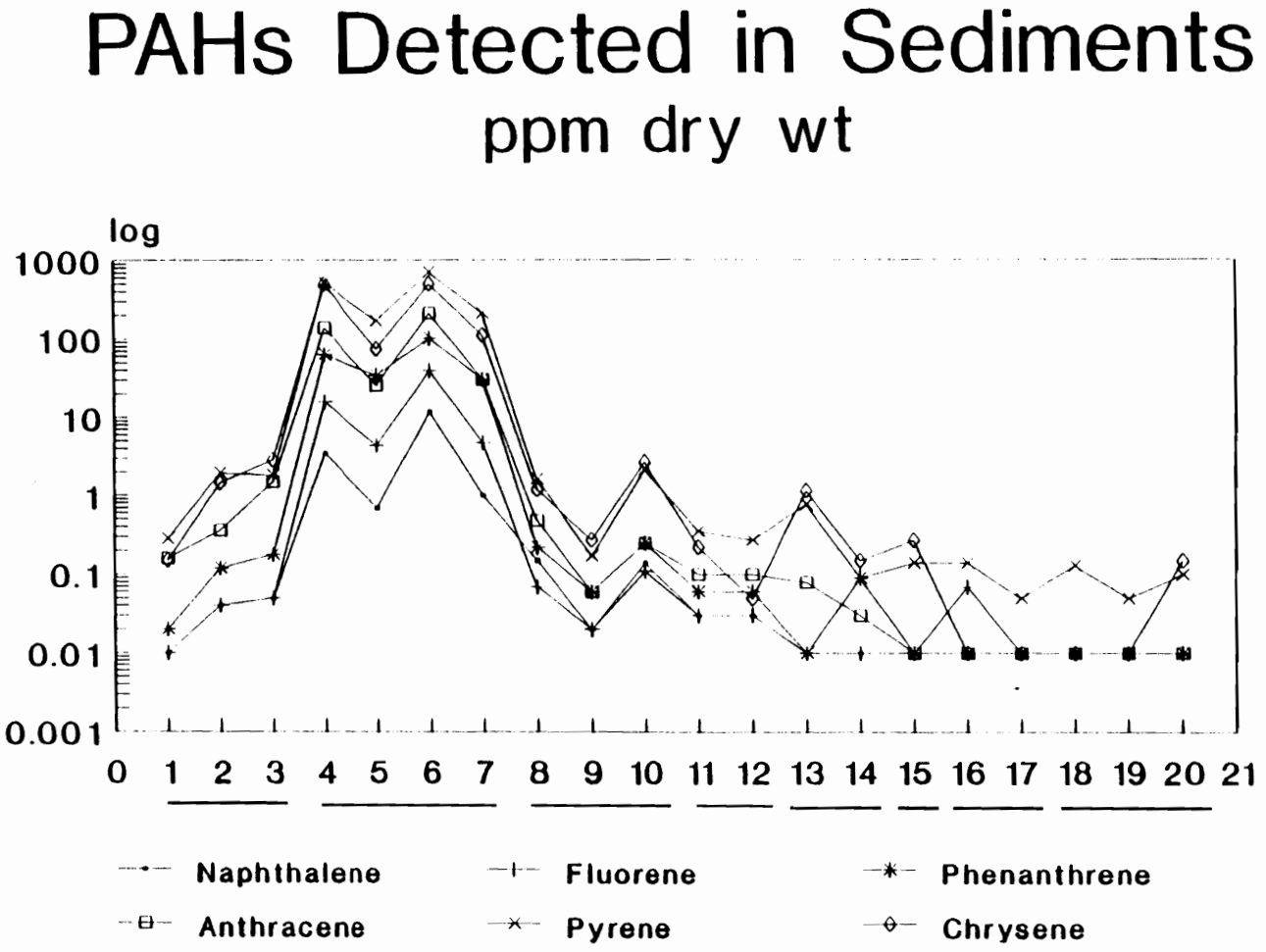

Figure 5. Polynuclear aromatic hydrocarbons (PAHs) detected in surface sediments from the lower region (1 - 10) and upper region (11 - 15) of the Elizabeth River and from the Nansemond River (16 - 20). Bars under the sample numbers connect samples collected from the same location. These were the only PAHs also detected in muskrats collected during this study.

Table 5. Polynuclear Aromatic Hydrocarbons detected[1] (ppm dry wt) in surface sediment samples from the Elizabeth and Nansemond Rivers, Va. 1988.

Polynuclear Aromatic Hydrocarbon	Elizabeth River		Nansemond River	Kruskal-Wallis
	Lower Region $\bar{X} \pm SE$	Upper Region $\bar{X} \pm SE$	$\bar{X} \pm SE$	P
Napthalene	1.74 ± 1.17 (N = 10) (1.94 ± 1.29 N = 9)[3]	0.00 (N = 5) (0.03 ± 0.00 N = 2)	ND[2]	0.003
Fluorene	6.51 ± 4.00 (N = 10) (7.26 ± 4.39 N = 9)	0.00 (N = 5) (0.03 ± 0.00 N = 2)	0.00 (N = 5) (0.07 ± 0.00 N = 1)	0.012
Phenanthrene	23.26 ± 11.20 (N = 10)	0.05 ± 0.02 (N = 5) (0.09 ± 0.01 N = 3)	ND	0.001
Anthracene	41.00 ± 23.33 (N = 10)	0.12 ± 0.07 (N = 5) (0.15 ± 0.08 N = 4)	ND	0.001
Fluoranthrene	186.14 ± 90.73 (N = 10)	0.49 ± 0.22 (N = 5)	0.10 ± 0.01 (N = 5)	0.001
Pyrene	162.56 ± 81.04 (N = 10)	0.32 ± 0.12 (N = 5)	0.09 ± 0.02 (N = 5)	0.001
1,2-benzanthracene	105.27 ± 52.61 (N = 10)	0.18 ± 0.11 (N = 5) (0.23 ± 0.13 N = 4)	0.03 ± 0.01 (N = 5) (0.05 ± 0.00 N = 3)	0.001
Chrysene	118.61 ± 64.00 (N = 10)	0.37 ± 0.20 (N = 5)	0.06 ± 0.04 (N = 5) (0.15 ± 0.01 N = 2)	0.001
Benzo(b)fluoranthrene	49.22 ± 23.94 (N = 10)	0.26 ± 0.07 (N = 5)	0.06 ± 0.00 (N = 5)	0.001
Benzo(k)fluoranthrene	21.69 ± 10.17 (N = 10)	0.08 ± 0.02 (N = 5)	0.05 (N = 1)	0.001
Benzo(e)pyrene	97.49 ± 49.63 (N = 10)	0.24 ± 0.09 (N = 5)	0.07 ± 0.02 (N = 5) (0.09 ± 0.02 N = 4)	0.003
Benzo(a)pyrene	72.99 ± 35.87 (N = 10)	0.22 ± 0.07 (N = 5)	0.06 ± 0.00 (N = 5)	0.001
1,2,5,6-dibenzanthracene	34.88 ± 17.38 (N = 10)	0.05 ± 0.01 (N = 5)	0.07 (N = 1)	0.005
Benzo(g,h,i)perylene	68.73 ± 34.38 (N = 10)	0.14 ± 0.07 (N = 5)	0.13 ± 0.08 (N = 5)	0.004

[1]Lower limit of detection was 0.03 ppm.
[2]None detected.
[3]Means in parenthesis are computed from samples with detectable levels.

Table 6. Polynuclear Aromatic Hydrocarbons detected[1] (ppm dry wt) in surface sediment samples from the Elizabeth and Nansemond Rivers, Va. 1988. (4 samples from lower region have been eliminated).

Polynuclear Aromatic Hydrocarbon	Elizabeth River		Nansemond River	Kruskal-Wallis
	Lower Region $\bar{X} \pm SE$	Upper Region $\bar{X} \pm SE$	$\bar{X} \pm SE$	P
Napthalene	0.07 ± 0.03 (N = 6)	0.00 ± 0.00 (N = 5)	ND[2]	0.020
Fluorene	0.05 ± 0.02 (N = 6)	0.00 ± 0.00 (N = 5)	0.00 ± 0.00 (N = 1)	0.112
Phenanthrene	0.14 ± 0.04 (N = 6)	0.05 ± 0.02 (N = 5)	ND	0.008
Anthracene	0.48 ± 0.21 (N = 6)	0.12 ± 0.07 (N = 5)	ND	0.006
Fluoranthrene	1.31 ± 0.40 (N = 6)	0.49 ± 0.22 (N = 5)	0.10 ± 0.01 (N = 5)	0.007
Pyrene	1.33 ± 0.36 (N = 6)	0.32 ± 0.12 (N = 5)	0.09 ± 0.02 (N = 5)	0.008
1,2-benzanthracene	0.70 ± 0.20 (N = 6)	0.18 ± 0.11 (N = 5)	0.03 ± 0.01 (N = 5)	0.004
Chrysene	1.44 ± 0.48 (N = 6)	0.37 ± 0.20 (N = 5)	0.06 ± 0.04 (N = 5)	0.007
Benzo(b)fluoranthrene	1.51 ± 0.52 (N = 6)	0.26 ± 0.07 (N = 5)	0.06 ± 0.00 (N = 5)	0.006
Benzo(k)fluoranthrene	0.37 ± 0.10 (N = 6)	0.08 ± 0.02 (N = 5)	0.05 (N = 1)	0.006
Benzo(e)pyrene	1.10 ± 0.37 (N = 6)	0.24 ± 0.09 (N = 5)	0.07 ± 0.02 (N = 5)	0.018
Benzo(a)pyrene	1.16 ± 0.42 (N = 6)	0.22 ± 0.07 (N = 5)	0.06 ± 0.00 (N = 5)	0.006
1,2,5,6-dibenzanthracene	0.39 ± 0.29 (N = 6)	0.05 ± 0.01 (N = 5)	0.07 (N = 1)	0.029
Benzo(g,h,i)perylene	1.02 ± 0.52 (N = 6)	0.14 ± 0.07 (N = 5)	0.13 ± 0.08 (N = 5)	0.033

[1] Lower limit of detection was 0.03 ppm.
[2] None detected.

Table 7. Significant ($P < 0.001$) Pearson's correlation coefficients (r) between polynuclear aromatic hydrocarbons detected in surface sediment samples from the Elizabeth and Nansemond Rivers, Va. 1988.

	Fl	Ph	An	Flu	Py	Benz12	Chry	Benzob	Benzok	Benzoe	Benzoa	Dibenz	Benzog
Napthalene	0.99	0.91	0.97	0.89	0.92	0.91	0.90	0.90	0.83	0.91	0.88	0.88	0.93
Fluorene		0.95	0.99	0.94	0.95	0.94	0.94	0.94	0.89	0.95	0.93	0.93	0.97
Phenanthrene			0.96	0.99	0.99	0.98	0.95	0.99	0.97	0.98	0.98	0.98	0.99
Anthracene				0.97	0.98	0.97	0.98	0.97	0.93	0.98	0.97	0.97	0.98
Fluoranthrene					0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.99	0.99
Pyrene						0.99	0.98	0.99	0.98	0.99	0.99	0.99	0.99
1,2-benzanthracene							0.98	0.99	0.98	0.99	0.99	0.99	0.98
Chrysene								0.99	0.97	0.99	0.99	0.99	0.97
Benzo(b)fluoranthrene									0.99	0.99	0.99	0.99	0.99
Benzo(k)fluoranthrene										0.97	0.99	0.99	0.97
Benzo(e)pyrene											0.99	0.99	0.98
Benzo(a)pyrene												0.99	0.98
1,2,5,6-dibenzanthracene													0.98

Na = Naphthalene, Fl = fluorene, Ph = phenanthrene, An = anthracene, Flu = fluoranthrene, Py = pyrene, Benz12 = 1,2-benzanthracene, Chry = chrysene, Benzob = benzo(b)fluoranthrene, Benzok = benzo(k)fluoranthrene, Benzoe = benzo(e)pyrene, Benzoa = benzo(a)pyrene, Dibenz = 1,2,5,6-dibenzanthracene, Benzog = benzo(g,h,i)perylene.

Organochlorines

Dieldrin, PCB's (total), and p,p'-DDE were the only OC's detected in muskrat carcasses. One carcass from the lower region of the Elizabeth River had detectable concentrations of dieldrin, two carcasses from the upper region of the Elizabeth River had detectable concentrations of PCB's, and two carcasses from the upper region of the Elizabeth River and one from the Nansemond River had detectable concentrations of p,p'-DDE (Table 8). Only one muskrat had more than one detectable OC compound (PCB's and p,p'-DDE were both detected in muskrat 715 from the upper region of the Elizabeth River).

p,p'-DDE and p,p'-DDD were the only OCs detected in 20 surface sediment samples. Five sediment samples from the lower region and two from the upper region of the Elizabeth River had detectable concentrations of p,p'-DDE and three samples from the lower region of the Elizabeth River had detectable concentrations of p,p'-DDD (Table 9). Three sediment samples from the lower region of the Elizabeth River had detectable concentrations of both p,p'-DDE and p,p'-DDD. All other sediment samples with detectable OC concentrations had only one contaminant detected.

Heavy Metals

Twenty-seven of the 33 metals analyzed were detected in muskrat kidneys (Table 10). Nineteen metals were detected in a sufficient number of muskrat kidneys for statistical analysis. Tests for normality (PROC UNIVARIATE; SAS Institute Inc. 1982) and data plots indicated nongaussian distributions of some metals. Log transformations were used to improve the distributional normality. Results of ANOVA and nonparametric (Kruskal-Wallis) analyses of log transformed data were in agreement. Mean concentrations of 9 of the 19 metals were significantly

Table 8. Organochlorine contaminants detected[1] (ppm dry wt) in muskrats from the Elizabeth and Nansemond Rivers, Va. 1986 - 1988.

	Elizabeth River					
	Lower Region		Upper Region		Nansemond River	
Organochlorine	Muskrats with Detectable levels	PPM	Muskrats with Detectable levels	PPM	Muskrats with Detectable levels	PPM
Dieldrin	1 of 24	0.25 (N = 1)	0 of 6		0 of 5	
PCB's (total)	0 of 24		2 of 6	0.66 (N = 1) 0.45 (N = 1)	0 of 5	
p, p'-DDE	0 of 24		2 of 6	0.03 (N = 2)	1 of 5	0.03 (N = 1)

[1]Lower limit of detection was 0.03 ppm.

Table 9. Organochlorine contaminants detected[1] (ppm dry wt) in surface sediment samples from the Elizabeth and Nansemond Rivers, Va. 1988.

	Elizabeth River					
	Lower Region		Upper Region		Nansemond River	
Organochlorine	Samples with Detectable levels	PPM	Samples with Detectable levels	PPM	Samples with Detectable levels	PPM
p, p'-DDE	5 of 10	0.18 (N = 1) 0.09 (N = 1) 0.08 (N = 1) 0.04 (N = 1) 0.03 (N = 1)	2 of 5	0.03 (N = 2)	0 of 5	------
p, p'-DDD	3 of 10	0.18 (N = 2) 0.09 (N = 1)	0 of 5	------	0 of 5	------

[1]Lower limit of detection was 0.03 ppm.

different ($P \leq 0.05$) among regions (Table 11). Of the 9 metals that were significantly different, aluminum, cadmium, copper, nickel, and zinc mean concentrations were greatest in muskrat kidneys from the lower region of the Elizabeth River. Manganese, and vanadium mean concentrations were greatest in muskrat kidneys from the Nansemond River and selenium mean concentration was greatest in muskrat kidneys from the upper region of the Elizabeth River. Statistical analyses indicated significant differences ($P \leq 0.05$) between ages for the metals calcium, cadmium, and sodium (means were greater for adults in all three cases) and significant differences ($P \leq 0.05$) between sexes for the metal iron (mean was greater for females). Statistical analyses also indicated significant ($P \leq 0.05$) region by age interactions for copper, molybdenum, and zinc and region by sex by age interaction for selenium. The greatest mean concentrations of copper and zinc were in adults in the lower region of the Elizabeth River and in immatures in either the upper region of the Elizabeth River or Nansemond River. However, the mean concentrations of both metals from the lower region of the Elizabeth River for both adults and immatures were greater than mean concentrations of these metals in either adults or immatures in the other two regions. Therefore, differences in copper and zinc concentrations due to the effects of location appear to be valid. The region by age interaction for molybdenum and the region by sex interaction for selenium appear to exist and interpretation of locational differences are suspect for these metals. Three muskrats from the same section of the lower region of the Elizabeth River had extreme cadmium concentrations (22.1, 23.9, and 30.1 ppm) and were initially thought to be responsible for the significant difference observed among regions. However, an ANOVA analysis without these observations still indicated a significant difference among regions ($P < 0.001$) with the lower region of the Elizabeth River having the highest mean.

No antimony, arsenic, bismuth, chromium, silver, or tin were detected in any muskrat kidney. Boron, barium, beryllium, cobalt, tungsten, lithium, silicon, or thallium were detected in $< 80\%$ of the muskrat kidneys. Only one muskrat kidney (3%) from the lower region of the Elizabeth River had detectable concentrations of tungsten or thallium. Five muskrat kidneys (17%) from the lower region and one (5%) from the upper region of the Elizabeth River had detectable concentrations of boron and 8 muskrat kidneys (27%) from the lower region and one (5%) from

Table 10. Kidney mean, minimum, maximum, and median metal concentrations (ppm dry wt) detected[1] in muskrats from the Elizabeth and Nansemond Rivers, Va. 1986 - 1988.

	Elizabeth River											
	Lower Region				Upper Region				Nansemond River			
Metal	Mean	Min	Max	Med	Mean	Min	Max	Med	Mean	Min	Max	Med
Aluminum	13.19	0.0	61.0	5.5	3.90	0.0	7.0	4.0	3.45	0.0	10.0	3.5
Boron	0.87	0.0	11.0	0.0	0.2	0.0	4.0	0.0	0.0	0.0	0.0	0.0
Barium	0.06	0.0	0.25	0.0	0.06	0.0	0.34	0.0	0.07	0.0	0.2	0.09
Beryllium	0.002	0.0	0.05	0.0	0.05	0.0	0.10	0.0	0.004	0.0	0.06	0.0
Calcium	351.43	240.0	690.0	305.0	334.15	270.0	440.0	320.0	316.15	220.0	480.0	310.0
Cadmium	3.08	0.08	30.1	0.54	0.44	0.04	1.9	0.17	0.08	0.03	0.26	0.065
Cobalt	0.09	0.0	0.2	0.0	0.001	0.0	0.02	0.0	0.0	0.0	0.0	0.0
Copper	12.85	10.9	14.7	12.65	11.45	9.6	13.7	11.35	11.14	8.4	12.5	11.45
Iron	569.87	330.0	1010.0	517.5	546.25	364.0	1130.0	536	557.00	369.0	796.0	542.0
Potassium	11490.33	8940.0	14000.0	11950.0	11280.5	9410.0	15100.0	11000.0	11553.9	10200.0	13600.0	11500.0
Tungsten	0.07	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithium	0.05	0.0	0.3	0.0	0.003	0.0	0.03	0.0	0.002	0.0	0.03	0.0
Magnesium	734.93	642.0	849.0	730.5	748.95	645.0	924.0	744.5	733.23	653.0	811.0	728.5
Manganese	5.56	4.0	9.2	5.4	5.23	4.0	6.4	5.3	6.60	4.2	15.0	5.7
Molybdenum	0.92	0.56	1.6	0.91	0.84	0.56	1.2	0.87	0.73	0.53	0.96	0.72
Sodium	5007.67	3820.0	8120.0	4665.0	5274.00	4070.0	6190.0	5270.0	5142.31	3680.0	7210.0	5230.0
Nickel	0.50	0.0	1.1	0.43	0.20	0.0	0.5	0.2	0.22	0.0	0.95	0.2
Phosphorus	10060.0	8770.0	11400.0	10150.0	10057.0	9240.0	12100.0	10075.0	9926.0	9210.0	11100.0	9780.0
Lead	1.20	0.0	3.0	1.0	1.17	0.0	4.9	0.9	0.71	0.0	1.5	0.7
Selenium	4.63	2.8	7.6	4.2	5.31	2.9	11.0	5.1	4.33	2.9	5.8	4.35
Silicon	3.09	0.0	44.0	0.0	1.00	0.0	3.0	0.0	0.50	0.0	5.0	0.0
Strontium	0.64	0.28	1.4	0.57	0.72	0.41	1.5	0.71	0.83	0.43	1.4	0.80
Titanium	0.42	0.0	1.7	0.35	0.24	0.0	0.5	0.3	0.42	0.0	1.2	0.4
Thallium	0.01	0.0	0.40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vanadium	0.45	0.1	1.9	0.33	0.63	0.07	1.8	0.51	1.10	0.32	2.5	0.99
Zinc	88.38	76.2	110.0	88.6	78.21	69.8	90.6	76.95	81.36	73.5	93.3	81.35
Mercury	0.02	0.002	0.065	0.009	0.02	0.004	0.047	0.011	0.01	0.002	0.023	0.01

[1]No antimony, arsenic, bismuth, chromium, silver, or tin was detected in muskrat kidney.

Table 11. Mean kidney metal concentrations (ppm dry wt) detected[1] in muskrats from the Elizabeth and Nansemond Rivers, Va. 1986 - 1988.

Metal	Elizabeth River		Nansemond River	ANOVA
	Lower Region $\bar{X} \pm SE$	Upper Region $\bar{X} \pm SE$	$\bar{X} \pm SE$	P[2]
Aluminum	13.19 ± 2.94 (N = 30)[a] (14.94 ± 3.07 N = 28)[3]	3.90 ± 0.32 (N = 20)[b] (4.11 ± 0.26 N = 19)	3.45 ± 0.52 (N = 26)[b] (4.27 ± 0.49 N = 21)	0.016
Calcium	351.43 ± 20.54 (N = 30)	334.15 ± 11.28 (N = 20)	316.15 ± 12.93 (N = 26)	0.207
Cadmium	3.08 ± 1.40 (N = 30)[a]	0.44 ± 0.11 (N = 20)[b]	0.08 ± 0.01 (N = 26)[b]	< 0.001
Copper	12.85 ± 0.20 (N = 30)[a]	11.45 ± 0.22 (N = 20)[b]	11.14 ± 0.20 (N = 26)[b]	< 0.001
Iron	569.87 ± 26.69 (N = 30)	546.25 ± 34.54 (N = 20)	557.00 ± 18.58 (N = 26)	0.652
Potassium	11490.33 ± 283.58 (N = 30)	11280.50 ± 321.05 (N = 20)	11553.85 ± 181.47 (N = 26)	0.383
Magnesium	734.93 ± 8.54 (N = 30)	748.95 ± 14.34 (N = 20)	733.23 ± 7.79 (N = 26)	0.564
Manganese	5.56 ± 0.21 (N = 30)[a]	5.23 ± 0.16 (N = 20)[a]	6.60 ± 0.49 (N = 26)[b]	0.041
Molybdenum	0.92 ± 0.03 (N = 30)[a]	0.84 ± 0.03 (N = 20)[a]	0.73 ± 0.02 (N = 26)[b]	< 0.001
Sodium	5007.67 ± 174.72 (N = 30)	5274.00 ± 121.65 (N = 20)	5142.31 ± 191.75 (N = 26)	0.385
Nickel	0.50 ± 0.05 (N = 30)[a] (0.51 ± 0.05 N = 29)	0.20 ± 0.03 (N = 20)[b] (0.27 ± 0.03 N = 15)	0.22 ± 0.05 (N = 26)[b] (0.32 ± 0.05 N = 18)	< 0.001
Phosphorus	10060 ± 100 (N = 30)	10057 ± 156 (N = 20)	9926 ± 89 (N = 26)	0.746
Lead	1.20 ± 1.17 (N = 30)[a] (1.28 ± 0.13 N = 28)	1.17 ± 0.22 (N = 20)[a] (1.23 ± 0.22 N = 19)	0.71 ± 0.07 (N = 26)[b] (0.80 ± 0.05 N = 23)	0.067
Selenium	4.63 ± 0.24 (N = 30)[a]	5.31 ± 0.36 (N = 20)[b]	4.33 ± 0.17 (N = 26)[a]	0.027
Strontium	0.64 ± 0.05 (N = 30)[a]	0.72 ± 0.65 (N = 20)[a,b]	0.83 ± 0.04 (N = 26)[b]	0.057
Titanium	0.42 ± 0.08 (N = 30) (0.52 ± 0.08 N = 24)	0.24 ± 0.04 (N = 20) (0.34 ± 0.02 N = 14)	0.42 ± 0.05 (N = 26) (0.45 ± 0.05 N = 24)	0.322
Vanadium	0.45 ± 0.07 (N = 30)[a]	0.63 ± 0.11 (N = 20)[a]	1.10 ± 0.10 (N = 26)[b]	< 0.001
Zinc	88.38 ± 1.52 (N = 30)[a]	78.21 ± 1.34 (N = 20)[b]	81.36 ± 1.04 (N = 26)[b]	< 0.001
Mercury	0.019 ± 0.00 (N = 30)	0.017 ± 0.00 (N = 20)	0.011 ± 0.00 (N = 26)	0.343

[1]Antimony, arsenic, bismuth, chromium, silver, or tin was not detected in muskrat kidneys. Boron, barium, beryllium, cobalt, tungsten, lithium, silicon, or thallium was detected in < 80% of muskrat kidneys. Row means with different letter (a,b) are significantly different ($P \leq 0.10$).
[2]P values are based on analysis of log transformed data.
[3]Means in parenthesis are computed from samples with detectable levels.

the upper region of the Elizabeth River had detectable concentrations of cobalt. Seven muskrat kidneys (23%) from the lower region of the Elizabeth River and two from the upper region of the Elizabeth River and two from the Nansemond River (10% and 8% respectively) had detectable concentrations of lithium. Beryllium was detected in one muskrat kidney (3%) from the lower region and 10 muskrat kidneys (50%) from the upper region of the Elizabeth River and in two muskrat kidneys (8%) from the Nansemond River. Silicon was detected in 4 (13%) muskrat kidneys from the lower region and 9 (45%) muskrat kidneys from the upper region of the Elizabeth River and in 5 (19%) muskrat kidneys from the Nansemond River. Barium was detected in 13 (43%) muskrat kidneys from the lower region and 7 (35%) muskrat kidneys from the upper region of the Elizabeth River and in 20 (77%) muskrat kidneys from the Nansemond River. Significant ($P < 0.10$) but relatively low ($r \leq 0.63$) Pearson's correlation coefficients exist between several metals detected in $> 80\%$ of muskrat kidneys (Table 12).

Thirty of the 33 metals analyzed were detected in surface sediment samples (Table 13). The mean sediment concentrations of 21 of the 30 metals detected were significantly different ($P \leq 0.10$) among regions (Table 14). Of the metals that were significantly different among regions, cadmium, chromium, lead, tungsten, and mercury mean concentrations were greatest in the lower region of the Elizabeth River. Mean concentrations of 14 metals were greatest in surface sediments from the Nansemond River and in 2 surface sediment samples from the upper region of the Elizabeth River. No antimony, thallium, or tin was detected in sediment samples. Selenium was detected in only 1 sample from the lower region of the Elizabeth River, silver in only 3 sediment samples from the upper region of the Elizabeth River, and bismuth in only 2 sediment samples from the Nansemond River. Molybdenum was detected in only 4 sediment samples from the lower region and 2 sediment samples from the upper region of the Elizabeth River. Significant ($P < 0.10$) but varying ($0.97 > r > 0.38$) Pearson's correlation coefficients exist between metals detected in surface sediment samples (Table 15).

Of the metals detected in $> 80\%$ of the muskrat and surface sediment samples, significant Pearson's correlation coefficients were found for cadmium, iron, manganese, and vanadium. Means were highly correlated for cadmium ($r = 0.92$, $P = 0.001$) and moderately correlated for iron ($r = 0.67$,

Table 12. Significant Pearson's correlation coefficients (r) between metal concentrations detected in muskrat kidney samples collected from the Elizabeth (N = 15) and Nansemond (N = 5) Rivers Virginia, 1988.

Metals	Metals																		
	Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	Sc	Sr	Ti	V	Zn	Hg
Al		-----	-----	0.46[1]	-----	-0.37[1]	-----	-----	0.20[3]	-----	0.40[1]	-----	-----	0.27[2]	-0.24[2]	0.41[1]	-0.25[2]	0.25[2]	0.63[1]
Ca			0.36[1]	-----	-----	-----	0.20[3]	-----	0.26[2]	0.26[2]	-----	-----	-----	-----	0.33[1]	-----	-----	0.30[1]	-----
Cd				0.22[3]	-----	-----	-----	-----	0.32[1]	-----	0.37[1]	-----	0.35[1]	-----	-----	-----	-0.21[3]	0.57[1]	-----
Cu					-----	-----	0.31[1]	-----	0.37[1]	-----	0.45[1]	0.23[2]	0.41[1]	-----	-----	0.22[3]	-0.19[3]	0.59[1]	0.30[1]
Fe						0.33[1]	-----	-----	-----	-----	-----	-----	0.33[1]	-----	-----	-----	0.21[3]	-----	-----
K							0.35[1]	-----	-----	-----	-----	0.22[3]	-----	-----	0.22[3]	-----	-----	-----	-0.35[1]
Mg								-----	-----	-----	-----	0.43[1]	0.24[2]	-----	0.49[1]	-----	-----	0.29[2]	-----
Mn									-----	0.36[1]	-----	-----	-----	-----	0.29[2]	-----	0.19[3]	-----	-----
Mo										-----	0.44[1]	-----	0.48[1]	-----	-----	0.35[1]	-----	0.30[1]	-----
Na											-0.19[3]	-----	0.21[3]	0.19[3]	0.35[1]	-----	-----	-----	-----
Ni												-----	-----	-----	-----	0.34[1]	-----	0.40[1]	-----
P													0.30[2]	-----	-----	-0.21[3]	-----	0.30[1]	-----
Pb														-----	-----	-----	-----	0.36[1]	-----
Se															-----	-----	-----	-----	0.62[1]
Sr																-----	0.42[1]	-----	-0.22[3]
Ti																	0.26[2]	0.20[3]	0.21[3]
V																		-----	-0.25[2]
Zn																			-----

Al = aluminum, Ca = calcium, Cd = cadmium, Cu = copper, Fe = iron, K = potassium, Mg = magnesium, Mn = manganese, Mo = molybdenum, Na = sodium, Ni = nickel, P = potassium, Pb = lead, Se = selenium, Sr = strontium, Ti = titanium, V = vanadium, Zn = zinc Hg = mercury.

[1] $P \leq 0.01$

[2] $P \leq 0.05$

[3] $P \leq 0.10$

Table 13. Mean, minimum, maxium, and median metal concentrations (ppm dry wt) detected[1] in surface sediment samples from the Elizabeth and Nansemond Rivers, Va. June 1988.

	Elizabeth River											
	Lower Region (N = 10)				Upper Region (N = 5)				Nansemond River (N = 5)			
Metal	Mean	Min	Max	Med	Mean	Min	Max	Med	Mean	Min	Max	Med
Aluminum	16177.0	6510.0	27900.0	15800.0	21220.0	11700.0	30200.0	18900.0	39820.0	37300.0	45500.0	38900.0
Arsenic	18.0	9.0	30.0	19.5	11.4	7.0	20.0	10.0	30.0	20.0	40.0	30.0
Barium	59.45	35.90	85.10	58.8	46.7	27.1	78.3	43.3	144.0	120.0	167.0	137.0
Beryllium	1.26	0.56	4.40	0.96	0.81	0.46	1.40	0.69	1.52	1.40	1.70	1.50
Bismuth	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	6.0	0.0
Boron	17.7	10.0	30.0	16.5	20.0	15.0	25.0	20.0	26.2	23.0	30.0	26.0
Cadmium	1.08	0.00	2.60	0.78	0.36	0.20	0.50	0.40	0.22	0.00	0.30	0.30
Calcium	2581.0	1000.0	4650.0	2290.0	4758.0	1820.0	9040.0	3590.0	3654.0	2990.0	4550.0	3350.0
Chromium	43.4	24.0	70.0	43.0	31.4	27.0	36.0	32.0	30.0	25.0	35.0	30.0
Cobalt	17.2	10.0	37.0	15.5	16.6	11.0	27.0	15.0	19.0	14.0	30.0	17.0
Copper	68.01	13.0	178.0	56.4	32.28	17.0	51.9	31.4	26.0	19.0	32.0	24.0
Iron	20240.0	11300.0	35800.0	17000.0	13830.0	5750.0	25700.0	11800.0	37240.0	34200.0	39400.0	37900.0
Lead	104.0	15.0	290.0	90.5	43.2	30.0	66.0	41.0	37.0	33.0	44.0	35.0
Lithium	27.55	10.0	59.4	26.0	40.22	22.7	66.1	38.5	58.82	54.9	67.2	56.5
Magnesium	4205.0	2270.0	6880.0	4075.0	4650.0	3530.0	6210.0	4140.0	7784.0	7170.0	8730.0	7570.0
Manganese	100.21	60.5	194.0	88.8	76.22	44.7	124.0	71.0	2691.2	846.0	5960.0	2080.0
Molybdenum	1.1	0.0	5.0	0.0	1.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
Nickel	24.5	18.0	43.0	23.0	21.6	19.0	25.0	21.0	26.0	24.0	29.0	25.0
Phosphorus	967.0	240.0	2130.0	780.0	748.0	510.0	1100.0	710.0	1086.0	950.0	1300.0	1100.0
Potassium	2692.0	1100.0	4290.0	2800.0	2902.0	1900.0	4610.0	2600.0	6120.0	5750.0	6640.0	6190.0
Selenium	2.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silicon	803.4	363.0	1740.0	646.5	724.2	488.0	924.0	763.0	1814.0	1140.0	3280.0	1260.0
Silver	0.0	0.0	0.0	0.0	0.8	0.0	2.0	1.0	0.0	0.0	0.0	0.0
Sodium	12293.0	5330.0	27100.0	12050.0	14560.0	10800.0	17500.0	13900.0	16260.0	13500.0	18100.0	17300.0
Strontium	68.2	20.5	121.0	62.9	59.52	38.7	92.9	62.5	71.8	63.3	78.5	74.4
Titanium	494.9	334.0	680.0	474.0	477.8	316.0	755.0	437.0	960.4	822.0	1040.0	960.0
Tungsten	38.15	0.0	90.0	35.0	34.6	19.0	77.0	24.0	7.6	4.0	13.0	8.4
Vanadium	38.7	21.0	64.0	39.5	40.0	29.0	60.0	37.0	63.8	60.0	75.0	62.0
Zinc	232.8	51.6	455.0	198.5	116.2	53.0	207.0	121.0	124.8	115.0	149.0	118.0
Mercury	0.50	0.04	0.98	0.45	0.13	0.08	0.22	0.12	0.12	0.11	0.15	0.11

[1]No antimony, tin, or thallium was detected in sediment samples.

Table 14. Mean metal concentrations (ppm dry wt) detected[1] in surface sediment samples from the Elizabeth and Nansemond Rivers, Va. June 1988.

Metal	Elizabeth River		Nansemond River	Kruskal-Wallis
	Lower Region $\bar{X} \pm$ SE (N = 10)	Upper Region $\bar{X} \pm$ SE (N = 5)	$\bar{X} \pm$ SE (N = 5)	P
Aluminum	16177.0 ± 2407.9	21220.0 ± 4049.6	39820.0 ± 1470.5	0.004
Arsenic	18.0 ± 2.6	11.4 ± 2.2	30.0 ± 3.2	0.015
Boron	17.7 ± 2.1	20.0 ± 1.7	26.2 ± 1.2	0.031
Barium	59.5 ± 4.9	46.7 ± 8.5	144.0 ± 8.6	0.003
Beryllium	1.3 ± 0.4	0.8 ± 0.2	1.5 ± 0.04	0.013
Bismuth	0.5 ± 0.0	0.0 ± 0.0	2.2 ± 1.4	0.043
Cadmium	1.07 ± 0.3	0.36 ± 0.1	0.22 ± 0.1	0.079
Calcium	2581.0 ± 370.5	4758.0 ± 1398.4	3654.0 ± 283.9	0.193
Cobalt	17.2 ± 2.4	16.6 ± 2.8	19.0 ± 2.8	0.637
Chromium	43.4 ± 4.4	31.4 ± 1.6	30.0 ± 1.6	0.090
Copper	68.0 ± 16.3	32.3 ± 5.9	26.0 ± 2.6	0.129
Iron	20240.0 ± 2916.3	13830.0 ± 3278.6	37240.0 ± 935.2	0.004
Lead	104.0 ± 25.9	43.2 ± 6.0	37.0 ± 2.2	0.082
Lithium	27.6 ± 4.9	40.2 ± 7.2	58.8 ± 2.3	0.013
Magnesium	4205.0 ± 477.0	4650.0 ± 509.1	7784.0 ± 273.7	0.004
Manganese	100.2 ± 13.9	76.2 ± 13.0	2691.2 ± 886.9	0.005
Molybdenum	1.1 ± 0.5	1.0 ± 0.6	0.0 ± 0.0	0.267
Nickel	24.5 ± 2.2	21.6 ± 1.2	26.0 ± 0.9	0.100
Phosphorus	967.0 ± 190.2	748.0 ± 102.2	1086.0 ± 61.6	0.261
Potassium	2692.0 ± 370.1	2902.0 ± 469.8	6120.0 ± 159.5	0.005
Selenium	2.0 ± 2.0	0.0 ± 0.0	0.0 ± 0.0	0.607
Silicon	803.4 ± 124.2	724.2 ± 71.2	1814.0 ± 416.5	0.011
Silver	0.0 ± 0.0	0.8 ± 0.4	0.0 ± 0.0	0.007
Sodium	12293.0 ± 2138.7	14560.0 ± 1226.6	16260.0 ± 963.6	0.115
Strontium	68.2 ± 9.9	59.5 ± 10.0	71.8 ± 3.1	0.527
Titanium	494.9 ± 38.1	477.8 ± 73.6	960.4 ± 39.0	0.004
Tungsten	38.1 ± 7.6	34.6 ± 10.8	7.6 ± 1.7	0.015
Vanadium	38.7 ± 4.8	40.0 ± 5.2	63.8 ± 2.8	0.017
Zinc	232.8 ± 44.0	116.2 ± 27.1	124.8 ± 6.3	0.266
Mercury	0.50 ± 0.1	0.13 ± 0.02	0.12 ± 0.01	0.016

[1] Antimony, thallium, or tin was not detected in sediment samples.

Table 15. Significant Pearson's correlation coefficients (r) between metal concentrations detected in surface sediment samples collected from the Elizabeth (N = 15) and Nansemond (N = 5) Rivers Virginia, 1988.

	Metals																								
Metals	As	B	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe	Pb	Li	Mg	Mn	Ni	K	P	Si	Na	Sr	Ti	W	V	Zn	Hg
Al	0.79[1]	0.73[1]	0.85[1]	0.47[2]	-----	-----	-----	-0.49[2]	-----	0.88[1]	-0.45[2]	0.96[1]	0.95[1]	0.64[1]	0.47[2]	0.97[1]	0.39[3]	0.73[1]	0.57[1]	0.46[2]	0.91[1]	-0.75[1]	0.93[1]	-----	-----
As		0.71[1]	0.74[1]	0.60[1]	-----	-----	-----	-----	-----	0.87[1]	-----	0.73[1]	0.84[1]	0.41[3]	0.65[1]	0.80[1]	0.63[1]	0.70[1]	0.63[1]	0.60[1]	0.83[1]	-0.63[1]	0.90[1]	-----	-----
B			0.62[2]	0.61[1]	-----	-----	-----	-----	-----	0.64[1]	-----	0.75[1]	0.86[1]	0.46[3]	0.67[1]	0.70[1]	0.64[1]	0.61[1]	0.86[1]	0.49[2]	0.66[1]	-0.44[3]	0.81[1]	-----	-----
Ba				-----	-----	-----	-----	-----	-----	0.83[1]	-----	0.70[1]	0.84[1]	0.84[1]	-----	0.89[1]	-----	0.66[1]	-----	0.41[3]	0.91[1]	-0.60[1]	0.78[1]	-----	-----
Be					-----	0.38[3]	0.66[1]	-----	-----	0.62[2]	-----	0.59[1]	0.57[1]	-----	0.94[1]	0.41[3]	0.77[1]	0.50[2]	0.75[1]	-----	-----	-----	0.63[1]	0.52[2]	-----
Ca						-----	-----	-----	-----	-----	-----	0.40[3]	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Cd							-----	0.59[1]	0.85[1]	-----	0.66[1]	-----	-----	-----	0.45[2]	-0.38[3]	0.62[1]	-----	-----	-----	-----	0.39[3]	-----	0.96[1]	0.54[2]
Co								-0.40[3]	-----	-----	-----	-----	-----	-----	0.57[1]	-----	0.46[2]	-----	0.50[2]	-----	-----	-----	-----	-----	-----
Cr									0.75[1]	-----	0.63[1]	-0.54[2]	-----	-----	-----	-0.41[3]	-----	-0.42[3]	-----	-----	-----	-----	-----	0.53[2]	0.85[1]
Cu										-----	0.85[1]	-----	-----	-----	-----	-----	0.52[2]	-----	-----	-----	-----	-----	-----	0.83[1]	0.55[2]
Fe											-----	0.83[1]	0.89[1]	0.59[1]	0.60[1]	0.91[1]	0.51[2]	0.68[1]	0.54[1]	0.60[1]	0.83[1]	-0.67[1]	0.90[1]	-----	-----
Pb												-0.47[2]	-----	-----	-----	-0.45[2]	-----	-----	-----	-----	-----	-----	-----	0.64[1]	0.56[1]
Li													0.92[1]	0.51[2]	0.56[1]	0.90[1]	0.48[2]	0.66[1]	0.69[1]	0.49[2]	0.78[1]	-0.70[1]	0.93[1]	-----	-0.51[2]
Mg														0.63[1]	0.58[1]	0.95[1]	0.56[1]	0.70[1]	0.73[1]	0.54[2]	0.87[1]	-0.71[1]	0.95[1]	-----	-----
Mn															-----	0.66[1]	-----	0.42[2]	-----	-----	0.61[1]	-0.41[3]	0.54[1]	-----	-----
Ni																0.40[3]	0.77[1]	0.45[2]	0.77[1]	0.44[2]	-----	-----	0.64[1]	0.59[1]	-----
K																	-----	0.70[1]	0.52[2]	0.48[2]	0.93[1]	-0.76[1]	0.91[1]	-----	-0.41[2]
P																		-----	0.83[1]	0.55[1]	-----	-----	0.65[1]	0.76[1]	-----
Si																			0.39[3]	-----	0.73[1]	-0.51[2]	0.69[1]	-----	-----
Na																				0.54[1]	0.41[3]	-----	0.76[1]	0.43[3]	-----
Sr																					0.42[3]	-0.43[3]	0.64[1]	-----	-----
Ti																						-0.73[1]	0.85[1]	-----	-----
W																							-0.69[1]	-----	-----
V																								-----	-----
Zn																									0.51[2]

Al = aluminum, As = arsenic, B = boron, Ba = barium, Be = beryllium Ca = calcium, Cd = cadmium, Co = cobalt, Cr = chromium, Cu = copper, Fe = iron, Pb = lead, Li = lithium, Mg = magnesium, Mn = manganese, Ni = nickel, K = potassium, P = phosphorus, Si = silicon, Ti = titanium, W = tungsten, V = vanadium, Zn = zinc, Hg = mercury.

[1] $P \leq 0.01$

[2] $P \leq 0.05$

[3] $P \leq 0.10$

P = 0.068), manganese (r = 0.77, P = 0.027), and vanadium (r = 0.72, P = 0.046). Thirteen surface sediment metals had low to moderate but significant correlations (P < 0.10) with as many as 14 sediment PAH concentrations (Table 16).

DISCUSSION

Previous studies have indicated that, regardless of the method of administration, PAHs are initially taken up by the liver and kidney and quickly metabolized to hydrophilic metabolites that can be excreted via the bile and urine (Zedeck 1980). Therefore, it is not surprising that few PAH parent compounds were detected in muskrat carcasses. Six different PAH's were detected in muskrats from the lower region of the Elizabeth River whereas three and four of these PAH's were detected in muskrats from the upper region of the Elizabeth River and Nansemond River, respectively. The current study is the only known study to examine the effects of contaminants in the Elizabeth River on a mammalian species. Hargis et al. (1984) reported penetrating integumental lesions, severe fin and gill erosion, reduced hematocrits, and no weight gain in fish raised in an aquarium containing Elizabeth River sediments. This sediment was collected from the same section where the greatest PAH concentrations have been reported (see below). Huggett (1986) reported increases in fin erosion and cataracts in fish and a decrease in fish biomass in the region of the river with the greatest PAH concentrations. In this same study the bioavailability of PAHs was evident by the accumulation of these compounds in transplanted oysters. The greatest concentration (27 ppm total resolved aromatics) was reported in oysters located near the only operational wood preserving (creosote) plant on the river. Creosote contains numerous PAHs (Lu 1982).

^{32}P-postlabeling analysis of DNA adducts is a technique that has recently developed in studies of carcinogenesis and is being studied as a biological marker of exposure to certain environmental contaminants (Gupta et al. 1982, Dunn et al. 1987, Dunn and San 1988). This

Table 16. Significant Pearson's correlation coefficients (r) between metal and polynuclear aromatic hydrocarbon (PAH) concentrations detected in surface sediment samples from the Elizabeth (N = 15) and Nansemond (N = 5) Rivers Virginia, 1988.

	Metals												
PAH	Al	Cd	Cr	Cu	Fe	K	W	Li	Mg	Pb	V	Zn	Hg
Naphthalene	-0.41[3]	0.53[2]	0.56[2]	----	----	-0.41[3]	0.61[1]	-0.45[2]	----	----	-0.39[3]	0.39[3]	0.64[1]
Fluorene	-0.44[3]	0.59[1]	0.61[1]	0.45[2]	----	-0.44[2]	0.62[1]	-0.49[2]	----	0.44[3]	-0.40[3]	0.44[3]	0.67[1]
Phenanthrene	-0.53[1]	0.68[1]	0.71[1]	0.62[1]	-0.40[3]	-0.53[2]	0.61[1]	-0.59[1]	-0.43[3]	0.67[1]	-0.46[2]	0.54[2]	0.73[1]
Anthracene	-0.45[2]	0.66[1]	0.70[1]	0.55[2]	----	-0.44[2]	0.60[1]	-0.50[2]	----	0.49[2]	-0.39[3]	0.52[2]	0.69[1]
Fluoranthrene	-0.52[2]	0.71[1]	0.77[1]	0.65[1]	-0.39[3]	-0.51[2]	0.58[1]	-0.58[1]	-0.40[3]	0.64[1]	-0.43[3]	0.58[1]	0.75[1]
Pyrene	-0.51[2]	0.70[1]	0.75[1]	0.62[1]	-0.38[3]	-0.50[2]	0.59[1]	-0.57[1]	-0.40[3]	0.61[1]	-0.44[3]	0.56[2]	0.74[1]
1,2-benzanthracene	-0.51[2]	0.69[1]	0.76[1]	0.62[1]	-0.38[3]	-0.50[2]	0.58[1]	-0.57[1]	-0.39[3]	0.59[1]	-0.44[3]	0.56[2]	0.76[1]
Chrysene	-0.47[2]	0.72[1]	0.78[1]	0.66[1]	----	-0.45[2]	0.56[2]	-0.52[2]	----	0.55[2]	----	0.59[1]	0.71[1]
Benzo(b)fluoranthrene	-0.51[2]	0.71[1]	0.77[1]	0.65[1]	-0.38[3]	-0.50[2]	0.58[1]	-0.57[1]	-0.39[3]	0.62[1]	-0.43[3]	0.58[1]	0.75[1]
Benzo(k)fluoranthrene	-0.53[2]	0.76[1]	0.79[1]	0.74[1]	-0.40[3]	-0.52[2]	0.55[2]	-0.58[1]	-0.40[3]	0.72[1]	-0.42[3]	0.63[1]	0.73[1]
Benzo(e)pyrene	-0.50[2]	0.69[1]	0.77[1]	0.60[1]	----	-0.49[2]	0.57[1]	-0.56[2]	-0.38[3]	0.56[1]	-0.43[3]	0.55[2]	0.76[1]
Benzo(a)pyrene	-0.51[2]	0.73[1]	0.79[1]	0.67[1]	-0.38[3]	-0.50[2]	0.57[1]	-0.57[1]	-0.38[3]	0.63[1]	-0.42[3]	0.59[1]	0.75[1]
1,2,5,6-dibenzanthracene	-0.51[2]	0.73[1]	0.79[1]	0.67[1]	-0.37[3]	-0.49[2]	0.57[1]	-0.56[1]	-0.38[3]	0.62[1]	-0.41[3]	0.59[1]	0.75[1]
Benzo(g,h,i)perylene	-0.51[2]	0.69[1]	0.71[1]	0.62[1]	-0.38[3]	-0.51[2]	0.62[1]	-0.57[1]	-0.41[3]	0.63[1]	-0.44[3]	0.55[2]	0.72[1]

Al = aluminum, Cd = cadmium, Cu = copper, Fe = iron, K = potassium, Mg = magnesium, Pb = lead, V = vanadium, Zn = zinc Hg = mercury.
[1] $P < 0.01$
[2] $P < 0.05$
[3] $P < 0.10$

technique was used in the current study in attempts to detect differences in DNA adduct levels in muskrat liver tissue among regions. This is the first known study utilizing this technique to detect differences in DNA adducts *in situ* in a wild terrestrial (semi-aquatic) mammalian species and the first time that muskrats have been used in ^{32}P-postlabeling analysis. Original unsuccessful attempts to detect DNA adducts are thought to have resulted from excessive time between death of the muskrats and freezing of the liver samples used in this analysis and to a lesser extent from maintaining the tissues at -20^{o}C rather than -80^{o}C. Our initial results (failure to find adducts) were confirmed by an independent laboratory (College of Pharmacy, Rutgers University, Piscataway, New Jersey). Analyses of an additional 18 liver samples collected and immediately frozen at -80^{o}C indicated the presence of DNA adducts but statistical analysis (Wilcoxon) was not able to detect differences between regions. Few studies using ^{32}P-Postlabeling techniques to detect differences in DNA adduct concentrations in wild populations have been reported. Dunn et al. (1987) reported differences in the concentrations of DNA adducts detected in fish (brown bullheads, *Ictalurus nebulosus*) from polluted rivers compared to control specimens raised in clean aquariums. Attempts are currently underway to detect differences between polluted and nonpolluted (less polluted) rivers. Initial results have indicated a difference in DNA adduct concentrations in fish from rivers with varying degrees of pollution but not in marine mammals (beluga whales *Delphinapterus leucas* and harbor seals *Phoca vitulina*) (Dr. Bruce Dunn, Environmental Carcinogenesis Unit, British Columbia Cancer Research Center, British Columbia, Canada, personal communication). From the results of the current study and the initial results indicated for marine mammals, it appears that the differences in exposure to PAHs must be quite large before differences in DNA adduct concentrations can be detected.

Although ^{32}P-Postlabeling analysis of DNA adducts was not able to detect differences in exposure between muskrats from the lower region of the Elizabeth and those from the Nansemond River, pentobarbital sleeping times (used as a biomarker of hepatic microsomal enzyme induction) were significantly different among study regions. Pentobarbital sleeping times were significantly reduced in muskrats captured from the lower region of the Elizabeth River compared to those captured from the upper region of the Elizabeth River or the Nansemond River. Laboratory

studies indicate that barbiturate-induced sleeping time is a reliable and sensitive measure of change in hepatic microsomal enzyme activity resulting from exposure to a variety of hepatotoxins, anticholinesterases, chlorinated hydrocarbon insecticides, and polychlorinated biphenyls (Halbrook and Kirkpatrick 1990). Laboratory studies also have demonstrated that PAHs are inducers of microsomal enzymes (Conney 1982). However, the specific P450 enzymes induced by PAHs (3-methylcholanthrene (3-MC) type inducers) appear to be different from those induced by organochlorines (phenobarbital (PB) type inducers). Studies by Conney (1986) and Elangbam et al. (1989) indicate that exposure to benzo(a)pyrene (3-MC type inducer) results in the induction of cytochrome P450c, whereas hexobarbital (PB type inducer) results in the induction of cytochromes P450b and P450e. This knowledge has resulted in the use of compounds other than barbiturates to indicate exposure to 3-MC type inducers. No studies were found that indicate whether mixtures of PAHs or increased concentrations of PAHs would result in induction of a greater variety of P450 isozymes, nor were studies found of barbiturate induced sleeping times in PAH treated animals. The low number of OC compounds (PB type inducers) detected in surface sediment samples or muskrats from the lower region of the Elizabeth River and the decreased pentobarbital sleeping time would initially seem contradictory. However, the classification of xenobiotics as PB type inducers or 3-MC type inducers is a generalized attempt to organize these compounds. Several studies have indicated that there may be as many as 20 different forms of P450 isozymes and that metabolic action may involve the simultaneous induction of one or more of these isozymes (Madhukar and Matsumura 1979, Guengerich 1988, 1989). Studies also have indicated that although PAHs are classified as 3-MC type inducers and OCs are typically classified as PB type inducers, there can be overlapping induction, but to a lesser extent, between these general classifications (Gulyaeva 1985, Mitchell et al. 1987, Guengerich 1988, Gonzalez 1989). In addition, other microsomal biotransformation enzymes also can be induced. Microsomal UDP-glucuronosyltransferases and epoxide hydrolase are induced by phenobarbital, 3-methylcholanthrene, and related compounds (Sipes and Gandolfi 1986). Schlede et al. (1970) reported increased secretions of ^{3}H-labeled benzo(a)pyrene metabolites in bile of rats treated with labeled benzo(a)pyrene following pretreatment with benzo(a)pyrene or phenobarbitone. These

authors suggested that the two inducers operated by different mechanisms, benzo(a)pyrene by enhancing hydroxylation and phenobarbitone by enhancing conjugation. The decreased sleeping times observed in muskrats from the lower region of the Elizabeth River indicates that induction has occurred; however, the mechanism involved in that induction is unknown. The greater concentration of PAHs found in surface sediments and muskrats of this region are the most likely suspect in the absence of other known inducing agents.

Surface sediments from the lower region of the Elizabeth River had greater mean concentrations of 14 polynuclear aromatic hydrocarbons compared to surface sediments collected from the upper region of the Elizabeth River or Nansemond River. Finding significantly greater sediment PAH concentrations in the lower region of the Elizabeth River is consistent with previous studies. Lu (1982) reported high PAH concentrations in a single sediment core collected from the Elizabeth River in the vicinity of the site where the highest sediment PAH concentrations were detected in the current study. Both collections were from a section of the river where documented creosote spills have occurred (Lu 1982). Increasing concentrations of PAHs have been reported in surface sediments as one moves upstream from the mouth of the river with the greatest concentrations near abandoned wood treatment plants that used creosote (Bieri et al. 1984, Huggett 1986). The muskrat whose carcass had the highest concentration of a PAH compound (0.15 ppm phenanthrene) was trapped in the lower region of the Elizabeth River on the opposite side of the river from an operating creosote plant. The muskrat with the greatest number of different PAH compounds detected (4) was trapped in the same section of the lower region of the Elizabeth River with the greatest concentration of sediment PAHs (near abandoned wood preserving plant). It is apparent that PAHs are being assimilated by the muskrats studied and additional analyses to detect metabolites of specific PAHs would be helpful in clarifying the extent of exposure.

Of the 9 metals significantly different among study regions, aluminum, cadmium, copper, nickel, and zinc mean concentrations were greatest in kidneys of muskrats collected from the lower region of the Elizabeth River. Mean lead and molybdenum concentration was highest in the lower region of the Elizabeth River, although not significantly different from the mean lead concentration detected in the upper region of the Elizabeth River. Few studies investigating the accumulation of

metals in muskrats have been reported. Everett and Anthony (1976) reported a high of 1.071 ppm cadmium in kidneys of muskrats from one study site in southeastern Pennsylvania. Erickson and Lindzey (1983) reported a high of 0.157 ppm cadmium and 4.25 ppm lead in kidneys of muskrats from Tinicum National Environmental Center, Pennsylvania. Mean cadmium concentration detected in kidneys from muskrats collected in the lower region of the Elizabeth River (3.08 ppm) was higher than the concentrations reported above, whereas the mean cadmium concentrations detected in muskrats from the upper region of the Elizabeth River (0.44 ppm) and Nansemond River (0.08 ppm) were lower. The muskrat kidney lead concentration reported by Erickson and Lindzey (1983) is higher than the mean concentrations detected in muskrats from any region in the current study. No evidence of overt toxicity was reported by Everett and Anthony (1976) or Erickson and Lindzey (1983) and no evidence was detected in the current study, with the possible exception of necrotic lesions in the livers of two muskrats from the Elizabeth River (see Chapter 2). The metal concentrations reported for Pennsylvania muskrats and those detected in muskrats from the current study are not thought to be sufficient to cause overt toxicity (Goyer 1986).

In summary, the concentrations of PAHs and toxic metals detected in the surface sediments and muskrats from the lower region of the Elizabeth River indicate that the quality of the environment in this region is diminished compared to that in the upper region of the Elizabeth River or Nansemond River. Overt signs of toxicity in muskrats were absent, although necrotic lesions noted in the liver of two muskrats are suspect. ^{32}P-Postlabeling analysis was unable to detect differences in muskrat DNA adduct levels between muskrats from the lower region of the Elizabeth River and those from the Nansemond River. However, pentobarbital was metabolized more rapidly in muskrats from the lower region of the Elizabeth River than in muskrats from the upper region of the Elizabeth River or Nansemond River as indicated by reduced sleeping times. This indicates an increased induction of metabolizing enzymes in lower region Elizabeth River muskrats thought to be the caused by increased exposure to environmental contaminants (PAHs). The influence these contaminants might have on muskrats in this region is questionable and is discussed further in Chapters 2 and 3.

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CHAPTER 2: PHYSIOLOGICAL CHARACTERISTICS

INTRODUCTION

The effects of environmental contaminants on biological systems can be observed along a gradient from micro to macro in scale. At the micro end of this scale are changes in molecular interactions, changes in cellular production, and organelle or cellular damage. Depending on the toxicant and the degree of exposure, these effects can result in functional change or cell death that can affect organ or system function. Because of the lack of techniques that are sensitive enough to detect subtle changes, the effects of contaminants at the micro level can go unreported, leading to a false interpretation of no effects. At the macro end of the scale are changes in population or community structure. Changes in reproduction or differences in mortality among sex and/or age classes can be observed responses to exposure to environmental contaminants. These changes can occur in the absence of overt signs of toxicity. Because most studies are short term, changes at the macro level may go unnoticed due to subtle changes that occur over several years or generations.

Studies of the effects of exposure to environmental contaminants should include investigations at both ends of the scale of possible effects. Hopefully, investigations at both ends of the scale will complement each other, although observed effects at only one end can occur without observed effects at the other. This chapter deals with physiological characteristics that can be affected by environmental contaminants and are located at the lower end of the scale of possible effects.

METHODS

Physiological data were obtained from sixty-five muskrats live trapped from two regions in the Elizabeth River and one region in the Nansemond River during December 1986 - January 1987 and December 1987 - February 1988. These muskrats were transported to a research trailer for sleeping time analysis (see Chapter 1) and data collection. Upon awakening muskrats were euthanized with 60 mg (1 cc im) of pentobarbital and standard measurements (weight, total length, tail length, hindfoot length, and ear length) were recorded. A longitudinal incision was made from the sternum to the urethral opening and blood samples were collected in vacutainers from the inferior vena cava. Blood samples consisted of one 5 ml clot tube for serum analysis and one 5 ml tube containing ethylenediamine tetraacetate (EDTA) anticoagulant for hematological analysis. Blood samples were refrigerated and transported to Chesapeake County Hospital, Chesapeake, Virginia where blood analyses were performed. Muskrats were skinned and carcass weight (skinned weight) determined. During necropsy, liver and kidneys were towel dried and weighed. Prior to removal of kidneys, a subjective determination of adrenal fat (fat index, FI) was made using the amount of fat surrounding the adrenals (low (1) = thin line of fat between adrenal and kidney, medium (2) = obvious fat deposit between adrenal and kidney, and heavy (3) = adrenal partially enclosed in fat). Sections of liver and kidney were placed in 10% formalin for histological study and the remaining liver and kidney tissues were saved for contaminant study (see Chapter 1). Muskrats were then frozen and transported to the laboratory.

In the laboratory, carcasses were thawed and the spleen and adrenals were removed. Spleens were towel dried and weighed and adrenals were placed in 10% formalin and subsequently weighed following removal of attached fat tissue. Hematoxylin and eosin stained slides were prepared from formalin fixed liver and kidney tissue following standard protocols at the Virginia-Maryland Regional College of Veterinary Medicine, Blacksburg, Virginia. Additional slides using Brown-Hopps modified Gram stain and Ziehl-Neelsen acid-fast stain were prepared from liver

samples with necrotic lesions. PAS (para-aminosalicylic acid) and PAS-glycogen digested slides were prepared to confirm glycogen storage observed in hepatocytes.

In addition to muskrats trapped by me or employed technicians, 213 muskrat carcasses from the upper region of the Elizabeth River (193) and the Nansemond River (20) were obtained from cooperative trappers during legal muskrat trapping seasons of 1986 - 1987 and 1987 - 1988 (December - February both seasons). Carcasses obtained from cooperative trappers were frozen until necropsies could be performed. During necropsy, carcass, liver, kidney, and spleen weights and total, tail, and hindfoot lengths were recorded. Adrenals were placed in 10% formalin and subsequently weighed following removal of fat. Adrenal fat was evaluated as described above.

SAS computer software (SAS Institute Inc., 1985) was used for statistical analysis. All variables were checked for normal distributions using PROC UNIVARIATE (Shapiro-Wilk's) procedures. Means of variables that exhibited a normal distribution were compared among regions using ANOVA (General Linear Model (GLM)) procedures. Duncan's and Bonferroni's multiple comparison tests were used to separate means of variables found to be significantly different by the ANOVA. Variables that did not exhibit normal distributions were either transformed and compared using ANOVA procedures (if transformations resulted in normal distributions) or compared among regions using Kruskal-Wallis nonparametric analysis (PROC NPAR1WAY). All ANOVA procedures (when appropriate) included analysis of main effects for location, sex, and age and all interactions of these variables. Correlations between variables were obtained using Pearson's procedures (PROC CORR). If normality or interactions are not mentioned it should be assumed that the distributions were normal and/or that the statistical results were nonsignificant.

RESULTS

ANOVA results indicated that carcass, liver, spleen, and adrenal weights and tail and ear lengths were significantly different ($P<0.05$) among regions (Table 17). A region by age by sex interaction was indicated for carcass weights and a region by sex interaction was indicated for tail length. A plot of carcass weights indicated that the carcass weights of immature males and females from the lower region of the Elizabeth River were both less than the carcass weights of immature males or females in either of the other two regions with the exception of immature males in the Nansemond River. The carcass weights of adult males and females from the lower region of the Elizabeth River were both less than the carcass weights of adult males or females from either of the other two regions. Because sample sizes were greatly reduced when carcass weights were divided by region, sex, and age (resulted in three groups with ≤ 6 observations) and since no region by sex, region by age, or sex by age interactions were indicated, the differences in location are thought to be valid. A plot of tail lengths for region by sex did indicate an interaction; therefore, tests on the main effects were inappropriate. Mean carcass, spleen, and ear measurements were significantly less in muskrats collected from the lower region of the Elizabeth River. Adrenal weights were significantly lighter ($P = 0.004$) in upper region Elizabeth River muskrats than in lower region Elizabeth River or Nansemond River muskrats. Liver weights were significantly heavier ($P = 0.012$) in Nansemond River muskrats than in lower or upper region Elizabeth River muskrats. When organ weights were analyzed on a relative basis (organ weight/carcass weight), relative spleen weights remained significantly lighter ($P < 0.001$) and relative adrenal weights were significantly heavier ($P < 0.001$) in muskrats from the lower region of the Elizabeth River than in muskrats from the upper region of the Elizabeth River or Nansemond River. Relative liver weights were significantly heavier ($P = 0.015$) in Nansemond River muskrats than in upper region Elizabeth River muskrats but not significantly different between Nansemond River muskrats and lower region Elizabeth River muskrats.

Table 17. Comparison of body and organ measurements of muskrats trapped from the Elizabeth and Nansemond Rivers, Va. 1986 - 1988.

Measurement	Elizabeth River		Nansemond River	ANOVA
	Lower Region $\bar{X} \pm SE$	Upper Region $\bar{X} \pm SE$	$\bar{X} \pm SE$	P
Body weight (g)	950 ± 36.3 (N = 20) 950 ± 36.3 (N = 20)[a]	1037 ± 26.9 (N = 19) 1033 ± 13.0 (N = 209)[b]	1068 ± 41.1 (N = 26) 1154 ± 29.8 (N = 49)[c]	0.242 0.006[1]
Carcass weight (g)	768 ± 27.0 (N = 20)[a]	840 ± 11.3 (N = 209)[b]	944 ± 26.0 (N = 49)[c]	0.009
Total length (mm)	583 ± 7.6 (N = 20)	573 ± 4.5 (109)	582 ± 6.2 (N = 44)	0.548
Tail length (mm)	254 ± 3.9 (N = 19)[a]	263 ± 2.4 (N = 107)[a]	261 ± 3.7 (N = 44)[a]	0.017
Hind-foot length (mm)	80.5 ± 0.63 (N = 20)	79.5 ± 0.6 (37)	80.5 ± 0.52 (N = 46)	0.490
Ear length (mm)	20.2 ± 0.3 (N = 20)[a]	21.6 ± 0.4 (N = 19)[b]	21.9 ± 0.3 (N = 26)[b]	0.004
Liver weight (g)	29.3 ± 2.4 (N = 20)[a]	29.6 ± 6.1 (N = 209)[a]	37.6 ± 1.7 (N = 49)[b]	0.012
Kidney weight[2] (g)	2.86 ± 0.13 (N = 20)	2.90 ± 0.06 (N = 209)	3.47 ± 0.13 (N = 49)	0.107
Adrenal weight[2] (g)	0.102 ± 0.009 (N = 20)[a]	0.079 ± 0.002 (N = 200)[b]	0.096 ± 0.005 (N = 49)[a]	0.004
Spleen weight (g)	0.37 ± 0.03 (N = 20)[a]	0.64 ± 0.02 (N = 209)[b]	0.67 ± 0.05 (N = 49)[b]	< 0.001

[1]Analysis based on estimated body weights using regression equation $y = 66.9 + 1.15x$ (y = body weight, x = carcass weight).
[2]Average.
[a,b,c] Row means with different superscripts are significantly different (Duncan $P \leq 0.05$).

Using only data from live trapped muskrats, sample sizes were too small to detect significant differences in mean total weight among regions (65 total observations, $P = 0.242$). However, a trend towards lighter total weights in lower region Elizabeth River muskrats was indicated (Table 17). Carcass weights also were not significantly different among regions if only these 65 observations are used in ANOVA analysis. If the carcass weights of 213 muskrats obtained from cooperative trappers are included in the ANOVA analysis, the results indicate a significant difference in carcass weights among regions (as indicated above). Because total weights were correlated with carcass weights (see below) and because a trend towards lighter total weights was indicated for lower region Elizabeth River muskrats, regression analysis was used to increase the sample size of total weight observations. Regression analysis (using total and carcass weight data from 65 muskrats) indicated that the equation $Y = 66.9 + 1.15X$ was a good model for estimating total weights if carcass weights were know ($R^2 = 0.92$). Using this equation, it was possible to increase the sample size for total weight from 65 to 278. As expected, results of ANOVA analysis using these 278 observations indicated a significant difference ($P = 0.006$) in mean total weight among regions with lower region Elizabeth River muskrats having the lightest mean weight (Table 17).

No significant differences ($P<0.05$) in any body or organ measurements were detected among sexes. Significant differences ($P<0.05$) among ages were indicated for all measurements. When body and organ measurements were analyzed by age class, spleen weights ($P = 0.044$) and ear lengths ($P = 0.05$) were the only measurements significantly different among regions for the juvenile age class. Juvenile muskrats from the lower region of the Elizabeth River had a lower mean spleen weight than muskrats from the other two regions. Ear lengths of juvenile muskrats from the lower region of the Elizabeth River were less than the ear lengths of juvenile muskrats from the Nansemond River but not different in length from the upper region Elizabeth River juvenile muskrats. Results from analyses of adults were similar to results obtained from analyses using all age classes with the exception of adrenal weights and ear lengths. Adrenal weights were still significantly different ($P = 0.004$); however, Duncan's multiple comparison test indicated that there was only a difference between lower region Elizabeth River and upper region Elizabeth River muskrats. Adult ear lengths were significantly different ($P = 0.03$) between lower region Elizabeth

River and Nansemond River muskrats but not lower region and upper region Elizabeth River muskrats.

Mean, minimum, maximum, and median value for muskrat body and organ measurements are given in Table 18. Total body and carcass weights were the only measurements with significant ($P < 0.001$) and high ($r = .99$) Pearson's correlation coefficient. However, 96% of the correlation coefficients between body and/or organ measurements were significant ($P < 0.05$) with moderate ($50 < r < 90$, 44%) or low ($r < 50$, 51%) r values (Table 19).

Twenty-one blood variables had moderate to extreme outlying observations (Table 20). Shapiro-Wilk's analysis indicated that 13 blood variables had distributions that were not normal. Log transformations of these 13 variables resulted in 5 variables with normal distributions and 8 variables whose distributions remained non-normal. Results of nonparametric (Kruskal-Wallis) analyses indicated that the variables with non-normal distributions were not significantly different ($P<0.05$) among regions. The variables with normal distributions were analyzed using ANOVA procedures.

ANOVA results indicated that the blood variables glucose, alkaline phosphatase, mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) were significantly different among regions (Table 21). Mean glucose concentration was significantly greater ($P = 0.044$) in lower region Elizabeth River muskrats than in upper Elizabeth River or Nansemond River muskrats. A significant ($P<0.001$) region by age interaction was indicated for alkaline phosphatase. A plot of alkaline phosphatase region by age means indicated an orderly interaction; therefore, tests on the main effects were appropriate. Mean alkaline phosphatase was significantly ($P<0.001$) greater in Nansemond River muskrats than in lower or upper region Elizabeth River muskrats. Mean corpuscular hemoglobin ($P = 0.017$) and mean corpuscular hemoglobin concentration ($P = 0.038$) were greater in muskrats from the Nansemond River than in muskrats from the upper region of the Elizabeth River but not in muskrats from the lower region Elizabeth River. Differences between ages also were found in alkaline phosphatase ($P<0.001$, immature mean = 940 µl adult mean = 579 µl), bilirubin ($P = 0.004$, immature mean = 0.66 mg/dl adult mean = 0.54 mg/dl), hematocrit ($P = 0.006$, immature mean = 57% adult mean =

Table 18. Mean, minimum, maximum, and median values of body and organ measurements of muskrats from the Elizabeth and Nansemond Rivers, Va. during winter 1986 - 1988.

	Elizabeth River										Nansemond River				
	Lower Region					Upper Region									
Measurement	N	Mean	Min	Max	Med	N	Mean	Min	Max	Med	N	Mean	Min	Max	Med
Body weight (g)	20	950	760	1320	905	19	1037	775	1315	1030	26	1068	665	1460	1098
Carcass weight (g)	20	769	617	1095	741	209	840	387	1204	837	49	944	529	1239	1005
Total length (mm)	20	583	523	640	584	109	573	455	670	44	582	582	470	696	580
Tail length (mm)	19	254	222	283	256	107	263	215	315	263	44	261	215	313	264
Hind-Foot length (mm)	20	80.5	76	85	81	37	79.5	71	86	80	46	80.5	71	88	80
Ear length (mm)	20	20.2	17	23	20	19	21.6	17	23	22	26	21.9	19	25	22
Liver weight (g)	20	29.28	21.4	69.2	27.4	209	29.64	12.5	65.4	28.3	49	37.56	18.0	66.1	37.5
Kidney weight[1] (g)	20	2.86	2.0	4.0	2.8	209	2.90	0.9	6.0	2.8	49	3.47	1.6	5.5	3.6
Adrenal weight[1] (g)	20	0.102	0.05	0.19	0.09	200	0.079	0.02	0.17	0.08	49	0.096	0.04	0.21	0.09
Spleen weight (g)	20	0.371	0.09	0.65	0.38	209	0.642	0.18	1.94	0.56	49	0.665	0.21	2.15	0.63

[1]Average

Table 19. Significant Pearson's correlation coefficients (r) between body and organ measurements from muskrats (N = 278) trapped in the Elizabeth and Nansemond Rivers, Va. 1986 - 1988.

	Total Length	Tail Length	Hind-foot Length	Ear Length	Carcass Weight	Adrenal Weight	Liver Weight	Kidney Weight	Spleen Weight
Body weight	0.61	0.69	0.45	0.52	0.99	0.53	0.75	0.72	0.45
Total length		0.74	0.49	-----	0.61	0.56	0.38	0.45	0.27
Tail length			0.49	0.25[1]	0.69	0.43	0.50	0.47	0.42
Hind-foot length				0.43	0.45	0.57	0.26[1]	0.45	-----
Ear length					0.55	0.44	0.41	0.53	0.43
Carcass weight						0.53	0.76	0.73	0.45
Adrenal weight							0.46	0.66	0.15[1]
Liver weight								0.72	0.42
Kidney weight									0.29

[1]P-value for coefficients with a superscript 1 is < 0.05, for all other coefficients $P < 0.001$.

Table 20. Mean, minimum, maximum, and median values of blood variables measured in muskrats from the Elizabeth and Nansemond Rivers, Va. during winter 1986 - 1988.

	Elizabeth River											
	Lower Region (N = 20)				Upper Region (N = 19)				Nansemond River (N = 25)			
Measurement	Mean	Min	Max	Med	Mean	Min	Max	Med	Mean	Min	Max	Med
Sodium (meq/l)	145.20	141	156	145	144.78	135	151	145	143.64	139	150	144
Potassium (meq/l)	4.41	3.3	5.8	4.4	4.73	3.7	6.1	4.7	5.06	3.2	11.6°	4.5
Chlorides (meq/l)	93.65	83	100	93	91.11	82	97	90.5	88.08	9*	100	93
Glucose (mg/dl)	119.75	38	240	117	85.44	44	135	82.5	85.56	3	176	90
BUN[1] (mg/dl)	26.70	4	64	22	35.50	12	67	34.5	32.84	10	59	32
Creatinine (mg/dl)	1.19	1	1.4	1.2	1.12	0.8	1.7°	1.0	1.16	0.8°	1.6°	1.2
SGOT[2] (u/l)	429.30	124	805	450	376.16	207	630	333	472.24	169	999°	423
Alk phos[3] (u/l)	585.95	245	965	602	615.00	200	1093	593	892.24	253	2125	795
Bilirubin (mg/dl)	0.59	0.4	1.0	0.5	0.54	0.2*	0.9	0.5	0.61	0.3	0.9	0.6
Uric acid (mg/dl)	1.56	0.8	2.4	1.5	1.48	0.9	3.0°	1.3	1.68	0.8	5.4*	1.5
Calcium (mg/dl)	9.65	8.3	10.8	9.6	9.38	7.2°	10.8	9.4	9.12	7.8	11.5°	9.1
Inorg phos[4] (mg/dl)	8.24	3.9	17°	8.3	7.85	5.4	12.9	7.2	13.02	4.8	99.9*	8.6
Total protein (mg/dl)	5.80	4.6	6.9	5.9	5.62	5.0	6.7	5.5	5.58	4.8	6.9°	5.5
Albumin (mg/dl)	3.60	2.6°	4.1	3.7	3.60	3.0	4.2	3.6	3.57	3.0	4.4	3.5
Cholesterol (mg/dl)	36.45	16	76	34	32.74	13	70	29	39.72	14	72°	39
SGET[5] (u/l)	177.45	99	355°	160	161.05	109	405*	155	189.16	114	440*	164
WBC (× 10^4)	14.03	8.7	23°	13.5	12.86	5.5	21.5	12.3	13.94	8.8	19.8	14.2
RBC (× 10^6)	6.59	5.6	7.5	6.6	6.57	5.6	7.8°	6.6	6.31	5.5	7.8°	6.2
Hemoglobin (mg)	18.63	15.7	20.8	18.9	18.06	16.3	21.0°	17.9	18.28	16.2	20.8	18.3
Hematocrit (%)	56.54	48.7	62.3	57.4	55.98	48.4	65.7°	55.3	55.19	48.6	64.8	55.4
MCV[6] (μ^3)	86.00	75°	96°	86	85.53	80	93	85	87.72	76°	94	87
MCH[7] ($\mu\mu g$)	28.21	25.8	31.5	28.1	27.45	24.9°	29.4°	27.4	29.13	22.7	33.2	29
MCHC[8] (%)	32.83	30.5	35.6	32.6	32.18	28.8°	34.4	32.1	33.19	29.9	37.0	32.9
Platelet count (× 10^3)	434.70	295	571	419	505.21	369	767°	485	457.60	188°	779°	4
Lymphocytes (%)	15.95	6	41°	15	18.06	4	40	17.5	16.36	2	91*	14

[1]Blood urea nitrogen. [2]Serum glutamic oxaloacetic transaminase. [3]Alkaline phosphatase. [4]Inorganic phosphorus. [5]Serum glutamic pyruvic transaminase. [6]Mean corpuscular volume. [7]Mean corpuscular hemoglobin. [8]Mean corpuscular hemoglobin concentration.

* Extreme observation (> 3 × interquartile range).

° Moderate outlying observation (1.5 × interquartile range < obs. < 3 × interquartile range).

55%), MCH ($P = 0.008$ immature mean = 27.6μμg adult mean = 28.8 μμg), MCHC ($P = 0.018$, immature mean = 32.3% adult mean = 33.1%), and RBC ($P = 0.005$, immature mean = 6.7×10^6 adult mean = 6.3×10^6). Cholesterol ($P = 0.019$, male mean = 33 mg/dl female mean = 41 mg/dl) and alkaline phosphatase ($P = 0.043$, male mean = 752 μl female mean = 666 μl) were the only blood variables significantly different ($P<0.05$) among sexes. Significant ($P < 0.10$) but moderate ($50 < r < 90$, 4%) or low ($r < 50$, 26%) Pearson's correlation coefficients were indicated between 30% of the blood variables (Table 22).

Liver and kidney tissues from 73 muskrats were examined microscopically using hematoxylin and eosin stained sections. Liver tissues from two muskrats, one from the lower and one from the upper region of the Elizabeth River had multifocal coagulative necrotic lesions and one muskrat from the lower region had multifocal granulomas (Figure 6 and 7). The coagulative necrosis observed in the two Elizabeth River muskrats is compatible with viral or toxicological exposure and the granuloma is compatible with bacterial exposure. Paraportal vascular mononuclear infiltration (primarily lymphocytes, monocytes, and plasma cells) was observed in liver tissue from 7 (25%) of the muskrats from the lower region of the Elizabeth River, 2 (11%) of the muskrats from the upper region of the Elizabeth River, and 3 (12%) of the Nansemond River muskrats (Figure 8). The paraportal vascular infiltrations observed would be compatible with antigenic exposure secondary to bacterial, viral, or parasitic disease. Brown-Hopps modified gram stain and Ziehl-Neelsen acid-fast stain failed to reveal any evidence of remarkable bacterial infection. Coccoid type bacteria were observed randomly dispersed in liver tissue but were not associated with observed necrotic lesions. These results suggest that sufficient time had elapsed since bacterial exposure for antigenic responses to remove the etiologic agents. The histological results suggest that the incidence of disease is more common in lower region Elizabeth River muskrats compared to upper region Elizabeth River or Nansemond River muskrats. In all livers having multifocal necrosis, less than 20% of the liver tissue examined was affected. In addition to the lesions noted above, parenchyma cell glycogen storage was evident in 13 (50%) of the muskrats from the Nansemond River, 10 (36%) of the muskrats from the lower region of the Elizabeth River, and 5 (26%) of the muskrats from the upper region of the Elizabeth River. These proportions were not significantly

Table 21. Comparison of blood variables measured in muskrats trapped from the Elizabeth and Nansemond Rivers, Va. during the winters of 1986 - 1988.

Measurement	Elizabeth River: Lower Region $\bar{X} \pm SE$ (N = 20)	Elizabeth River: Upper Region $\bar{X} \pm SE$ (N = 19)	Nansemond River $\bar{X} \pm SE$ (N = 25)	ANOVA P
Sodium (meq/l)	145.20 ± 0.76	144.78 ± 0.94	143.64 ± 0.57	0.424
Potassium (meq/l)	4.41 ± 0.17	4.73 ± 0.16	5.00 ± 0.38	0.354
Chlorides (meq/l)	93.65 ± 0.91	91.11 ± 0.94	88.68 ± 3.43	0.540
Glucose (mg/dl)	119.75 ± 11.67[a]	85.44 ± 6.71[b]	85.56 ± 8.55[b]	0.044
Blood urea nitrogen (mg/dl)	26.70 ± 3.46	35.50 ± 3.25	32.84 ± 2.40	0.169
Creatinine (mg/dl)	1.19 ± 0.03	1.12 ± 0.05	1.16 ± 0.03	0.638
SGOT[1] (μ/l)	429.30 ± 36.50	376.16 ± 31.88	472.24 ± 43.20	0.100
Alkaline phosphatase (μ/l)	585.95 ± 43.10[a]	615.00 ± 55.24[a]	892.24 ± 89.65[b]	< 0.001
Bilirubin (mg/dl)	0.59 ± 0.04	0.54 ± 0.04	0.61 ± 0.03	0.761
Uric acid (mg/dl)	1.56 ± 0.10	1.48 ± 0.12	1.68 ± 0.17	0.234
Calcium (mq/dl)	9.65 ± 0.16	9.38 ± 0.20	9.12 ± 0.16	0.175
Inorganic phosphorus (mq/dl)	8.24 ± 0.63	7.85 ± 0.50	13.02 ± 3.70	0.061
Total protein (mq/dl)	5.80 ± 0.13	5.62 ± 0.10	5.58 ± 0.10	0.413
Albumin (mg/dl)	3.60 ± 0.08	3.60 ± 0.07	3.57 ± 0.07	0.913
Cholesterol (mg/dl)	36.45 ± 3.37	32.74 ± 3.42	39.72 ± 2.65	0.082
SGPT[2] (μ/l)	177.45 ± 12.57	161.05 ± 15.58	189.16 ± 15.58	0.211
WBC (× 10^3)	14.03 ± 0.81	12.86 ± 0.80	13.94 ± 0.57	0.302
RBC (× 10^6)	6.59 ± 0.12	6.57 ± 0.12	6.13 ± 0.11	0.057
Hemoglobin (mg)	18.63 ± 0.31	18.06 ± 0.27	18.28 ± 0.23	0.326
Hematocrit (%)	56.54 ± 0.96	55.98 ± 0.99	55.19 ± 0.79	0.192
Mean corpuscular volume (μ^3)	86.00 ± 0.92	85.53 ± 0.69	87.72 ± 0.76	0.307
Mean corpuscular hemoglobin (μμg)	28.21 ± 0.36[ab]	27.45 ± 0.27[b]	29.13 ± 0.46[a]	< 0.017
MCHC[3] (%)	32.83 ± 0.30[ab]	32.18 ± 0.32[b]	33.19 ± 0.34[a]	0.038
Platelet count (× 10^4)	434.70 ± 18.44	505.21 ± 26.56	457.60 ± 24.09	0.254
Lymphocytes (%)	15.95 ± 1.83	18.06 ± 2.54	16.36 ± 3.27	0.322

[1]Serum glutamic oxaloacetic transaminase.
[2]Serum glutamic pyruvic transaminase.
[3]Mean corpuscular hemoglobin concentration.
Row means with different superscripts are significantly different (Duncan, $P \leq 0.05$).

Table 22. Significant[1] Pearson's correlation coefficients (r) between blood variables measured in muskrats from the Elizabeth and Nansemond Rivers, Virginia, winters 1986 - 1988.

	Blood Variables																							
Blood variable	K	CHL	GLU	BUM	CRE	SGO	ALP	BIL	URI	CA	INP	PRO	ALB	CHO	SGL	WBC	RBC	HGB	HEC	MCV	MCH	MCC	PLA	LYM
NA	-----	.39	-----	-----	-----	-----	-.28[3]	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
K		.50	-----	.28[3]	.43	.23[3]	-----	-----	.64	-----	.32[3]	.33	.33	-----	.36	.25[3]	.26[3]	.24[3]	.33	-----	-----	-----	-.23[3]	-----
CHL			-----	-----	-----	-----	-----	-----	-----	-----	-----	-.34	-.38	-----	-----	-----	-----	-----	-----	-----	-----	-----	.30[3]	-----
GLU				-.30[3]	.23[3]	-----	-----	-----	-----	.31[3]	-----	-----	-----	-----	-.23[3]	-----	-----	-----	-----	-----	-----	-----	-.23[3]	-----
BUN					-----	-----	-----	-----	.38	-----	-----	-----	.22[3]	-----	-----	-----	-----	.25[3]	.23[3]	-----	-----	-----	-----	-----
CRE						-----	-----	-----	.52	.28[2]	-----	.30[3]	.32[3]	.23[3]	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
SGO							.25[3]	-----	.29[3]	-----	-----	-----	.33	-----	.75	-----	-----	-----	-----	-----	-----	-----	-.26[3]	.28[3]
ALP								.25[3]	-----	-----	.47	-----	-----	.37	.25[3]	-----	-----	-----	-----	-----	-----	-----	-----	-----
BIL									-----	-----	-----	-----	.35	.25[3]	.27[3]	-----	.21[3]	.28[3]	.23[3]	-----	-----	-----	-.24[3]	-----
URI										-----	.29[3]	-----	-----	-----	.34	-----	-----	-----	-----	-----	-----	-----	-----	-----
CA											-----	.42	.37	.23[3]	-----	-----	-----	-----	-----	-----	-----	-.23[3]	-----	-----
INP												-----	-----	.28[3]	-----	-----	.32	-----	-----	.29[3]	-.33	-.23[3]	-----	-----
PRO													.75	.23[3]	-----	-----	.39	.46	.45	-----	-----	-----	-.21[3]	-----
ALB														.24[3]	.25[3]	-----	-----	.31[3]	.23[3]	-----	-----	-----	-.29[3]	.23[3]
CHO															-----	-----	.24[3]	-----	-----	-----	-.22[3]	-----	-----	-----
SGL																-----	-----	-----	-----	-----	-----	-----	-.29[3]	-----
WBC																	-.29[3]	-----	-----	-----	.26[3]	-----	-----	-----
RBC																		.63	.84	-.44	-.66	-.53	-----	-----
HGB																			.81	-----	-----	-----	-.32[2]	-----
HEC																				-----	-.30[2]	-.53	-.29	-----
MCV																					.73	-----	-----	-----
MCH																						.76	-----	-----
MCC																							-----	-----
PLA																								-----

NA = sodium, K = potassium, CHL = chlorides, GLU = glucose, BUN = blood urea nitrogen, CRE = creatinine, SGO = serum glutamic oxaloacetic transaminase, ALP = alkaline phosphatase, BIL = bilirubin, URI = uric acid, CA = calcium, INP = inorganic phosphorus, PRO = total protein, ALB = albumin, CHO = cholesterol, SGL = serum glutamic pyruvic transaminase, WBC = white blood cells, RBC = red blood cells, HGB = hemoglobin, HEC = hematocrit, MCV = mean corpuscular volume, MCH = mean corpuscular hemoglobin, MCC = mean corpuscular hemoglobin concentration, PLA = platelet count, LYM = lymphocytes.

[1] $P \leq 0.01$

[2] $P \leq 0.05$

[3] $P \leq 0.10$

different ($\chi^2 = 2.74$, $P = 0.254$). PAS (*para*-aminosalicylic acid) and PAS/glycogen digested stains confirmed the presence of glycogen in parenchymal cells. Binucleate cells and variations in nuclear size were commonly observed in hepatocytes. No lesions were noted in kidney tissue.

Gross examination of 325 livers (60 from the lower region of the Elizabeth River, 213 from the upper region of the Elizabeth River, and 52 from the Nansemond River) revealed cysts containing the larval stage (*Cysticercus fasciolaris*) of the adult tapeworm (*Taenia taeniaeformis*) in 16 (27%) muskrats from the lower region and 6 (3%) muskrats from the upper region of the Elizabeth River. No tapeworm cysts were observed in 52 muskrats necropsied from the Nansemond River. Tapeworm cysts were not found in muskrats with necrotic tissue or vascular infiltration lesions.

Mean fat indexes (FI) were significantly different ($P = 0.002$) among regions. Lower region Elizabeth River muskrats had a lower mean index ($\bar{x}_{FI} = 1.47$, $N = 18$) than muskrats from either the upper region of the Elizabeth River ($\bar{x}_{FI} = 1.90$, $N = 206$) or Nansemond River ($\bar{x}_{FI} = 2.18$, $N = 40$). There were significant differences between age classes ($P = 0.025$, immature mean = 1.85 adult mean = 1.98) but not between sexes ($P = 0.668$). Lipid levels (%) from 22 muskrats sent to the Mississippi State Chemistry Laboratory for organochlorine analysis (see Chapter 1) were compared with the FI assigned to those muskrats during necropsy. Lipid levels differed significantly (Kruskal-Wallis $P = 0.033$) among FI groups (Table 23).

DISCUSSION

In the current study, differences among regions were found for several body and organ measurements. Specifically, mean total, carcass, and spleen weights were lowest in muskrats collected from the lower region of the Elizabeth River (contaminated region). These results suggest that the quality of the environment may be different among the three regions studied. Whether

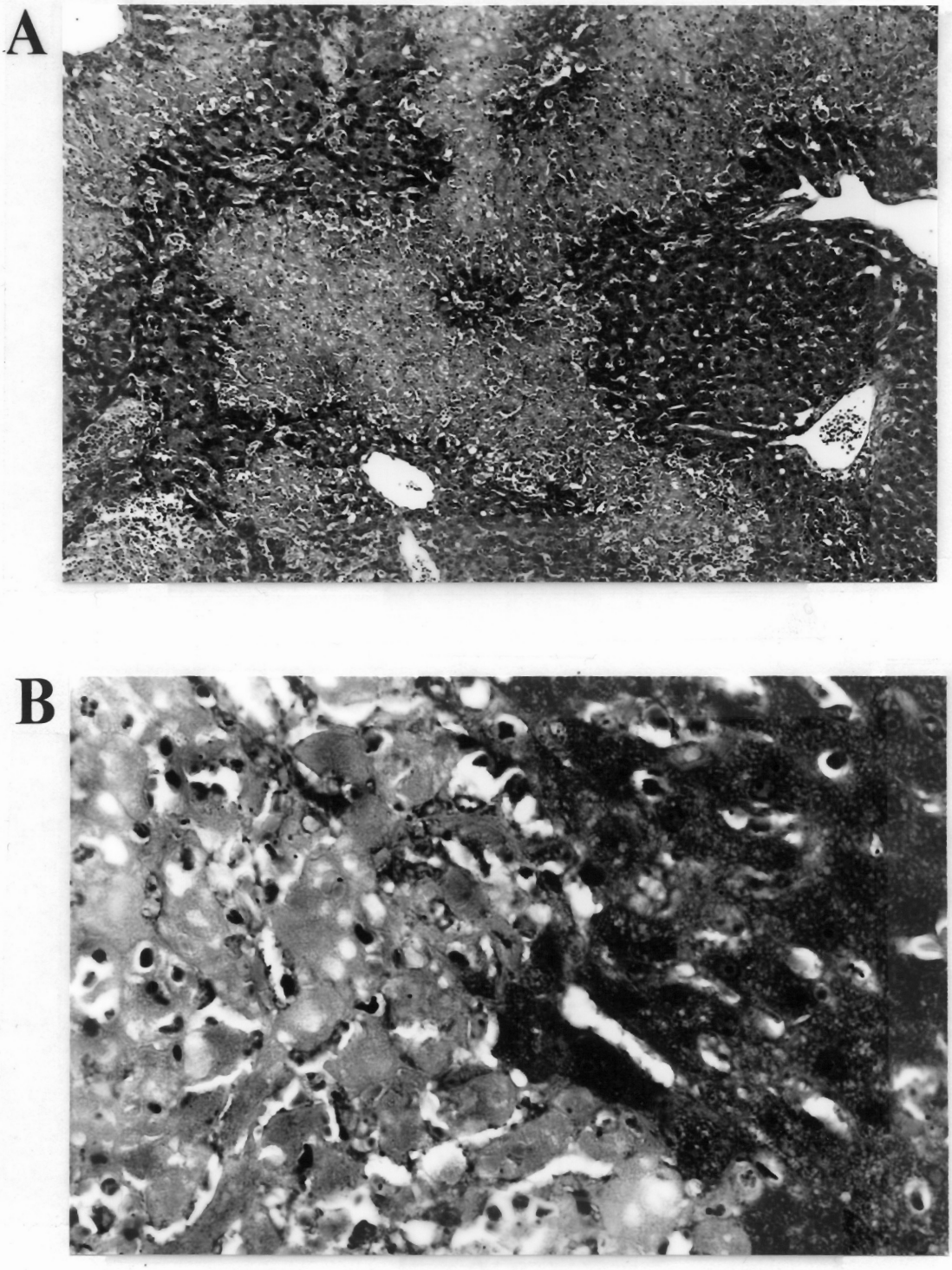

Figure 6. Microscopic preparation of muskrat liver tissue showing multifocal coagulative necrotic lesion (A = 200X, B = 1320x).

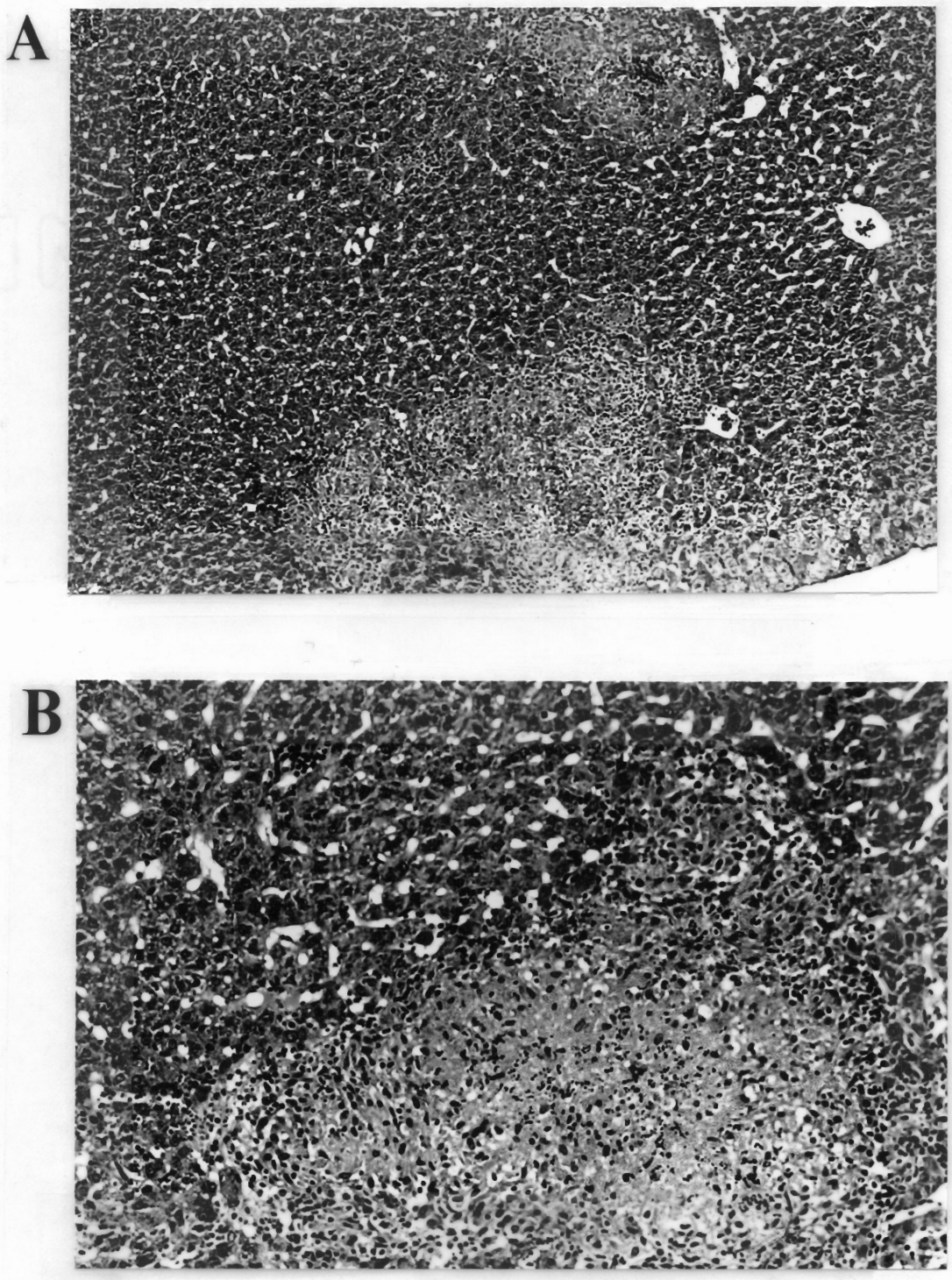

Figure 7. Microscopic preparation of muskrat liver tissue showing granuloma lesion (A = 200x, B = 400x).

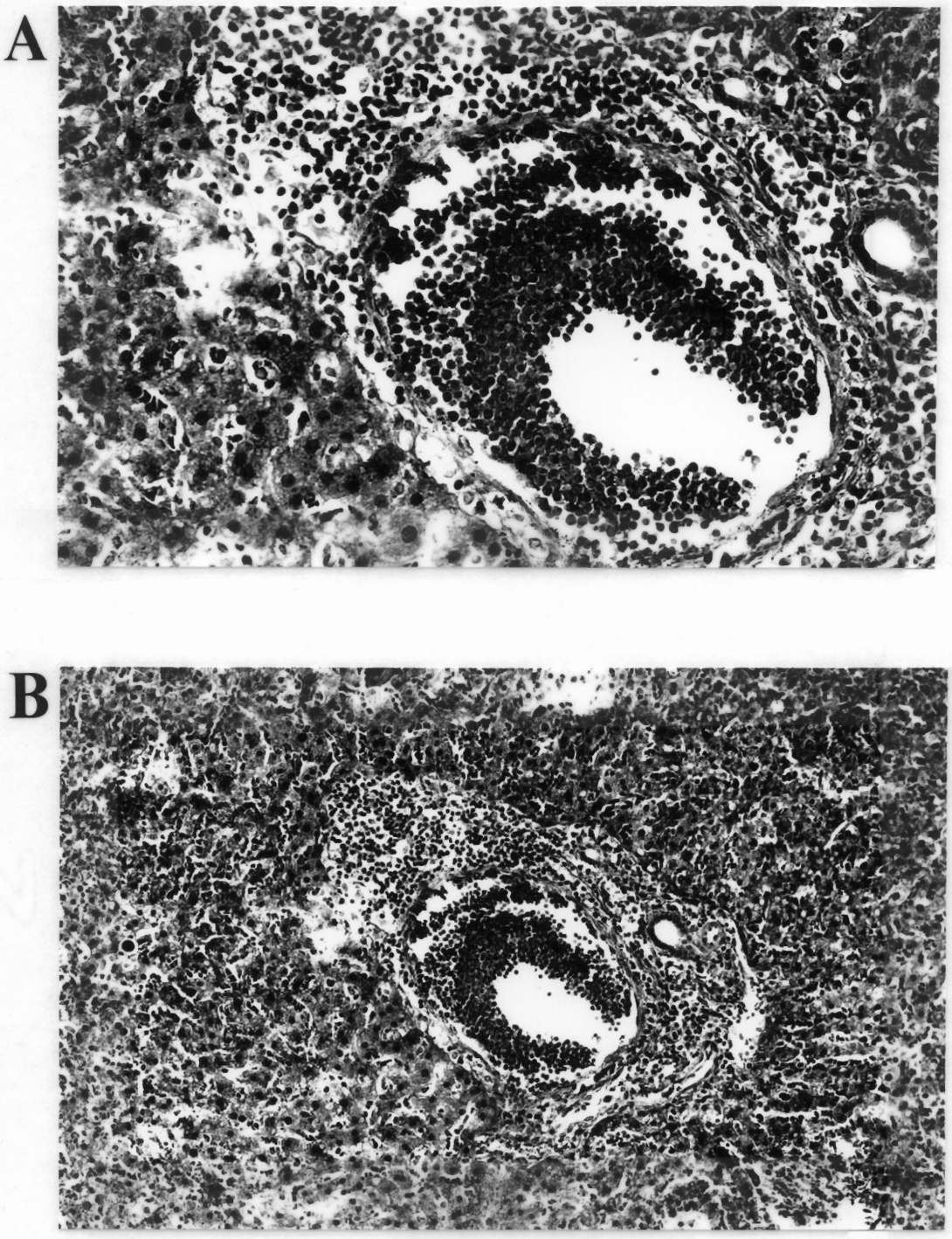

Figure 8. Microscopic preparation of muskrat liver tissue showing paraportal vascular mononuclear infiltration lesion (A = 330x, B = 660x).

Table 23. Comparison of lipid levels (% ± SE) with subjective adrenal fat indexes[1] determined from muskrat collected from the Elizabeth and Nansemond Rivers, VA from 1986 - 1989.

	Fat index groups				Kruskal-Wallis
	Group 1.0	Group 1.5	Group 2.0	Group 2.5	P
lipid levels	2.94 ±0.43	4.32 ± 0.00	4.32 ± 0.48	5.63 ± 1.29	0.033
N	10	1	7	4	
Min	1.06	4.32	2.43	3.48	
Max	5.98	4.32	6.37	9.18	

[1]Subjective fat index was assigned during necropsy (1 = thin line of fat between adrenal and kidney, 2 = obvious fat deposit between adrenal and kidney, 3 = adrenal partially enclosed in fat, values of 1.5 or 2.5 were assigned for intermediate fat deposits).

these differences can be attributed to environmental contaminants is speculative. Most body and organ measurements were quite variable and their use as indicators of environmental quality is questionable.

Differences in the quality of the diet in muskrats from the three study regions also could result in changes in body and/or organ measurements similar to those detected in the current study. Muskrat food habits analyses indicate that muskrats are resourceful and that food preferences vary considerably (Butler 1940, Takos 1947, Errington 1963). Olney threesquare, big cordgrass, and reed grass are considered preferred muskrat food plants and were relatively abundant in all three study regions. In addition to plant material, muskrats have been reported to consume animal tissues (clams, fish etc.) (Stearns and Goodwin 1941, Errington 1963). In the current study, shells left at middens indicated that muskrats occasionally fed on clams (*Polymesoda caroliniana*) and mussels (*Geukensia demissa*) that appeared to be common in all three regions studied, although this was not quantitatively determined. Based on the similarity of plant and animal food available among study regions and the resourcefulness of the muskrat, I do not think that lack of food is a reasonable explanation for the differences in body and organ measurements noted between muskrats from the lower region of the Elizabeth River and those from the other two regions studied.

Few studies have attempted to use differences in muskrat body or organ measurements as an indication of the effects of exposure to environmental contaminants. Erickson (1977) found no differences in total weight, total length, kidney/kidney fat ratios, or adrenal weights in muskrats from four different sites at Tinicum National Environmental Center, Pennsylvania; although differences in environmental quality (water quality parameters and mean soil heavy metal concentrations) were significant among sites. The author stated "while environmental levels of cadmium, zinc, and copper differed significantly among sites, the magnitude of these differences was not sufficient to induce variation in animal tissues" (Erickson 1977, page 71). Everett and Anthony (1976) reported no significant differences in physical condition indices (weight/length ratios and kidney fat index) in muskrats collected from four areas in southeastern Pennsylvania contaminated with significantly different concentrations of soil heavy metals. Cadmium concentrations in plants from one of their study areas were considered high enough that anemia in

muskrats was a concern. These authors indicated that high correlations between certain heavy metals (cadmium, zinc, and copper) in plants and muskrats indicated that muskrats were valid indicators of heavy metal contamination in semi-aquatic environments. Apparently the exposure levels were not sufficient to elicit detectable changes in muskrat physical measurements in the study by Everett and Anthony (1976) or in the study by Erickson (1977). No studies of body burdens or effects of organochlorines or PAHs in muskrats were found.

Parasitism of muskrats by helminths has been reported by numerous authors. In the current study, the incidence of parasitism by the tapeworm *Taenia taeniaeformis* varied from none detected in the Nansemond River to 24% in the lower region of the Elizabeth River. A literature review by Jilek (1977) revealed 66 species of helminths parasitizing muskrats, including 11 species of cestodes. Infestation of the liver of muskrats by *Cysticercus fasciolaris*, the larval form of the adult tapeworm *Taenia taeniaeformis*, has been reported from Ontario (Sweatman 1952), Maine (Meyer et al 1950, genus only), Ohio (Rausch 1946), and Virginia (Byrd 1953). In areas where this species has been reported, the degree of infestation has varied from 1.8% (N = 55) (Sweatman 1952) to 42% (N = 60) (Byrd 1953). None of these authors reported evidence of adverse affects on muskrats from infestations of this parasite. There are several factors involved in the perpetuation of *Taenia taeniaeformis* in the muskrat. The muskrat serves as the intermediate host with a carnivore (domestic cat, wild felid, dog) serving as the definitive host (Leiby and Dyer 1971, Flynn 1973). The parasite's life cycle requires a carnivore to ingest the infected liver of the intermediate host and the intermediate host to ingest the parasites eggs that pass in the feces of the definitive host (Leiby and Dyer 1971). Therefore, a low density of definitive or intermediate host would reduce the incidence of this desease. Muskrat density in the Nansemond River was low (see Chapter 3) and may have limited the distribution of the parasite in that region. However, low muskrat density was not observed in the upper region of the Elizabeth River; therefore, intermediate host density does not explain the low incidence of this parasite in that region. Only one record of *Taenia taeniaeformis* has been reported in the raccoon (Boddicker and Progulske 1968) and the raccoon was the only carnivore observed in the Nansemond River and upper region of the Elizabeth River. Therefore, the lack of a suitable definitive host (assuming the raccoon is not a suitable definitive

host) may have contributed to the low incidence of this parasite in muskrats examined from the upper region of the Elizabeth River and its absence from the muskrats in the Nansemond River. It is possible that the parasite is being perpetuated by some other host-predator cycle, such as rodent-housecat, and muskrats are ingesting eggs incidentally. This explanation is feasible because predators, other than raccoons (i.e. cats and dogs), were seen more in the lower region of the Elizabeth River than in the other regions.

Although glucose, alkaline phosphatase, MCH, and MCHC concentrations were significantly different among regions, blood characteristics in general did not provide much additional information for separating the muskrats from the three regions studied. Comparisons with muskrat hematological data reported by Lord et al. (1954) and Doyle et al. (1988) suggest that the blood characteristics of the current study are within a normal range for this species; at least for those characteristics for which data were available for comparison (Table 24).

The use of adrenal fat as an index of carcass fat content (general physical condition) in muskrats appears promising and worthy of additional study. A significant difference was indicated among regions with the lowest fat index observed in lower region Elizabeth River muskrats. This result is compatible with the significantly lower whole body and carcass weights observed in muskrats from this region. Although only 22 observations were available for comparison, there was a significant difference in percent lipid among fat index groups indicating the subjective fat index was fairly accurate. Subjective fat indexes have previously been used in evaluation of muskrat populations. Schatcher (1974) subjectively evaluated internal abdominal fat in muskrats collected from the Holston River, Tennessee as low (1), medium (2), or heavy (3). He found an increase in fat index in males from spring through fall (spring = 1.098, summer = 1.158, fall = 2.000) followed by a decrease during winter (1.783). Erickson (1977) calculated kidney weight/kidney fat ratios for muskrats collected from the Tinicum National Environmental Center, Pennsylvania. No significant differences were reported among study sites or between sexes or age groups (juveniles and adults).

In summary, there were several physiological characteristics that tend to separate muskrats from the lower (contaminated) region of the Elizabeth River from those of the upper region of the

Table 24. Comparison of blood variables reported in various studies.

Blood variable	Current study N = 64 $\bar{X} \pm$ SE (Range)	Doyle et al. 1988[1] N = 25 $\bar{X} \pm$ SE (Range)	Lord et al. 1954 N = 71 $\bar{X} \pm$ SE (Range)
RBC ($\times 10^6$)	6.47 ± 0.07 (5.5 - 7.8)	5.30 ± 0.11 (4.0 - 6.7)	6.38 ± 0.10 (4.3 - 8.0)
WBC ($\times 10^3$)	13.65 ± 0.42 (5.5 - 23.0)	11.20 ± 0.72 (4.6 - 19.1)	7.51 ± 0.35 (3.3 - 25.0)
Hemoglobin (mg)	18.33 ± 0.15 (15.7 - 21.0)	16.15 ± 0.31 (13.3 - 20.2)	13.65 ± 0.33 (6.6 - 19.8)
Hematocrit (%)	55.84 ± 0.52 (48.4 - 65.7)	42.55 ± 0.85 (38.0 - 56.7)	50.29 ± 0.74 (34.0 - 68.0)
MCV[2] (μ^3)	86.53 ± 0.47 (75.0 - 96.0)	79.00 ± 0.62 (71.0 - 85.0)	79.90 ± 1.39 (64.7 - 119.0)
MCH[2] ($\mu\mu$g)	28.34 ± 0.24 (22.7 - 33.2)	29.55 ± 0.28 (25.4 - 32.2)	21.61 ± 0.48 (13.4 - 29.2)
MCHC[2] (%)	32.78 ± 0.19 (28.8 - 37.0)	37.30 ± 0.33 (32.8 - 39.6)	27.16 ± 0.80 (19.4 - 38.3)
Total protein (mq/dl)	5.66 ± 0.07 (4.6 - 6.9)	6.10 ± 0.09[3] (5.3 - 7.2)	--------
BUN[2] (mg/dl)	31.65 ± 1.74 (4.0 - 67.0)	26.05 ± 0.84[4] (15.7 - 40.4)	--------
Glucose (mg/dl)	96.38 ± 5.63 (3.0 - 240)	109.00 ± 9.65[5] (51 - 159)	--------
Sodium (meq/l)	144.46 ± 0.43 (135 - 156)	146.40 ± 0.65[3] (142 - 153)	--------
Potassium (meq/l)	4.76 ± 0.17 (3.2 - 11.0)	4.65 ± 0.11[3] (3.3 - 6.4)	--------
Chlorides (meq/l)	90.95 ± 1.41 (9.0 - 100)	102.15 ± 0.45[3] (98.0 - 107)	--------

[1]Average of male and female data.
[2]MCV = mean corpuscular volume, MCH = mean corpuscular hemoglobin, MCHC = Mean corpuscular hemoglobin concentration, BUN = blood urea nitrogen.
[3]N = 27.
[4]N = 26.
[5]N = 11, males only.

Elizabeth River and/or Nansemond River. Several body and organ measurements were significantly lower, adrenal fat index was significantly lower, and the incidence of disease and parasitism was higher in lower Elizabeth River muskrats. With the absence of reasonable evidence to suggest lack of food in the lower region of the Elizabeth River, and with the significant increase in environmental contaminants in this region (see Chapter 1), and the apparent increase in incidence of disease, it appears that toxicological factors may be influencing the physical condition of the muskrats of this region.

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CHAPTER 3: POPULATION DYNAMICS

INTRODUCTION

Investigations of contaminant induced changes at the population level of the biological hierarchy are helpful in the interpretation of effects that may be observed at the cellular or organ level (see Chapter 2). With short term biological studies, observed changes in population dynamics are accomplished through comparisons among populations and not the actual observing of changes in a single population. These types of investigations are complicated by normal variations in populations that make interpretation of results difficult. An assessment of the effects of exposure to environmental contaminants will require an integrated interpretation of several or all of the parameters examined.

This chapter deals with an investigation of population changes that may have occurred in the muskrats associated with the lower region of the Elizabeth River due to their exposure to environmental contaminants. The integration of the results from this investigation with those reported in Chapter 1 and 2, will provide a basis for the evaluation of the effects of environmental contaminants on the muskrats in the lower region of the Elizabeth River.

MATERIALS AND METHODS

Two hundred and eighty-nine muskrats were live trapped, marked, and released from regions of the study area during July - August 1986 and May 1987 - August 1988. Trapping was done using modified "family traps" described by Snead (1950), and Havahart, Tomahawk, or #2 rubber jawed leg hold traps. The majority of the trapping sites were located in tidal areas that necessitated the use of the modified family traps. Live traps were baited with 1/4 - 1/2 apple slices.

All sections of each region were searched for signs of muskrats and subjectively classified as good, marginal, or poor habitat. All sections with visible signs of muskrats were trapped. In addition, sections classified as suitable, marginal, or poor with no signs of muskrats also were trapped. Suitability classifications were subjectively determined using vegetative cover, food availability, slope, soil texture, distance to low water, water level and presence or absence of burrows (see Study Area).

Captured muskrats were transferred to a wire restraining funnel, weighed using a spring balance, and sexed and aged as immature or adult by genital palpation (Baumgartner and Bellrose, Jr. 1943). Numbered #1 monel ear tags (National Band and Tag Co., Newport KY) were placed in each ear and the muskrat was released. Muskrats found dead in traps or that died during handling were transported to a research trailer and frozen until necropsies could be performed.

Seventy-six live trapped muskrats were collected for contaminant study during December 1986 - January 1987 and December 1987 - February 1988. These muskrats were transported to a research trailer for sleeping time analysis and then euthanized (60 mg sodium pentobarbital, 1 cc i.m.) for further data collection (see Chapter 1). During May - July 1988 and May - June 1989, 25 female muskrats were collected to obtain additional reproductive data. In addition to muskrats trapped by me or employed technicians, muskrat carcasses from the upper region of the Elizabeth River and Nansemond River were obtained from cooperative trappers during the legal muskrat trapping seasons of 1986 - 1987 and 1987 - 1988 (December - February both years). These carcasses were frozen until necropsies could be performed.

The number of placental scars was recorded for each female necropsied and the females were classified as adult or immature based on the presence or absence of placental scars. Testes were removed from males, placed in formalin, and subsequently weighed, and the lengths, widths and volumes (water displacement in a graduated cylinder) were recorded. Cluster analyses of testis measurements aided in assignment of age classifications to male muskrats.

The Petersen Mark-Recapture Method, Schnabel Method, and program CAPTURE (Otis et al. 1978) were used to estimate muskrat population size. The closure assumption was relaxed by using only adult muskrats and by assuming equal probability of loss between marked and unmarked individuals (Seber 1973). The assumption of equal probability of capture may have been violated (see results). Other assumptions are thought to have been met. Regions were trapped for 10 day periods with approximately 28 days between trapping occasions from May 1987 through January 1988 and from March 1988 through June 1988. Spring and summer trapping occasions were combined to provide inital marked individuals and fall and winter trapping occasions were combine to provide marked and unmarked individuals for the Petersen estimate in 1987. Spring trapping occasions provided the marked individuals and summer trapping occasions provided the marked and unmarked individuals for the Petersen estimate in 1988. Four trapping occasions were used for the Schnabel estimate in 1987 and three were used in 1988. Immatures and mortalities due to handling were added to the estimates after calculations. In addition to the population estimates listed above, an estimate based on the number of den sites found in the lower region of the Elizabeth River also was determined. This method of estimating population size was not possible in the upper region of the Elizabeth River because numerous underground passages and steep river banks below water level prevented the location of some den sites. Population densities for the lower and upper regions of the Elizabeth River were estimated as number/ha and as number/100 m of shore line.

SAS computer software (SAS Institute Inc., 1985) was used for statistical analysis. All variables were checked for normal distributions using PROC UNIVARIATE (Shapiro-Wilk's) procedures. Means of variables that exhibited a normal distribution were compared among regions using ANOVA (General Linear Model (GLM)) procedures. Duncan's and Bonferroni's multiple

comparison tests were used to separate means of variables found to be significantly different ($\alpha = 0.05$) by the ANOVA. Variables that did not exhibit normal distributions were either transformed and compared using ANOVA procedures (if transformations resulted in normal distributions) or compared among regions using Wilcoxon or Kruskal-Wallis nonparametric analysis (PROC NPAR1WAY). All ANOVA procedures (when appropriate) included analysis of main effects for location, sex, and age and all interactions of these variables. If normality or interactions are not mentioned it should be assumed that the distributions were normal and/or that the statistical results were nonsignificant. Correlations between variables were obtained using Pearson's procedures (PROC CORR). Differences in the proportions of adults and immatures between muskrats aged by palpation and those aged by internal examination and between muskrats live trapped and kill trapped were analyzed using the z-test for comparing two binomial proportions. Chi-square analysis was used to indicate whether the proportions of males to females differed from 1:1.

RESULTS

Population Size Estimations

A total of 2494 trap-nights resulted in 230 captures (10.84 trap-nights/muskrat captured) in the lower region of the Elizabeth River, while 2051 trap-nights resulted in 135 captures (15.19 trap-nights/muskrat captured) in the upper region of the Elizabeth River. Due to low trapping success in the Nansemond River (2989 trap-nights, 60 captures), trapping to obtain data for population estimations in that river was discontinued in the spring of 1988.

Population estimations for the lower and upper regions of the Elizabeth River for 1987 and 1988 are given in Table 25. The lower estimates observed in 1988 were expected because most

muskrats captured at the end of 1987 were removed for environmental contaminant studies. Because the proportion of males to females was significantly different from 1:1 (see below) and because subjective field observations indicated that females tend to avoid traps more than males, there may be a difference in the probability of capture between males and females. Therefore, population sizes also were estimated using males only and these results also are presented in Table 25. Lack of a sufficient number of repeated recaptures precluded the use of the program CAPTURE in estimating population sizes when males only were use in the calculations. Seventeen den sites were located in the lower region of the Elizabeth River. If an average of five muskrats per den site is assumed, the population estimate for this region would be 85 muskrats. An estimated range based on 17 den sites and assuming 2 - 9 muskrats per den would be 34 - 153. Because the assumption of equal probability of capture was thought to be violated, population estimates using males only were thought to be more accurate than those using both males and females. The population estimates based on the Petersen and Schnabel methods using males only were both within the range estimated for the lower region of the Elizabeth River based on the number of den sites and were thought to be reasonable estimates. The average of these two estimates (115 muskrats) will be used to estimate the density of the lower region of the Elizabeth River. Similarly, the average of the Petersen and Schnabel methods using males only (105 muskrats) will be used to estimate the density of muskrats in the upper region of the Elizabeth River. Available habitat in the lower region of the Elizabeth River was estimated to be 6.15 ha (see Study Area). Therefore, the estimated density for the lower region of the Elizabeth River was 18.7 muskrats/ha. (115/6.15) for 1987 and 6.8 muskrats/ha (42/6.15) for 1988. Available habitat in the upper region of the Elizabeth River was estimated to be 50.01 ha. Using calculations similar to those given above, the estimated density for the upper region of the Elizabeth River was 2.1 muskrats/ha (105/50.01) in 1987 and 0.8 muskrats/ha (38/50.01) in 1988. The lower region of the Elizabeth River had 13290 m of shore line and the upper region had 9209 m of shore line (see Study Area). Density estimates based on number/100 m of shore were 0.86 (1987) and 0.32 (1988) for the lower region and 1.14 (1987) and 0.41 (1988) for the upper region of the Elizabeth River.

Table 25 Estimations of population sizes and densities of muskrats captured from the lower and upper regions of the Elizabeth,*Va. May 1987 - January 1988 and March - July 1988.

Region	Date	Sex Used In Estimation	Petersen Estimate (±SE)	Schnabel Estimate (±SE)	Program Capture M(h) Estimate (±SE)
Lower Elizabeth River	1987	Males and Females	95 ± 7.8	86 ± 11.3	145 ± 40.9
Density (#/ha)[1]			15	14	24
Density (#/100 m of shore)[2]			0.71	0.65	1.09
		Males	129	101	----------
Density (#/ha)[1]			21	16	----------
Density (#/100 m of shore)[2]			0.97	0.76	----------
	1988	Males and Females	26 ± 1.1	32 ± 10.4	46 ± 9.9
Density (#/ha)[1]			4	5	7
Density (#/100 m of shore)[2]			0.20	0.24	0.35
		Males	44	40	----------
Density (#/ha)[1]			7	7	----------
Density (#/100 m of shore)[2]			0.33	0.30	----------
Upper Elizabeth River	1987	Males and Females	91 ± 12.3	79 ± 21.3	118 ±18.9
Density (#/ha)[3]			1.8	1.6	2.4
Density (#/100 m of shore)[4]			1.00	0.86	1.28
		Males	120	90	----------
Density (#/ha)[3]			2.4	1.8	----------
Density (#/100 m of shore)[4]			1.30	0.86	----------
	1988	Males and Females	40 ± 2.8	35 ± 7.7	43 ± 3.1
Density (#/ha)[3]			0.80	0.70	0.86
Density (#/100 m of shore)[4]			0.43	0.38	0.47
		Males	48	40	----------
Density (#/ha)[3]			1.00	0.80	----------
Density (#/100 m of shore)[4]			0.52	0.43	----------

[1]Area = 6.15 ha.
[2]Shore length = 13290 m.
[3]Area = 50.01 ha.
[4]Shore length = 9209 m.

Reproduction

Seventy-five female muskrats had a total of 637 placental scars ($\bar{x}$ = 8.49) ranging from 1 - 20 (Table 26). The number of placental scars per female did not differ significantly (P = 0.821) among regions. Twelve pregnant female muskrats had a total of 54 fetuses ($\bar{x}$ = 4.50, range = 3 - 6) (Table 27).

The birth months of 62 immature muskrats (weighing under 700 g) collected during 1987 and 1988 were estimated based on weights given by Errington (1963) for Iowa muskrats and Dorney and Rusch (1953) for Wisconsin muskrats. These results indicate two periods of births for muskrat in Elizabeth and Nansemond Rivers, April - May and September (Figure 9). Seven females with fetuses also had placental scars indicating a previous litter. The fetuses of all seven females were in early gestation. Assuming that female muskrats breed shortly after weaning their first litter, the estimated birth months of the first litters would be 3 in April, 3 in May, and 1 in July.

Age Structure and Sex Ratios

Of the 289 muskrats live trapped and aged by genital palpation (Baumgartner and Bellrose 1943) 202 (70%) were adults (> 8 months old) and 87 (30%) were immatures (Table 28). The proportions of adults and immatures were not significantly different among regions (χ^2 = 0.57 $\underline{P}$ = 0.752). Sixty-five muskrats (37 males and 28 females) collected during December 1987 - February 1988 were aged by internal examination of their reproductive tracts, a more accurate technique (Schofield 1955, Errington 1963). Aging of females by the presence or absense of placental scars was straightforward and resulted in classification of 11 females as immature and 17 females as mature. Thirty-seven males were separated by cluster analysis using average testes

Table 26 Number of placental scars found in female muskrats collected from the Elizabeth and Nansemond Rivers VA 1987 - 1989.

Location	No. of Females	No. of Placental Scars	Range	Mean	No. of Litters/year[1]
Elizabeth River					
Lower region	16	135	(5 - 13)	8.44	1.88
Upper region	50	433	(1 - 20)	8.66	1.92
Nansemond River	9	69	(3 - 13)	7.67	1.70
Total	75	637	(1 - 20)	8.49	1.89

[1] Based on a mean of 4.5 muskrats per litter (see Table 27)

Table 27 Number of fetuses found in female muskrats collected from the Elizabeth and Nansemond Rivers VA 1987 - 1989.

Location	No. of Females	No. of Fetuses	Range	Mean
Elizabeth River				
Lower region	8	37	(3 - 6)	4.63
Upper region	3	14	(4 - 5)	4.67
Nansemond River	1	3	----	3.00
Total	12	54	(3 - 6)	4.50

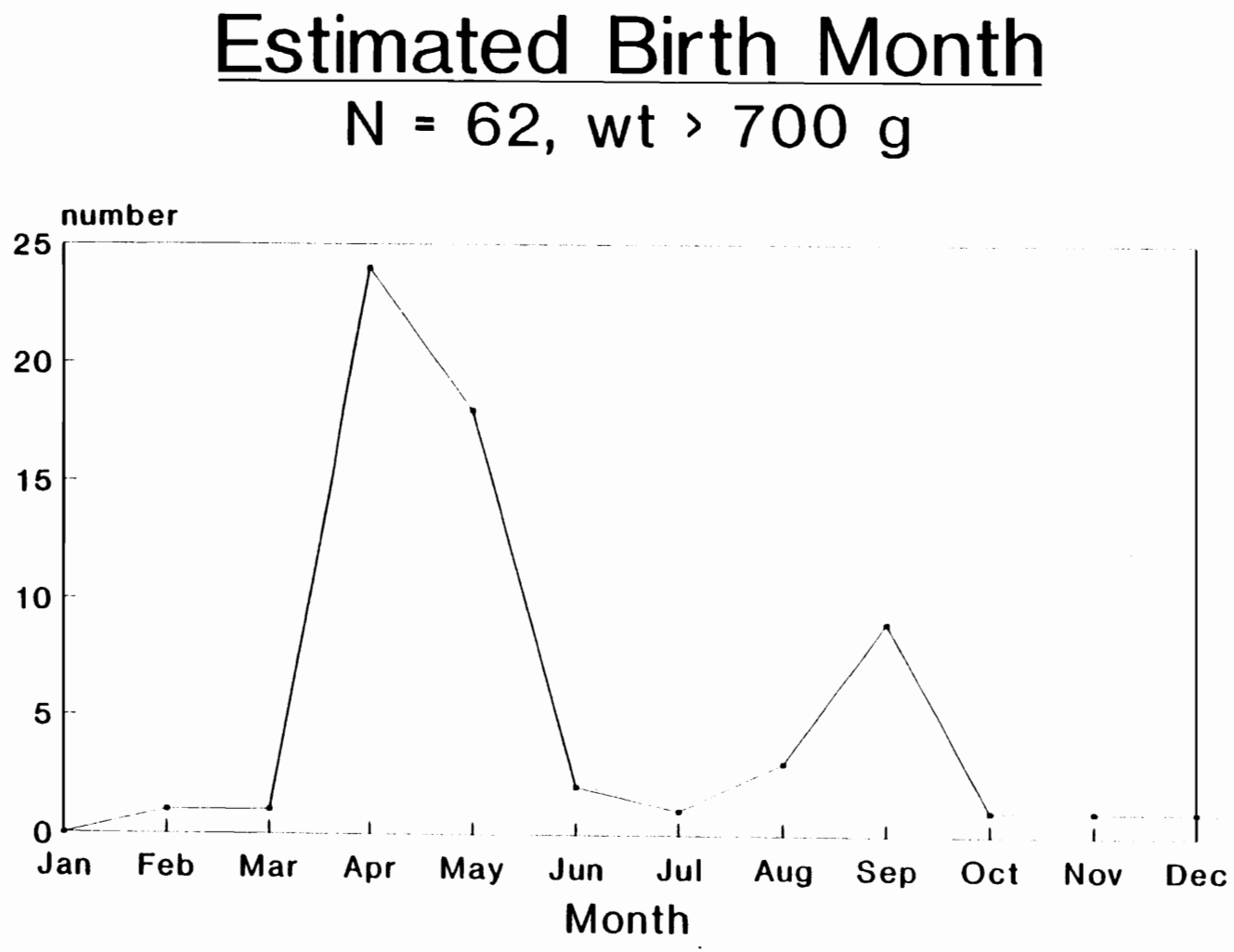

Figure 9. Estimated birth months of muskrats (< 700 g) trapped during 1987 and 1988 in the Elizabeth and Nansemond Rivers, Virginia (based on weights described by Errington (1963)).

weight, length, width, and volume. Plots of average testes weights and lengths produced three groups. Group one consisted of 7 males with average testes weights less than 1 g and lengths less than 14 mm. Group two consisted of 5 males with average testes weights between 1.0 g and 2.3 g and lengths between 14 mm and 18 mm. Group three consisted of 25 males with average testes weights greater than 2.3 g and lengths greater than 18 mm. These groups are thought to represent juveniles (group 1), subadults (group 2), and adults (group 3). Because muskrats in the current study were separated into two groups (immatures and adults), cluster groups 1 and 2 were combined into one group representing 12 immature male muskrats and group 3 represented 25 adult male muskrats. Therefore, of the 65 muskrats aged by internal examination, forty-two (65%) were adults and 23 (35%) were immatures. There were no significant differences ($z = 0.794$, $\underline{P} > 0.05$) in the proportions of adults and immatures between live trapped muskrats aged by palpation and those aged by internal examination of their reproductive tracts. Two hundred and twelve muskrats obtained from trappers (all kill-trapped in winter) were aged by internal examination of their reproductive tracts. Forty-one percent were adults and 59% were immatures. There was a significant difference ($z = 6.30$, $\underline{P} < 0.05$) between the proportion of adults live-trapped and the proportion of adults obtained from trappers (kill-trapped).

One hundred and seventy-eight of the 289 muskrats were males and 111 were females resulting in a sex ratio of 160M:100F. This proportion differed significantly from a 1:1 ratio ($\chi^2 = 15.53$ $\underline{P} < 0.001$). Chi-square analyses indicated that the proportion of males and females from the lower and upper regions of the Elizabeth River but not from the Nansemond River were significantly different from 1:1 (Table 28). The nonsignificant difference observed in the Nansemond River probably resulted from small sample size.

Analysis of initial capture data by seasons indicated a significant difference in the proportion of males and females in spring (April - July, 100M:54F, $\chi^2 = 13.74$ $\underline{P} < 0.005$) but not in fall (August - November, 34M:27F) or winter (December - February, 44M:30F). When analyzed by seasons and regions, the proportion of males and females captured from the lower region of the Elizabeth River and upper region of the Elizabeth River differed from a 1:1 ratio ($\underline{P} < 0.05$) in spring but not in fall or winter. Because of small sample sizes, analyses by seasons did not indicate

Table 28. Sex and age data from 289 muskrats live trapped in the Elizabeth and Nansemond Rivers, Va. during 1986 - 1988.

Location	Sex	Adults	Age ratios[1] (A:I)	Immatures	Row total	Sex ratios (M/F)
Elizabeth River						
Lower region						
	Males	64		27	91	
	Females	38		18	56	
Subtotal		102	69:31	45	147	163:100[2]
Upper region						
	Males	43		13	56	
	Females	23		12	35	
Subtotal		66	73:27	25	91	160:100[3]
Nansemond River						
	Males	24		7	31	
	Females	10		10	20	
Subtotal		34	67:33	17	51	155:100[4]
Column total		202	70:30	87	289	160:100[5]

[1] Percent
[2] Significantly different from 1:1 ($\chi^2 = 8.33$, $P < 0.05$).
[3] Significantly different from 1:1 ($\chi^2 = 4.85$, $P < 0.05$).
[4] Not significantly different from 1:1 ($\chi^2 = 2.37$, $P > 0.05$).
[5] Significantly different from 1:1 ($\chi^2 = 15.53$, $P < 0.001$).

that the male : female proportions differed from 1:1 in the Nansemond River at any time (Table 29).

One hundred and thirty-one (65%) of the 202 adult muskrats were males and 71 (35%) were females. Forty-seven (54%) of the 87 immatures were males and 40 (46%) were females (Table 28). The sex ratio of adults differed from 1:1 ($\chi^2 = 17.82$ $\underline{P} < 0.001$) but sex ratio of immatures did not. This significant difference in the proportions of adult males and females also was observed in analyses by region. The sex ratios of immature muskrats did not differ significantly from 1:1 in any region or during any season.

DISCUSSION

Petersen and Schnabel population estimates were consistently lower when males and females were used in calculations than when males only were used. The population estimate based on program CAPTURE using males and females was much greater than either the Petersen or Schnabel methods using males and females. Program CAPTURE indicated that the model M(h) (heterogeneity in capture probability) gave the best results. Model M(h) allows capture probabilities to vary by individual animal (Otis et al. 1978). This model would account for the difference in capture probability that was thought to exist between males and females. Therefore, estimates derived by program CAPTURE would be expected to be greater than estimates that did not account for these differences. The population range estimated from the number of den sites (34 - 153) includes the estimates derived by Petersen, Schnabel, or program CAPTURE.

Muskrat density estimates reported by previous authors are quite variable ranging from approximately 1/ha to approximately 90/ha (Perry 1982). Arata (1959) reported Illinois muskrat

Table 29. Sexual classification and ratios of live trapped muskrats from the Elizabeth and Nansemond Rivers, VA from 1986 - 1989.

Location	Season	Initial Captures	Males	Females	Sex Ratios Males : Females
Elizabeth River					
Region 1	Spring	79	51	28	
	Fall	42	23	19	
	Winter	26	17	9	
	Total	147	91	56	163:100*
Region 2	Spring	56	36	20	
	Fall	13	10	3	
	Winter	22	10	12	
	Total	91	56	35	160:100*
Nansemond River					
Region 3	Spring	19	13	6	
	Fall	6	1	5	
	Winter	26	17	9	
	Total	51	31	20	155:100
Total		289	178	111	160:100*

* Proportions of males and females significantly different ($P \leq 0.05$).

density in ponds associated with strip mines to be 6.9/ha, whereas Gashwiler (1950) reported much lower muskrat densities (0.3 - 1.8/ha) in Maine. After investigating muskrats in Iowa, Errington (1949) concluded that a muskrat density of 49/ha may be expected in cattail (Typha spp.) marsh and 25/ha may be expected in bulrush (Scirpus spp.) marsh. O'Neil (1949) reported muskrat densities in good *Scripus olneyi* marshes of Louisiana to be 38/ha. The muskrat density estimates for the lower region of the Elizabeth River (18.7/ha in 1987 and 6.8/ha in 1988) appear to be in the middle to low range of densities reported in other studies. The muskrat density estimate for the upper region of the Elizabeth River (2.10/ha in 1987 and 0.88 in 1988) appears to be low compared to other studies. Several factors may account for the differences observed in density between the two study regions. The fringe marsh (marsh immediately adjacent to the river extending only a few meters inland) located in the upper region of the Elizabeth River is probably not utilized as much as the fringe marsh in the lower region. Fringe marsh was considered poor muskrat habitat and since there were several marshes that provided good muskrat habitat located within a few hundred meters of the river in the upper region, the muskrats probably would tend to stay in the good marshes and avoid the fringe marshes. In the lower region of the Elizabeth River there were no large marshes providing good muskrat habitat (the largest marsh providing good habitat in this region was 1.69 ha); therefore, muskrats made more use of the fringe marshes in this region. Because of the tidal fluctuation (approximately 1 m) and storm tides that may be 1 - 2 m above normal high tide, most of the marsh areas in both regions are unavailable for den sites or lodges. Therefore, the marsh area recorded for the upper region of the Elizabeth River, although larger, did not provide proportionately more den sites. If shore line alone is used in estimating muskrat densities in 1987, the density in the lower region would be 0.87 muskrats/100 m of shore (115 muskrats/(13290 m of shore/100 m)) and 1.14 muskrats/100 m of shore (105 muskrats/(9209 m of shore/100 m)) in the upper region. Gashwiler (1948) reported a similar situation in estimating muskrat density in Maine. When open water was included in density estimates, the muskrat density was 0.3 - 1.8 muskrats/ha; however, when open water was excluded from calculations the density was 1.1 - 3.9 muskrats/ha. It appears that the relative densities of the lower region and upper region of the Elizabeth River are not drastically different and that the differences observed in this study

are probably due to differences in the habitat composition between regions and not to a physical difference (i.e. reproductive differences) in the muskrats inhabiting each region.

The size and number of litters produced by muskrats have been studied extensively and the results of the current study are consistent with results of other studies (Table 30). Litter sizes have been reported to range from 2 to 8 young per litter, with populations in southern latitudes having smaller litters than those in northern latitudes (Boyce 1977, Perry 1982). Data obtained from the current study by backdating the birth dates of immature muskrats (< 700g) (Figure 7) indicated April - May and September as the peak periods for births, although some births occurred during most months of the year, February - December. No pregnant females were found among muskrats collected from mid December - early February. Pregnant female muskrats were collected during April, May, June, and August with estimated birth months of their litters being May, June, July, and September (Table 31). First litter birth months were estimated to be April, May, and July for pregnant females with placental scars. These estimates are based on the assumption that postpartum breeding occurs (McLeod and Bondar 1952, Errington 1963) and that observed placental scars are from the current year.

Wilson (1954) reported year round breeding in muskrat populations from tidal marshes of Currituck and Dare Counties in northeastern North Carolina. Breeding was reported to subside during June and July and during periods of extreme cold and to peak from mid February - early May and from mid August - September. I believe that breeding may occur year round in muskrats inhabiting the Elizabeth and Nansemond Rivers and that peak periods of birth occur during April - May and September. Winter breeding (December - February) probably only occurs during warm winters. Mean litter size and litters per year are consistent with results reported for muskrat populations in the mid-Atlantic states.

Trapping success within the study regions was complicated by several factors. Tidal fluctuations of approximately 1 m have resulted in the eroding of soil in marsh areas bordering the rivers. This erosion has created a labyrinth of exposed and unexposed channels that provide muskrats with numerous choices of routes of travel and make placement of traps difficult. Bait eaten by nontarget species also was a complicating factor. On many occasions bait was absent from

Table 30 Comparison of mean litter sizes and number of litters per year of muskrats live trapped from the Elizabeth and Nansemond Rivers, Va. with those reported by various authors.

Location	$\bar{X}$ Litter size	No. of Litters/year	Reference
New Brunswick	6.8[1]	2.5[1]	Parker and Maxwell (1980)
Ohio	7.1[2]	1.5 - 2.0	Clay and Clark (1985)
New York	6.3[3]	1.5	Erickson (1963)
Iowa	6.5[4]	2.0	Errington (1939)
France	6.0	2.0	Vincent and Quere (1972)
Louisiana	3.7[2]	-----	Svihla and Svihla (1931)
Louisiana	3.8[2]	-----	Arthor (1931) in Errington (1939)
Maryland	4.4[2]	-----	Smith (1938) in Errington (1939)
North Carolina	3.7[2]	2.9[5]	Wilson (1954)
Virginia	4.5[2]	1.9	Current Study

[1]Estimated by authors.
[2]Based on embryo/fetus counts.
[3]Based on young in litters and placental scars.
[4]Based on young in litters.
[5]Calculated from data presented in reference.

Table 31 Fetal measurements and estimated birth months of muskrats captured from the Elizabeth and Nansemond Rivers VA 1988 - 1989.

Female Tag No.	Date of Capture	No. of Placental Scars	No. of Fetuses	Fetal Weight (g)	Fetal Length (mm)	Estimated Birth Date
788	4/17/88	0	5	0.42	21	May
				0.56	22	
				0.45	21	
				0.25[1]	21	
				0.58	22	
810	5/04/88	0	6	24.39	123	May
				17.24[1]	112	
				22.92	118	
				23.37	118	
				22.81	118	
				20.28	117	
821	5/11/88	5	4	-----[2]	-----	June
845	5/25/88	0	5	0.25	14	June
				0.24	14	
				0.24	12	
				0.24	13	
				0.21	13	
696	5/24/89	5	5	-----[2]	-----	June
694	5/25/89	7	4	-----[2]	-----	June
799	6/04/88	7	5	-----[2]	-----	July
672	6/11/89	5	3	-----[2]	-----	July
874	6/21/88	4	4	-----[2]	-----	July
607	8/04/88	0	5	21.76	126	August
				23.06	131	
				24.62	136	
				21.69	124	
				19.12	115	
608	8/04/88	0	3	2.69	66	August
				1.45	57	
				2.61	65	
766	8/08/88	5	5	-----[2]	-----	September

[1]Fetus damaged, weight may not be accurate.
[2]Fetus too small to measure.

all traps set at a trapping site and raccoon tracks were adjacent to traps. Several raccoons were caught in family traps, further implicating them in bait removal. In addition to raccoons, marsh birds, turtles, crabs, rats, and rabbits also were caught in traps and are thought to have played a role in the removal of bait. In addition to removal of bait by these animals, predation by raccoons on trapped muskrats is believed to have influenced trapping success. On several occasions traps were lying on their side several feet from where they had been set and raccoon tracks were present. On one occasion an inverted skin of a muskrat was found near a trapping site in the Nansemond River. The inverted skin is reported to be a sign of predation by raccoons (Joe Brescia, Professional Trapper, Chesapeake, Va., personal communication). At several trapping sites it was necessary to trap and remove raccoons in conjunction with the trapping of muskrats. This problem was most obvious when trapping in the Nansemond River.

Trapping success in the Nansemond River (49.8 trap-nights/muskrat) was poor, although all trapping locations were considered good muskrat habitat. Possible explanations for poor trapping success include abundant food making bait less attractive, a low muskrat population, and trap avoidance. I do not believe that abundant food is a satisfactory explanation for poor trapping success in the Nansemond River. During the first year of this study few signs of muskrat activity were seen in this region. Traps set at sites without signs usually were unsuccessful; however, when signs were located, trapping usually resulted in captures. In addition, good habitat (food) also was abundant in several areas in the Elizabeth River and trapping was more successful.

Low muskrat density may provide an explanation for poor trapping success in the Nansemond River. The lack of muskrat signs (droppings, dens, lodges, feeding areas, tracks) was apparent in numerous searches in this region. In addition, discussions with local trappers indicated that they thought that the muskrat population in the Nansemond River had declined during the years just prior to initiation of this study. No muskrat trappers were known to be trapping in this region during the time of this study. Assuming this explanation to be true, the cause of low muskrat numbers needs to be explored. As mentioned previously, raccoon signs (tracks, droppings) were evident in this region and predation by raccoons on muskrats does occur (Wilson 1954, Mathiak 1966). Wilson (1954) investigated the cause of declining muskrat populations in tidal marshes of

Currituck and Dare counties in northeastern North Carolina during the 1940's and early 1950's. His conclusion was that raccoon predation on muskrat litters was responsible for the decline. Arata (1959) reported a low percentage of subadults (43%) in muskrat populations inhabiting strip-mine ponds in southern Illinois. The author suggested that adverse environmental conditions on strip-mined lands may have been an influencing factor. However, he also reported that 25 raccoons had been incidentally trapped along with 105 muskrats. Predation on young muskrats by raccoons was not mentioned but may have been a contributing factor, especially since raccoons were apparently abundant. Dozier (1945) reported that predation on muskrats was serious adjacent to swamp woods and that raccoons, mink, and foxes were increasing. He also reported considerable variation in sex ratios of several weight and age groups and indicated predation as one of the possible causes. These studies suggest that predation by raccoons on young muskrats may occur, and in areas of high raccoon density may influence muskrat populations. Although predation by raccoons is a possible explanation for low muskrat populations in the Nansemond River, disease and natural cycling also are factors that cannot be eliminated as alternative explanations; however, little evidence was found to substantiate either.

The third possible explanation is that trap avoidance by muskrats was responsible for poor trapping success in the Nansemond River. Trap avoidance was noted during the current study. For example, while trapping during the spring of 1989 near a den site with fresh muskrat signs, three immature muskrats (< 450g) were captured, marked and released during one night's trapping. The size of tracks at this trapping site indicated that a larger muskrat also utilized this den. However, several night's trapping using modified family traps and tomahawk live traps failed to capture this individual although signs continued to be seen. Finally, rubber jawed leg hold traps placed at the trap site resulted in the capture of an adult male muskrat. From this and similar observations, it was evident that trap avoidance did occur in the Nansemond River. Therefore, trap avoidance is at least partially responsible for the poor trapping success in this region. Of the explanations postulated for poor trapping success in the Nansemond River, low population numbers (possibly caused by predation by raccoons) and trap avoidance behavior offer the best explanation based on the information available.

Due to low trapping success in the Nansemond River regular trapping in this region was discontinued in the spring of 1988. The following discussion of sex and age ratios represents data collected primarily from the Elizabeth River along with data that was obtained from the Nansemond River prior to cessation of trapping. Some information on reproduction was obtained from female muskrats captured in the Nansemond River during the spring of 1989.

The ratio of adults (70%) to immatures (30%) in the current study is inconsistent with the results reported in other studies (Table 32). This inconsistency could result from inaccuracy of aging, a difference in capture probabilities between adults and immatures, or may reflect a true difference in comparisons with other studies.

The proportion of adults and immatures aged in the field by external palpation was not significantly different from the proportions obtained from internal examination of a subsample of these individuals. Aging by internal examination of reproductive tracts has been reported to be highly accurate (Schofield 1955, Errington 1963). Separation of immature and adult females based on presence or absence of placental scars was straightforward. Separation of immature and adult males was more difficult during late fall and winter sampling. The results of Cluster Analysis using testes measurements separated juvenile from subadult males based on testes lengths less than or greater than 14 mm. This result is slightly higher but consistent with the < 11.5 mm used by Schofield (1955) to separate juvenile from adult muskrats in Michigan. Errington (1963) examined 97 subadult males during the last days of December and reported 29% with testes lengths ≥ 12 mm and averaging 13.9 mm. The two greatest lengths he reported were 18.0 mm and 17.0 mm. Five of 37 male muskrats from the current study had testes lengths between 14 mm and 18 mm and they were considered to be subadults and were classified as immatures. Based on these comparisons, I do not think that the discrepancy observed in the percentages of immatures and adults in the current study compared with studies previously reported resulted from improper aging.

The percentage of adults and immatures reported in the current study was calculated from data obtained by live trapping and is inconsistent with results reported in other studies (Table 32). The percentage of adults and immatures found in muskrats obtained from trappers using kill trapping techniques in the current study (41% and 59% respectively, N = 212) approach the

Table 32 Comparison of percent immatures in muskrats live trapped from the Elizabeth and Nansemond Rivers, Va. with those reported by various authors.

Location	Season	Sample Size	% Immatures	Reference
New Brunswick	May 24 - October 22	129[1]	75	Parker and Maxwell (1980)
New Brunswick	Fall	149[2]	74	Parker and Maxwell (1980)
Maine	Fall	951[2]	72	Gashwiler (1950)
New York	September	364[1]	77	Erickson (1963)
New York	Jan. 1 - March 20	541[2]	72	Alexander (1951)
Wisconsin	November	733[2]	72	Mathiak (1966)
Illinois	Dec. 1 - Jan. 15	105[2]	43	Arata (1959)
North Carolina	Winter	406[2 3]	42	Wilson (1954)
Virginia	Winter	76[1]	41	Current study (1989)

[1] From live-trapping data.
[2] From kill-trapping data.
[3] Females only.

percentages reported from other studies. Studies by Erickson (1963) and Parker and Maxwell (1980) using live trapping techniques resulted in immature to adult ratios that were consistent with those reported in other studies (Table 32). Although comparing live trap data with kill trap data in the current study indicates a greater probability of capture for adult muskrats, I cannot accept this as an accurate reflection of capture probabilities at this time (see below).

The possibility that the proportion of immature and adult muskrats captured in this study is a true reflection of the populations sampled cannot be rejected. If the muskrat population along the rivers studied were declining, the proportion of immatures would be decreasing as a result of low recruitment. Subjective evaluation by local trappers indicated that muskrat populations have declined over several years prior to the initiation of the current study. These subjective evaluations may or may not be accurate, but they do present the possibility that muskrat populations in the rivers being studied have been declining. However, from personal observations, muskrat signs were difficult to find in most sections of the study areas (especially the Nansemond River) from 1986 through the end of 1987. From the beginning of 1988 through 1989, these signs gradually became more numerous, although never abundant. These observations do not support speculation of a declining population but may indicate gradual changes that are occurring in population size simply due to annual fluctuations.

It may be possible that several of the trapping areas included in the current study are peripheral areas used occasionally by wandering adults. Several of the sections trapped were subjectively evaluated as poor muskrat habitat during initial surveys (see Methods). However, muskrats were regularly trapped in these areas although no lodges or dens could be located. In the lower region of the Elizabeth River during 1987, 74% of the muskrats captured in poor habitat were adults compared to 54% adults captured in suitable habitat. Even in suitable habitats within the lower region of the Elizabeth River the percentage of immatures is less than would be expected for a healthy productive muskrat population. Elangbam et al. (1989) reported a lower percentage of juveniles (11%) in cotton rats (*Sigmodon hispidus*) trapped at a toxic waste disposal site compared to controls (20%). Greater concentrations of environmental contaminants were detected in the sediment samples and muskrats from the lower region of the Elizabeth River (see Chapter 1) and

may have an influence on the age structure of the population in that region through increased mortality in the immature age class. However, the lower region of the Elizabeth River is not trapped annually and the ratio of adults to immatures is more likely an accurate reflection for a nontrapped muskrat population. Because the lower region is not normally trapped, the adult : immature ratio in suitable habitat was not surprising. Therefore, it is possible that the percentages of adults and immatures reported in the current study are reflective of the actual percentages in the muskrat populations inhabiting or utilizing the areas trapped during this study.

At this time, the actual proportion of adults and immatures in the muskrat populations in the various regions of the study areas cannot be stated with confidence. However, I believe that the muskrats captured were aged correctly and that there is insufficient evidence to assert that the probability of capture between adults and immatures is different. I further believe that, based on the age ratio observed in good habitat, the proportion of adults to immatures is approximately 50:50 in suitable habitats in the lower region of the Elizabeth River and that marginal or poor habitats are utilized primarily by wandering adults. Therefore, I would suggest that the population in the lower region of the Elizabeth River is stable with low productivity. The lower than expected percentage of immatures in suitable habitats within this region probably results from greater survival of adults due to no trapping pressure rather than from the influence of environmental contaminants. I believe that the age ratio in the upper region Elizabeth River population in suitable habitat is approximately 40:60 (adults to immatures, based primarily on kill trap data). The upper region of the Elizabeth River was regularly trapped by a professional trapper. The areas live trapped in the upper region of the Elizabeth River were mainly peripheral areas immediately adjacent to the river and utilized primarily by adults, accounting for the lower percentage of immatures live trapped in this region. Although there were increased signs of muskrat activity in the Nansemond River during the last half of this study, live and kill trapping data indicated an adult to immature ratio of 67:33 suggesting a declining population. Some possible explanations for this decline were previously discussed.

The literature on sex ratios in muskrat populations is abundant, varied, and confounded by inconsistencies in methods. Results of my study indicated a sex ratio in favor of males, which is

consistent with sex ratios reported in most studies (Table 33). Several explanations have been proposed for the discrepancies in sex ratios. These include differences in mortality between the sexes, greater tendency of males to wander, and time of year of trapping (Dozier and Allen 1942, Gashwiler 1950, Perry 1982). In studies involving live trapping, the potential also exists for differences in capture probabilities between males and females. In the current study significant differences in sex ratios occurred in muskrats collected from the Elizabeth River in the spring but not in Fall or Winter. The sex ratios of muskrats collected from the Nansemond River did not differ significantly from 1:1 during any season, although small sample sizes are thought to have contributed to the nonsignificance observed in this region. Erickson (1963) also indicated a seasonal variation in sex ratio in live trapped muskrats. He reported 62% males in muskrats captured and recaptured from February - October.

The sex ratio of immature muskrats in the current study did not differ significantly from 1:1. Erickson (1963) reported a near equal sex ratio in nestlings (105 M : 100 F), and an unbalanced ratio (no statistical analysis was indicated) in favor of males (118 M : 100 F) in immatures captured in the fall. The sex ratio reported by Erickson (1963) for immatures is the same as observed in the current study. Other studies have reported quite different sex ratios for the immature age class. Parker and Maxwell (1980) reported immature sex ratios of 175 M : 100 F (1976) and 251 M : 100 F (1977) in live trapped muskrats from New Brunswick, Canada. Their results not only differ with the results observed in the current study and those reported by Erickson (1963), but also vary considerably between the two years of their study. Parker and Maxwell (1980) also indicated that sex ratios of harvested muskrats (kill trapped during the regular trapping seasons) favored males in all seasons, especially in the fall when immature males were predominant.

Based on the nonsignificant difference observed in the sex ratio of immatures from the current study and the significantly different ratios observed in adults in the spring, but not the fall or winter, a difference in probability of capture between males and females is suspected, at least in spring. Although unlikely, a differential mortality between males and females cannot be totally rejected. For differential mortality to have been affecting muskrat populations in the study areas, the following scenario would have to exist: the immature age class has a 1:1 sex ratio; over winter the

Table 33 Comparison of sex ratios of muskrats live captured from the Elizabeth and Nansemond Rivers, Va. with those reported by various authors.

Location	Age	Sex ratio Males : Females	Reference
New Brunswick	Adults	150:100[1]	Parker and Maxwell (1980)
Maine	Adults	125:100	Gashwiler (1950)
New York	Adults	163:100[1]	Erickson (1963)
Wisconsin	Adults	98:100	Beer and Truax (1950)
Maryland	Adults	142:100	Dozier (1944)
Virginia	Adults	185:100[1]	Current Study
New Brunswick	Immatures	251:100[1]	Parker and Maxwell (1980)
New York	Immatures	118:100[1]	Erickson (1963)
Wisconsin	Immatures	132:100	Mathiak (1966)
Wisconsin	Immatures	134:100	Beer and Truax (1950)
Virginia	Immatures	118:100[1]	Current Study

[1] Results from live trapping.

female mortality is greater than male mortality resulting in unequal sex ratios in favor of males in the spring; followed by a greater mortality in males during the summer resulting in a fall sex ratio of 1:1 in the adult age class. Whether such a scenario exists is speculative.

In the current study density estimates based on 1987 data were similar for lower region (0.87 muskrats/100 m of shore) and upper region (1.14 muskrats/100 m of shore) Elizabeth River muskrats and no significant difference in the number of placental scars/female was noted. Reproductive activity (births) appear to peak in April - May and September with some births occurring during all seasons except during extreme winters. The muskrat population in the lower and upper regions of the Elizabeth River appeared to be stable; however, survival dynamics between these regions were apparently different as indicated by differences in adult and immature age ratios (50:50 in the lower region and 40:60 in the upper region) probably resulting from differences in trapping pressure.

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CHAPTER 4: SUMMARY AND CONCLUSIONS

Surface sediments from the lower region of the Elizabeth River had greater mean concentrations of 14 polynuclear aromatic hydrocarbons (PAH's) and greater mean concentrations of the toxic metals cadmium, lead, and mercury than either of the other two regions studied. Six PAH compounds were detected in muskrats from the lower region of the Elizabeth River and mean kidney aluminum, cadmium, copper, nickel, and zinc concentration were significantly greater in lower region Elizabeth River muskrats than in muskrats from the other two regions. This indicates that the contaminants detected in the sediments of the lower region are assimilated by the muskrats of this region and that the quality of this environment is reduced compared with that of the other two regions studied. However, density and reproductive rates were similar between the muskrat populations in the lower and upper regions of the Elizabeth River. No overt signs of toxicity were indicated, with the possible exception of necrosis in the livers of two muskrats from the Elizabeth River. However, environmental exposure to PAHs and heavy metals may result in adverse affects unaccompanied by clinical signs of toxicity (Koller 1979, 1980).

In the current study, differences among regions were found for several body and organ measurements. Specifically, mean total, carcass, and spleen weights were lowest in muskrats

collected from the lower region of the Elizabeth River. In addition, microscopic examinations of liver sections suggested that the incidence of disease was greatest in muskrats from this region. Following administration of various PAH compounds to different species, decreases in body and spleen weights and dysfunction of the immune system have been observed. Hargis et al. (1984) reported no weight gain in fish exposed for 28 days to sediments from the Elizabeth River contaminated with PAHs. Huggins (1961) reported a decrease in body weight for 48 hrs followed by normal weight gain after a single oral dose of the PAH compounds 3-methylcholanthrene (3-MC, 100mg) or 7,12-dimethylbenz(a)anthracene (DMBA, 20mg) in female rats. In tests developed by the National Toxicology Program at the National Institute of Environmental Health and Sciences, spleen weight is included in a panel of tests to detect immune alterations following chemical or drug exposure in rodents (Luster et al. 1988). Marked decreases in spleen weights have been reported following administration of the PAH compounds benzo(a)pyrene and DMBA (Dean et al. 1986). White et al. (1985) reported significant decreases in spleen weights in female mice following subchronic 14 day dosing (160 μmol/kg/day) with benzo(a)pyrene and dibenz(a,h)anthracene. In these same mice, immunosuppression (decrease in antibody-forming cells) was significant with exposure to benz(a)anthracene (-56%, percent change from controls), benzo(a)pyrene (-64%), dibenz(a,c)anthracene (-55%), and dibenz(a,h)anthracene (-91) but not with exposure to anthracene, chrysene, benzo(e)pyrene, and perylene. Natural killer cells are one of the most intensely studied components of innate immunity. These cells participate in host resistance against bacterial, viral, and protozoan parasite exposure. Several carcinogenic PAHs have been shown to cause dysfunction of the immunological system through decreases in natural killer cell activity (White 1986). DMBA administered orally (1 mg/week) to various strains of mice for 5 to 6 weeks produced significant decreases in natural killer cell activity that persisted for at least 100 days (Ehrlich et al. 1980, Argov et al. 1981).

Anthracene, chrysene, benzo(a)pyrene, and benzo(e)pyrene were the only PAHs that were reported in the references above and also were analyzed in the current study. Levels of all four compounds were significantly greater in sediment samples from the lower region of the Elizabeth River than in sediment samples from the upper region of the Elizabeth River or Nansemond River.

Anthracene and chrysene also were detected in muskrats from the lower region of the Elizabeth River (see Chapter 1). It is possible that other PAH compounds are present in muskrats from this region. Only 14 PAH compounds were analyzed in the current study and an additional 29 unknown compounds were detected. Previous studies have reported approximately 300 aromatic compounds (mostly PAH) in Elizabeth River sediment (Lu 1982, Bieri et al. 1986, Huggett et al. 1986). PAH compounds are rapidly metabolized and the detection of high concentrations of the parent compounds was not anticipated.

Exposure to subclinical doses of cadmium, lead, mercury, and nickel have all been shown to result in immunological suppression in experimental animals. Lead, cadmium, nickel, and mercury (methyl and inorganic) compounds have been reported to reduce the effectiveness of the immune system in rabbits and mice (Koller 1973, 1975, Gainer 1977, Koller et al. 1977, Graham et al. 1978, Adkins et al. 1979, Goyer 1986). Cadmium and nickel concentrations in the kidneys of muskrats from the lower region of the Elizabeth River were significantly greater than in the kidneys of upper region Elizabeth River or Nansemond River muskrats. Kidney lead concentrations were significantly greater in muskrats from the lower region of the Elizabeth River than in muskrats from the Nansemond River but not in muskrats from the upper region of the Elizabeth River. Kidney mercury concentrations were numerically greater in lower region Elizabeth River muskrats but not significantly different from those found in upper region Elizabeth River or Nansemond River muskrats (see Chapter 1). No studies of immunological suppression in muskrats resulting from exposure to heavy metals were found.

Weeks et al. (1986) and Weeks and Warinner (1986) reported decreased chemotactic activity (macrophage chemotaxis) and decreased phagocytic efficiencies in fish collected from the Elizabeth River that was related to exposure to environmental contaminants. In the current study, subtle physiological differences were noted in the muskrats from the lower region of the Elizabeth River compared to muskrats from the other two regions (see Chapter 2). Significantly lower spleen weights and the indication of increased incidence of disease in lower region Elizabeth River muskrats suggest immunological suppression.

In summary, the concentrations of PAHs and toxic metals detected in the sediment samples and muskrats from the lower region of the Elizabeth River indicate that the quality of the environment in this region is diminished compared to that in the upper region of the Elizabeth River or Nansemond River. The influence these contaminants have on physiology and population dynamics of muskrats in this region appears minimal. Although ^{32}P-Postlabeling of DNA adducts did not detect a significant difference in adduct levels between muskrats from the lower region of the Elizabeth River and Nansemond River, decreased pentobarbital sleeping times indicate that muskrats from this region have been exposed to xenobiotics that have resulted in the induction of metabolizing enzymes. Liver histological data suggested an increase in the incidence in disease, the incidence of parasitism was increased, and body and spleen weights were reduced in muskrats from this region. Overt signs of toxicity were absent, although necrotic lesions noted in the liver of two muskrats are suspect. Previous studies have indicated that exposure to subclinical concentrations of PAHs and heavy metals can result in immunological dysfunction. Decreased spleen weights and increased incidence of disease would be manifestations of immunosuppression. Although these results are circumstantial, I suspect that the environmental contaminants found in the lower region of the Elizabeth River do have an influence on the muskrats from this region, through subtle, negative effects, primarily involving immunological function. The muskrat density in this region appears to be stable and similar to the density in a less contaminated area (although survival dynamics are apparently different), and reproduction does not appear to be affected (see Chapter 3). However, if immunological suppression is occurring, this population of muskrats would probably be susceptible to greater fluctuations resulting from introduction of additional stress (i e. disease, severe weather etc.).

Several previous studies have indicated that environmental contaminants (heavy metals) do accumulate in muskrats and some have suggested that muskrats may be useful as an indicator species of environmental contamination (Everett and Anthony 1976, Sheffy 1977, Erickson and Lindzey 1983). The current study is the only known study to analyze muskrat tissues for organochlorine and PAH compounds and is the most extensive study of heavy metals accumulation in muskrats. Of the 33 heavy metals detected in $> 80\%$ of both sediment and muskrat samples,

only cadmium, iron, manganese, and vanadium were significantly correlated and cadmium was the only metal with a high (> 0.90) Pearson's correlation coefficient. Therefore, the use of muskrats as indicator species of heavy metal contamination appears limited. Four hundred and forty assays of sediment samples for organochlorine compounds (20 sediment samples × 22 compounds assayed) resulted in the detection of 10 OC compounds and 770 assays of muskrat tissues for organochlorine compounds (35 muskrat samples × 22 compounds assayed) resulted in 6 detection of OC compounds. These results do not indicate whether muskrats are good indicators of the presence of organochlorines. PAHs (parent compounds) were detected in 63% of the muskrat carcasses analyzed, which is higher than initially expected because these compounds are rapidly metabolized. Additional studies will be necessary before it is known whether muskrats are good indicators of OC or PAH environmental contamination. However, the current study indicates that such studies would be worthy of consideration.

The muskrat is a wildlife resource with a long history of economic, recreational, and esthetic value. It's ability to survive in an environment heavily contaminated with the products and by-products of an industrialized society is noteworthy. In the face of continued usurping of suitable habitat to meet the demands of an increasing human population, wild species populations are decreasing in number. Hopefully, humanity will realize the significant role that wild species play in the quality of their lives before suitable habitats are no longer sufficient to support an abundant and diverse wild fauna. The muskrat is a resourceful and resilient animal that should continue to be a wildlife resource even in harsh environments where less resourceful or more sensitive species are no longer able to survive.

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Appendix A. ^{32}P-POSTLABELING OF DNA ADDUCTS.

The following are the methods used in DNA isolation and ^{32}P-postlabeling of DNA adducts. The DNA isolating methods are similar to those reported by Hogeboom (1952, 1955) and the postlabeling are similar to those reported by Gupta (1985) and Reddy and Randerath (1986).

DNA EXTRACTION:

1. Muskrat liver tissue (~1 g) was homogenized in 10 ml/g 0.25 M sucrose/1.8 mM $CaCl_2$ using a hand held Potter-Elvehjem homogenizer, layered over 2 volumes of 0.34 M sucrose/0.18 mM$CaCl_2$ and spun for 15 min at 1000 × g, 4^0.

2. The supernate was discarded and the pellet resuspended in 5 ml 0.25 sucrose/0.18 mM $CaCl_2$ homogenized and layered over 10 ml 0.34 M sucrose/0.18 mM $CaCl^2$ and spun at 1000 × g, 4^{0}C.

3. The supernate was discarded and the pellet resuspended in 2 ml/g lysis solution (50 mM Tris pH 8.0, 50 mM EDTA, 0.5% sodium dodecyl sulfate, 200 µg/ml proteinase K) and incubated for 3 hr at 50^0 C.

4. Three ml phenol was added and incubation was continued for 1 hr., followed by spinning at 1000 × g, 4^{0}C. The aqueous phase (DNA solution) was transferred using a wide-bore transfer pipet to a clean centrifuge tube and another 3 ml phenol added and incubated for 1 hr, followed by spinning at 1000 × g, 4^{0}C.

5. The aqueous phase was transferred to a clean tube and RNASE (1 unit activity/µl) added and incubated at room temperature for 1 hr. The solution was transferred to a dialysis bag (50 kdaltons) and dialyzed against 2 l 0.01 M EDTA. The 2 l of 0.01 EDTA was changed every hour for 3 hrs and then dialysis was continued overnight.

6. DNA solutions were transferred from dialysis bags to clean tubes and the A270 checked spectrophotometrically (check for presence of RNA - reading below 0.05 were accepted).

7. One half vol. 7.5 M ammonium acetate and then 2 vols. ice cold 100% ETOH were added and the sample placed in the freezer (-20^{0}C) overnight. Samples were centrifuged at 12,000 × g, room temperature for 30 min, the liquid was decanted and 1 ml 70% ETOH added to wash. Samples were spun at 12,000 × g, room temperature for 5 min and the liquid decanted.

8. Samples were vacuum dried (approximately 45 min) and resuspended in 500 µl TE buffer (10 mM Tris pH 7.5, 1 mM EDTA), swirled and left at room temperature overnight. Samples were dissolved in 500 µl dH_2O, the total volume determined, and transferred to a 1.5 ml microcentrifuge tube. A260/A280 ratios were determined and µg of DNA calculated (A260/A280 ratio × 50 µg DNA/ml × dilution factor = µg DNA/ml).

DNA HYDROLYSIS

1.5 µl micrococcal nuclease, 1.5 µl spleen phosphodiesterase, and an appropriate volume of succinate, $CaCl_2$ (pH 6.0) buffer were added to sample volume containing 5 µg DNA to give a total volume of 12.5 µl. This solution was incubated for 3.5 hrs at 38° C. After incubation 37.5 µl H_20 was added to give a total volume of 50 µl (DNA concentration = 0.1 µg/µl).

ISOLATION OF ADDUCTS

10 µl hydrolyzed DNA (1 µg DNA) was mixed with 5 µl 100 mM ammonium formate (pH 3.5), 5 µl 10 mM tetrabutylammonium chloride, and 30 µl H_20. Extracted 2 × 1 vol with H_20 saturated butanol (Spectral grade). Extraction was done in a 1.5 µl microcentrifuge tube with vortexing for 30 sec followed by centrifugation for 1 min. The butanol phase was back extracted with 2 × 90 µl H_20. 1 µl of 200 mM tris HCL (pH 9.5) was added and the sample taken to dryness on a rotary evaporator (heated to 50°C for approximately 30 min).

^{32}P-POSTLABELING OF ADDUCTS

Residues for the 1 µg samples of DNA were dissolved in 10 µl H_20. To this was added 5 µl of radioactive mixture containing 2.25 µl 10X buffer (300 mM tris-HCL (pH 9.5), 100 mM $MgCl_2$, 100 mM DTT, and 10 mM spermidine), 1.9 µl carrier-free (γ-^{32}P)ATP (200 µCi, approximately 6000 Ci/mM), 1.5 µl polynucleotide kinase, and 1.85 µl H_20 (final volume of radioactive mixture was 7.5 µl). This solution was pipetted in the microcentrifuge tube for mixing and then incubated at 38°C for 30 min.

FINGERPRINTING OF ^{32}P-Adducts

1. Polyethyleneimine cellulose plates were washed overnight in H_2O in a closed tank (when the solvent front reached the top of the plate, the tank was partially opened to allow yellow impurities to concentrate at the top of the plate). The plate was air dried or dried with a hair dryer before use.

2. The plate was marked as described by Gupta (1985) for running 2 samples per plate.

3. A 13 µl aliquot of sample was applied at the origin. A wick (Whatman #1 filter paper was attached to the top of the plate. Development in direction D1 was begun before the applied sample dried on the plate. The buffer for D1 was 1.0 M Na"P", pH 6.5. Development was done overnight. The wick and top 5 cm of plate were then cut off and discarded. The plate was washed in 2 - 3 l of H_2O for ~10 min with constant motion and then placed in a tank containing H_2O (~1.5 l) for and additional 5 min with periodic agitation. All water was changed prior to each washing. The plate was then dried, using a hair dryer, prior to further developing.

4. The plate was developed in direction D2 using 3.75 M ammonium formate, pH 3.5. Requiring ~2 hrs to reach the top of the plate. The plate was cut as described by Gupta (1985). The plate was washed as described above.

5. The plate was developed in direction D3. The plate was first dipped in ~1/2 cm of H_2O and developed up to the origin, blotted fry and then placed in 5.3 M Li formate, pH 3.5 containing 8.5 M urea and developed to the top of the plate (~3 hrs). The plate was cut as indicated to yield 2 square pieces that were washed as described above.

6. The plate was next developed in direction D4 in 1.2 M LiCl:0.5 M Tris, pH 8.0 and 8.5 M urea. About 3 hrs was required to reach the top of the plate. The plate was washed as described above.

7. The plate were developed in direction D5 using 1.7 M Na″P″, pH 6.0. A wick was attached to the top of the plate and development proceeded overnight. The plate was washed as described above.

TOTAL NUCLEOTIDE DETERMINATION

5 µl of DNA digest was diluted to 500 µl with H_2O. A 5 µl aliquot was then mixed with 2.5 µl radioactive mix and incubated for 30 min. 1.5 µl of carrier and 1 µl potato apyrase was then added to each sample and incubation was continued for another 30 min. 240 µl Tris EDTA was added to the sample following incubation. 5 µl of this mix was then placed on a PEI-cellulose plate and developed in 150 ml of 40 mM ammonium sulfate (~1.5 hrs). The plate was dried and exposed to film at room temperature for ~2 hrs.

AUTORADIOGRAPHY

Plates were placed on an 8 X 10 piece of XAR-5 film. The film was exposed for 24 -72 hrs at -80°C prior to development. The PEI-cellulose plate was aligned with the developed film and the radioactive areas were marked. Marked areas were cut out and scintillations were counted. The nmoles of DNA adducts per mole of normal nucleotide was calculated as described by Gupta (1985).

Appendix B. HEAVY METAL ANALYSIS

The following were methods used at the Environmental Trace Substance Research Center, Columbia, Missouri for metal analysis. Kidneys from 76 muskrats and 20 surface sediment samples collected during the current study were sent to this laboratory for metal analysis. This facility was chosen for metal analysis because it has been approved by the U.S. Fish and Wildlife Service and is familiar with analysis and handling of animal tissues.

INDUCTIVELY COUPLED PLASMA (ICP)

The instrument used for ICP analysis was a Jarrell-Ash Model 1100 Mark III with 40 analytical channels, controlled by a Digital Equipment Company (DEC) 11/23+ computer with two RLO2 disk drives, DEC VTIOO terminal, and DEC LAl2O decwriter III.

The instrument was standardized with a series of seven standards containing 36 elements. After the standardization, the detection limit was determined by taking ten integrations of the zero standard; three times the standard deviation of the mean was used as the detection limit. Instrumental quality control samples were then analyzed to check the ICP operation. If the values were acceptable, the samples were then analyzed. Standards were run every 10-15 samples to check for drift. If the drift was more than 5%, the instrument was restandardized. After the analysis was completed, the data was transferred to the Perkin-Elmer LIMS 2000 computer for calculation. The final detection limit for each element was further increased by 4% of the magnitude of the spectral interferences from the other elements. The data was checked before calculation to correct for possible errors in sample number, weight, volumes and dilution. The data was calculated using the ICP calculation program written by ETSRC computer staff, which corrected for blanks, standard drift, spectral interferences, sample weight, sample volume, and dilution. After the quality control was reviewed, a final report was generated using a Hewlett-Packard laser jet printer.

NITRIC - PERCHOLORIC DIGESTION - (ICP)

Approximately 0.5 g of sample was weighed into a freshly cleaned 100 ml quartz Kjeldahl flask. (Samples containing a high percent of silica and sediment samples were digested in 100 ml teflon beakers.) Slowly 15 ml of concentrated sub-boiled HNO_3 and 2.5 ml of concentrated sub-boiled $HClO_4$ were added. Foaming may occur with some samples. If the foaming started to become excessive, the container was cooled in a beaker of cold water. After the initial reaction had subsided, the sample was placed on low heat until the evolution of dark red fumes had ceased. Gradually, the heat was increased until the HNO_3 began refluxing, samples were allowed to reflux overnight. (This decreased the chance for charring during the reaction with $HClO_4$). After the refluxing, the heat was gradually increased until the HNO_3 had been driven off, and the reaction with $HClO_4$ had occurred. When dense white fumes from the $HClO_4$ were evident, the samples were removed from the heat and allowed to cool. Two ml of concentrated sub-boiled HCl was added. The flasks were replaced on the heat and warmed until the containers were hot to the touch or started to boil. They were removed from the heat, and 5-10 ml of deionized water was added. Samples were allowed to cool. They were then diluted using deionized water in a 50 ml volumetric flask and transferred to a clean, labeled, 2 oz polyethylene bottle.

MERCURY - COLD VAPOR ATOMIC ABSORPTION

Equipment used for Cold Vapor Atomic Absorption include: Perkin-Elmer Model 403 AA; Perkin-Elmer Model 056 recorder; Technicon Sampler I; Technicon Pump II; a glass cell with quartz windows and capillary tube for entry and exit of the mercury vapor; and a liquid-gas separator.

The samples were placed in 4 ml sample cups at least 3/4 full. The samples were mixed with hydroxylamine for preliminary reduction, then stannous chloride for reduction to the mercury vapor. The vapor was separated from the liquid and passed through the cell mounted in the light path of the burner compartment. The peaks were recorded and the peak heights measured. The standardization was done with at least 5 standards in the range of 0 to 10 ppb. The correlation coefficient was usually 0.9999 or better and must have been at least 0.999 to have been acceptable. A standard was run every 8-10 samples to check for drift in the standardization. This was usually less than 5%. Standards were preserved with 10% v/v HNO_3, 1% v/v HCl and 0.05% w/v $K_2Cr_2O_7$. The solution concentrations were calculated and the data entered into the AA calculation program which corrected for blank, dilution, sample weight, sample volume and entered the data into the LIMS system for report generation.

NITRIC REFLUX DIGESTION FOR MERCURY

Approximately 0.5 g of sample was weighed into a freshly cleaned 50 ml round bottom flask with 24/40 ground glass neck. Five ml of concentrated sub-boiled HNO_3 was added and the flask was placed under a 12 inch water cooled condenser with water running through the condenser. The heat was turned up to allow the HNO_3 to reflux no more than 1/3 the height of the columns. Samples were allowed to reflux for two hours. Then the heat was turned off

and the samples allowed to cool. The condensers were rinsed with 1% v/v HCI and the flasks removed. The samples were diluted with 1% v/v HCI in a 50 ml volumetric flask and then transferred to a clean, labeled, 2 oz flint glass bottle.

Appendix C. ORGANOCHLORINE AND POLYNUCLEAR AROMATIC HYDROCARBON ANALYSIS

The following methods were used at the Mississippi State Chemical Laboratory, Mississippi State, Mississippi for organochlorine and polynuclear aromatic hydrocarbon analysis. Thirty-five muskrat carcasses and 20 surface sediment samples collected during the current study were sent to this laboratory for analysis. This laboratory was chosen because it has been approved by the U.S. Fish and Wildlife Service and because they are familiar with analysis and handling of animal tissues.

ANALYSIS FOR ORGANOCHLORINE PESTICIDES AND PCBs IN ANIMAL TISSUE.

Ten gram tissue samples are thoroughly mixed with anhydrous sodium sulfate and soxhlet extracted with hexane for seven hours. The extract is concentrated by rotary evaporation; transferred to a tared test tube, and further concentrated to dryness for lipid determination. The weighed lipid sample is dissolved in petroleum ether and extracted four times with acetonitrile saturated with petroleum ether. Residues are partitioned into petroleum ether which is washed, concentrated, and transferred to a glass chromatographic column containing 20 grams of Florisil. The column is eluted with 200 ml 6% diethyl ether/94% petroleum ether (Fraction I) followed by 200 ml 15% diethyl ether/85% petroleum ether (Fration II). Fraction II is concentrated to appropriate volume for quantification of residues by packed column electron capture gas chromatography. Fraction I is concentrated and transferred to a Silicic acid chromatographic column for additional cleanup required for separation of PCBs from other organochlorines. Three fractions are eluted from the Silicic acid column. Each is concentrated to appropriate volume for quantification of residues by packed or megabore column, electron capture gas chromatography. PCBs are found in Fraction II.

ANALYSIS FOR ALIPHATIC AND POLYNUCLEAR AROMATIC HYDROCARBONS IN ANIMAL TISSUE

A sample of appropriate size (i.e. 15 grams animal tissue) is digested in 6N aqueous potassium hydroxide for 24 hours at 35°C. Cool digestate thoroughly in an ice bath and carefully neutralize with glacial acetic acid. Extract the neutralized reaction mixture three times with methylene chloride; concentrate the combined extracts to near dryness and reconstitute in petroleum ether for transfer to a 20 gram 1% deactivated silica gel column, topped with 5 grams neutral alumina. Aliphatic and polynuclear aromatic hydrocarbon residues are separated by eluting aliphatics from the column with 100 ml petroleum ether (Fraction I) followed by elution of aromatics using first, 100 ml 40% methylene chloride/60% petroleum ether, then 50 ml methylene chloride (Combined eluates, Fraction II). If needed, Fraction I containing aliphatics is subjected to additional cleanup by concentration and transfer to a deactivated (2% water) Florisil column. Aliphatic residues are eluted from the Florisil column using 200 ml 6% diethyl ether/94% petroleum ether. The eluate is concentrated to appropriate volume for quantification by capillary column, flame ionization gas chromatography. The silica gel Fraction II containing aromatic hydrocarbons is concentrated, reconstituted in methylene chloride, and subjected to gel permeation chromatographic (GPC) cleanup prior to quantification by capillary, flame ionization gas chromatography and fluorescence HPLC.

ELUTION PROFILES FOR FLORISIL, SILICA GEL AND SILICIC ACID COLUMN SEPARATIONS

A. Florisil Column:

1. Fraction I (6% ethyl ether with 2% ethanol, 94% petroleum ether).

   HCB, alpha-BHC, beta-BHC, gamma-BHC, delta-BHC, oxychlordane heptachlor epoxide, gamma-chlordane, trans-nonachlor, toxaphene PCB's, o,p'-DDE, alpha-Chlordane, p,p'-DDE, o,p'-DDT, cis-nonachlor, o,p'-DDT, p,p'-DDD, p,p'-DDT, mirex, dicofol, encosulfan I (Split with FII).

2. Fraction II - (15% ethyl ether with 2% ethanol, 85% petroleum ether).

   dieldrin, endrin, dacthal, endosulfan I (split with FI) endosulfan II (split with FIII), endosulfan sulfate (split with FIII).

3. Fraction III - (50% ethyl ether with 2% ethanol, 50% petroleum ether).

   endosulfan II (split with FII), endosulfan sulfate (split with FII), malathion.

B. Florisil Mini-Column:

1. Fraction I - (12 ml hexane followed by 12 ml 1% methanol in hexane).

HCB, gamma-BHC (25%), alpha-BHC (splits with FII), trans-nonachlor, o,p′-DDE, p,p′-DDE, o,p′-DDD, p,p′-DDD (splits with FII), o,p′-DDT, p,p′-DDT, mirex, cis-nonachlor, cis-chlordane, trans-chlordane, PCB′s.

2. Fraction II - (24 ml 1% methanol in hexane).

   gamma BHC (75%), beta-BHC, alpha-BHC (splits with FI), delta-BHC, oxychlordane, heptachlor epoxide, toxaphene, dicofol, dacthal.

C. Silica Gel:

1. SG Fraction I - (100 ml petroleum ether).

   n-dodecane, n-tridecane, n-tetradecane, octylcyclohexane, n-pentadecane, nonylcyclohexane, n-hexadecane, n-heptadecane, pristane, n-octadecane, phytane, n-nonadecane, n-eicosane.

2. SG Fraction II (100 ml 40% methylene chloride in petroleum ether followed by 50 ml methlene chloride).

   naphthalene, fluorene, phenanthrene, anthracene, fluoranthrene, pyrene, 1,2-benzanthracene, chrysene, benzo [b] fluoranthrene, benzo [k] fluoranthrene, benzo [e] pyrene, benzo [a] pyrene, 1,2:5,6-dibenzanthracene, benzo [g,h,i] perylene.

D. Silicic Acid:

1. SA Fraction I (20 ml petroleum ether).

   HCB, mirex.

2. SA Fraction II (100 ml petroleum ether).

   PCB′s, p,p′-DDE (splits with SA III).

3. SA Fraction III (20 mls-mixed solvent: 1% acetonitrile, 80 % methylene chloride, 19% hexane).

   alpha-BHC, beta-BHC, gamma-BHC, delta-BHC, oxychlordane, hextachlor epoxide, gamma-chlordane, trans-nonachlor, toxaphene, o,p′-DDE, alpha-chlordane, p,p′-DDE (splits with SA II), o,p′-DDT, cis-nonachlor, o,p′-DDT, p,p′-DDD, p,p′-DDT, dicofol.

Appendix D. METAL, BLOOD, AND BODY MEASUREMENT TABLES

The following tables contain metal data from surface sediment samples collected from the Elizabeth and Nansemond Rivers and metal, blood, and body and organ measurement data from muskrats that were live trapped from the Elizabeth and Nansemond Rivers during this study and body and organ data from muskrats obtained from cooperative trappers. The following code was used: NUM = muskrat number, RV = river (1 = Elizabeth, 2 = Nansemond), RG = region (1 = lower region Elizabeth River, 3 = upper region Elizabeth River, 5 = Nansemond River), SC = numbered sections within each region where muskrats were trapped, AGE = age (1 = immature, 3 = adult), Sex = sex (1 = male, 3 = female).

Table 34. Metal[1] concentrations (ppm dry wt) detected in surface sediment samples from the Elizabeth and Nansemond Rivers, Va., 1988.

OBS	RV	RG	SC	AGS	ALS	ASS	BS	BAS	BES	BIS	CAS	CDS	COS	CRS	CUS	FES	KS	MS	LIS	MGS
1	1	1	7	0	16100	23	25	71.7	1.20	0	4210	2.60	13	70	178.0	17200	2800	34.0	25.8	5360
2	1	1	7	0	9580	19	12	46.5	0.79	0	2330	1.60	13	40	132.0	11300	1500	47.0	17.0	2930
3	1	1	7	0	6510	10	17	57.8	0.85	0	2480	1.90	20	56	78.5	12300	1100	90.0	10.0	2830
4	1	1	7	0	8280	10	14	59.8	0.64	0	4650	0.95	10	52	52.8	11600	1400	36.0	12.0	3000
5	1	1	20	0	15500	9	10	40.2	0.92	0	1000	0.00	14	31	13.0	16800	2800	22.0	26.2	3450
6	1	1	20	0	27900	30	30	55.3	4.40	0	3430	2.20	37	24	57.2	35800	3680	37.0	59.4	6880
7	1	1	20	0	22500	20	23	72.2	1.00	0	1950	0.40	19	29	24.0	20600	3830	27.0	34.1	4700
8	1	1	29	0	23300	30	20	70.0	1.10	0	2110	0.60	11	46	66.0	30000	3720	0.0	38.4	5310
9	1	1	29	0	9200	9	10	35.9	0.56	0	1400	0.00	18	37	23.0	14200	1800	59.0	14.0	2270
10	1	1	29	0	22900	20	16	85.1	1.10	0	2250	0.50	17	49	55.6	32600	4290	29.0	38.6	5320
11	1	3	2	0	36200	20	22	78.3	1.40	0	9040	0.50	17	29	51.9	25700	4610	24.0	66.1	6210
12	1	3	2	0	20800	10	15	45.4	0.85	0	1820	0.40	15	33	31.4	14200	2600	31.0	40.9	3900
13	1	3	16	2	18900	10	18	39.4	0.69	0	6990	0.50	13	32	36.7	11700	2300	19.0	32.9	4140
14	1	3	25	1	11700	7	20	27.1	0.46	0	2350	0.20	27	27	17.0	5750	1900	77.0	22.7	3530
15	1	3	25	1	18500	10	25	43.3	0.67	0	3590	0.20	11	36	24.4	11800	3100	22.0	38.5	5470
16	2	5	5	0	37900	30	23	120.0	1.50	0	2990	0.30	16	30	32.0	37900	6200	8.4	56.5	7570
17	2	5	5	0	39500	30	27	137.0	1.50	0	3350	0.00	30	31	23.0	39400	6190	4.0	60.6	8020
18	2	5	28	0	38900	30	26	136.0	1.50	6	3320	0.20	14	25	19.0	34200	5750	8.6	54.9	7170
19	2	5	28	0	45500	40	30	160.0	1.70	0	4060	0.30	18	35	24.0	38600	6640	4.0	67.2	8730
20	2	5	28	0	37300	20	25	167.0	1.40	5	4550	0.30	17	29	32.0	36100	5820	13.0	54.9	7430

OBS	RV	RG	SC	MNS	MOS	NAS	NIS	PS	PBS	SBS	SES	SIS	SNS	SRS	TIS	TLS	VS	ZNS	HGS
1	1	1	7	115.0	2	19200	27	1730	170	0	0	615	0	84.9	606	0	49	455.0	0.670
2	1	1	7	69.6	2	11100	20	1300	290	0	0	558	0	52.1	434	0	34	307.0	0.320
3	1	1	7	63.8	0	8140	21	680	130	0	0	363	0	50.5	334	0	21	293.0	0.980
4	1	1	7	66.7	0	7080	24	530	130	0	0	678	0	47.5	469	0	21	206.0	0.920
5	1	1	20	139.0	0	5330	20	240	15	0	0	595	0	20.5	396	0	26	51.6	0.040
6	1	1	20	194.0	5	27100	43	2130	48	0	0	1740	0	81.7	479	0	64	438.0	0.200
7	1	1	20	63.5	2	13100	24	770	31	0	0	1080	0	73.7	680	0	45	115.0	0.170
8	1	1	29	122.0	0	13500	26	790	95	0	20	779	0	108.0	660	0	51	191.0	0.580
9	1	1	29	60.5	0	5380	18	400	45	0	0	606	0	42.3	369	0	26	82.5	0.250
10	1	1	29	108.0	0	13000	22	1100	86	0	0	1020	0	121.0	522	0	50	189.0	0.820
11	1	3	2	124.0	0	17000	25	1100	66	0	0	924	0	92.9	755	0	60	207.0	0.220
12	1	3	2	69.5	0	10800	21	710	41	0	0	677	0	39.3	437	0	37	131.0	0.120
13	1	3	16	71.0	3	13900	24	600	38	0	0	763	0	64.2	460	0	36	121.0	0.130
14	1	3	25	44.7	2	13600	19	510	30	0	0	488	0	38.7	316	0	29	53.0	0.081
15	1	3	25	71.9	0	17500	19	820	41	0	0	769	0	62.5	421	0	38	68.9	0.100
16	2	5	5	846.0	0	18100	25	980	35	0	0	1260	0	63.3	960	0	62	115.0	0.140
17	2	5	5	2080.0	0	18000	27	1300	40	0	0	1140	0	74.4	950	0	62	125.0	0.150
18	2	5	28	1600.0	0	13500	24	950	33	0	0	3280	0	65.6	1030	0	60	117.0	0.110
19	2	5	28	2970.0	0	17300	29	1100	44	0	0	2210	0	77.0	1040	0	75	149.0	0.110
20	2	5	28	5960.0	0	14400	25	1100	33	0	0	1180	0	78.5	822	0	60	118.0	0.110

[1]ags = silver, als = aluminum, ass = arsenic, bs = boron, bas = barium, bes = beryllium, bis = bismuth, cas = calcium, cds = cadmium, cos = cobalt, crs = chromium, cus = copper, fes = iron, ks = potassium, ws = tungsten, lis = lithium, mgs = magnesium, mns = manganese, mos = molybdenum, nas = sodium, nis = nickel, ps = phosphorus, pbs = lead, sbs = antimony, ses = selenium, sis = silicon, sns = tin, srs = strontium, tis = titanium, tls = thallium, vs = vanadium, zns = zinc, hgs = mercury.

Table 35. Kidney metal[1] concentrations (ppm dry wt) detected in muskrats from the Elizabeth and Nansemond Rivers, Va., 1986 - 1988.

OBS	NUM	RV	RG	SC	AGE	SX	AG	AL	AS	B	BA	BE	BI	CA	CD	CO	CR	CU	FE	K	M	LI	MG
1	526	1	1	1	3	2	0	14.0	0	0	0.25	0.00	0	580	1.000	0.0	0	12.50	710	10600	0	0.2	674
2	871	1	1	1	3	1	0	43.0	0	7	0.10	0.00	0	346	1.300	0.2	0	14.70	461	9700	0	0.0	712
3	873	1	1	1	1	2	0	33.0	0	0	0.20	0.00	0	300	0.820	0.4	0	13.40	488	10300	0	0.0	736
4	701	1	1	5	3	1	0	4.0	0	0	0.08	0.05	0	300	0.360	0.0	0	11.50	468	9450	0	0.0	767
5	560	1	1	7	1	2	0	7.0	0	0	0.08	0.00	0	260	0.600	0.0	0	12.90	617	11900	0	0.0	704
6	561	1	1	7	1	2	0	6.0	0	0	0.00	0.00	0	330	0.870	0.0	0	12.60	690	13600	0	0.0	738
7	564	1	1	7	3	2	0	5.0	0	0	0.15	0.00	0	690	23.900	0.0	0	13.00	453	9830	0	0.0	759
8	565	1	1	7	3	1	0	2.0	0	0	0.00	0.00	0	450	22.100	0.0	0	11.60	470	12500	0	0.0	791
9	717	1	1	7	3	1	0	4.0	0	0	0.00	0.00	0	330	30.100	0.0	0	14.20	496	9210	2	0.0	754
10	232	1	1	20	1	2	0	3.0	0	0	0.00	0.00	0	250	0.440	0.0	0	10.90	591	14000	0	0.0	696
11	523	1	1	20	3	1	0	5.0	0	0	0.00	0.00	0	410	1.100	0.0	0	12.60	1010	13600	0	0.2	698
12	542	1	1	20	1	1	0	9.7	0	0	0.00	0.00	0	460	0.460	0.0	0	12.10	517	12900	0	0.3	717
13	554	1	1	20	1	1	0	2.0	0	0	0.00	0.00	0	240	0.082	0.0	0	11.10	777	11500	0	0.2	642
14	580	1	1	20	1	1	0	3.0	0	0	0.00	0.00	0	250	0.250	0.0	0	11.10	441	11300	0	0.0	691
15	908	1	1	20	3	1	0	5.0	0	0	0.00	0.00	0	460	1.600	0.0	0	12.60	455	12100	0	0.0	706
16	870	1	1	20	1	2	0	42.0	0	0	0.00	0.00	0	280	0.620	0.2	0	12.00	449	8940	0	0.0	692
17	874	1	1	20	3	1	0	15.0	0	0	0.00	0.00	0	270	1.600	0.3	0	13.10	478	10300	0	0.0	757
18	875	1	1	20	3	1	0	29.0	0	0	0.00	0.00	0	433	0.360	0.5	0	14.30	531	10300	0	0.0	786
19	280	1	1	25	1	2	0	3.0	0	2	0.08	0.00	0	280	0.130	0.0	0	12.70	518	12400	0	0.2	745
20	511	1	1	25	3	2	0	4.0	0	3	0.00	0.00	0	310	0.800	0.0	0	12.50	676	12200	0	0.0	674
21	876	1	1	25	3	1	0	41.0	0	11	0.00	0.00	0	260	0.210	0.3	0	13.90	452	10700	0	0.0	725
22	878	1	1	25	1	1	0	30.0	0	0	0.10	0.00	0	290	0.390	0.5	0	14.60	733	9490	0	0.0	711
23	879	1	1	25	3	1	0	61.0	0	0	0.20	0.00	0	260	0.470	0.4	0	12.60	330	9090	0	0.0	697
24	253	1	1	29	3	1	0	7.3	0	0	0.00	0.00	0	330	0.900	0.0	0	12.70	501	13300	0	0.0	755
25	552	1	1	29	1	1	0	0.0	0	0	0.07	0.00	0	260	0.260	0.0	0	13.60	459	13200	0	0.2	812
26	557	1	1	29	3	1	0	0.0	0	0	0.00	0.00	0	280	0.100	0.0	0	12.10	545	12300	0	0.0	719
27	559	1	1	29	3	1	0	3.0	0	3	0.10	0.00	0	260	0.240	0.0	0	13.40	706	12300	0	0.3	755
28	562	1	1	29	3	2	0	5.0	0	0	0.20	0.00	0	370	1.000	0.0	0	14.30	850	13600	0	0.0	815
29	563	1	1	29	1	2	0	7.4	0	0	0.10	0.00	0	470	0.080	0.0	0	12.30	589	12000	0	0.0	849
30	877	1	1	29	1	2	0	25.0	0	0	0.00	0.00	0	534	0.330	0.0	0	14.50	635	12100	0	0.0	771
31	712	1	3	.	3	2	0	5.0	0	0	0.16	0.10	0	410	1.900	0.0	0	11.80	552	11600	0	0.0	740
32	715	1	3	.	3	2	0	3.0	0	0	0.00	0.00	0	440	0.820	0.0	0	12.10	526	10400	0	0.0	720
33	294	1	3	2	3	2	0	3.0	0	0	0.06	0.00	0	320	0.840	0.0	0	12.00	513	15100	0	0.0	844
34	706	1	3	2	3	1	0	4.0	0	0	0.00	0.09	0	290	0.110	0.0	0	10.30	364	11000	0	0.0	749
35	707	1	3	2	1	2	0	5.0	0	0	0.33	0.10	0	320	0.130	0.0	0	13.70	1130	11900	0	0.0	749
36	586	1	3	5	1	2	0	5.0	0	0	0.00	0.00	0	320	0.140	0.0	0	12.30	572	10700	0	0.0	713
37	703	1	3	5	3	1	0	3.0	0	0	0.00	0.06	0	410	0.080	0.0	0	10.90	449	10300	0	0.0	751
38	708	1	3	5	3	2	0	3.0	0	0	0.00	0.09	0	330	1.100	0.0	0	11.40	514	10300	0	0.0	729
39	549	1	3	8	3	2	0	4.0	0	0	0.34	0.00	0	370	0.770	0.0	0	12.20	574	12300	0	0.2	924
40	217	1	3	8	3	1	0	7.0	0	4	0.00	0.00	0	313	0.230	0.2	0	11.30	563	12400	0	0.0	811
41	547	1	3	9	1	1	0	5.0	0	0	0.00	0.00	0	330	0.170	0.0	0	12.00	442	9690	0	0.3	763
42	713	1	3	12	3	1	0	4.0	0	0	0.00	0.10	0	410	0.130	0.0	0	11.20	439	10400	0	0.0	815
43	714	1	3	12	3	1	0	3.0	0	0	0.00	0.10	0	270	0.170	0.0	0	10.20	488	10200	0	0.0	649
44	702	1	3	15	3	1	0	4.0	0	0	0.09	0.00	0	280	0.150	0.0	0	11.60	672	12300	0	0.0	750
45	716	1	3	15	3	1	0	0.0	0	0	0.08	0.00	0	320	0.040	0.0	0	9.60	546	9410	0	0.0	645
46	711	.	3	16	3	1	0	3.0	0	0	0.00	0.10	0	320	0.290	0.0	0	10.80	400	9410	0	0.0	689
47	247	1	3	22	3	2	0	6.0	0	0	0.00	0.00	0	290	1.200	0.0	0	11.20	549	12100	0	0.0	732
48	532	1	3	25	3	2	0	3.0	0	0	0.05	0.00	0	370	0.380	0.0	0	12.80	553	13600	0	0.0	767
49	704	1	3	25	1	2	0	4.0	0	0	0.00	0.10	0	290	0.130	0.0	0	11.30	574	11500	0	0.0	738
50	705	1	3	25	3	1	0	4.0	0	0	0.00	0.09	0	280	0.088	0.0	0	10.30	505	11000	0	0.0	701
51	724	2	5	.	1	2	0	4.0	0	0	0.00	0.00	0	260	0.089	0.0	0	11.80	470	11900	0	0.0	714
52	725	2	5	.	3	2	0	4.0	0	0	0.09	0.00	0	360	0.260	0.0	0	10.30	528	12600	0	0.0	732
53	573	2	5	5	1	2	0	2.0	0	0	0.08	0.00	0	430	0.040	0.0	0	11.50	630	10300	0	0.0	734
54	574	2	5	5	3	1	0	0.0	0	0	0.00	0.00	0	480	0.200	0.0	0	9.94	796	11300	0	0.0	682
55	545	2	5	19	1	1	0	10.0	0	0	0.10	0.00	0	310	0.060	0.0	0	12.10	455	12100	0	0.3	796

Table 35. (continued)

OBS	NUM	RV	RG	SC	AGE	SX	MN	MO	NA	NI	P	PB	SB	SE	SI	SN	SR	TI	TL	V	ZN	HG
1	526	1	1	1	3	2	5.2	1.60	4290	0.88	8770	1.8	0	5.5	0.0	0	0.73	1.70	0.0	0.91	86.1	0.0040
2	871	1	1	1	3	1	4.0	1.00	5790	0.50	10100	2.0	0	6.6	44.0	0	0.54	0.65	0.0	0.26	91.7	0.0520
3	873	1	1	1	1	2	5.4	1.00	4570	0.61	9890	2.1	0	7.3	0.0	0	0.60	0.88	0.0	0.29	88.6	0.0600
4	701	1	1	5	3	1	6.0	0.90	5480	0.30	9720	1.0	0	5.9	4.0	0	0.68	0.50	0.0	0.44	89.9	0.0140
5	560	1	1	7	1	2	4.8	0.80	4570	0.30	10200	0.6	0	4.8	0.0	0	0.45	0.50	0.0	0.46	87.3	0.0097
6	561	1	1	7	1	2	6.1	0.73	6260	0.40	10200	0.6	0	4.4	0.0	0	0.71	0.20	0.0	0.32	89.9	0.0041
7	564	1	1	7	3	2	9.2	1.10	6730	1.00	10800	1.6	0	4.1	0.0	0	1.30	0.40	0.0	0.16	104.0	0.0045
8	565	1	1	7	3	1	5.5	1.20	4240	0.48	9500	2.0	0	2.8	0.0	0	0.58	0.00	0.0	0.25	99.2	0.0069
9	717	1	1	7	3	1	5.4	1.00	6210	0.88	10500	3.0	0	3.8	0.0	0	0.26	0.40	0.4	0.28	110.0	0.0064
10	232	1	1	20	1	2	5.7	1.00	6260	0.30	10000	0.9	0	5.2	0.0	0	1.00	0.30	0.0	0.31	84.4	0.0110
11	523	1	1	20	3	1	5.1	1.00	5260	0.62	10400	0.8	0	3.9	0.0	0	0.49	0.20	0.0	0.39	81.3	0.0095
12	542	1	1	20	1	1	7.3	0.56	4920	0.30	9790	0.8	0	4.1	0.0	0	0.81	0.00	0.0	0.17	89.9	0.0020
13	554	1	1	20	1	1	4.5	0.73	4180	0.20	9100	0.0	0	3.3	0.0	0	0.42	0.20	0.0	0.37	77.1	0.0063
14	580	1	1	20	1	1	5.7	0.80	4450	0.30	9950	0.8	0	3.1	0.0	0	0.45	0.20	0.0	0.28	76.7	0.0020
15	908	1	1	20	3	1	5.4	0.74	4340	0.47	10400	0.5	0	4.0	0.0	0	0.57	0.40	0.0	0.20	86.8	0.0086
16	870	1	1	20	1	2	4.8	0.90	5000	0.36	9390	0.8	0	7.6	0.0	0	0.49	0.20	0.0	0.10	77.2	0.0650
17	874	1	1	20	3	1	5.2	0.80	4950	0.39	10500	1.0	0	6.5	0.0	0	0.45	0.80	0.0	0.37	90.2	0.0280
18	875	1	1	20	3	1	4.4	0.80	5430	0.49	10200	0.5	0	6.3	0.0	0	0.61	0.30	0.0	0.21	84.6	0.0520
19	280	1	1	25	1	2	8.4	0.91	4310	0.75	10200	0.7	0	5.2	0.0	0	0.59	0.00	0.0	0.33	90.1	0.0130
20	511	1	1	25	3	2	6.7	0.83	4280	0.92	9590	0.0	0	5.7	0.0	0	0.43	0.00	0.0	0.18	88.6	0.0350
21	876	1	1	25	3	1	5.6	0.80	4040	0.63	10200	0.6	0	4.6	7.6	0	0.38	0.50	0.0	0.37	90.7	0.0420
22	878	1	1	25	1	1	5.0	0.90	4460	1.10	9470	0.7	0	5.1	0.0	0	0.56	1.70	0.0	0.48	88.8	0.0420
23	879	1	1	25	3	1	5.7	1.00	4830	0.98	9680	1.0	0	5.4	0.0	0	0.42	0.96	0.0	0.24	85.8	0.0200
24	253	1	1	29	3	1	4.4	0.92	4550	0.20	9890	2.1	0	4.3	0.0	0	0.57	0.50	0.0	0.53	88.4	0.0066
25	552	1	1	29	1	.	4.6	0.97	4070	0.30	10800	1.0	0	3.8	0.0	0	0.56	0.00	0.0	0.60	88.8	0.0088
26	557	1	1	29	3	1	4.6	0.99	3820	0.20	9860	1.0	0	3.1	0.0	0	0.52	0.20	0.0	0.26	76.2	0.0042
27	559	1	1	29	3	1	5.4	1.20	8120	0.40	11400	2.6	0	3.6	0.0	0	1.40	0.30	0.0	1.90	92.2	0.0058
28	562	1	1	29	3	2	5.2	0.99	4550	0.46	10200	2.4	0	3.7	0.0	0	0.95	0.40	0.0	1.40	81.4	0.0042
29	563	1	1	29	1	2	6.5	0.77	4760	0.20	10200	1.4	0	3.9	0.0	0	0.72	0.60	0.0	0.95	78.5	0.0048
30	877	1	1	29	1	2	5.0	0.80	5510	0.00	10900	1.6	0	5.3	37.0	0	1.10	0.40	0.0	0.51	107.0	0.0340
31	712	1	3	.	3	2	5.3	0.87	5280	0.20	9740	0.9	0	4.9	2.0	0	0.55	0.40	0.0	0.57	83.9	0.0300
32	715	1	3	.	3	2	5.6	1.00	6190	0.20	9240	1.0	0	6.5	0.0	0	0.73	0.40	0.0	0.47	79.1	0.0420
33	294	1	3	2	3	2	6.0	0.56	5190	0.20	10800	0.5	0	6.5	0.0	0	0.83	0.30	0.0	0.13	86.9	0.0110
34	706	1	3	2	3	1	5.1	0.89	5610	0.40	10400	1.6	0	4.8	0.0	0	0.74	0.40	0.0	1.80	76.1	0.0150
35	707	1	3	2	1	2	6.1	0.93	5080	0.20	10300	4.9	0	5.1	3.0	0	0.82	0.30	0.0	0.95	84.2	0.0043
36	586	1	3	5	1	2	5.3	0.84	5750	0.00	9460	0.8	0	5.5	2.0	0	0.62	0.20	0.0	1.20	76.3	0.0110
37	703	1	3	5	3	1	5.2	0.63	4320	0.00	10500	0.7	0	3.9	2.0	0	0.77	0.00	0.0	0.54	70.2	0.0042
38	708	1	3	5	3	2	6.3	0.83	5920	0.20	9340	0.7	0	5.7	2.0	0	0.62	0.40	0.0	0.61	77.6	0.0400
39	549	1	3	8	3	2	4.6	0.99	5860	0.42	10300	0.9	0	5.1	0.0	0	1.50	0.00	0.0	0.16	83.6	0.0055
40	217	1	3	8	3	1	4.6	0.90	5230	0.00	12100	2.3	0	5.7	0.0	0	0.66	0.30	0.0	0.24	84.6	0.0470
41	547	1	3	9	1	1	5.6	1.20	5310	0.20	9410	0.9	0	6.3	0.0	0	0.73	0.30	0.0	0.50	78.4	0.0260
42	713	1	3	12	3	1	6.0	0.70	5260	0.20	10400	1.0	0	4.1	2.0	0	1.20	0.00	0.0	0.46	76.3	0.0081
43	714	1	3	12	3	1	4.0	0.69	5820	0.20	9470	0.9	0	4.5	0.0	0	0.53	0.00	0.0	0.26	73.8	0.0083
44	702	1	3	15	3	1	5.3	0.76	5300	0.00	9950	1.6	0	5.5	3.0	0	0.59	0.40	0.0	1.30	82.5	0.0066
45	716	1	3	15	3	1	4.5	0.75	4990	0.20	9780	0.0	0	2.9	0.0	0	0.71	0.08	0.0	0.07	71.3	0.0200
46	711	1	3	16	3	1	4.6	0.71	5700	0.00	10200	0.9	0	4.4	1.0	0	0.44	0.00	0.0	0.19	69.8	0.0095
47	247	1	3	22	3	2	6.4	1.00	5160	0.37	9470	1.0	0	11.0	0.0	0	0.58	0.50	0.0	0.51	74.3	0.0330
48	532	1	3	25	3	2	5.3	0.88	4930	0.40	10700	1.0	0	4.4	0.0	0	0.75	0.20	0.0	0.15	90.6	0.0037
49	704	1	3	25	1	2	4.5	0.89	4070	0.50	9280	0.9	0	5.1	3.0	0	0.71	0.30	0.0	1.40	71.2	0.0110
50	705	1	3	25	3	1	4.2	0.87	4510	0.20	10300	0.8	0	4.2	0.0	0	0.41	0.40	0.0	0.99	73.5	0.0039
51	724	2	5	.	1	2	5.8	0.85	5200	0.30	10400	0.6	0	5.5	0.0	0	0.79	0.60	0.0	0.99	73.5	0.0130
52	725	2	5	.	3	2	6.7	0.79	6400	0.00	10400	0.7	0	5.8	0.0	0	0.71	0.40	0.0	0.67	79.3	0.0220
53	573	2	5	5	1	2	10.0	0.64	5650	0.00	9370	0.0	0	4.5	0.0	0	1.10	0.20	0.0	0.99	82.0	0.0140
54	574	2	5	5	3	1	6.1	0.71	6480	0.00	10200	1.0	0	5.7	0.0	0	0.72	0.66	0.0	1.40	80.0	0.0120
55	545	2	5	19	1	1	4.2	0.77	3790	0.75	10400	1.0	0	4.7	0.0	0	1.20	1.20	0.0	2.50	88.2	0.0210

Table 35. (continued)

OBS	NUM	RV	RG	SC	AGE	SX	MN	MO	NA	NI	P	PB	SB	SE	SI	SN	SR	TI	TL	V	ZN	HG
56	553	2	5	19	3	1	4.7	0.53	4200	0.40	10300	0.8	0	4.0	0	0	1.10	0.30	0	0.91	80.1	0.0250
57	577	2	5	19	1	2	5.5	0.68	4640	0.20	10300	0.8	0	4.4	0	0	0.96	0.40	0	1.60	86.1	0.0130
58	595	2	5	19	3	1	5.5	0.66	5610	0.00	9490	0.6	0	4.3	2	0	0.70	0.30	0	0.62	80.7	0.0150
59	596	2	5	19	1	1	6.1	0.78	3750	0.20	9950	0.7	0	4.4	2	0	0.64	0.94	0	1.40	93.3	0.0120
60	527	2	5	20	1	1	4.6	0.85	4260	0.20	9520	0.6	0	4.1	0	0	0.56	0.50	0	0.65	84.4	0.0076
61	599	2	5	20	1	1	5.8	0.85	4280	0.30	10300	0.6	0	5.0	2	0	0.82	0.67	0	0.32	88.8	0.0130
62	576	2	5	22	1	1	4.7	0.62	3680	0.00	9790	0.7	0	3.5	0	0	0.80	0.20	0	0.70	84.8	0.0210
63	566	2	5	28	3	2	6.6	0.68	5700	0.20	9210	0.9	0	4.7	0	0	0.85	0.50	0	1.60	73.5	0.0077
64	567	2	5	28	1	2	5.6	0.63	4690	0.30	9430	0.6	0	3.8	0	0	0.64	0.20	0	1.60	82.1	0.0220
65	568	2	5	28	3	1	5.0	0.59	5930	0.00	9650	0.5	0	2.9	0	0	0.92	0.30	0	0.72	75.9	0.0020
66	570	2	5	28	3	1	5.2	0.77	5080	0.53	11100	0.7	0	3.4	0	0	0.58	0.00	0	0.74	74.5	0.0020
67	572	2	5	28	3	1	4.8	0.67	6130	0.00	9710	0.7	0	3.8	0	0	0.43	0.40	0	0.94	74.1	0.0049
68	578	2	5	28	1	1	10.0	0.77	5260	0.20	10200	1.0	0	3.3	0	0	1.00	0.20	0	1.20	85.9	0.0077
69	579	2	5	28	3	2	15.0	0.75	6540	0.30	9700	1.0	0	3.4	0	0	0.74	0.50	0	1.20	74.6	0.0065
70	581	2	5	28	3	1	10.0	0.96	5640	0.20	10200	1.5	0	5.0	0	0	0.67	0.40	0	0.52	83.9	0.0110
71	582	2	5	28	1	2	5.9	0.67	5370	0.20	9740	0.8	0	4.6	0	0	1.00	0.40	0	1.50	88.2	0.0069
72	583	2	5	28	3	1	5.5	0.76	3880	0.20	9550	0.8	0	3.3	2	0	0.70	0.40	0	0.86	79.4	0.0090
73	585	2	5	28	3	1	11.0	0.92	7210	0.20	9310	1.0	0	5.7	5	0	1.40	0.50	0	2.20	83.3	0.0066
74	593	2	5	28	3	2	5.6	0.72	5500	0.00	9700	0.9	0	5.4	0	0	0.84	0.40	0	0.49	82.4	0.0087
75	569	2	5	29	1	2	6.2	0.67	4560	0.20	9770	0.0	0	3.7	0	0	0.98	0.50	0	1.20	77.4	0.0070
76	571	2	5	29	3	1	5.6	0.67	4270	0.95	10400	0.0	0	3.6	0	0	0.69	0.00	0	1.10	79.0	0.0030

OBS	NUM	RV	RG	SC	AGE	SX	AG	AL	AS	B	BA	BE	BI	CA	CD	CO	CR	CU	FE	K	M	LI	MG
56	553	2	5	19	3	1	0	2.0	0	0	0.05	0.00	0	220	0.070	0	0	10.60	459	10400	0	0.2	711
57	577	2	5	19	1	2	0	0.0	0	0	0.10	0.00	0	300	0.050	0	0	11.80	445	12000	0	0.0	758
58	595	2	5	19	3	1	0	6.6	0	0	0.00	0.06	0	270	0.070	0	0	8.40	508	11000	0	0.0	676
59	596	2	5	19	1	1	0	9.3	0	0	0.09	0.00	0	250	0.050	0	0	10.20	556	12600	0	0.0	765
60	527	2	5	20	1	1	0	3.0	0	0	0.00	0.00	0	310	0.030	0	0	10.50	496	11800	0	0.0	700
61	599	2	5	20	1	1	0	6.7	0	0	0.10	0.05	0	310	0.060	0	0	11.60	490	12100	0	0.0	765
62	576	2	5	22	1	1	0	4.0	0	0	0.06	0.00	0	280	0.060	0	0	12.20	564	12900	0	0.0	811
63	566	2	5	28	3	2	0	5.0	0	0	0.20	0.00	0	320	0.170	0	0	11.00	732	11700	0	0.0	725
64	567	2	5	28	1	2	0	4.0	0	0	0.09	0.00	0	230	0.110	0	0	11.40	596	10400	0	0.0	716
65	568	2	5	28	3	1	0	3.0	0	0	0.09	0.00	0	350	0.040	0	0	10.20	581	11300	0	0.0	709
66	570	2	5	28	3	1	0	0.0	0	0	0.07	0.00	0	270	0.030	0	0	11.10	369	10200	0	0.0	759
67	572	2	5	28	3	1	0	2.0	0	0	0.10	0.00	0	310	0.100	0	0	9.51	628	10900	0	0.0	653
68	578	2	5	28	1	1	0	0.0	0	0	0.10	0.00	0	260	0.030	0	0	12.40	579	10800	0	0.0	769
69	579	2	5	28	3	2	0	2.0	0	0	0.09	0.00	0	280	0.100	0	0	11.60	617	11700	0	0.0	721
70	581	2	5	28	3	1	0	4.0	0	0	0.10	0.00	0	310	0.098	0	0	12.20	655	11200	0	0.0	686
71	582	2	5	28	1	2	0	5.0	0	0	0.00	0.00	0	320	0.070	0	0	11.90	649	10800	0	0.0	718
72	583	2	5	28	3	1	0	0.0	0	0	0.00	0.00	0	290	0.050	0	0	11.50	500	13100	0	0.0	707
73	585	2	5	28	3	1	0	3.0	0	0	0.15	0.00	0	480	0.110	0	0	10.70	636	13600	0	0.0	806
74	593	2	5	28	3	2	0	4.0	0	0	0.08	0.00	0	370	0.080	0	0	12.30	518	12100	0	0.0	751
75	569	2	5	29	1	2	0	4.0	0	0	0.09	0.00	0	310	0.040	0	0	12.50	515	10500	0	0.0	741
76	571	2	5	29	3	1	0	2.0	0	0	0.08	0.00	0	340	0.050	0	0	10.50	510	11100	0	0.0	759

[1]ags = silver, als = aluminum, ass = arsenic, bs = boron, bas = barium, bes = beryllium, bis = bismuth, cas = calcium, cds = cadmium, cos = cobalt, crs = chromium, cus = copper, fes = iron, ks = potassium, ws = tungsten, lis = lithium, mgs = magnesium, mns = manganese, mos = molybdenum, nas = sodium, nis = nickel, ps = phosphorus, pbs = lead, sbs = antimony, ses = selenium, sis = silicon, sns = tin, srs = strontium, tis = titanium, tls = thallium, vs = vanadium, zns = zinc, hgs = mercury.

Table 36. Blood variables[1] collected from muskrats trapped in the Elizabeth and Nansemond Rivers, Va., 1986 - 1988.

OBS	NUM	RV	RG	SC	DATE	AGE	SEX	K	CHL	GLU	BUN	CRE	SGOT	ALPH	BIL	URIC	CA	INP
1	526	1	1	1	880112	3	2	4.8	96	99	29	1.3	254	635	0.7	1.5	9.5	3.9
2	701	1	1	5	880120	1	1	3.8	92	79	33	1.1	530	645	0.5	1.7	10.4	7.8
3	560	1	1	7	880113	1	2	3.5	91	39	35	1.0	805	720	0.7	1.2	8.7	8.5
4	561	1	1	7	880113	1	2	5.4	92	137	64	1.2	600	750	0.8	1.6	9.8	11.5
5	564	1	1	7	880118	3	2	3.3	97	107	56	1.1	254	348	0.5	1.4	9.5	8.3
6	565	1	1	7	880119	3	1	3.6	95	143	34	1.3	530	640	0.4	2.3	10.3	8.9
7	717	1	1	7	880217	1	1	3.3	94	137	15	1.1	361	548	1.0	1.4	8.6	7.0
8	523	1	1	20	871207	3	1	4.4	93	38	18	1.2	124	381	0.4	1.8	9.3	5.9
9	542	1	1	20	871207	1	1	4.8	92	115	20	1.3	450	861	0.5	1.7	10.8	8.8
10	554	1	1	20	880108	1	1	4.8	92	106	36	1.4	450	965	0.9	2.0	9.6	17.0
11	580	1	1	20	880109	3	1	4.9	98	74	23	1.3	320	740	0.8	1.1	10.8	7.3
12	908	1	1	20	880108	3	1	4.0	94	240	4	1.1	440	473	0.4	1.0	10.3	5.6
13	280	1	1	25	880108	1	2	4.4	83	119	16	1.2	470	490	0.8	0.8	9.8	9.3
14	511	1	1	25	880108	3	2	5.5	91	157	19	1.2	515	247	0.6	1.2	10.4	5.3
15	253	1	1	29	871207	3	1	4.1	89	155	39	1.4	249	639	0.4	2.4	9.2	11.1
16	552	1	1	29	880108	1	1	3.6	90	216	7	1.3	510	790	0.4	1.2	9.3	6.6
17	557	1	1	29	880113	1	1	4.8	97	150	11	1.2	610	545	0.4	2.0	10.2	9.0
18	559	1	1	29	880113	1	1	5.8	97	75	39	1.0	345	489	0.7	1.4	9.0	8.9
19	562	1	1	29	880114	3	2	4.3	100	144	16	1.0	224	245	0.4	1.5	8.3	8.3
20	563	1	1	29	880117	1	2	5.0	100	65	20	1.1	545	568	0.5	1.9	9.1	5.7
21	712	1	3	.	880208	3	2	5.6	90	81	48	1.7	347	491	0.4	2.1	10.8	9.5
22	715	1	3	.	880211	3	2	4.3	94	79	57	1.0	287	200	0.6	1.3	9.3	5.4
23	294	1	3	1	871213	3	2	4.8	90	133	12	.	580	770	0.5	1.1	10.4	7.2
24	706	1	3	1	880205	3	1	5.0	91	65	35	1.0	630	1093	0.8	1.1	9.8	7.0
25	707	1	3	2	880205	1	2	4.5	89	65	34	1.0	228	735	0.9	1.0	9.3	10.0
26	586	1	3	5	880203	1	2	.	.	.	.	1.0	301	465	0.6	1.4	9.1	5.5
27	703	1	3	5	880202	3	1	4.6	92	44	20	1.0	296	593	0.5	1.6	9.3	8.2
28	708	1	3	5	880205	3	2	4.0	94	51	44	0.8	495	350	0.5	2.0	9.0	10.2
29	549	1	3	8	871214	3	2	5.3	86	70	67	1.1	573	702	0.5	1.8	9.6	12.9
30	547	1	3	9	881211	3	1	4.2	93	106	24	1.0	251	464	0.5	0.9	10.0	5.9
31	713	1	3	12	880209	1	1	5.2	95	84	34	1.0	264	1006	0.6	1.1	8.6	8.2
32	714	1	3	12	880209	3	1	4.2	90	58	36	1.1	356	384	0.2	1.8	8.1	6.5
33	702	1	3	15	880201	3	1	5.6	86	126	19	1.3	291	615	0.5	1.2	10.6	6.2
34	716	1	3	15	880215	1	1	5.1	97	94	37	1.2	207	708	0.8	1.3	9.6	6.3
35	711	1	3	16	880206	3	1	3.8	97	94	27	1.1	470	705	0.4	1.0	8.4	8.2
36	247	1	3	22	880210	3	2	3.7	89	48	40	1.0	221	328	0.4	1.9	7.2	5.9
37	532	1	3	25	871205	3	2	6.1	95	135	47	1.5	432	534	0.5	3.0	10.3	12.0
38	704	1	3	25	880204	1	2	4.7	82	108	33	1.4	585	1000	0.5	1.5	9.5	7.5
39	705	1	3	25	880204	3	1	4.4	90	97	25	1.0	333	542	0.6	1.1	9.4	6.5
40	724	2	5	.	880302	3	2	4.0	95	68	20	1.3	242	420	0.8	2.0	8.3	7.3
41	725	2	5	.	880302	3	2	4.5	100	65	31	0.9	250	253	0.7	1.6	8.7	6.0
42	573	2	5	5	880126	1	2	3.6	96	51	26	1.0	320	2125	0.5	1.1	9.2	8.3
43	574	2	5	5	880126	3	1	4.3	95	59	59	0.8	327	431	0.5	1.6	8.9	9.2
44	545	2	5	19	871211	1	1	4.8	86	133	52	1.1	585	1285	0.5	2.0	9.7	11.0
45	553	2	5	19	880108	3	1	4.5	93	103	36	1.2	730	935	0.7	1.3	7.8	8.5
46	577	2	5	19	880109	1	2	4.6	93	167	27	1.1	270	1030	0.6	1.0	9.3	12.0
47	595	2	5	19	871215	3	1	9.9	9	90	37	1.3	423	831	0.6	2.1	9.6	14.1
48	596	2	5	19	871215	1	1	5.5	86	121	48	1.5	237	1260	0.6	2.2	9.1	12.9
49	527	2	5	20	871211	3	1	5.1	88	88	34	1.2	445	730	0.6	1.3	9.1	12.0
50	599	2	5	20	871215	3	1	4.9	87	39	35	1.2	384	858	0.6	1.5	8.4	8.6
51	576	2	5	22	871220	1	1	6.4	81	94	41	1.0	380	1830	0.8	2.2	8.8	99.9
52	566	2	5	28	880122	3	2	3.8	89	35	21	1.1	900	640	0.7	1.2	9.4	7.1
53	567	2	5	28	880122	1	2	3.2	89	32	26	1.1	730	1420	0.9	1.5	9.6	6.7
54	568	2	5	28	880123	3	1	.	.	.	.	.	.	.	.	.	.	.
55	570	2	5	28	880123	3	1	4.1	94	37	23	1.1	340	970	0.4	1.2	9.4	6.9

Table 36. (continued)

OBS	NUM	RV	RG	SC	DATE	AGE	SEX	TPRO	ALBU	CHO	SGLT	WBC	RBC	HGB	HEC	MCV	MCH	MCM	PLA	LYM
1	526	1	1	1	880112	3	2	6.3	3.7	56	119	8.7	7.19	20.8	62.3	87	26.4	30.5	353	13
2	701	1	1	5	880120	1	1	6.2	3.9	29	160	18.3	6.54	18.5	56.3	86	28.3	32.9	394	21
3	560	1	1	7	880113	1	2	5.5	3.5	52	220	12.8	6.94	18.7	57.3	83	26.9	32.6	386	22
4	561	1	1	7	880113	1	2	6.1	3.9	52	355	12.4	7.53	19.4	61.6	82	25.8	31.5	295	9
5	564	1	1	7	880118	3	2	6.3	3.7	36	154	14.4	6.35	20.0	57.8	91	31.5	34.6	502	8
6	565	1	1	7	880119	3	1	6.3	4.0	49	221	12.9	5.90	17.1	52.5	89	29.0	32.6	440	18
7	717	1	1	7	880217	1	1	4.8	3.5	22	163	10.6	5.62	17.0	48.7	87	30.2	34.9	431	23
8	523	1	1	20	871207	3	1	6.4	3.5	44	99	12.8	6.95	18.5	52.0	75	26.6	35.6	547	12
9	542	1	1	20	871207	1	1	5.0	3.5	43	145	9.3	6.12	17.1	52.0	85	27.9	32.9	571	24
10	556	1	1	20	880108	1	1	5.6	3.7	76	224	14.1	7.15	20.3	61.5	86	28.4	33.0	386	20
11	580	1	1	20	880109	3	1	5.9	4.1	32	155	15.5	6.13	19.2	54.8	89	31.3	35.0	515	17
12	908	1	1	20	880108	3	1	5.9	3.7	36	151	12.7	5.90	15.7	49.6	84	26.6	31.7	523	18
13	280	1	1	25	880108	1	2	6.3	3.9	32	143	15.0	7.09	19.8	60.9	86	27.9	32.5	421	41
14	511	1	1	25	880108	3	2	6.9	4.1	28	214	13.8	7.11	19.4	61.3	86	27.3	31.6	366	10
15	253	1	1	29	871207	3	1	5.8	3.2	27	112	20.4	6.13	17.2	54.5	89	28.1	31.6	556	6
16	552	1	1	29	880108	1	1	5.3	3.5	25	174	15.9	6.29	16.9	52.2	83	26.9	32.4	375	14
17	557	1	1	29	880113	1	1	6.1	3.4	20	215	15.9	7.08	19.8	61.7	87	28.0	32.1	503	12
18	559	1	1	29	880113	1	1	5.6	3.6	18	207	8.9	6.88	19.4	57.5	84	28.2	33.7	412	6
19	562	1	1	29	880114	3	2	4.6	2.6	16	158	13.1	6.10	18.6	58.7	96	30.5	31.7	301	9
20	563	1	1	29	880117	1	2	5.1	3.0	36	160	23.0	6.75	19.1	57.5	85	28.3	33.2	417	16
21	712	1	3	.	880208	3	2	5.3	3.3	29	213	12.6	6.36	17.4	54.0	85	27.4	32.2	529	19
22	715	1	3	.	880211	3	2	5.4	3.6	22	171	21.5	6.11	17.4	52.2	85	28.5	33.3	485	16
23	294	1	3	1	871213	3	2	6.0	3.8	57	191	12.2	6.49	18.1	55.0	85	27.9	32.9	395	26
24	706	1	3	1	880205	3	1	5.7	3.9	36	405	14.4	6.58	17.9	56.4	86	27.2	31.7	470	29
25	707	1	3	2	880205	1	2	6.0	3.6	45	109	12.3	6.70	17.9	62.1	93	26.7	28.8	403	21
26	586	1	3	5	880203	1	2	5.3	3.6	43	109	12.3	7.12	18.1	57.3	80	25.4	31.6	384	12
27	703	1	3	5	880202	3	1	5.8	3.6	24	115	14.2	6.34	17.7	53.6	85	27.9	33.0	661	25
28	708	1	3	5	880205	3	2	5.5	3.3	33	170	16.3	6.56	17.7	55.3	84	27.0	32.0	399	9
29	549	1	3	8	871214	3	2	6.7	4.2	48	159	5.5	7.41	20.4	62.2	87	27.5	32.8	491	5
30	547	1	3	9	881211	3	1	5.1	3.6	19	125	10.4	6.68	18.5	53.8	81	27.7	34.4	369	20
31	713	1	3	12	880209	1	1	5.4	3.7	22	120	9.4	6.83	18.5	57.8	85	27.1	32.0	536	38
32	714	1	3	12	880209	3	1	5.0	3.3	13	160	10.9	5.64	16.5	50.2	89	29.3	32.9	526	13
33	702	1	3	15	880201	3	1	5.9	3.4	35	111	11.2	6.56	17.9	57.5	88	27.3	31.1	477	8
34	716	1	3	15	880215	1	1	6.3	3.9	17	123	11.5	7.79	21.0	65.7	84	24.9	29.5	394	.
35	711	1	3	16	880206	3	1	5.1	3.2	22	196	15.7	5.72	16.6	48.4	85	29.0	34.3	475	23
36	247	1	3	22	880210	3	2	5.1	3.0	23	110	15.7	6.46	19.0	57.6	89	29.4	33.0	751	5
37	532	1	3	25	871205	3	2	5.9	3.9	70	133	7.1	6.02	16.3	51.0	85	27.1	32.0	767	4
38	704	1	3	25	880204	1	2	5.9	3.8	41	185	12.7	7.09	18.7	58.2	82	26.4	32.1	550	40
39	705	1	3	25	880204	3	1	5.4	3.7	23	155	18.5	6.34	17.6	55.3	87	27.8	31.8	537	12
40	724	2	5	.	880302	3	2	5.5	3.4	35	139	12.0	6.29	17.1	52.2	83	27.2	32.8	503	12
41	725	2	5	.	880302	3	2	5.7	3.4	23	124	15.1	5.96	18.0	51.2	86	30.2	35.2	676	10
42	573	2	5	5	880126	1	2	4.8	3.2	48	118	14.2	6.61	17.6	55.4	84	26.6	31.8	779	24
43	574	2	5	5	880126	3	1	5.5	3.0	44	139	15.1	6.25	18.3	56.1	90	29.3	32.6	667	5
44	545	2	5	19	871211	1	1	5.8	3.9	37	146	16.3	5.69	16.5	49.7	87	29.0	33.2	408	10
45	553	2	5	19	880108	3	1	5.1	3.5	14	204	14.4	5.84	18.7	51.5	88	32.0	36.3	399	19
46	577	2	5	19	880109	1	2	5.2	3.7	42	114	13.2	5.52	16.8	48.6	88	30.4	34.6	418	26
47	595	2	5	19	871215	3	1	6.9	4.4	40	180	15.5	6.15	19.3	57.8	94	31.4	33.4	188	11
48	596	2	5	19	871215	1	1	5.9	3.9	62	120	15.0	7.28	20.8	64.8	89	28.6	32.1	400	12
49	527	2	5	20	871211	3	1	5.8	3.8	45	186	13.0	6.00	19.9	53.8	90	33.2	37.0	486	15
50	599	2	5	20	871215	3	1	5.4	3.4	26	246	15.3	6.26	19.4	55.5	89	31.0	35.0	529	9
51	576	2	5	22	871220	1	1	5.2	3.3	60	218	10.6	7.80	17.7	59.2	76	22.7	29.9	542	14
52	566	2	5	28	880122	3	2	6.0	3.8	46	350	15.4	6.46	18.2	55.4	86	28.2	32.9	432	16
53	567	2	5	28	880122	1	2	5.6	3.8	55	290	14.7	6.48	18.6	56.5	87	28.7	32.9	384	19
54	568	2	5	28	880123	3	1	.	.	.	.	.	.	.	.	.	.	.	.	.
55	570	2	5	28	880123	3	1	5.2	3.1	24	144	19.4	5.91	16.2	50.7	86	27.4	32.0	444	17

Table 36. (continued)

OBS	NUM	RV	RG	SC	DATE	AGE	SEX	K	CHL	GLU	BUN	CRE	SGOT	ALPH	BIL	URIC	CA	INP
56	572	2	5	28	880124	3	1	4.1	94	56	19	1.0	585	572	0.6	0.8	9.6	6.9
57	578	2	5	28	880109	1	1	4.5	91	102	46	1.1	460	1170	0.6	1.2	9.2	9.7
58	579	2	5	28	880109	3	2	5.1	95	95	33	1.4	780	670	0.4	2.1	10.2	8.1
59	581	2	5	28	880110	3	1	3.8	93	119	32	1.2	169	561	0.6	1.3	8.3	9.0
60	582	2	5	28	880110	1	2	11.6	91	3	52	1.6	999	1220	0.7	5.4	7.8	24.0
61	583	2	5	28	880111	3	1	3.9	93	176	10	1.2	490	501	0.3	1.8	9.1	6.6
62	585	2	5	28	880114	3	1	6.1	99	109	25	1.2	310	512	0.4	1.4	11.5	4.8
63	593	2	5	28	880108	3	2	4.8	91	130	39	1.2	525	567	0.8	1.7	8.3	9.4
64	569	2	5	29	880123	1	2	4.1	96	63	29	1.1	415	720	0.5	1.4	9.1	8.9
65	571	2	5	29	880124	3	1	5.2	93	104	20	1.2	510	795	0.8	1.1	9.6	7.5

OBS	NUM	RV	RG	SC	DATE	AGE	SEX	TPRO	ALBU	CHO	SGLT	WBC	RBC	HGB	HEC	MCV	MCH	MCM	PLA	LYM
56	572	2	5	28	880124	3	1	5.2	3.3	40	207	14.1	5.85	16.6	50.4	86	28.4	32.9	494	12
57	578	2	5	28	880109	1	1	5.5	3.8	33	209	17.5	5.96	18.6	56.0	94	31.2	33.2	436	14
58	579	2	5	28	880109	3	2	6.7	4.1	39	241	10.9	6.91	19.2	60.4	87	27.8	31.8	454	91
59	581	2	5	28	880110	3	1	5.3	3.3	26	129	9.6	6.04	19.5	55.8	92	32.3	34.9	366	17
60	582	2	5	28	880110	1	2	5.9	3.8	34	440	8.8	6.97	19.0	60.5	87	27.3	31.4	361	14
61	583	2	5	28	880111	3	1	5.1	3.3	29	145	9.6	6.92	18.3	58.5	85	26.4	31.3	375	19
62	585	2	5	28	880114	3	1	5.6	3.3	34	187	10.7	6.42	19.3	59.5	93	30.1	32.4	389	2
63	593	2	5	28	880108	3	2	5.9	4.1	47	164	19.8	5.86	18.7	52.9	90	31.9	35.3	337	10
64	569	2	5	29	880123	1	2	5.1	3.0	72	145	14.1	6.07	17.0	52.2	86	28.0	32.6	460	19
65	571	2	5	29	880124	3	1	5.5	3.7	38	144	14.1	6.14	17.8	55.1	90	29.0	32.3	513	8

[1]K = potassium, CHL = chlorides, GLU = glucose, BUN = blood urea nitrogen, CRE = creatinine, SGOT = serum glutamic oxaloacetic transaminase, ALPH = alkaline phosphatase, BIL = bilirubin, URIC = uric acid, CA = calcium, INP = inorganic phosphorus, TPRO = total protein, ALBU = albumin, CHO = cholesterol, SGLT = serum glutamic pyruvic transaminase, WBC = white blood cells, RBC = red blood cells, HGB = hemoglobin, HEC = hematocrit, MCV = mean corpuscular volume, MCH = mean corpuscular hemoglobin, MCM = mean corpuscular hemoglobin concentration, PLA = platelet count, LYM = lymphocytes.

Table 37. Body and organ measurements[1] of muskrats live trapped from the Elizabeth and Nansemond Rivers, Va., 1986–1988

OBS	NUM	RV	RG	SC	AGE	SEX	CARHT	LGTH	TLGTH	HFOOT	EAR	LVHT	RA	LA	RKID	LKID	SPHT
1	526	1	1	1	3	2	947	59.3	26.1	7.7	1.7	32.6	0.072	0.083	3.5	3.4	0.39
2	701	1	1	5	1	1	658	52.9	22.7	8.3	2.1	23.0	0.053	0.084	2.9	2.8	0.30
3	560	1	1	7	1	2	688	60.3	25.9	8.2	2.1	27.2	0.055	0.068	2.4	2.4	0.36
4	561	1	1	7	1	2	644	52.3	.	8.0	1.9	21.4	0.081	0.104	2.5	2.4	0.19
5	564	1	1	7	3	2	806	62.7	28.1	8.3	2.3	30.2	0.167	0.214	3.9	4.1	0.47
6	565	1	1	7	3	1	831	59.5	27.0	8.5	2.2	30.4	0.105	0.131	3.1	3.1	0.25
7	717	1	1	7	1	1	632	56.4	24.8	8.3	1.9	22.3	0.055	0.066	2.5	2.6	0.42
8	523	1	1	20	3	1	815	64.0	25.6	8.1	2.2	25.2	0.109	0.139	3.1	3.1	0.54
9	542	1	1	20	1	1	725	56.4	24.8	7.9	1.8	26.6	0.069	0.104	2.3	2.3	0.33
10	554	1	1	20	1	1	637	54.1	22.2	7.6	2.0	21.7	0.046	0.050	2.1	2.1	0.41
11	580	1	1	20	3	1	845	61.0	26.2	8.2	2.1	32.2	0.099	0.141	2.6	2.7	0.51
12	908	1	1	20	3	1	1095	62.6	28.3	8.3	2.2	69.2	0.176	0.201	3.8	3.7	0.51
13	280	1	1	25	1	2	617	56.1	24.5	7.8	1.8	21.5	0.062	0.061	2.0	2.0	0.28
14	511	1	1	25	3	2	841	62.1	26.0	8.1	2.0	36.7	0.116	0.149	3.6	3.4	0.40
15	253	1	1	29	3	1	775	57.4	23.6	7.9	1.9	29.2	0.083	0.093	2.7	2.7	0.27
16	552	1	1	29	1	1	741	56.7	24.2	7.6	2.0	27.6	0.066	0.077	2.5	2.5	0.09
17	557	1	1	29	1	1	723	58.1	24.7	7.9	2.1	30.5	0.095	0.116	3.3	3.4	0.40
18	559	1	1	29	1	1	741	58.7	25.7	8.2	2.0	21.4	0.099	0.125	2.8	2.8	0.36
19	562	1	1	29	3	2	903	61.0	27.7	8.2	2.0	33.9	0.137	0.184	3.6	3.3	0.65
20	563	1	1	29	1	2	708	54.4	23.6	7.8	2.0	22.8	0.044	0.099	2.1	2.1	0.28
21	712	1	3	.	3	2	863	58.5	25.6	8.0	2.3	33.9	0.110	0.141	4.2	4.0	0.29
22	715	1	3	.	3	2	927	60.2	26.5	7.9	2.3	37.7	0.118	0.152	4.4	4.7	0.76
23	294	1	3	1	3	2	810	56.3	24.8	7.4	1.8	29.6	0.096	0.109	2.8	2.8	0.66
24	706	1	3	1	3	1	893	60.1	27.3	8.6	2.2	39.6	0.158	0.180	5.8	6.1	0.35
25	707	1	3	2	1	2	649	53.9	23.2	7.6	2.1	20.9	0.064	0.092	2.7	2.7	0.41
26	586	1	3	5	1	2	774	56.8	23.0	8.0	2.2	27.6	0.094	0.079	2.4	2.4	0.43
27	703	1	3	5	3	1	927	60.9	25.8	7.9	2.2	32.8	0.124	0.127	3.9	4.2	0.23
28	708	1	3	5	3	2	873	59.7	27.0	7.9	2.3	35.1	0.103	0.153	4.4	4.1	0.62
29	549	1	3	8	3	2	800	59.9	25.3	7.4	2.2	23.8	.	0.118	3.3	3.5	0.86
30	547	1	3	9	3	1	790	62.5	27.8	8.4	2.2	29.6	0.160	0.161	3.4	3.5	0.40
31	713	1	3	12	1	1	799	58.2	25.6	8.3	2.1	32.7	0.115	0.147	3.9	4.0	0.39
32	714	1	3	12	3	1	883	62.3	27.8	8.3	2.2	48.1	0.145	0.175	4.4	4.6	0.51
33	702	1	3	15	3	1	924	61.4	28.5	8.3	2.3	35.5	0.136	0.139	3.7	3.6	0.38
34	716	1	3	15	1	1	797	62.2	28.3	8.4	2.1	32.9	0.083	0.081	3.9	4.1	0.32
35	711	1	3	16	3	1	1068	60.2	26.3	8.1	2.3	47.9	0.146	0.143	5.9	5.7	0.60
36	247	1	3	22	3	2	790	61.6	27.0	8.2	2.2	33.0	0.145	0.175	3.9	3.8	0.37
37	532	1	3	25	3	2	725	61.8	28.0	7.9	1.7	26.1	0.100	0.154	3.5	3.6	0.32
38	704	1	3	25	1	2	764	58.5	23.5	8.0	2.1	25.7	0.109	0.120	2.5	2.3	0.18
39	705	1	3	25	3	1	919	60.3	25.9	8.1	2.2	34.1	0.105	0.135	4.3	4.4	0.40
40	724	2	5	.	3	2	959	59.6	26.6	8.7	2.2	38.1	0.142	0.208	3.8	3.6	0.75
41	725	2	5	.	3	2	858	60.5	27.5	8.5	2.2	27.2	0.163	0.176	4.4	4.5	0.84
42	573	2	5	5	1	2	610	52.2	22.5	7.7	2.1	24.8	0.037	0.035	2.3	2.2	0.32
43	574	2	5	5	3	1	897	62.7	27.1	7.9	2.2	35.1	0.207	0.222	5.9	5.1	0.96
44	545	2	5	19	1	1	550	51.7	23.3	8.0	2.1	24.5	0.056	0.052	2.2	2.3	0.21
45	553	2	5	19	3	1	1038	61.9	26.3	8.4	2.3	39.3	0.108	0.111	3.8	3.7	0.60
46	577	2	5	19	1	2	723	57.0	24.1	8.0	2.1	29.1	0.053	0.051	2.6	2.6	0.45
47	595	2	5	19	3	1	910	58.3	25.8	8.3	2.1	44.3	0.094	0.140	3.5	3.6	0.62
48	596	2	5	19	1	1	755	56.4	25.0	8.4	2.1	23.3	0.070	0.084	2.8	2.7	0.33
49	527	2	5	20	3	1	750	58.4	25.9	8.2	2.1	24.7	0.085	0.107	3.0	3.0	0.60
50	599	2	5	20	3	1	963	59.8	26.4	8.6	2.2	28.3	0.131	0.128	3.1	3.2	0.43
51	576	2	5	22	1	1	529	56.0	22.7	7.8	1.9	18.1	0.032	0.041	2.0	2.0	0.26
52	566	2	5	28	3	2	1047	64.2	28.1	8.7	2.5	30.1	0.141	0.164	3.6	3.5	0.86
53	567	2	5	28	1	2	720	54.7	23.8	7.8	2.3	24.5	0.081	0.083	2.4	2.5	0.39
54	568	2	5	28	3	1	1033	54.2	21.5	8.2	2.3	43.9	0.128	0.130	4.2	4.4	0.41
55	570	2	5	28	3	1	1010	28.6	24.1	8.2	2.5	40.4	0.090	0.114	4.6	4.5	0.74

Table 37. (continued)

OBS	NUM	RV	RG	SC	AGE	SEX	CARHT	LGTH	TLGTH	HFOOT	EAR	LVHT	RA	LA	RKID	LKID	SPHT
56	572	2	5	28	3	1	1209	69.6	28.7	8.8	2.3	48.2	0.176	0.150	5.3	5.0	0.67
57	578	2	5	28	1	1	716	55.9	22.8	7.8	2.1	29.3	0.069	0.084	2.8	2.8	0.23
58	579	2	5	28	3	2	882	61.5	24.6	7.8	2.1	35.1	0.122	0.152	3.2	3.1	0.60
59	581	2	5	28	3	1	1008	60.9	24.5	8.1	2.1	31.5	0.104	0.139	4.1	3.1	0.41
60	582	2	5	28	1	2	664	54.9	23.0	7.8	1.9	22.9	0.056	0.087	2.8	2.6	0.33
61	583	2	5	28	3	1	975	56.6	24.3	7.9	2.1	35.5	0.085	0.108	2.9	3.1	0.72
62	585	2	5	28	3	1	1103	65.6	27.8	8.1	2.2	33.8	0.145	0.188	3.4	3.9	0.70
63	593	2	5	28	3	2	898	56.5	23.8	7.7	2.2	28.8	0.108	0.107	3.5	3.3	0.73
64	569	2	5	29	1	2	687	53.4	22.5	7.4	2.3	19.9	0.077	0.083	2.3	2.2	0.31
65	571	2	5	29	3	1	1109	63.3	26.6	8.8	2.4	36.9	0.092	0.114	4.7	5.0	0.63

[1]wt = weight, lgth = total length, tlght = tail length, hfoot = hind foot, carwt = carcass weight, la = left adrenal, ra = right adrenal, lkid = left kidney, rkid = right kidney, spwt = spleen weight, sleep = sleep time.

Table 38. Body and organ measurements[1] of muskrats from the Elizabeth and Nansemond Rivers, Va., 1986 - 1988 (obtained from cooperative trappers).

OBS	NUM	RV	RG	SC	AGE	SEX	CARHT	LGTH	TLGTH	HFOOT	EAR	LVHT	RA	LA	RKID	LKID	SPHT
1	88117	1	3	2	3	2	775.5	57.5	25.8	.	.	27.28	0.0808	0.1134	2.91	3.08	0.36
2	88118	1	3	2	1	1	666.5	.	.	.	.	17.11	0.0495	0.0538	1.85	1.81	0.27
3	871	1	3	3	1	1	557.4	46.8	21.5	7.1	.	22.44	0.0287	0.0377	2.10	2.20	0.34
4	872	1	3	3	1	1	599.2	48.2	23.2	7.6	.	27.24	0.0362	0.0254	2.40	2.24	0.45
5	873	1	3	3	3	1	720.9	55.1	25.7	7.6	.	30.04	0.0853	0.0626	3.28	3.39	0.76
6	874	1	3	3	1	2	626.7	47.6	21.8	7.2	.	21.89	0.0327	0.0320	2.29	2.41	0.33
7	875	1	3	3	1	1	888.3	53.4	25.5	8.0	.	65.39	0.0861	0.0638	3.25	3.49	0.96
8	876	1	3	3	1	2	598.3	48.4	23.2	7.2	.	33.91	0.0492	0.0460	2.83	2.48	0.44
9	877	1	3	3	3	1	1006.4	56.3	28.0	8.1	.	51.62	0.1093	0.1186	3.38	4.15	0.63
10	878	1	3	3	3	1	990.0	59.3	29.2	8.2	.	39.49	0.1003	0.1322	3.75	3.74	0.53
11	879	1	3	3	1	2	751.8	53.9	25.5	7.9	.	32.59	0.0560	0.0726	2.82	3.03	0.26
12	8710	1	3	3	3	2	926.4	59.9	26.9	8.1	.	38.70	0.0673	0.0679	3.11	2.97	0.46
13	8711	1	3	3	1	1	949.0	55.4	25.1	8.6	.	35.96	0.1697	0.1132	3.65	3.52	0.69
14	8712	1	3	3	3	2	865.4	59.2	29.9	8.2	.	36.72	0.1577	0.1082	4.01	4.22	0.68
15	881	1	3	3	1	2	823.5	.	.	.	.	32.05	0.1536	0.1003	2.90	2.83	0.66
16	882	1	3	3	1	2	702.9	.	.	.	.	25.15	0.0429	0.0770	2.27	2.42	0.58
17	883	1	3	3	3	2	944.0	.	.	.	.	34.12	0.0821	0.0855	3.27	3.07	0.59
18	884	1	3	3	3	2	970.5	.	.	.	.	35.17	0.0811	0.1150	3.04	2.95	0.44
19	885	1	3	3	1	2	900.0	.	.	.	.	20.06	0.0429	0.0557	2.62	2.93	0.53
20	886	1	3	3	1	2	999.1	.	.	.	.	41.85	0.0701	0.1110	3.12	2.91	0.60
21	887	1	3	3	1	2	766.4	.	.	.	.	28.08	0.0707	0.0947	2.49	2.42	1.06
22	888	1	3	3	3	2	1122.0	.	.	.	.	33.35	0.1077	0.1444	3.32	3.66	0.67
23	889	1	3	3	1	2	729.9	.	.	.	.	33.84	0.0534	0.0685	2.62	2.66	0.74
24	8810	1	3	3	3	2	1132.7	.	.	.	.	36.13	0.1068	0.1214	3.54	3.54	1.17
25	8811	1	3	3	1	2	789.2	.	.	.	.	29.92	0.0608	0.0865	2.25	2.53	1.28
26	8812	1	3	3	3	2	1042.6	.	.	.	.	40.10	0.0985	0.1430	4.39	4.26	0.92
27	8813	1	3	3	1	2	766.5	.	.	.	.	20.62	0.0841	0.0862	1.90	2.06	0.50
28	8814	1	3	3	1	2	942.2	.	.	.	.	39.53	0.1087	0.0972	3.48	3.15	0.78
29	8827	1	3	3	1	2	961.9	.	.	.	.	41.67	0.0989	0.0979	3.63	3.67	0.48
30	8828	1	3	3	1	2	852.7	.	.	.	.	35.86	0.0826	0.0968	2.90	3.15	0.61
31	8829	1	3	3	3	2	1088.2	.	.	.	.	38.21	0.0865	0.0956	4.03	3.66	0.72
32	8830	1	3	3	1	2	814.6	.	.	.	.	36.35	0.0888	0.1144	3.74	3.46	0.85
33	8831	1	3	3	1	2	803.0	.	.	.	.	25.75	0.0437	0.0369	2.53	2.24	1.02
34	8832	1	3	3	1	2	865.4	.	.	.	.	21.73	0.0367	0.0537	2.28	2.29	0.47
35	8833	1	3	3	1	1	836.1	.	.	.	.	28.78	0.0781	0.1082	2.51	2.73	0.48
36	8834	1	3	3	1	1	727.8	.	.	.	.	24.25	0.0334	0.0439	2.82	2.57	0.77
37	8835	1	3	3	1	1	678.8	.	.	.	.	19.96	0.0503	0.0512	2.14	2.23	0.60
38	8836	1	3	3	3	1	1045.8	.	.	.	.	39.37	0.0846	0.1408	2.66	3.11	0.59
39	8837	1	3	3	3	2	1103.7	.	.	.	.	40.13	0.1359	0.1264	3.65	3.32	0.87
40	8838	1	3	3	3	2	1036.6	.	.	.	.	29.68	0.0907	0.1263	3.55	3.04	0.84
41	8839	1	3	3	1	1	574.8	.	.	.	.	16.13	0.0280	0.0353	1.97	1.70	0.20
42	8840	1	3	3	3	2	862.8	.	.	.	.	23.68	0.0639	0.0758	2.71	2.38	0.60
43	8841	1	3	3	1	2	561.5	.	.	.	.	27.33	0.0380	.	1.80	1.84	0.69
44	8842	1	3	3	3	2	1027.3	.	.	.	.	40.19	0.0707	0.1048	3.68	3.67	1.41
45	8843	1	3	3	1	2	773.2	.	.	.	.	24.58	0.0722	0.0816	2.62	2.50	0.33
46	8844	1	3	3	1	2	814.8	.	.	.	.	23.12	0.0691	.	2.12	2.18	0.39
47	8845	1	3	3	1	2	788.6	.	.	.	.	25.56	0.0615	0.0788	2.39	2.47	0.34
48	8846	1	3	3	3	2	866.0	.	.	.	.	27.77	0.1067	0.0893	3.27	2.80	0.40
49	8861	1	3	3	1	2	863.9	.	.	.	.	27.41	0.0850	0.0891	2.50	2.25	1.65
50	8862	1	3	3	3	2	845.0	.	.	.	.	25.75	0.0667	0.0833	2.33	2.52	0.45
51	8863	1	3	3	1	2	597.6	.	.	.	.	20.14	0.0991	0.0912	2.04	1.81	0.19
52	8864	1	3	3	3	2	821.3	.	.	.	.	20.91	0.0690	0.0792	2.09	2.51	0.50
53	8871	1	3	3	3	1	907.2	.	.	.	.	25.43	0.0576	0.0671	2.43	3.31	0.71
54	8872	1	3	3	3	1	892.8	.	.	.	.	29.50	0.0750	0.0653	2.85	2.76	0.56
55	8873	1	3	3	3	1	1052.4	.	.	.	.	60.28	0.0742	0.0822	3.39	3.47	1.45

Table 38. (continued)

OBS	NUM	RV	RG	SC	AGE	SEX	CANHT	LGTH	TLGTH	HFOOT	EAR	LVHT	RA	LA	RKID	LKID	SPHT
56	8874	1	3	3	1	1	664.6	.	.	.	.	27.46	0.0364	0.0416	2.81	2.44	0.65
57	8875	1	3	3	3	1	1153.4	.	.	.	.	50.34	0.1144	0.1536	4.63	4.82	1.56
58	8876	1	3	3	3	1	1053.8	.	.	.	.	33.07	0.0534	0.0514	3.82	3.52	0.60
59	8877	1	3	3	3	1	1076.7	.	.	.	.	41.12	0.0759	0.0854	3.20	3.25	0.45
60	8878	1	3	3	3	1	1190.7	.	.	.	.	43.74	0.0687	0.1063	4.44	4.84	0.92
61	8879	1	3	3	1	1	1079.3	.	.	.	.	38.39	0.0542	0.0532	3.25	2.90	0.54
62	8880	1	3	3	3	1	976.6	.	.	.	.	35.16	0.0723	0.0975	3.64	3.96	1.07
63	8881	1	3	3	3	1	1036.6	.	.	.	.	41.49	0.0919	0.0929	4.85	4.95	0.68
64	8882	1	3	3	3	1	886.9	.	.	.	.	39.34	0.0741	0.0842	3.84	3.45	0.48
65	8886	1	3	3	1	2	950.6	.	.	.	.	33.76	0.0929	0.1288	3.18	3.21	0.76
66	8887	1	3	3	1	2	991.5	.	.	.	.	31.54	0.0686	0.0995	2.81	3.11	0.82
67	8888	1	3	3	1	2	790.3	.	.	.	.	28.00	0.0440	0.0829	2.79	3.00	0.39
68	8889	1	3	3	1	2	1119.1	.	.	.	.	41.03	0.1203	0.1713	3.88	3.44	0.87
69	8893	1	3	3	1	2	885.0	.	.	.	.	26.08	0.0556	0.0460	2.60	2.65	1.11
70	8894	1	3	3	1	2	813.5	.	.	.	.	26.04	0.0392	0.0567	2.38	2.50	0.82
71	8895	1	3	3	3	2	1138.0	.	.	.	.	32.82	0.0931	0.1799	3.53	3.73	0.95
72	8896	1	3	3	1	2	900.0	.	.	.	.	27.34	0.0622	0.0663	2.48	2.27	1.17
73	8897	1	3	3	3	2	922.5	.	.	.	.	24.91	0.0858	0.0831	3.44	3.02	0.85
74	8898	1	3	3	3	2	831.5	.	.	.	.	22.16	0.1083	0.0739	3.88	3.10	0.71
75	8899	1	3	3	1	2	844.5	.	.	.	.	23.74	.	.	2.92	2.81	0.51
76	88100	1	3	3	1	2	481.8	.	.	.	.	12.48	0.0197	0.0110	1.50	1.28	0.41
77	88101	1	3	3	1	2	790.0	.	.	.	.	21.21	0.0298	0.0553	2.93	2.26	0.35
78	88102	1	3	3	3	2	1006.0	.	.	.	.	38.83	0.0865	0.0866	3.11	3.15	1.33
79	88103	1	3	3	3	1	1203.5	62.8	28.5	.	.	56.16	0.0793	0.1286	4.91	5.46	0.69
80	88104	1	3	3	3	1	1121.0	62.2	27.5	.	.	51.00	0.0890	0.1305	4.63	4.86	1.15
81	88105	1	3	3	1	1	864.0	56.5	26.3	.	.	38.08	0.0445	0.0647	2.57	2.64	0.73
82	88111	1	3	3	1	2	810.5	58.4	27.8	.	.	27.01	0.0800	0.1323	2.37	2.38	0.33
83	88112	1	3	3	1	2	649.5	51.9	23.6	.	.	27.94	0.0336	0.0560	2.06	2.33	0.48
84	88113	1	3	3	3	1	1077.0	63.6	31.1	.	.	32.34	0.1129	0.1385	4.71	4.51	0.90
85	88114	1	3	3	1	1	695.5	54.1	24.7	.	.	28.50	0.0220	0.0465	1.70	2.46	0.54
86	88115	1	3	3	1	2	599.0	52.2	23.8	.	.	22.25	.	0.0562	1.99	2.80	0.59
87	88116	1	3	3	1	1	541.5	47.0	.	.	.	20.30	0.0248	0.0401	2.32	2.32	0.38
88	88127	1	3	3	1	1	592.7	53.0	24.5	.	.	14.46	0.0339	0.0171	0.94	1.03	0.21
89	88128	1	3	3	1	2	632.3	52.0	22.2	.	.	20.72	0.0323	0.0249	1.90	1.87	0.42
90	88135	1	3	3	1	2	565.4	53.0	24.5	.	.	22.78	0.0381	0.0372	1.88	2.02	0.65
91	88136	1	3	3	1	1	771.6	55.6	26.0	.	.	18.46	0.0321	0.0419	1.42	2.21	0.53
92	88137	1	3	3	1	1	887.6	61.0	28.8	.	.	28.45	0.0895	0.0919	2.28	2.60	0.75
93	88138	1	3	3	1	1	610.1	52.5	23.0	.	.	19.62	.	0.0267	2.41	2.34	0.56
94	88139	1	3	3	3	1	1125.6	67.0	31.5	.	.	33.81	0.1134	.	3.77	3.99	0.46
95	88140	1	3	3	1	2	815.7	60.5	28.5	.	.	25.42	0.0570	0.0837	2.09	2.09	1.03
96	88141	1	3	3	1	2	762.5	56.0	26.5	.	.	22.69	0.0428	0.0548	1.18	1.74	0.44
97	88142	1	3	3	1	1	665.6	55.0	25.5	.	.	22.78	0.0506	0.0423	1.86	2.16	0.87
98	88143	1	3	3	1	2	712.7	57.5	27.5	.	.	22.44	0.0441	0.0408	1.82	2.13	0.66
99	88144	1	3	3	3	1	991.8	66.0	31.5	.	.	51.46	0.0693	0.0402	4.24	4.15	1.65
100	88145	1	3	3	1	1	789.7	58.0	27.0	.	.	35.66	0.0680	0.0711	3.70	3.64	0.56
101	88146	1	3	3	3	1	1030.9	65.5	30.5	.	.	51.38	0.1723	0.1299	3.73	3.99	1.94
102	88147	1	3	3	3	1	1040.0	61.0	28.0	.	.	31.83	0.0644	0.0506	3.25	3.60	0.50
103	88148	1	3	3	3	1	899.8	60.5	27.5	.	.	28.80	0.0658	0.0721	4.05	3.67	0.40
104	88149	1	3	3	1	1	768.1	59.5	26.0	.	.	24.22	0.0375	0.0520	2.40	2.62	0.48
105	88150	1	3	3	3	1	889.5	57.5	24.5	.	.	30.46	0.0709	0.0868	2.72	2.65	0.41
106	88151	1	3	3	3	1	775.2	54.5	.	.	.	27.99	0.0425	0.0351	1.70	1.73	0.65
107	8713	1	3	4	1	1	700.4	52.7	25.0	7.9	.	29.76	0.0681	0.0513	3.08	2.25	0.46
108	8714	1	3	4	1	2	888.7	52.5	24.6	8.1	.	31.42	0.0657	0.0536	3.11	3.49	0.47
109	8715	1	3	4	3	2	840.0	59.2	29.4	8.0	.	36.15	0.0757	0.0888	3.79	3.88	0.73
110	8716	1	3	4	1	2	813.2	51.7	23.9	7.9	.	27.06	0.0966	0.0854	2.83	3.03	0.53

Table 38. (continued)

OBS	NUM	RV	RG	SC	AGE	SEX	CARHT	LGTH	TLGTH	HFOOT	EAR	LVHT	RA	LA	RKID	LKID	SPHT
111	8717	1	3	4	3	1	921.9	53.8	25.3	7.9	.	32.52	0.0613	0.0789	3.61	4.11	0.56
112	8718	1	3	4	1	1	863.0	58.1	28.3	7.9	.	37.73	0.0777	0.0638	3.85	3.40	0.54
113	8815	1	3	4	1	2	848.0	.	.	.	.	24.87	0.1105	0.1282	2.84	2.86	0.46
114	8816	1	3	4	1	2	704.1	.	.	.	.	27.66	0.0487	0.0723	1.77	1.86	0.54
115	8817	1	3	4	3	2	973.9	.	.	.	.	28.23	.	0.1041	3.62	3.55	0.58
116	8818	1	3	4	1	2	982.6	.	.	.	.	34.65	0.0677	0.1020	2.76	2.70	0.96
117	8819	1	3	4	3	2	836.4	.	.	.	.	25.31	0.0977	0.1206	2.91	2.82	0.59
118	8820	1	3	4	1	1	773.0	.	.	.	.	22.81	0.0538	0.0583	2.56	2.70	1.18
119	8821	1	3	4	1	2	719.2	.	.	.	.	24.97	0.0482	0.0633	2.51	2.80	0.51
120	8822	1	3	4	1	2	836.1	.	.	.	.	27.50	0.0386	0.0577	2.55	2.77	0.82
121	8823	1	3	4	1	2	850.4	.	.	.	.	34.10	0.1013	0.1325	3.05	2.96	0.40
122	8824	1	3	4	1	2	880.5	.	.	.	.	30.89	0.0717	0.0987	2.27	2.45	0.41
123	8825	1	3	4	1	2	963.6	.	.	.	.	28.29	0.0798	0.0989	2.92	2.86	0.73
124	8826	1	3	4	1	2	514.7	.	.	.	.	13.73	0.0334	0.0264	1.89	1.84	0.28
125	8847	1	3	4	3	1	991.3	.	.	.	.	34.13	0.0683	0.0744	3.94	4.05	0.52
126	8848	1	3	4	3	1	707.5	.	.	.	.	25.83	0.0508	0.0707	2.45	2.36	0.70
127	8849	1	3	4	3	1	906.5	.	.	.	.	28.00	0.0794	0.1056	2.90	3.73	0.78
128	8850	1	3	4	3	1	1183.3	.	.	.	.	32.99	0.0690	0.0641	4.29	4.35	0.76
129	8851	1	3	4	3	1	978.4	.	.	.	.	33.66	0.0732	0.0899	3.94	3.98	0.48
130	8852	1	3	4	3	1	757.0	.	.	.	.	19.74	0.1074	0.1552	3.65	3.21	0.38
131	8853	1	3	4	3	1	1164.8	.	.	.	.	44.44	0.0500	0.0868	4.41	4.60	1.27
132	8854	1	3	4	3	1	884.8	.	.	.	.	23.86	0.0915	0.1167	3.64	3.93	0.41
133	8855	1	3	4	3	1	783.1	.	.	.	.	33.97	0.0736	0.0791	3.18	2.93	0.45
134	8856	1	3	4	1	1	700.6	.	.	.	.	24.08	0.0319	0.0404	2.38	2.56	0.31
135	8857	1	3	4	1	2	854.5	.	.	.	.	24.09	0.0823	0.0800	2.39	2.49	0.33
136	8858	1	3	4	3	2	1021.1	.	.	.	.	33.64	0.0896	0.0725	3.37	3.30	1.29
137	8859	1	3	4	1	2	582.6	.	.	.	.	14.50	0.0402	0.0262	1.83	1.82	0.28
138	8860	1	3	4	1	2	984.1	.	.	.	.	31.08	0.0843	0.1005	2.56	2.76	0.85
139	8865	1	3	4	1	2	918.8	.	.	.	.	25.68	.	0.0604	2.63	2.80	0.51
140	8866	1	3	4	3	2	1106.4	.	.	.	.	25.34	0.0757	0.0838	3.02	3.60	0.82
141	8867	1	3	4	1	2	596.5	.	.	.	.	19.11	0.0417	0.0569	1.71	1.93	0.26
142	8868	1	3	4	1	2	526.2	.	.	.	.	14.76	0.0249	0.0427	1.54	1.98	0.42
143	8869	1	3	4	1	2	905.0	.	.	.	.	21.40	0.0691	0.0912	2.27	2.38	1.11
144	8870	1	3	4	1	2	669.1	.	.	.	.	22.76	0.0698	0.0604	1.91	1.58	0.29
145	88162	1	3	4	3	2	894.5	59.5	27.0	.	.	23.43	0.0820	0.1040	2.73	2.71	0.45
146	88163	1	3	4	1	2	824.5	59.0	28.0	.	.	23.86	0.1076	0.1559	3.19	2.54	0.43
147	88164	1	3	4	1	2	1121.5	64.5	29.0	.	.	42.51	0.1163	0.1395	4.41	3.93	0.90
148	88165	1	3	4	1	2	386.8	50.5	22.5	.	.	16.05	0.0430	0.0487	1.44	1.59	0.37
149	88166	1	3	4	1	2	884.2	60.5	28.5	.	.	33.35	0.0638	0.0618	2.50	2.26	1.08
150	88167	1	3	4	3	2	826.0	63.0	29.5	.	.	24.85	0.0717	0.0699	2.67	2.33	0.42
151	88168	1	3	4	1	2	839.4	59.0	27.0	.	.	24.94	0.0789	0.1294	1.99	2.33	0.45
152	8883	1	3	5	1	2	1013.1	.	.	.	.	34.13	0.0555	0.0682	3.50	2.86	0.54
153	8884	1	3	5	3	2	1114.1	.	.	.	.	40.50	0.0685	0.0866	3.02	2.98	0.67
154	8885	1	3	5	3	2	917.3	.	.	.	.	37.09	0.1413	0.1303	3.58	2.55	0.52
155	88106	1	3	5	1	1	593.5	53.1	25.4	.	.	15.42	0.0245	0.0067	1.93	2.30	0.46
156	88107	1	3	5	1	2	590.5	50.8	24.0	.	.	18.64	0.0279	0.0382	1.81	2.00	0.92
157	88108	1	3	5	1	2	578.5	49.8	23.7	.	.	18.02	0.0264	0.0392	0.81	1.07	0.44
158	88109	1	3	5	1	2	560.0	52.7	23.8	.	.	16.81	0.0314	0.0514	2.47	2.05	0.37
159	88110	1	3	5	1	2	457.0	45.5	21.7	.	.	14.86	0.0130	0.0241	1.62	1.58	0.54
160	88119	1	3	5	3	2	956.5	62.0	27.5	.	.	31.87	0.0668	0.1268	2.69	2.78	1.05
161	88120	1	3	5	3	2	939.5	60.2	27.5	.	.	30.96	0.0924	0.0951	3.07	3.08	0.47
162	88121	1	3	5	1	2	812.1	58.0	27.0	.	.	29.33	0.0731	0.0728	2.39	1.90	0.65
163	88122	1	3	5	1	2	664.8	52.0	23.0	.	.	20.30	0.0525	0.0300	1.96	1.84	0.28
164	88123	1	3	5	1	2	687.6	52.0	23.7	.	.	23.25	0.0247	0.0360	1.85	1.53	0.55
165	88124	1	3	5	1	2	562.2	50.0	23.0	.	.	16.85	0.0197	0.0304	2.12	2.01	0.52

Table 38. (continued)

OBS	NUM	RV	RG	SC	AGE	SEX	CARWT	LGTH	TLGTH	HFOOT	EAR	LVWT	RA	LA	RKID	LKID	SPWT
166	88125	1	3	5	3	2	999.0	63.0	28.0	.	.	30.28	0.0786	0.0749	2.30	2.55	1.54
167	88126	1	3	5	3	2	936.6	61.0	27.5	.	.	27.42	0.1047	0.0839	2.37	2.42	0.69
168	88129	1	3	5	1	2	568.7	49.5	22.0	.	.	17.12	0.0285	0.0151	1.62	1.67	0.44
169	88130	1	3	5	1	2	795.7	61.0	27.0	.	.	25.45	0.0491	0.0571	2.50	2.55	0.81
170	88131	1	3	5	1	2	724.0	57.0	24.0	.	.	29.75	0.0499	0.0577	2.40	2.30	0.65
171	88132	1	3	5	1	2	822.9	62.0	28.0	.	.	23.32	0.0368	0.0524	1.56	1.43	0.48
172	88133	1	3	5	1	2	548.9	49.0	22.0	.	.	14.76	0.0214	0.0359	1.55	1.58	0.42
173	88134	1	3	5	1	2	757.5	51.0	26.5	.	.	22.58	0.0976	0.0608	2.03	2.05	0.64
174	88152	1	3	5	1	1	765.0	59.5	28.0	.	.	23.26	0.0418	0.0433	1.86	2.41	0.66
175	88153	1	3	5	1	1	735.1	58.0	28.0	.	.	31.84	0.0868	0.0923	2.07	2.19	0.65
176	88154	1	3	5	3	1	914.4	58.0	26.0	.	.	33.89	0.0936	0.0794	3.61	3.52	0.53
177	88155	1	3	5	1	1	787.4	55.0	23.0	.	.	28.17	0.0421	0.0444	1.45	2.17	0.60
178	88156	1	3	5	3	1	937.4	63.0	27.5	.	.	37.20	0.1075	0.0922	2.64	3.10	1.57
179	88157	1	3	5	1	1	726.0	55.5	24.0	.	.	19.98	0.0460	0.0495	2.42	2.49	0.85
180	88158	1	3	5	1	1	775.5	59.0	26.0	.	.	34.48	0.0833	0.0575	3.08	2.73	0.41
181	88159	1	3	5	1	1	795.7	56.5	25.0	.	.	33.45	0.0963	0.0611	3.17	2.60	0.59
182	88160	1	3	5	1	1	834.9	60.0	26.0	.	.	25.01	0.0408	0.0855	1.69	1.45	0.89
183	88161	1	3	5	1	1	735.5	60.0	28.0	.	.	17.56	0.0496	0.0441	1.80	1.95	0.29
184	88169	1	3	5	3	1	836.7	61.0	28.5	.	.	28.76	0.0803	0.0827	3.93	3.40	1.14
185	88170	1	3	5	1	1	643.8	54.5	23.0	.	.	29.61	0.0525	0.0521	2.29	2.47	0.79
186	88171	1	3	5	1	1	962.5	62.5	31.0	.	.	34.70	0.0767	0.1117	2.67	2.39	0.58
187	88172	1	3	5	3	1	1046.6	62.5	29.0	.	.	37.33	0.0743	0.0985	3.58	3.80	0.60
188	88173	1	3	5	1	1	821.3	62.0	31.0	.	.	20.37	0.0917	0.1011	2.89	2.65	0.56
189	88174	1	3	5	3	1	853.0	61.5	30.0	.	.	23.83	0.0913	0.0736	2.84	2.92	0.57
190	88175	1	3	5	3	2	831.1	64.0	31.0	.	.	26.20	0.1375	0.1320	2.41	2.75	1.13
191	8890	2	5	1	3	1	1055.5	.	.	.	.	28.18	0.0554	0.0624	2.57	2.29	0.66
192	8891	2	5	1	1	2	839.5	.	.	.	.	18.00	0.0400	0.0505	1.64	1.65	0.48
193	8892	2	5	1	3	1	1173.0	.	.	.	.	37.46	0.0978	0.1370	4.32	4.88	0.90
194	8719	2	5	19	3	1	1238.5	63.6	31.3	8.2	.	58.24	0.0783	0.0994	4.47	4.85	0.65
195	8720	2	5	19	3	1	1186.6	61.4	29.6	7.5	.	57.31	0.0564	0.0762	4.40	4.30	0.80
196	8721	2	5	19	1	2	1005.2	56.5	27.9	8.0	.	39.20	0.0774	0.0609	2.86	3.50	0.62
197	8722	2	5	19	3	1	1130.9	60.1	29.2	7.9	.	52.41	0.0709	0.0895	4.48	3.88	0.66
198	8723	2	5	19	3	2	1065.1	60.5	28.8	8.1	.	45.30	0.1045	0.0788	3.18	3.56	0.45
199	8724	2	5	19	1	2	885.9	57.3	27.3	8.0	.	38.81	0.0604	0.0559	2.84	2.85	0.54
200	8725	2	5	19	1	2	1021.3	57.9	28.2	7.9	.	43.28	0.0881	0.0985	2.91	2.84	0.48
201	8726	2	5	19	3	1	1213.8	60.9	29.3	8.1	.	59.66	0.0695	0.0916	4.97	4.53	0.76
202	8727	2	5	19	3	1	1081.5	60.7	29.5	8.1	.	46.83	0.0674	0.0856	4.40	3.65	0.34
203	8728	2	5	19	3	2	1045.3	56.5	26.9	8.0	.	54.62	0.0771	0.0560	3.13	3.36	0.68
204	8729	2	5	19	3	1	880.9	57.1	27.2	7.8	.	42.25	0.0797	0.1177	3.84	4.15	0.93
205	8730	2	5	19	3	1	1115.4	61.5	28.6	8.3	.	66.18	0.0893	0.0672	3.71	4.39	1.03
206	8731	2	5	19	1	2	1068.9	.	.	7.9	.	53.78	0.0648	0.0836	4.24	4.35	1.93
207	8732	2	5	19	1	2	823.2	53.1	25.9	7.7	.	37.48	0.1118	0.0983	3.53	3.88	1.07
208	8733	2	5	19	3	1	1038.2	55.7	25.5	8.2	.	41.96	0.0755	0.0672	3.86	3.86	0.69
209	8734	2	5	19	1	2	868.0	53.4	25.6	7.5	.	38.15	0.0820	0.0622	2.37	2.38	0.53
210	8735	2	5	19	3	1	1063.2	56.7	26.8	7.8	.	44.36	0.1111	0.1126	3.94	4.62	0.44
211	8736	2	5	19	1	2	1137.3	58.7	29.6	8.2	.	49.24	0.1109	0.1043	3.78	4.24	2.15
212	8737	2	5	19	3	2	1091.7	.	.	8.2	.	41.45	0.1178	0.0817	3.08	3.01	1.05
213	8738	2	5	19	1	1	671.0	47.0	22.0	7.1	.	28.78	0.0581	0.0458	2.35	2.64	0.74

[1]lgth = total length, tlght = tail length, hfoot = hind foot, carwt = carcass weight, la = left adrenal, ra = right adrenal, lkid = left kidney, rkid = right kidney, spwt = spleen weight, sleep = sleep time.

Vita

Richard Scott Halbrook was born to Luther L. and Katherine P. Halbrook on October 19, 1946 in San Juan, Puerto Rico. He graduated from Frederick Military Academy in 1964. After completing Officers Candidate School at Fort Sill, Oklahoma in 1967, he served as a commissioned army officer until 1971. He completed a B.S. degree in Biology at Valdosta State College, Valdosta, Georgia in 1973 and an M.S. degree in Forest Resources at the University of Georgia, Athens, Georgia in 1978. His thesis title was "Environmental Pollutants in the River Otter of Georgia". From 1979 - 1986 he taught wildlife management courses in the Agricultural and Biological Sciences Department at Haywood Community College, Clyde, North Carolina. From July 1986 to February 1990, he attended Virginia Polytechnic Institute and State University, Blacksburg, Virginia where he completed a Doctor of Philosophy degree in Wildlife Science. The title of his dissertation was "Muskrat Populations in Virginia's Elizabeth River: Influence of Environmental Contaminants". His research interest is the study of wild species as indicators of environmental contaminants.