4.2 Zooplankton

Introduction

Zooplankton is a diverse assemblage of microscopic and macroscopic aquatic animals that include rotifers, cladocerans and copepods. There are planktonic (open water) and sessile (attached) forms, as well as freshwater and marine forms, although the great percentage are freshwater (Pennak 1978). Most zooplankters live in the epilimnion ($>$ 50%), although some species can be found in the metalimnion and hypolimnion (Makarewicz and Likens 1979). The majority of zooplankters restrict themselves to the epilimnion in the summer, possibly due to an anoxic and toxic metalimnetic barrier (Taggart 1984).

Seasonal cycles of zooplankton abundance are dependent on food and temperature, and variations in seasonal cycles are common (Edmondson 1965; Pennak 1978). Temperature, food quality and quantity are dominant factors in the regulation of rotifer reproductive rates and population succession. Copepod seasonal cycles are variable, but numbers appear to increase in spring and summer. Cladoceran seasonal cycles are variable among species and within species. In general, cladoceran populations are low in winter and increase in spring with increasing food supply from photosynthesis and rising temperatures. Population cycles in the summer are more variable, as mortality and competition are highest during this period (Pennak 1978).

Temperature is important for distribution and generation time of zooplankton species (Pennak 1978). It accounts for a large degree of the variation found in zooplankton populations, as they are poikilothermic animals (their temperature fluctuates with that of their surroundings) (Armitage 1972; Moore 1978; Makarewicz 1985). Growth and reproduction of temperate zone warmwater invertebrate species mostly occurs between the temperatures of 10°-30°C, with the rates usually being highest in the range of 20°-30°C, depending on the species and food availability. The tolerance limit for survival varies with the species and also depends on the acclimation temperature and exposure time. Freshwater invertebrates acclimated to 25°-26°C have been shown to tolerate temperatures of 36°-38°C for 60 minutes and 32°-35°C for 24 hours, depending on the species (Ecological Analysis, Inc. 1978; Ginn et al. 1974; Lauer et al. 1974). Similarly, invertebrates acclimated at 30°-32°C would be able to tolerate even higher temperatures than those acclimated to 25°-26° (Carlson 1974).

Food supply is also closely related to temperature in determining seasonal abundance cycles. Herbivorous zooplankton are influenced most by algal food supply, along with temperature and predation, whereas carnivorous zooplankton are most influenced by food supply (Moore 1978). Rotifers consume large and small algae, detritus, bacteria and other rotifers (Pennak 1978; Pontin 1978). Cladocerans eat algae, protozoa, organic detritus and bacteria.

Calanoid copepods filter plankton, while cyclopoids feed on unicellular plants and animals, other crustaceans and organic debris (Pennak 1978).

The type of algae consumed by herbivores is as important as how much is consumed (Martin 1966). Some algae species such as blue-green algae can inhibit feeding, growth and reproduction (Wetzel 1975; Gannon and Stemberger 1978). High densities of the green algae Chlorella were reported toxic as well. In addition, toxic pollutants from industrial and municipal sources, and sites of nutrient loading are detrimental to zooplankton. Toxic substances, however, can be detrimental to some species and not to others, causing spatial and temporal differences in distribution of zooplankters (Gannon and Stemberger 1978).

A few predatory species of rotifers and Cladocera will eat other zooplankton (Wetzel 1975; Pennak 1978). Cyclopoid copepods eat other crustaceans, and cannibalism on immature stages is common (Wetzel 1975). Free-living cyclopoids also attack fish larvae (Hartig and Jude 1984; Smith and Kernehan 1981). But, for the most part, zooplankton are the prey rather than the predator. Zooplankton provide an important link in the trophic chain (see Fig. 4-1) between phytoplankton and higher animals, i.e. macroinvertebrates and fishes (Pennak 1978; Pontin 1978). The balance of these upper trophic levels can cause shifts in the zooplankton community composition. Increasing the stock of large predatory fish can decrease vertebrate planktivore densities, increasing invertebrate planktivory and causing a shift in the population toward the larger crustacean zooplankton. A decrease in piscivore density causes a rise in vertebrate planktivory, a decrease in invertebrate planktivory and high densities of small crustaceans and rotifers (Dumont 1977; Carpenter et al. 1985).

Zooplankton has a relatively quick population response time, due to their short generation times. Their numbers respond quickly to environmental change and may be effective indicators of subtle alterations in water quality. Rotifers have the highest intrinsic rate of natural increase among the major zooplankton groups and exhibit high population turnover rates in nature (Gannon and Stemberger 1978). The average rotifer life span is 5.6 - 14.1 days (Makarewicz and Likens 1979; Makarewicz 1985). Cladocerans mature from egg to juvenile instar in about two days, and live for about 20-30 days (increasing with decreasing temperature) (Pennak 1978; Makarewicz and Likens 1979). Copepod life expectancy ranges from 7-180 days to one year. The number of generations a year varies from one generation to year-round reproduction (Wetzel 1975; Pennak 1978).

Most zooplankton are capable of producing overwintering eggs. A sexual generation is induced by conditions such as food supply, crowding, water temperature, light intensity and accumulation of substances such as excretory products or pheromones. This sexual reproduction results in the production of thick-walled resting eggs that are highly resistant to adverse environmental conditions

(Hutchinson 1967; Birky and Gilbert 1971; Wetzel 1975; Pennak 1978).

The zooplankton of Lake Anna has been studied for 14 years to determine the seasonal abundance and distribution of the community. This information, along with information from the literature will be used to evaluate the zooplankton community for the 316(a) demonstration.

Information Base for Evaluation

The Lake Anna zooplankton community has been studied since 1972, when the reservoir was created. During the 316(a) study, zooplankton was collected from eight stations on Lake Anna during the January 1984-December 1985 study period (Fig. 4.2-1). At each station, samples were collected at 0 and 4 meters with a 5-liter Niskin water bottle. To supplement these data, a vertical tow net sample was also collected at each station, either from a depth of 5 or 10 meters, depending on station depth. For a more detailed procedures discussion, see Appendix D.

The vertical tow collections were added to the regular Niskin sampling program in 1983 to ascertain whether the Niskin bottle was collecting a representative sample of the larger, faster swimming crustaceans, which could possibly avoid the bottle sampler. After three years of sampling, evaluation of the tow sampling program verified that the Niskin bottle was collecting a representative cross section of the zooplankton community. Tow samples only collected greater numbers of the same crustacean genera collected by the Niskin (Appendix B-Table 1).

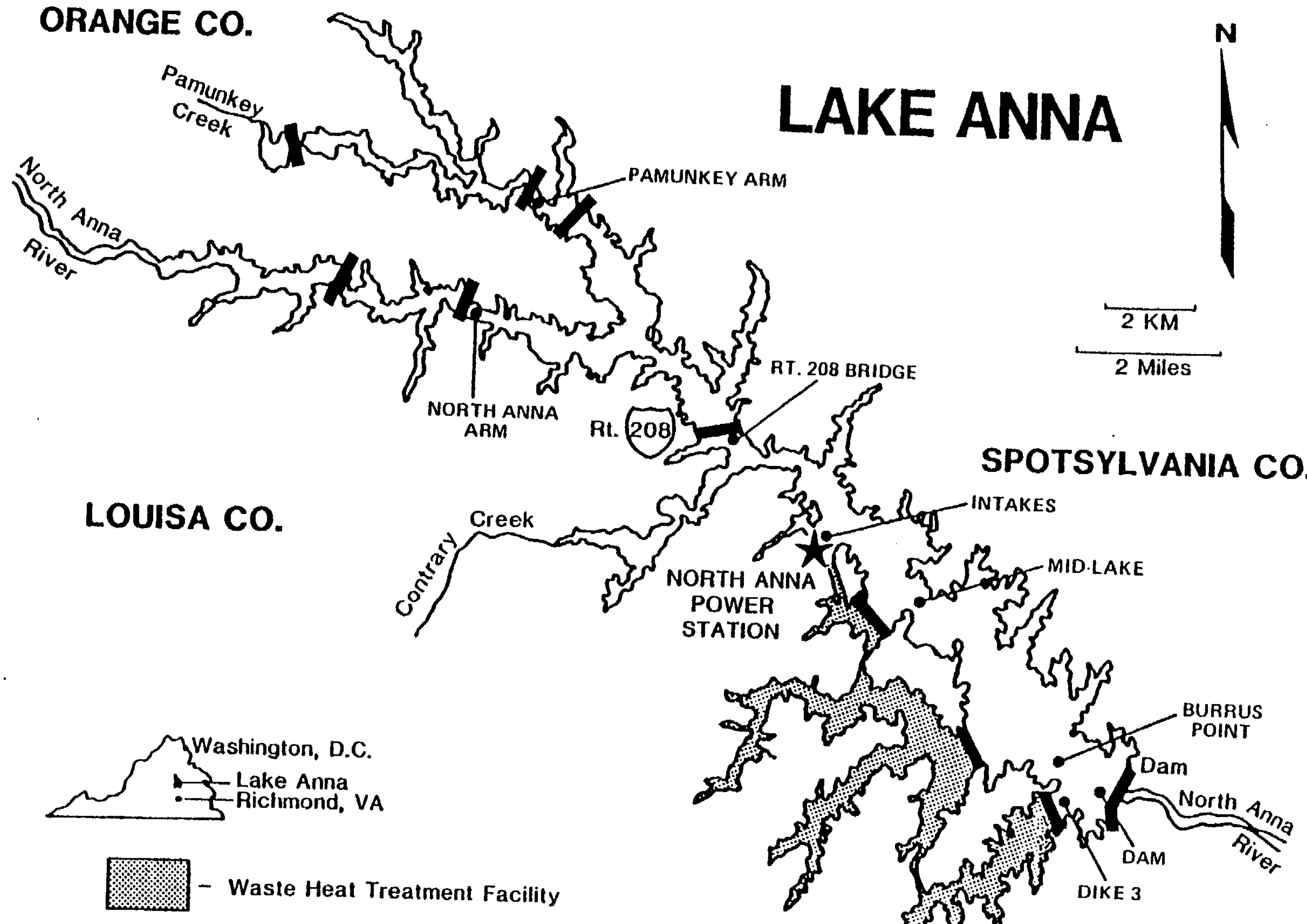


Figure 4.2-1. Location of 316(a) zooplankton sampling stations.

The purpose of the study was to determine if there were any discernable effects of the thermal discharge from the power station on the zooplankton community of Lake Anna. These effects would be evident in major community shifts in taxa, distribution and abundance that could affect the balance of the ecosystem.

Zooplankton data were available for the pre-operational years 1972-1976 and the operational years 1978-1985. Because the years 1972-1974 were transitional (riverine ecosystem changing to a lake ecosystem) and the data base for these years was sporadic, most comparisons with pre-operational years emphasize 1975-1976.

The sampling program was designed to show seasonal and geographic trends in zooplankton compostion, distribution and abundance. Cluster analysis of stations and taxa illustrated the general distribution and abundance patterns. Histograms of all years (1972-1976, 1978-1985) were prepared to illustrate any density changes, total and within the three major groups (rotifers, cladocerans and copepods).

In August 1984, five additional plankton stations between the intakes and dam were sampled in conjunction with the regular stations, to determine if the existing stations in this area were adequate for characterizing the zooplankton community (Appendix B-Fig. 1). The ANOVAs of community density detected no significant differences between the regular and/or additional stations (Appendix B-Table 2). Diversity and richness were also similar for adjacent stations, and dominant taxa were the same throughout this area. Based on these findings, it was concluded the plankton stations between the intakes and dam were providing a representative sample of the zooplankton community, and additional stations would be redundant.

Temperature is an important variable in determining zooplankton abundance and seasonal trends. Data analysis made use of pre-operational/operational density and taxa comparisons, as well as uplake/downlake station density comparisons, to detect any changes in the zooplankton community. Factors other than station operation, such as lake maturation and nutrient gradients, could produce geographic and temporal community shifts and should be considered in assessing the data.

A presence/absence taxa list of all years (1972-1976, 1978-1985) allowed comparisons of the zooplankton community over time, and emphasized any pre-operational/operational changes. Information values such as number of taxa, diversity and amount of change in community composition helped to further clarify any changes.

Two-way ANOVAs and Duncan's Multiple Range Test for the Dam and Intake stations (consistent historical stations) using year and month as independent variables tested for significant differences in zooplankton densities over years and between months over years. The data were divided into pre-operational and operational years to detect changes in seasonal patterns. Significant differences between zooplankton densities at the Intake, Mid Lake, Burrus Point, Dike 3 Endeco and Dam stations were also tested by a one-way ANOVA and Duncan's Multiple Range Test for the years 1984 and 1985.

Food quantity, in addition to temperature, is also an important variable in determining zooplankton abundance. Phytoplankton/zooplankton seasonal abundance patterns were compared to examine this relationship for Lake Anna. Stepwise multiple regressions tested the significance of the relationship between temperature, food supply and the zooplankton of Lake Anna.

Assessment

Lake Anna zooplankton data were examined in various ways to detect any significant changes that might have occurred over the pre-operational (1972-1976) and operational (1978-1985) years. Mean annual zooplankton densities were compared among the four consistent historical stations-Dam, Intake, Pamunkey Arm and North Anna Arm (Fig. 4.2-2).

The Dam and Intake station densities have remained relatively stable over the years. A one-way analysis of variance (ANOVA) of the Intake mean annual densities for the years 1972-1985 (excluding 1977) showed no significant differences between annual means. An ANOVA of the Dam station mean annual densities for the same years did detect significant differences (.05 level) between some years. However, pre-operational /operational differences were not evident, as shown in the following Duncan's Multiple Range

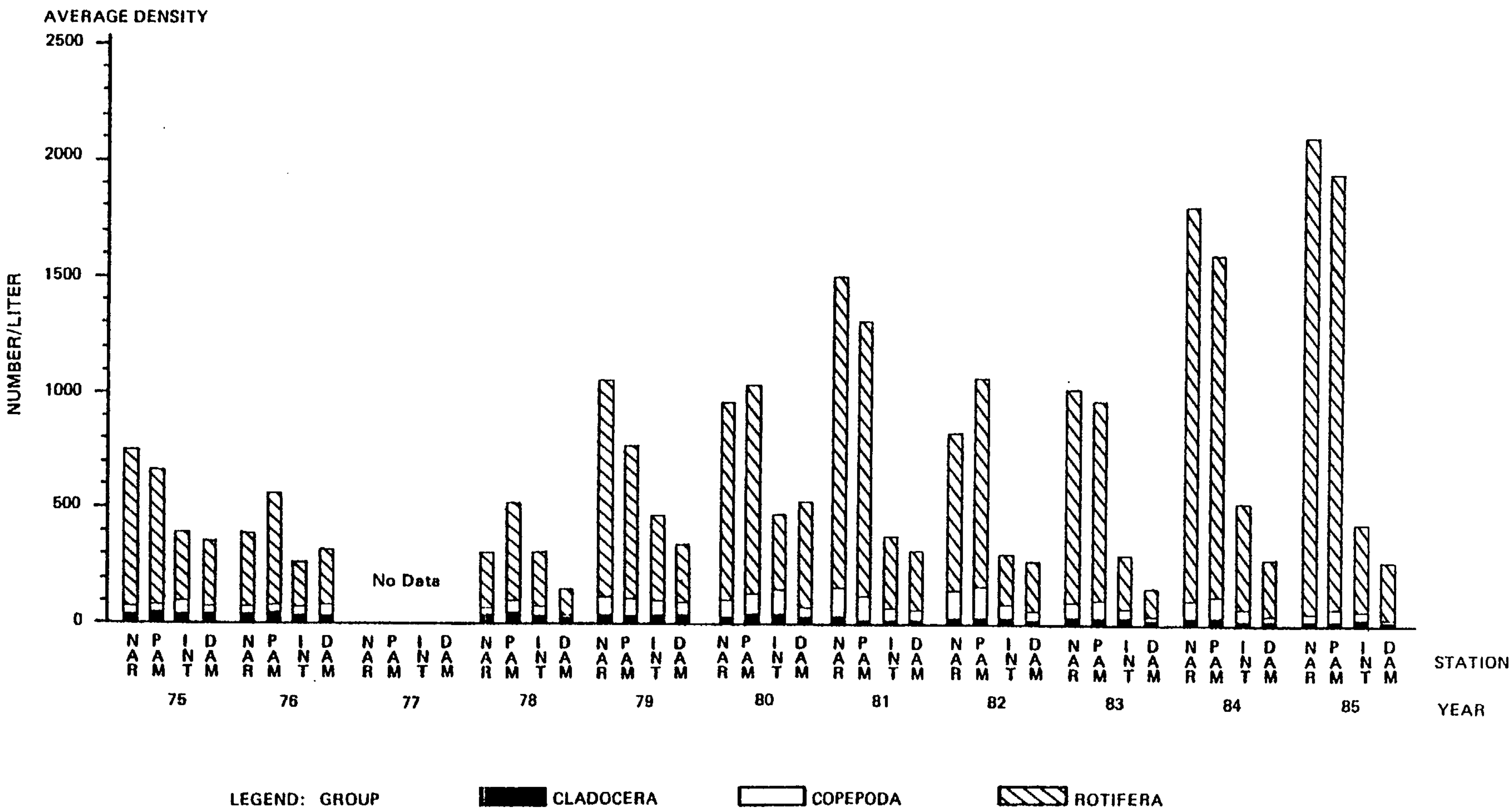


Figure 4.2-2. Comparison of month/depth average mean annual densities (NO./L) between North Anna Arm, Pamunkey Arm, Intake and Dam stations for the major zooplankton groups (Cladocera, Copepoda, and Rotifera) collected at Lake Anna, Va. 1972 - 1985 (1977 data are missing).

Test (years are listed in order of decreasing densities left to right).*

O	P	P	O	O	O	P	O	P	O	O	O	P
79	75	76	80	85	84	74	81	73	82	83	78	72

*O = operational year, P = pre-operational year

The North Anna Arm and Pamunkey Arm stations showed a trend toward increasing densities over the years. These stations are out of the influence of the power station, however, so these changes are not operation related.

Although annual density trends in the Mid-Lower Lake have not changed, seasonal trends have shifted. Zooplankton typically exhibits a spring/summer density peak (Anderson and Lenat 1978; Weiss 1978; Carolina Power and Light Company 1981; Duke Power Company 1982). At both the Dam and Intake stations, the typical spring/summer density peaks have occurred earlier (April-May) in the operational years than in the pre-operational years (July) (Table 4.2-1). This phenomenon also was noted in the Lake Sangchris study when comparing ambient temperatures in an adjacent reservoir with elevated temperatures in Lake Sangchris (Waite 1981). Because zooplankton spring peaks correspond with initiation of fish spawning (see Ichthyoplankton section 4.4), there should be an adequate food base for larval fish.

Table 4.2.1. Duncan's Multiple Range Test for significant differences (.01 level) between monthly log-transformed zooplankton densities over pre-operational years 1972-1976 and operational years 1978-1985. Months are listed in order of decreasing density left to right.

DAM (Pre-Operational)

July	Aug.	Apr.	May	Sep.	Dec.	June	Oct.	Nov.	Mar.	Jan.	Feb.

DAM Operational)

Apr.	May	June	July	Aug.	Mar.	Jan.	Feb.	Nov.	Sep.	Oct.	Dec.

INTAKE (Pre-Operational)

July	Aug.	May	Sep.	June	Apr.	Mar.	Oct.	Nov.	Dec.	Jan.	Feb.

INTAKE Operational)

May	Apr.	June	Aug.	July	Sep.	Oct.	Dec.	Feb.	Nov.	Jan.	Mar.

A Duncan's Multiple Range Test performed on significantly different (.05 level) mean annual station densities (Intake through Dam stations) for 1984 and 1985 depicted a density gradient (decreasing densities in a down-lake direction) (Table 4.2-2). This trend was apparent during the pre-operational years as well. In addition, the analysis detected no significant difference between the Intake and Dam stations mean annual densities in 1985, a two-unit, high operational year. A yearly mean of the monthly Shannon-Wiener diversity indices for the Intake through Dam stations showed all five stations to be similarly, if moderately, diverse.

	Dam	Intake	Mid Lake	Burrus Pt.	Dike 3
Endeco					
1984	1.4	1.5	1.3	1.4	1.4
1985	1.3	1.4	1.4	1.4	1.4

The zooplankton community compostion of Lake Anna has historically been dominated by the rotifers; copepods and cladocerans have been a minor constituent (Fig. 4.2-2).

Table 4.2-2. Duncan's Multiple Range Test for significant differences (.05 level) between monthly log-transformed mean annual zooplankton densities for 1984 and 1985. Stations are listed in order of decreasing densities left to right.

1984

Intake Mid Lake Dam Burrus Point Dike 3 Endeco

1985

Intake Mid Lake Dam Dike 3 Endeco Burrus Point

This trend of relative abundance is true of other eastern, temperate reservoirs as well (Appendix B - Table 3). The early pre-operational years were transitional, as species present in the riverine system were eliminated from the planktonic community (Table 4.2-3). Other investigators have found that the zooplankton communities of newly inundated reservoirs take about three years to stabilize (Munro and Bailey 1980; Carolina Power and Light Company 1983). Nevertheless, the dominant genera have been community dominants since the pre-operational years--*Polyarthra*, *Keratella* and *Bosmina* (for a complete species list, see Appendix A - Table 3). These genera are typically numerous in other eastern temperate reservoirs (Appendix B - Table 3). In pre-operational/operational lake-wide taxa comparisons, diversity and total number of taxa have remained relatively constant (Table 4.2-3).

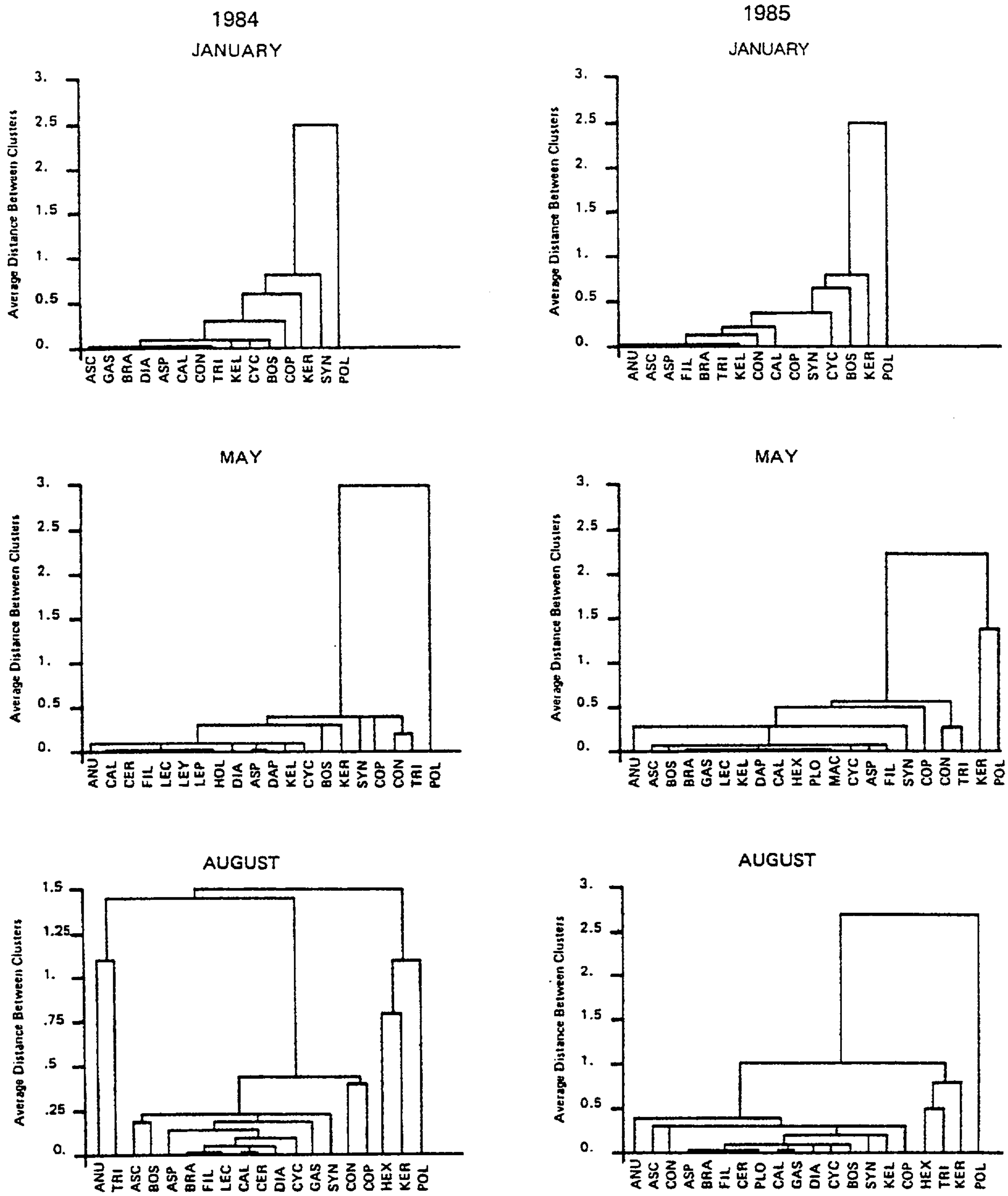
Cluster analysis of zooplankton genera using relative abundance depicted the general abundance/distribution pattern for the reservoir (a few selected months in 1984 and 1985 representing various seasons are shown in Fig. 4.2-3). The taxa are arranged by the analysis with rarer (less abundant) taxa on the left. Taxa densities and evenness of distribution increase left to right. The analysis corroborated the density data --

Table 4.2-3 Zooplankton taxa list for pre-operational years 1972-1976 and operational years 1978-1985 for Lake Anna, Virginia. The list includes the information measures total number of taxa, Shannon-Wiener diversity index and change in numbers of taxa from previous year.

	pre-operational years					operational years							
	1972	1973	1974	1975	1976	1978	1979	1980	1981	1982	1983	1984	1985
Alona			X	X									
Alonella													X
Anuraeopsis		X	X	X	X				X	X	X	X	X
Ascomorpha		X	X	X	X	X	X	X	X	X	X	X	X
Asplanchna	X	X	X	X	X	X	X	X	X	X	X	X	X
Bosmina	X	X	X	X	X	X	X	X	X	X	X	X	X
Brachionus	X	X	X	X	X	X	X	X	X	X	X	X	X
Calanoida	X	X	X	X	X	X	X	X	X	X	X	X	X
Cephalodella		X			X		X	X		X			
Ceriodaphnia	X	X	X	X	X	X	X	X	X			X	X
Chromogaster	X	X	X	X					X				
Chydorus	X	X	X	X	X	X					X		
Collotheca			X	X	X		X	X	X	X	X	X	
Colurella		X	X										
Conochilus	X	X	X	X	X	X	X	X	X	X	X	X	X
Copepod nauplii	X	X	X	X	X	X	X	X	X	X	X	X	X
Cyclopoida	X	X	X	X	X	X	X	X	X	X	X	X	X
Daphnia	X	X	X	X	X	X	X	X	X	X	X	X	X
Diaphanosoma		X	X	X	X	X	X	X	X	X	X	X	X
Euchlanis										X		X	X
Filinia		X	X	X	X	X	X	X	X	X	X	X	X
Gastropus		X	X	X	X	X	X	X	X	X	X	X	X
Hexarthra	X	X	X	X		X	X	X	X		X	X	X
Holopedium		X	X	X	X		X	X	X	X	X	X	
Kellicottia	X	X	X	X	X	X	X	X	X	X	X	X	X
Keratella	X	X	X	X	X	X	X	X	X	X	X	X	X
Lecane			X	X	X			X	X	X	X	X	X
Lepadella			X							X	X		X
Leydigia			X										
Limnias									X				
Macrochaetus		X			X					X			

Table 4.2-3 (continued)

	pre-operational years					operational years							
	1972	1973	1974	1975	1976	1978	1979	1980	1981	1982	1983	1984	1985
Monostyla	X	X	X	X	X		X		X				
Philodina			X										
Platyias						X			X		X	X	
Ploesoma			X	X	X		X	X		X			X
Polyarthra	X	X	X	X	X	X	X	X	X	X	X	X	X
Pompholyx	X		X										
Ptygura		X	X	X	X				X				
Rotaria									X				
Sida										X			
Simocephalus						X							
Synchaeta	X	X	X	X	X	X	X	X	X	X	X	X	X
Testudinella									X				
Trichocerca	X	X	X	X	X	X	X	X	X	X	X	X	X
Trichotria													X
Trochosphaera									X				
Total # of taxa	19	28	34	29	28	22	24	24	31	27	25	25	26
Diversity	2.73	3.05	3.52	3.40	3.26	2.91	3.09	2.98	3.18	3.17	2.97	3.06	3.13
Species #:													
Additional	0	10	8	0	2	3	5	1	9	6	3	2	4
Lost	0	1	2	5	3	9	3	1	2	10	5	2	3



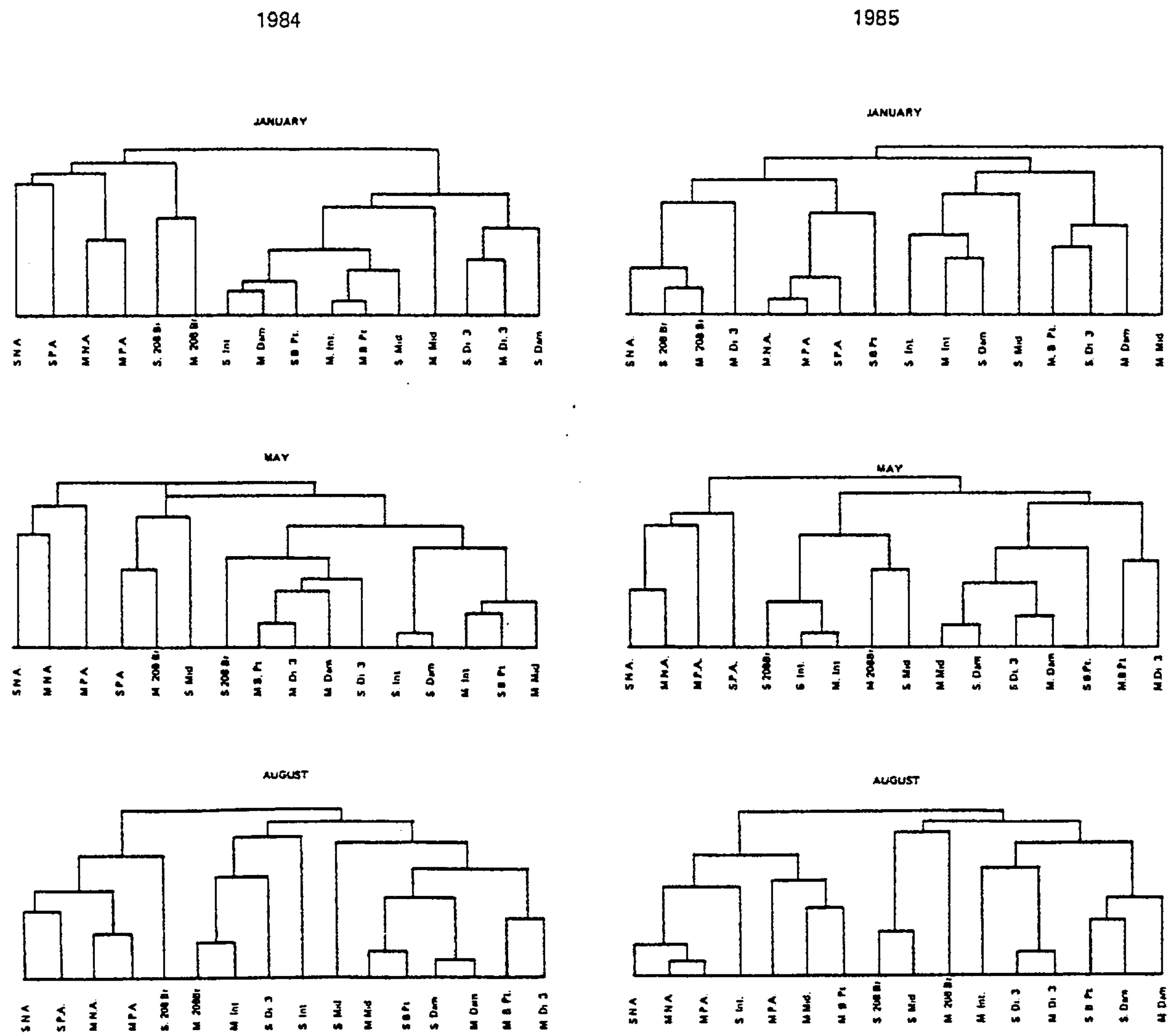
ANU	Anuraeopsis	COP	Copepod Nauplii	KEL	Kellicottia
ASC	Ascomorpha	CYC	Cyclopoida	KER	Keratella
ASP	Asplanchna	DAP	Daphnia	LEC	Lecane
BOS	Bosmina	DIA	Diaphanosoma	MAC	Macrochaetus
BRA	Brachionus	FIL	Filinia	PLO	Ploesoma
CAL	Calanoida	GAS	Gastropus	POL	Polyarthra
CER	Cariodaphnia	HEX	Hexarthra	SYN	Synchaeta
CON	Conochilus	HOL	Holopedium	TRI	Trichocerca

Figure 4.2-3. Average linkage cluster analysis of zooplankton taxa from Lake Anna, Va., for selected months in 1984-1985.

Polyarthra and *Keratella* were the most abundant and universally distributed zooplankton genera. Other taxa (occurring on the left side of the clusters) either occur year-round at low densities or exhibit seasonal abundance, but were shown to be limited to one area of the lake. Monthly data (Appendix B - Table 5) show these genera occur in the Upper Lake. Station clusters using relative abundance confirmed what the biological/chemical data have indicated--Upper Lake area supports a more dense, diverse, and therefore different zooplankton community from the Mid and Lower Lake areas (Fig. 4.2-4). This zooplankton community difference in the feeder arms of reservoirs has been noted in other studies as well (Duke Power Company 1976; Carolina Power and Light Company 1981).

Zooplankton/phytoplankton seasonal density trends were overlaid for selected pre-operational and operational years to examine the interrelationship of the plankton cycles (Fig. 4.2-5). The classical trend of a spring phytoplankton abundance peak followed by a zooplankton abundance peak existed in some years (1974, 1985), but in other years, the spring/summer zooplankton maxima appeared to be dependent on some other variable(s). The absence of any consistent cyclic trends was evident for the Upper Lake stations as well. This fact, along with the occurrence of inconsistent trends in the Mid-Lower Lake (Intakes through Dam stations) during the pre-operational years, suggests that the phenomenon is not station related.

In an attempt to identify the variable(s) controlling the zooplankton density trends, step-wise multiple regressions were performed with the log-transformed zooplankton densities



S.N.A. = Surface North Anna Arm
M.N.A. = 4 meter North Anna Arm
S.P.A. = Surface Pamunkey Arm
M.P.A. = 4 meter Pamunkey Arm
S. 208 Br. = Surface 208 Bridge
M. 208 Br. = 4 meter 208 Bridge
S. Int. = Surface Intake
M. Int. = 4 meter Intake
S. Mid. = Surface Midlake
M. Mid. = 4 meter Midlake
S.B. Pt. = Surface Burrus Point
M.B. Pt. = 4 meter Burrus Point
S. Di. 3 = Surface Dike 3 Endeco
M. Di. 3 = 4 meter Dike 3 Endeco
S. Dam = Surface Dam
M. Dam = 4 meter Dam

Figure 4.2-4. Ward's cluster analysis of stations on Lake Anna, Va. for selected months in 1984–1985.

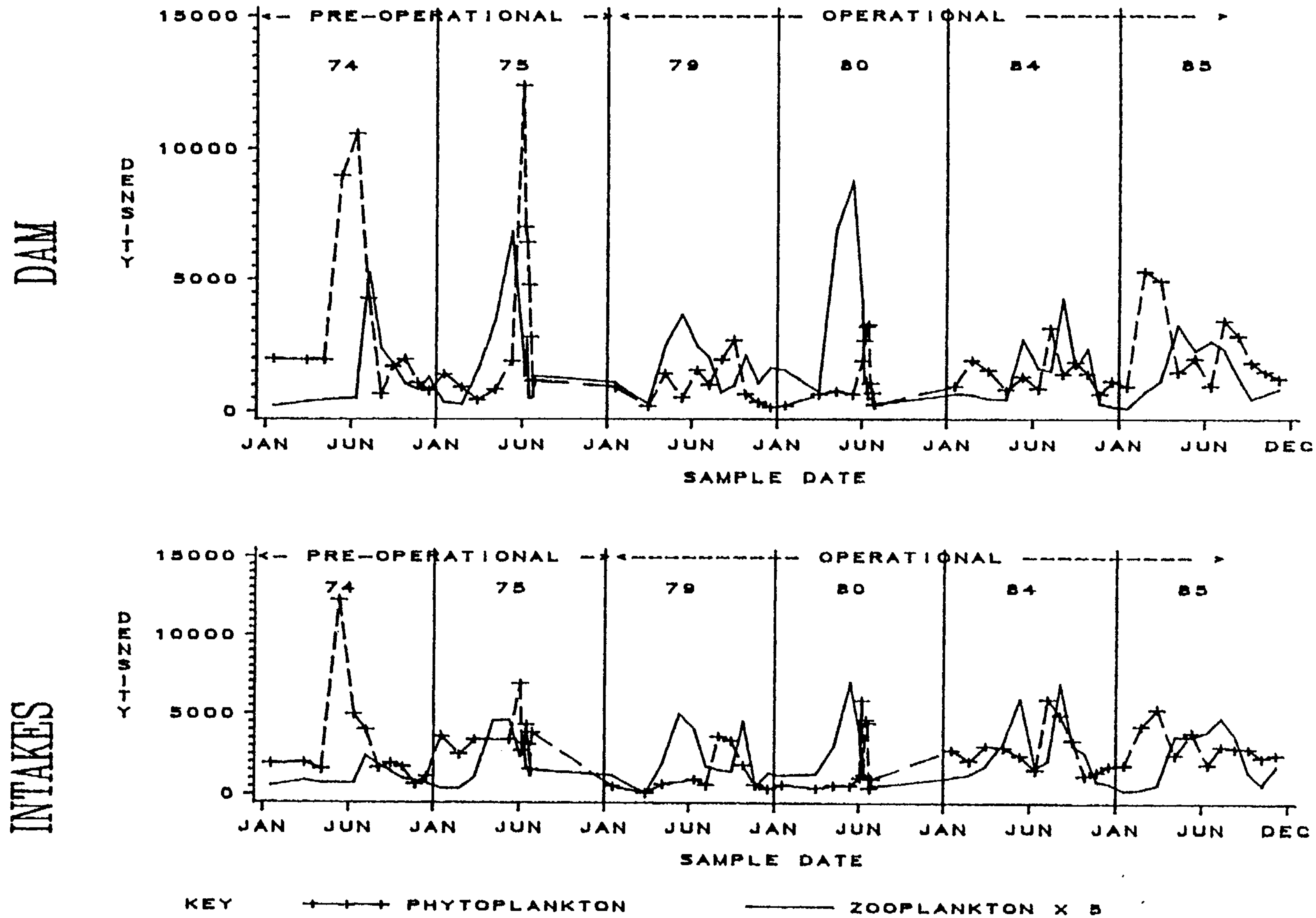


Figure 4.2-5. Pre-operational and operational comparison of zooplankton (#/L) and phytoplankton (#/ML) cycles of average abundance for selected years at the dam and intake stations, Lake Anna, Virginia.

from individual or combinations of historical stations. The data were partitioned into pre-operational and operational years. Variables tested included pH, alkalinity, total log-transformed phytoplankton, temperature and dissolved oxygen. No temporal consistency was noted in the importance of the above variables in controlling zooplankton abundance. Changes in seasonal distribution of planktonic rotifer populations are complex and generalizations are difficult to make (Wetzel 1975).

Summary

The zooplankton community of Lake Anna has remained stable and moderately diverse through pre-operational and operational years. There have been no major changes in the community composition or shifts toward a less diverse community, and no unusual or nuisance populations have been detected. Although the variables that control population levels are unclear, the community composition and annual abundance cycles are typical of eastern temperate reservoirs. No factor or factors appear to be interfering with the zooplankton community's ability to propagate and survive, and consequently, there should be no adverse impact on dependent trophic levels.

4.3 Benthic Macroinvertebrates

Introduction

Benthic macroinvertebrates (including shellfish) are those organisms living on or in the bottom substrates. They may exist beneath, within, and above the sediment layers in burrows, interstitial spaces, and on submerged twigs, stems, and root masses, respectively. As processors and regulators of energy flow, they function to both directly and indirectly cycle nutrients and to effect their translocation or export (Resh and Rosenburg 1984). As reservoirs of stored energy themselves, they act as an intermediate "sink" for much of the energy that is continuously passing from the primary producers (phytoplankton) to the gamefishes (see Fig. 4-1). Within this "sink", they are of differential importance to the higher secondary consumers as some (caddisflies, midges, worms) are utilized more than others (Asiatic clams).

The benthos have various physical (substrate type, photoperiod, temperature), chemical (dissolved oxygen, alkalinity, turbidity, pH, absence of toxics), and nutritional (food quantity and quality) requirements, within certain ranges, that must be met in order for them to survive and reproduce. Temperature, as just one variable in temperate regions, may range from 0°-40°C and provide optimum conditions for growth, maintenance, and reproduction only at certain times (UWAG 1978). For this reason, aquatic insects in temperate zones characterized by seasonal and even daily fluctuations have thus had to adapt to the direct and even more complex indirect influence of temperature on various life functions such as feeding rates, timing of molting and emergence, duration of egg development, and adult size and fecundity (Resh and Rosenberg 1984). Limited (in the sense that simulating any actual, constantly interfacing environment in a microcosm is very difficult) temperature studies have shown that factors such as exposure time and ambient temperature (Ginn et al. 1974; Zimmerman and Wissing 1978), season (Moore 1981), rate of temperature change (Salih and Grainger 1977), and thermal history or acclimation (Nelson and Hooper 1982) may be important.

The energy sources for the benthos are located within three primary reservoirs: 1) detritus, 2) phytoplankton and 3) zooplankton (see Fig. 4-1). Organisms such as the aquatic worms (Oligochaeta) and the burrowing mayfly (*Hexagenia munda*) exist largely on the energy stored within the detrital reservoir. As such, their distribution will depend, in part, on the availability of this resource as determined by the rates, amounts, and subsequent physical weathering of allochthonous inputs to Lake Anna. Some types of benthos are largely primary consumers of phytoplankton (Asiatic clams, midges), some are predaceous (dragonflies, midges), and still others are more facultative and can switch from one trophic base to another (caddisflies, midges).

Other factors that may both directly or indirectly influence benthic community structure, abundance and/or function include water depth (Thorp and Diggins 1982), adult emergence, increased sedimentation due to storm runoff (Shaffer 1984), current velocity and predation (Thorp and Bergey 1981; Gilinsky 1984), larval and adult behavior (Resh and Rosenberg 1984), invasion of exotic species such as the Asiatic clam and natural succession. When considering potential effects from any of these influences, one must keep in mind the intrinsic ecosystem "resiliency" that exists as a result of differential species tolerances and recovery response times.

Aquatic macroinvertebrates are considered by many to be excellent indicators of environmental stress due to their lack of mobility, sensitivity to various environmental perturbations and extended life cycles (Hynes 1965; Cairns and Dickson 1971; Lehmkuhl 1979). For these reasons monitoring the benthic community is considered to be an integral part of any ecological evaluation. The purpose of the macroinvertebrate sampling program in Lake Anna, undertaken over the last 13 years including both pre-operational (6 years) and operational (7 years) periods, has been to provide data to assess changes in the benthic community abundance, structure and/or function.

Information Base For Evaluation

Benthic artificial substrate samples were collected in Lake Anna from 1973 to 1985 on a monthly, bimonthly, or summer-only basis. In addition to the artificial substrates, bimonthly Ekman dredge sampling was initiated in

March 1984 and continued through November 1985. The artificial substrate collecting system was developed (Voshell and Simmons 1977) during the early formative years of Lake Anna as a reliable and cost-effective alternative to the more commonly used dredge methods. This has been the primary method of collection to date. Its basic advantage lies in its ability to eliminate different sediment types as a source of variation thereby providing an estimate of "what can live in Lake Anna given similar substrate conditions under varying thermal (and other) regimes." On the other hand, its principal disadvantage may be that "actual" substrate-dependent community structure and abundance may be misrepresented. For example, although population numbers of <u>C. fluminea</u> are available from the substrate baskets these numbers could be misleading. Asiatic clams collected in the baskets tend to be numerous and small in size due to the mesh size of the substrate material, the limited mobility of the adult and the propensity of substrate baskets to concentrate organisms (Voshell and Simmons 1977). Therefore, to assess "natural" substrate population densities dredge samples were begun as supplements to the benthic program. Independent examination of these data, influenced as they are by sediment composition, must be done with caution. Higher sedimentation rates in the Upper Lake and sediments influenced by flow patterns in the Lower Lake, make it difficult to separate temperature and substrate as sources of variation. Both gear types will readily produce estimates of benthic density. Due to size variation, however, among naturally occurring assemblages of similar organisms, it was also decided limited Ekman dredge samples would be used to analyze biomass (weight) as another, possibly more indicative measure of benthic productivity. Data obtained by both of these gear types were used to compare and assess, within their limitations, the state of the resident macrobenthic community in Lake Anna. For a more complete description of sample collecting and processing methodologies refer to Appendix D. Sample locations for these studies are as depicted in Figure 4.3-1 and will be referred to as Lower, Mid, and Upper Lake.

Much information exists regarding the benthic macroinvertebrate community in Lake Anna extending from its early filling stage(s) to the present. These studies consisted of both consultant and in-house staff assessments (Appendix E). In addition, published sources of information by independent authors, other southeastern utilities (Carolina Power and Light Company; Duke Power Company), and government agencies (U.S. EPA 1977), were drawn upon to further characterize and supplement the findings in this report.

Three basic indices (abundance, structure, function) representative of community health were examined. For the operational years, 1981-85, average monthly density values were analyzed using a one-way ANOVA and Duncan's Multiple Range Test to determine if differences existed between years at a given station. This allowed for the examination and comparison of benthic density responses to

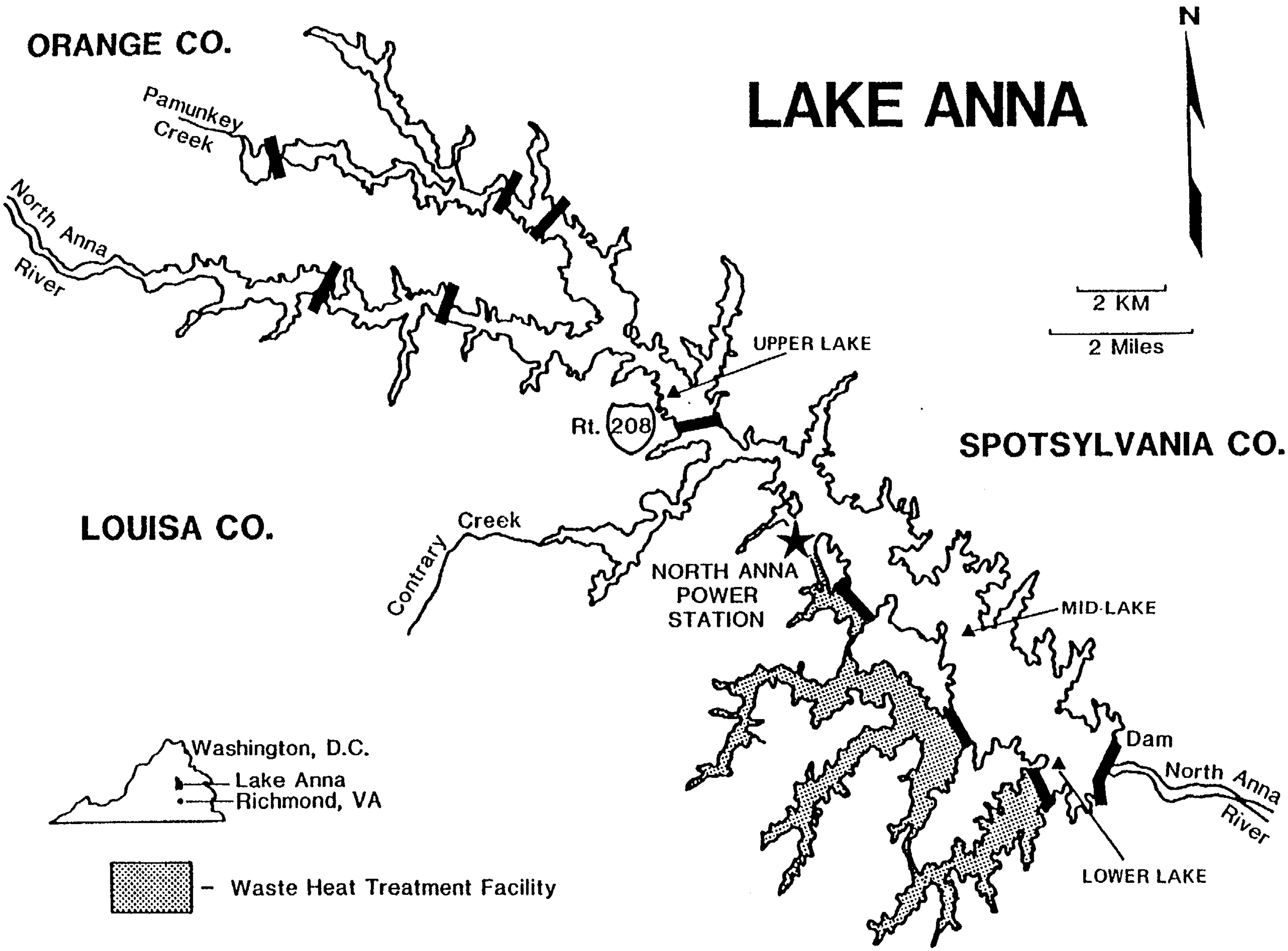


Figure 4.3-1. Location of 316(a) benthic macroinvertebrate sampling stations.

known station operational levels within each time period. Since all of the historical data prior to 1981 were reported initially as averages, this specific one-way model could not be extended to include those earlier years. The Shannon-Wiener diversity index was used, along with major benthic group compositional plots, to portray structural changes from 1981-85 and 1976-85, respectively. The level of taxonomic characterization prior to 1981 prohibited using the diversity index for those earlier years. Cluster analysis (Ward's) combines and conceptually depicts both community abundance and structure. For this analysis, it was used to group stations based on the type and relative proportions of organisms present during each year from 1981-85.

Assessment

During 1984, five benthic taxa consistently comprised the majority of each month's catch throughout the lake (Appendix B-Tables 1-12). These were the caddisflies *Cyrnellus fraternus* and *Polycentropus* sp., midges *Ablabesmyia parajanta* and *Dicrotendipes neomodestus*, and the Asiatic clam (*Corbicula fluminea*). *Cyrnellus fraternus* exhibited distinct late-year (Sept., Nov.) increases in the Upper Lake much like its close relative *Polycentropus* did in the Lower Lake. Seasonal numbers of *Ablabesmyia* and *Dicrotendipes* were very similar in all areas of the lake. The Asiatic clam exhibited a temporal and spatial distribution similar to *Cyrnellus fraternus*, i.e. becoming quite abundant in the latter part of the year in the Upper Lake.

During 1985, more of the aquatic worms (Oligochaeta) were collected than in the previous year thereby replacing, on a more frequent basis, midges *Ablabesmyia* and *Dicrotendipes* as numerical dominants (Appendix B-Tables 1-23). The Asiatic clam remained a perennial dominant as did *Cyrnellus fraternus* and *Polycentropus*. The spatial preference of the latter two taxa continued whereby *Cyrnellus fraternus* attained greater densities in the Upper Lake comparable to levels attained by *Polycentropus* in the Lower Lake.

The average seasonal density of benthos in the Lower Lake showed reductions beginning in the summer of 1979 during the second year of station operation (Fig. 4.3-2). Densities then fluctuated inconsistently to finally reach a period of steady lows from 1982-1983. Increases occurred in 1984 and 1985 to levels approaching those of pre-operational years. During 1981, 1983, and 1985, annual and summer station operational levels were at their highest, averaging 69% (annual)/ 67% (summer), 72% (annual)/96% (summer) and 83% (annual)/79% (summer), respectively. Numbers of benthos in these years were, in certain seasons, greater than densities recorded during lesser operational periods (1979, 1980, 1982). Much attention has been directed towards the summer season as being one where the biotic community might be additionally stressed by high thermal output. Based on the historical density data, this did not appear to be evident in the Lower Lake. For example, the low summer densities recorded in 1979 were exceeded in subsequent summers (1981, 1983, 1985) under the highest summer operational levels to date. Average annual densities in the Lower Lake (over 11 months: Nov., Dec., Jan.-Sept.) for the second and third years following initial impoundment were reported to be 105 and 142 per year, respectively (Reed and Simmons 1975). Comparing these early annual averages to the seasonal averages in Figure 4.3-2 shows that 1975-1976 represented that period of time 3-4 years after impoundment when benthic densities were at their historical peak in the Lower Lake.

Steady reductions in the average seasonal density of benthos were evident in the Mid-Lake from 1976-1978. These reductions occurred over periods of both no unit (1977) and one unit (1978, 50%) station operation and apparently began somewhat earlier than in the Lower Lake. Annual lows were reached in 1980. Since then, densities fluctuated slightly upwards over the remaining years through 1985 but not to levels comparable to those of pre-operational years. Compared again to average annual densities evident just after impoundment, historical peaks in this area appeared to occur in 1976 and 1977 (4-5 years later).

The average seasonal densities of benthos in the Upper Lake declined rather steadily over all seasons from the spring of 1976 to the summer of 1980. Fluctuations then followed for several years with subsequent increases in 1984

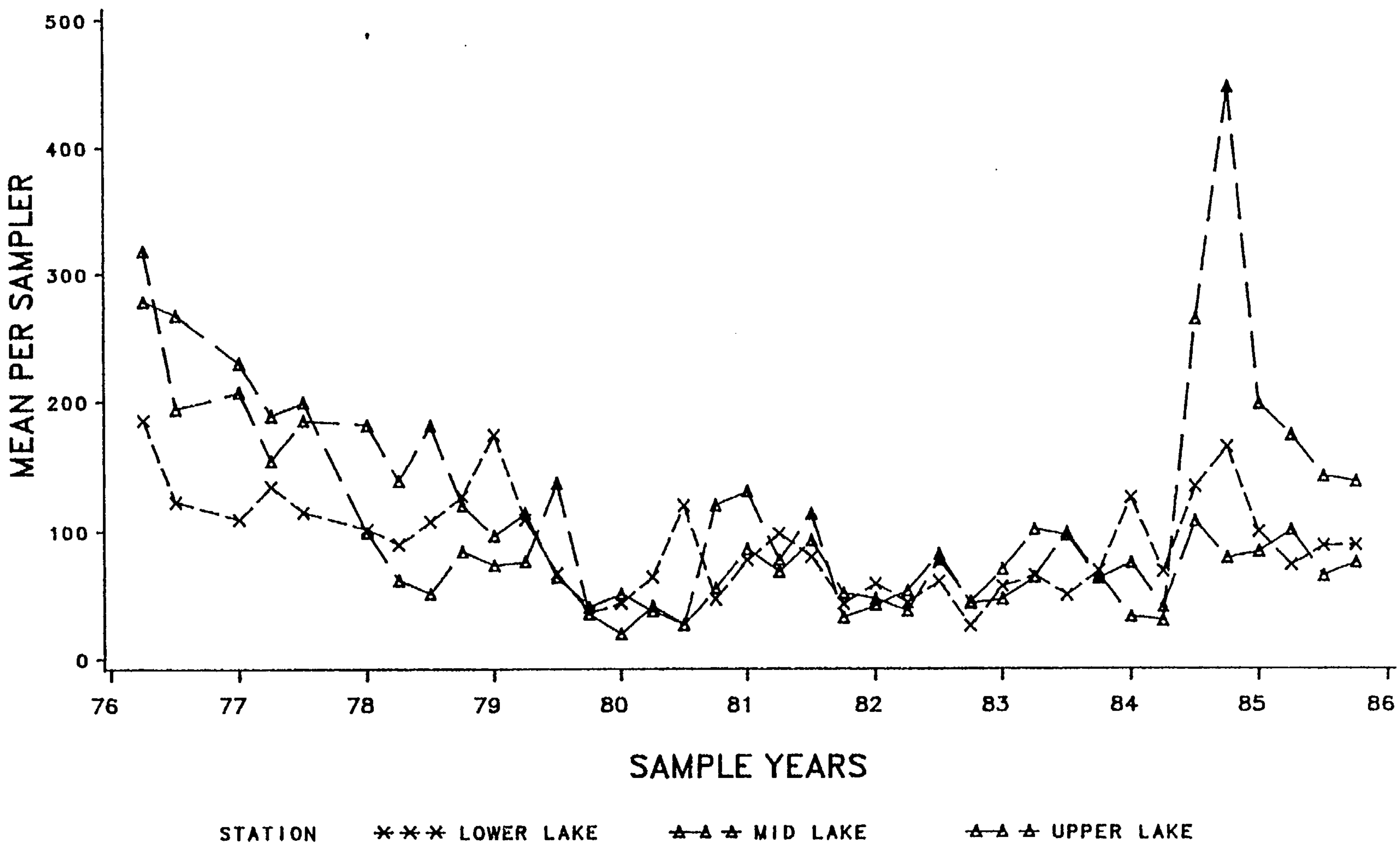


Figure 4.3-2. Average seasonal density of benthos, by station ,on artificial substrates in Lake Anna, Virginia , 1976-1985.

and 1985 to levels comparable to and above those of pre-operational years. As in both the Lower and Mid-Lake, the high average annual and summer operational levels evident in 1981, 1983, and 1985, did not appear to adversely influence benthic production (densities) during those immediate or subsequent years. Historical peak densities in the Upper Lake appeared to occur, as they did in the Lower Lake, 3-4 years after impoundment.

For the operational years, 1981-85, average monthly density values were analyzed using a one-way ANOVA and Duncan's Multiple Range Test to determine if statistically significant differences existed between years at a given station (Tables 4.3-1 and 4.3-2). In the Lower Lake the year 1982 ranked lowest most often (7/11 months) followed by 1983 (3/11). During 1981, 1983 and 1985, both average annual and summer operational levels were the highest to date. The relative ranking of these years during each month, including summer, does not indicate that greater operational levels will subsequently lead to reduced densities in this area. The 1985 monthly density trend in the Mid-Lake was very similar to that of the Lower. Again, 1982 ranked lowest most often (7/11 months) followed by 1981 (3/11). In the Upper Lake during 1985, the density values for January, March, May and July were greater than in previous years (Table 4.3-2). The year 1982 ranked lowest most often (7/11 months) and ranked consistently lower at each of the stations. In summary, the relative ranking and frequency of statistical significance for monthly densities

Table 4.3-1 Duncan's Multiple Range Test for Log transformed mean monthly benthic densities collected by artificial substrates in the Lower and Mid-Lake, Lake Anna, Virginia, 1981-1985. Years underscored by the same line were not significantly different (.05 level). Years are listed in order of decreasing densities left to right.

LOWER LAKE

Jan	85	84	83		
Feb	81	82			
Mar	84	85	81	82	83
Apr	81	82			
May	81	85	84	83	82
Jun	81	82			
Jul	84	81	83	85	82
Aug	81	82			
Sep	84	85	81	82	83
Nov	84	83	81	82	
Dec	81	82			

MID LAKE

Jan	85	83	84		
Feb	81	82			
Mar	84	81	85	83	82
Apr	82	81			
May	85	83	81	84	82
Jun	81	82			
Jul	84	81	83	85	82
Aug	81	82			
Sep	82	83	84	85	81
Nov	84	83	82	81	
Dec	81	82			

Table 4.3-2 Duncan's Multiple Range Test for Log transformed mean monthly benthic densities collected by artificial substrates in the Upper Lake, Lake Anna, Virginia, 1981-1985. Years underscored by the same line were not significantly different (.05 level). Years are listed in order of decreasing densities left to right.

Jan	85	83			
Feb.	81	82			
Mar	85	81	82	83	84
Apr	82	81			
May	85	81	83	82	84
Jun	81	82			
Jul	85	84	81	83	82
Aug	81	82			
Sep	84	83	81	85	82
Nov	84	83	82	81	
Dec	81	82			

in each area of the lake from 1981-1985 does not indicate greater operational levels will subsequently lead to reduced densities anywhere.

In the first year after reservoir filling (October 1972 - July 1973) the most numerous benthic groups throughout the lake were, in order, the amphipod Hyalella azteca, midges and the snails (Voshell and Simmons 1984). The second year (November 1973 - September 1974) was characterized by continued high numbers of the midges, declines in amphipods and snails, and the appearance of large numbers of aquatic worms. Declines in the amphipods and snails is believed to have occurred as a result of the early changes in physical habitat (i.e. loss of inundated terrestrial vegetation, increased siltation) subsequent to basin flooding and development (Voshell and Simmons 1984). By the second year and into the third when the numbers of caddisflies increased substantially making them the third most abundant group, the midges and aquatic worms had become established as the numerically dominant benthic groups throughout the lake. Subsequent changes in the benthic community structure from 1976-1985 are shown in Figures 4.3-3 through 4.3-5. It is evident aquatic worms soon declined throughout the lake to be replaced by the ever-increasing caddisflies. The continued developmental history of the dominant groups in the Lower Lake (excluding the caddisflies which, over all of the remaining years, have repeatedly made up a major portion of the community) has been one of alternating periods of dominance by midges -

bivalves - mixture of both - midges - and a mixture of both (Fig. 4.3-3). Within this framework of successional development, it appears that the bivalve Asiatic clam population has stabilized and been successfully integrated into the system to the extent that none of the other major groups such as the caddisflies, midges, or aquatic worms have been displaced subsequent to the clams invasion in 1979.

The Asiatic clam's sharp increase from 1979-81 is indicative of its high, post-invasion reproductive capability and will not likely occur on a similar scale in the future as the carrying capacity of Lake Anna for this organism has apparently been reached. Since its initial discovery in 1938 in the Columbia River, Washington (Sinclair and Isom 1963), the Asiatic clam has rapidly spread to extend its range across the United States into the Eastern regions (Sickel 1973; Diaz 1974; Rodgers et al. 1977; Jenkinson 1979; Cohen et al. 1984). This success has been due to many factors which include its' rapid growth to sexual maturity (within 1 year), wide range of environmental tolerances, highly prolific reproductive nature resulting in planktonic larvae independent of any host fish, resistance to biocides, and adult mobility (Sinclair and Isom 1963; Cherry et al. 1980; Prezant 1984). For several years just after impoundment, the bivalve fauna of Lake Anna consisted of a single family, the fingernail clams (Sphaeriidae), that never represented greater than 1.0% of the annual catch (Simmons and Reed 1975) and are of no known commercial

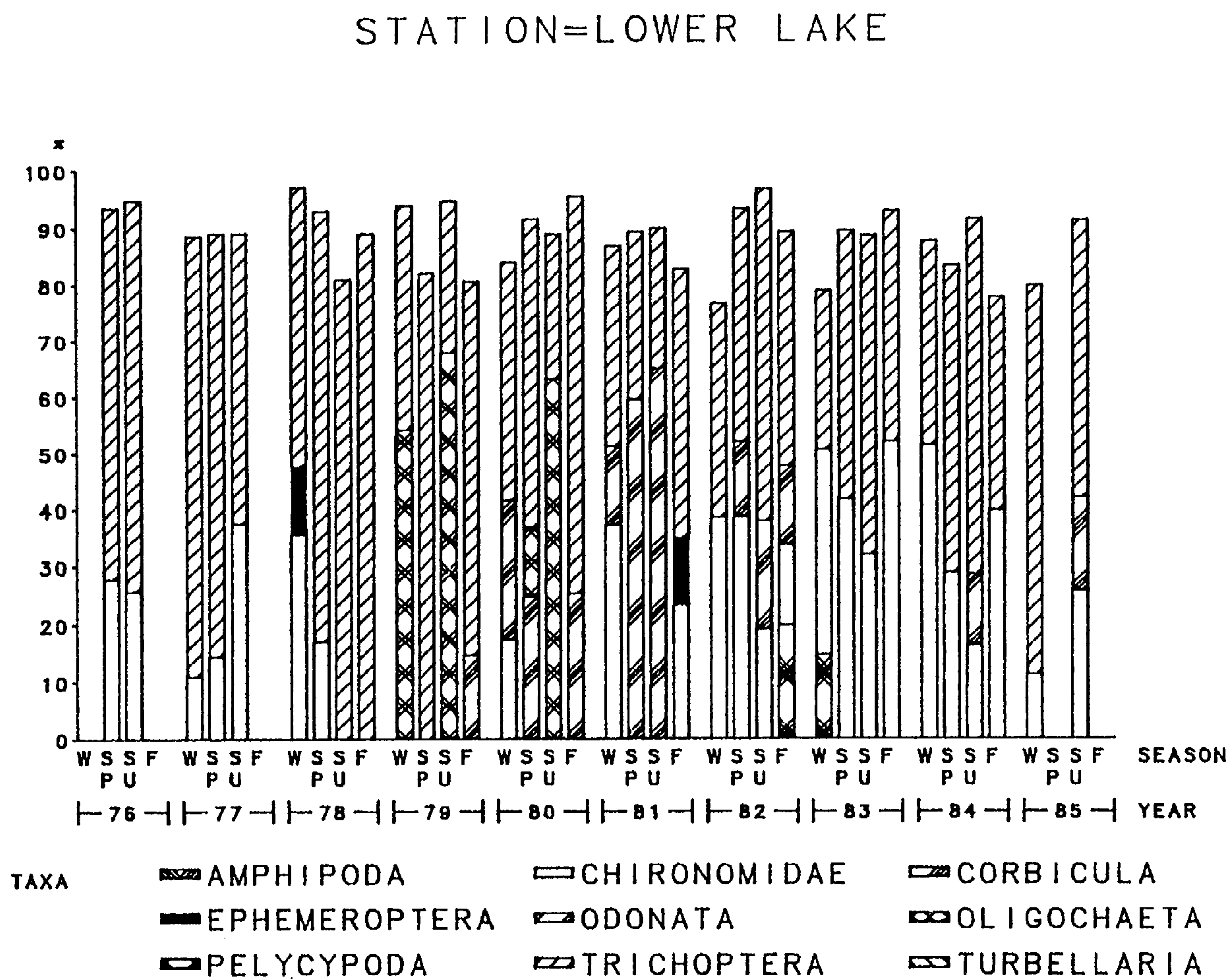


Figure 4.3-3. Average seasonal percent composition of the major(>10%) benthic groups collected on artificial substrates in the Lower Lake, Lake Anna, Virginia, 1976-1985.

importance. This family continued to be represented by low numbers in all subsequent years until the winter of 1979 when densities appeared to suddenly increase. This apparent increase of clams, that had for six years previously represented such a small fraction of the total community, was probably mistaken for the actual initial invasion of the Asiatic clam which soon led to its establishment and subsequent occupation of the available niche.

The major structural changes that occurred in the Lower Lake from 1976-85 also were evident in both the Mid and Upper Lake (Fig. 4.3-3 and 4.3-4) whereby the longstanding dominance of the caddisflies and midges was likewise followed by an increased percentage of bivalves around the sixth year of lake development.

A closer examination of the taxonomic list of macrobenthos compiled for both pre-operational and operational periods largely reveals the natural transition of species that would occur as a result of impounding a free-flowing river. During the pre-operational period from October 1973 - March 1978, a total of 111 taxa was collected in Lake Anna (Appendix A-Table 1). Riverine types such as certain members of mayflies(2), caddisflies(5), beetles(2), true-flies(1), and all of the stoneflies(4) have obvious flowing-water habitat requirements (Edmunds et al. 1976; Wiggins 1977; Merritt and Cummins 1978; Brigham et al. 1982) which excluded them from the developing lake whereas others (Boyeria sp., Sisyridae), though more generally lotic by nature, were likewise displaced. Habitat preferences of

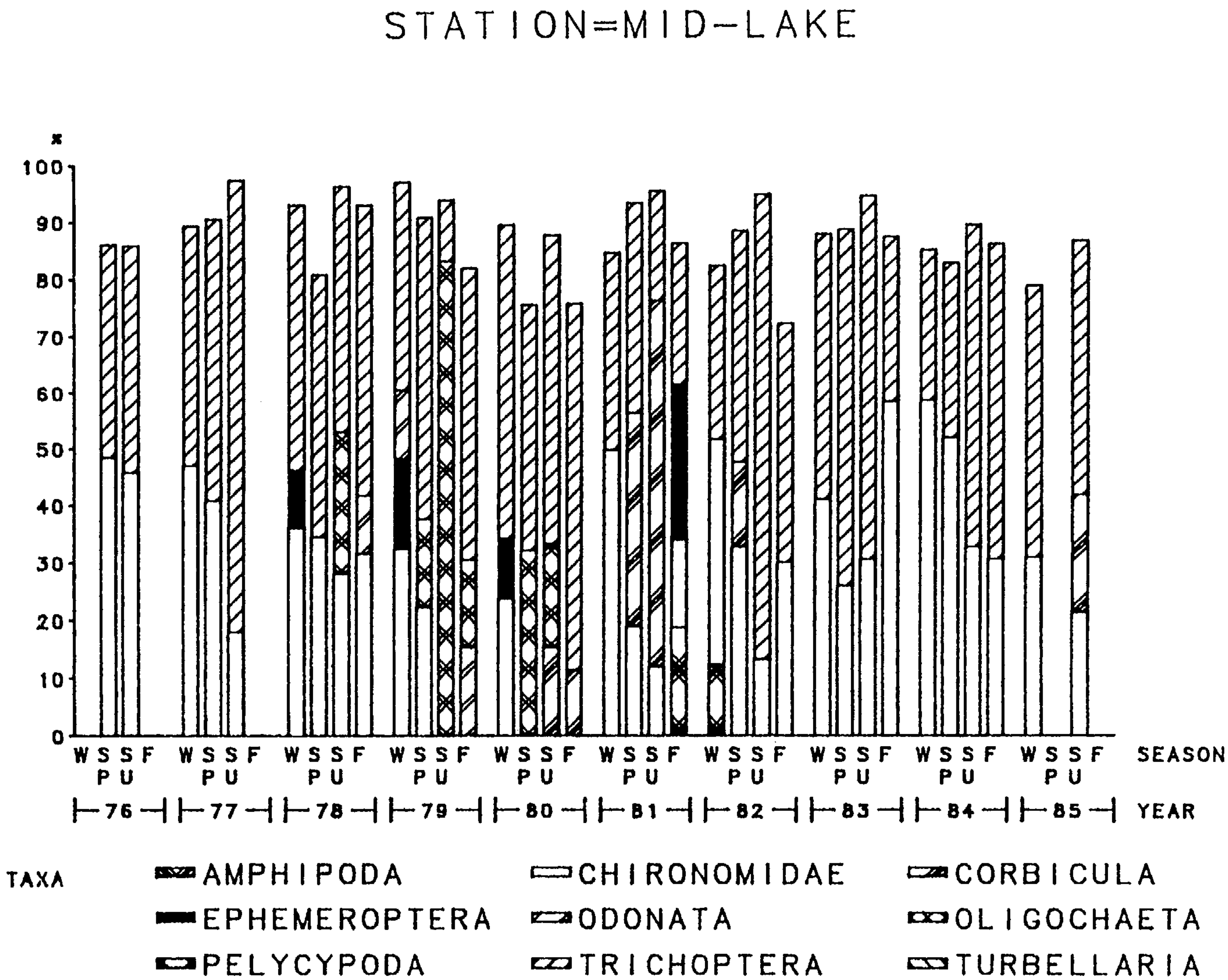


Figure 4.3-4. Average seasonal percent composition of the major(>10%) benthic groups collected on artificial substrates in the Mid-Lake, Lake Anna , Virginia ,1976-1985.

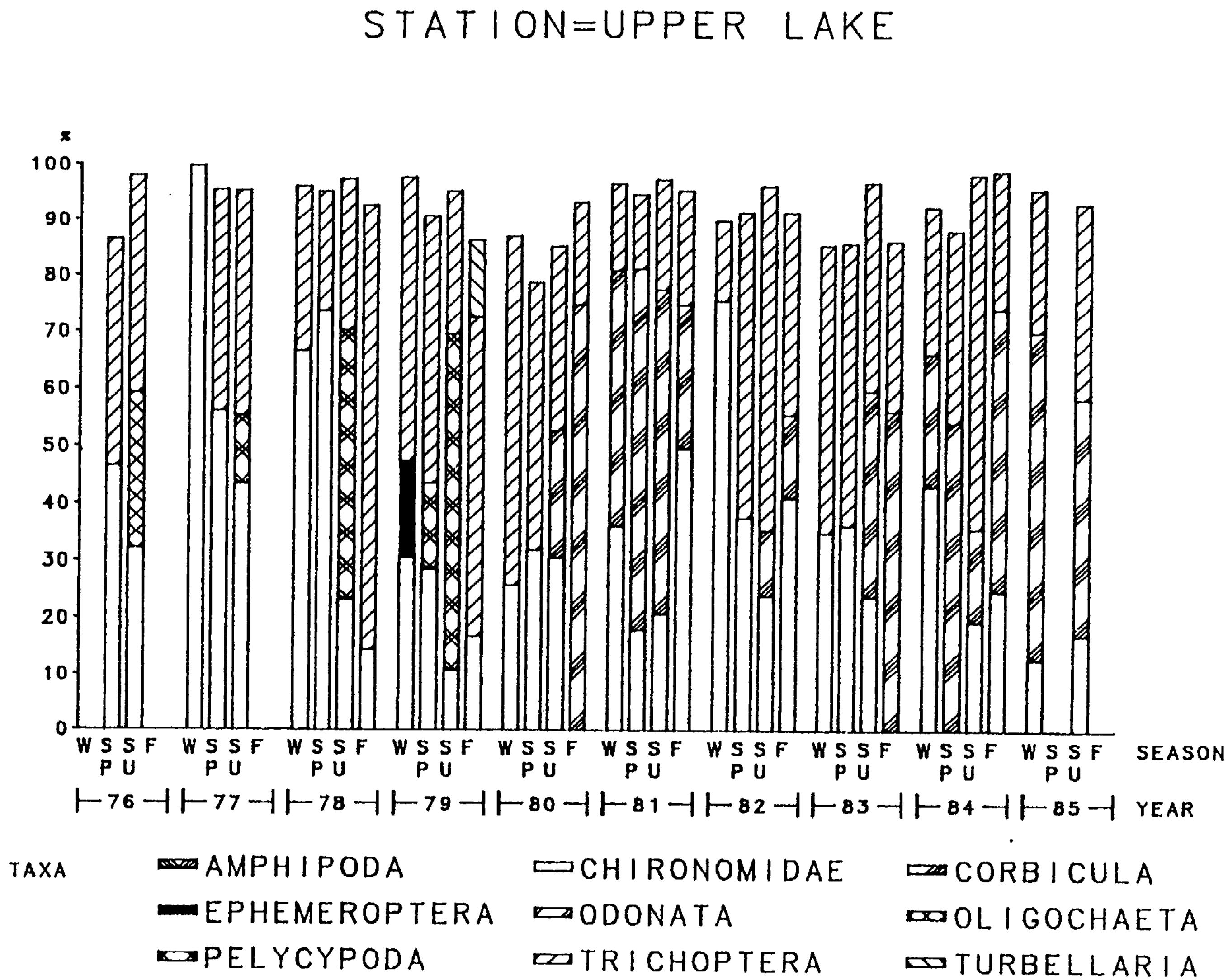


Figure 4.3-5. Average seasonal percent composition of the major(>10%) benthic groups collected on artificial substrates in the Upper Lake, Lake Anna , Virginia ,1976-1985.

most of the aquatic beetles (11) that were not found in subsequent years, along with the grass-shrimp Palaeomonetes sp., have been associated with aquatic vegetation and/or the quiet margins of stream banks (Merritt and Cummins 1978, Brigham et al. 1982, Voshell and Simmons 1984) that so characterized the previous river and early stages of the recently inundated basin. As would be expected, many of these strictly lotic and facultative species continue today to live in portions of their former habitat as it now exists downstream of Lake Anna. Reasons for the presence/absence of the other individual organisms can only be speculative, at best, due to sampling differences between periods, the frequency of collection of some of the rarer types, and the lack of definitive life history and habitat preference data.

Slightly more taxa (124) were collected during the operational study period. Many new kinds of midge larvae were found, some of which probably were present prior to station operation though just not identified. Earlier surveys (pre-1978) complete with thorough midge identifications occurred only on a quarterly basis, if at all, whereas surveys between 1978-1980 did not include any higher level taxonomic work for this group. Thus, their respective times of arrival within the newly formed lacustrine system cannot be determined.

Overall, the differences in the benthic taxonomic composition of Lake Anna evident between pre-operational and operational periods were primarily due to the gross ecological changes associated with the river-to-lake transition. According to Simmons and Reed (1975) the most evident changes occurred directly after impoundment when the rheophilic fauna of the river was replaced by the limnophilic fauna and then between the first and second years of impoundment, four years prior to the beginning of station operation. Shannon-Wiener's diversity index, calculated for the more current data from 1981-85, shows the Lower and Mid-Lake stations compare favorably to the Upper Lake with respect to magnitude and relative direction of change in diversity (H') (Fig. 4.3-6). During the study period 1984-85, diversity in the Lower Lake only once dropped below that of the Upper Lake. There has been no indication the benthic community structure has decreased or become more simplified over the past five years.

Additional statistical analyses and regional comparisons were undertaken to further investigate the possibility of station influence and to determine the standing of the Lake Anna benthos in relation to other thermal and ambient southeastern U. S. lakes. Cluster analysis was used to statistically integrate the types and relative proportions of different organisms to provide an index to structural differences or similarities. In this case, each year's data from 1981-85 taken during the seasonally warmer months (March-September) was compared to determine if known high operational periods might have influenced community development. Distinct community groups were formed, but not on the basis of proximity to the source of thermal effluent or relation to times of high thermal

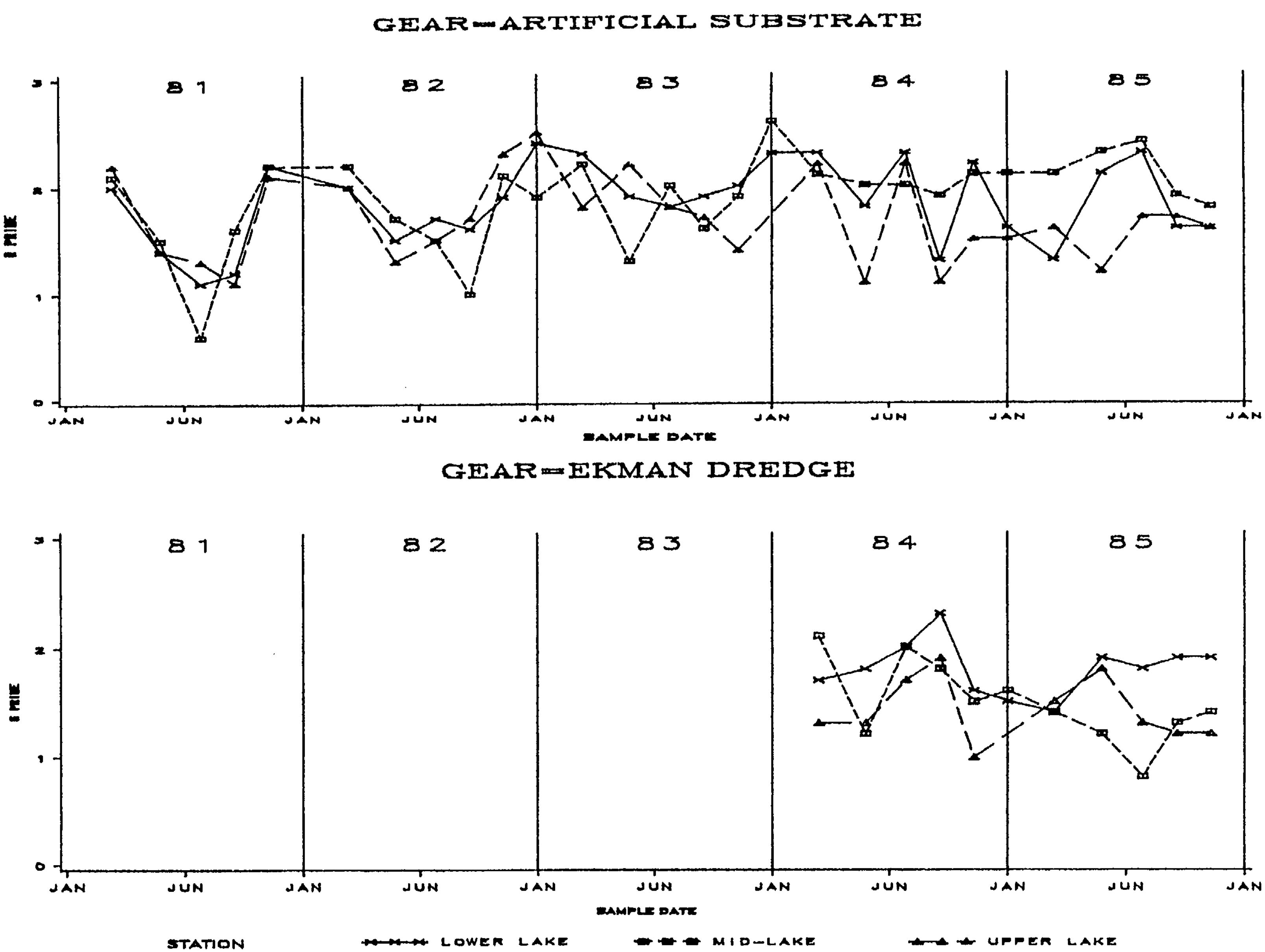


Figure 4.3-6. Benthic diversity trends, by gear type ,at three stations on Lake Anna, Virginia, 1981-1985. No Ekman samples taken prior to 1984.

output (Fig. 4.3-7). The benthic community was most similar in 1984 and 1985 at stations in opposing areas of the lake. These same communities at this time were likewise most different from those of earlier years due, in large part, to the increased abundance of caddisflies, midges and Asiatic clams. Within the 1981-83 timeframe, no spatial grouping existed which might suggest the formation of a localized, thermally influenced benthic community.

The benthos of other regional water bodies were compared to Lake Anna in order to broadly assess their respective community structure, density and biomass components. The insect fauna of Lake Anna is composed of all of the major groups and genera that would be expected to occur in a freshwater thermal impoundment (Table 4.3-3). Compared to some of the Carolina thermal impoundments (Hyco Reservoir, Lake Julian, Lake Norman, Robinson Impoundment), Lake Sangchris in Illinois, and the ambient temperature Kerr Reservoir Va./N.C., relative proportions of the major groups and the absolute numbers of insect taxa within each group in Lake Anna are quite similar. Additionally, Lake Anna hosts the majority of the same taxa that appear to be indicative of all the other comparable water bodies. The other (non-insect) major groups of benthic macroinvertebrates are also well represented. Compared to some of the same water bodies, the average density and biomass data recorded for Lake Anna is suggestive of its biological capability to produce benthos at levels comparable to other areas (Table 4.3-4). (Note: Density and biomass data used in this table

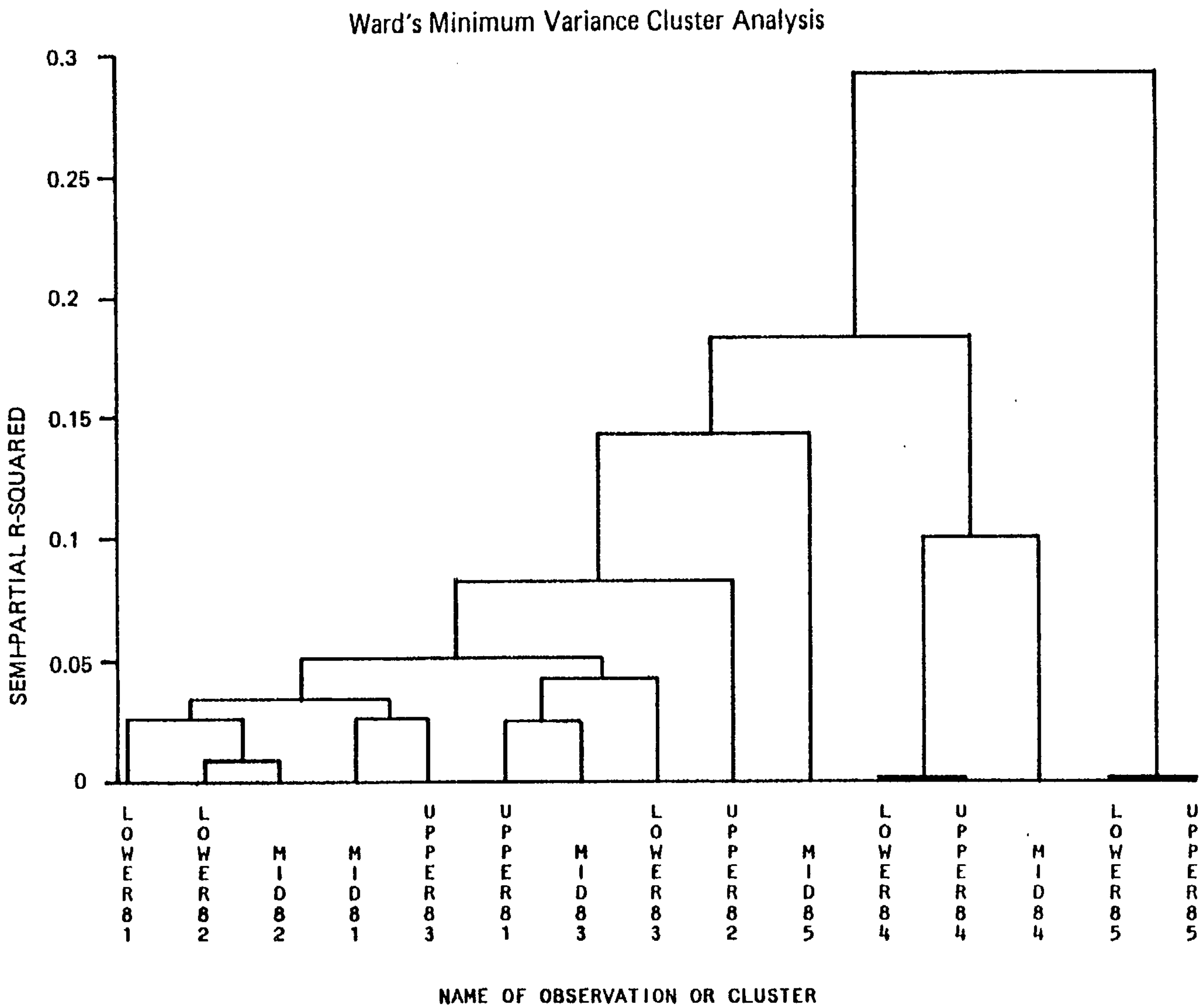


FIG. 4.3.3-7 Dendogram of cluster analysis for similarity between 3 stations on Lake Anna, Va., from 1981–1985. Monthly data used to compare across years included March, May, July and September. Lower-Lower Lake, Mid-Mid-Lake, Upper-Upper Lake.

Table 4.3-3 Comparison of numbers of resident benthic taxa occurring in Lake Anna, Virginia, to various other regional impoundments.

	Lake Anna	Hyco Reservoir	Lake Julian	Lake Norman	Robinson Impoundment	Lake Sangchris	Kerr Reservoir
Data for year(s)	1984-85	1979-80	1979	1974-80	1982	1973-76	1973-74
Post-impoundment year(s)	12-13	15-16	16	12-15	22	8-11	21
Gear Type	AS,DR	DR,DN	DR	DR,DN,C	DR,DN,AS	AS,DR	DR
Insecta							
Chironomidae	52	45	14	56	39	14	22
Coleoptera	0	0	0	5F	2	0	0
Diptera	3F	3F	2	7F	5F	5F	3F
Ephemeroptera	6	4	0	3	4	2	2
Megaloptera	1	1	0	1	0	0	0
Odonata	11	4	0	9	3	1	0
Trichoptera	13	10	2	14	4	1	0
Coelenterata	+	+	+	+	+		
Decapoda					+		
Ectoprocta	+	+		+	+		
Hirudinea	+	+		+	+	+	
Amphipoda	+	+		+	+		+
Hydracarina	+		+	+			+
Mollusca	5G	5G		3G	2G	1G	
Oligochaeta	4F	4F	2F	3F	2F		2F
Turbellaria	+	+		+	+		+
Total Insecta	86	67	18	95	57	23	27
% Shared		72%	76%	64%	67%	87%	85%

Note: The above list includes taxa collected by all gear types from all stations and depths at each respective location. AS = artificial substrate, DR = dip net, C = corer. F = family and G = genera.

165jw043,,29-1
5 /1986

Table 4.3-4 Benthic density and biomass comparisons of Lake Anna, Virginia, 1984-85, to various other regional impoundments.

	Gear Type	Depth	Mean Density/m^2	Mean biomas (gm/m^2)
Lake Anna, Va.	Dredge	2m	3000(Sep)-5700(Nov) 2500(LL) -5400(UL)	0.4(July)-2.2(Sep)
	Artificial substrate	2m	1000(May)-2850(Nov) 1000(LL) -2350(UL)	
Lake Norman, N.C.	Dredge	6-11m	800(July)-3000(Jan)	1.4(July)-5.2(Jan)
Lake Sangchris, Ill.	Dredge	6-13m	100(July)-2300(Sep)	0.4(July)-1.5(Nov)
Robinson Impoundment, N.C.	Dredge	?	5000(NF) -9000(FF)	
Kerr Reservoir, Va./N.C.	Dredge	3-7	3400(Aug)-9750(Feb)	

NOTE: Sample years for each respective location are as listed in Table 4.3.3-8. NF = near field, FF = far field, LL = Lower Lake, UL = Upper Lake.

165jw046,,29-1
4/28/1986

was taken directly from their respective reports, hence the values presented in terms of monthly and sample site averages). The range of average density and biomass values for both months and stations in Lake Anna falls well within the range of those estimates established elsewhere.

In addition to the artificial substrate samples, bimonthly Ekman dredge sampling was initiated in March 1984 and continued through the end of 1985. Gear type, to a limited extent, does influence perception of the benthic community structure. In particular, dredge estimates of aquatic worms and caddisflies were much higher and lower, respectively, than artificial substrates (Figs. 4.3-8 and 4.3-9). Aquatic worms exist within the sediments feeding on detritus and accomplishing local movements within the interstitial spaces by peristaltic contractions of the body. On the other hand, Trichoptera are better adapted to a more epibenthic existence attached to larger rocks or twigs just above the sediments. Segmented legs enable their movement in search of prey or filtering sites. As a result of the above habitat preferences, it is not surprising some gear selectivity is evident with respect to these two groups. In summary, both gear types reflect the relative dominance of two (Asiatic clams, midges) of the four major benthic groups, the difference being dredge samples tended to collect a higher percentage of aquatic worms whereas artificial substrates seemed to selectively collect more caddisflies. Shannon-Wiener's diversity index calculated for the Ekman dredge data collected over the last two years

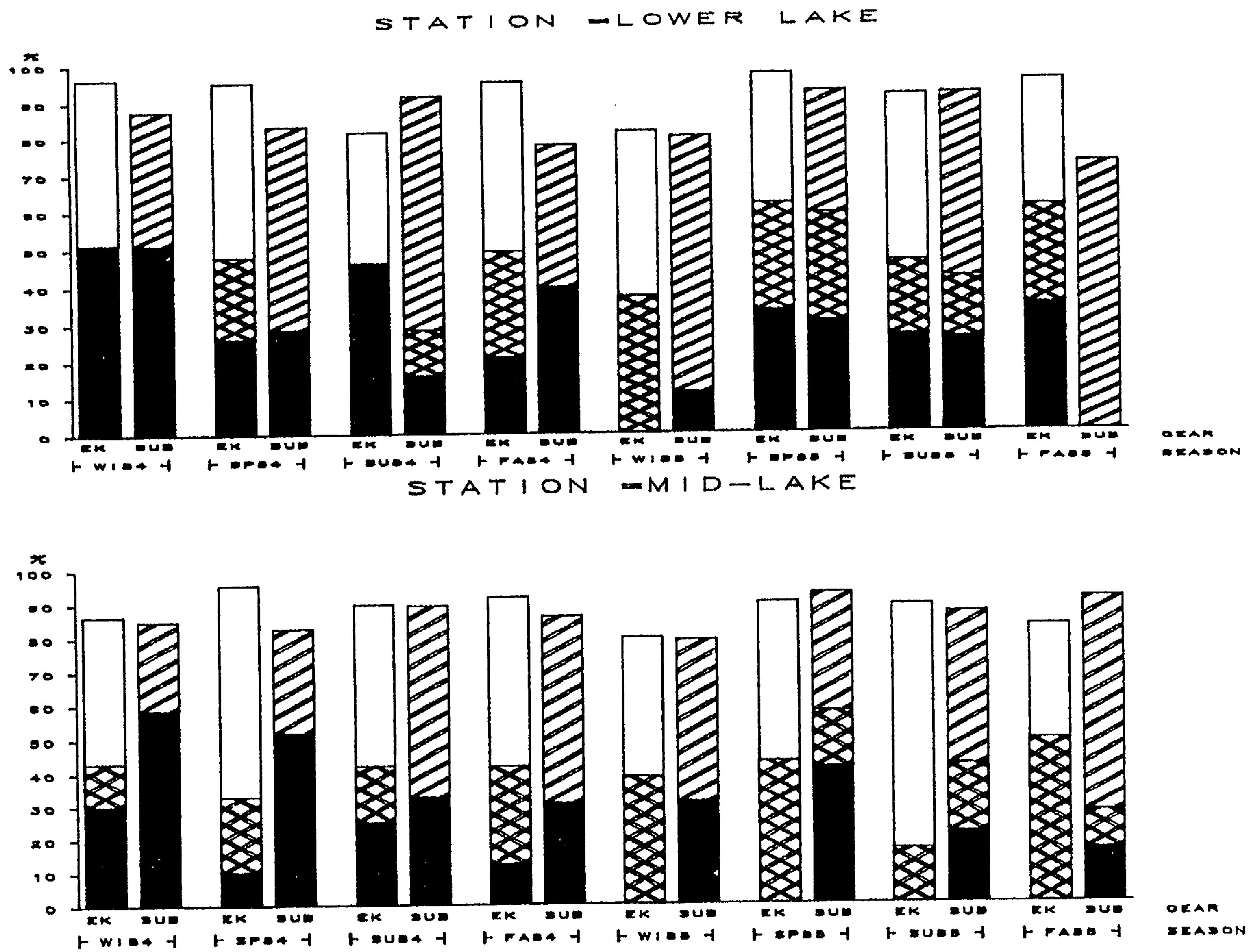


Figure 4.3-8. Average seasonal percent composition of the major (>10%) benthic groups collected by artificial substrate (SUB) and ekman dredge (EK) in Lake Anna, Virginia.

STATION =UPPER LAKE

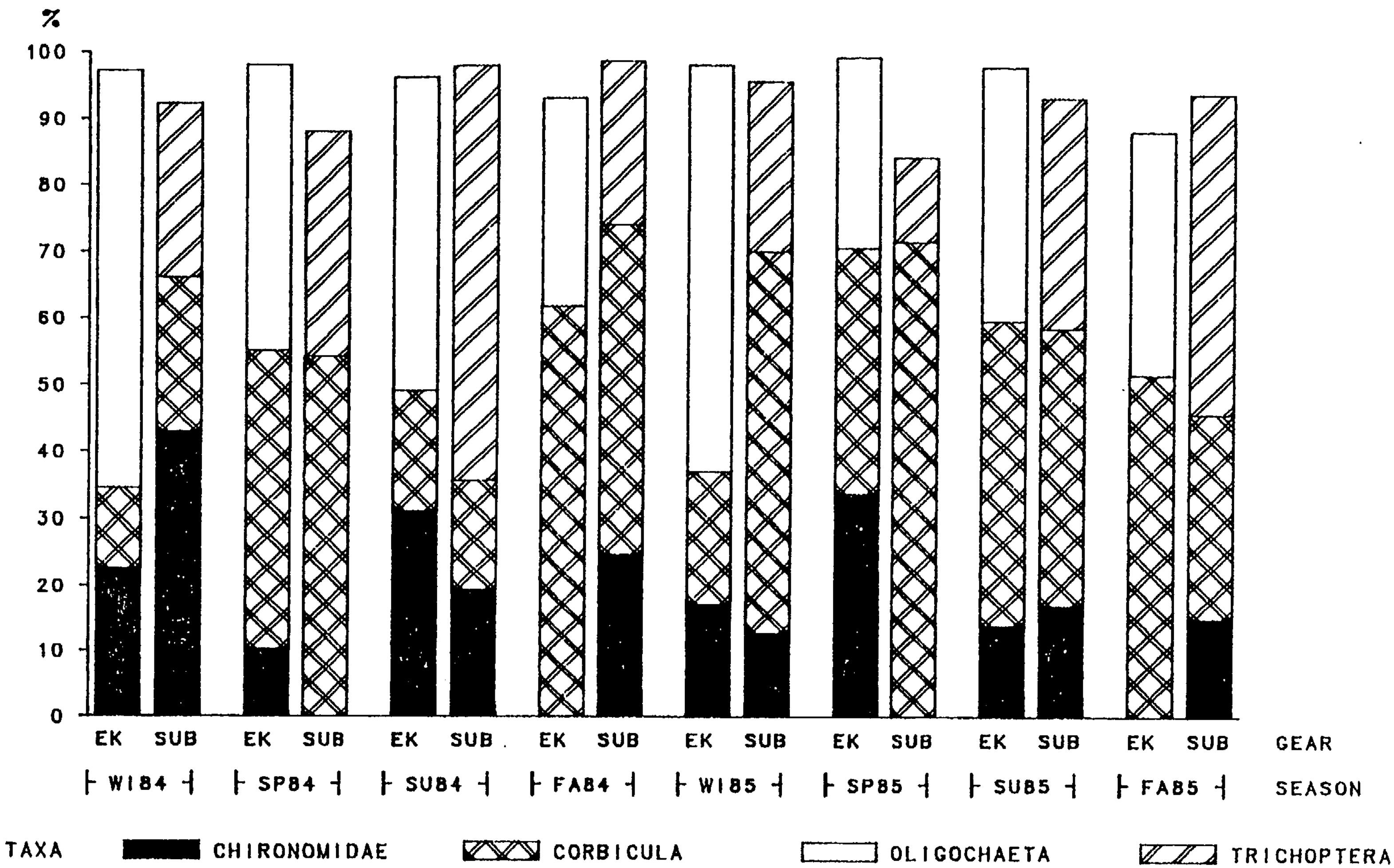


Figure 4.3-9. Average seasonal percent composition of the major (>10%) benthic groups collected by artificial substrate (SUB) and ekman dredge (EK) in the Upper Lake, Lake Anna, Virginia, 1984-1985.

at the same three stations support the substrate data in that the Upper Lake does not appear to be consistently more diverse than other areas nearer the thermal effluent (Fig. 4.3-6).

Discussion

In terms of community structure, Lake Anna appears to harbor an equally diverse assemblage of organisms in the Lower and Upper Lake. The same dominant species existed lake-wide and similar changes in the major groups were evident in all areas from 1976-85. Statistical estimates of the structural make-up of the Lake Anna benthos from 1981-85, using two different sampling methodologies, agree in that the far-field study area does not appear to be consistently more diverse than other areas nearer the thermal effluent, and there has been no indication the benthic community structure has decreased or became more simplified. Overall, the differences in the benthic taxonomic composition evident between operational periods were primarily due to the gross ecological changes associated with the river-to-lake transition. Most of the changes occurred directly after impoundment when rheophilic fauna of the river was replaced by the limnophilic fauna and then between the first and second years of impoundment, four years prior to the beginning of station operation.

Historical seasonal and annual abundance patterns viewed in the context of station operational levels, did not appear to be adversely influenced by the relatively high average annual and summer output evident in 1981, 1983 and 1985. The relative ranking and frequency of statistical significance for average monthly densities in each area of the lake from 1981-85 suggested likewise. Cluster analysis additionally showed that warm season (March-September) communities in all areas over the last five years did not tend to group together based on proximity to the source of thermal effluent or to times of high thermal output.

Gear type, to a limited extent, does influence perception of the benthic community structure. Both the artificial substrates and the Ekman dredge reflect the relative dominance of two (Asiatic clams, midges) of the four major benthic groups, the difference being dredge samples tended to collect more of the aquatic worms whereas substrates collected more caddisflies. As a result of habitat preference of these two benthic groups, it is not surprising some gear selectivity is evident.

The insect fauna of Lake Anna is composed of all of the major groups and genera that would be expected to occur in a southeastern freshwater thermal impoundment. Compared to some of the Carolina thermal impoundments, Lake Sangchris in Illinois, and Kerr Reservoir (ambient) in VA./N.C., it is evident the relative proportions of the major groups and the absolute numbers of insect taxa within each group in Lake Anna are quite similar. Average density and biomass data for Lake Anna is suggestive of its biological capability to produce benthos at levels comparable to other southeastern areas.

After examining the distributional pattern of the numerically dominant species and the historical density and community developmental trends of the major groups, it would appear the benthic population in Lake Anna has been maintained over time. Both the types and amounts of benthos available for the food chain and other critical functions such as nutrient cycling have continued to persist with no grossly discernable differences evident between any area of the lake. The community structure has undergone distinct changes, most notably during the early years of impoundment and then again during the subsequent immigration of the Asiatic clam. Midges, aquatic worms, caddisflies, and mayfly nymphs are all available to alternately provide both food and decompositional capabilities so necessary to the continued success of the system. Even the Asiatic clam has apparently been successfully integrated as evidenced by the continued presence of previously dominant indigenous organisms along with its observed capability to serve as food for the redear sunfish.

This page left intentionally blank.

This page left intentionally blank.

4.4 Fishes

Introduction

The condition of the fishery in a lake or river is usually considered to be the most important measure of the health or stability of the aquatic environment. This is true not only because of the popularity of sport fishing, but also because fish occupy the upper level of the food chain (see Fig. 4-1). A given species of fish may be affected by changes in water quality, phytoplankton, zooplankton, macrophytes, benthic invertebrates, other species of fish, and/or exploitation by other predators, including man.

Temperature is the environmental factor which most consistently influences the life history and habits of freshwater fishes. Temperature affects spawning time, maturation rates, hatching success, feeding and growth rates, and can cause death at extremes. Temperature preferences are generally around 20°C for cool water species in this area, e.g. yellow perch and walleye, above 24°C for most cyprinids (minnows) and above 29°C for most centrarchids, e.g. black bass and sunfish (Cherry et al. 1977; Ney 1978). Maximum temperatures at which walleye survive and continue to grow (for 75 days) have been determined to be 32-33°C (Wrenn and Forsythe 1978). Largemouth bass were observed to grow until a temperature of 35.5°C was reached, while a temperature of 36.8°C proved lethal (Coutant 1975). During this two-year study, according to the previous section, the highest hourly temperature measured in the lake was 32.0°C (Upper Lake, August 1984) and the monthly average high temperature (means of daily highs) did not exceed 29.5°C, also in the Upper Lake (Section 3.5.2).

Certain beneficial aspects to fishes related to moderate temperature increases (delta T = 2-10°C) include enhancement of growth and reproduction (perhaps due to a longer growing season), and increased thermal tolerance. Thermal enrichment increases primary and secondary productivity resulting in a broader food base more easily exploited by higher level consumers. This is a positive factor when either, fishes are not stressed by higher temperatures, or fishes can remain in cooler water (below the thermocline or cool microhabitats) when not feeding to avoid a higher metabolic cost (Gibbons and Sharitz 1981). Under either of these conditions, the net result to the fish would be an increased rate of growth. When temperatures consistently exceed those necessary for continued growth the fish become emaciated and susceptible to disease (Bennett 1979). It has been demonstrated, however, that relatively high temperatures (33-35°C) encountered in a summer discharge effluent will not create a thermal barrier to the movement of certain species, including largemouth bass (Wrenn 1976).

Increased growth rates due to thermal enrichment have been demonstrated for largemouth bass in several studies (Coutant and Cox 1976; Perry and Tranquilli 1984).

Increased thermal tolerance due to thermal enrichment has also been demonstrated for certain species, e.g. bluegill (Holland et al. 1974; Murphy et al. 1976).

The habitat a fish occupies is also dependent on other factors, such as turbidity, structure, presence of predators, food abundance, crowding, etc. (Werner et al. 1983a). The effects of interaction between these factors are sometimes easily observed but most often are quite subtle.

When a physical or man-made condition is imposed on a body of water the character of that water body changes from the normal seasonal cycle. For example, increased mixing of Lake Anna due to the circulatory water pump activity of the power station has increased the percent of lake volume which comprises the epilimnion during the summer months (June-September), thus increasing the amount of living space (habitat) available to the indigenous warm water fishes (see Table 3.5). Pre-operational values ranged from 38.5-55.9 percent (avg. 45.7) with operational values from 66.2-93.8 percent (avg. 82.3) during the summer months (Section 3.5.2). This has extended the habitat available for most indigenous fish species although it may have reduced the habitat availability for the introduced species striped bass.

There are other more subtle examples of variables interacting to influence habitat selection and population changes. It is possible the mere presence of a predator population could result in the extirpation of a species not consumed by the predator due to predator-induced increased competition in protected habitats (Werner et al. 1983(a)). Shifts in habitat usage by some species, e.g. bluegill, have been shown to follow shifts in the availability of certain prey species (Werner et al. 1983b).

What a fish feeds on and what feeds on it are very important in determining where the fish is found. Competition for the same food resources can cause geographic shifts in population abundance or displacement of a species not as well adapted to feed on the same resources. For this and other reasons the introduction of new species into an established system must be carefully studied to ensure a positive overall result. Species composition and standing crop of fish populations can be greatly affected by introduction of new fish species. Some species, stocked as forage fish, have been observed feeding on larvae of other forage species (Baker and Schmitz 1971) and even competing with young sport fishes (largemouth bass and black crappie) for the same food resources (Mosher 1984; von Geldern and Mitchell 1975). Since 1972 Lake Anna has been subject to numerous stockings of nine different species of fishes . Because of this in conjunction with lake aging, habitat changes, etc., it is expected that fluctuations in species composition would occur as competition for food and space varies.

Availability of cover (structure) can also influence habitat choice by fishes (Aggus and Elliott 1975; Paxton and Stevenson 1979; Holland and Huston 1985).

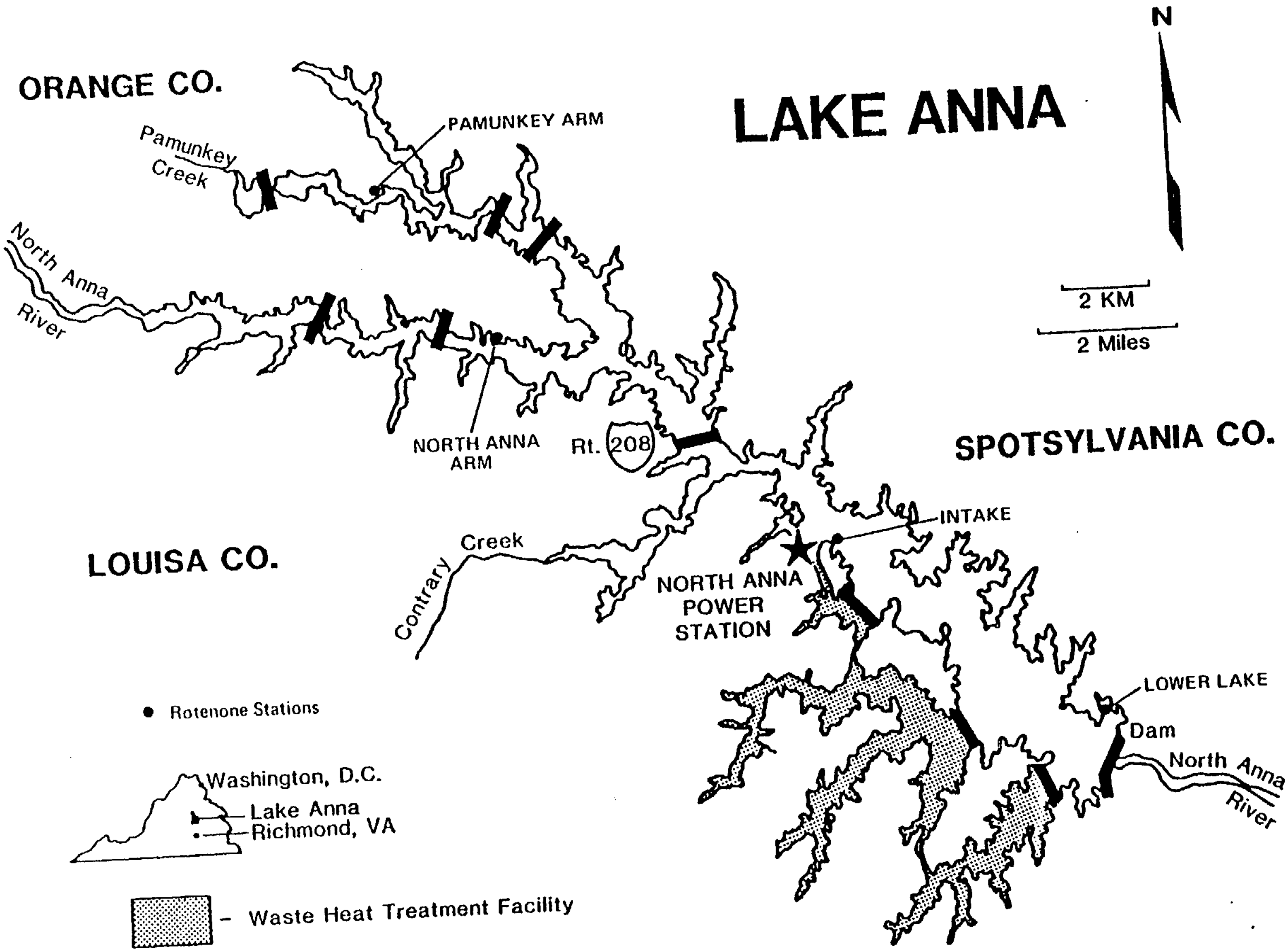
Increased physical structure in a lake creates more microhabitat types, resulting in a greater total number of niches. This is especially relevant to Lake Anna as the lake was clear cut before impoundment. To compensate for this lack of shallow water structure Virginia Power built a series of underwater artificial structures in the lake in an attempt to increase production and standing crop of fishes especially for sunfishes such as black crappie.

Information Base for Evaluation

Monitoring of fish populations is essential in determining changes that occur in reservoirs. Sampling is complicated, however, by the fact that regardless of the sampling technique or gear employed, each has its own degree of selectivity depending on the situation (Lagler 1968; Everhart et al. 1975). Fish behavior, habitat preference and environmental conditions affect the efficiency of gear and are major considerations when selecting sampling methods (Welcomme 1975). Because of these factors it is especially important that several different types of sampling gear or methods be employed in order to obtain a representative sample of the entire multispecies fish complex in a reservoir (Aggus et al. 1980a).

Extensive fish studies have been conducted on Lake Anna since 1976 with emphasis on the last two years of this period, 1984 and 1985. During this two year study three primary collection methods were used to monitor the fish community - mid-water gill net, shoreline electrofishing and cove rotenone, (Appendix B-Table 3-5; collection sites are shown in Fig. 4.4.-1 and 4.4.-2). Fishes were collected bimonthly from February through December both years by gill netting (5 stations) and electrofishing (7 stations). Rotenone sampling (4 stations) was conducted during August by Virginia Power and Virginia Commission of Game and Inland Fisheries personnel. Generally, bottom types were similar for the same sampling method. Shoreline electrofishing station habitats included the natural shoreline with a beaver lodge - brush pile, except at dike stations which uniformly consisted of a rocky substrate. Experimental gill nets were set, where possible, near littoral drop-off areas. Rotenone coves encompassed at least one brush pile. For detailed sampling procedures refer to Appendix D.

Each of these three sampling methods is designed to capture fish that normally frequent different habitats. Gill nets normally capture fishes that inhabit deeper strata of the reservoir, or exhibit diel movement to and from the shoreline. Species selectivity of experimental gill nets has been well documented (Berst 1961; Heard 1962; Yeh 1977). Shoreline electrofishing samples populations of the usually small fishes of that habitat. Brush piles were included in cove stations as these structures attract fishes, especially largemouth bass, and electroshocking near structure is more effective than in areas without structure (Reynolds 1983). Cove rotenoning collects many of the species taken by the preceeding two methods and other less common species not



LAKE ANNA
N
2 KM
2 Miles
ORANGE CO.
Pamunkey Creek
PAMUNKEY ARM
North Anna River
NORTH ANNA ARM
Rt. 208
SPOTSYLVANIA CO.
LOUISA CO.
Contrary Creek
INTAKE
NORTH ANNA POWER STATION
LOWER LAKE
Dam
North Anna River
● Rotenone Stations
Washington, D.C.
Lake Anna
Richmond, VA
- Waste Heat Treatment Facility

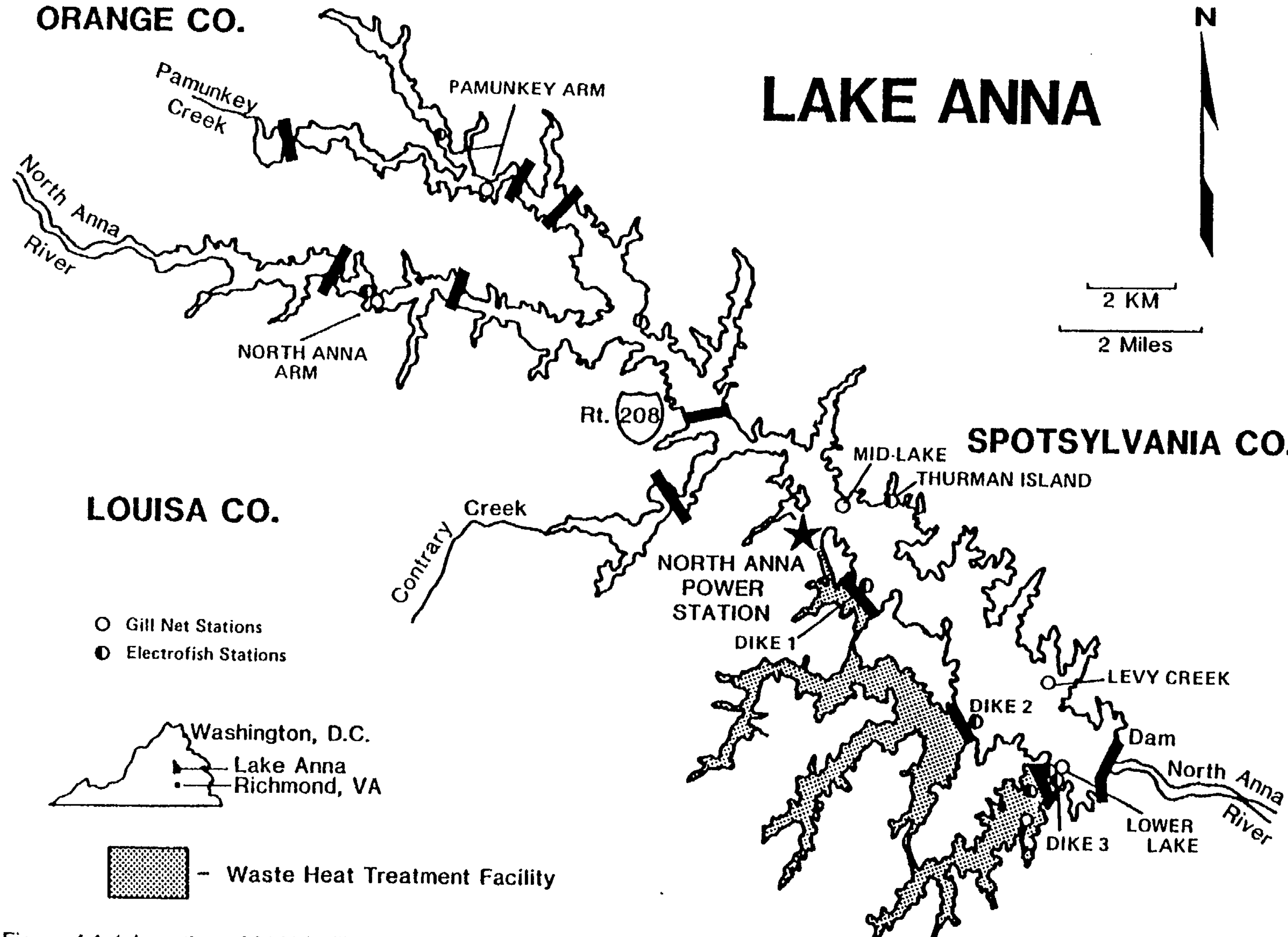


Figure 4.4-1. Location of 316(a) gill net and electrofish stations.

normally collected. This latter method, in addition, provides a better estimate of standing crop and recruitment success for many species (Davies and Shelton 1983). Repeated electrofishing or rotenoning of fixed areas provides acceptable values for developing valid estimates of population parameters and does little harm as fishes removed by sampling are rapidly replaced by immigration from adjacent areas (Sandoz 1959; King et al. 1981).

Of these three primary sampling methods cove rotenone is the most comprehensive, and probably the most controversial, when interpretating the results. Fish population studies in Lakes Barkley (Aggus et al. 1980b) and Douglas (Hayne et al. 1968) have indicated that when results of cove rotenone studies (standing crop estimate) were compared to estimates from larger areas of the reservoir the differences could not be adjusted by a single correction factor. In both studies, the estimates from open water areas and shoreline samples varied depending on species present, their sizes and the size of the coves sampled (Davies and Shelton 1983). Unlike Barkely or Douglas reservoirs all rotenone coves in Lake Anna contain a beaver lodge-brush pile. Hence, cove rotenone results may tend to yield higher total estimated standing crops for some species, e.g. bluegill, which congregate around these structures. On the other hand estimates of the numbers and size distribution of pelagic and/or schooling fishes are extremely difficult to determine from cove rotenone studies as they may or may not be present during sampling (Carter

1958). In spite of these complications, rotenoning is considered one of the most effective means of obtaining fish population information (Davies and Shelton 1983).

Many methods for analyzing data obtained from the sampling methods were examined during this study. The object of these analyses was to determine if there had been any appreciable change to the fish population of Lake Anna and whether a balanced, indigenous community was being maintained. Some of the methods which were examined, but not used, included: proportional stock density (PSD) for selected species was not used because sample size was usually small and it was not a good tool for trend analysis; and catch per unit effort (CPE) was hard to quantify for sampling method combinations and other lake comparisons. Methods used to analyze data included: correlation analysis of electrofishing and gill netting data with environmental variables; combining electrofishing, gill netting and rotenone data for comparisons of length classes of selected species; diversity over time; and use of rotenone data for comparison of weight and number per hectare, total and by selected species. Results were compared with past years data (pre- and post-operation) and similarly derived data from other reservoirs. Rotenone data for Lake Anna were available for 1975-1985, gill netting data for 1973-1985 and electrofishing data for 1980-1985.

Additional fish sampling procedures were also used to supplement data collected by the primary sampling procedures. These additional procedures included supplementary electrofishing and gill netting for life history studies of selected species, ichthyoplankton surveys and creel census.

Supplementary gill netting and electrofishing were conducted as needed to provide data for life history (age and growth, food studies, and reproduction) for selected species and for striped bass tracking studies. The complete procedures are described in Appendix D. The species selected for these supplementary studies are important game and pan fish such as largemouth bass, striped bass and black crappie. These species are among the top carnivores in the lake and changes in their life history can provide good indices of environmental perturbations.

Larval fish (ichthyoplankton) sampling has been conducted on Lake Anna since 1979. This sampling was designed primarily to monitor fish spawning activity and to determine the initiation of spawning for selected species. Changes in larval abundance were impossible to determine with any accuracy due to the patchy nature of ichthyoplankton and the vast area of the reservoir. For example, sampling for one season filtered only 1/1,000th of one percent of the lakes' volume. Ichthyoplankton samples were collected with a side towed plankton net bi-weekly from mid-March through mid-September at six locations in the lake (Fig. 4.4.3). Complete sampling procedures can be found in Appendix D.

Creel surveys (access point) were conducted by Virginia Power and Virginia Commission of Game and Inland

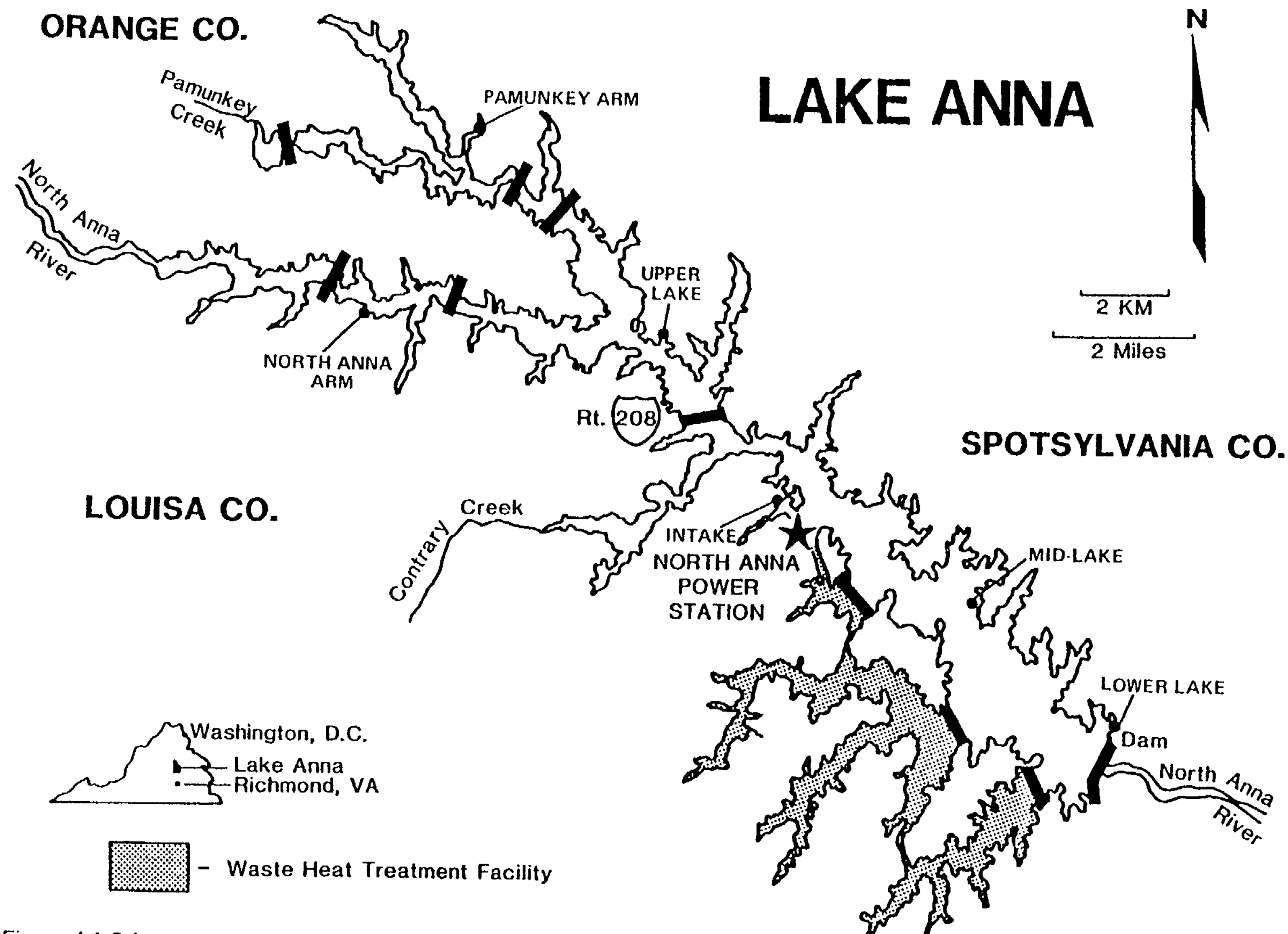


Figure 4.4-3. Location of 316(a) ichthyoplankton sampling stations.

Fisheries creel clerks from March through November, 1984 and 1985. Survey procedures and estimation of fishing effort and catch were identical to those used in creel surveys of Lake Anna conducted by representatives of the Virginia Commission of Game and Inland Fisheries 1976-1980 (Sledd and Shuber 1981). Although a creel census will sample only a part of the total fish community, many large game fish are selected by anglers and changes in the harvest of these fishes, as in their life history, can provide good indices of environmental or biological perturbations (Aggus et al. 1980a).

Assessment

Community Structure

The community structure of fishes in Lake Anna has remained relatively stable since sampling began in 1975. Since 1975, 39 species of fish representing 12 families have been collected by at least one of three sampling methods employed: cove rotenone, shoreline electrofishing or gill netting (Table 4.4-1). Of these 39 species, four are non-indigenous introductions; forage species, blueback herring, (*Alosa aestivalis*) and threadfin shad (*Dorosoma petenense*); game species, striped bass, (*Morone saxatilis*), and walleye, (*Stizostedion vitreum*). Striped bass and walleye could not sustain themselves in Lake Anna without annual stockings and threadfin shad could not survive the winter without the introduction of heated water from the

Table 4.4-1: List of fishes, common and scientific names, collected from Lake Anna (1975-1985) by gear type.

Scientific Name	Common Name	Electrofishing	Gillnetting	Rotenone
Anguillidae				
Anguilla rostrata	American eel	*		*
Clupeidae				
Dorosoma cepedianum	gizzard shad	*	*	*
D. petenense	threadfin shad	*	*	*
Alosa aestivalis	blueback herring		*	*
Umbridae				
Umbra otgnaea	eastern mudminnow			*
Poeciliidae				
Gambusia affinis	mosquitofish			*
Catostomidae				
Catostomus commersoni	white sucker	*	*	*
Erimyzon oblongus	creek chubsucker	*	*	*
Moxostuma macrolepidotum	shorthead redhorse	*	*	
Hypentelium nigricans	northern hog sucker	*	*	
Esocidae				
Esox niger	chain pickerel	*	*	*
E. Lucius	Northern pike			*
Cyprinidae				
Cyprinus carpio	common carp	*	*	*
Nocomis leptocephalus	bluehead chub	*		
Nocomis micropogon	river chub	*		
Notoemigonus crysoleucas	golden shiner	*	*	*
Notropis analostanus	satinfin shiner	*		*
Notropis procne	swallowtail shiner	*		*
Notropis hudsonius	spottail shiner	*		*
Aphredoderidae				
Aphredoderus sayanus	pirate perch	*		*
Ictaluridae				
Ictalurus catus	white catfish		*	*
I. nebulosus	brown bullhead	*	*	
I. natalis	yellow bullhead	*	*	
I. punctatus	channel catfish	*	*	*
Noturus insignis	margined madtom			*
Centrarchidae				
Enneaceanthus gloriosus	bluespotted sunfish			*
Lepomis auritus	redbreast sunfish	*	*	*

Table 4.4-1 (continued):

Scientific Name	Common Name	Electrofishing	Gillnetting	Rotenone
L. gibbosus	pumpkinseed	*	*	*
L. gulosus	warmouth	*	*	*
L. macrochirus	bluegill	*	*	*
L. microlophus	redear sunfish	*	*	*
Acantharchus pomotis	mud sunfish	*		*
Micropterus salmoides	largemouth bass	*	*	*
Pomoxis nigromaculatus	black crappie	*	*	*
Percidae				
Perca flavescens	yellow perch	*	*	*
Stizostedion vitreum	walleye		*	*
Etheostoma olmstedi	tessellated darter	*		*
Percichthyidae				
Morone americana	white perch	*	*	*
M. saxatilis	striped bass		*	*

power station. Pre-operational results of these studies from rotenone biomass 1975-1977 and gill netting (numerical percent composition) 1977, are very similar in species composition and numbers to operational data (Fig 4.4-4, through 4.4-6). Electrofishing data were collected only from 1980-1985 (Fig. 4.4-7).

Seasonal Shannon-Wiener diversity values were examined for combined electrofishing and gill netting data for 1981-1985 from Lake Anna. Diversity analyses of these two methods combined should be a good indicator of general species diversity in Lake Anna. The lake was divided into upper, mid and lower sections and was analyzed by a two factor, year and season (warming: February-April; summer: June-August; cooling: October-December) analysis of variance. Interaction of season and year was not significant in either test at the 0.05 level in any section of the lake. Seasonal patterns were apparently similar during the years tested and seasonal changes in mean diversity values were not significant throughout the lake. It seems a diverse assemblage of fishes is being maintained over time in Lake Anna.

Rotenone, gill netting and electrofishing results (1975-1985) were examined extensively for Upper, Mid and Lower lake. Although the three sections of the lake are somewhat different in species composition, due to different habitat, similar trends were evident in all areas. Bluegill (*Lepomis macrochirus*) and gizzard shad (*Dorosoma cepedianum*) have been consistently dominant in number and weight,

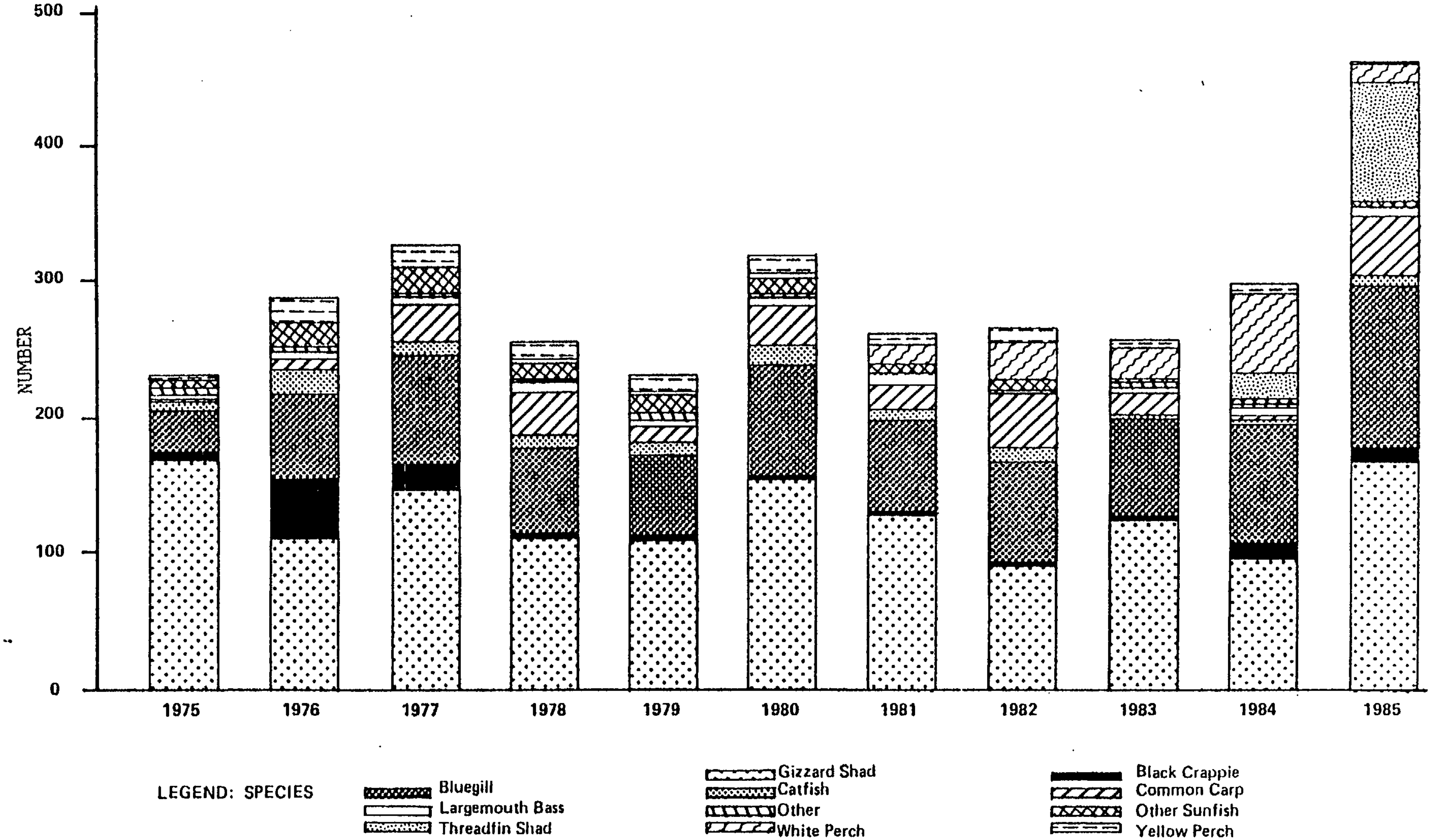


FIGURE 4.4-4 Estimated catch (kilograms per hectare) total reservoir.

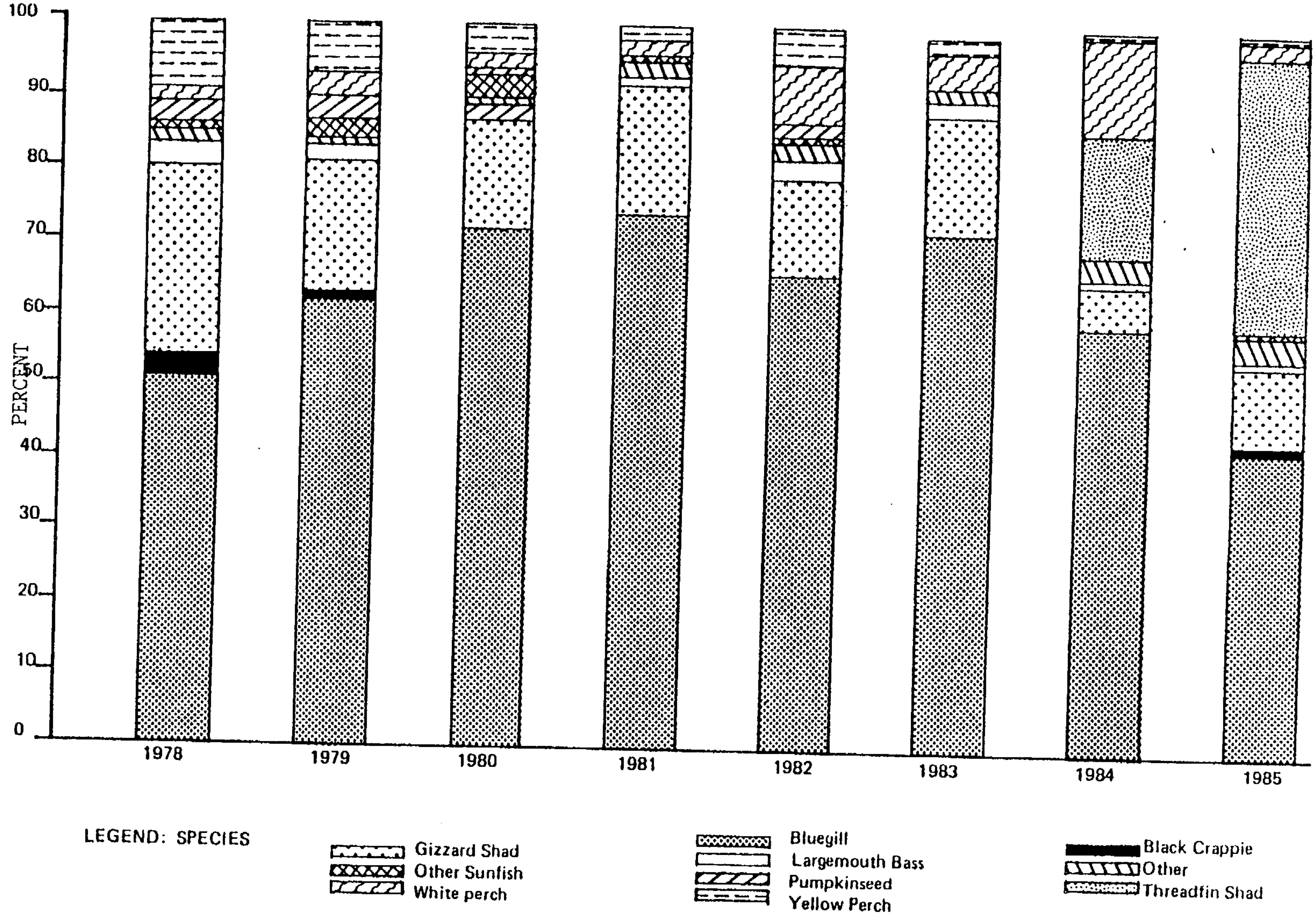


FIGURE 4.4-5 Percent composition for Lake Anna (rotenone)

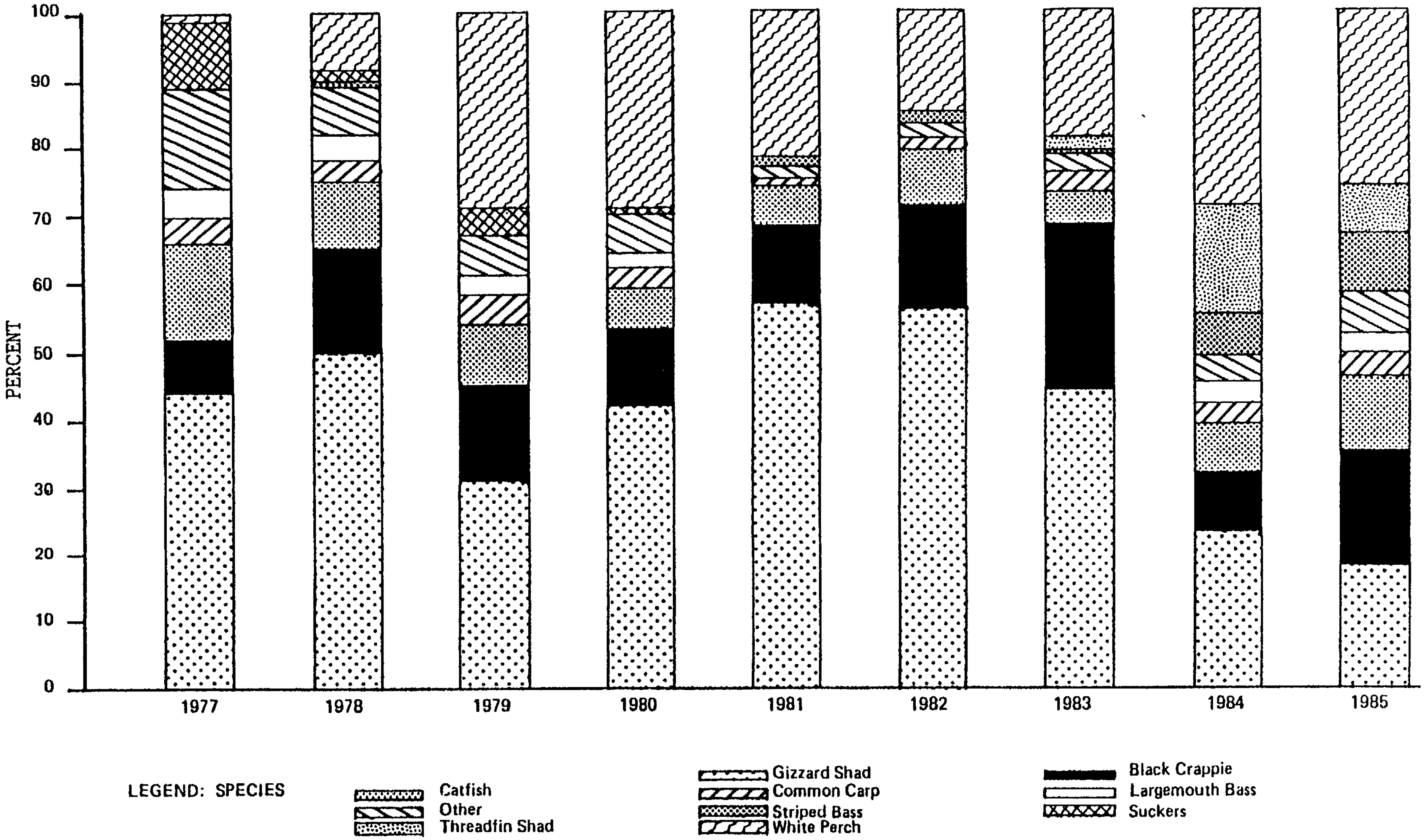


FIGURE 4.4-6 Percent composition for Lake Anna (gill net)

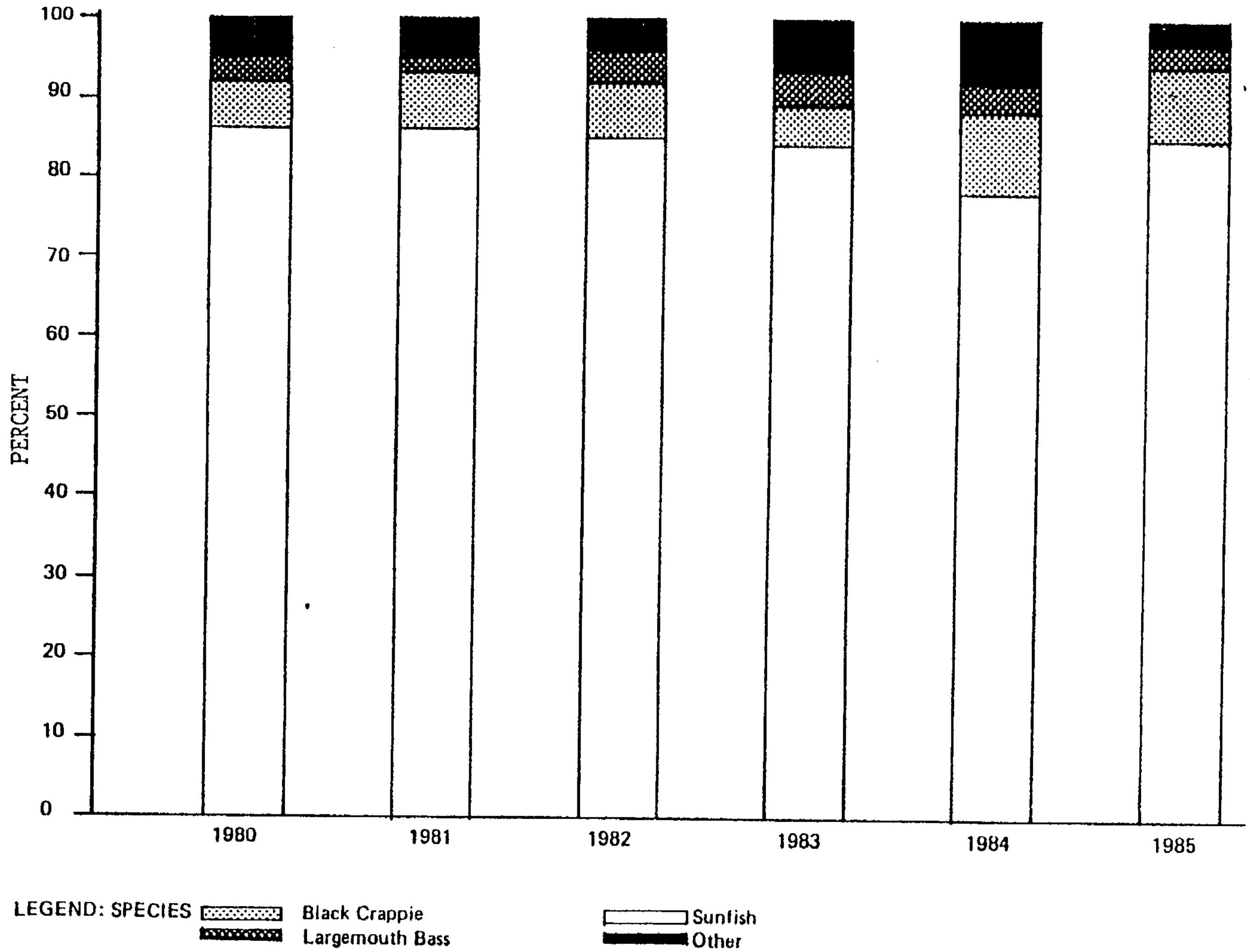


FIGURE 4.4-7 Percent composition for Lake Anna (electrofish)

respectively, in collections throughout the lake since 1975 (Fig 4.4-4 through 4.4-7). Major differences that have occurred in fish species composition since 1975 are: a decline in the yellow perch (*Perca flavescens*) population since 1976; a decline in the black crappie (*Pomoxis nigromaculatus*) population between 1978-1984 (appears to be reversing during 1984 and 1985) and an increase in the population of white perch (*Morone americana*) (since 1981) and threadfin shad (since 1984) populations following earlier introduction (Fig 4.4-4 through 4.4-7 and Appendix B-Table 1, Fig 1-12). There have also been other smaller changes and shifts in species composition which will be discussed below.

Because of the highly variable nature of gill netting data (Fig 4.4-6) and the lack of electrofishing data prior to 1980 (Fig 4.4-7) the following discussions concerning fish species in Lake Anna and biomass comparisons with other lakes and reservoirs are based primarily on rotenone results. Individual species discussions are based primarily on data contained in Appendix B-Table 1, which summarizes rotenone data from 1975-1985 for each lake station and each species. Species discussed are important for at least one of the following reasons; significant contribution to biomass or number during one or more years of the study, game fish species or introduced species.

Gizzard shad is a major forge species in Lake Anna and its biomass has remained relatively stable in rotenone collections since 1975, ranging from 91 to 168 kg/ha (Fig 4.4-4).

Threadfin shad, introduced into the lake in 1983, have made a major contribution to the forage base and also fish biomass levels in Lake Anna, particularly during 1985 (Fig 4.4-4 and 4.4-5). The species is extremely sensitive to cold water (Griffith 1978) but is able to over-winter in Lake Anna due to the thermal input from the power station. The Virginia Commission of Game and Inland Fisheries is exploring ways to collect live threadfin shad from Lake Anna in the spring to repopulate other Virginia reservoirs which experience a threadfin shad die off each winter. Both species of shad are most abundant in the upper areas of the lake as has been found in other reservoirs (Netsch et al 1971; Siler et al 1986). This is probably due to a concentration of plankton, which shad feed upon, in this more productive area (Baker and Schmitz 1971).

Another member of the herring family Clupeidae, blueback herring, was also introduced into Lake Anna for forage by Virginia Commission of Game and Inland Fisheries personnel in 1980 and 1981. This species has not established itself in Lake Anna as well as the threadfin shad, but it does appear to be reproducing, as young, healthy specimens are collected occasionally.

The sucker population, Catostomidae, in Lake Anna, originally concentrated in the more lotic Upper Reservoir, has never been very large and has declined steadily since 1975. This is not surprising as suckers generally prefer a riverine environment (Jones 1978).

Chain pickerel (Esox niger) is a sport fish native to streams and rivers in this area. This species has been declining in Lake Anna, at least since 1975 when rotenone studies began. The decline of this species in the lake is possibly due to a lack of suitable spawning area as it prefers marshy, vegetated areas for spawning (Breder and Rosen 1966; Jones 1978).

Common carp (Cyprinus carpio) is a bottom feeding "rough" fish naturalized to this area. It is not a desirable form as its method of feeding, rooting in the bottom sediment, disrupts aquatic vegetation (Pflieger 1975). Common carp biomass does not appear to have increased significantly in Lake Anna since about 1977, although rotenone catch returns for this species are quite variable (Fig 4.4-4).

Members of the catfish family, Ictaluridae, have maintained a relatively stable average biomass in Lake Anna since 1975, although brown bullhead (Ictalurus nebulosus) appears to have declined somewhat in recent years.

The centrarchid, bluegill, is primarily a forage species in Lake Anna but is an excellent pan fish at large sizes. Bluegill has been the dominant sunfish species in Lake Anna since studies began in 1975 and also numerically dominant among all species in rotenone and electrofishing collections (Fig 4.4-5 and 4.4-7). Average lake bluegill biomass and numbers appear to have increased in recent years.

Pumpkinseed (*Lepomis gibbosus*) another sunfish species in the lake, has always been more abundant in the Upper Lake, but since 1977 it has declined throughout the lake and is now found almost exclusively in the Upper Lake. Redear sunfish (*Lepomis microlophus*) on the other hand, is concentrated primarily in the Lower-Mid Lake area and has increased in the lake appearing to displace the pumpkinseed in the lower-mid lake area. Redear sunfish grow to a larger size than pumpkinseed and are therefore considered more desirable by anglers (Manooch 1984). It is not surprising that the redear sunfish would displace the pumpkinseed as it is the Southern equivalent of the latter species (Pflieger 1975). The redear sunfish is better adapted to feed on the hard shelled Asiatic clam, which is more abundant in the Lower Reservoir (Pflieger 1975; Keast 1978); whereas the pumpkinseed is better adapted to feed on softer shelled molluscs or aquatic insects (Keast 1978).

The standing crop (kg/ha) of largemouth bass (*Micropterus salmoides*) the premier sport fish in Lake Anna, has remained quite stable throughout the lake since rotenone studies began in 1975 ranging from 3.6 kg/ha to 8.2 kg/ha (Fig 4.4-4) while numbers have generally increased. This species appears to be thriving in the lake and Lake Anna led the state in number of largemouth bass citations ($\geq$8 lbs) during 1985; however, there has been a decline in the number of citations in recent years.

The introduction of threadfin shad as well as the construction of artificial reefs in Lake Anna may have helped to sustain the population of largemouth bass at high levels in the lake. The availability of cover appears to profoundly influence the early survival of young largemouth bass in other areas (Aggus and Elliott 1975). The rate of growth of young largemouth bass during this period may be even more important to annual survival and recruitment. Other studies have shown largemouth bass that begin feeding on other fish early (primarily threadfin and small gizzard shad) had a greatly accelerated growth during the remainder of the summer. Variations in the number of fast growing bass were found to be due to the availability of desirable forage fish. Those fish feeding on plankton and bottom organisms suffered nearly 100% mortality during winter in other lakes (Aggus and Elliott 1975; Dewey et al 1981). In Lake Anna, winter mortality may be suppressed due to thermal enrichment, which allows warm water food organisms to survive later into the winter in addition to reducing the amount of cold stress to which young bass are subjected.

During 1984, a number of largemouth bass and striped bass were found to be infected with the anchor parasite (*Lernea elegans*) a parasitic copepod. This parasite is ubiquitous in North America, has an optimum temperature range of 23 to 40°C (Hoffman 1976) and shows no host specificity. In natural systems it does not cause a threat to fish populations. Parasites normally attack fish which are weakened by some other stress. This is the only known outbreak of this parasite in Lake Anna and no infected fish were found during 1985. No other parasites or disease were found in fishes from Lake Anna during this two year study.

Length frequencies of largemouth bass collected from rotenone studies in the lake were also examined. Fish were divided into three length classes; young-of-the-year, less than 150 mm; juveniles, 150-250 mm; and adults, greater than 250 mm. The plot of juveniles is logged one year later than the young- of-the-year plot and the adult plot is logged two years later than the juvenile plot in order to better indicate recruitment into these categories (Fig 4.4-8). The plots indicate the number of young-of-the-year largemouth bass collected showed the greatest variability from year to year, adults the least and juveniles intermediate. This is what one would expect in a normally developing largemouth bass population. Data do not show any relationship between year class strength and recruitment. When these data were broken down into Upper, Mid and Lower Lake areas, the results were the same in the individual areas as found in the combined lake data (Appendix B; Fig 13-15).

Black crappie, a sport fish/pan fish in Lake Anna, underwent a decline in 1978 throughout the lake according to rotenone (Fig 4.4-4) and creel data (Sledd and Shuber 1981). This decline does not appear in gill netting percent composition results (Fig. 4.4-6), but this method is a less reliable indicator of trends than the other two (rotenone and creel). Results of rotenone and creel studies indicate a resurgence of this species in the lake during 1984 and

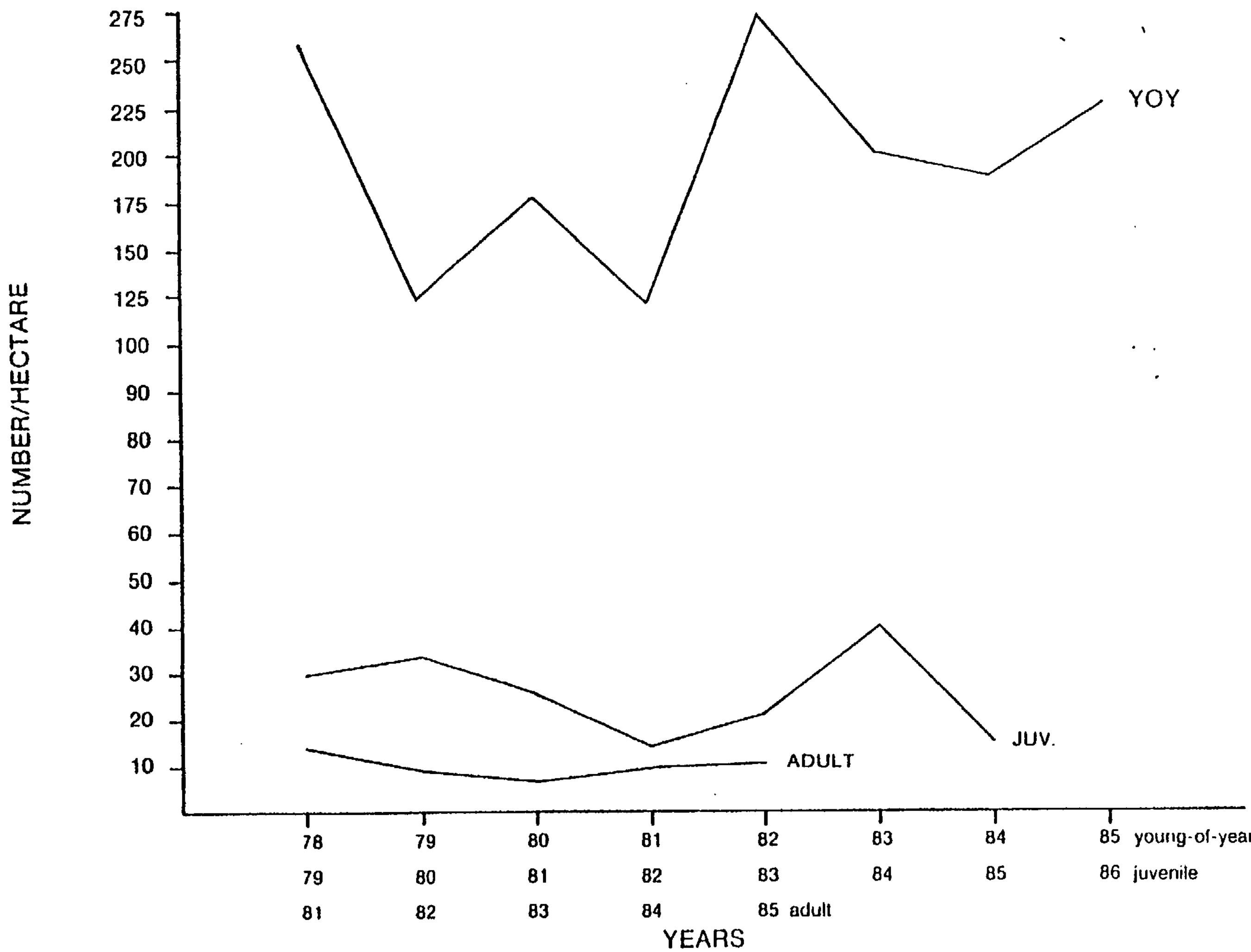


Figure 4.4-8 Results of Lake Anna largemouth bass rotenone data, young-of-year ≤ 150 mm, 250 mm > juveniles > 150 mm, and adults ≥ 250 mm with plots lagged to indicate recruitment.

1985, especially in the Mid-Lake area. Large unexplained natural fluctuations are common for black crappie (Swingle and Swingle 1967). Black crappie have been postulated to respond negatively to increased shore development and total dissolved solids (Jenkins 1970). There is considerable shore development and runoff-erosion in the Upper Reservoir, perhaps accounting for their scarcity in this area. Virginia Commission of Game and Inland Fisheries biologists postulated that the decline of black crappie may have been due, at least in part, to the absence of good shoreline structure (Sledd and Shuber 1981). Abundant cover has been stated to be necessary for black crappie growth and reproduction (Edwards et al. 1982).

The introduction of threadfin shad as an additional forage species in 1983 may have served to encourage this increase in the size of the black crappie population. The introduction of threadfin shad has had favorable results in most areas as they are heavily utilized by sport fish as forage with resulting improved growth rates for largemouth bass, black crappie and striped bass (VonGeldern and Mitchell 1975).

The construction of underwater artificial reefs in Lake Anna in 1984 and 1985 may also have had a positive effect on the black crappie population. Artificial reefs created structure which may improve black crappie reproduction success and recruitment. Reefs provide increased survival rates of young-of-the-year fishes through reduced predator success for larger fish (Savino and Stein

1982; Anderson 1984). Black crappie length frequencies show there were more larger fish collected from rotenone studies during 1985 than for the years 1982-1984 (Appendix B-Fig. 16).

Yellow perch, a sport/pan fish, has been declining in the lake since 1976. This decline was probably due to increased competition with other fishes as the lake matured and initial high nutrient levels and associated productivity declined thus decreasing the available resource base in conjunction with additional fish introductions. The species is also a more Northern fish (Ruelle et al 1977) near the edge of its range in Lake Anna.

White perch is primarily a "rough" fish in Lake Anna and was first collected in rotenone surveys during 1976. They comprised a small percentage of the standing crop until about 1981. White perch reached their highest level during 1984 and declined in 1985. This species is a potential competitor with black crappie for food resources at both larval and adult stages (Reid 1972; Keast 1978). However, it is unlikely the white perch increase precipitated the black crappie decline, as rotenone data indicate the major black crappie decrease occurred during 1976 and 1977 when white perch still comprised an insignificant portion of the standing crop. White perch may have expanded into the niche formally occupied by black crappie when the latter populations declined due to natural fluctuations. Accordingly the decline in the white perch population noted during 1985 coincided with the increase in number of black crappie collected.

Many species of fish have been introduced into Lake Anna since 1972 (Table 4.4-2). Forage fish introductions were discussed previously, while game fish introductions include striped bass, and walleye. Neither of these game fish species is presently self-sustaining in the lake but both are sought-after sport fish. Observations indicate that walleye are doing well in the lake as are striped bass except perhaps for older fish (2+ years) (see striped bass age and growth section). Since 1972 Lake Anna has been subject to numerous stockings of nine different species of fish. All of these species, except Florida largemouth bass, are now found in the lake.

Average lake mean standing crop (kg/ha) has remained constant from 1975 until 1985 when a large increase occurred:

Year	#Species	Percent Composition of major species: Bluegill	Grizzard Shad	Threadfin Shad	Common Carp	Lake Mean Standing Crop (rotenone) Kg/ha
1975	21	12	66	0	1	253.9
1976	22	22	38	0	3	295.9
1977	24	25	44	0	8	332.0
1978	25	25	43	0	12	259.2
1979	26	25	47	0	5	232.7
1980	23	26	48	0	9	321.5
1981	27	26	49	0	7	263.3
1982	27	28	34	0	14	265.1
1983	24	28	48	1	6	257.4
1984	27	29	32	6	1	298.5
1985	27	25	36	19	9	467.0

The 1985 increase in average standing crop was primarily due to extremely large threadfin shad concentrations as well as an increase in gizzard shad population in the Upper Lake.

Species / Year	Largemouth Bass	Channel Cat	Bluegill	Redear	Striped Bass	Walleye	Florida Largemouth	Blueback Herring	Threadfin Shad
1972	357,820	394,458	3,493,477	[1]795,401					
1973					95,000				
1974				201,136					
1975					96,997	58,220			
1976		194,550			293,620		18,650		
1977					[2]164,395		43,639		
1978					208,568				
1979				389,724	367,828				
1980				104,826	213,131			9,000	
1981					238,171	[3]183,663		2,600	
1982					224,787	59,667			
1983					255,613	197,250			5,000
1984					97,900	[4]320,189			
1985					178,040	128,953			

[1]Redear shipments contained unestimated percentage of Bluegill.

[2]Excludes an extimated 9,556 lost on June 29,1977 shipment.

[3]10,000 fry in poor shape also stocked in 1981.

[4]128,140 fry and 192,049 fingerling Walleye were stocked in 1984.

TABLE 4.4-2. Lake Anna Fingerling Stocking History

Throughout this study period the 11 year average standing crops of shad, carp and sunfish comprised 82% of the total standing crop ranging from 69% in 1976 and 1984 to 92% in 1985. Similar results were attained in Beaver Lake, Arkansas. During an 18 year study of this lake after impoundment it was found that shad, carp and sunfish made up 85% of the total standing crop. Biomass was higher in the Upper Lake, as in Lake Anna, which probably could be attributed to higher nutrient levels that allow more abundant food production in shallower water than in the deeper Mid and Lower Lake areas. Unlike Lake Anna, the number of fish species collected each year in Beaver Lake was found to decline (Rainwater and Houser 1982). The number of species collected in yearly rotenone surveys has not declined in Lake Anna, probably due, in part, to species introductions.

From results of a fish biomass study of 173 reservoirs (average size 15,000 acres), Jenkins (1975) created a simplified model of the fish carrying capacity of an "average" reservoir partitioned into three trophic levels. This "average" reservoir had a mean standing crop of 224 kg/ha composed of 12% predators (largemouth bass, walleye, striped bass, chain pickerel, white perch, large crappie, large yellow perch and large catfish), 38% plankton feeders (primarily threadfin shad, small gizzard shad, small black crappie, small yellow perch and sunfish) and 50% bottom feeders (adult gizzard shad, carp, small catfish and sucker). In Lake Anna, the nine year average of lake biomass (1975-1983) was 276 kg/ha and the two year mean (1984 and 1985) was 382 kg/ha (before and after threadfin shad introduction), while the 11 year mean was 295.1 kg/ha. All three values are above the "average" reservoir standing crop value. When the Lake Anna nine year average biomass is broken into its component parts, according to Jenkins' division, 13% is composed of predators, 42% plankton feeders and 46% bottom feeders. These results are similar to Jenkins' finding for an "average" reservoir. Examining the 1984-85 average standing crop, after threadfin shad introduction, the percentage of bottom feeders (rough fish) declined (33%) whereas plankton feeder and predator biomass increased (52% and 15%, respectively). The introduction of threadfin shad appears to have had the desired positive effect on the forage and predator populations in Lake Anna.

In order to facilitate comparison of Lake Anna fish biomass to that of other lakes, species were divided into categories of game fish, non-game fish and forage fish which conform to the Virginia Commission of Game and Inland Fisheries designations used in the Dingell-Johnson reports on various lakes in Virginia. The only change was the movement of bluegill and other sunfishes from game fish category to forage category because of the small sizes of these species generally collected in rotenone samples. When the percent values in these categories for Lake Anna were compared with the <u>actual</u> average values found by Jenkins (1975) in his survey of 173 reservoirs the results again were similar. The percentage of game fishes from Lake Anna is slightly lower and the percentage of forage fishes higher. This is probably due to the fact that the two largest predators in Lake Anna, striped bass and walleye, are midwater fishes rarely collected (as adults) in cove rotenone surveys on Lake Anna. In 1975 and earlier, when data on Jenkins' lakes were collected, there were few lakes containing walleye and none with striped bass included in his survey.

When the 1984-85 average total estimated Lake Anna standing crop (382.4 kg/ha) was compared to three other similar thermally enriched reservoirs (two to three years studies; Appendix B-Table 2), it was higher than any of the three, (Lake Norman, North Carolina, 126.7 kg/ha; Lake Sangchris, Illinois, 351.8 kg/ha; and Lake Julian, North Carolina, 120.9 kg/ha). The 11 year mean for Lake Anna (295.1 kg/ha) was higher than Lakes Norman and Julian but lower than Lake Sangchris.

A comparison of Lake Anna with non-thermal lakes in this area of the country (three to six year studies; Appendix B-Table 2) showed it had a higher average estimated mean total standing crop during 1984 and 1985 than did Lake Chesdin, 165.8 kg/ha; Kerr Reservoir, 219.5 kg/ha; and Claytor Lake 354.8 kg/ha. Smith Mountain Lake, 586.7 kg/ha, ranked higher than Lake Anna due to an extremely high gizzard shad standing crop (401 kg/ha) in that lake. The 11 year mean for Lake Anna (295.1 kg/ha) was higher than Lake Chesdin and Kerr Reservoir but lower than Claytor Lake and Smith Mountain Lake.

The morphoedaphic index MEI (total dissolved solids in mg/l divided by mean depth in meters) has been shown to be a valid estimator of fish standing crop in some reservoirs (Jenkins 1982). The MEI for Lake Anna predicts a standing crop of about 200 kg/ha, lower than either the nine or two year averages. Perimeter-to-area and area-to-volume ratios are important in MEI prediction. Lakes with a long shoreline (e.g. Lake Anna) should have a larger than predicted (MEI) fish standing crop due not only to higher nutrient availability but also due to the ecotone formed with a diverse physical structure which provides shelter, food and spawning amenities for many fish species. The ecotone has been enhanced by construction of artificial reefs in Lake Anna. Productivity is also improved if sunlight penetrates the water column to the substrate, which then may support a dense concentration of macrophytes, sessile algae and periphyton. These may be grazed upon by epibenthic organisms and the aufwuchs community, which, in turn, provide food for fishes (Ryder 1982).

There is another method for predicting fish standing crop that utilizes the same parameters as the MEI (dissolved solids and mean depth) but uses logs in a different formula (Jenkins 1968).

$$\log(\text{standing crop}) = 2.005 + 0.655 \log\left(\frac{\text{dissolved solids}}{\text{mean depth}}\right) - 0.230\left[\log\left(\frac{\text{dissolved solids}}{\text{mean depth}}\right)\right]^2$$

This formula predicts a standing crop for Lake Anna of 269.4 kg/ha, very close to the nine year average of 276 kg/ha before threadfin shad introduction, but still well below the 1984-85 average.

Lake Anna appears to have a standing crop (kg/ha) comparable with other lakes in this area of the country. It has a fish community composition and trends similar to other lakes and a good community structure balance between predators, plankton feeders and bottom feeders. Changes within species populations have occurred since the lake was formed, but the basic integrity of the fish community has been maintained. Generally biomass levels have stayed the same except for threadfin shad increases during 1984 and 1985. The number of species has increased, primarily due to introductions.

Ichthyoplankton

Ichthyoplankton samples have been collected in Lake Anna since 1979 using methods described in Appendix D. The study objectives were to document spawning and to attempt to determine the spatial and temporal distribution of larvae. The successful use of ichthyoplankton for the prediction of year class strength has been described as "difficult, if not untenable" due to the intricacies of variables which affect larval survival and collection (Smith 1981; Snyder 1983). Therefore, analyses of ichthyoplankton sampling in Lake Anna beyond the study objectives, while attempted, were inconsistent and deemed unreliable.

The larvae of the lake's five numerically dominant fish species, sunfish (as a group), shad (gizzard and threadfin), yellow perch, white perch, and black crappie were consistently collected during each of the seven years of surveys (unpublished Vepco data, Vepco 1982, Vepco 1983, Vepco 1984, Appendix B-Tables 1-2). In addition, largemouth bass appeared in two collections, while chain pickerel and carp were represented by single captures. Although several other species of fish reproduce in Lake Anna, their spawning and/or larval habits caused them not to be collected by the sampling methods employed.

Spawning parameters were determined by the presence of larvae in collections. Spawning occurred at the appropriate time of year for each of the species collected. For sunfish, shad, yellow perch and white perch, the difference between the first and last collecting station in the lake to initiate spawning was no more than two weeks. When compared across the years, spawning was initiated within three weeks of the earliest date for each of these four species. These slight temporal differences are within the range of natural variation which suggests that elevated water temperature form the power station discharge did not substantially change the time of spawning for these four species in Lake Anna. The initiation of black crappie spawning varied throughout the lake as much as four weeks within each year and within two weeks of the earliest date across years. However, larval collections of black crappie varied greatly and were generally low, making the validity of conclusions drawn from these data questionable.

Larvae of sunfish, shad and yellow perch were collected at all stations for all years sampled. White perch were absent from collections at four stations during 1985 (Lower Lake, Mid Lake, and two arm stations) as were black crappie. In addition, black crappie were absent from the Pamunkey Arm station in 1982 and 1983. Due to the highly variable nature of ichthyoplankton sampling, the presence of young-of-the-year in rotenone sampling may be a better determinant of spatial distribution.

Largemouth Bass Life History Studies

Reproduction

Largemouth bass were stocked in Lake Anna in 1972 and spawned successfully in subsequent years, precluding the necessity of additional stocking. In an effort to characterize the reproductive development of this species in the lake, gonadosomatic index (GSI), fecundity, and average egg size were studied, in some combination, from 1976 through 1984 (Reed 1977, Reed 1978, Reed 1979, Reed 1980, Reed 1981, Vepco 1982, Vepco 1983, Appendix B-Table 1). Values of each of the three parameters studied were similar across years and compared favorably with literature values (Bagenal and Braum 1971, Kelley 1962, Timmons et al. 1980, Bennett and Gibbons 1975). Spawning is preceded by peaks in fecundity and GSI values, which consistently occurred in Lake Anna from mid to late April. Lippson and Moran (1974) reported a largemouth bass spawning temperature range of 15.5°C to 25°C with an optimum range of 16°C to 18°C in the Potomac River. Kramer and Smith (1960) reported the first spawning of largemouth bass in Minnesota occurred two to five days after water temperatures reached 15.2°C. These temperatures were recorded in Lake Anna by early May and coincide with the apparent initiation of spawning.

Food Studies

Stomach contents of largemouth bass were analyzed to determine feeding success (measured by the presence of food in the stomach), and to determine prey selection preferences. Data on adult bass food habits were collected for the years 1977 through 1982 and 1984. Juvenile food habits were studied in 1982 and 1984; and larval food studies were conducted in 1982 (Reed 1978, Reed 1979, Reed 1980, Reed 1981, Vepco 1982, Vepco 1983, Appendix B-Table 2). It was decided the data base was sufficient and largemouth bass food studies could be discontinued in 1985.

In general, the food habits exhibited by largemouth bass in Lake Anna compare favorably with the findings of similar studies which characterize largemouth bass as being highly opportunistic feeders (Eddy and Underhill 1974, Manooch 1984). The highest percentage of fish with empty stomachs for a given year in Lake Anna was 49% in 1982. Comparable studies of other systems that contain healthy bass populations report values of 50% and 56% of fish with empty stomachs (Lewis 1971, Zweiacker and Summerfelt 1974). Because the diet of bass changes as they grow, specimens were classified by length, for the purpose of analysis, into four general groups: larvae, small juveniles, large juveniles-small adults, and adults.

Larval bass food habits studied in 1982 indicated they fed exclusively on zooplankton as has been reported in other systems (Kramer and Smith 1962, Sule 1981). The cladoceran Bosmina longirostris was the dominant food item and has been described as a readily available and suitable food source for larval bass (Zaret and Kerfoot 1975).

Small juvenile bass in Lake Anna also were found to feed principally on zooplankton selecting the larger cladocerans and copepods Daphnia sp. and Cyclops sp., respectively. In addition to zooplankton, dipterans were observed in a small percentage of the stomach samples.

Larger juvenile and small adult bass showed greater diversity in prey selection as they consumed a variety of organisms. Fish was the dominant food item of this group in both 1982 and 1984, appearing in 66% and 72% of the full stomachs, respectively. Bluegill was the only prey species identified; however, more than 70% of the fish remains were unidentifiable in both years of the study. Given the large percentages of unidentifiable fish, species preference could not be determined with certainty. Aquatic insects, followed by crustaceans and aerial insects, made up the majority of the remaining food items.

Adult bass were almost entirely piscivorous. Prey species in 1984 included bluegill, gizzard shad, threadfin shad, yellow perch, white perch and golden shiner. In past years black crappie and catfish also were observed as food items. Studies conducted from 1977 through 1981 indicated gizzard shad was the dominant prey species for adult bass. In 1982 and 1984, bluegill appeared to be the dominant prey species; however, during these two years, the percentage of unidentified fish remains was high at 50% and 57% (compared to 27% in 1981 and below 9% prior to 1981); therefore, it was not possible to identify dominant prey species.

In summary, the largemouth bass population in Lake Anna has experienced feeding success that is similar to other populations. The organisms that comprise the diet of all size groups of bass are abundant in the lake. Should the abundance of a particular food item change, the opportunistic feeding behavior which characterizes largemouth bass would allow the bass to exploit other prey species to accommodate their dietary needs. An example of this situation may have occurred with small gizzard shad becoming less abundant and being replaced in bass diets by bluegill; however, insufficient data preclude a final assessment of the situation.

Age and Growth

Age and growth data were examined for largemouth bass collected in Lake Anna from 1978 to 1985. The study included 600 largemouth, of which 359 were collected from the Mid-Lake area, 164 from the Upper Lake and 58 from the Lower Lake. The remaining 39 largemouth were captured by anglers during tournaments from unknown capture locations. Data back-calculated to the 1971 and 1972 year classes were not included in analyses as some of the fish were subjected to growth conditions outside the lake environment.

Growth rates have been determined for Lake Anna fish by back-calculating the body length of each individual fish at the time of scale annulus formation (Table 4.4-3) using the formula presented in the striped bass studies section of this report with a standard intercept of 20 mm. A second method, suggested by TAC, was utilized that only used data derived from the age of fish at time of capture (Table 4.4-4). The results of the two methods were compared

Table 4.4-3 Age and Growth Data of Largemouth Bass in Lake Anna, Virginia Based on Back-Calculated Data

Year Class		Age 1	2	3	4	5 (Pre-Op Growth)	6 (Op Growth)	7	8	9	10	11
1973	Mean Length	134	232	310	370	423	455	513	499	518	527	536
	(N)	(19)	(19)	(19)	(19)	(19)	(15)	(2)	(1)	(1)	(1)	(1)
	(Range)	(75-216)	(113-334)	(206-387)	(261-454)	(341-471)	(393-504)	(481-545)	(--)	(--)	(--)	(--)
	Annual Increment	134	98	78	60	53	32	58	-14	19	9	9
1974	Mean Length	137	236	319	390	434	486	507	530	544	555	556
	(N)	(33)	(33)	(33)	(33)	(30)	(9)	(7)	(6)	(3)	(3)	(2)
	(Range)	(81-223)	(150-349)	(228-425)	(318-487)	(360-522)	(425-551)	(451-551)	(515-560)	(529-569)	(543-578)	(553-558)
	Annual Increment	137	99	83	71	44	52	21	23	14	11	1
1975	Mean Length	126	228	315	378	464	469	490	525	540		
	(N)	(34)	(34)	(34)	(31)	(13)	(3)	(2)	(1)	(1)		
	(Range)	(76-243)	(144-299)	(229-410)	(310-465)	(397-533)	(442-497)	(464-515)	(--)	(--)		
	Annual Increment	126	102	87	63	86	5	21	35	15		
1976	Mean Length	125	235	316	421	451	471	492	510	492		
	(N)	(69)	(69)	(66)	(25)	(18)	(12)	(4)	(4)	(1)		
	(Range)	(67-240)	(124-391)	(205-439)	(330-515)	(398-543)	(435-520)	(458-536)	(477-555)	(--)		
	Annual Increment	125	110	81	105	30	20	21	18	-18		
1977	Mean Length	124	249	333	403	435	457	486	499	Pre-op Year Classes		
	(N)	(109)	(103)	(71)	(31)	(14)	(8)	(7)	(2)			
	(Range)	(61-229)	(152-388)	(231-447)	(291-485)	(336-506)	(377-523)	(417-536)	(449-550)			
	Annual Increment	124	125	84	70	32	22	29	13			
1978	Mean Length	125	244	335	409	361	412			Op Year Classes		
	(N)	(111)	(78)	(43)	(17)	(1)	(1)					
	(Range)	(56-233)	(157-388)	(245-433)	(305-490)	(--)	(--)					
	Annual Increment	125	119	91	74	-48	51					
1979	Mean Length	123	228	309	365	425	450					
	(N)	(42)	(38)	(35)	(14)	(11)	(2)					
	(Range)	(49-253)	(116-326)	(212-423)	(268-432)	(347-483)	(425-475)					
	Annual Increment	123	105	81	56	60	25					
1980	Mean Length	138	246	321	388	400						
	(N)	(44)	(36)	(20)	(20)	(7)						
	(Range)	(66-217)	(164-350)	(232-409)	(298-496)	(317-468)						
	Annual Increment	138	108	75	63	16						
1981	Mean Length	133	215	286	334							
	(N)	(40)	(31)	(30)	(15)							
	(Range)	(59-227)	(121-380)	(167-390)	(227-408)							
	Annual Increment	133	82	71	48							
1982	Mean Length	122	218	251								
	(N)	(48)	(47)	(21)								
	(Range)	(62-203)	(140-303)	(199-308)								
	Annual Increment	122	96	33								
1983	Mean Length	152	217									
	(N)	(47)	(12)									
	(Range)	(69-230)	(185-270)									
	Annual Increment	152	65									
1984	Mean Length	115										
	(N)	(2)										
	(Range)	(69-160)										
	Annual Increment	115										
Lake Anna Mean												
	Mean Length	129	236	315	388	435	465	497	517	530	548	549
	(N)	(598)	(500)	(372)	(205)	(113)	(50)	(22)	(14)	(6)	(4)	(3)
	(Range)	(49-253)	(113-391)	(167-447)	(267-515)	(317-543)	(377-551)	(417-551)	(449-560)	(492-569)	(527-578)	(536-558)
	Annual Increment	129	107	79	73	47	30	32	20	13	18	1
Va. State Average (for Reservoirs)												
	Mean Length	124	246	328	378	434	462	508	564	559		
	Annual Increment	124	122	82	50	56	28	46	56	-5		
Mean Growth Before and During Station Operation												
Pre-operation	Mean Length	127	234	315	383	423						
	(N)	(264)	(155)	(86)	(52)	(19)						
	(Range)	(61-243)	(113-391)	(206-425)	(261-487)	(341-471)						
	Annual Increment	127	107	81	68	40						
Operational	Mean Length	131	231	305	375	413	437					
	(N)	(334)	(242)	(149)	(66)	(19)	(3)					
	(Range)	(49-253)	(116-388)	(167-433)	(227-496)	(317-483)	(413-475)					
	Annual Increment	131	100	74	80	38	24					

Table 4.4-4 Age and Growth Data of Largemouth Bass in Lake Anna, Virginia
Based on Age at Capture

Year Class		1	2	3	4	5	6	7	8	9	10	11
				Age	Pre-Op Growth		Op Growth					
1973	Mean Length					435	451	545				536
	(N)					(4)	(13)	(1)				(1)
	(Range)					(414-456)	(393-504)	(--)				(--)
	Annual Increment					—	16	94				—
1974	Mean Length				383	427	495	451	525		578	556
	(N)				(3)	(21)	(2)	(1)	(3)		(1)	(2)
	(Range)				(355-423)	(360-481)	(439-551)	(--)	(515-536)		(--)	(555-558)
	Annual Increment				—	44	68	-44	74		—	-22
1975	Mean Length			274	356	470	497	464		540		
	(N)			(3)	(18)	(10)	(1)	(1)		(1)		
	(Range)			(258-305)	(310-411)	(429-533)	(--)	(--)		(--)		
	Annual Increment			—	82	114	25	-33		—		
1976	Mean Length,		226	298	435	463	474		521	492		
	(N)		(3)	(42)	(7)	(6)	(8)		(3)	(1)		
	(Range)		(198-260)	(205-384)	(400-491)	(402-543)	(435-520)		(491-555)	(--)		
	Annual Increment		—	72	137	28	11		—	-29		
1977	Mean Length	132	249	322	411	440	419	488	500			
	(N)	(6)	(32)	(40)	(17)	(6)	(1)	(5)	(2)			
	(Range)	(110-163)	(181-316)	(231-419)	(379-467)	(379-491)	(--)	(417-536)	(449-550)	Pre-op		
	Annual Increment	132	117	73	89	29	-21	69	12	Year Classes		
1978	Mean Length	129	241	330	414		413			Op Year		
	(N)	(33)	(35)	(26)	(16)		(1)			Classes		
	(Range)	(70-201)	(165-388)	(264-388)	(305-490)		(--)					
	Annual Increment	129	112	89	84		—					
1979	Mean Length	196	286	325	330	427	450					
	(N)	(4)	(3)	(21)	(3)	(9)	(2)					
	(Range)	(146-253)	(238-324)	(233-423)	(268-387)	(347-483)	(425-475)					
	Annual Increment	196	90	39	5	97	23					
1980	Mean Length	187	265		388	400						
	(N)	(9)	(16)		(14)	(7)						
	(Range)	(140-255)	(219-343)		(287-496)	(317-468)						
	Annual Increment	187	78		—	12						
1981	Mean Length	180	206	286	334							
	(N)	(9)	(1)	(15)	(15)							
	(Range)	(135-227)	(--)	(167-390)	(227-408)							
	Annual Increment	180	26	80	48							
1982	Mean Length	84	234	250								
	(N)	(1)	(26)	(21)								
	(Range)	(--)	(177-303)	(199-308)								
	Annual Increment	84	150	16								
1983	Mean Length	157	217									
	(N)	(35)	(12)									
	(Range)	(69-229)	(185-270)									
	Annual Increment	157	60									
1984	Mean Length	115										
	(N)	(2)										
	(Range)	(69-160)										
	Annual Increment	115										
				Lake Anna Mean								
	Mean Length	150	243	304	384	436	460	488	517	516	578	549
	(N)	(99)	(128)	(167)	(92)	(63)	(28)	(8)	(8)	(2)	(1)	(3)
	(Range)	(69-253)	(165-388)	(167-423)	(227-496)	(317-543)	(393-551)	(417-545)	(449-555)	(492-540)	(--)	(536-558)
	Annual Increment	150	93	61	80	52	24	28	29	-1	62	-29
				Va. State Average (for Reservoirs)								
	Mean Length	124	246	328	378	434	462	508	564	559		
	Annual Increment	124	122	82	50	56	28	46	56	-5		
				Mean Growth Before and During Station Operation								
	Pre-operation (Mean Length)	132	226	274	383	435						
	(N)	(6)	(3)	(3)	(3)	(4)						
	(Range)	(110-163)	(198-260)	(258-305)	(355-423)	(414-456)						
	Annual Increment	132	94	48	109	52						
	Operational (Mean Length)	151	241	301	378	415	438					
	(N)	(92)	(93)	(83)	(47)	(16)	(3)					
	(Range)	(69-255)	(167-388)	(167-423)	(227-496)	(317-483)	(413-475)					
	Annual Increment	151	90	60	77	37	23					

and found to be in agreement, but because the back-calculated method makes possible analysis of growth in years prior to the year that fish were collected, all further analyses are based on back-calculated growth data.

Overall, the growth of largemouth bass in Lake Anna compares favorably with the Virginia state average growth rate for bass in reservoirs and also with two other out of state cooling impoundments, Lake Sangchris, Illinois and Keowee Reservoir, South Carolina (Table 4.4-5). Growth of largemouth between different areas in Lake Anna, the Upper Lake versus the Mid and Lower Lake, was comparable.

Growth of largemouth bass during station operational years was compared to the growth of largemouth prior to station operation. Pre-operational growth of fish was defined as all growth that occurred prior to 1978, whereas operational growth was defined as growth of fish from the 1978 year class and later (see divisions of Table 4.4-3). Growth data from fish subjected to a combination of the two conditions were excluded from the comparison. Growth of largemouth in the reservoir was similar between pre-operational and operational years (Fig. 4.4-9). Analysis of incremental growth, however, suggests a slight overall reduction in growth of two, three and four year old largemouth beginning in the years 1978, 1980, and 1979 respectively, and a reduction in growth of all ages for which data were available during 1984 (Fig. 4.4-10). The trend was lake wide and began earlier in the Upper Lake. The decrease did not appear in pre-operation versus

Table 4.4-5 Comparison of Largemouth Bass Growth From Three Cooling Impoundments and The Virginia State Average Growth for Reservoirs (in mm)

	AGE										
	1	2	3	4	5	6	7	8	9	10	11
Lake Anna, Virginia	129	236	315	388	435	465	497	515	530	548	549
Virginia State Average[1] For Reservoirs	124	246	328	378	434	462	508	564	559		
Lake Sangchris, Ill.[2]	100	260	325	378	415	441					
Keowee Reservoir, SC[3]	138	280	351	394							

---

1 Smith and Kauffman 1982

2 Larimore, et al. 1979

3 Barwick and Lorenzer 1984

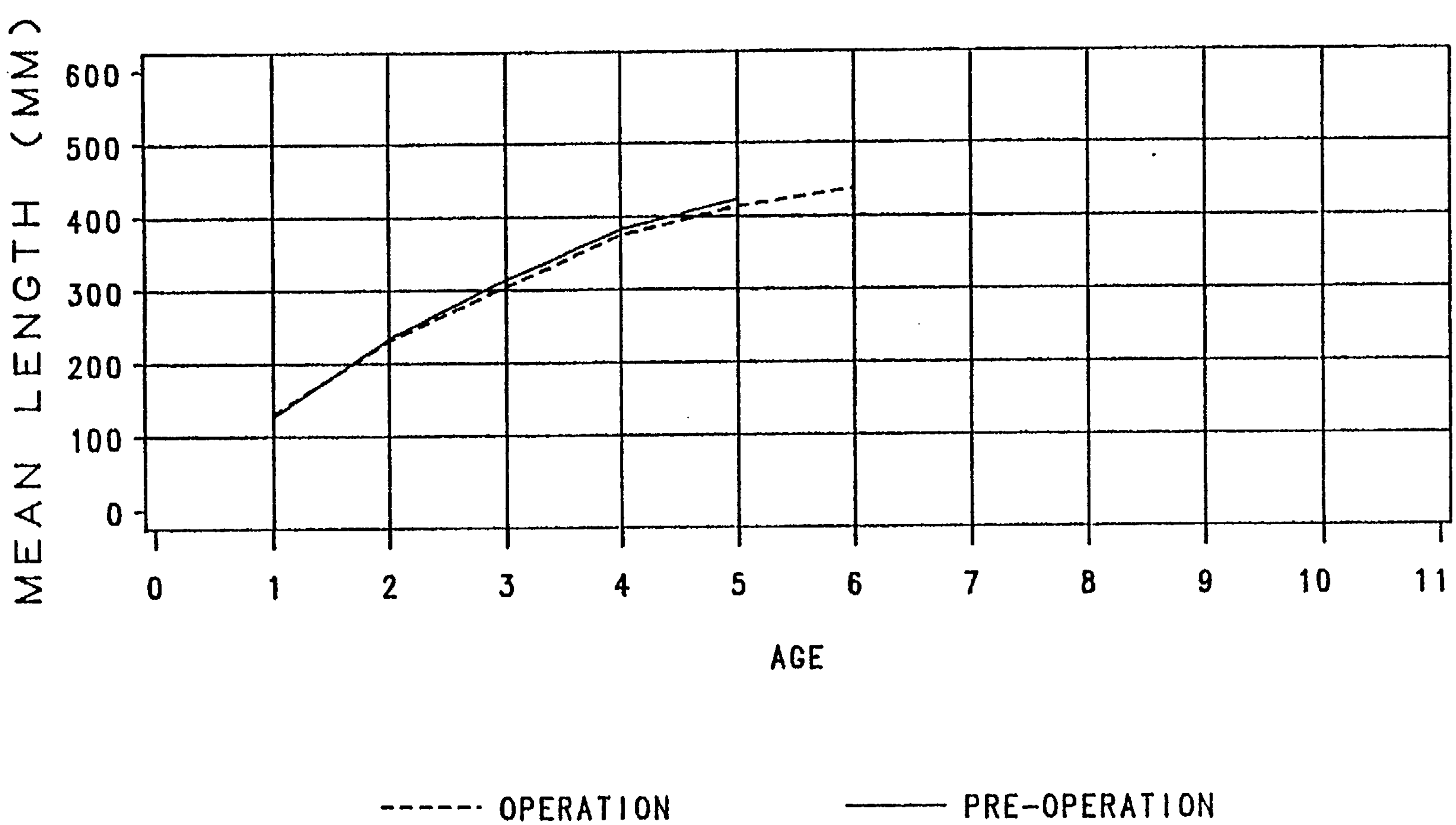


Figure 4.4-9. Comparison of growth of largemouth bass before and during station operation in Lake Anna, Virginia (collected from 1978 - 1985.)

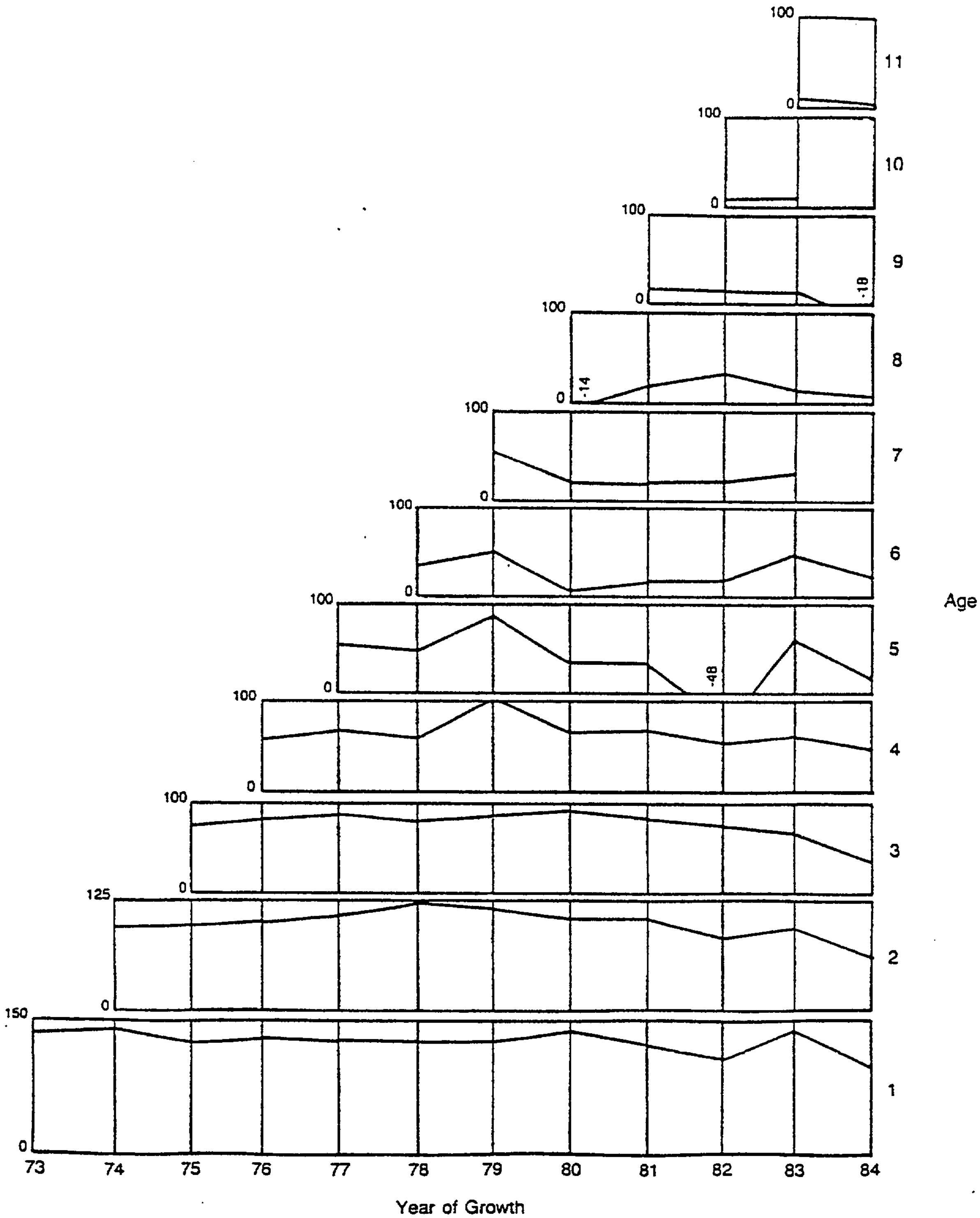


Figure 4.4-10 Incremental growth values for largemouth bass at each age plotted over time. (Increment scale in mm)

operational comparisons because it was offset by above average growth during 1978 and 1979. Factors influencing growth of largemouth bass include the amount of food available, temperature of the water, reservoir aging and number of bass present (Carlander 1972; Mirander and Durocher 1986).

Food studies conducted in Lake Anna suggest that largemouth experienced feeding success comparable to those reported in the literature (see largemouth bass food study section). In addition, the forage base (bluegill up to 102 mm and shad up to 127 mm) has remained abundant, if not slightly increased, over the past several years with a substantial increase in 1984, the year growth of all ages of largemouth decreased. Therefore, it is not likely that lack of food caused the apparent growth reduction of largemouth in Lake Anna.

Temperature has a positive effect on growth of largemouth bass as is evidenced by the greater growth of largemouth in southern waters when compared to northern waters. Stuber et al. (1982) said a temperature range of 24 to 30°C is optimal for growth of largemouth bass, Carlander (1977) reported the fastest growth of bass occurs in waters 26 to 28°C, and Coutant (1975) indicated an optimum temperature of 27°C for largemouth bass. Surface water temperatures in Lake Anna seldom exceed Stuber's 30°C parameter for optimal growth and the amount of water in the 26-28°C range with ample dissolved oxygen (≥ 5 ppm) for growth of largemouth has generally increased during August in operational years. Largemouth bass in the WHTF, which were subjected to higher temperatures than those in Lake Anna, exhibit similar growth (see Fig. 7.2-12). Elevated water temperatures due to a nuclear power station or Keowee Reservoir, South Carolina apparently had no measurable effect on the growth rate of largemouth bass (Barwick and Lorenzen 1984). Based on the above information, the growth reduction of largemouth bass in Lake Anna was probably not due to excessive temperature.

Growth data from Lake Anna indicated a distinct inverse relationship between total bass density and growth which was probably a primary factor in the slight decrease in the growth of largemouth bass over the past few years. Carlander (1977) and Latta (1977) described a similar inverse relationship of these variables in several systems. Annual mean growth increments were calculated for each of the years 1978 through 1984 by averaging growth increments of bass ages one through six. Older bass were not included in the analysis due to small sample sizes. Year to year changes in these values were compared to year to year changes in total largemouth bass densities based on rotenone data (Fig. 4.4-11). The direction of change in annual mean growth increments between each successive pair of years was inversely related to the direction of change in bass density. This inverse relationship was statistically significant ($p = .016$) based on a randomization test. This suggests a slight overall increase in density from 1979 to 1984 may be responsible for the slight overall decrease in

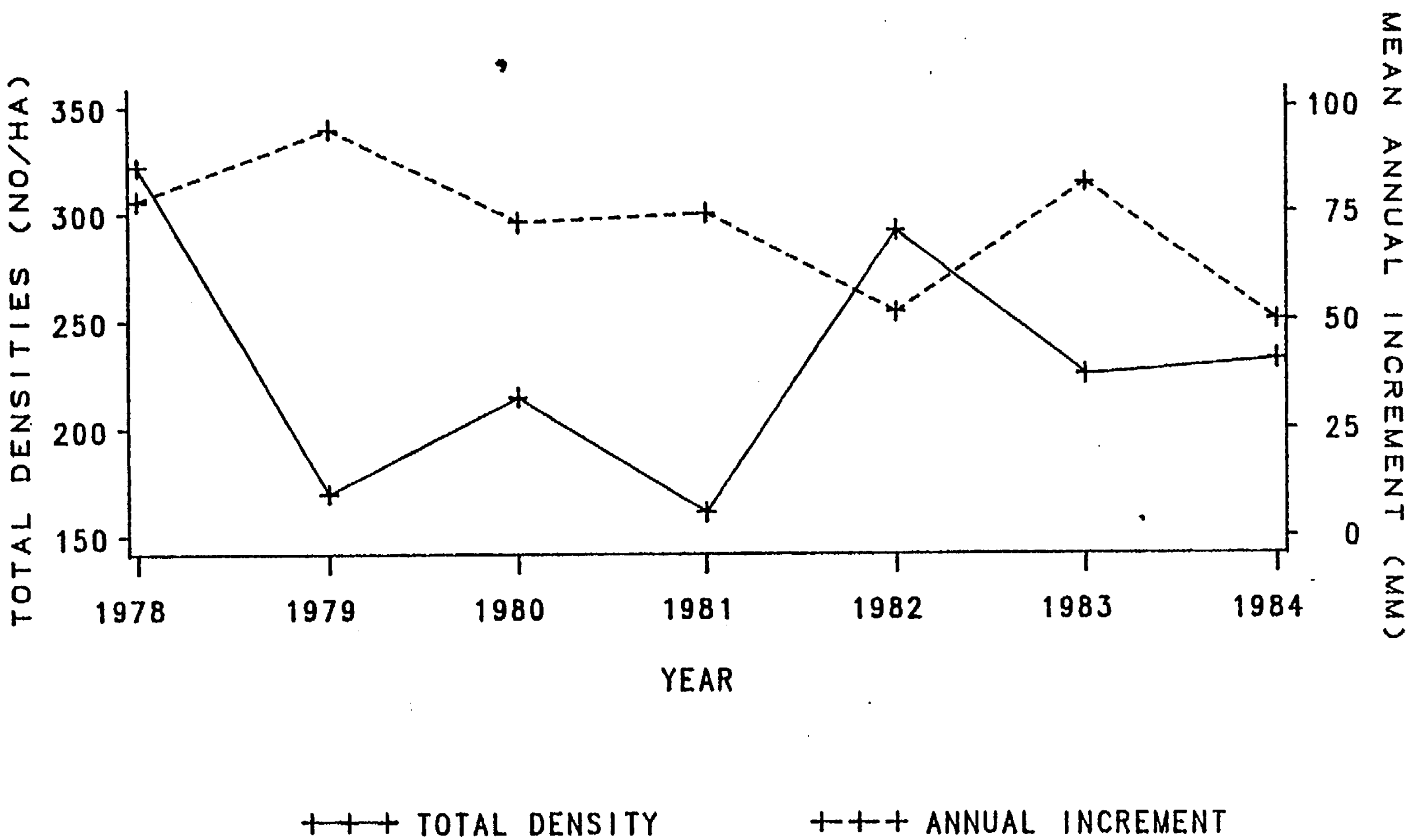


Figure 4.4-11. Comparison between total density and mean annual growth increments of largemouth bass in Lake Anna, Virginia.

growth of two, three and four year old largemouth during the same period.

Growth of largemouth bass has also been shown to be negatively correlated with reservoir age (Mirander and Durocher 1986). Largemouth tend to grow rapidly during the first few years following reservoir formation and grow more slowly as reservoirs age.

Condition factors (K) were calculated to determine the relative health of the largemouth. Bennet (1970) said that K values between 1.27-1.52 are considered normal. Carlander (1977) reported K factors increased with age with one year old fish below the range indicated by Bennet. In Lake Anna, mean K factors of two and three year old largemouth were within the range indicated by Bennet and older fish exceeded the range with K values of 1.6 to 2.2. This would suggest the largemouth in Lake Anna are of average to above average condition. Carlander (1977) also said K factors were positively related to fish length and age. This situation was observed in Lake Anna. No general trend in K factors over time was apparent.

In summary, largemouth bass in Lake Anna have exhibited growth comparable to that of the Virginia state average and to largemouth bass populations in similar impoundments. Over the past several years, there appears to be a slight decrease in the growth of two, three, and four year old bass as evidenced by incremental growth values. Four variables were considered as possible causes for the reduced growth; food availability, water temperature, population density, and reservoir aging. Of these four variables, population density and reservoir aging appear to be the two most likely to have been involved in the growth reduction of largemouth bass in Lake Anna.

Black Crappie Life History Studies

Food Study

Feeding habits of black crappie vary from population to population and by the size of the fish (Keast 1968). In general, as crappie grow they undergo a dietary progression from zooplankton to aquatic insects to fish. This dietary shift can be advanced or retarded by environmental factors (e.g. food availability, habitat suitability and overcrowding). As a result, any factors that affect the dietary shift could affect the overall growth rate of a population (Goodson 1966). The present study was undertaken in an attempt to characterize the food habits of black crappie in Lake Anna.

The stomach contents of 127 black crappie ranging in size from 150 mm to 290 mm T.L., (the vast majority of which were in the lower half of this range) were examined (Appendix B-Table 1). These fish were separated into four groups based on diet: insects combined with zooplankton, insects, insects combined with fish, and fish. The percentages of crappie in each category were 15%, 50%, 12% and 13%, respectively, with 11% of the stomachs empty. The mean lengths of fish in these groups were 165 mm, 182.5 mm, 196.2 mm and 209.3 mm, respectively.

Insects were present in 87% of the stomach samples. The most frequently encountered food items were ephemeropterans (mayflies) and chironomids (midges) occurring in 55% and 81%, respectively, of the stomachs containing food. Although chironomids were found most frequently, because of their small size, they often were less than 5% of the total food volume. On the other hand, ephemeropterans, almost exclusively Hexagenia sp., usually comprised over 90% of the food volume when present in samples. Chaoborans and ceratopogonids (two additional midges) also were frequent food items, but being small dipterans like chironomids, comprised a low percentage of total food volume.

When fish were present in stomach samples, they comprised the largest portion of the food volume. Threadfin shad were the principal forage species occurring in 53% of the samples containing fish; bluegill were present in 37% of the samples. Following their introduction in other systems, threadfin shad became an important component of the diet of crappie (Hepworth and Pettengill 1979; Beers and McConnell 1966).

The diet of crappie in Lake Anna was similar in composition to the diet of crappie in other systems (Keast 1968; Schneberger 1977). In comparing the diet of crappie from the Mid- and Upper Lake to the diet of crappie from the Lower Lake, there appeared to be some differences. The percentages of crappie feeding on insects and insects combined with fish were similar between the two areas. However, a smaller percentage of crappie in the Upper and Mid-Lake fed on fish and a greater percentage fed on insects in combination with zooplankton compared to the Lower Lake. These dietary differences may be due to the greater proportion of small crappie collected from the Upper and Mid- Lake, or may be due to differences in food availability (i.e. insects and/or forage fish) between the various areas of the lake which would in turn determine the size of fish (Edwards et al 1982).

Age and Growth

Black crappie were collected for age and growth studies in Lake Anna from 1982-1985. The majority of samples were taken in 1984 in conjunction with a Master of Science thesis study being conducted by a graduate student of the University of Richmond. Growth determination methods described in the striped bass in section of the present report were also employed for black crappie using a standard intercept of 35 mm.

Back-calculated growth values generally agreed with age-at-capture growth values (Fig. 4.4-12), but in some analyses, age-at-capture better described particular aspects of growth. Back-calculated values were used to describe overall growth curves, but both methods were used to describe details of growth (Table 4.4-6; Table 4.4-7).

Growth curves of crappie in Lake Anna suggest the population has experienced slow growth for all ages over one year when compared to the Virginia state average for reservoirs, and impoundments in other states (Table 4.4-8). This stunting phenomenon was best illustrated by the

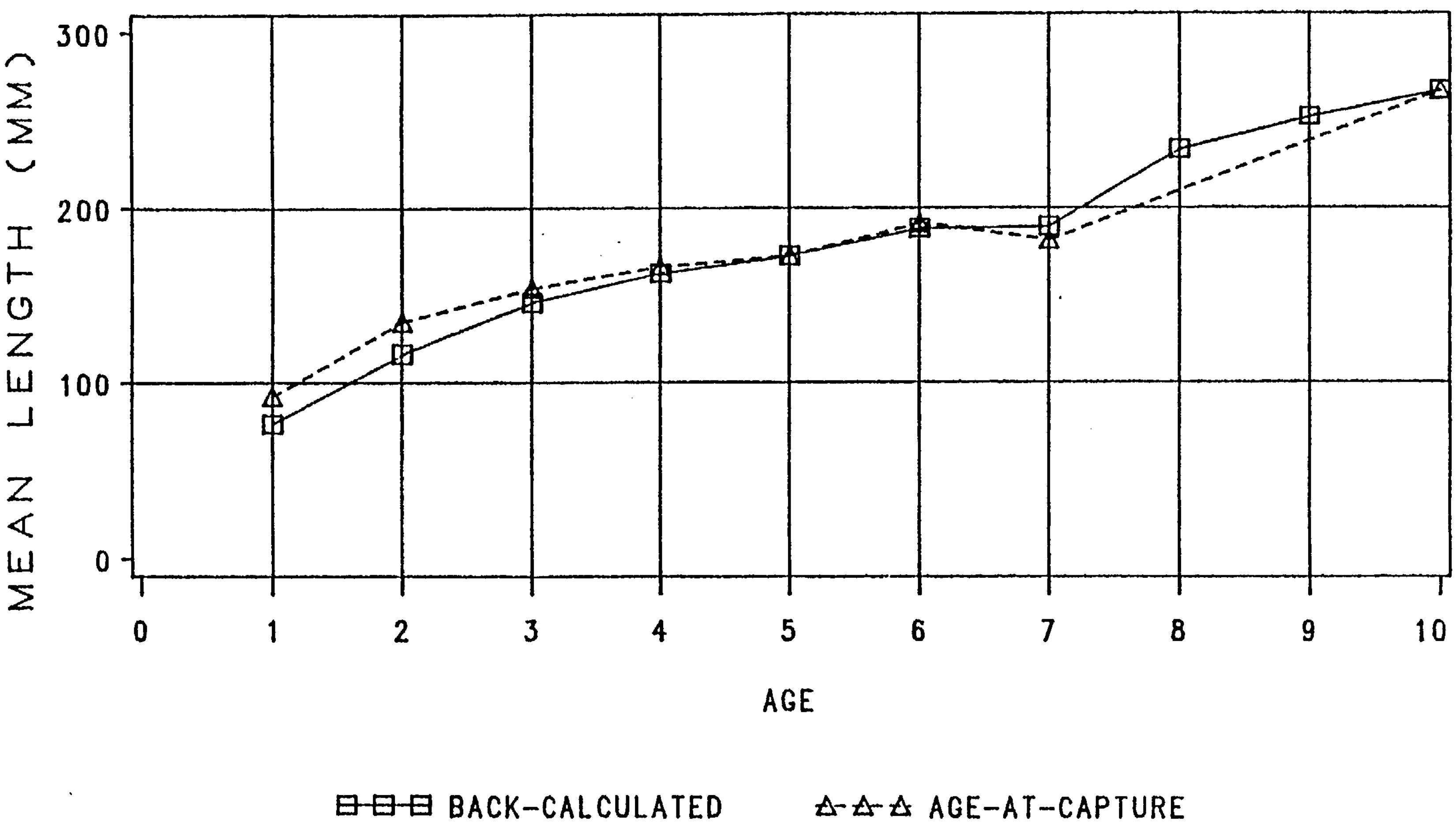


Figure 4.4-12. Comparison of back-calculated and age-at-capture growth curves for black crappie collected from 1982 to 1985 in the reservoir, Lake Anna, Virginia.

Table 4.4-6 Age and Growth Data of Black Crappie in Lake Anna, Virginia
Based on Back-calculated data.

Year Class		Age 1	2	3	4	Pre-Op Growth 5	Op Growth 6	7	8	9	10	
1974	Mean Length	71	95	134	160	177	192	221	233	252	267	
	(N)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	
	(Range)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)			
	Annual Increment	71	24	39	26	17	15	29	12	19	15	
1975	Mean Length	58	75	98	126	141	160	184				
	(N)	(1)	(1)	(1)	(1)	(1)	(1)	(1)				
	(Range)	(-)	(-)	(-)	(-)	(-)	(-)	(-)				
	Annual Increment	58	17	23	28	15	19	24				
1976	Mean Length	65	87	116	139	163	177	181				
	(N)	(6)	(6)	(6)	(6)	(6)	(6)	(2)				
	(Range)	(57- 83)	(65-125)	(100-152)	(124-166)	(148-181)	(163-193)	(175-186)				
	Annual Increment	65	22	29	23	24	14	4				
1977	Mean Length	70	104	131	153	180	194	179				Pre-Op Year Classes
	(N)	(8)	(8)	(8)	(8)	(8)	(8)	(1)				
	(Range)	(63- 78)	(83-126)	(105-163)	(127-191)	(148-219)	(166-230)	-				
	Annual Increment	70	34	27	22	27	14	-15				
1978	Mean Length	71	107	139	161	173	178					Op Year Classes
	(N)	(45)	(45)	(45)	(45)	(39)	(17)					
	(Range)	(57- 88)	(82-139)	(103-176)	(128-204)	(140-226)	(136-239)					
	Annual Increment	71	36	32	22	12	5					
1979	Mean Length	73	114	143	160	171	232					
	(N)	(109)	(109)	(109)	(106)	(92)	(5)					
	Range	(55- 94)	(87-166)	(107-205)	(123-247)	(136-251	(179-290)					
	Annual Increment	73	41	29	17	11	61					
1980	Mean Length	77	118	147	165	179						
	(N)	(158)	(158)	(157)	(157)	(13)						
	(Range)	(89-184)	(184)	(120-180)	(130-214)	(159-217)						
	Annual Increment	77	41	29	48	14						
1981	Mean Length	82	124	152	167							
	(N)	(56)	(56)	(56)	(10)							
	(Range)	(89-184)	(99-163)	(125-192)	(138-194)							
	Annual Increment	82	42	28	15							
1982	Mean Length	88	130	148								
	(N)	(13)	(13)	(1)								
	(Range)	(64-108)	(103-168)	(1)								
	Annual Increment	88	42	18								
1983	Mean Length	92										
	(N)	(16)										
	(Range)	(65-141)										
	Annual Increment	92										

Lake Anna Mean

	1	2	3	4	5	6	7	8	9	10
Mean Length	76	116	145	162	172	188	189	233	252	267
(N)	(413)	(397)	(385)	(334)	(160)	(38)	(5)	(1)	(1)	(1)
(Range)	(55-170)	(45-184)	(79-205)	(84-247)	(136-251)	(156-290)	(175-221	(-)	(-)	(-)
Annual Increment	77	40	29	17	10	16	1	44	19	15

Va. State Average (for Reservoirs)

	1	2	3	4	5	6	7
Mean Length	86	155	218	249	292	310	345
Annual Increment	86	69	63	31	43	18	35

Mean Growth Before and During Station Operation

	1	2	3	4	5	6
Pre-operation	68	87	116	160		
	(16)	(8)	(2)	(1)		
	(57- 83)	(65-125)	(98-134)	(-)		
	68	19	29	44		
Operation	77	117	146	163	172	190
	(397)	(381)	(368)	(318)	(144)	(22)
	(55-141)	(82-184)	(103-205)	(123-247)	(136-251)	(156-290)
	77	40	29	17	9	18

Table 4.4-7 Age and Growth Data of Black Crappie in Lake Anna, Virginia Based on age-at-capture.

Year Class		Age 1	2	3	4 (Pre-Op Growth)	5 (Op Growth)	6	7	8	9	10
1974	Mean Length (N) (Range) Annual Increment										267 (-) -
1975	Mean Length (N) (Range) Annual Increment							183 (1) (-) -			
1976	Mean Length (N) (Range) Annual Increment						179 (4) (162-193) -	181 (2) (175-186) 2			
1977	Mean Length (N) (Range) Annual Increment						198 (6) (171-230) -	179 (1) (-) -19		Pre Op Year Classes	
1978	Mean Length (N) (Range) Annual Increment				171 (6) (159-196) -	180 (22) (158-226) 9	178 (17) (156-239) -2			Op Year Classes	
1979	Mean Length (N) Range Annual Increment			152 (3) (147-158) -	179 (14) (152-247) 27	170 (87) (136-222) -9	232 (5) (179-290) 62				
1980	Mean Length (N) (Range) Annual Increment		184 (1) (-) -		164 (145) (123-213) -	179 (13) (159-217) 15					
1981	Mean Length (N) (Range) Annual Increment			154 (46) (131-192) -	167 (10) (138-194) 13						
1982	Mean Length (N) (Range) Annual Increment		130 (12) (103-148) -	148 (1) (-) 18							
1983	Mean Length (N) (Range) Annual Increment	92 (16) (65-141) 92									
Lake Anna Mean											
	Mean Length (N) (Range) Annual Increment	92 (16) (65-141) 92	134 (13) (103-184)	153 (50) (131-192)	166 (175) (123-247)	172 (122) (136-226)	191 (33) (156-290)	181 (4) (175-186)			267 (1) (-)
Va. State Average (for Reservoirs)											
	Mean Length	86	155	218	249	292	310				
	Annual Increment	86	69	63	31	43	18				
Mean Growth Before and During Station Operation											
	Pre-operation	-	-	-	-	-	-	-	-		
	Operational	92 (16) (65-141) 92	134 (13) (103-184) 42	153 (50) (131-192) 19	166 (175) (123-247) 13	172 (122) (136-226) 6					

Table 4.4-8 Mean Back-calculated Lengths for Black Crappie (in mm)

	AGE									
	1	2	3	4	5	6	7	8	9	10
Lake Anna, Virginia	76	116	145	162	172	188	189	233	252	267
Mean for Virginia Reservoirs [1]	86	155	218	249	292	310	345			
Keowee Reservoir [2]	74	145	206	246						
Mean for Delaware Maryland, North Carolina, South Carolina Waters [3]	75	148	197	242	291	323	350	360		

[1] Smith and Kauffman 1982

[2] Barwick and Larengen 1984

[3] Carlander 1977

age-at-capture plot of each age collected over the four years of the study (Fig. 4.4-13). The plot depicted crappie of several different ages attaining total lengths between 150 to 200 mm, most of which were close to 175 mm. The Outdoor Report, published by the Virginia Game Commission, frequently reported in recent years much larger crappie being caught by anglers in Lake Anna than were in collections made during the 316(a) study.

It is unlikely elevated water temperatures (due to station operation) directly affected the growth of crappie in the reservoir as crappie in the WHTF experienced similar or greater growth (Fig. 4.4-14). Water temperatures in Lake Anna were within the range proposed by Edwards, et al. (1982) for optimal growth of this species. In Keeowee Reservoir, South Carolina, growth of crappie appeared to increase when water temperatures were elevated due to the operation of a nuclear power station, and threadfin shad were stocked (Barwick and Lorenzen 1984).

Comparison of growth before and during station operation suggested growth of one and two year old fish improved from pre-operational to operational years in the Lake (Fig. 4.4-15). Pre-operational data from crappie older than two years were too limited for reliable analysis. Because all specimens were collected during operational years, no age-at-capture values from pre-operational years were available for comparison. The increase of growth in six year old crappie during 1984 may be due to fish that experienced growth in the WHTF and migrated to the Lower

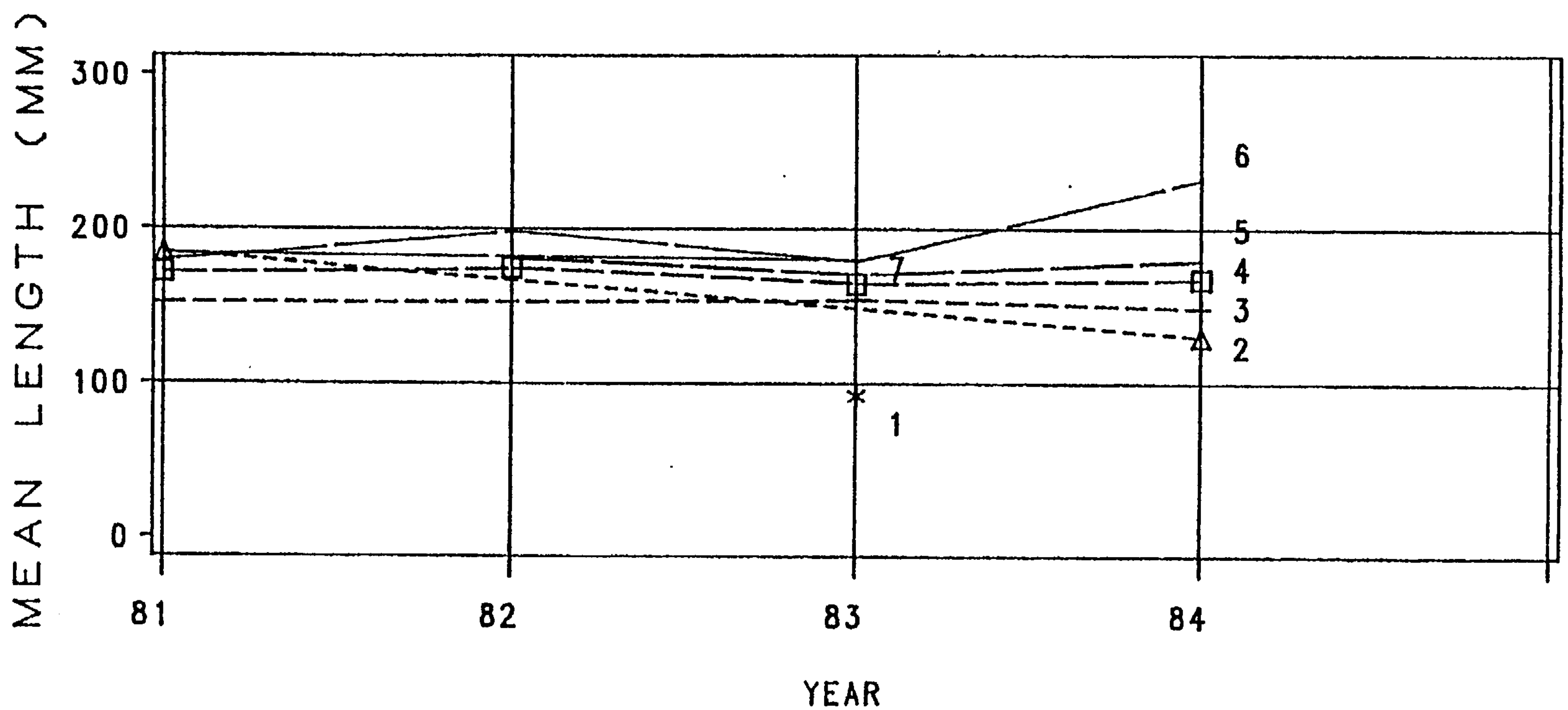


Figure 4.4-13. Lengths attained by black crappie of each age for four years of collection (1982 - 1985) from the reservoir, Lake Anna, Virginia.

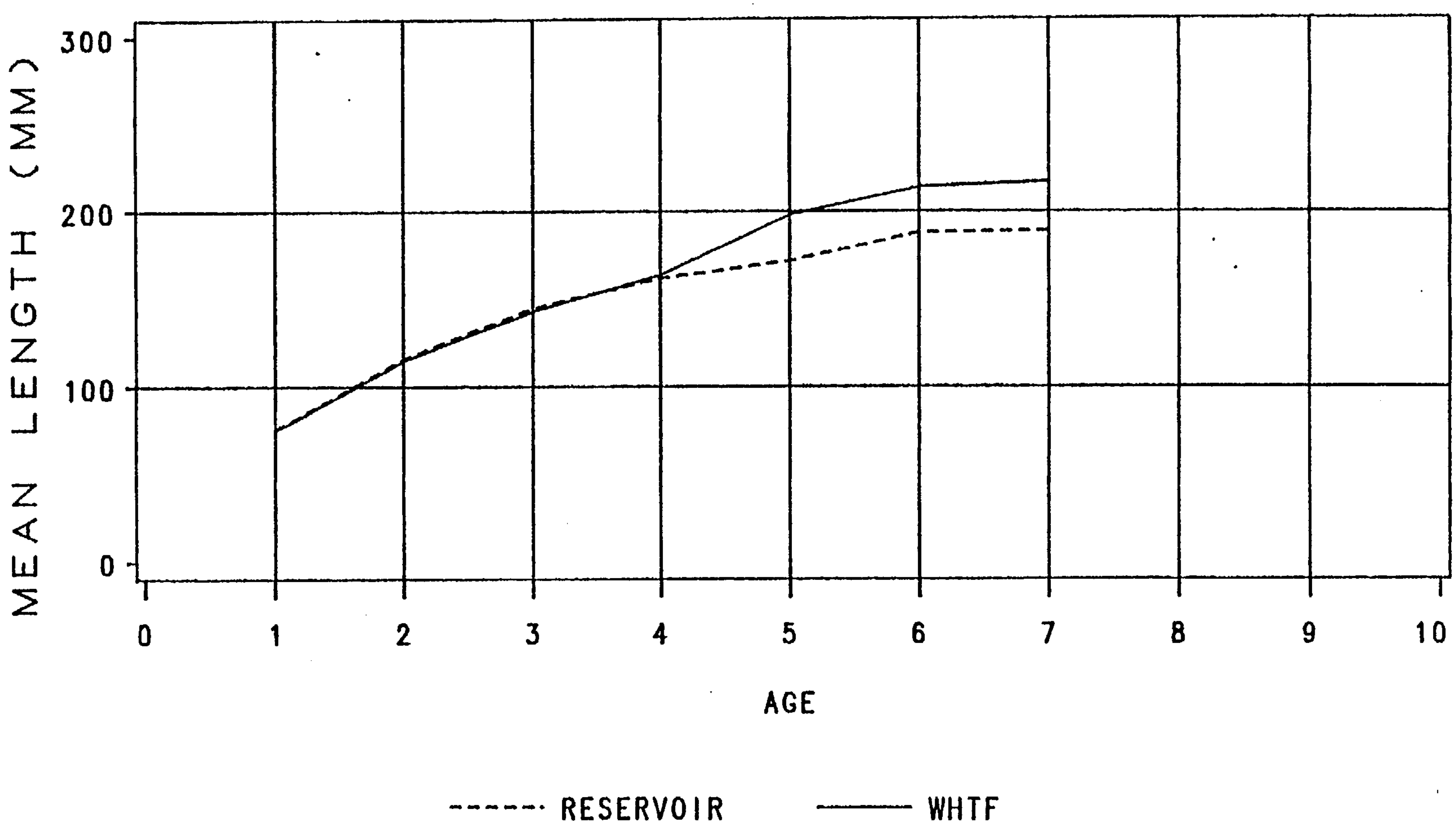


Figure 4.4-14. Comparison of growth between black crappie from the WHTF and Lake Anna, Virginia, (collected from 1982 to 1985).

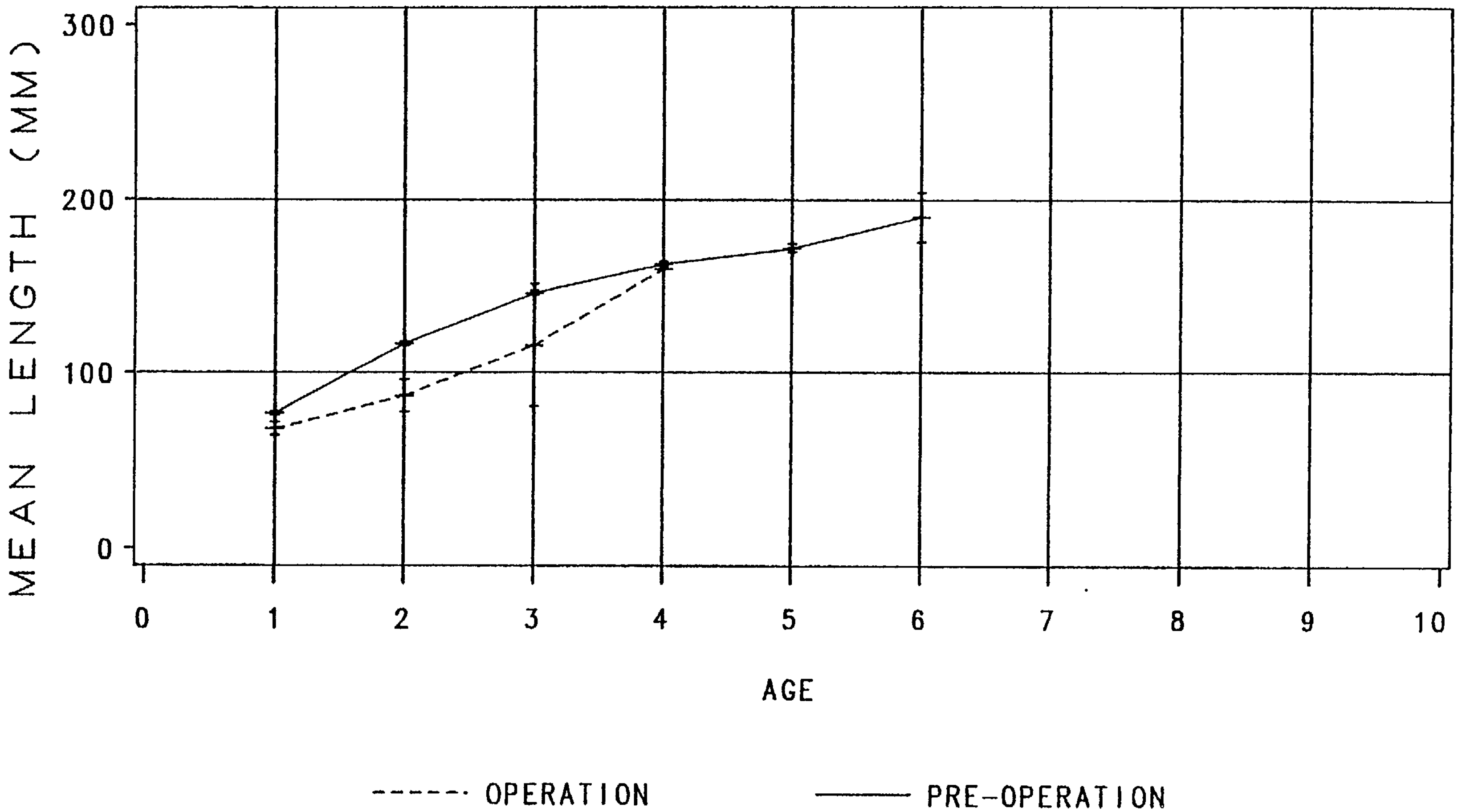


Figure 4.4-15. Comparison of growth of black crappie before and during station operation in Lake Anna, Virginia (collected from 1982 to 1985). Two standard errors of the mean are indicated.

Lake (Dike 3 area) where they were collected as scale patterns of these fish were consistent with those from WHTF-2.

Crappie tend to stunt easily. Some factors involved are quality and availability of food and overpopulation (Schneberger 1977; Edwards et al. 1982; Mitzner 1984). It is possible that these conditions may be limiting growth of crappie in Lake Anna.

Growth of crappie can be greatly influenced by food availability, especially small forage fish (Edwards et al. 1982). The principle forage item of black crappie in Lake Anna was mayflies, which based on substrate sampling are at low levels. Crappie in the reservoir do not appear to have utilized the threadfin, or any other fishes to any great degree dispite the apparent increased densities of forage fish. Stomach analyses of crappie in the WHTF, however, suggest threadfin shad were frequently consumed and may have accounted for the increases in growth of those crappie after threadfin introduction (Fig. 4.4-16). The apparent lack of utilization of threadfin shad in the reservoir was also noted for largemouth bass (see largemouth bass food study). For some reason, threadfin shad may be less available to fish in the reservoir than in the WHTF.

Although the density of crappie is low in Lake Anna compared to other reservoirs, there is a scarcity of habitat (e.g. submerged brush and shoreline vegitation) in the lake suitable for optimal growth of crappie. What little there is may have quickly populated, and overcrowding of these

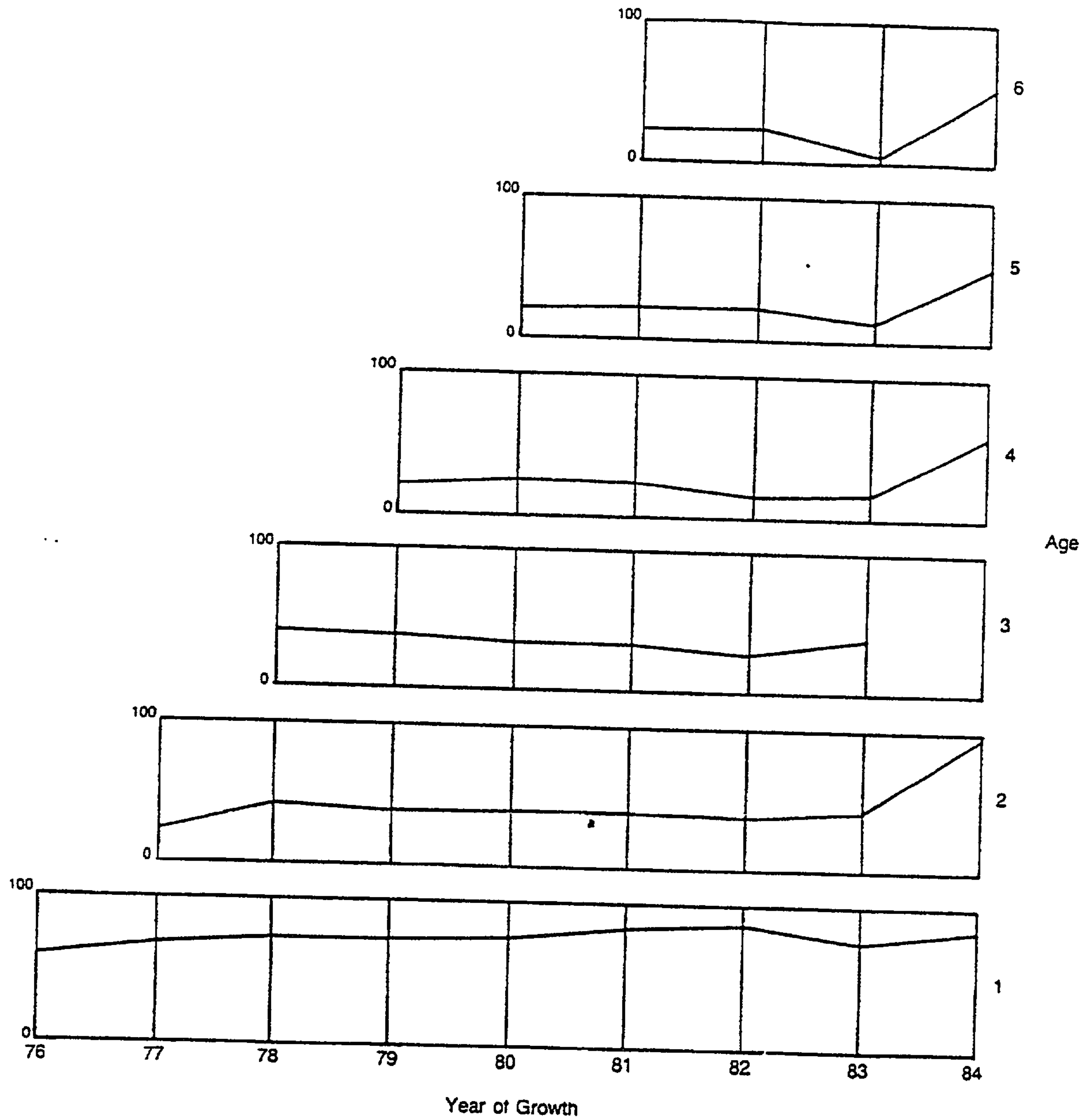


Figure 4.4-16 Incremental growth values for black crappie at each age plotted over time.
(Increment scale in mm) (Data for 7 year old fish were too few to plot.)

microhabitats may have occurred. Crappie prefer structure such as submerged brush and shoreline vegetation, both of which are minimal in Lake Anna. In addition, the cleared bottom characteristic of Lake Anna is not optimal for growth of crappie (Edwards et al. 1982). The areas of Lake Anna best suited for crappie are the beaver lodges, small areas of shoreline vegetation, fish structures Virginia Power has constructed, and bridge pilings; all of which comprise a small area of the lake relative to it's expansive shoreline.

Due to the lack of habitat and possible limited availability of forage (especially mayflys), black crappie in Lake Anna have experienced slow growth. Fish structures constructed in Lake Anna and stocking of threadfin shad may help the growth of crappie, but the full impact of these programs cannot yet be determined.

Striped Bass Studies

Introduction

Studies by Scruggs (1955) on striped bass (Morone saxatilis) in Santee-Cooper Reservoir, South Carolina, showed the species was able to complete a full life cycle without returning to salt water. However, striped bass reproduction in reservoirs is uncommon and most reservoir striped bass fisheries are maintained through stocking programs (Baily 1974).

Striped bass were introduced into Lake Anna by the Virginia Commission of Game and Inland Fisheries in 1973 and have been stocked annually since 1975 (see Table 4.4-2). The fishery has not, and is not expected to, become self sustaining. Lake Anna has insufficient flow to suspend fertilized eggs and allow them to develop and hatch (Fish and McCoy 1959). The state's stocking program has been successful in providing a productive and popular striped bass fishery for anglers on Lake Anna as evidenced by the numbers of fish caught annually weighing in excess of 15 pounds (citation size) (see Table 4.4-19). The lake's record striped bass was caught in April of 1985 (23 pounds 6 ounces, pers. commun. C. Sledd). Striped bass are third order consumers in the food web of Lake Anna (see Fig. 4.1-1) and range widely throughout the system in pursuit of their preferred food item, shad (Dorosoma spp.), during the fall, winter and spring seasons.

Studies by Schaich and Coutant (1978), Coutant and Carroll (1980) and Cheek et al. (1983) indicate it may be necessary for reservoirs with striped bass populations to have areas of cool habitat ("thermal refuges") during the summer months to ensure continued growth and survival of adult fish. Criteria for this cool habitat has been proposed as water with a temperature less than or equal to 25°C with a dissolved oxygen (D.O.) concentration greater than or equal to 2 ppm (Coutant 1985). Cool habitat is often eliminated in reservoirs during summer months due to a temperature/D.O. "squeeze" in the metalimnion. As the lake's epilimnion warms, cool habitat is found at greater depths. Coinciding with this is an upward expansion of the anoxic water in the lake's hypolimnion. As a result of these changes in temperature and D.O. the cool habitat is compressed to a narrow stratum and can be eliminated during the summer months if the epilimnion continues to warm.

In 1984 an ultrasonic tagging study of striped bass was begun at Lake Anna to determine the effects of the lake's summer conditions on the striped bass fishery. The effects of summer conditions more extreme than those in Lake Anna were also able to be studied. A number of the tagged fish were located in the warmer Waste Heat Treatment Facility Number 2 (WHTF-2) during the summer months. These data were useful in assessing Coutant's criteria for cool habitat.

Information Base

The 316(a) study of striped bass at Lake Anna utilized data from:

- The 1972-1985 water quality surveys: these data were used to assess Lake Anna's cool habitat availability.

- The 1978-1985 meteorological data on precipitation and average daily air temperature: These data were used in studies of habitat dynamics.

- The 1978-1985 data on power station operation: These data were used to classify operational years.

- The 1981-1985 striped bass life history studies: These data were used for determining biological change in the striped bass population over time.

- The 1984-1985 Lake Anna, striped bass, ultrasonic tagging study: This study provided data for determining the behavioral response of striped bass to varying and observable temperature and D.O. regimen.

Year to year comparisons were used to determine the differences in cool habitat availability during pre-operational years and operational years. Upper Lake/Lower Lake comparisons were used to determine any uplake-downlake variations in cool habitat availability as well as any thermal plume induced variations. Year to year comparisons of life history data and tagging study data were used to determine the effects of power station operation on the behavior and biology of the striped bass fishery. Upper Lake/Lower Lake comparisons were not useful in these determinations because of the species' mobility.

Results of Striped Bass Studies at Lake Anna:

Habitat Availability

Temperature and D.O. are two basic parameters whose regimen determine the quality of habitat in aquatic environments. An organism's temperature and D.O. requirements encompass a range of values. The range includes values that reflect optimal, sub-optimal and unsuitable habitat conditions. Optimal habitat has temperature and D.O. values that allow an organism to grow and survive normally. Sub-optimal habitat allows for the survival of an organism but at some cost, such as reduced growth or reproduction. Unsuitable habitat would have conditions that would cause significant mortality in the population after an appropriate exposure time (Pianka 1974). Studies by Schaich and Coutant (1978), Coutant and Carroll (1980), Coombs and Peltz (1982), Lewis (1983), Moss (1985) have indicated that the optimal and sub-optimal temperature critera for striped bass shift downward as the individuals grow. The criteria for adult striped bass differs form that of juvenile striped bass in that the adults can not tolerate long exposures to temperatures as warm as those tolerated by juveniles. Adopting Pianka's (1974) terminology to Coutant's (1985) criteria for adult striped bass, produces the following definitions:

- Optimal habitat: water temperatures less than or equal to 22°C with a D.O. concentration greater than or equal to 4 ppm.
- Sub-optimal habitat: water temperatures between 22°C and 25°C with a D.O. concentration between 2 ppm and 4 ppm.
- Unsuitable habitat: water temperatures greater than 25°C and/or a D.O. concentration less than 2 ppm

Studies by Mathews, Hill and Schellhaass (1985) dispute the above criteria. Their work on Lake Texoma (Oklahoma-Texas) indicated striped bass can tolerate exposure to water temperatures of 28.5°C with D.O. concentrations of 7.2 ppm for approximately two months. The role of temperature in the vertical zonation of striped bass was felt to be problematic and likely small with D.O. depletion being more important.

Habitat availability analyses were done to quantify the amounts of striped bass habitat present in Lake Anna from Rt. 208 to the dam during the month of August (Fig. 4.4-17; Appendix B-Fig. 1-14). The analyses results indicated the following:

1) the presence of small amounts of optimal habitat during pre-operation and its disappearance during operational periods.

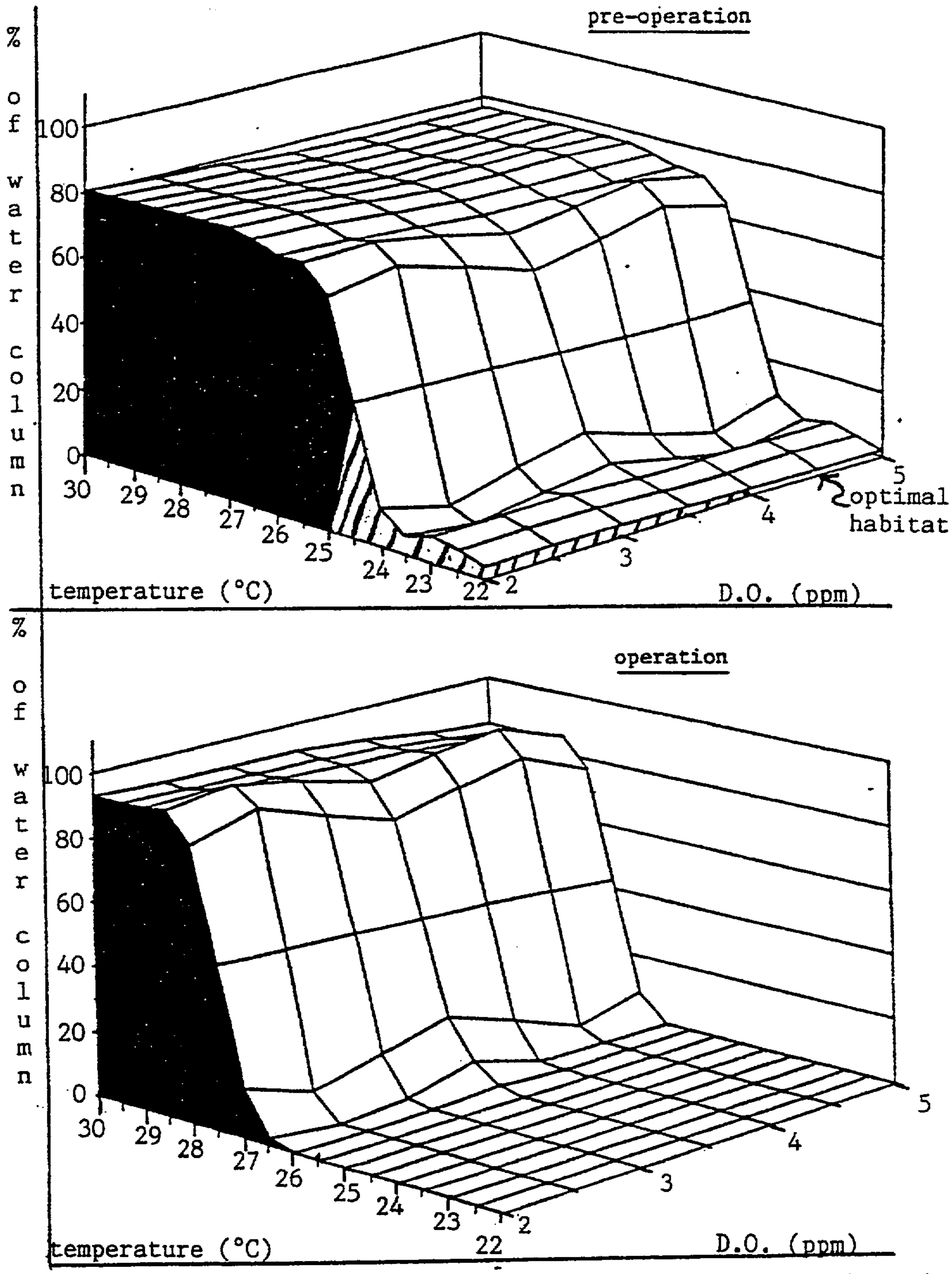
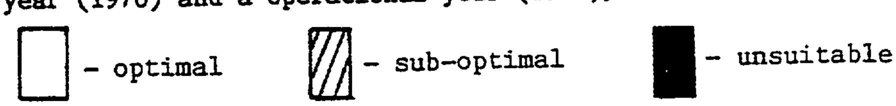


Figure 4.4 - 17 Comparison of the amounts of optimal, sub-optimal and unsuitable striped bass habitat in Lake Anna during August of a pre-operational year (1976) and a operational year (1985).



2) the presence of large amounts of sub-optimal habitat during pre-operation and its apparent disappearance during operational periods. The habitat available during operational years borders between sub-optimal and unsuitable.

A more detailed understanding of the annual sub-optimal habitat availability was developed by using Coutant's specific criteria of 25°C/2 ppm D.O. and splitting the analyses out by station (Fig. 4.4-18). Environmental conditions during the first two years of impoundment (1972, 1973) were considered as atypical due to reservoir filling and stabalizing. The most "typical" pre-operational conditions Lake Anna achieved are reflected in the 1976 and 1977 analyses (four and five years post impoundment) this may, or may not, have been long enough to develop stable pre-operational environmental conditions. Baxter (1977) and Jenkins (1977) have indicated a period of five to ten years is necessary to achieve stability in reservoir aquatic systems. The more detailed analyses confirm Lake Anna had large amounts of sub-optimal habitat during the summer months of pre-operational years and since 1978 there has been a near total disappearance of this habitat.

Exceptions to the sub-optimal habitat disappearance trend were seen in 1979 and to a lesser degree in 1982. The 1985 thermal plume survey data (Figs. 4.4-19 and 20) also indicated small areas of sub-optimal habitat present in 1985 that were not observable using regular water quality survey data.

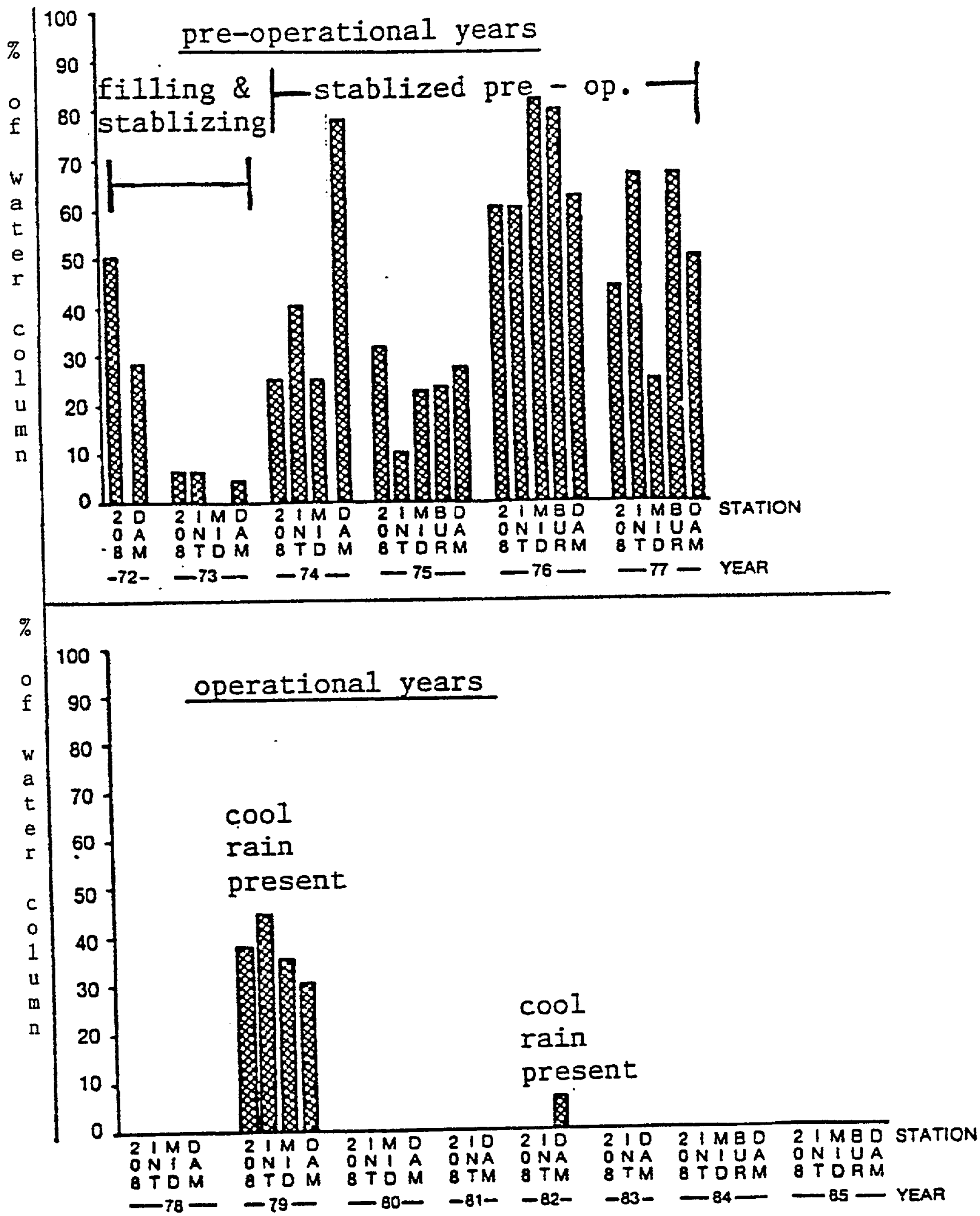


Figure 4.4-18 Comparison of the amounts of sub-optimal striped bass habitat in Lake Anna during August of pre-operational (1972-1977) and operational (1978-1985) years.

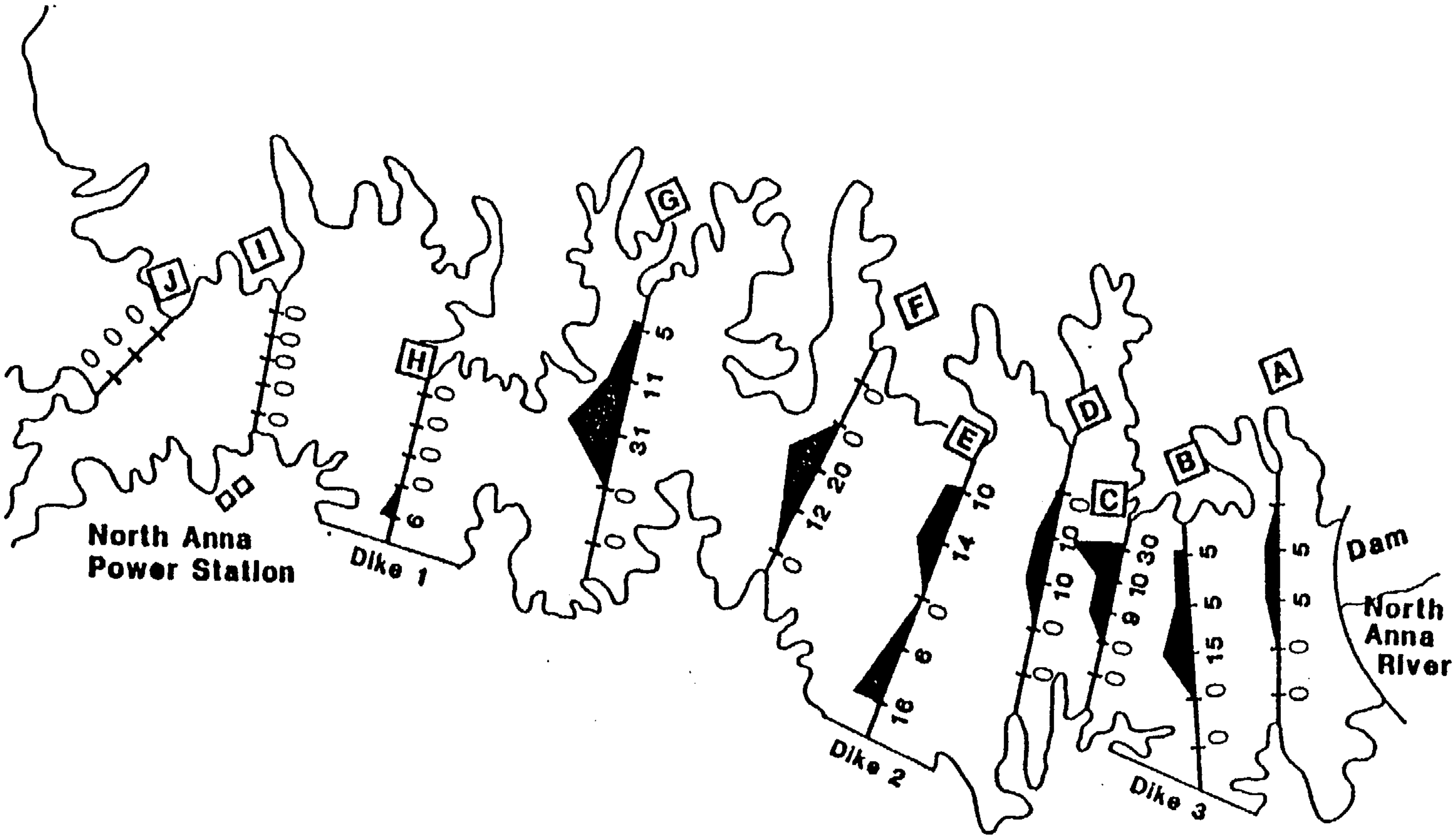


Figure 4.4-19 Sub-optimal striped bass habitat availability as indicated by the July, 1985, plume survey data. Numbers indicate the percent of the water column available.

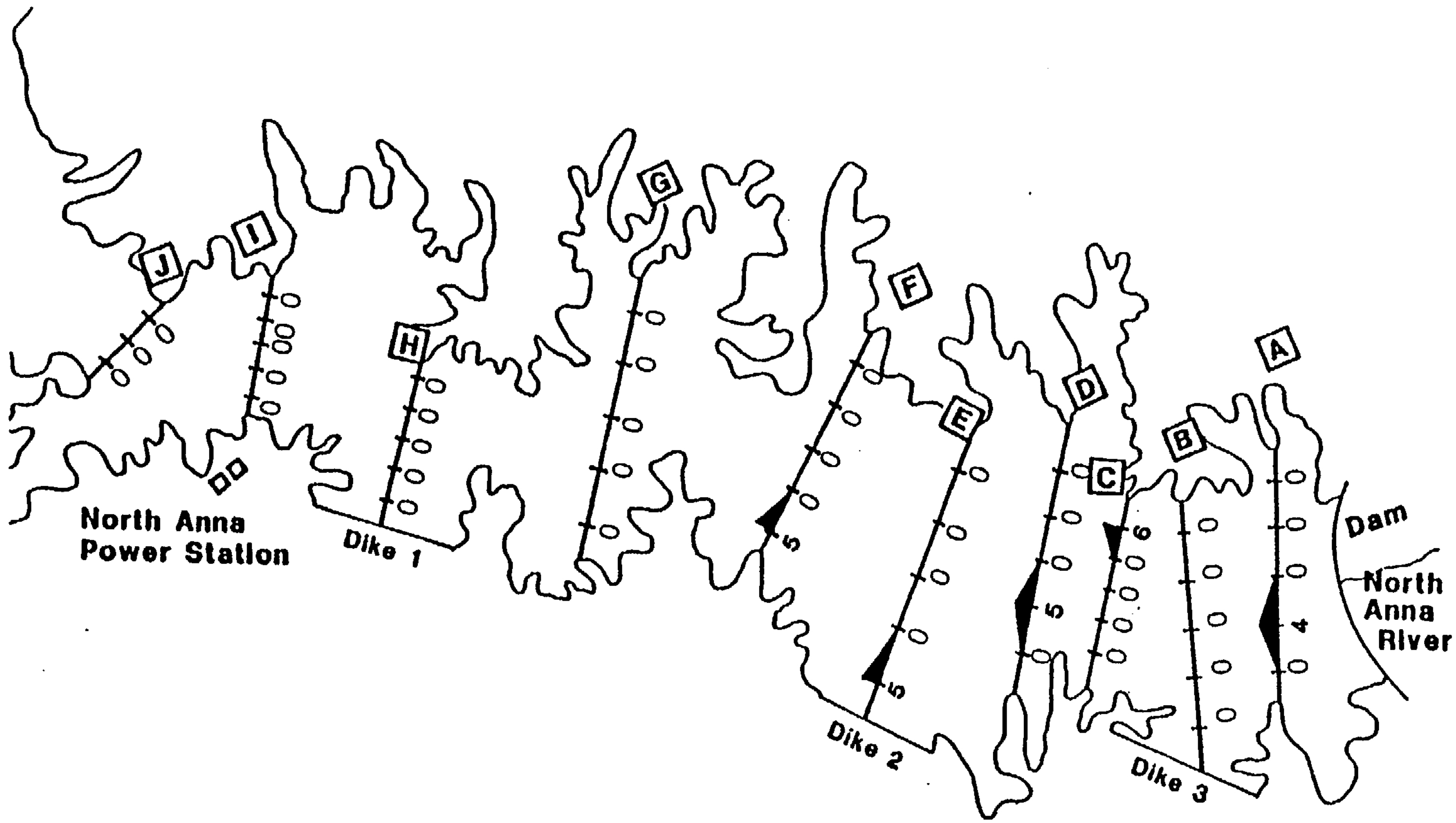


Figure 4.4-20 Sub-optimal striped bass habitat availability as indicated by the August, 1985, plume survey data. Numbers indicate the percent of the water column available.

Habitat availability analyses were done using the criteria 26°C/2 ppm D.O., 27°C/2 ppm D.O. and 28°C/2 ppm D.O. to determine sub-optimal habitat availability under the criteria suggested by the work of Matthews et al. (Figs. 4.4-21-23). The analyses indicated consistant sub-optimal habitat availability at temperatures of 27°C-28°C with 2 ppm D.O., however, oxygen requirements for striped bass have been shown to increase with increasing water temperatures (Kruger and Brocksen 1978). D.O. concentrations of 27°C water in Lake Anna are rarely less than 3 ppm and are typically $>$5 ppm. D.O. concentrations of 28°C water in Lake Anna are rarely below 6 ppm. Striped bass tracked during the 1985 study were found in habitat with temperatures between 27°C - 29°C with D.O. valves ranging between 2 ppm - 7 ppm. The exposure time to these temperatures was approximately one month. The effects of these conditions on striped bass are discussed below, but in general, the effects do not preclude these temperature and D.O. regimens from being considered as maximums for sub-optimal striped bass habitat.

Habitat Dynamics

Sub-optimal habitat, as defined by Coutant's criteria (25°C, 2 ppm D.O.), was present in August 1979 and to a lesser degree in August 1982, whereas all other operational years had unsuitable habitat. Station operation data showed there was low station operation during August 1979 and 1982 (see Table 3.3-1). Meteorological data for

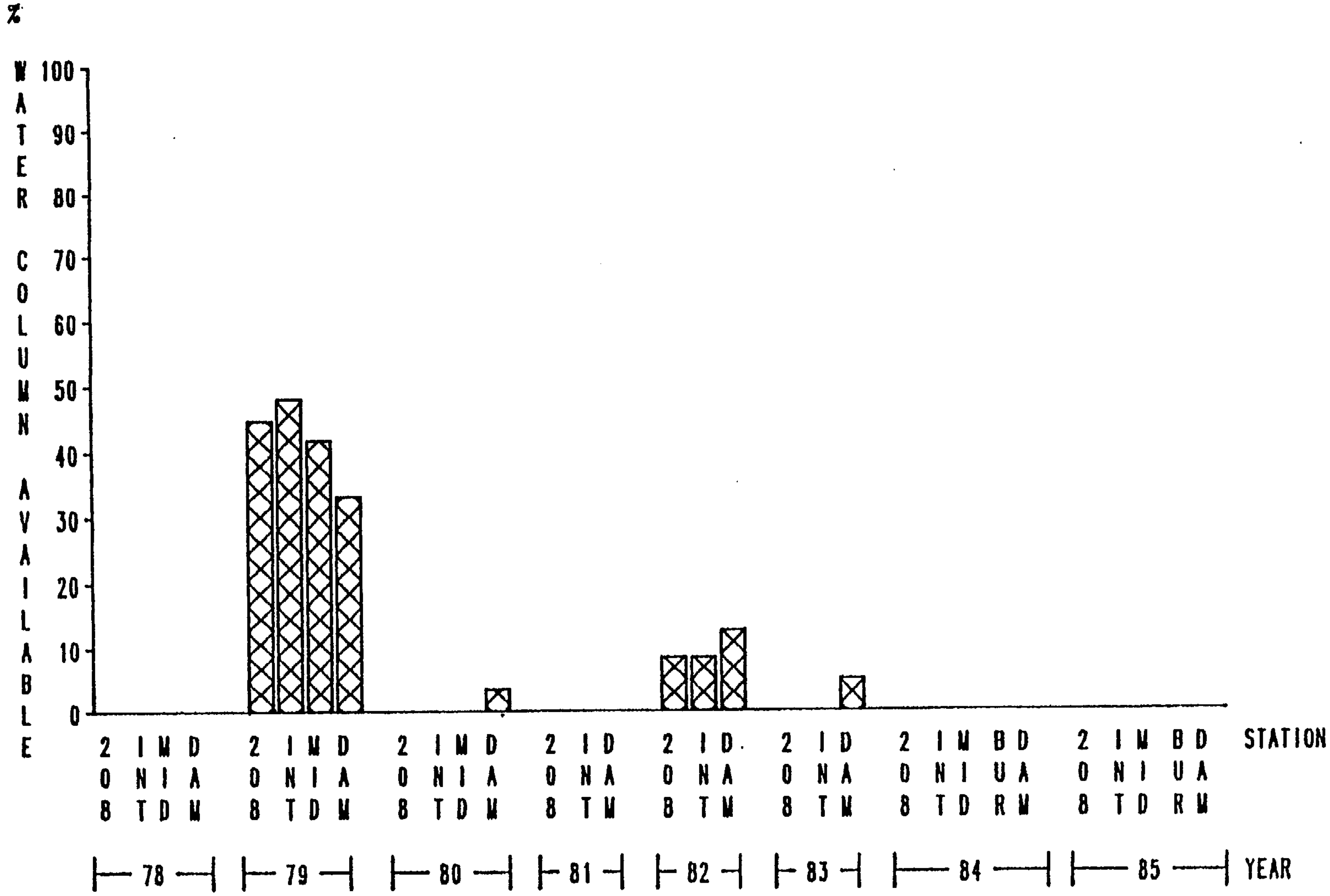


Figure 4.4-21 Striped bass habitat availability (26°C = max temp, 2ppm = min D.O.).

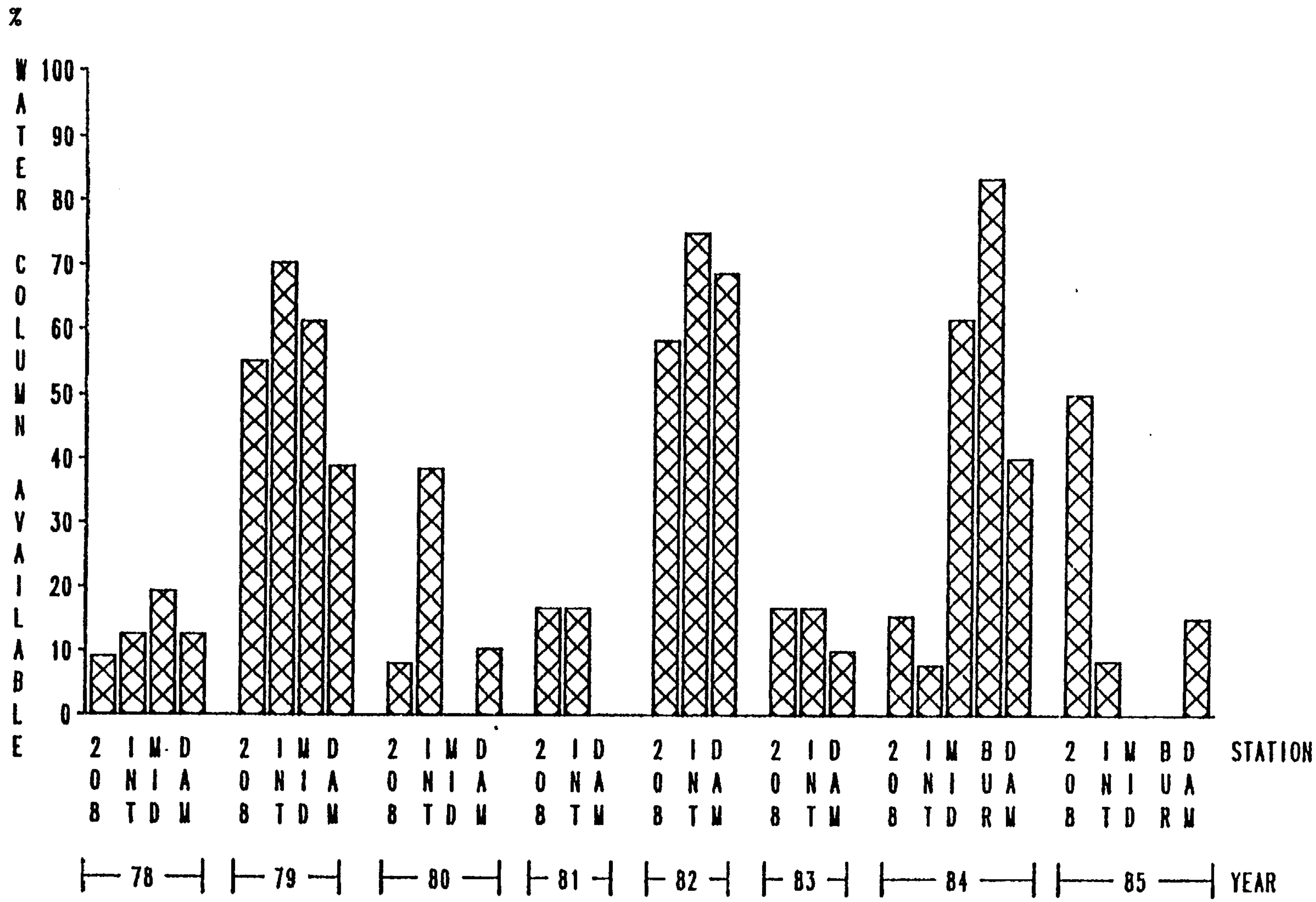


Figure 4.4-22 Striped bass habitat availability (27°C = max temp, 2ppm = min D.O.).

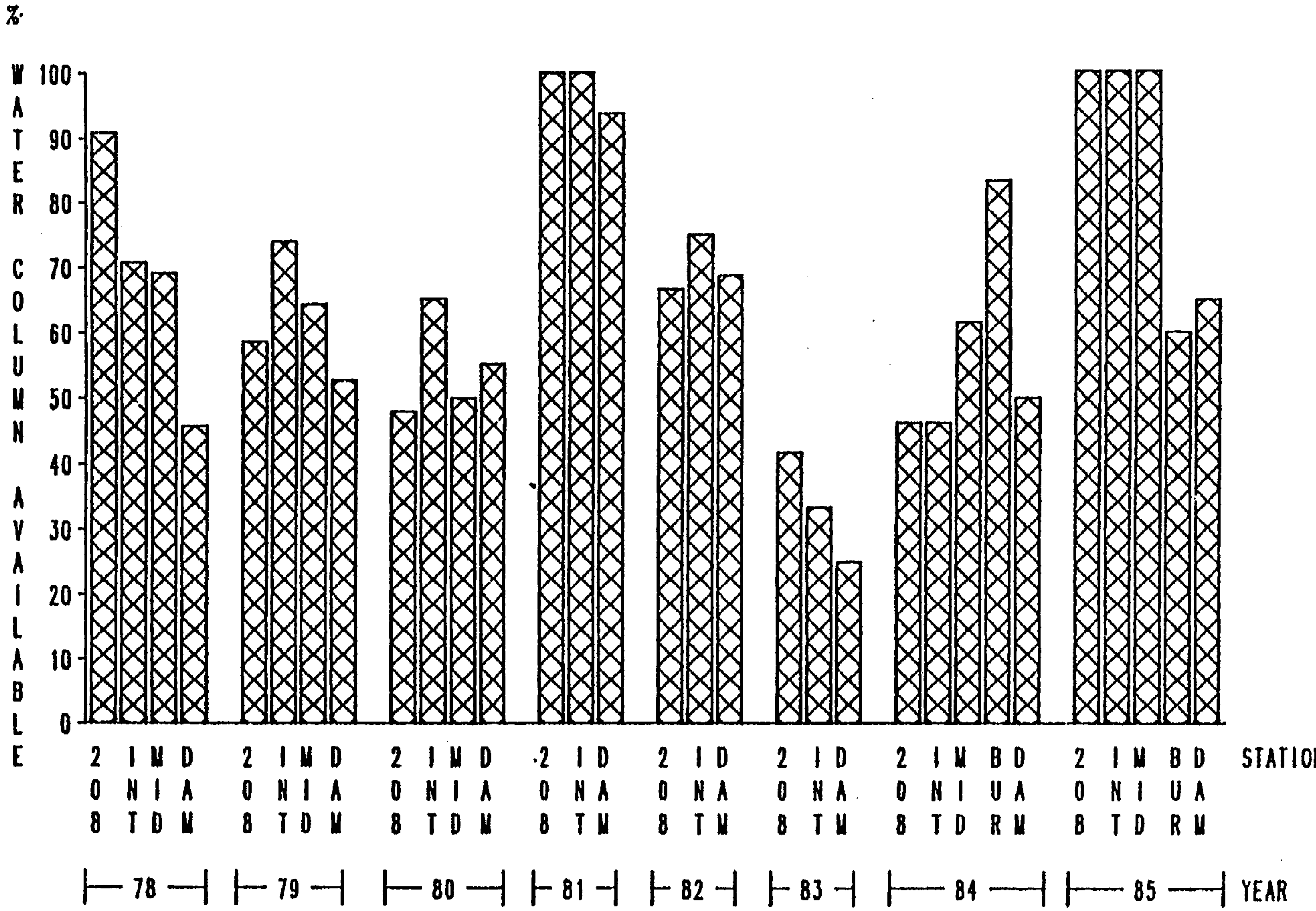


Figure 4.4-23 Striped bass habitat availability (28°C = max temp, 2ppm = min D.O.).

these periods showed higher than average precipitation just prior to the surveys dates (Fig. 4.4-24). Similar amounts of rain prior to the August survey dates occurred in 1980 and 1984; however, the average daily air temperatures were higher in 1980 and 1984 than in 1979 and 1982. The data suggests that if there is sufficient rain over a short period of time when there is low station operation and the average daily air temperatures are relatively cool there is a potential to temporarily improve existing habitat.

Studies were conducted in 1985 to determine how much habitat improvement would occur during the summer months of a two-unit operational year. Temperature-D.O. profiles were taken in WHTF-2 shortly before and immediately after the rains associated with Hurricane Danny (8/18/85-8/19/85). The profiles were taken in WHTF-2 for two reasons: first, a number of the tagged striped bass were located there in a restricted zone of sub-optimal or unsuitable habitat hence any effects of the rain on the striped bass could be observed; secondly, water temperatures in this area were generally 2-3°C higher than those in the lake, therefore, if a habitat improvement effect was seen in WHTF-2 it would imply the effect was also occuring in the lake and probably to a greater degree.

The rain associated with Hurricane Danny totaled 13.6 cm for the 24 hour period. Average air temperatures for this period were between 21.1°C (70°F) and 23.9°C (75°F). Much of the rain fell during the evening of the 18th when the minimum air temperature of 20.1°C (68.2°F)

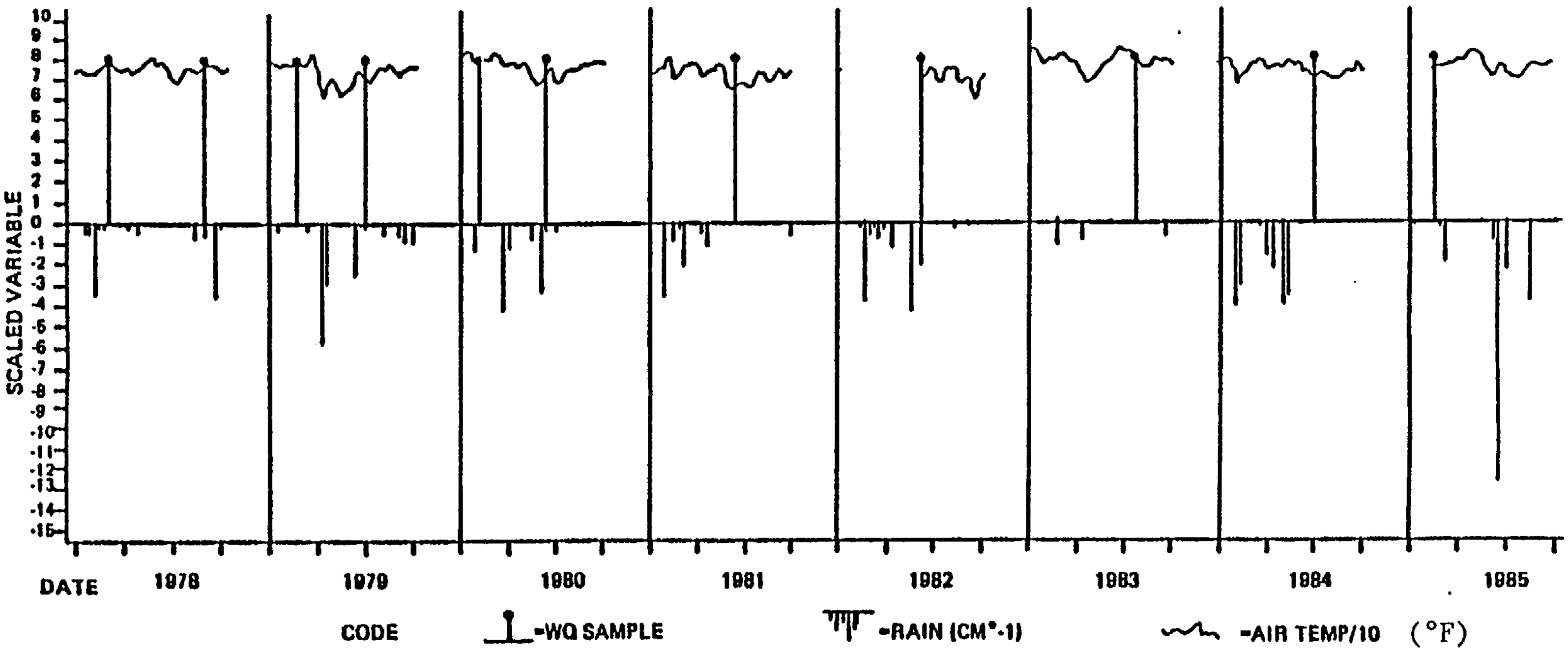


Figure 4.4 - 24 Daily precipitation (cm), dates of water quality sampling and average daily air temperatures for August from 1978 - 1985.

occurred. Profiles taken on 8/14/85 (Table 4.4-9) showed the best available habitat before the storm had temperatures between 27.6°C and 28.1°C with D.O. values between 1.2 ppm and 3.4 ppm. Temperature - D.O. profiles taken on 8/19/85 (Table 4.4-9) showed the best available habitat after the storm had a temperature of 26.6°C with a D.O. concentration of 3.7 ppm. Temperatures in WHTF-2 after the rain storm were approximately 2°C cooler than that of the pre-storm habitat. Habitat in the lake, being cooler initially, was probably improved well into the sub-optimal habitat range. Improvement of striped bass habitat due to cool summer rain is of a short duration, but it may create some semblance of a thermal refuge for striped bass. During periods when their is no habitat improvement striped bass in Lake Anna occupy the coolest, normally occurring habitat; i.e. they locate the best availalbe refuges. Large "classic" thermal refuges, created by cool water inflows such as springs, do not exist to any detectable degree in Lake Anna. The area's soil and bedrock are of a granite, metamorphic composition which retards the rate of water movement through it unlike porous limestone rock which is a common feature in systems with "classic" striped bass thermal refuges (Wooley and Crateau 1983).

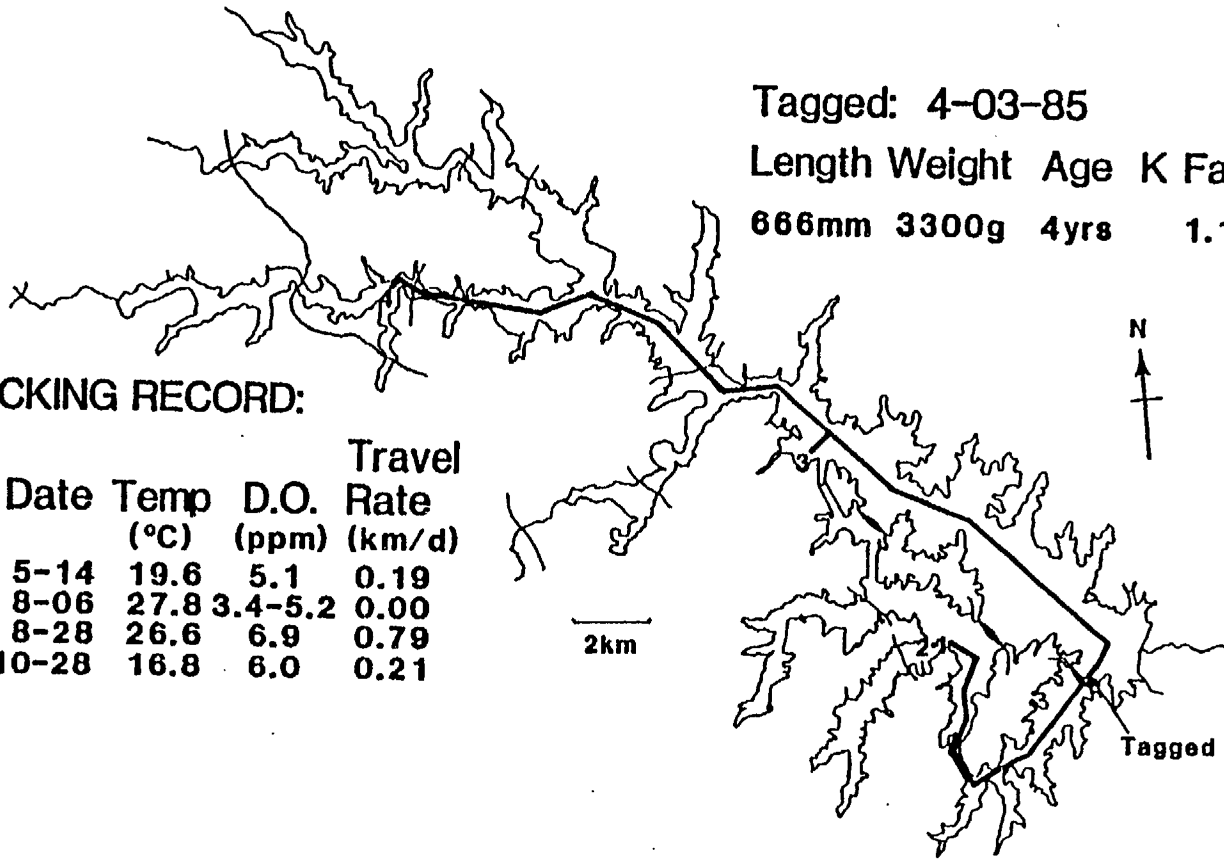
Tracking Studies

The 1984 and 1985 tracking data shows striped bass in Lake Anna locate in a narrow band of water (1m thick) at

Lake Anna system. Five striped bass were tracked in August 1985 before and after Hurricane Danny (Figs. 4.4-25-29). Striped bass with tag numbers: 75-9, 75-24, 78-9 and 78-13 showed substantial movement out of WHTF-2 after the August 1985 rains. Striped bass with tag number: 78-15 (the only one of the five found in the lake prior to the rains) did not show any marked increase in movement during this period. Temperatures experienced by this fish were cooler than those in WHTF-2 (temperatures $\leq$ 27°C). Numbers 75-24 and 78-9 were found to have moved up Millpond Creek where as numbers 75-9 and 78-13 had moved through WHTF-3 to the lake. Number 75-24 was found in the upper reaches of Millpond Creek on 8/21/85 (two days after the rain storm). Number 78-9 apparently moved up Millpond Creek after this date as it was not found there until the next tracking survey of this area on 9/13/85. The habitat conditions of the area were not greatly different from those at the mouth of Millpond Creek (temperatures = 28.6°C vs 28.8°C respectively). However, the upper reaches of Millpond Creek had been cooled from temperatures near 30°C to temperatures slightly less than those the fish had been experiencing, allowing the fish to move into a area that was thermally blocked. During the summer months large schools of shad are seen in the upper reaches of the lake's tributaries. The movement of striped bass up Millpond Creek after the storm allowed them to feed on these shad. Predator/prey separation, as a result of habitat restriction, has been proposed by Coutant and Carroll (1980) on the basis that shad have a higher thermal

Tagged: 4-03-85

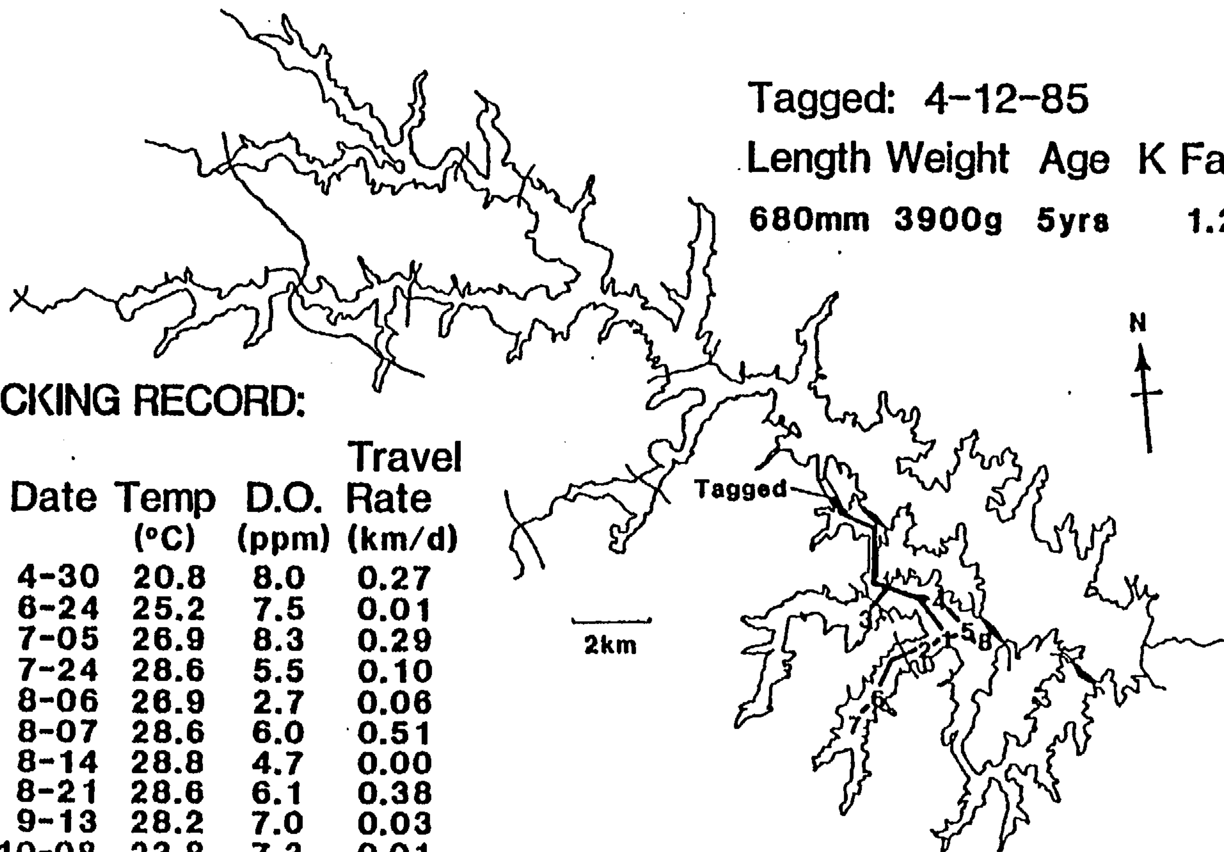
Length	Weight	Age	K Factor
666mm	3300g	4yrs	1.12



TRACKING RECORD:

Loc	Date	Temp (°C)	D.O. (ppm)	Travel Rate (km/d)
1	5-14	19.6	5.1	0.19
2	8-06	27.8	3.4-5.2	0.00
3	8-28	26.6	6.9	0.79
4	10-28	16.8	6.0	0.21

Figure 4.4-25 1985 striped bass - tag no. 75-09, tracking record.



Tagged: 4-12-85

Length	Weight	Age	K Factor
680mm	3900g	5yrs	1.24

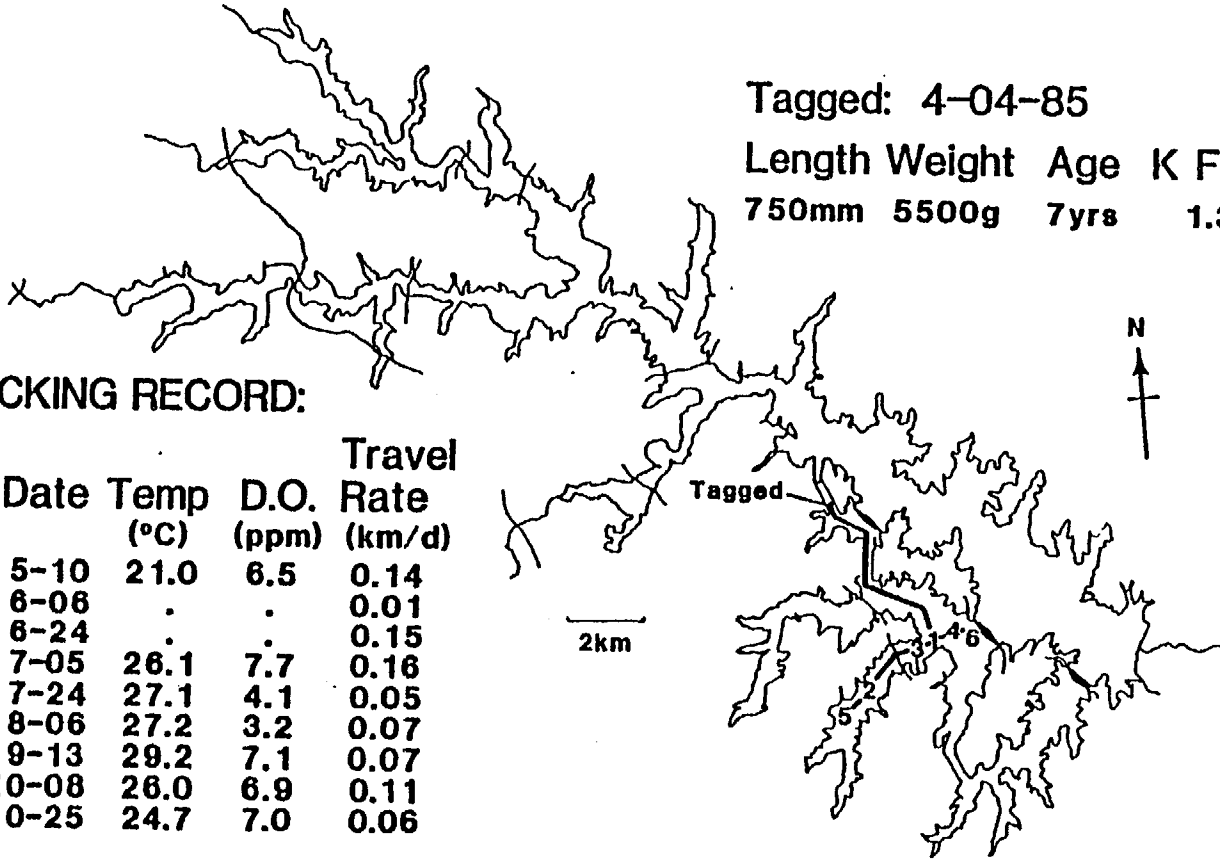
TRACKING RECORD:

Loc	Date	Temp (°C)	D.O. (ppm)	Travel Rate (km/d)
1	4-30	20.8	8.0	0.27
2	6-24	25.2	7.5	0.01
3	7-05	26.9	8.3	0.29
4	7-24	28.6	5.5	0.10
1	8-06	26.9	2.7	0.06
5	8-07	28.6	6.0	0.51
5	8-14	28.8	4.7	0.00
6	8-21	28.6	6.1	0.38
7	9-13	28.2	7.0	0.03
7	10-08	23.8	7.3	0.01
8	10-25	23.0	6.2	0.22

Figure 4.4-26 1985 striped bass - tag no. 75-24, tracking record.

Tagged: 4-04-85

Length	Weight	Age	K Factor
750mm	5500g	7yrs	1.30



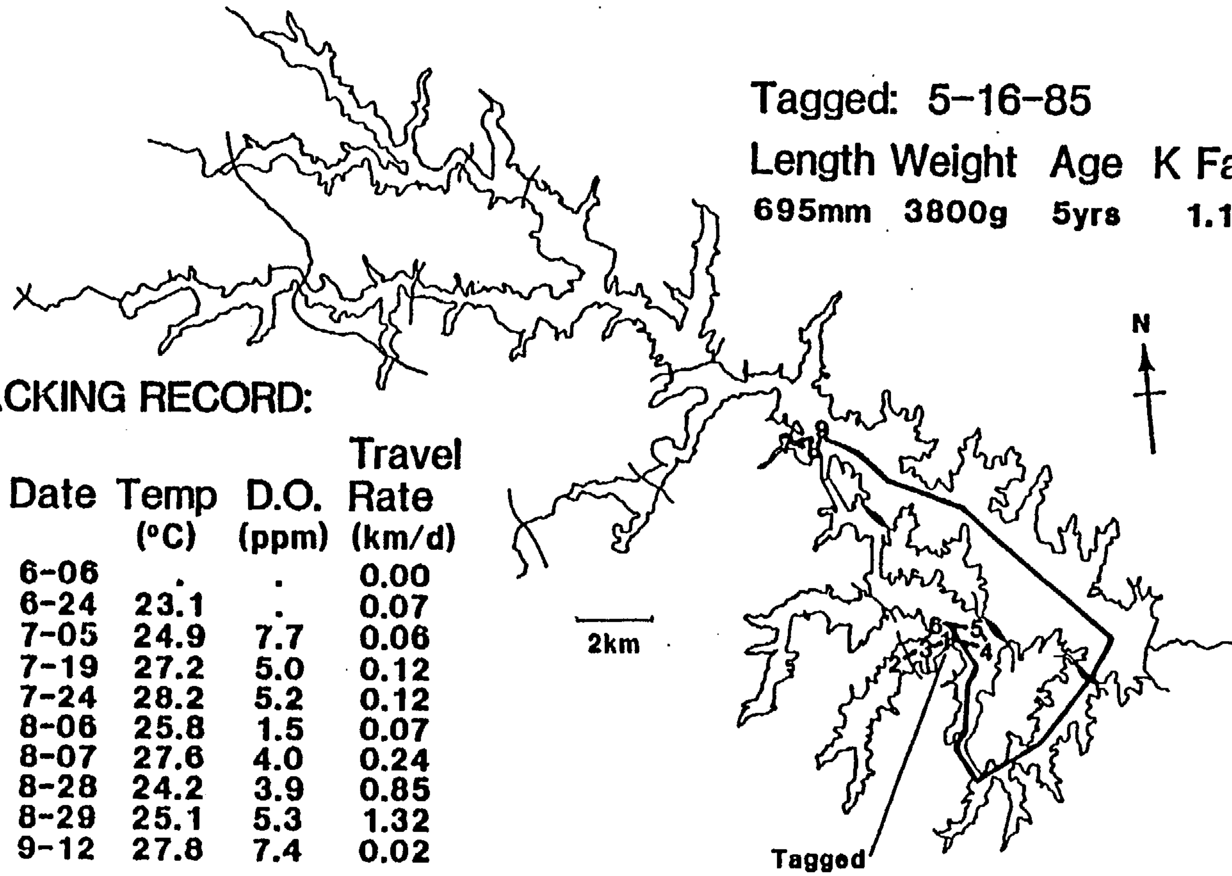
TRACKING RECORD:

Loc	Date	Temp (°C)	D.O. (ppm)	Travel Rate (km/d)
1	5-10	21.0	6.5	0.14
1	6-06	.	.	0.01
2	6-24	.	.	0.15
3	7-05	26.1	7.7	0.16
4	7-24	27.1	4.1	0.05
3	8-06	27.2	3.2	0.07
5	9-13	29.2	7.1	0.07
3	10-08	26.0	6.9	0.11
6	10-25	24.7	7.0	0.06

Figure 4.4-27 1985 striped bass - tag no. 78-09, tracking record.

Tagged: 5-16-85

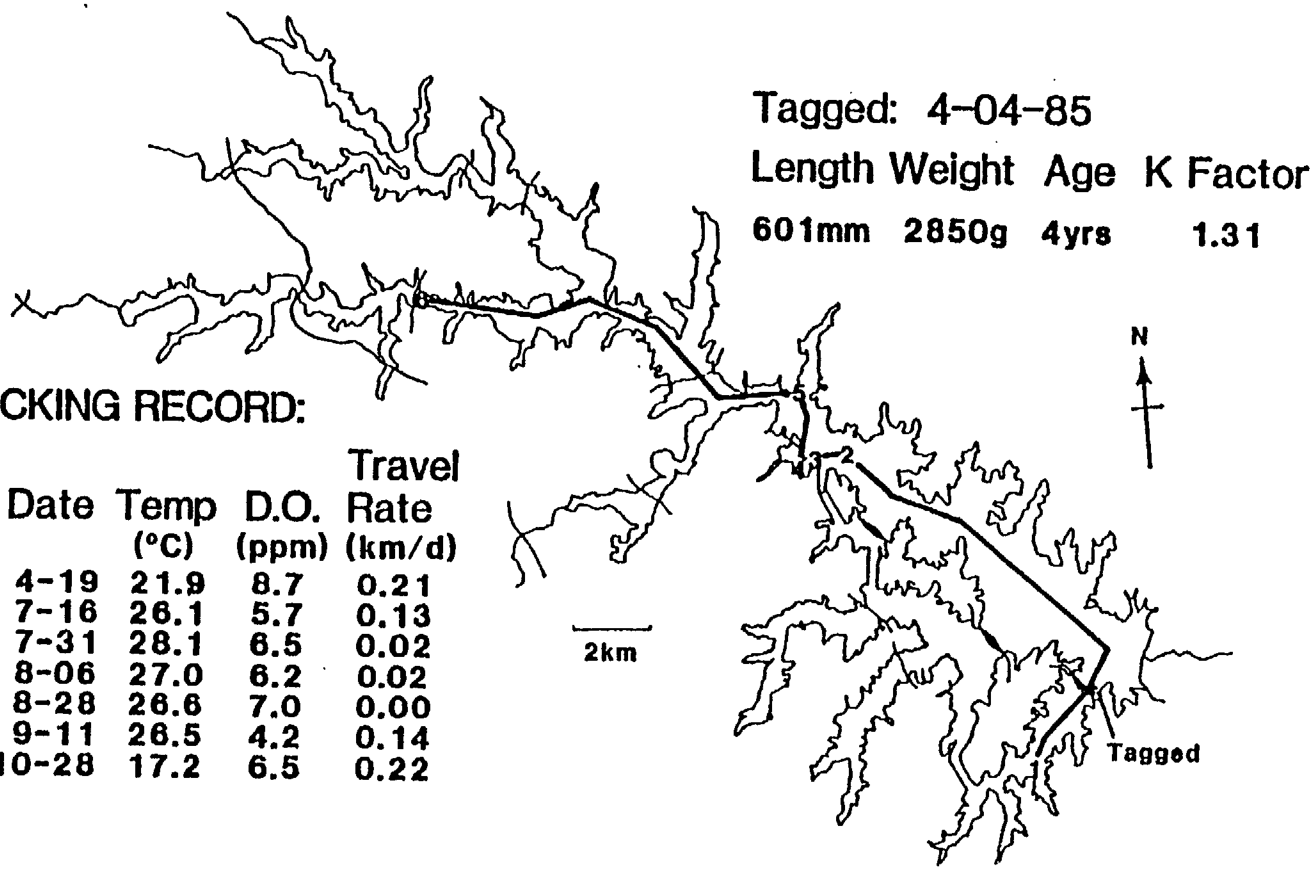
Length	Weight	Age	K Factor
695mm	3800g	5yrs	1.13



TRACKING RECORD:

Loc	Date	Temp (°C)	D.O. (ppm)	Travel Rate (km/d)
1	6-06	.	.	0.00
2	6-24	23.1	.	0.07
3	7-05	24.9	7.7	0.06
4	7-19	27.2	5.0	0.12
5	7-24	28.2	5.2	0.12
6	8-06	25.8	1.5	0.07
6	8-07	27.6	4.0	0.24
7	8-28	24.2	3.9	0.85
8	8-29	25.1	5.3	1.32
9	9-12	27.8	7.4	0.02

Figure 4.4-28 1985 striped bass - tag no. 78-13, tracking record.



TRACKING RECORD:

Loc	Date	Temp (°C)	D.O. (ppm)	Travel Rate (km/d)
1	4-19	21.9	8.7	0.21
2	7-16	26.1	5.7	0.13
3	7-31	28.1	6.5	0.02
4	8-06	27.0	6.2	0.02
4	8-28	26.6	7.0	0.00
5	9-11	26.5	4.2	0.14
6	10-28	17.2	6.5	0.22

Figure 4.4-29   1985 striped bass - tag no. 78-15, tracking record.

preferendum than striped bass (Coutant 1977). The 9/13/85 tracking survey of this area showed both fish still present. Water temperature data for number 78-9 was 29.2°C. Temperature data for number 75-24 was 28.2°C indicating that water cooler than 29.2°C was available. The higher temperature recording of 29.2°C was probably due to a short excursion by number 78-9 into warmer water. Such excursions have been reported in other field studies (Moss 1985).

Numbers 75-9 and 78-13, by moving into the lake, were able to relocate in habitat that was cooler than that available in WHTF-2. The decrease in temperature experienced by these fish following their move ranged from 1.2°C - 3.4°C. The location of number 78-13 after the rainstorm in August 1985 coincided with the location of the largest detected inflow of cool water to Lake Anna.

Temperature and D.O. profiles taken on 8-6-85 (Table 4.4-10) in WHTF-3 (prior to the August 1985 rains) indicated that temperatures in WHTF-3 were a thermal barricade to the movement of striped bass through the area.

Table 4.4-10. August 6, 1985, temperature profile for WHTF-3.

Depth (m)	Temperature (°C)
0	29.8
1	29.8
2	29.8
3	29.8
4	29.8
5	29.8
6	29.8
7	29.8
8	29.8

The isothermal temperature profiles of WHTF-3 were probably a result of the aforementioned morphometry of the canal connecting WHTF-2 and WHTF-3. The August 1985 rains decreased the temperature of WHTF-3 to 28.6°C (Table 4.4-11), a temperature slightly cooler than the temperature being experienced by the fish in WHTF-2, thereby allowing striped bass in WHTF-2 to move to the Lake.

Table 4.4-11. August 19, 1985, temperature profile for WHTF-3.

Depth (m)	Temperature (°C)
0	28.6
1	28.6
2	28.6
3	28.6
4	28.6
5	28.6
6	28.6
7	28.6
8	28.6

The cooling effect in WHTF-3 was of a very short duration, possibly due to the previously discussed skimming action of the canal between WHTF-2 and WHTF-3. Profiles taken on 8-23-85 (Table 4.4-12) indicated that WHTF-3 was already returning to the 29°C+ state.

Table 4.4-12. August 23, 1985, temperature profile for WHTF-3.

Depth (m)	Temperature (°C)
0	29.2
1	29.2
2	29.2
3	29.1
4	29.1
5	29.0
6	28.8
7	28.7
8	28.6

Movement of tagged striped bass, after cool summer rains in 1984, were not detected. Temperatures these fish experienced during the summer months were generally in the 25°C - 26°C range. Power generation levels for July-September 1984 were low (see Table 3.3-1), which resulted in better habitat availability. That 25°C, 2ppm D.O. sub-optimal habitat was not available during the summer of 1984 may indicate sub-optimal habitat unavailability is largely caused by station operation during spring stratification periods.

Age and Growth

Studies by Cox and Coutant (1981), Bryce and Shelton (1982), Wooley and Crateau (1983) and Coutant (1985) have shown condition and growth of striped bass are directly influenced by habitat temperature, D.O. and prey availability. The temperature-D.O. regimen of Lake Anna in combination with the high thermal preferendum of shad may cause a substantial decrease in prey availability for striped bass during summer periods, which would cause a reduction in condition and growth. Intermitent summer feeding during periods of habitat improvement would decrease this effect. Temperatures above 25°C may decrease conversion efficiencies (Coutant 1985) and cause a slowing of growth (Cech et al. 1984). Dorfman and Westman (1970) have also shown that low D.O. concentrations can also cause a significant decrease in growth. Sub-optimal temperatures in conjunction with low D.O. concentrations create a poor environment for growth, a condition prevalent in Lake Anna during the summer months.

Life history studies of striped bass have been conducted at Lake Anna since 1981. From 1981-1985, 385 striped bass (length 87mm - 902mm T.L., weight 4g - 7600g) were collected. In addition to the collection of length-weight data, age and growth data were obtained through the collection and processing of scales. Otoliths and other bony structures were collected from 1983-1985, and used to verify age determinations as it was often difficult to age fish by scale analysis alone.

When the data were used in a length-total scale radius regression for determining the value of C, for use in the back calculated length formula $L' = C + S'/S\ (L-C)$ (Everhart and Youngs 1981), a value of 138 mm was obtained. This length at scale formation was felt to be too large to use and is probably the result of having insufficient age and growth data for juvenile striped bass. Literature searches for a standard C value were not successful. The C value = 35 mm was obtained from the Virginia Commission of Game and Inland Fisheries (pers.commun.-C. Sledd) based on the state's striped bass work on Lake Anna in 1982. This data set consisted primarily of one and two year old fish.

Back calculated length data and length at age of capture data were compared to assess what, if any, error was present in the back calculated data due to scale measurement error (Fig. 4.4-30, Tables 4.4-13 and 14). The error associated with the back calculated method appears minimal. The difference between the two methods may be more attributable to the different N values rather than error in

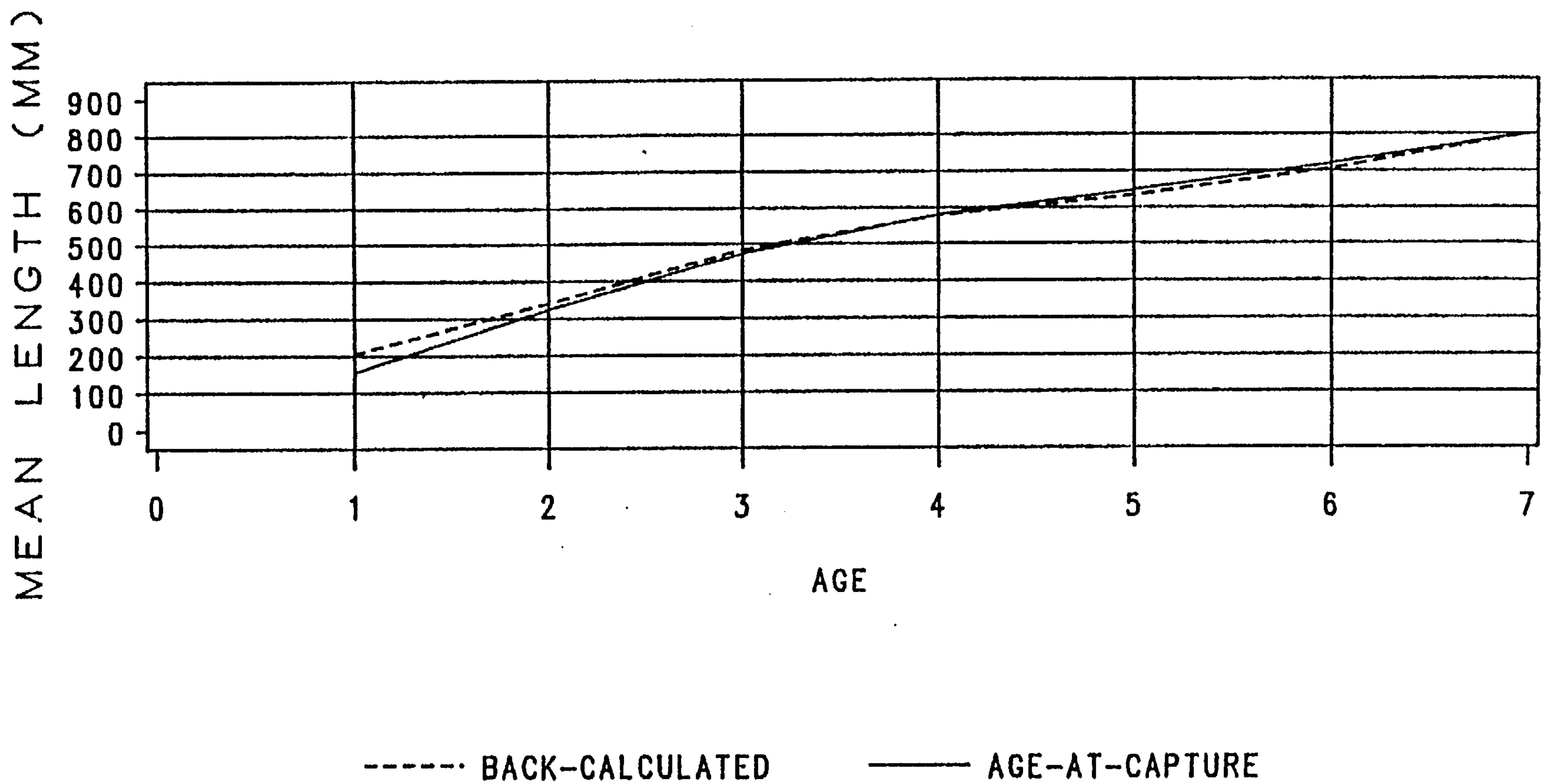


Figure 4.4-30 Comparison of back-calculated and age-at-capture growth curves for striped bass from Lake Anna, Virginia, collected from 1981 - 1985.

Table 4.4-13 Mean back-calculated lengths (mm) and annual increments (mm) for striped bass from Lake Anna, Virginia.

Year Class		Length at Annulus 1	2	3	4	5	6	7	8	9
1975	Mean Length	123	337	532	678	775	795			
	(N)	(1)	(1)	(1)	(1)	(1)	(1)			
	(Range)	-	-	-	-	-	-			
	Annual Increment	123	214	195	146	97	20			
1976	Mean Length	116	394	546	655	696				
	(N)	(2)	(2)	(2)	(2)	(2)				
	(Range)	(101-131)	(274-514)	(414-677)	(527-783)	(600-792)				
	Annual Increment	116	278	151	109	41.3				
1977	Mean Length	144	353	519	667	718	778	810		
	(N)	(7)	(7)	(7)	(7)	(3)	(3)	(3)		
	(Range)	(120-166)	(205-479)	(318-627)	(539-713)	(596-798)	(670-848)	(692-880)		
	Annual Increment	144	209	167	148	51	59	32		
1978	Mean Length	130	339	510	586	649	696	786		
	(N)	(58)	(58)	(58)	(20)	(15)	(12)	(2)		
	(Range)	(81-214)	(202-477)	(336-603)	(433-705)	(530-772)	(572-820)	(738-833)		
	Annual Increment	130	210	171	76	63	47	89		
1979	Mean Length	140	296	442	546	609	731			
	(N)	(58)	(58)	(46)	(35)	(27)	(4)			
	(Range)	(86-344)	(207-519)	(295-582)	(390-648)	(488-710)	(687-765)			
	Annual Increment	140	156	146	104	63	122			
1980	Mean Length	140	300	442	559	706				
	(N)	(68)	(68)	(31)	(23)	(9)				
	(Range)	(79-298)	(214-555)	(280-699)	(423-742)	(650-794)				
	Annual Increment	140	160	143	117	146				
1981	Mean Length	171	322	469	630					
	(N)	(43)	(31)	(26)	(17)					
	(Range)	(87-382)	(205-569)	(286-684)	(523-761)					
	Annual Increment	171	151	147	161					

Table 4.4-13 (continued)

Year Class		Length at Annulus 1	2	3	4	5	6	7	8	9
1982	Mean Length	141	342	474						
	(N)	(39)	(39)	(19)						
	(Range)	(83-262)	(237-424)	(402-541)						
	Annual Increment	141	201	133						
1983	Mean Length	194	364							
	(N)	(65)	(36)							
	(Range)	(111-283)	(296-446)							
	Annual Increment	194	170							
1984	Mean Length	209								
	(N)	(9)								
	(Range)	(113-273)								
	Annual Increment	209								
Lake Anna Mean*										
	Mean Length	154	324	474	581	647	720	800		
	(N)	(350)	(293)	(181)	(105)	(57)	(20)	(5)		
	(Range)	(79-382)	(202-569)	(280-699)	(390-783)	(488-798)	(572-848)	(692-833)		
	Annual Increment	154	170	150	107	66	73	80		
Va. State Average (for Reservoirs)										
	Mean Length	193	381	498	610	709	787	838		
	Annual Increment	193	188	117	112	99	79	51		
Mean Growth Before and During Station Operation										
	Pre-operation**	136	375	532						
		(10)	(3)	(1)						
		(101-166)	(205-514)	--						
		136	239	156						
	Operation+	154	323	471	573	638	705	786		
		(340)	(290)	(180)	(95)	(51)	(16)	(2)		
		(79-382)	(202-569)	(280-699)	(390-761)	(488-794)	(572-820)	(738-833)		
		154	169	148	102	65	67	81		

←0 Pre-operational growth of pre-operational year classes
0→ Operational growth of pre-operational year classes
0↓ Operational growth of operational year classes
* Mean lengths calculated using all year classes
** Mean lengths calculated using year class '75 ages 1-3, year class '76 ages 1-2 and year class '77 age 1
\+ Mean lengths calculated using year classes $\geq$ '78

Table 4.4-14 Mean lengths at age-at-capture (mm) and annual increments (mm) for striped bass from Lake Anna, Virginia.

Year Class		Length at Annulus 1	2	3	4	5	6	7	8	9
1975	Mean Length						795			
	(N)						(1)			
	(Range)						-			
	Annual Increment									
1976	Mean Length					696				
	(N)					(2)				
	(Range)					(600-792)				
	Annual Increment					-				
1977	Mean Length				682			810		
	(N)				(4)			(3)		
	(Range)				(630-713)			(692-880)		
	Annual Increment				-			-		
1978	Mean Length			532	619	653	687	786		
	(N)			(38)	(5)	(3)	(10)	(2)		
	(Range)			(417-603)	(541-705)	(608-715)	(572-820)	(738-833)		
	Annual Increment			--	87	35	34	99		
1979	Mean Length		346	458	520	597	731			
	(N)		(12)	(11)	(8)	(23)	(4)			
	(Range)		(266-519)	(307-582)	(423-640)	(488-710)	(687-765)			
	Annual Increment		-	112	62	78	134			
1980	Mean Length		315	430	509	706				
	(N)		(37)	(8)	(14)	(9)				
	(Range)		(222-504)	(355-501)	(423-596)	(650-794)				
	Annual Increment		-	115	79	197				
1981	Mean Length	181	359	387	629					
	(N)	(12)	(5)	(9)	(18)					
	(Range)	(129-264)	(332-412)	(286-486)	(522-761)					
	Annual Increment	181	178	28	243					
1982	Mean Length		338	474						
	(N)		(20)	(19)						
	(Range)		(299-400)	(402-541)						
	Annual Increment		-	136						

Table 4.4-14 (continued)

Year Class		Length at Annulus 1	2	3	4	5	6	7	8	9
1983	Mean Length	214	364							
	(N)	(29)	(36)							
	(Range)	(141-283)	(296-446)							
	Annual Increment	214	150							
1984	Mean Length	209								
	(N)	(9)								
	(Range)	(114-273)								
	Annual Increment	209								
Lake Anna Mean*										
	Mean Length	205	341	484	579	633	706	800		
	(N)	(50)	(110)	(85)	(49)	(47)	(15)	(5)		
	(Range)	(114-283)	(222-519)	(286-603)	(423-761)	(488-794)	(572-820)	(692-833)		
	Annual Increment	205	136	143	95	54	73	94		
Va. State Average (for Reservoirs)										
	Mean Length	193	381	498	610	709	787	838		
	Annual Increment	193	188	117	112	99	79	51		
Mean Growth Before and During Station Operation										
	Pre-operation**	- no data available using the age - at -capture method -								
	Operation+	205	341	484	570	630	700	786		
		(50)	(110)	(85)	(45)	(45)	(14)	(2)		
		(114-283)	(222-519)	(286-603)	(423-761)	(488-794)	(572-820)	(738-833)		
		205	136	143	86	60	70	86		

←O Pre-operational growth of pre-operational year classes
O→ Operational growth of pre-operational year classes
O↓ Operational growth of operational year classes
* Mean lengths calculated using all year classes
** Mean lengths calculated using year class '75 ages 1-3, year class '76 ages 1-2 and year class '77 age 1
\+ Mean lengths calculated using year classes ≥ '78

scale measurements. The advantage of using the back calculated method is that it allows for the comparison of growth between earlier years, the age at capture method does not.

The average growth of striped bass in Lake Anna is greatest during the first two years after which growth increments are reduced. Some reduction in growth increments as fish get older is expected. As fish reach sexual maturity energy and nutrients are channeled into sperm and egg production leaving less for growth (Lagler et al. 1962). Gonadosomatic indices for Lake Anna striped bass indicate this process begins when the fish are approximately 400 mm long (2-3 years old) (Table 4.4-15).

Table 4.4-15. Gonadosomatic indicies for female Lake Anna striped bass.

Date	Length (mm)	G.S.I.
4/82	469	.3
	485	.2
	533	4.7
	652	6.0
4/84	320	1.2
	330	1.1
	340	.4
	340	.6
	352	.4
	355	.4
	385	.3
	400	.3
	415	9.7
	450	8.5
	490	4.6
	520	7.2
	535	12.0
	605	17.0
	625	.8
	661	9.2
	680	11.4

Mean lengths attained by all age groups of striped bass in Lake Anna are below the Virginia average (Smith and Kauffman 1982) for other reservoirs (Table 4.4-16). Lake Anna ranks fifth out of six for Virginia's reservoirs. The lowest mean lengths for striped bass in Virginia are from Western Branch Reservoir; a small (1579 acres), shallow (Max. Depth = 30 ft.) reservoir located in the southeast corner of Virginia. The growth achieved by Lake Anna striped bass is also below that reported for Santee Cooper Reservoir, S.C. (Stevens 1957), Keystone Reservoir, Okl. (Mensinger 1971), Watts Bar, Tenn. (Van Den Aryle and Higginbotham 1978) and Cherokee Reservoir (Nifong 1982).

Growth increment data indicated there has been a general decrease in the growth increments of age 2 striped bass since 1978 (Fig. 4.4-31). This may also be true for age 3 striped bass but the data is inconclusive. The shift in striped bass thermal preferenda is thought to occur at 2-3 years of age (Coutant 1985). It may be that the fish are especially sensitive to temperature - D.O. stresses during this time and aclimate to them as they age. Annual increment data also show an increase in growth during 1984 for age 4-7 striped bass. This increase could be the result of threadfin shad stocking in 1983 and the low station operation in 1984. These events would reduce the effect of predator prey isolation in 1984 due to habitat conditions and thereby promote better growth.

Table 4.4-16. Comparison of mean striped bass lengths (mm) between Lake Anna and other reservoirs.

Reservoir	Length at Annulus						
	1	2	3	4	5	6	7
Kerr-Va.	211	414	546	640	721	777	820
Smith Mt. - Va.	188	389	539	658	757	856	917
Leesville - Va.	211	399	516	610	711	767	803
Claytor Lake - Va.	229	394	498	605	671	772	813
Lake Anna - Va.	154	323	471	573	638	705	786
Western Branch - Va.	189	304	401	506	686	765	
Keystone - Okl.	258	455	541	607			
Watts Bar - Tenn.	182	361	541	688	793	906	992
Cherokee - Tenn.	231	445	599	688	743	794	796
Santee-Cooper - S.C.	216	399	503	582	655	724	767

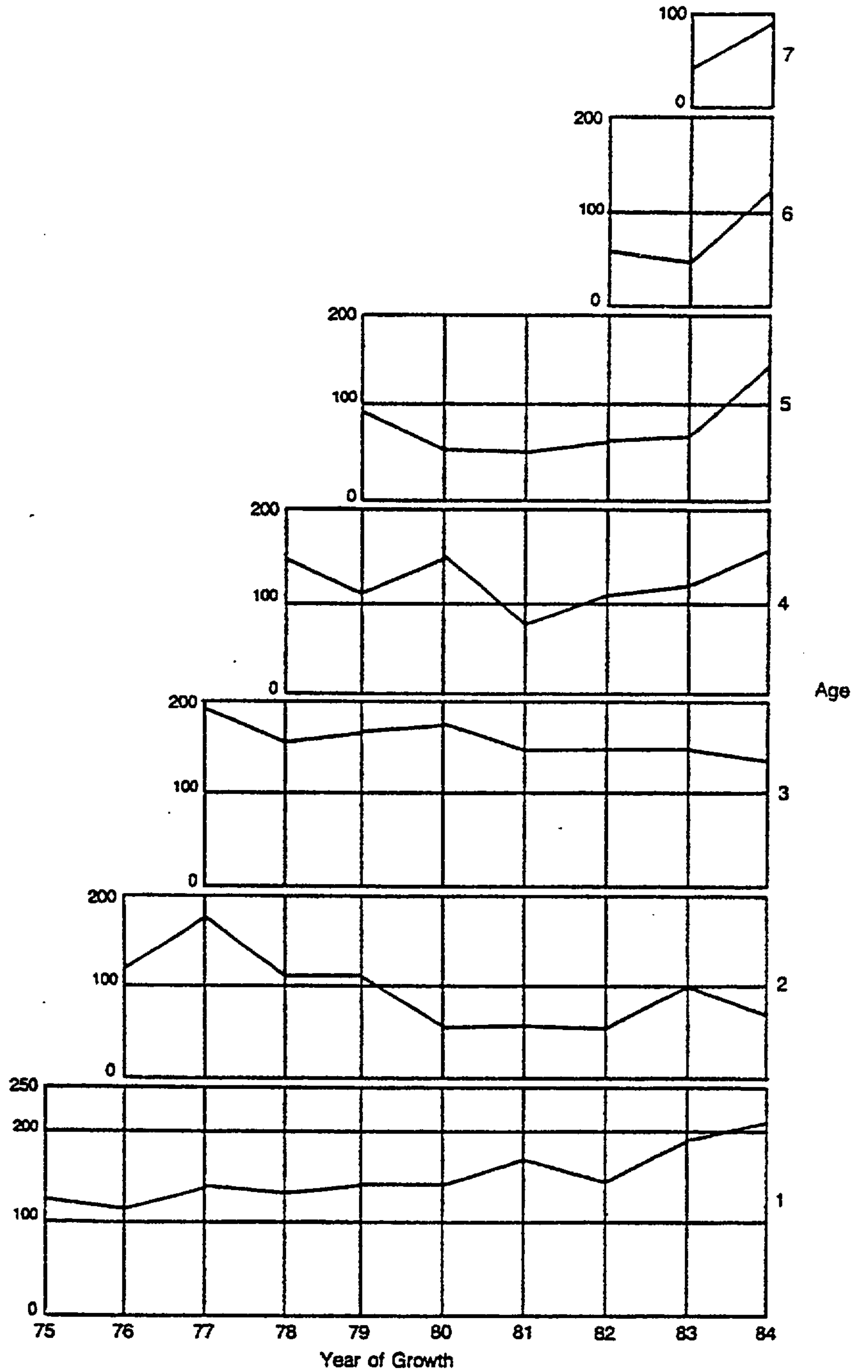


Figure 4.4-31. Growth increments (mm) over time for Lake Anna striped bass (ages 1-7).

Condition Factors

Studies by Schaich and Coutant (1978), Waddle (1979) and Wooley and Crateau (1983) have shown striped bass inhabiting water with temperatures above their optimal thermal preferendum during the summer exhibit a loss of condition, suggesting either less feeding activity and/or an increased metabolic demand. Poor condition has been correlated with the presence of false annuli on striped bass scales (Wooley and Crateau 1983, Bryce and Shelton 1982). False annuli are seen on the scales of Lake Anna striped bass.

In 1985, gill nets were set to collect striped bass from Lake Anna to obtain summer condition factors. During the summer of 1985 striped bass in Lake Anna commonly experienced temperatures of 27°C+. The data (Table 4.4-17) for the fish collected (N=12) show a condition factor less than 1.0 for 10 of the 12 fish. A condition factor of 1.0 indicates a fish is using all its energy intake to meet its basic metabolic demands. A value higher than 1.0 indicates the energy intake is high enough to meet the fish's basic requirements and also promote growth. A value lower than 1.0 indicates the fish is utilizing stored energy reserves to meet its basic energy needs. The smallest fish collected in the survey had a length of 460 mm; its weight of 943 g was below the weight of 1133.8 predicted by the age and growth data set's length-weight equation (Log W = -5.2 + (3.1) (Log L)). Ages of the fish collected were between 2 and 6 years old. Data from these fish indicate that the habitat available to striped bass in Lake Anna during the

Table 4.4-17. Condition factors of striped bass gill netted in Lake Anna during July and August 1985.

Date	Age	Weight	Length	Location	K Factor
7/15	5	3679g	750mm	Elk Creek	0.87
7/25	4	2437g	631mm	W.H.T.F.-2	0.97
8/01	3	2064g	585mm	W.H.T.F.-2	1.03
8/06	6	3369g	736mm	Intake Cove	0.85
8/06	2	1600g	545mm	Intake Cove	0.99
8/06	3	2144g	595mm	Intake Cove	1.02
8/09	3	1518g	545mm	Discharge Canal	0.94
8/09	2	943g	460mm	Discharge Canal	0.97
8/23	6	2769g	711mm	Intake Cove	0.77
8/28	3	2116g	615mm	Intake Cove	0.91
8/28	3	1810g	585mm	Intake Cove	0.90
9/26	4	3400g	705mm	W.H.T.F.-2	0.97

summer of 1985 was at least sub-optimal. The 27°C+ temperatures did not cause a summer die off; however, the exposure time was only about one month, if it were longer the habitat may have been more toward the unsuitable end of the range than toward the sub-optimal part of the range.

Summary of Striped Bass Studies at Lake Anna:

1) Analysis of striped bass habitat availability in Lake Anna for pre-operational years and operational years indicated the following (using Pianka's (1974) terminology and Coutant's (1985) criteria):
   a) There was optimal striped bass habitat (Temp $\leq$ 22°C, D.O. $\geq$ 4 ppm) available during pre-operational years. This habitat is not seen during operational years.
   b) There were large amounts of sub-optimal habitat (Temp $\geq$ 22°C but $\leq$ 25°C, D.O. $\leq$ 4 p.p.m. but $\geq$ 2 ppm) available during the pre-operational years. This habitat, is greatly reduced or eliminated during operational years.
   c) Habitat availability analysis using criteria suggested by Matthews et al. (Temp = 28°C) show consistently available sub-optimal habitat during August of operational years.
2) Investigations of sub-optimal habitat availability (25°C/2 ppm D.O.) during August of 1979 and 1982 indicated precipitation and air temperatures were significant factors, along with station operation, influencing the condition of striped bass habitat during the summer months.

3) Cool summer rains have the potential to temporarily improve striped bass summer habitat.

4) Large "classic" thermal refuges created by cool water inflows, such as springs, do not exist to any detectable degree in Lake Anna due to the granite, volcanic metamorphic composition of the area's soil and bedrock.

5) Adult striped bass appear to be confined to a narrow band of water directly above the anoxic hypolimnion during operational summers due to the temperature and dissolved oxygen regimen of Lake Anna. The temperatures at which striped bass were found during the summer of the 1985 tracking study ranged from 24.7°C to 29.2°C.

6) Station operation was low during July-September of 1984. Habitat availability during this period was not reflective of pre-operational habitat availability which may indicate summer habitat conditions are largely dependent on the effects of station operation on spring stratification patterns.

7) Striped bass in Lake Anna are smaller, relative to age group, than the average for Virginia reservoirs. This may be due to the decline seen in the growth of age 2, and possibly age 3, striped bass since 1978.

8) Condition factors of striped bass collected in the summer of 1985 indicate that the habitat available to striped bass (2+ years old) in Lake Anna during summers of two unit operation is at least sub-optimal.

9) The summer habitat conditions of Lake Anna have not resulted in summer die offs of striped bass.

Creel Surveys

Creel surveys in Lake Anna were conducted during 1976-1979 and in 1984 and 1985 from March through November by clerks selected by the Virginia Commission of Game and Inland Fisheries. The surveys were "access point" surveys where anglers were contacted generally at the end of their fishing trips. The advantage of this type of survey compared to the roving survey is that information is based on completed trips rather than incomplete trips. There are, however, two general problems inherent in creel surveys: (1) the problem of relating survey results to the entire population and (2) the logistical problems of contacting a representative sample of anglers in a large lake such as Lake Anna (Malvestuto 1983). These problems are minimized with a good statistical survey design and associated analyses as was done for Lake Anna. The Lake Anna creel surveys were stratified by time of day (morning or afternoon) and type of day (weekend or weekday) by application of non-uniform sampling probabilities. Boat access areas were also surveyed on a non-uniform probability basis (Sledd and Shuber 1981). As the same sampling methods and data analysis were applied to Lake Anna creel surveys during both the 1976-1979 and the 1984-1985 study, data comparisons can be made between these years with a high degree of reliability.

Angler usage of Lake Anna during 1985 was higher than any year previously studied (1976-1979 and 1984) (Table

4.4-18). The estimated total number of fish creeled during 1985 was lower than earlier years (1976-1979), but the expanded total weight was comparable to that of 1976 and greater than 1979. One would expect, as these creel data indicate, early levels of fish biomass and harvest to be somewhat higher in a newly formed lake than those found 15 years later. Upon initial formation of a lake by stream impoundment, there are very high productivity levels and fish biomass levels. After five to ten years environmental conditions and fish biomass tend to stabilize at levels below those associated with initial formation (Baxter 1977; Jenkins 1977; Kimmel and Groeger 1986).

Bluegill and black crappie showed the greatest difference in number of fish creeled between 1976-1979 and 1985 (Table 4.4-18) The number of largemouth bass creeled during 1985 is comparable to the 1976-1979 year average (Table 4.4-18). The decline in number of black crappie creeled reflects the general decline of this species in Lake Anna. The decline in number of bluegill creeled between 1976-1979 and 1984-1985 may reflect, to some extent, a change in fishing pressure (preference) away from sunfish to other, larger species such as striped bass, walleye and largemouth bass since 1979. This trend is indicated in species preference data from these surveys (Table 4.4-18).

The number of largemouth bass creeled during 1985 is similar to the average number creeled during the 1976-1979 survey and higher than 1984 results. This is significant in view of the heavy and constantly increasing

Table 4.4-18 Results of creel surveys from all years for which data is available, Lake Anna Virginia.

	1985	1984	Average 1976-1979
Expanded number of fishermen	32,341	26,280	30,778
Expanded number of hours fished	209,309	172,005	181,952
Expanded number of fish creeled	51,615	38,110	122,952
Expanded weight of fish creeled (lbs)	54,228.6	35,041.3	64,343
Average weight of fish creeled (lbs)	1.05	0.920	0.54
Pounds creeled per acre	5.66	3.65	6.70
Pounds creeled per angler hour	0.26	0.21	0.67
Types of Fishing (%)			
Boat	96.2	97.2	N/A
Shore	3.8	2.8	N/A
Fishermen Species Preference (%)			
General Fish	31.66	32.63	34.17
Rough Fish	.59	1.58	0.10
Pickeral	.00	0.05	0.44
Walleye	.00	0.07	-
Largemouth bass	63.05	63.26	52.98
Black crappie	2.94	1.29	7.29
Striped bass	1.67	0.82	0.10
Sunfish	0.08	0.29	0.60
Species Creeled			
largemouth bass number	10,273	6,802	10,865
largemouth bass weight (lbs)	27,602.9	15,612.9	18,218.4
largemouth bass average weight(lbs)	2.687	2.295	2.13
black crappie number	25,130	15,992	89,915
black crappie weight (lbs)	7,399.3	2,723.3	31,708.3
black crappie average weight (lbs)	0.294	0.170	0.35
bluegill number	9,770	9,056	14,605
bluegill weight (lbs)	2,246.8	1,784.6	3,901.2
bluegill average weight (lbs)	0.230	0.197	0.27
white perch number	1,859	2,610	86
white perch weight (lbs)	599.9	583.3	44.5
white perch average weight (lbs)	0.323	0.223	0.48

Table 4.4-18 continued

	1985	1984	Average 1976-1979
channel catfish number	2,610	2,733	1,430
channel catfish weight (lbs)	10,162.3	9,611.3	1,788.8
channel catfish average weight(lbs)	3.894	3.517	1.23
yellow perch number	683	107	1,828
yellow perch weight (lbs)	260.5	76.6	868.6
yellow perch average weight (lbs)	0.381	0.716	0.48
striped bass number	798	171	24
striped bass weight	4,847.3	1,639.7	119.8
striped bass average weight	6.074	9.589	4.39
walleye number	23	9	26
walleye weight	28.8	23.1	62.8
walleye average weight	1.252	2.567	1.16
common carp number	59	282	12
common carp weight	317.4	2,566.0	82.3
common carp average weight	5.380	9.099	1.42
brown bullheads number	11	43	2,464
brown bullheads weight	7.4	6.9	582.6
brown bullheads average weight	0.673	0.159	0.28
eel number	29	-	-
eel weight	71.3	-	-
eel average weight	2.459	-	-
chain pickeral number	372	305	857
chain pickeral weight	744.5	413.3	1,888.7
chain pickeral average weight	2.001	1.355	4.39

fishing pressure exerted on this species. During 1985 there were 11 largemouth bass fishing tournaments out of a single marina on Lake Anna. High bass fishing pressure has been postulated to be the primary cause of declines in the harvestable largemouth bass populations in other areas (Coomer and Holder 1981). Also, a catch survey in North Carolina initiated in 1975 to monitor angler success has shown a steady decline in number of largemouth bass creeled per hour fished from 1977 to 1980 (Van Horn and Birchfield 1981). In spite of heavy fishing pressure Lake Anna continues to produce high numbers of citation-size fish, although numbers have declined in recent years following a statewide trend. Lake Anna was second in the state in largemouth bass citations during 1984 and led the state in 1985 (Table 4.4-19). The lake had the second highest number of channel catfish citations in the state during 1985 (90) and also produced 46 striped bass citations (Table 4.4-19) (Virginia Commission of Game and Inland Fisheries 1986).

The estimated number of fishermen, hours fished and number of fish creeled increased during 1985 compared to 1984 (Table 4.4-18). The number of pounds creeled per angler hour also increased during 1985. This indicates that, although fishing pressure was greater during 1985, fishing success also increased. The average weight of fish creeled during 1985 also was higher than found during the 1984 survey.

Generally, the creel data indicate an increase in sport fish harvest and a decrease in rough fish and catfish

Table 4.4-19 Number of citation largemouth bass (greater than eight pounds) and striped bass (greater than fifteen pounds) caught from Lake Anna.*

Year	Largemouth Bass	Striped Bass
1976	2	
1977	7	
1978	9	
1979	27	5
1980	34	10
1981	58	42
1982	126	60
1983	81	53
1984	42	57
1985	41	40

*Personal communication C. Sledd, Virginia Commission of Game and Inland Fisheries.

caught during 1985. Three species of fish primarily contributed to the substantial increase (35%) in the number of fish creeled during 1985 compared to 1984. The number of largemouth bass estimated to have been creeled during 1985 increased 51%, black crappie increased 57% and striped bass increased 366%. Other species showing increases were yellow perch, bluegill, chain pickeral and walleye. Species showing large declines in the number estimated to have been creeled during 1985 were white perch (29%) and common carp (79%). Brown bullhead and channel catfish were other species with creel declines.

The increase in number of fish creeled and the increase in fishing success during 1985 would appear to indicate a larger standing crop of sport fish available for capture. The possible reasons for this increase are the presence of underwater structure, constructed in 1984 and 1985, and the introduction of threadfin shad, a new forage species, in 1983. Freshwater artificial reefs have been shown to have higher harvest rates for some species than areas without artificial reefs (Paxton and Stevenson 1979). It is not known whether this is an actual population increase relating to the reefs or simply a result of concentration due to increased forage availability or protection from predators for smaller fishes. Threadfin shad introductions have been shown to cause expansions of existing fish populations in other lakes (Swingle and Swingle 1967).

Direct comparisons of creel harvest from Lake Anna with other lakes may not be totally reliable because of differences in methodology. A survey of angler harvest from 103 reservoirs throughout the United States derived an area-weighted mean of 16.4 kg/ha (14.6 lbs/acre) (Jenkins and Morais 1971) which is well above the 1984 and 1985 means for Lake Anna (4.09 kg/ha -3.65 lbs/acre and 6.3 kg/ha - 5.66 lbs/acre, respectively). Jenkins (1968) also determined a formula for establishing sport fish harvest capacity for lakes utilizing lake area, shore development, total dissolved solids, length of growing season and lake age. When this formula was applied to Lake Anna the result was 13.0 kg/ha (11.6 lbs/acre), a value below the mean of the 103 lakes mentioned earlier, but still much higher than that found by creel surveys. A similar formula designed to indicate total fish biomass was close to that estimated for Lake Anna from rotenone surveys. A possible reason for the apparent discrepancy in creel survey versus formula and comparison creel harvest may be angler species preference and even size preference within a species in Lake Anna. Most of the fishing pressure in Lake Anna is from fisherman who travel some distance to get to the lake since it is in a relatively rural area. Fishing parties utilizing Lake Anna during 1985 traveled an average of 77.9 miles. These fisherman invest considerable time and money in this pursuit and are usually interested in keeping only a few large fish, i.e. largemouth bass, striped bass, walleye and black crappie, as is evidenced in the angler species preference poll where about 68% of the fishermen interviewed in 1985 fished for these four species. Fishing from the shore accounted for less than 4% of the fishing modes used on Lake Anna during 1985 (Table 4.4-18). This trend may also be seen in the decline of bluegill creeled during 1984/1985 compared to 1976-1979 data mentioned earlier.

The 1984-85 creel survey data from Lake Anna indicate the continuance of an abundant healthy sport fish population. This population appears to be flourishing even under increasing, though selective, fishing pressure.

Summary

The results from 11 years of fish population studies on Lake Anna indicate that the community structure has remained relatively stable since 1975. During the early years of these studies, 21 and 22 species were collected from Lake Anna by rotenone sampling (1975 and 1976) whereas in later years (1984 and 1985) 27 species have been collected annually. Four of the species in the lake are non-indigenous introductions, of which striped bass and walleye must be restocked annually and threadfin shad must have an inflow of heated water to survive the winter. Limited pre-operational data appear similar to operational results. No significant differences (.05 level) in diversity values were found in electrofishing and gill netting data examined seasonally for Upper, Mid and Lower Lake areas from 1981-1985. Trends for changes in fish species composition were similar in the Upper, Mid and Lower

Lake. Changes in species composition since 1975 were primarily due to lake aging, possible natural population fluctuation, and in response to numerous species introductions.

The introduction of threadfin shad into the lake in 1983 appears to have increased the total forage base in Lake Anna in conjunction with an increase in predator fish biomass levels. Levels of largemouth bass biomass have remained fairly constant in the lake since 1975. This species appears to be spawning and developing normally with yearly growth comparable to the Virginia State average. Lake Anna led the state in number of Largemouth bass citations ($\geq$8 pounds) during 1985 (41), it was second in the state during 1984. Black crappie appear to have experienced slow growth in Lake Anna, possibly due to a lack of suitable habitat and limited availability of preferred forage. The recent construction of artificial structures and introduction of threadfin shad may improve black crappie growth in the lake. Walleye appear to be growing well in the lake but do not reproduce there, so require annual stocking. There is a good striped bass fishery in Lake Anna, however, striped bass in Lake Anna are smaller, relative to age group, than for most other Virginia reservoirs, possibly reflecting a low level of habitat availability. The number of striped bass citations during 1985 (40) was similar to the number of largemouth bass citations. An outbreak of a parasitic copepod infestation occurred among large game fish during 1984. No cases were observed during 1985 and fish disease is not a problem in the lake.

Fishing pressure in Lake Anna has increased since an earlier study (1975-1979) whereas success has declined, primarily due to lake aging and perhaps a shift in angler preference. The estimated total weight of fish creeled annually has remained high as has the number of largemouth bass creeled.

The lake wide fish standing crop (kg/ha) remained relatively stable from 1975 through 1984, and increased in 1985 due primarily to threadfin shad. Fish population trends in Lake Anna are consistent with those found in other reservoirs. The balance between predators, plankton feeders and bottom feeders is similar to that of a typical reservoir. Increased mixing of lake water from the operations of station circulating water pumps has increased the lake epilimnion by about 27% over pre-operation levels. This has increased the amount of living space available to indigenous warm water fishes, but reduced that available to striped bass. The Lake Anna mean fish standing crop is comparable to that of other reservoirs in this area of the country. Since the development of the lake, fish population changes have occurred primarily due to lake aging and introductions, but the basic integrity of the fish community has been maintained. Biomass levels have generally remained constant except for increases due to threadfin shad introductions, in 1984 and 1985, and the number of species regularly collected has increased.