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Threadfin Shad Impingement; Effect of Cold Stress

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ENVIRONMENTAL SCIENCES DIVISION

Publication No. 1495

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THREADFIN SHAD IMPINGEMENT: EFFECT OF COLD STRESS

Report to the Nuclear Regulatory Commission for
period October 1, 1976, to September 30, 1978

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ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1495

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ABSTRACT

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Temperature greatly influenced impingement of threadfin shad, young-of-the-year gizzard shad, and probably young-of-the-year river herring. Temperature also greatly influenced any potential effects that loss of these prey had on predators. Natural cold kills of threadfin and young-of-the-year gizzard shad masked any ecological effects due to impingement. Most of the shad, had they not been impinged, would have died due to cold stress, and these dead shad would have decomposed rather than been eaten by scavengers. Loss of shad had a measurable short-term effect on sauger, as determined by changes in condition factor, and this loss of shad contributed to an increase in percent empty stomachs of skipjack herring, striped bass, and white bass. Thermal refuges, including the Kingston Steam Plant discharge, were identified for gizzard shad and hybrid shad. Hybrid shad made up 11.2% of the total threadfin population sampled both years (1976-77 and 1977-78). Blood serum electrolytes (Na^+, K^+, Cl^-) were not found to be good predictable indicators of cold stress of young gizzard shad.

SUMMARY

The objectives of the research were to (1) determine the physical and biological causes of threadfin shad impingement at the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, (2) quantify the effects of impingement on threadfin shad population number and structure, (3) quantify the effects of impingement of threadfin shad on threadfin predators, and (4) determine the feasibility of using blood serum electrolytes to quantify cold stress of shad.

The study was conducted between November 1976-April 1977 and September 1977-April 1978. The results of our research are as follows:

1. The first year an estimated 240,000 threadfin shad were impinged, representing 96% of the fish of all species impinged. The second year, 560,000 threadfin, 354,000 gizzard shad, and 338,000 skipjack herring were impinged. Peaks of impingement of threadfin and young-of-the-year gizzard shad coincide with rapid drops in temperature. Intake hydrology and negative rheotoxis behavior of threadfin may cause threadfin to concentrate in the intake canal at the power plant, thus contributing to their impingement.
2. Effects of impingement of threadfin shad on threadfin population number and structure could not be determined. A standing stock estimate, using cove rotenone samples, could be made only during the summer when water temperatures were high. Thus, changes in population number and structure between July and the beginning of impingement in November could not be estimated. Impingement plus reservoir-wide mortality of threadfin due to cold stress during the winters of 1976-77 and 1977-78 may have resulted in a 95%

reduction in the population each winter. The population rebounded by early fall each year.

3. Impingement of threadfin shad and young-of-the-year gizzard shad, the principal forage species, coupled with reservoir-wide mortality of threadfin due to cold stress, had a measurable effect on sauger and resulted in an increase in the percentage of empty stomachs of skipjack herring, striped bass, yellow bass, and white bass. During periods of low prey availability, large sauger lost relatively more condition than small sauger due to the energy demands of gonadal development of the large sauger. The loss of condition was minimized, however, because of prey switching and stores of visceral fat.

4. Threadfin shad rebounded after mass mortality. A remnant of the population may have overwintered in thermal refuges and spawned both in the spring and summer. Threadfin hatched in spring, spawned by summer. It is our hypothesis that hybridization of threadfin with gizzard shad produces a cold-tolerant fish that is also reproductively viable.

5. Short- and long-term ecological effects of the loss of a principal forage species can be determined (a) if the percent of the forage population affected is determined, (b) if the condition of the predators is monitored, (c) if the ability of predators to switch prey and store energy reserves is quantified, and (d) if resiliency of the forage population is defined.

6. Blood serum electrolytes (Na^+, K^+, Cl^-) were not found to be good predictive indicators of cold stress of shad. Electrolyte levels were sensitive to a variety of stresses, making it difficult to isolate those changes due only to temperature.

TABLE OF CONTENTS

Page

APPENDIX D

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Threadfin shad (Dorosoma petenense) a fish native to the Gulf Coast from Florida to Texas, was found in the mainstream Tennessee impoundments in 1948 and has in recent years been stocked in many states including Virginia, Georgia, Pennsylvania, California, Nevada, Arizona, Kansas, New Mexico, Hawaii (Minckley and Krumholz 1960), and Tennessee (Ihrie 1970). Since the introduction and subsequent proliferation of threadfin shad, these fish comprise 90% of all fish impinged in 11 areas across the southeastern United States (Loar et al. 1978). As a result of their proliferation, threadfin have also become an important forage fish. Therefore, impingement of these fish may affect not only threadfin populations but predator populations as well.

The objectives of this study which covers the time period between November 1976 and April 1978 are (1) to identify the physical and biological parameters that contribute to the impingement of threadfin shad, (2) to define effects of threadfin impingement on threadfin population numbers and structure, and (3) to demonstrate effects of threadfin impingement on threadfin predators and a scavenger.

Each of the above objectives involves a relatively discrete area of research and is presented separately in the methods sections. Results are separated both by subject and year of study. The contribution of each of the above three areas in helping to reach the overall objective of providing answers to the generic problems of cause and effects of impingement and in aiding the process of environmental impact assessment is integrated into a single discussion section. The value of impingement monitoring as an environmental assessment tool is also emphasized.

Study Area

Watts Bar Reservoir, beginning at River Mile (RM) 529.9 on the Tennessee River, impounds 13,300 ha at minimum navigation pool 224 m above mean sea level. The upper portion of the reservoir is characterized by riverine reaches of the Emory, Clinch, and upper Tennessee River tributaries (Fig. 1). The Emory River is unimpounded above Watts Bar Reservoir, whereas flows and temperatures of the Clinch and upper Tennessee Rivers are influenced by upriver dams at Clinch River Mile (CRM) 23.4 and Tennessee River Mile (TRM) 602.3.

The Tennessee Valley Authority's Kingston Steam Plant, located at CRM 2.7, 48.3 km west of Knoxville, Tennessee (Fig. 1), is a fossil-fuel facility with a generating capacity of 1700 MW and cooling water requirements of 65 m^3/s. Cooling water is withdrawn from either Clinch or Emory sources, depending on reservoir level and the temperature and flow of each. A skimmer wall at the mouth of the intake canal and a 6-m-high underwater dam 0.8 km downstream from the confluence of the Emory and Clinch Rivers were designed to direct cold water from the Clinch River through the plant intake in summer. Discharge temperature is elevated 7.8 C during maximum power generation.

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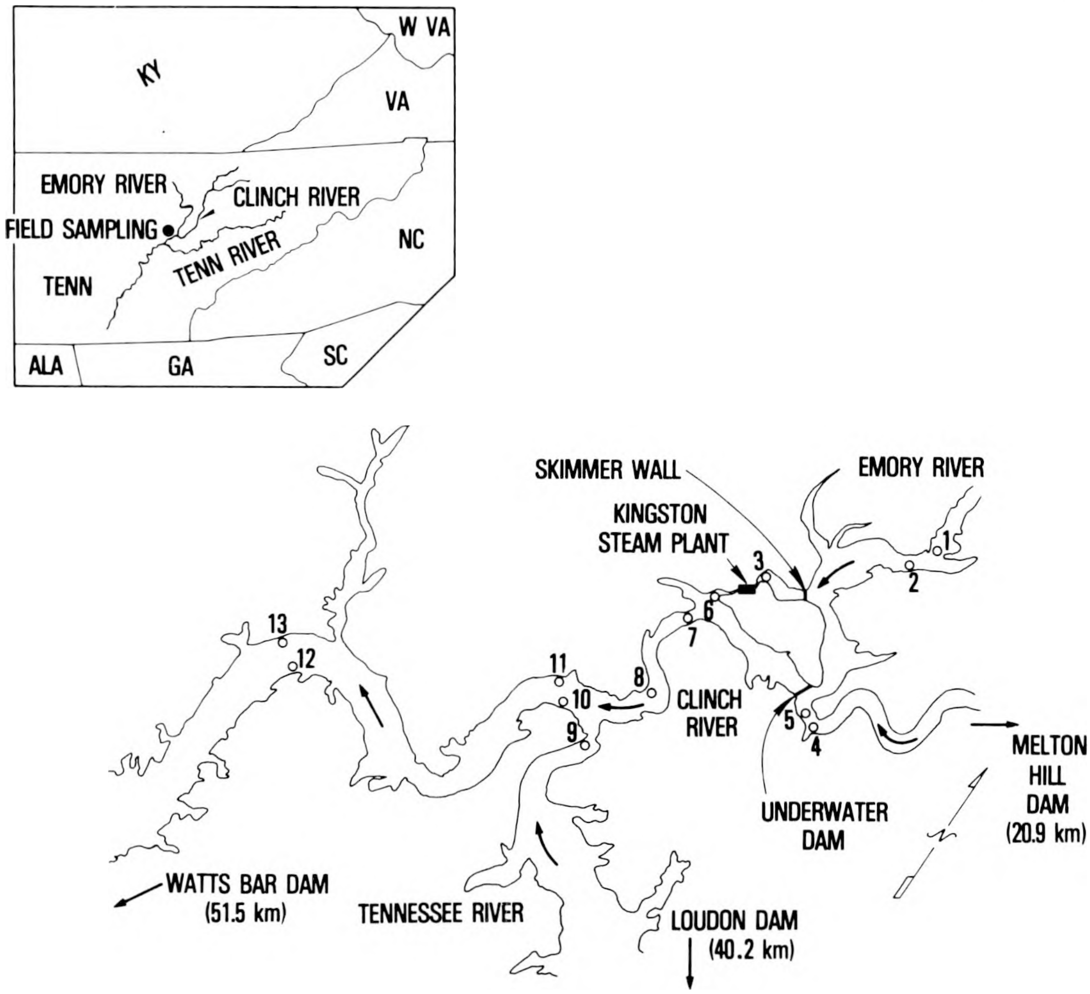

Fig. 1. Location of sampling stations and Kingston Steam Plant on Watts Bar Reservoir, Tennessee.

THREADFIN IMPINGEMENT

The impingment of fish on intake screens of power plants is believed to be a result of the intake design, physical parameters such as temperature, and biological parameters such as fish behavior and local abundance. A review and analysis of the impingement data at power plants in the Southeast (Loar et al. 1978) indicates impingement of threadfin increases as temperature drops below 10 C. Threadfin schooling behavior and temperature-related movement may also contribute to their impingement. This section deals with the subject of impingement at the Kingston Steam Plant as a function of physical and biological variables measured there.

Methods

Impingement was monitored for three 24-h periods weekly from mid-November 1976 through April 1977 and September 1977 through April 1978. All of the 18 vertical traveling screens that were associated with operational pumps were rotated and washed at 0900 hours on Sunday, Tuesday, and Thursday of each week. Twenty-four hours later, screens were rewashed and impinged fish were collected in a catch basket installed in the screen wash-water sluiceway. Fish were separated by species into 25-mm length classes (total length), counted, and weighed. If samples were too large to be processed in several hours, a subsample was taken and extrapolated to the total fish impinged.

To determine the relative abundance of threadfin at stations heated by the power plant discharge compared to those unheated, bottom-set gill nets were used during the period of impingement monitoring at 13 sites within 15 km of the steam plant (Fig. 1). Gill nets were set for 24 h each week in the Clinch and Emory Rivers (sites 1 to 4) and biweekly at the other sites. Four types of nets were used according to water currents and fish abundance: (1) two 22-m panels, 13- and 25-mm bar mesh (Stations 2 and 4); (2) two 15-m panels, 13- and 25-mm bar mesh (Station 6); (3) four 15-m panels, 13-, 25-, 38-, and 51-mm bar mesh (Station 3); and (4) five 8-m panels, 13-, 19-, 25-, 32-, and 38-mm bar mesh (Stations 2, 5, 7-13). All data were normalized for a 24-h set of an 8-m panel with 13-, 25-, or 38-mm bar mesh which is defined as a standard gill-net unit. The Mann-Whitney statistic was used to examine the differences in catch-per-unit-effort (CPUE) between stations. Ice cover on the reservoir prevented gill-netting at some sites from mid-January through early February 1977. Temperature-depth profiles were taken at the time of each set, and continuous recordings of intake and discharge temperatures were obtained from the Hydraulic Data Branch of the TVA.

Results, 1976-77

An estimated 240,000 threadfin shad were impinged at the Kingston Steam Plant from mid-November 1976 through April 1977 (Appendix A). This species represented 96% of all fish impinged during the study. These data underestimate the number impinged by perhaps as much as 10% because some fish were not retained in the catch basket on days of very high impingement and because impingement rates began to increase in October and November before we began monitoring. Steam plant personnel noted that threadfin shad impingement began to increase (from a background level of a few dozen shad per day) during the last week of October as intake temperatures first dropped below 15 C.

Increases in impingement of threadfin shad were strongly associated with the seasonal cooling of reservoir waters (Fig. 2). Approximately 3000 individuals per day were impinged throughout the latter half of November when intake water was being pulled from the Clinch River. Unusually cold weather the first week of December lowered intake temperatures to 7 C on December 5, and increased impingement to approximately 5000 threadfin shad per day.

The sudden increase in impingement to approximately 42,000 on December 8 occurred as 4 C water from the Emory River displaced warmer Clinch River water on December 7 and began flowing through the submerged skimmer opening. By the next day, water from the Emory had reached 2.7 C and had severely stressed large numbers of shad present in the intake canal. By January 5, 99.8% of all fish during the sampling period had been impinged (Figs. 3 and 4).

The proportion of size classes changed as the temperature decreased. From mid-November to mid-December the $\leq$ 100-mm size class dominanted (Fig. 5) comprising 61.3% of all impinged threadfin. However, the larger size classes dominated the samples during the remainder of December through April. Scale analysis indicated that the young-of-the-year threadfin shad ranged from 93 to 112 mm and those of age 1+ from 133 to 159. Percent of total number by size class is shown in Table 1. Hybrids (gizzard shad x threadfin shad) were also noted on the screens during the latter months. Although no quantitative record

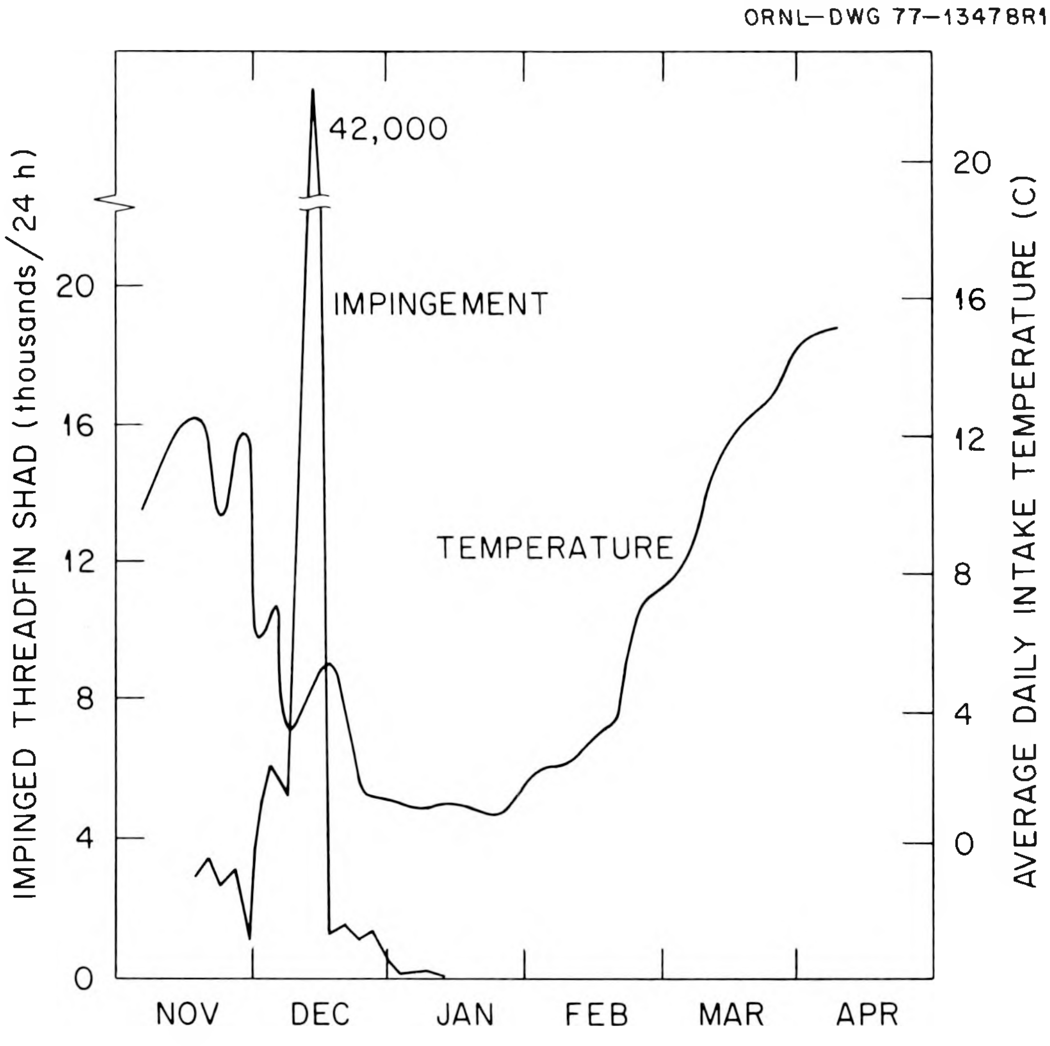

Fig. 2. Impingement of threadfin shad at Kingston Steam Plant, Watts Bar Reservoir, Tennessee, and water temperatures at the intake canal from November 1976 to April 1977.

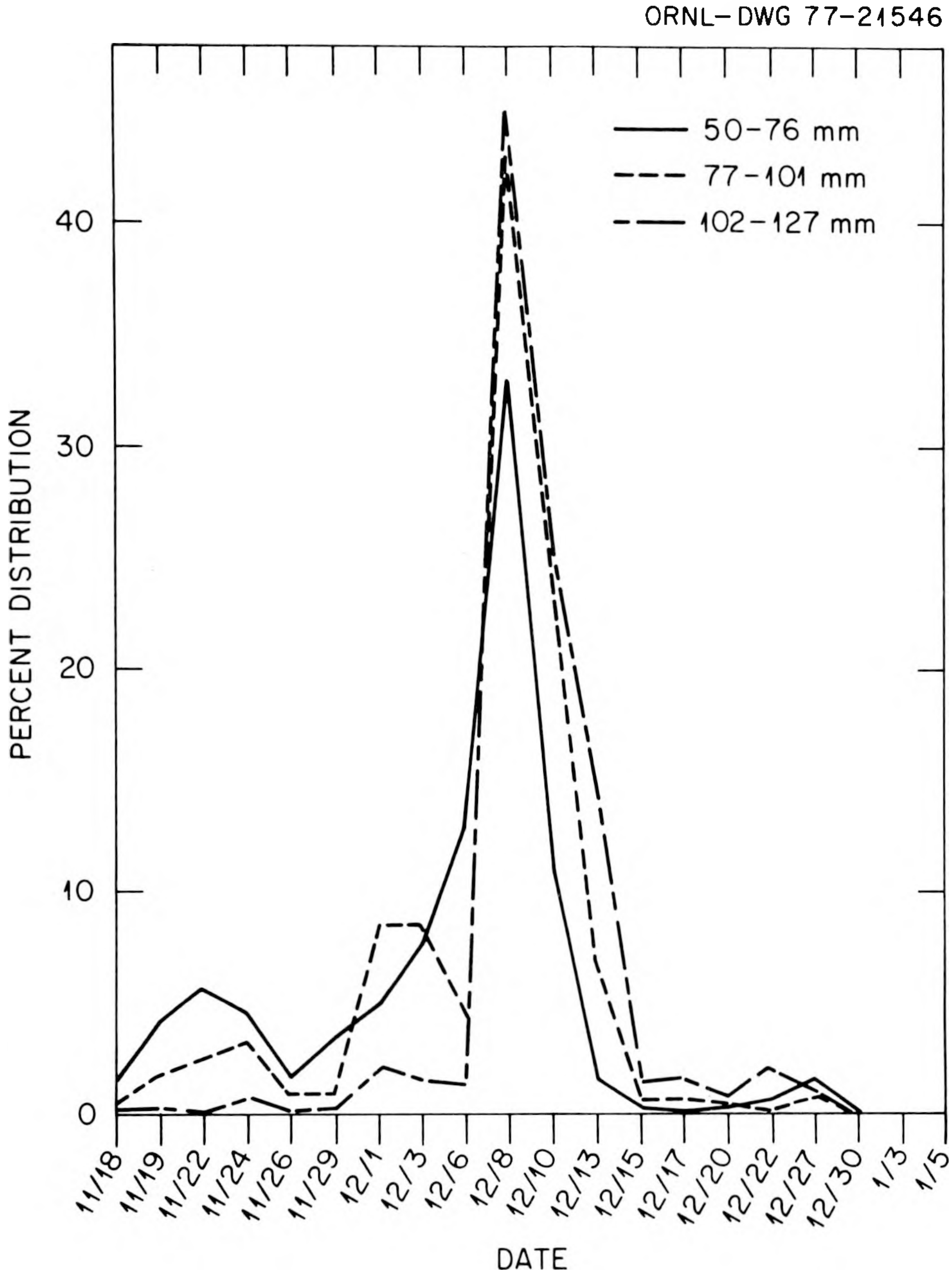

Fig. 3. Percent distribution with time of each of three of the smallest size classes of threadfin shad impinged at Kingston Steam Plant, Watts Bar Reservoir, Tennessee, November 18, 1976, through January 5, 1977 (cumulative percent distribution for each size class equals 100%).

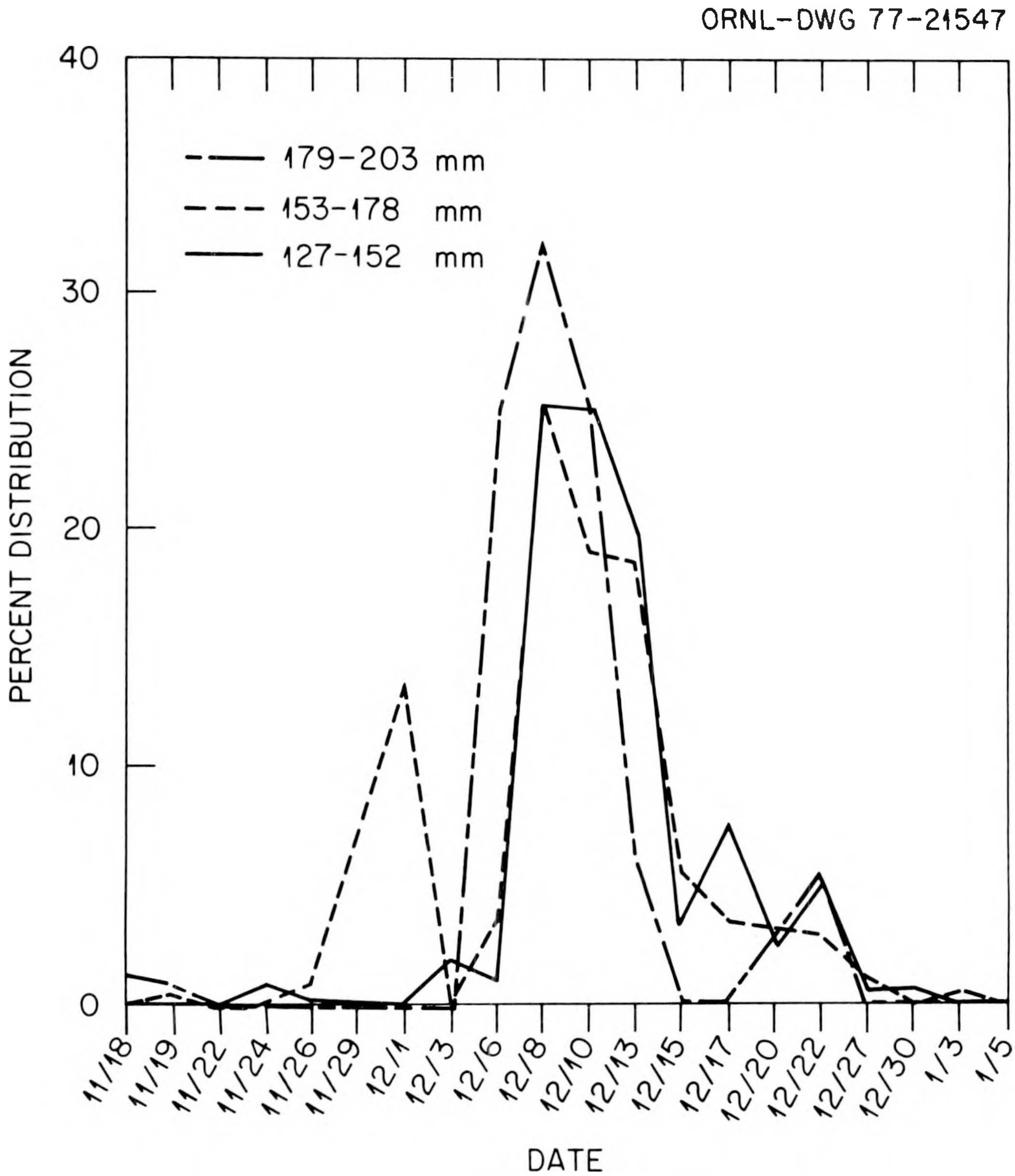

Fig. 4. Percent distribution with time of each of three of the largest size classes of threadfin shad impinged at Kingston Steam Plant, Watts Bar Reservoir, Tennessee, November 18, 1976, through January 5, 1977 (cumulative distribution for each size class equals 100%).

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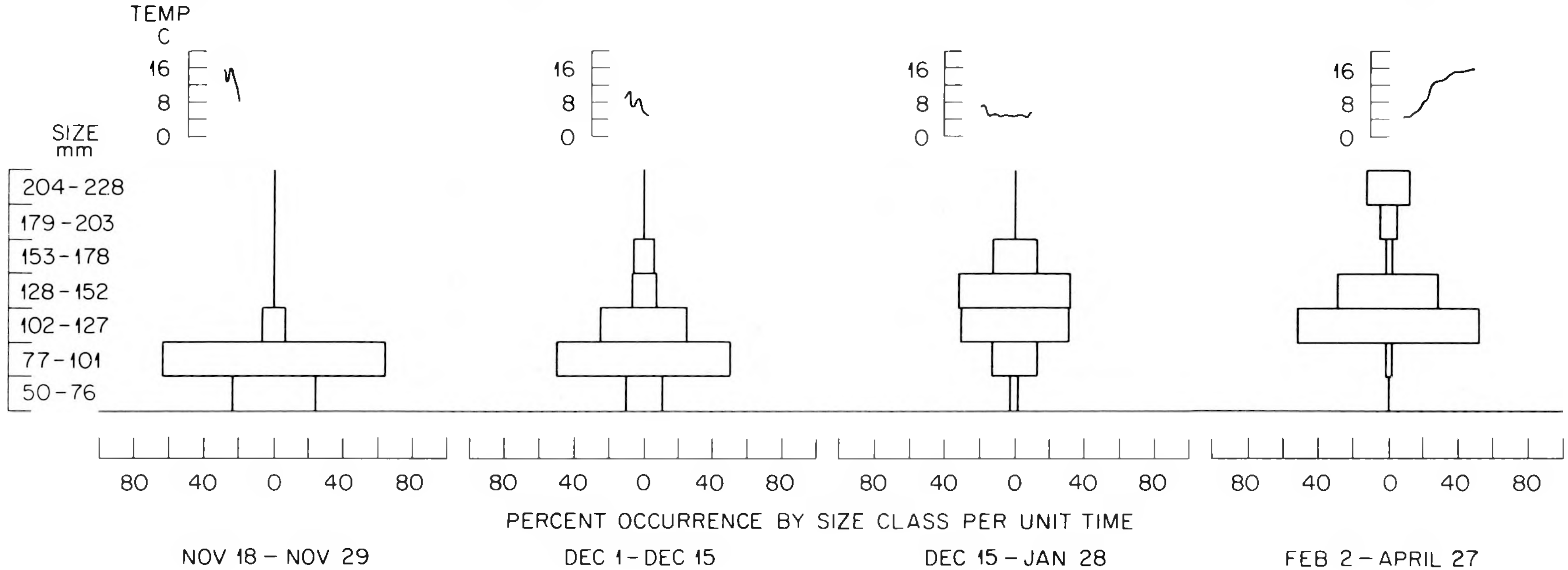

Fig. 5. Percent occurrence by size class of threadfin shad (Dorosoma petenense) impinged during four time periods at Kingston Steam Plant, Watts Bar Reservoir, Tennessee, and water temperatures for each time period between November 18, 1976, through April 27, 1977.

Table 1. Percent of total number impinged, percent of total weight impinged, and mean weight per fish by size class of threadfin shad impinged at Kingston Steam Plant, Watts Bar Reservoir, Tennessee, November 18, 1976, through April 27, 1977

	Size class (mm)						
	50-76	77-101	102-127	128-152	153-178	179-203	204-228
Percent of total number impinged	10.7	50.6	28.4	6.4	3.5	0.3	0.005
Percent of total weight impinged	3.0	31.5	30.5	18.8	14.5	1.7	0.06
Mean weight per fish (g)	2.7	6.0	10.3	28.1	39.5	51.6	101.8

was kept, we estimated that these comprised less than 0.5% of the total impinged threadfin.

Gill-netting data indicated that threadfin were relatively abundant in January only at the thermally affected stations (Nos. 6, 7, 8; Fig. 1). During the period December 23 to January 25, when ambient water temperatures were approaching the lower lethal limits of threadfin of 5 to 7 C (Griffith 1978), significantly ($P > 0.01$) more fish were caught in the thermally affected stations than during the warmer period (October 24-December 21, Fig. 6) (Appendix B and C). A rapid drop in temperature resulted in a massive kill of threadfin shad in the reservoir in January. No fish were detected in any areas monitored except for a remnant in the discharge. The number of fish caught per net unit peaked in January, due mainly to an increased concentration of fish in the discharge (Fig. 7).

Secchi disc readings in the intake indicated lower suspended solids in the water during the months of heavy impingement. During December through February, the average reading in the intake was 163 cm compared to normal readings of 20 to 80 cm during summer and early fall. Reduced visibility, therefore, probably did not contribute to impingement.

Results, 1977-78

Few threadfin shad were expected to be impinged during 1977-78 because the winter kill of 1976-77 decimated the population. However, 560,000 threadfin were impinged between September 27, 1977, and April 28, 1978, compared to 240,000 during November 1976 - April 1977

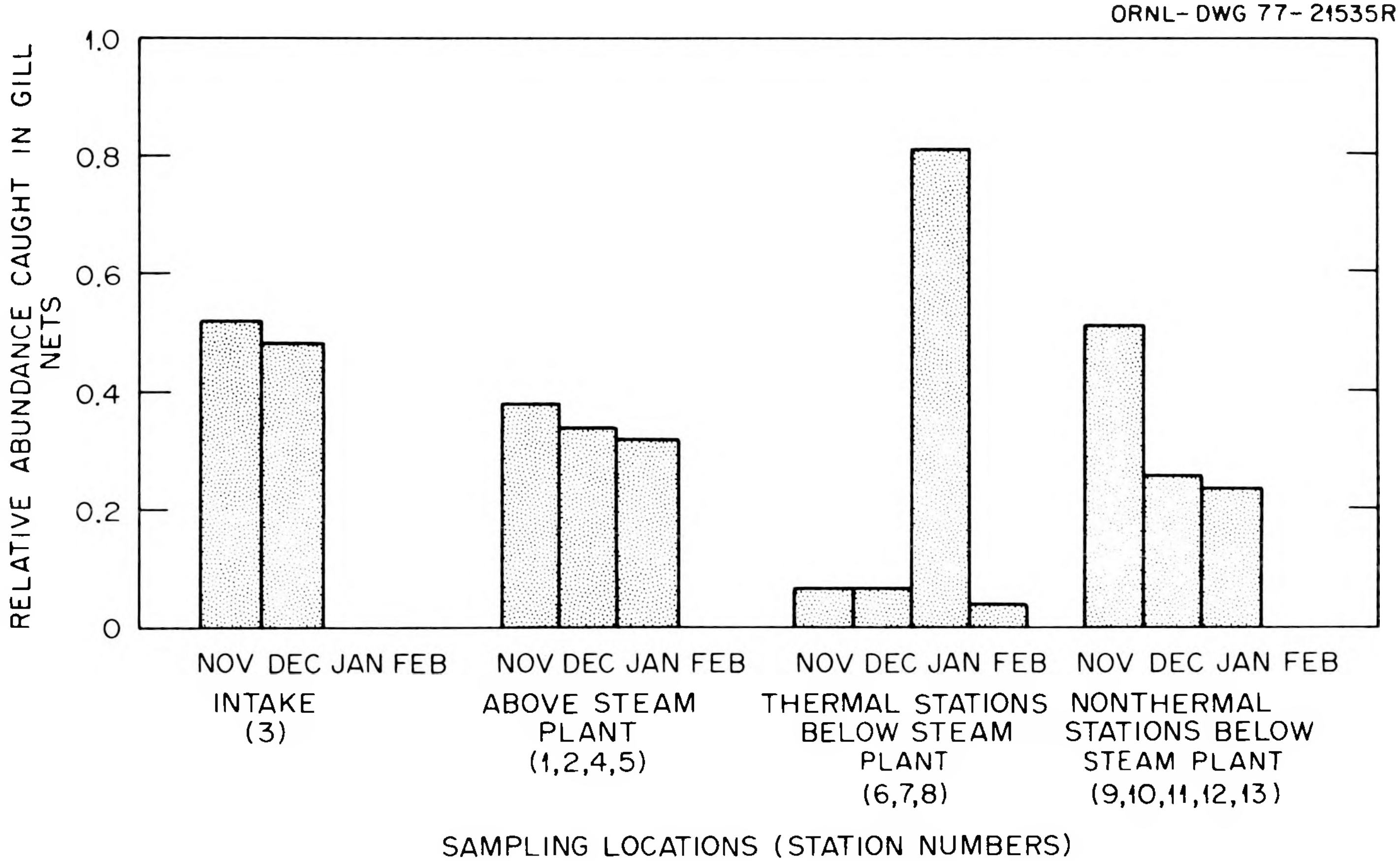

Fig. 6. Relative abundance of threadfin shad during November 1976 through February 1977 at four groups of sampling stations (see Fig. 1 for sampling locations) as determined by mean number of fish caught per standard gill-net unit (cumulative relative abundance at each group of sampling stations equals 1.0).

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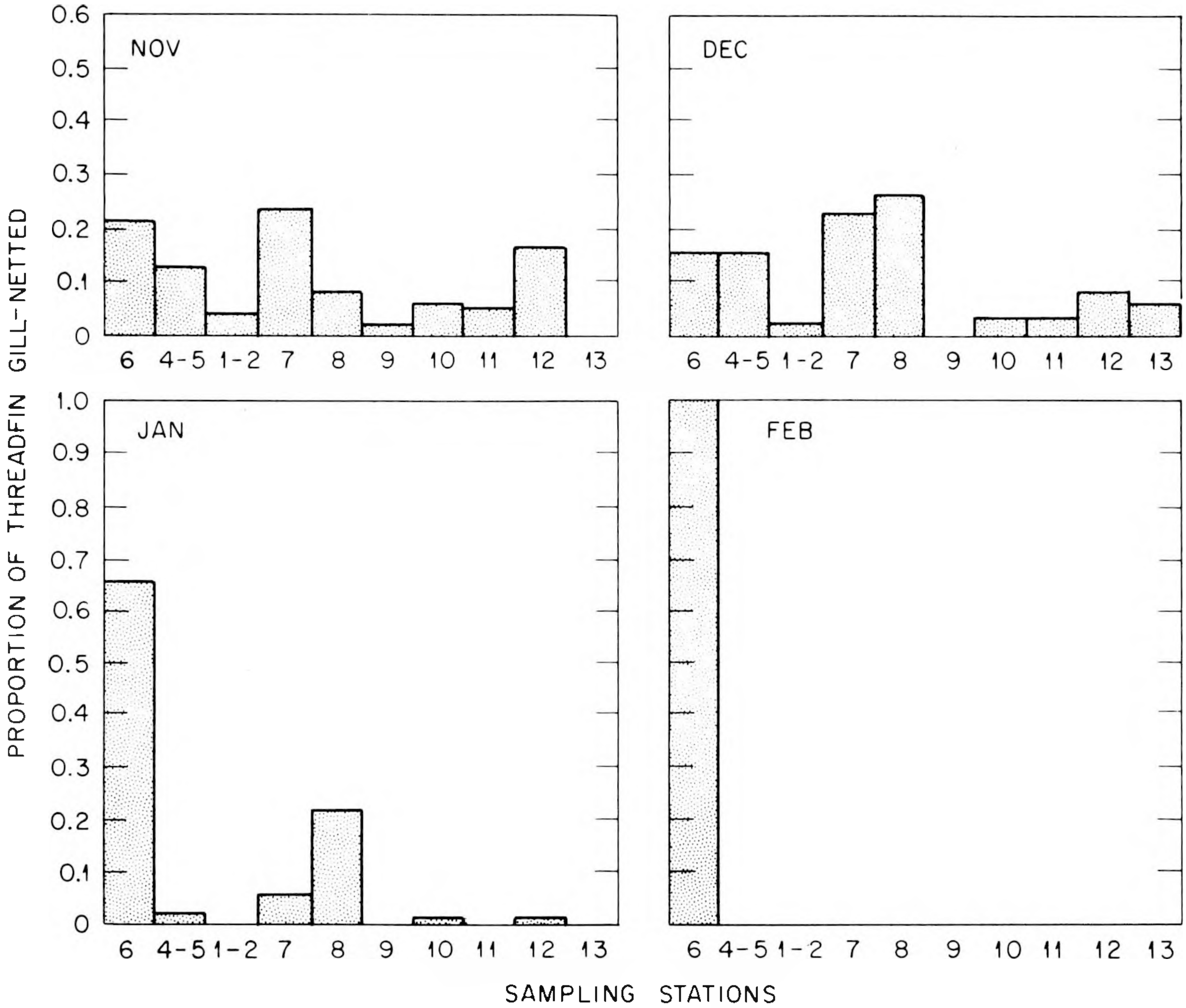

Fig. 7. Relative abundance of threadfin shad during November 1976 through February 1977 at each sampling station (see Figure 1 for locations) as indicated by mean number of fish caught per standard gill-net unit (cumulative relative abundance for each month equals 1.0).

(Fig. 8). Despite this increased number, threadfin represented only 43.8% of the impinged fish, compared to 96% in 1976-77, with gizzard shad (D. cepedianum) and skipjack herring (Alosa chrysochloris) comprising 27.6 and 26.3%, respectively. Forty-five other species including white crappie, freshwater drum, bluegill, white bass, yellow bass, mooneye, and striped bass, in decreasing order of abundance, made up the remaining 2.3%.

Impingement of threadfin in 1977-78 followed a temporal pattern similar to that of the previous year. Peaks of numbers impinged corresponded to rapid drops in temperature (Fig. 8) with most threadfin being impinged by January 25, 1978, when intake temperatures dropped to 1.8 C. Some differential impingement by size class was also observed. Threadfin in the 76- to 101-mm size range comprised 99% of all threadfin impinged during the year and dominated each impingement count. The smaller fish (50 to 76 mm) began to decrease in relative abundance after December, and larger fish (102 to 127 mm) increased (Table 2).

Unlike the year before, gizzard shad and skipjack herring were impinged concurrently with threadfin. Impingement of young-of-the-year gizzard shad (Fig. 9) followed a pattern similar to that of threadfin, but peaks in numbers of river herring impinged (Fig. 10) did not correspond with those of shad (Table 3). Young-of-the-year of both gizzard shad and skipjack herring made up the majority of impinged fish of both species. Gizzard shad were also impinged later in the year than either threadfin or river herring.

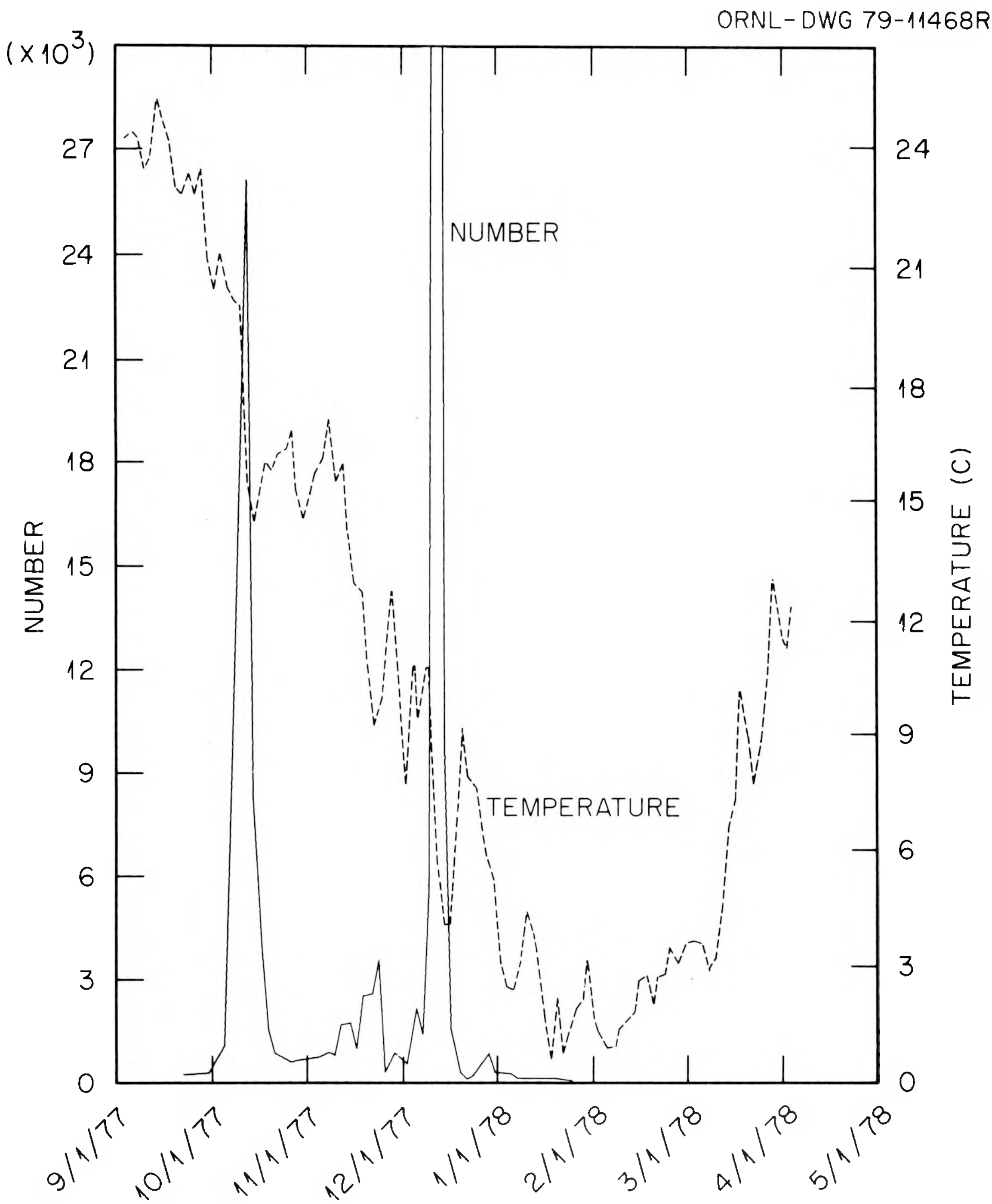

Fig. 8. Number of threadfin shad impinged and water temperature at the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, September 1977 to April 1978.

Table 2. Monthly percent occurrence by size class of threadfin shad (*Dorosoma petenense*) impinged at the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, September 1977 through February 1978

	Size class (mm)			
Date	50-76	77-101	102-127	128-152
1977				
September	10	81	8	0
October	11	88	1	0
November	8	91	0.6	0.4
December	2	91	7	0.2
1978				
January	0.3	77	22	1
February	0	64	36	0

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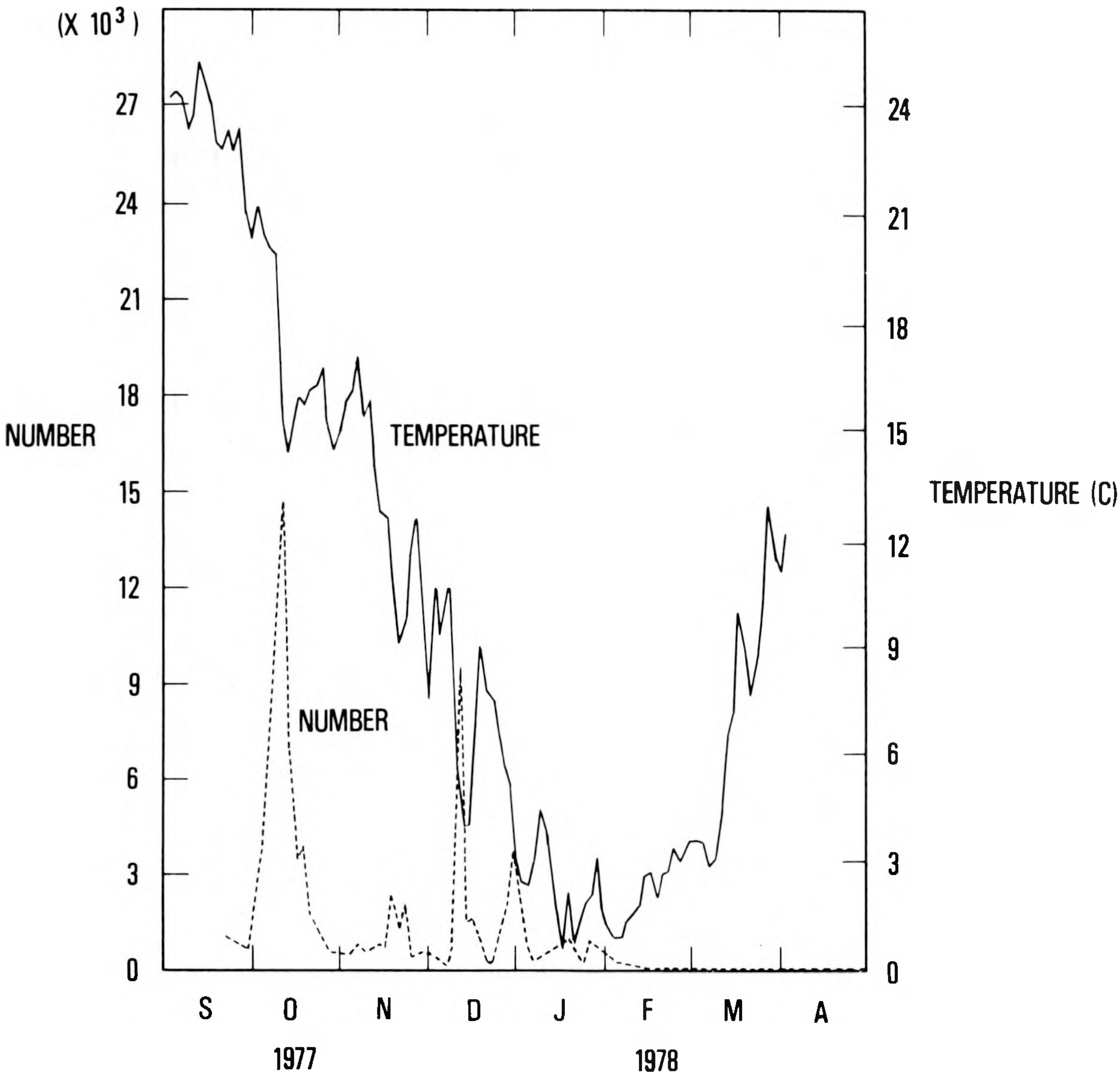

Fig. 9. Impingement of gizzard shad at Kingston Steam Plant, Watts Bar Reservoir, Tennessee, and water tempertures at the intake canal from September 1977 to April 1978.

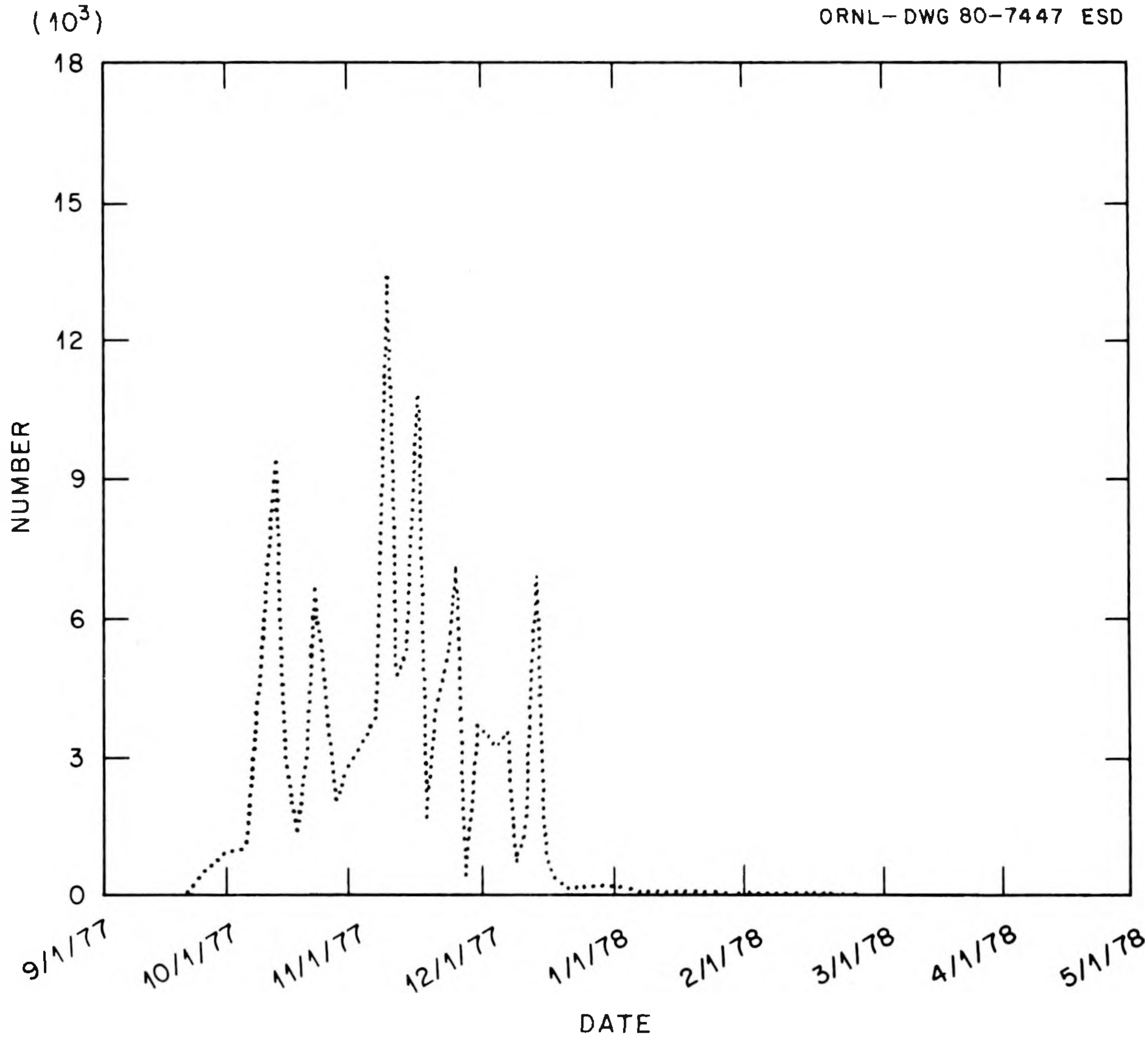

Fig. 10. Impingement of river herring at the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, from September 1977 to April 1978.

Table 3. Size classes of threadfin shad (Dorosoma petenense) gizzard shad (D. cepedianum) and skipjack herring (Alosa chrysochloris) that are positively correlated ($P \leq 0.001$) with respect to relative number and time of impingement at the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, between September 1977 and April 1978

Species[a]	Correlated species[b]
TFS-3	TFS-4, GIZ-3, GIZ-4, GIZ-7, GIZ-9
TFS-4	TFS-3, TFS-5, GIZ-4, GIZ-7, GIZ-8, GIZ-9, GIZ-13, RIH-3
TFS-5	TFS-4, TFS-7, RIH-9, RIH-10
TFS-6	TFS-7, TFS-8, RIH-5
TFS-7	TFS-5, TFS-6, TFS-8, RIH-9, RIH-10, RIH-11
TFS-8	TFS-6, TFS-7, TFS-10
GIZ-3	
GIZ-4	TFS-3, TFS-4, GIZ-7, GIZ-8, GIZ-9, GIZ-13, RIH-3
GIZ-5	GIZ-11, GIZ-12, RIH-10, RIH-13
GIZ-6	
GIZ-7	TFS-3, TFS-4, GIZ-4, GIZ-9, GIZ-13
GIZ-8	TFS-4, GIZ-4, GIZ-9
GIZ-9	TFS-3, TFS-4, GIZ-4, GIZ-7, GIZ-8, GIZ-13, RIH-3
GIZ-10	GIZ-11, GIZ-12, GIZ-13
GIZ-11	GIZ-5, GIZ-10, GIZ-12, GIZ-13, RIH-10, RIH-13
GIZ-12	GIZ-5, GIZ-10, GIZ-11, GIZ-13, RIH-10
GIZ-13	TFS-4, GIZ-4, GIZ-7, GIZ-9, GIZ-10, GIZ-11, GIZ-12
RIH-3	TFS-4, GIZ-4, GIZ-9
RIH-4	
RIH-5	TFS-6, RIH-6
RIH-6	RIH-5
RIH-7	RIH-8
RIH-8	RIH-7
RIH-9	TFS-5, TFS-7, RIH-10, RIH-11, RIH-12
RIH-10	TFS-5, TFS-7, GIZ-5, GIZ-11, GIZ-12, RIH-9, RIH-11
RIH-11	TFS-7, RIH-9, RIH-10, RIH-12

[a]Species code: TFS - threadfin shad, GIZ - gizzard shad, RIH - skipjack herring.

[b]

Size class code			
Code	mm	Code	mm
3	50-76	9	204-228
4	77-101	10	229-253
5	102-127	11	254-278
6	128-152	12	279-303
7	153-178	13	304-328
8	179-203		

Hybrid shad (threadfin x gizzard shad) were defined as those *Dorosoma* species having 26 to 29 anal fin rays. The presence of these fish on the intake screen was monitored because hybrid shad may provide a gene pool for threadfin shad if hybrids can withstand cold stress better than threadfin. Hybrid shad made up 11.2% of the threadfin population sampled during the two years studied (Table 4). There was no significant difference between threadfin shad and hybrids with respect to sex ratios (Table 4) or gonadal condition of the females (Table 5). Females of threadfin made up about the same proportion (between 74 and 91%) of the population as females of hybrids (between 74 and 100%) during both winters (Table 4), and a high percentage of the females had developing gonads (Table 5). Similarities between the two groups support the hypothesis that hybrids can reproduce. Fertilization experiments, however, must be done to prove this hypothesis.

THREADFIN-PREDATOR DYNAMICS

Laboratory studies by Griffith and Tomljanovich (1975) revealed that cold-induced (below 12 C) behavioral changes in threadfin result in decreased swimming and schooling abilities. In addition to impingement, these changes also cause an increased vulnerability of the threadfin to predation by larger fishes which remain active during these months. Cool-water species such as the sauger (*Stizostedion canadense*) and walleye (*S. vitreum*), which occur near the southeastern margin of their range in Tennessee, may especially benefit from the increased availability of food at this time. In Norris Reservoir,

Table 4. Percent of the threadfin shad population composed of hybrids (threadfin x gizzard shad) and the ratio of males to females within each group impinged monthly at the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, during the winters of 1976-77 and 1977-78

			Total		Total	Females		Males		Indeterminate	
	Date	Species[a]	No.	%	Dissected	No.	%	No.	%	No.	%
Winter of 1976-77	November	TFS	184	90.6	54	40	74.1	0	0.0	14	25.9
		HYB	19	9.4	19	14	73.7	0	0.0	5	26.3
	December	TFS	192	89.3	84	81	96.4	0	0.0	3	3.6
		HYB	23	10.7	23	20	87.0	0	0.0	3	13.0
	January	TFS	31	83.8	31	31	100.0	0	0.0	0	0.0
		HYB	6	26.2	6	5	83.3	0	0.0	1	16.7
	February	TFS	22	78.6	22	21	95.5	0	0.0	1	4.5
		HYB	6	21.4	6	6	100.0	0	0.0	0	0.0
	Over months[b]	TFS	429	88.8	191	173	91.0	0	0.0	173	9.0
		HYB	54	11.2	54	45	100.0	0	0.0	18	0.0
Winter of 1977-78	October	TFS	85	87.6	30	25	83.3	2	6.7	3	10.0
		HYB	12	12.4	12	9	75.0	3	25.0	0	0.0
	November	TFS	403	90.4	148	123	83.1	13	8.8	12	8.1
		HYB	43	9.6	43	39	90.7	0	0.0	4	9.3
	December	TFS	386	88.1	126	94	74.6	10	7.9	22	17.5
		HYB	52	11.9	42	25	59.5	5	11.9	12	28.6
	January	TFS	61	96.8	30	11	36.7	13	43.3	6	20.0
		HYB	2	3.2	1	1	100.0	0	0.0	0	0.0
	February	TFS	34	77.3	28	15	53.6	12	42.8	1	3.6
		HYB	10	22.7	8	4	50.0	3	37.5	1	12.5
	Over months[c]	TFS	969	88.8	362	268	74.0	50	13.8	44	12.2
		HYB	119	11.2	106	78	73.6	11	10.4	17	16.0

[a]TFS = threadfin shad, HYB = hybrid shad.

[b]Total number and percent of threadfin and hybrids for all months.

Table 5. Comparison of the gonadal development of female threadfin shad and hybrid shad (threadfin shad x gizzard shad) impinged monthly at the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, between November 1976 and February 1978

				Condition of ovaries					
				Undeveloped		Developing		Spent	
	Date	Species[a]	Number dissected	No.	%	No.	%	No.	%
Winter of 1976-77	November	TFS	33	7	21.2	23	69.7	3	9.1
		HYB	12	3	25.8	5	41.7	4	33.3
	December	TFS	71	7	9.9	61	85.9	3	4.2
		HYB	19	1	5.3	18	94.7	0	0.0
	January	TFS	28	4	14.3	23	82.1	1	3.6
		HYB	5	1	20.0	4	80.0	0	0.0
	February	TFS	21	0	0.0	21	100.0	0	0.0
		HYB	6	0	0.0	6	100.0	0	0.0
Winter of 1977-78	October	TFS	22	4	18.2	14	63.6	4	18.2
		HYB	9	4	44.4	5	55.6	0	0.0
	November	TFS	96	29	24.4	63	52.9	4	3.4
		HYB	36	11	30.6	23	63.9	2	5.6
	December	TFS	87	28	32.2	39	44.8	20	23.0
		HYB	23	6	26.1	6	26.1	11	47.8
	February	TFS	15	1	6.7	14	93.3	0	0.0
		HYB	4	0	0.0	4	100.0	0	0.0

[a]TFS = threadfin shad, HYB = hybrid shad.

Tennessee, adult sauger consumed large quantities of gizzard shad in the winter and had an abundance of visceral fat (Dendy 1946, Hassler 1953). Walleye in Norris Reservoir also consumed small shad, and stomachs were generally well-filled in winter (Stroud 1949).

Since the introduction and subsequent proliferation of threadfin shad in the Southeast, this species has become a major component of the winter diet of sauger and walleye as well as of white bass (*Morone chrysops*), yellow bass (*M. missippiensis*), striped bass (*M. saxatilis*), and river herring (*Alosa chrysochloris*) in Tennessee (Dryer and Benson 1957, Scott 1976, McGee et al. 1977). One objective of this study was to determine if, in reservoirs supplying cooling water for electric power plants, the annual recurrence of winter impingement and mortality of threadfin possibly reduces forage available to these predators.

Methods, 1976-77

Sauger were collected (from November 1976 through September 1977) in the gill nets described in the previous section. Sex, length, weight, and stomach contents were recorded for each fish. In addition, visceral fat weight was recorded for fish collected in March, April, and September.

Laboratory experiments were conducted to assess effects of low temperatures on the digestive rates of sauger. Sauger weighing from 277 to 1029 g were held in 770-liter circular fiberglass tanks at 5, 10, and 15 C and force-fed 4 to 7 g of fathead minnows (*Pimephales promelas*). Meal sizes were expressed as milligrams of food per gram of sauger. Sauger were anesthetized with MS-222 before feeding and again when stomachs were pumped to recover partially digested meals. Food materials from stomachs were blotted dry and weighed to the nearest 0.1 g. Rate of digestion was expressed as the percent digestion which occurred in the time interval allotted.

Methods, 1977-78

Sampling was conducted from October 1977 to April 1978, and sauger were processed the same as the preceding year except gonadal tissue and visceral fat were also weighed. In addition, the stomach contents of white, yellow, and striped bass and river herring were enumerated and the length and weight of these predators recorded.

Results, 1976-77

Stomach Content Analysis

Examination of stomach contents of 499 sauger revealed that food consumption and prey selection differed substantially throughout the year (Appendix D). Threadfin shad were the only positively identified food item in 243 sauger stomachs examined from November to January. Fifty-two percent of sauger that preyed on threadfin contained more then one in the stomach, with a maximum of seven. Such prey were usually in different states of digestion, but in some cases up to five were judged to be taken in the same feeding. Seventeen percent of the stomachs were empty during this period.

A comparison of the percent occurrence of threadfin shad in sauger stomachs (Fig. 11) and threadfin shad impingement (Fig. 2) from November to January demonstrate that for both the power plant and

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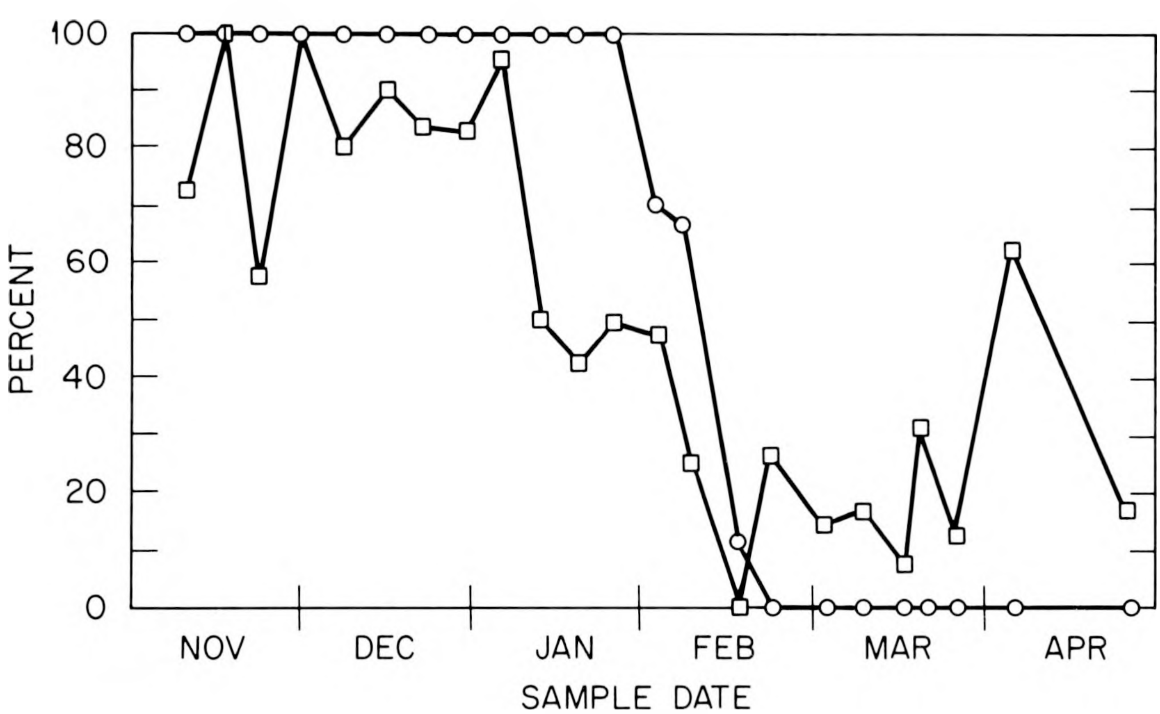

Fig. 11. Percent of stomachs of sauger, gill-netted in Watts Bar Reservoir, Tennessee, containing prey (□-□), and percent of that prey which was threadfin shad (O-O), between November 1976 and April 1977.

sauger the peak of predation on threadfin shad occurred at the same time. Impingement declined rapidly in late December while water temperatures remained low, probably indicating depletion of the threadfin population in the vicinity of the intake canal. The decline in sauger predation on threadfin shad lagged several weeks behind the drop in impingement, indicating that shad were still available to the sauger in other areas of the reservoir (Fig. 11).

During February, the percent occurrence of threadfin in sauger stomachs progressively decreased and the frequency of empty stomachs and occurrence of alternate prey in February increased (Table 6). By February, continued cold weather and low water temperatures resulted in cold-induced mortality of most threadfin as indicated by gill-net catches, electrofishing, and observations of threadfin dying in coves. During February, freshwater drum (Aplodinotus grunniens) comprised 38% of the positively identified prey and threadfin the remaining 62%. Two-thirds of the stomachs were empty. By March, threadfin shad were not found in any sauger stomachs. Freshwater drum, logperch (Percina caprodes), bluegill (Lepomis macrochirus), and mayfly (Hexagenia sp.) nymphs comprised the total of identifiable prey utilized in March and April. During these two months 85% of the 189 sauger stomachs were empty (Table 6). After sauger spawned in late March and early April, they seemed to disperse and were less vulnerable to capture by gill nets.

During May, June, and July, no shad were identified from stomachs of the few fish that were caught and food consumption remained low. Several catfish were found in stomachs for the first time. Stomachs of

Table 6. Stomach contents of 253 sauger collected in Watts Bar Reservoir, Tennessee, February through April 1977 (data from all sites combined)

Collection date	No. sauger	Number of stomachs containing: Threadfin	Drum	Logperch	Bluegill	Mayflies	Unidentified	No. of empty stomachs
Feb. 2	21	6	1				4	11
9	8	2					1	5
16	1							1
23	34	1	5				3	25
Mar. 2	33		2	1			2	28
9	53		2	1	1	1	3	46
17	22						1	21
24	21		1	1	1		4	15
30	24				1		2	21
Apr. 13	13			1	2	1	2	7
26	23		1	1				21

sauger captured on September 1 contained only young-of-the-year threadfin or gizzard shad, indicating sauger consume these prey prior to their being cold-stressed.

Amounts of visceral fat of sexually mature sauger during the study period ranged from 0.2 to 5.5% with a mean of $\approx$ 3.5% and no significant ($P > 0.1$) difference between months or sexes. Immature fish had significantly ($P < 0.1$) less visceral fat ($\bar{x}$ = 2.3% of body wt) than mature males and females ($\bar{x}$ = 3.1%) in October 1977.

Lengths of Threadfin and Selectivity of Sauger

Sauger size influenced the size of threadfin taken as forage. The mean length of female, male, and immature sauger was 41.4, 36.8, and 30.5 cm respectively. The majority of threadfin consumed by sauger were 8 to 10 cm in length, although sauger over 42 cm also ate 12- to 15-cm threadfin (Fig. 12). Maximum lengths of threadfin which were consumed ranged from 29 to 35% of body length of sauger from 22 to 50 cm long. Sauger under 30 cm consumed very few threadfin and were probably limited by the availability of shad less than 8.0 cm.

Effect of Temperature on Sauger Digestion

During the months when threadfin were still abundant, water temperatures less than 12 C may have reduced the ability of sauger to quickly utilize this forage. Results of laboratory studies indicate a significant reduction in digestion at 5 and 10 C when compared with that at 15 C ($P < 0.01$). Regression lines expressing the relationship between percent digestion and time at the different temperatures are plotted in Fig. 13. Extrapolation from these lines allows estimation

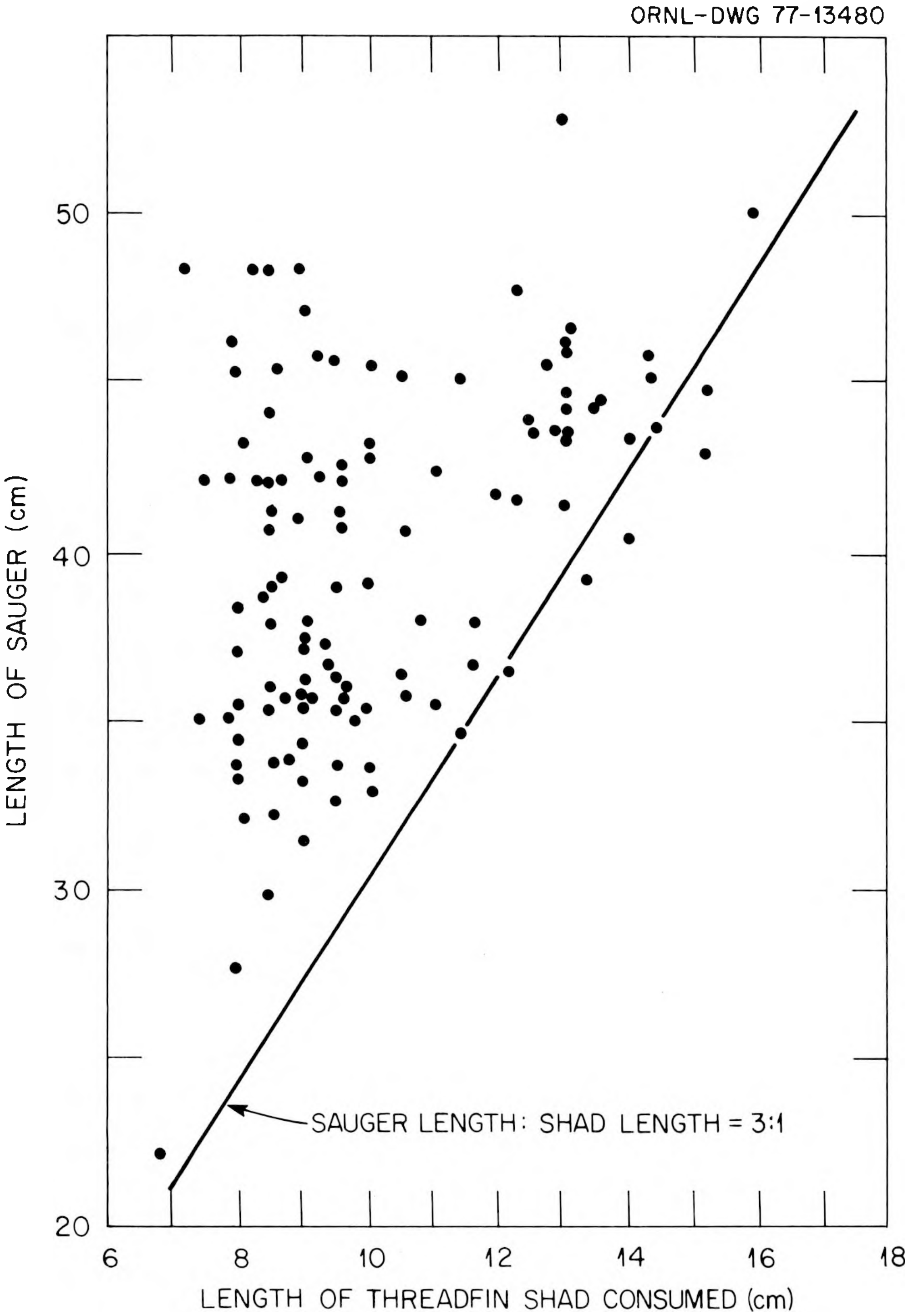

Fig. 12. Length distribution of threadfin shad consumed by sauger.

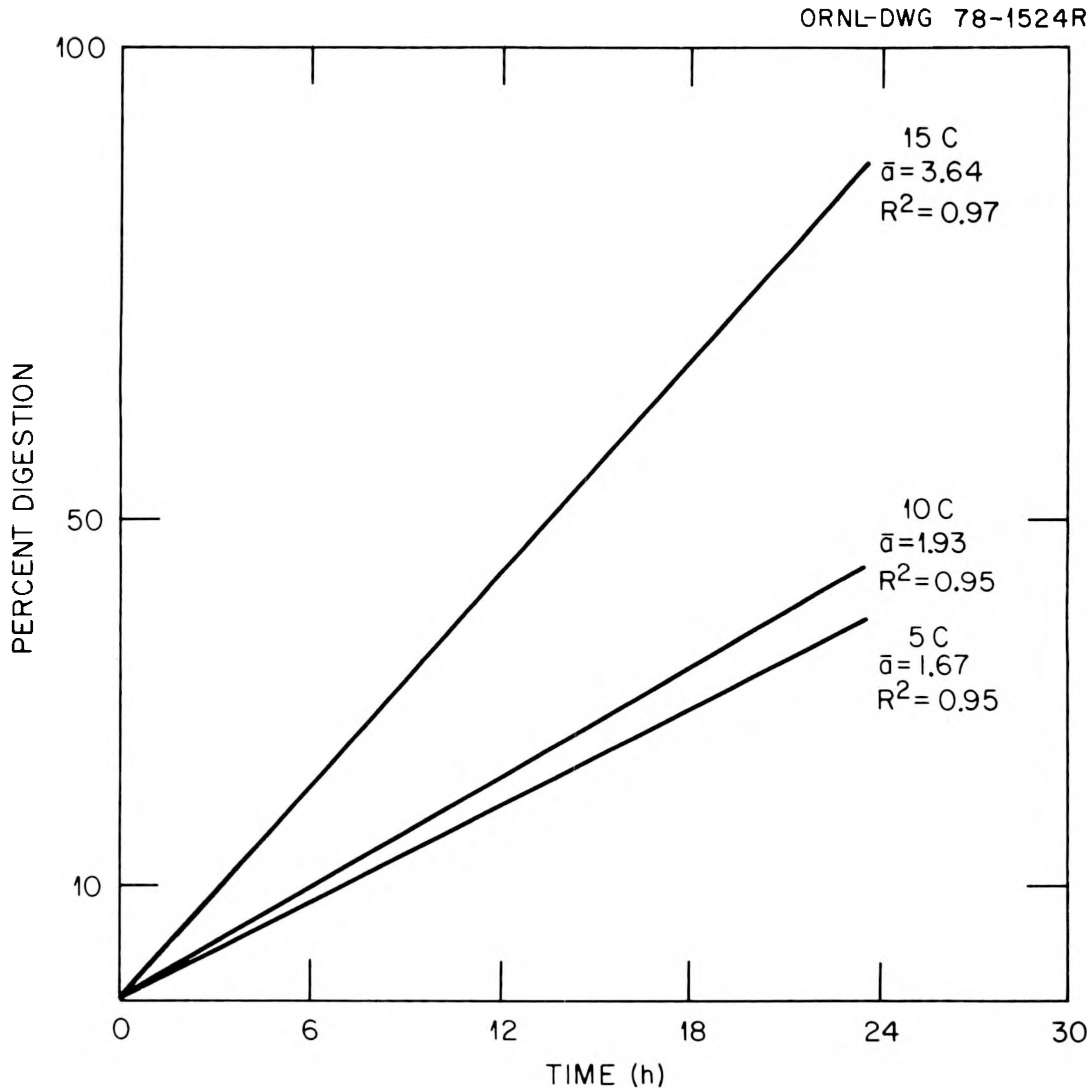

Fig. 13. Calculated mean regression slopes ($\bar{a}$) describing digestion of a 4- to 7-g meal by sauger at 5, 10, and 15 C.

of the time required for sauger in Watts Bar to digest a meal at temperatures encountered during the winter months. At temperatures between 5 to 10 C, sauger would require 46 to 55 h to digest (90% complete) a 4.0- to 7.0-g meal.

To determine the effect of force-feeding on digestion, a second experiment was conducted at 15 C in which sauger voluntarily consumed or were alternately force-fed an equivalent meal. Prior to each experiment, sauger were allowed three days of ad-libitum feeding. Food was then withheld for 24 h to ensure complete evacuation of any food remaining in the stomachs and to increase acceptance of experimental meals. Results of comparisons of 30 paired observations after 8 h of digestion indicated no significant differences in digestion existed (t-test, $P < 0.01$) between force-fed, and voluntarily consumed meals. This is in contrast to results presented by Swenson and Smith (1973) who showed that force-feeding significantly reduced the digestion rate of sauger at 14.5 C.

Other factors do influence digestion. In studies with sauger and walleye at 20 and 14.5 C, Swenson and Smith (1973) found the amount of food digested per hour increased with meal size and fish size. Later Swenson (1977) concluded that high stomach volumes tended to compensate for the effects of low temperature (14.5 C) on digestion. Results from this study suggest these same factors continue to exert influence at lower temperatures (5 to 10 C).

While digestion can continue at a reduced but sufficient rate to permit continued feeding, utilization of energy for growth by sauger and walleye stops at low temperatures (Hassler 1953, Stroud 1949, Kelso

1973). Adult sauger probably use this energy in late fall and winter for maintenance and gonadal development. Excess energy may be stored as fat. Almost all adult sauger examined during the winter contained large stores of visceral fat (∿ 3 to 10% of body wt). This stored energy may be important for maintenance and growth in spring when food supplies are apparently lower.

Results, 1977-78

Sauger

Stomach content analysis of 1011 sauger showed that threadfin and gizzard shad constituted 4.6 and 6.1%, respectively, of the prey by number (Table 7). Partitioning of the unidentified shad (UDS) into threadfin and gizzard shad categories, based on the proportion of shad that could be identified to species, indicates that these fish made up 31.7 and 42.8% respectively, of the diet of sauger. Percent of the diet composed of shad prey peaked in December and January and reached the lowest point in March (Fig. 14). The amount of food, in general, dramatically decreased after January. The number of prey items per stomach was consistently 1.2 from October through January, and then fell to a low of 0.08 in March (Table 7).

Prey size remained constant throughout the sampling period with only 4.5% of the shad exceeding 10.1 cm total length. Shad less than 10.1 cm were eaten by all size classes of predators, although there were monthly differences in the percentage of stomachs that were empty between size classes of sauger (Table 8). After January, large sauger

Table 7. Stomach content analysis of sauger (Stizostedion canadense) gill-netted in Watts Bar Reservoir, Tennessee, September 1977 through April 1978. Prey are given by species, number, and percent (by number) of diet. Predators are given by number dissected, number and percentage of empty stomachs

	Prey[a] in stomach														Predators				
	TFS		GIZ		UIDS		RH		DR		CE		UID		Total number of prey	Number of sauger dissected	Empty stomachs		Prey/ predator
Month	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%			No.	%	
September, 1977			2	6.7	14	46.7							14	46.7	30	41	14	34	0.7
October	5	4.6	1	0.9	68	62.4	1	0.9	4	3.7	3	2.8	27	24.8	109	90	31	34	1.2
November	26	6.3	15	3.6	250	60.5	5	1.2	10	2.4	5	1.2	102	24.7	413	354	113	32	1.2
December	9	3.2	36	12.7	194	68.3	1	0.4	14	4.9	3	1.1	26	9.2	283	231	74	32	1.2
January, 1978	3	4.1	4	5.4	55	74.3			9	12.2	1	1.4	2	2.7	74	64	27	42	1.2
February					11	61.1			3	16.7	1	5.6	3	16.7	18	47	31	66	0.4
March					4	30.8			7	53.8			2	15.4	13	165	144	87	0.08
April									1	33.3	1	33.3	1	33.3	3	19	16	84	0.16
TOTALS	43		58		596		7		48		14		177		943	1011	450		
%		4.6		6.1		63.2		0.7		5.1		1.5		18.8				45	

[a]TFS - threadfin shad, GIZ - gizzard shad, UIDS - unidentified shad, RH - river herring, DR - freshwater drum, CE - centrarchids, UID - unidentified fish.

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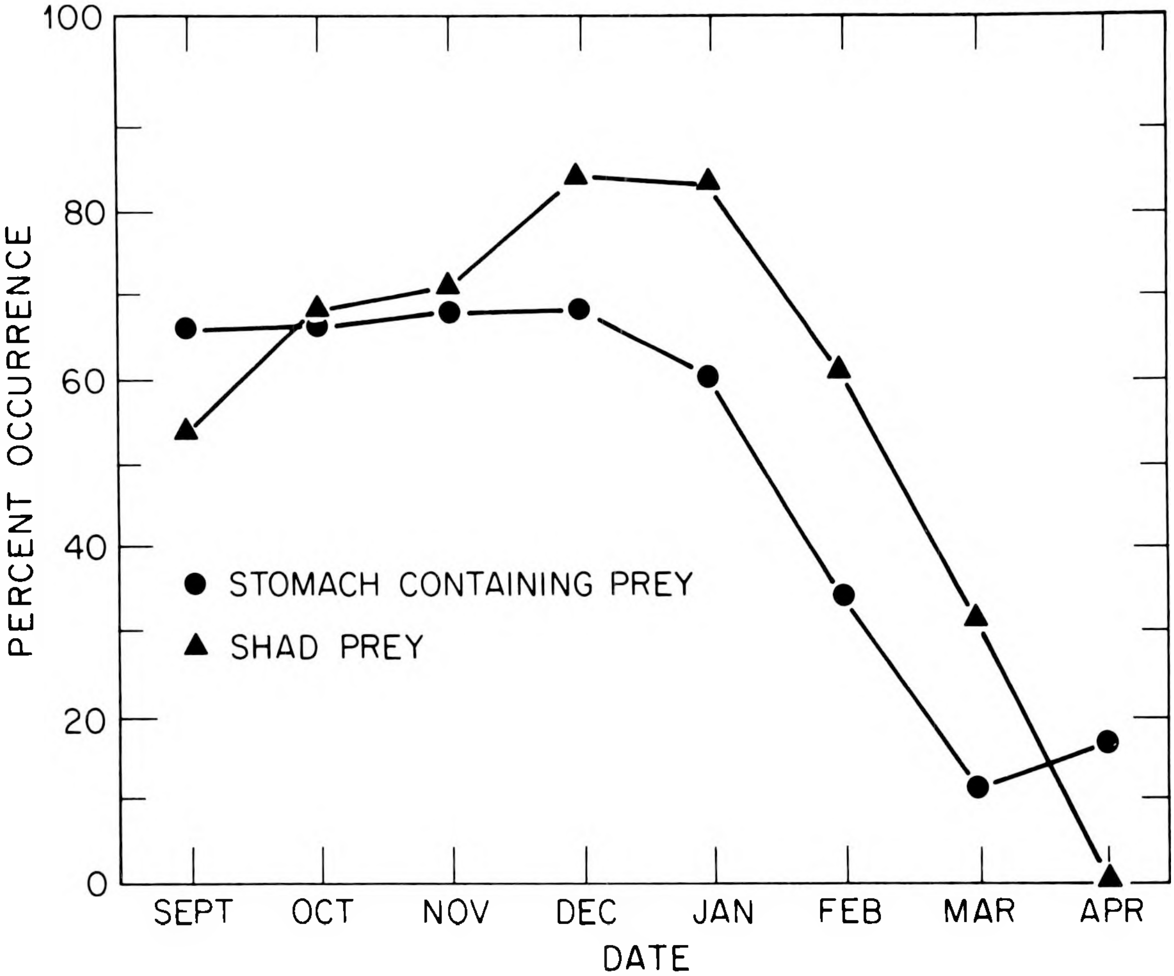

Fig. 14. Percent stomachs of sauger containing prey and percent of those prey that were threadfin and gizzard shad in Watts Bar Reservoir, Tennessee, September 1977 to April 1978.

Table 8. Percentage of empty stomachs for three size classes of sauger (Stizostedion canadense) gill-netted in Watts Bar Reservoir, Tennessee, September 1977 through April 1978

Date	20.3-30.5 mm	30.6-40.6 mm	40.7-50.8 mm
September, 1977	67	34	33
October	33	36	17
November	28	28	43
December	23	24	25
January, 1978	73	22	43
February	81	40	40
March	97	87	67
April	87	92	70

(40.7 to 50.8 cm) had a lower percentage of empty stomachs than did small (20.3 to 30.5 cm) sauger.

Sauger Condition

Sauger condition is expressed as a monthly percent weight change for three representative size fish (Fig. 15). Interpretation of the relative condition is aided by the evaluation of the percentage of body weight that is visceral fat as well as the gonadal somatic index ($\frac{\text{body wt}}{\text{gonadal wt}}$ X 100). Slow or no growth at temperatures below 12 C (Kelso 1973) enables between-month comparisons to be made. Condition of smaller sauger was relatively poorer than that of larger sauger. Sauger during the 1977-78 sampling period gained condition quickly and maintained it through April. Percent body weight that was visceral fat did not significantly change from month to month (Fig. 16), although there was an upward trend from September to April. The percentage of body weight that was gonadal tissue, however, did increase significantly during this time (Fig. 17).

Skipjack Herring

Stomach contents of 506 skipjack herring (*Alosa chrysochloris*) showed this species to be an active predator, consuming threadfin and gizzard shad, young-of-the-year river herring and mayflies (Table 9). Shad comprised 81% of the diet (threadfin shad 27% and gizzard shad 54%). The number of prey per stomach peaked in September at 2.2 and decreased to zero in March and April. Non-shad prey made up between 11 and 43% of the total diet.

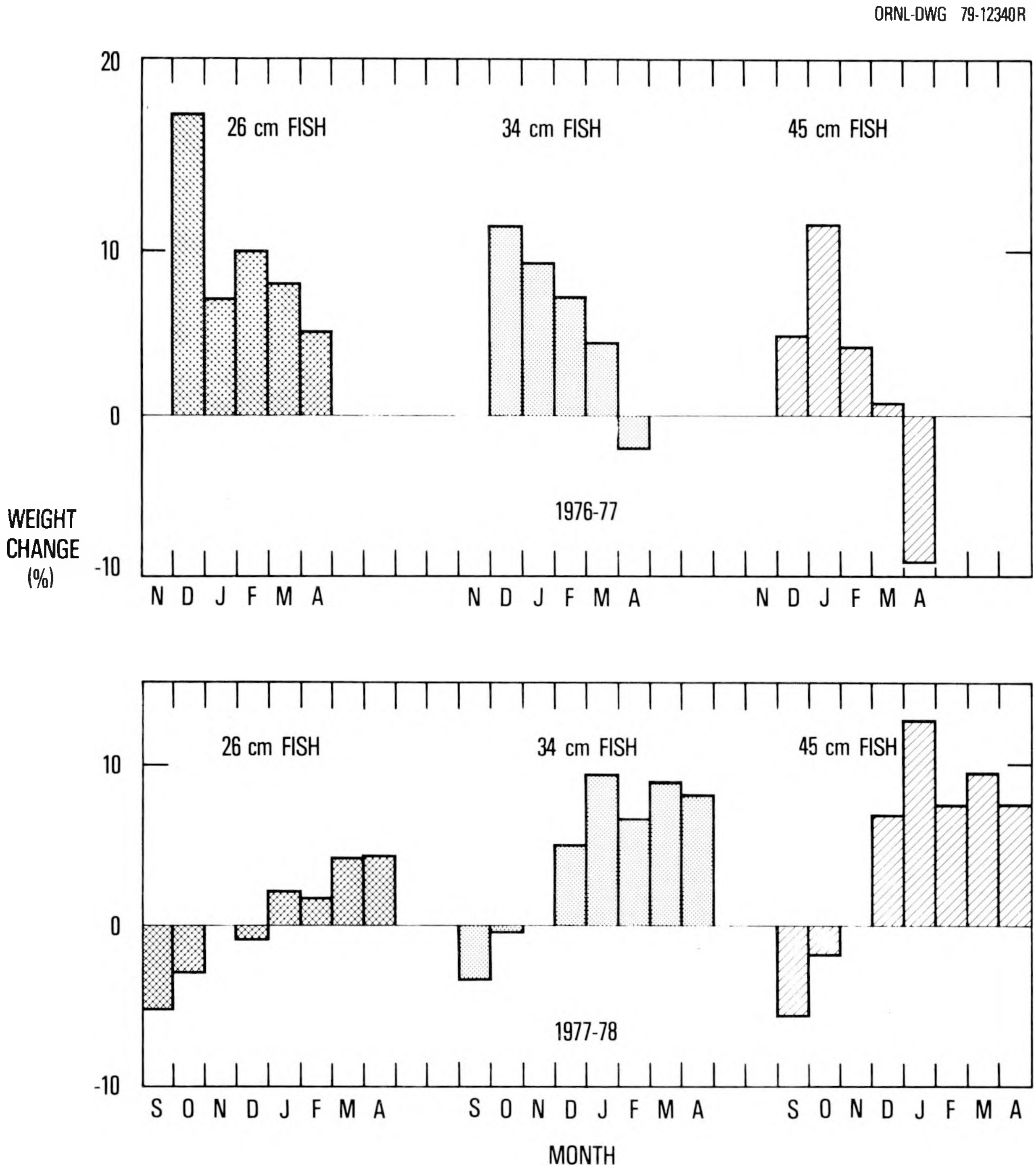

Fig. 15. Monthly percent weight change (based on November weight) of three representative size of sauger gill-netted in Watts Bar Reservoir, Tennessee, November 1976 to April 1978.

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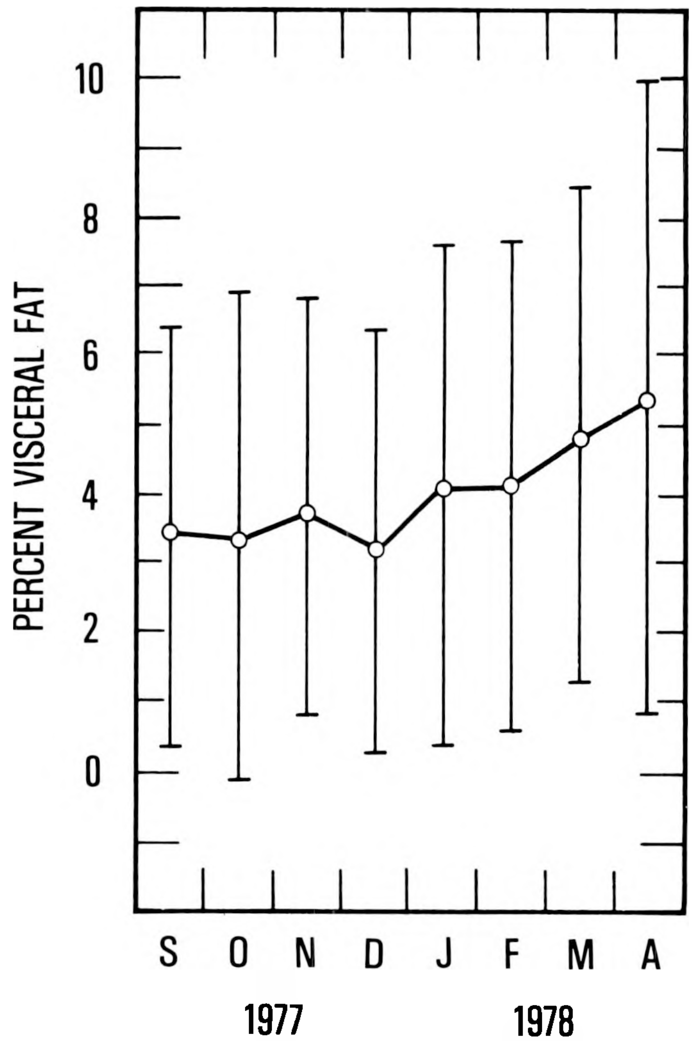

Fig. 16. Percent visceral fat $(\frac{\text{fat wt}}{\text{total body wt}}) \times 100$ of all sauger gill-netted in Watts Bar Reservoir, Tennessee, September 1977 to April 1978.

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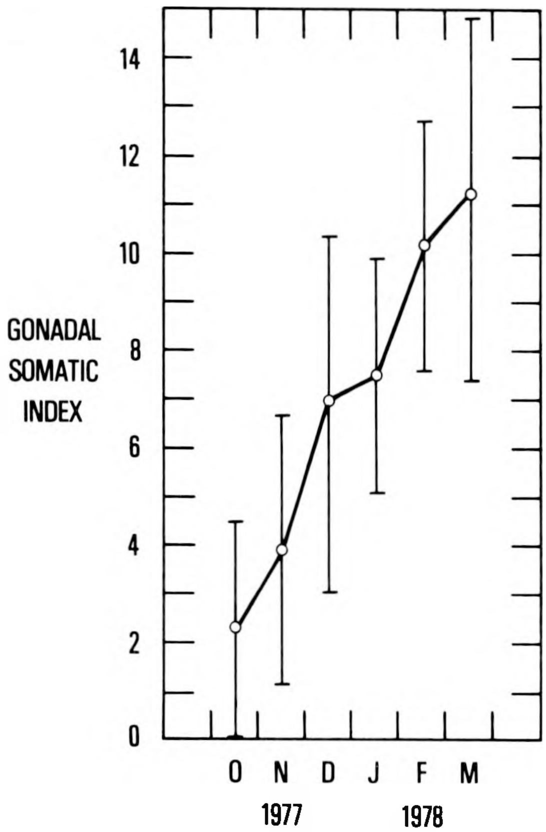

Fig. 17. Monthly gonadal somatic index ($\frac{\text{gonadal wt}}{\text{total body wt}}$ x 100) for mature female sauger (Stizostedion canadense) gill-netted in Watts Bar Reservoir, Tennessee, between October 1977 and March 1978.

Table 9. Stomach content analysis of skipjack herring (<u>Alosa</u> <u>chrysochloris</u>) gill-netted in Watts Bar Reservoir, Tennessee, between September 1977 through April 1978

Date	Number dissected	Percent empty	Number prey/ stomach	Percentage of stomachs containing:					
				Threadfin shad	Gizzard shad	Unidentified shad	Skipjack herring	Mayflies	Unidentified fish
September, 1977	68	25	2.2	5	7	67			21
October	68	26	1.5	2	14	74	3	3	12
November	104	24	1.5	8	18	53	14		7
December	113	37	1.2	9	30	49	1		11
January, 1978	117	36	0.7	19	11	47			23
February	59	69	0.4	4	16	40			40
March	6	100	0						40
April	4	100	0						

Basses

White bass, yellow bass, and striped bass ate threadfin and gizzard shad but also preyed upon centrarchids, young-of-the-year river herring, and mayflies. Yellow bass had the most varied diet, although striped bass had the lowest percentage of empty stomachs (Table 10). The percentage of empty stomachs of the three species varied during the year. White bass had the lowest percentage of empty stomaches in the late fall, yellow bass in winter and early spring, and striped bass in late fall and early winter.

THREADFIN-SCAVENGER INTERACTION

During severe winters in the Southeast, large numbers of threadfin shad succumb to cold stress (Parsons and Kimsey 1954, Dryer and Benson 1957). These fish may sink to the bottom to decompose, may be eaten by benthic scavengers, or may float and be washed onshore to be eaten by terrestrial scavengers.

This study sought to examine the ability of scavengers to utilize both freshly dead and decomposing threadfin shad at temperatures representative of winter conditions in the Tennessee Valley. Since studies of cultured channel catfish (*Ictalurus punctatus*) have indicated a cessation or inhibition of feeding at 12 to 15 C (Swingle 1959, Bulow 1967, Randolph and Clemens 1976), a group of wild fish from Watts Bar Reservoir, Tennessee, were studied to see if they would respond similarly. Field observations were also made to determine the fate of floating shad and those washed onshore.

Table 10. Stomach content analysis of striped bass (*Morone saxatilis*), yellow bass (*M. mississippiensis*), and white bass (*M. chrysops*), gill-netted in Watts Bar Reservoir, Tennessee, between September 1977 and April 1978

		Number dissected			Percentage of empty stomachs			Percent of predator[a] stomachs containing: Threadfin shad			Gizzard shad			Unidentified shad			River herring			Centrarchids			Drum			Mayflies			Unidentified fish		
	Date	SB	YB	WB	SB	YB	WB	SB	YB	WB	SB	YB	WB	SB	YB	WB	SB	YB	WB	SB	YB	WB	SB	YB	WB	SB	YB	WB	SB	YB	WB
1977	Sept.	15	6	6	40	60	83	4						81	50	100				15										50	
	Oct.	5	5	6	80	100	67									50				100											50
	Nov.	18	11	13	33	100	46	13						32		36	50		46	5											18
	Dec.	4	7	26	25	57	81				20	40		60		60				20	40			20	20			20			
1978	Jan.	5	0	9	0	-	100							100																	
	Feb.	1	6	6	0	83	83							100													100				100
	March	6	13	20	100	62	80								67	70												25		33	
	April	0	17	14	-	65	100																				67			33	

[a]Predators: SB - striped bass, YB - yellow bass, and WB - white bass.

Methods

Benthic Scavengers

Hatchery channel catfish, ranging from 135 to 260 g and reared on trout chow at 20 C, were obtained as fingerlings from the Cohutta National Fish Hatchery, Georgia. One year later, Watts Bar Reservoir channel catfish, ranging from 312 to 705 g, were collected at about 10 C by electrofishing and gill-netting. Three groups of four hatchery-reared catfish and two groups of four wild catfish were placed in separate 770-liter circular fiberglass tanks. Eight freshly killed and eight decomposing shad (whole or halves) were given to each group of catfish, and the remains removed when approximately 50% of the total was eaten. Shad 5.0 to 5.2 cm long and weighing an average of 12.3 g were fed to hatchery-reared catfish. During the experiments with the wild fish, 5-cm shad suffered extensive cold-induced mortality in the reservoir and were not available, so threadfin 13.5 to 14.5 cm were cut in half and trimmed so that each piece weighed 10 g. Decomposing shad for both experiments were held at 20 C, for 96 h, at which time they were soft but intact.

Hatchery-reared channel catfish were first studied at 20 C, with the above procedure carried out for two consecutive periods of 10 d each and with feeding on alternate days. Water temperature was then dropped to 10 C, in steps of 1 C every second day, and the procedure was repeated. Wild catfish were tested at 10 C for 10 d (feeding on alternate days), then were acclimated to 20 C for 10 d of tests, and finally were reacclimated to 10 C and tested for 10 d.

Terrestrial Scavengers

Threadfin in a backwater cove of the Tennessee River were observed during February and March in order to determine the fate of the fish carcasses resulting from cold-induced mortality. Periodic observations of the fish were made over a period of three weeks in December and January, and temperature records of the cove were taken. Freshly killed shad were placed on the shoreline and monitored for utilization by bird scavengers.

Results

Benthic Scavengers

At 20 C, hatchery-reared channel catfish actively fed on fresh shad, but they seldom consumed those that were decomposing (Table 11). Of the 177 shad eaten in both trials, only 14 (7.9%) were not freshly killed. The catfish, which fed readily in the presence of an observer, often bit into decomposing shad and rejected them. In trials at 10 C, the hatchery-reared fish did not feed. The observation period was extended by four weeks, but no food was consumed.

Wild catfish showed similar patterns of food selection and temperature response. In contrast to hatchery-reared individuals which ate half of the shad offered within 10 min, wild fish would not feed with an observer nearby and fed only at night. During both of the periods in which the fish were held at 10 C, no shad were consumed.

At 20 C, each group of wild catfish ate most of the 40 fresh shad that were offered to each (34 and 36 eaten). No preference for shad heads or tails was shown. Only three of the 80 decomposing shad

Table 11. Number of fresh and decomposing (after 96 h at 20 C) threadfin shad eaten by three groups of four hatchery-reared channel catfish and two groups of wild catfish at 20 C. Forty fresh and forty decomposing shad were offered to each group in each trial

	Catfish group					
	A		B		C	
	Shad condition		Shad condition		Shad condition	
Trial	Fresh	Decomposed	Fresh	Decomposed	Fresh	Decomposed
Hatchery-reared fish						
1	28	5	25	3	31	3
2	29	0	22	2	28	1
Total	57	5	47	5	59	4
Wild fish						
1	34	0	36	3		

available were taken. Bite marks indicated that several of those not eaten had been mouthed and rejected by the catfish.

Terrestrial Scavengers

Threadfin in the backwater cove schooled in shallow water influenced by relatively warm (9 C) ground-water input. Over a period of severe cold weather, however, all threadfin in the cove were eventually killed. Birds such as starlings, crows, and herons were observed to feed on them as they floated to shore. Those that sank were decomposed within two weeks. Threadfin freshly killed and placed on shore were all partly eaten by birds within 24 h.

THERMAL REFUGES

Threadfin shad and young-of-the-year gizzard shad are killed by cold during the winter in Watts Bar Reservoir and other water bodies in the southeast. In many areas, these winter kills have resulted in the threadfin population disappearing (A. Houser, 1978, personal communication). The Watts Bar Reservoir threadfin population, however, rebounded after a large percentage ($\approx$ 95%) of them were killed in the winter of 1977. During December and January of that winter, threadfin shad were observed in a small backwater cove that was partially heated by ground-water input. This suggests thermal refuges, if large enough, could be the key to winter survival of a remnant of the threadfin population, as well as of the young-of-the-year gizzard shad population.

The purpose of this study was (1) to determine if thermal refuges exist in the reservoir, (2) to quantify the extent to which these refuges are used by threadfin and young-of-the-year gizzard shad, and (3) to quantify the extent to which predatory fish utilize prey in these refuges.

Methods

A thermal survey of the middle portion of Watts Bar Reservoir, Tennessee River Mile (TRM) 543 to 580, was made by the TVA on February 15, 1978, by overflying the area and scanning it electronically. A temperature survey of the area scanned was conducted simultaneously by boat. Five thermal areas which had temperatures not lower than 8.4 C compared to 3.5 to 5 C ambient reservoir temperatures and areas of approximately 1 x 10^3 to 1 x 10^5 m^2 were identified. The lower lethal temperature for 10-cm threadfin is about 5 C (Griffith 1978), and the LD_{50} for young-of-the-year gizzard shad is 10.4 C (R. B. McLean, in preparation). Lethal temperatures occurred in the reservoir from late December through March (Table 12).

To determine if Dorosoma species use these areas as refuges, gill nets were set weekly in thermal and nonthermal areas during March 1978. Nets were placed biweekly in the thermal discharge of the Kingston Steam Plant from September to April as a part of the regular netting schedule. Stomach contents of sauger, skipjack herring, and striped bass caught in the gill nets were examined for the presence of threadfin and gizzard shad.

Results

Five locations were identified as thermal areas. These are located at TRM 540.6, 547.5, 558.2, and 564.8 and at Clinch River Mile

Table 12. Gill-net catch-per-unit-effort (no. fish caught/8-m panel/24 h) of threadfin shad (Dorosoma petenense) and water temperature at the Kingston Steam Plant (Watts Bar Reservoir, Tennessee) discharge and two nonthermal upstream stations between September 1977 and March 1978

	Discharge		Station 4 and 5	
Date	Catch/effort	Temperature (C)	Catch/effort	Temperature (C)
9/14	1.0	28.4	69.8	24.4
10/19	2.0	21.2	0.0	14.5
11/2	2.0	19.5	1.0	14.1
12/28	0.0	11.2	1.3	9.1
1/24	6.0	9.2	0.0	3.8
2/24	5.0	8.4	0.0	3.7
3/7	0.0	7.8	0.0	4.0

(CRM) 6.8. These locations ranged from 7.2 km upstream of the Kingston Steam Plant to 46.7 km downstream.

Threadfin shad were caught in the thermal discharge September through February, but the catch-per-unit-effort exceeded that of nonthermal stations only in January and February (Table 12). No threadfin were gill-netted in March in the reservoir, including in the thermal areas. In addition, no threadfin were identified in the stomachs of predators caught in March, although river herring and, to some extent, sauger and striped bass preyed on threadfin in the steam plant discharge from October through January.

Young-of-the-year gizzard shad were seldom caught in the gill nets anywhere in the reservoir, although thousands were observed to inhabit the thermal areas in January and February. During this time they were preyed on by yellow bass, sauger, and striped bass. Gizzard shad were found in the stomachs of river herring caught in the steam plant thermal discharge from October through February.

Hybrid shad were caught at one natural thermal area and in the thermal discharge after January. None were identified in the stomach of any predators.

BLOOD ELECTROLYTE STUDY

The purpose of this study was to determine the feasibility of using blood electrolytes as an indicator of the degree of cold stress experienced by shad. The capability to quantify the degree of stress would enable one to determine the probability that fish, residing in stressful cold temperatures, would live or die. With this information an evaluation could be made of the fate of fish found in thermal refuges, power plant intakes in the winter, etc.

Fish hematology has become an increasingly important tool as an indicator of physiological well-being of the fish. Parameters such as hematocrit volume, erthrocyte and leucocyte numbers, hemoglobin content, and electrolyte levels have been measured to indicate the response of fish to chlorine (Zeitoun and Hughes 1977, Katz 1975) and cold stress (Umminger 1969). Serum electrolyte levels have been widely studied in relation to cold stress of marine fish. Umminger (1969), in an extensive literature review, found that serum electrolyte concentrations increased in the cold in virtually every marine fish studied.

Methods

Two sets of experiments were performed using 1+ to 3+ aged gizzard shad. Threadfin shad were not used because none were found in the reservoir. Gizzard shad were collected from Watts Bar Reservoir on May 7-9 and July 31, 1978, for experiment one and two, respectively.

For the first experiment, 123 fish were acclimated in the laboratory at 14 C for 5 to 7 d. At the end of acclimation, 10 fish were placed in each of 16 pairs of test and control, 757-liter tanks. Water temperatures were kept at 14 C in the control tanks throughout the experiment and lowered 1 C per day in the test tanks. Temperature regulation was performed by means of computer-controlled temperature values. Blood was removed, using heart puncture, from all fish in a randomly selected test tank and control tank on days that temperature reached 14, 10, 8, 6, 4, and 2 C in the test tanks.

Length, weight, scale samples, fin-ray counts (to identify any hybrids), sex, and general condition of each fish were recorded. The blood sample was allowed to clot, then the serum was decanted and analyzed for sodium and potassium, using flame atomic adsorption and for chloride using a Technicon Autoanalyzer.

The second experiment was similar to the first, except four pairs of tanks were used containing 24 or 25 fish per tank. Ten fish were removed from one randomly chosen control and test tank at temperatures of 12.8, 7.6, 3.6, and 2.6 C. These temperatures were chosen because preliminary results during test one indicated these temperatures to result in measurable stress. Fish remaining in the test and control tanks sampled were observed in order to determine mortality due to holding stress and declining temperatures.

Results

Blood electrolyte levels of the fish exposed to decreasing temperatures and those kept at a constant temperature are presented in Table 13 for both experiments. In both experiments there were significant differences between tests and controls at various temperatures. In both experiments the pattern of change was the same. Sodium levels decreased early but increased again at the lowest temperatures. Potassium increased initially then decreased. Chloride ocillated between high and low levels as the temperature decreased.

Variation in the electrolyte level of the controls between dates makes it difficult, however, to use the data for predicting electrolyte levels at any given temperature. The electrolyte levels were sensitive

Table 13. Blood serum electrolyte levels[a] of gizzard shad exposed to decreasing temperature (1 C/d) compared to control fish held at a constant temperature of 13.5 ± 0.3 C

Experiment I

Test temp. (C)	Electrolyte	Electrolyte levels (μg/ml) Control	Electrolyte levels (μg/ml) Test	P ≤ 0.1
13.5	Na^+	2850 ± 113.2 (10)	2836 ± 97 (10)	
	K^+	345 ± 61.5	358 ± 71	
	Cl^-	3295 ± 145.1	3226 ± 195	
9.7	Na^+	2968 ± 92.1 (10)	3169 ± 23 (10)	
	K^+	355 ± 47.6	82 ± 31	P = 0.003
	Cl^-	3520 ± 118.2	3692 ± 80	
7.4	Na^+	2037 ± 24.7 (9)	1986 ± 207 (9)	
	K^+	1393 ± 70.9	966 ± 92	P = 0.002
	Cl^-	3299 ± 102.5	2558 ± 223	P = 0.01
5.6	Na^+	2046 ± 62.1 (10)	2234 ± 132 (10)	
	K^+	1466 ± 57.5	1061 ± 92	P = 0.002
	Cl^-	3892 ± 175.4	3026 ± 128	P = 0.001
3.5	Na^+	3200 ± 48.2 (9)	2852 ± 125 (9)	P = 0.02
	K^+	120 ± 52.3	172 ± 67	
	Cl^-	3923 ± 82.3	3518 ± 181	P = 0.05
1.5	Na^+	3271 ± 59.4 (7)	2074 ± 194 (7)	P = 0.006
	K^+	100 ± 72.5	408 ± 227	P = 0.001
	Cl^-	3353 ± 183.2	2753 ± 156	P = 0.03

Experiment II

Test temp. (C)	Electrolyte	Electrolyte levels (μg/ml) Control	Electrolyte levels (μg/ml) Test	P ≤ 0.1
13.8	Na^+	2552 ± 587 (10)	2724 ± 34 (10)	P = 0.02
	K^+	101 ± 29	105 ± 17	
	Cl^-	2400 ± 161	2906 ± 94	P = 0.02
7.5	Na^+	2936 ± 63 (12)	2534 ± 189 (10)	P = 0.07
	K^+	266 ± 60	207 ± 41	
	Cl^-	2813 ± 126	2766 ± 245	
3.5	Na^+	2707 ± 105 (10)	2823 ± 120 (11)	
	K^+	177 ± 86	152 ± 89	
	Cl^-	2476 ± 615	2800 ± 535	
2.5	Na^+	3198 ± 83 (10)	2799 ± 61 (7)	P = 0.003
	K^+	186 ± 139	213 ± 118	
	Cl^-	3070 ± 154	2544 ± 170	p = 0.04

[a]Data presented as concentration ± one standard error (number of observations).

not only to temperature changes but they also reflect stress due to holding time in the laboratory. Therefore, electrolyte changes due to holding stress may overshadow changes due to decreasing temperature.

Plots of the meristic parameters (length, weight, and fin-ray count) against the blood parameters showed no significant relationships. A comparison of length and weight of fish used for tests with those used for controls did show a difference for the 13.8 C group of experiment II (Table 13). Na^+ and Cl^- levels between the test and controls of this group were also different. However, size differences probably do not account for the difference in electrolyte levels, because the largest and smallest fish of each group did not have the highest or lowest levels of electrolytes.

In summary, blood electrolyte levels of gizzard shad are sensitive to cold stress. Unfortunately, the levels are also sensitive to other stresses which are difficult to control. Thus, use of blood electrolyte levels to predict the magnitude of stress the fish are undergoing is probably not practical.

DISCUSSION

Impingement

Impingement of threadfin shad at the Kingston Steam Plant during the winters of 1977 and 1978 was caused by a combination of factors including river hydrology, ambient temperatures, and fish behavior. The obvious immediate causal factor of major peaks in impingement was a general decline in water temperatures followed by sudden temperature shocks. Laboratory data of Griffith (1978) show that 9- to 14-cm threadfin decreased feeding activity and schooled less compactly beginning at 9 C. At lower temperatures they lost orientation, and none survived exposure to 4 C.

The general decline in water temperature was a system-wide phenomenon due to cold air temperatures. However, sudden temperature shocks were caused by shifts in source of intake water from the Clinch to the Emory River. Since the Emory originates in the Cumberland Plateau, it is colder in the winter than the Clinch and Tennessee which originate at lower elevations. The source of intake water is controlled by the relative levels or flow rates of the Emory, Clinch, and Tennessee Rivers. If the levels and/or flows of the Clinch and Tennessee are lower than those of the Emory, water from the Emory flows into the intake.

The Clinch and Tennessee Rivers are dam-controlled and river levels can be manipulated. Even though it may be possible to prevent a switch in the source of intake water during the early winter, once the fish enter the intake, they will eventually be impinged. Ambient river temperature in the Clinch and Emory went below the lower lethal limit for threadfin during December of both years.

It is our hypothesis that the threadfin in the Clinch River, the largest population near the steam plant, could have been prevented from entering the intake canal if the water had been withdrawn from the Emory River starting in October. Gill-net catches in the Emory indicate a movement of fish out of that river after the first fall storms began to cool the water. Only two threadfin were taken in the

Emory after November 10, 1976, and none during 1977. Downstream movement of threadfin in the vicinity of the intake would result in movement into the intake canal. Gill nets placed in the skimmer wall openings of the intake canal during 1976 indicated all fish were moving with the current. Thus, if water were taken from the Emory instead of the Clinch beginning in early fall, threadfin in the Clinch would probably continue to swim down the Clinch, past the confluence of the Emory, and thus bypass the intake canal which is located on the Emory (Fig. 1). This possible solution to threadfin impingement at the Kingston Steam Plant, however, is probably not feasible because the level of water in the river systems is controlled by power and flood-control needs of the surrounding Tennessee Valley.

It is interesting to note that water clarity increases during the winter. This observation supports the hypothesis that temperature is the main causal factor of impingement, as opposed to the inability of fish to detect the intake structures. It is also supportive of the hypothesis that shad are mortality-stressed before being impinged. Unfortunately, the results of the changes in serum electrolytes as an indication of this stress were inconclusive. Stress behavior of fish in the laboratory prior to cold-induced mortality, however, is similar to the behavior of fish we observed prior to their impingement. It is still our opinion that most of these fish would have died had they not been impinged.

Secondary factors related to the response of threadfin to cold could also be responsible for the rate of impingement. Cessation of feeding could result in additional stress. Griffith (1978) noted that threadfin ceased feeding as temperatures dropped below 9 C. Stomach content analysis of impinged fish indicated almost 100% empty stomachs. In addition, the quality of food available during the winter may not be good. Analysis of the contents of stomachs of threadfin caught outside the intake shows ash content to be consistently in the 70 to 80% range, indicating that only 20 to 30% is digestible. Impingement of gizzard shad and young-of-the-year skipjack herring during the second year of study was not expected to occur since few were impinged the first year. However, the population crash of threadfin shad after the winter of 1976-77 may have triggered the population explosion of river herring and gizzard shad. Possible mechanisms responsible for the explosion may be that adult threadfin do not compete for food with gizzard shad and river herring larvae, and/or that there is a lack of predation on these larvae by threadfin. Dendy (1946) observed threadfin and gizzard shad to be cannibalistic.

Ecological Ramifications of Impingement

One approach to the problem of the effect of impingement on the population of threadfin is to determine what would have happened to the threadfin had they not been impinged. Within-year and between-year comparisions of laboratory data, field observations of feeding behavior of scavengers and predators, and stomach content analysis of predators all contribute to this determination.

Some threadfin survived to reproduce despite cold water and impingement. Griffith (1978) showed that 9- to 14-cm threadfin that were cold-shocked until equilibrium was lost for 12, 30, and 90 min before being returned to warmer waters experienced mortalities of 32, 79, and 94% respectively. He also showed that the final low temperature to which the fish were exposed, not the magnitude of the drop of temperature, was responsible for the deaths. Thus, a small percentage of the threadfin not in the intake canal may have been able to survive the rapid drop of temperature in the Clinch and Tennessee Rivers if thermal refuges were available. We found refuges which included five backwater coves and the power plant discharge. Ground-water input in the coves was 9 to 12 C, when ambient water was 3.5 to 5 C, and the ΔT in the discharge was 6 C compared to intake temperatures. After fish had disappeared from most of the other areas monitored, threadfin were still found both in the power plant discharge and in one cove the first year and in the discharge the second year. Large numbers of gizzard shad were found in several refuges the second year and were preyed upon by all predators monitored in those refuges. Even though there was predator pressure in these areas, we believe refuges are important to survival of fish intolerant of low temperatures. The reason for our inability to catch threadfin shad in these refuges is a mystery that needs further investigation.

A second possible fate of threadfin, had they not been impinged, is that they would have been preyed upon. Stomach content analysis showed that sauger, catfish, white bass, yellow bass, striped bass, and skipjack herring all fed on threadfin. An in-depth look at sauger predation showed that threadfin shad were the single most important food item for sauger during the first year of study, and they composed 31.7% of diet the second. Sauger consumed considerable numbers of threadfin from November through December 1976 and both threadfin and young-of-the-year gizzard shad from September through January 1977-78. These prey probably became more available during these months because they became cold-stressed.

The predator-prey relationships of sauger, threadfin shad, and gizzard shad appear unique in that a relatively cold-tolerant predator is feeding in winter, primarily on cold-sensitive prey. During the summer months, young-of-the-year shad are found primarily in the warm surface waters. Sauger at this time seek cooler water and during most of the day are spatially isolated from threadfin. Walleye preying on young-of-the-year gizzard shad in Hoover Reservoir are subject to similar constraints, resulting in decreased growth rates (Momot et al. 1977). Optimal feeding conditions for sauger occur in fall as water temperatures become more uniformly cool throughout the water body and as young-of-the-year shad become stressed. Shorter day lengths in these months increase the hours of twilight and darkness, during which sauger are more efficient predators (Ryder 1977). Impingement of threadfin shad and young-of-the-year gizzard shad in fall and winter could only create an adverse impact on sauger if a large proportion of the total shad population were removed, resulting in inadequate forage.

Any effect of impingement of threadfin and gizzard shad on sauger, if present, could not be measured. A change in condition of sauger due to reservoir-wide mortality of these forage fish, however, was documented. Condition is defined as weight per unit length and is affected by visceral fat reserves and gonadal weight.

During 1976 to 1977, the steady decline in sauger condition, after an initial rapid weight gain (Fig. 15), can be attributed to a lack of threadfin prey after February (Fig. 11). As the demand for growth began (above 12 C), additional energy requirements were imposed on the fish, which, in the absence of food, resulted in an accelerated loss of condition. During the second year of study, sauger condition was maintained throughout the winter. This improved condition corresponds to increased prey availability through March (Figs. 11 and 14) and lower metabolic requirements due to colder temperatures in March (Fig. 18).

Differences in condition of separate size classes of sauger were observed during both years (Fig. 15). These differences can also be explained in terms of prey availability and metabolic requirements. For example, the first year, small sauger had a higher condition relative to large sauger. Concurrently, shad prey were not available after February. Thus, even though both small and large predators had no food, the large sauger were producing gonadal material for the spring spawning season (Fig. 17). This additional energy demand helps account for the relatively lower condition of the larger fish. The lower condition may not be detrimental to the sauger in the long term, however, if there are sufficient fat stores for reproduction. Fat stores of fish during March and April 1977, the period of lowest condition recorded for sauger, were not significantly different than those during periods of relatively good condition during the winter of 1977-78.

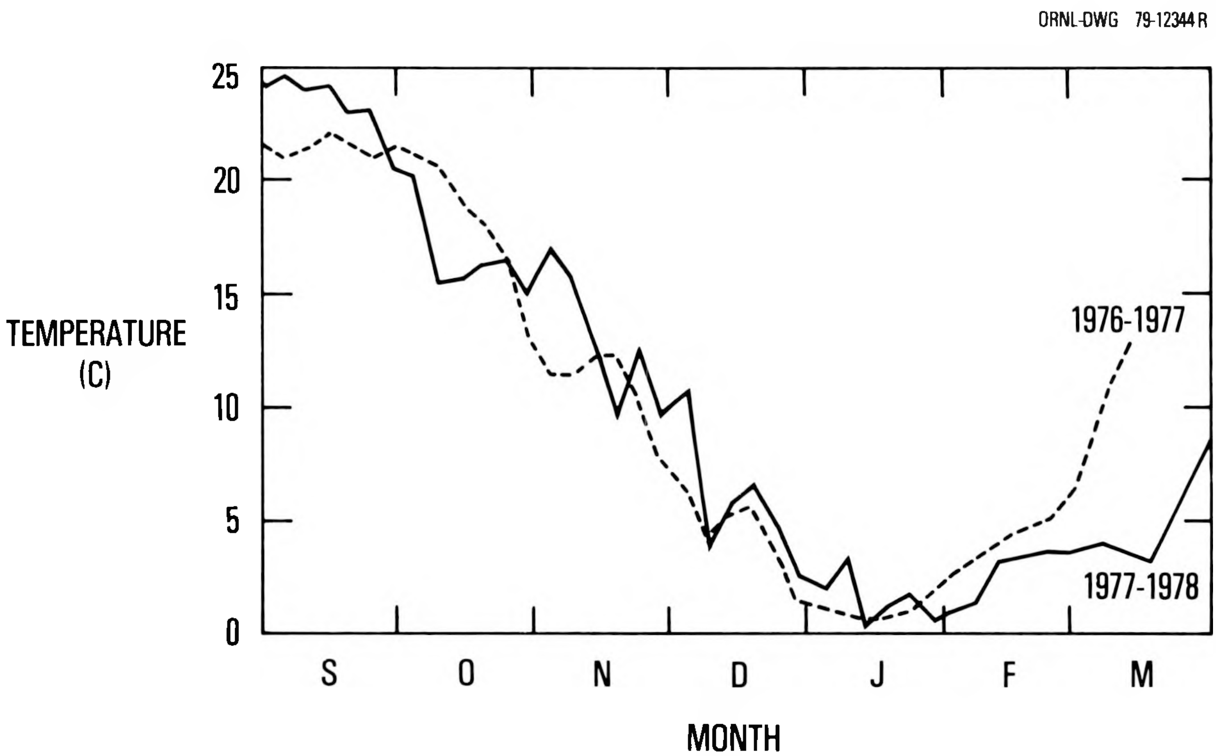

Fig. 18. Water temperatures in the vicinity of the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, September 1976 to April 1978.

A third possible fate of shad, had they not been impinged, is that they could be eaten by scavengers after they die and sink to the bottom or after they float and are washed onto shore. The results from laboratory studies on catfish feeding, in which we showed temperature-dependence of feeding and food selectivity, suggest that the channel catfish, normally an important scavenger, probably play a minor role in the utilization of winter-killed threadfin shad. Cold stress of the shad would be primarily expected below 10 C, and food consumption of wild channel catfish would, in all likelihood, be negligible at this temperature. If the catfish were to feed, perhaps as temperatures subsequently increased, the data suggest that they would reject decomposing shad.

Observations of fish washed onto the shoreline and of fish freshly killed and placed there indicate birds such as starlings, crows, and herons are effective scavengers. The majority of dead threadfin, however, did sink and were decomposed within several weeks.

These data indicate, therefore, that the majority of threadfin, had they not been impinged, would have died (perhaps over 95%). Some would have been eaten by predators and scavengers, but most would have decomposed.

Impingement Monitoring as an Ecological Assessment Tool

The total sampling program was aimed at answering the basic questions of cause of threadfin impingement and of the effects of that impingement on population structure of threadfin and predator-prey dynamics. It is important to know the relative amounts of information that can be derived from each sampling technique. It is especially of interest to know the value of impingement monitoring in addressing the above questions of concern. Therefore, the three quantitative sampling techniques used, impingement monitoring, gill-netting, and sauger stomach content analysis, will be compared as to the types of information each yielded and to the degree to which the techniques were complementary.

Impingement monitoring resulted in three basic types of information: (1) numbers of fish impinged over time, (2) species composition of fish impinged, and (3) size classes of each species impinged. These types of data, coupled with temperature monitoring and laboratory studies on the response of threadfin to low temperatures, enabled us to pinpoint the causal factors resulting in impingement. Additionally, the size-class information showed a change in the proportion in lengths of fish impinged as the temperature became colder. This finding supports previous laboratory data on 10- to 15-cm fish and suggests a higher (i.e., not as cold) lethal limit for younger fish.

The importance of this differential mortality of size classes of threadfin, based on temperature, can be assessed by looking at the stomach contents of sauger (Fig. 19 and Table 8). The smallest sauger had the greatest percentage of empty stomachs in winter of both years. During the first year the smallest size classes of threadfin (50 to 101 mm) were quickly killed due to cold stress. During the second year, the 77- to 101-mm size class dominated the entire year. This dominant class was not utilized heavily by small sauger after January,

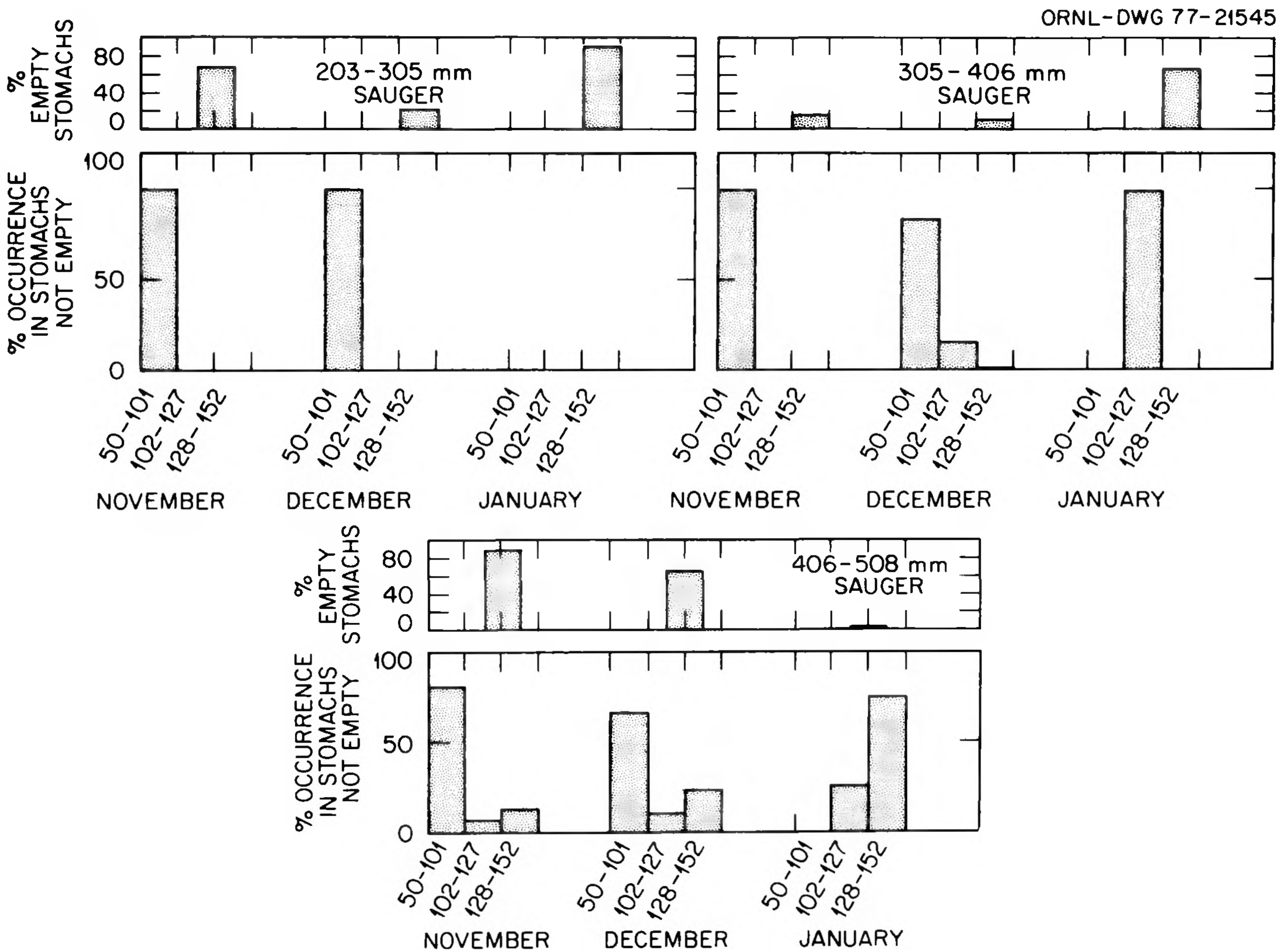

Fig. 19. Percent occurrence by size class of threadfin shad (Dorosoma petenense) in stomachs of three size classes of sauger (Stizostedion canadense) during November 1976 through January 1977.

as indicated by the percentage of empty stomachs (Table 8). This reduction in feeding may be related to a reduction in prey density and a reduction in metabolic requirements. More than 50% of the larger sauger continued to feed through February. Energy demands of gonadal development may have prompted this feeding.

A comparison of the size classes of threadfin shad impinged, with those gill-netted and found in sauger stomachs, shows similar results. The first year, when seven size classes of threadfin were impinged, the size classes dominating impingement counts were the same classes preyed upon by sauger and gill-netted (Fig. 20). In each case, the trend is toward larger fish as the temperatures decline. Thus, these sampling techniques yielded the same types of information, with impingement monitoring providing the largest sample size.

Impingement monitoring also indicated that fish other than threadfin were constantly impinged. This information became important when prey selectivity by sauger was examined. During the winter of 1976-77 the presence of non-threadfin prey impinged prior to February, but the absence of these prey in sauger stomachs during this time, indicates a prey preference based on more than availability alone. In addition, the proportion of non-shad species on the intake screens from February through April, closely parallels the proportion of those species in sauger stomachs at that time (Fig. 21). Therefore, impingement monitoring could have been used to estimate the proportion of prey species taken by sauger once the prey species were identified. During 1977-78, the proportion of species on the intake screens from February to April does not reflect the proportion of those species in

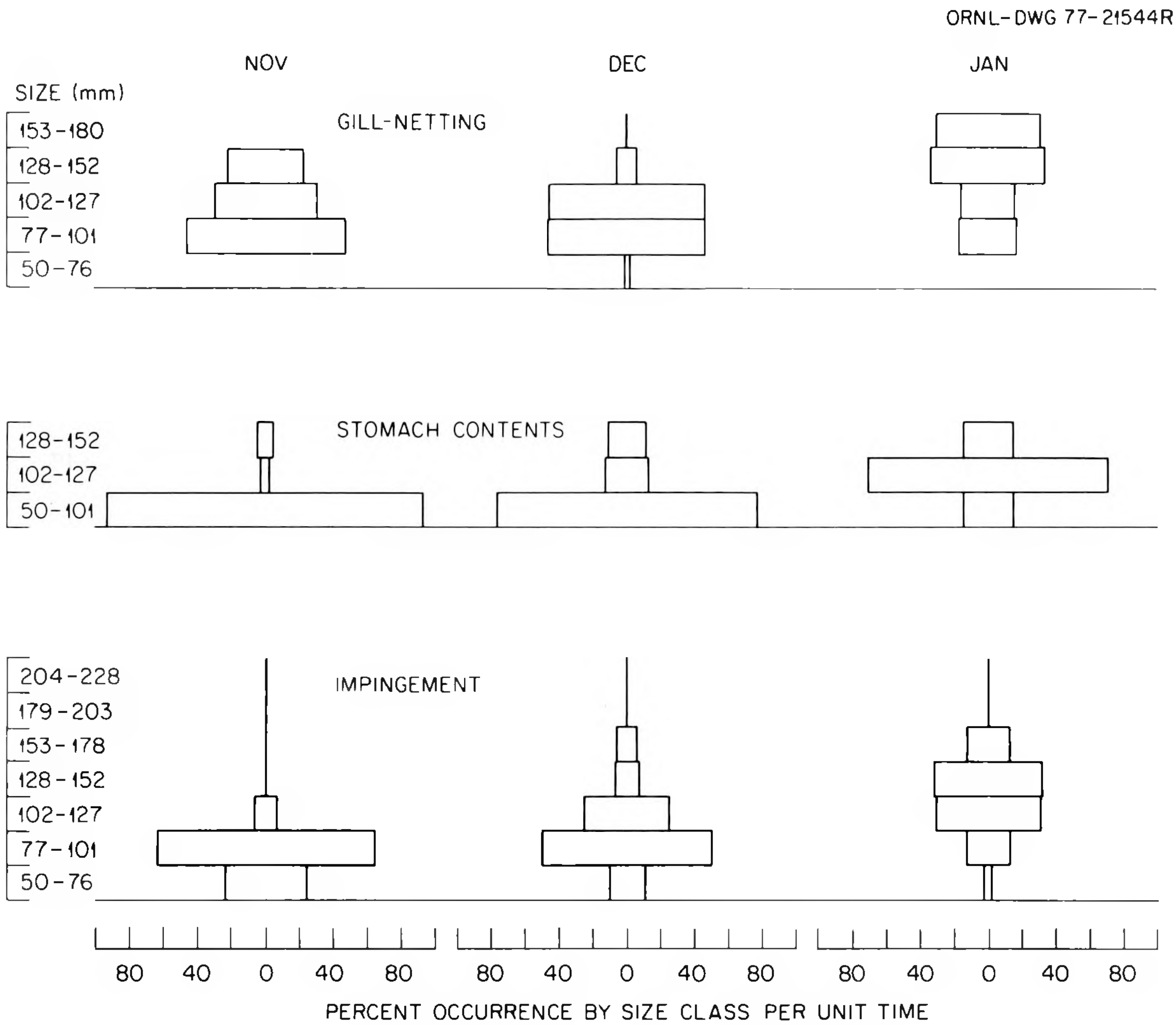

Fig. 20. Comparison of size class distributions of threadfin shad gill-netted in Watts Bar Reservoir (Tennessee), in sauger stomachs, and collected on intake screens at the Kingston Steam Plant, November 1976 through 1977.

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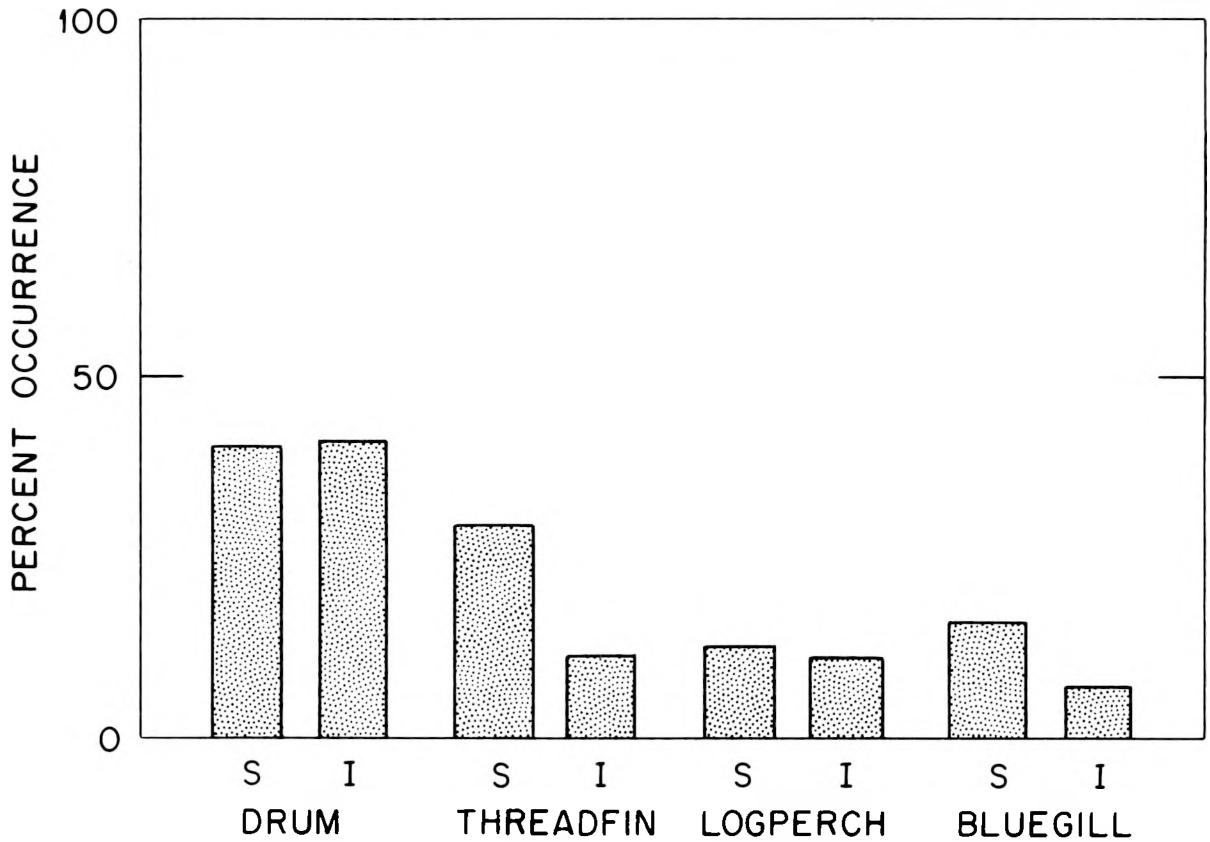

Fig. 21. Comparison of sauger predation on fish species (S) and impingement of these species (I) between February 2 and April 26, 1977.

sauger stomachs (Table 14). The data in Table 14 and Fig. 22, suggest that the sauger switched to an alternate prey source, freshwater drum, much more readily and completely the second year than the first. This switching is not surprising since freshwater drum consistently dominated the non-shad prey of sauger in every month sampled the second year, suggesting that they were actively sought. As shad densities decreased, sauger may have preferred drum over shad because of the higher relative availability of drum.

Impingement monitoring obviously identifies the peak period of fish impingement. Gill-netting, if it is a sensitive indicator of fish densities, should reflect this buildup of the threadfin population in the vicinity of the intake. Figure 22 indicates that gill nets set both in the intake and upstream of the intake reflect this buildup. Gill-net catches the second year, however, did not reflect the abundance of gizzard shad and skipjack herring impinged. These fish were co-dominant with threadfin on the intake screens but were not present in the gill-net catches. These differences probably can be explained as a result of net avoidance behavior of gizzard shad and skipjack herring.

Finally, cove-rotenoning in June and July 1976 (funded by DOE) reflects the size distribution of threadfin that were impinged during the peak period that year. Allowing for the size classes to shift up one level due to growth, the proportion of classes are closely correlated (Fig. 23). This correlation indicates that impingement monitoring can also give a good indication of size-class strength of the threadfin population, given that temperatures are low enough to

Table 14. A comparison of the relative abundance of four groups of fish impinged on the intake screens of the Kingston Steam Plant and found in the stomachs of sauger gill-netted in Watts Bar Reservoir between February and April 1978

	"Prey" species (%)			
"Predator"	Shad	Drum	Centrarchids	River herring
Power plant	68.9	22.5	7.5	1.1
Sauger	30.8	61.5	7.7	0.0

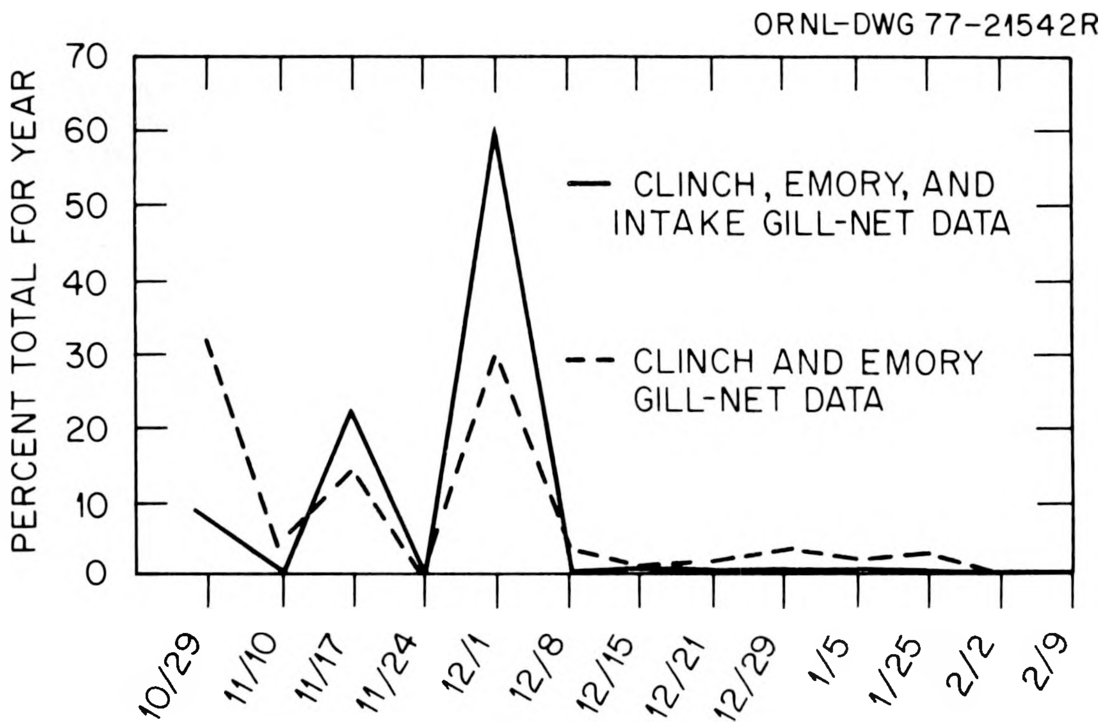

Fig. 22. Relative temporal abundance of threadfin with time at stations near the intake and at these same stations but including the intake canal.

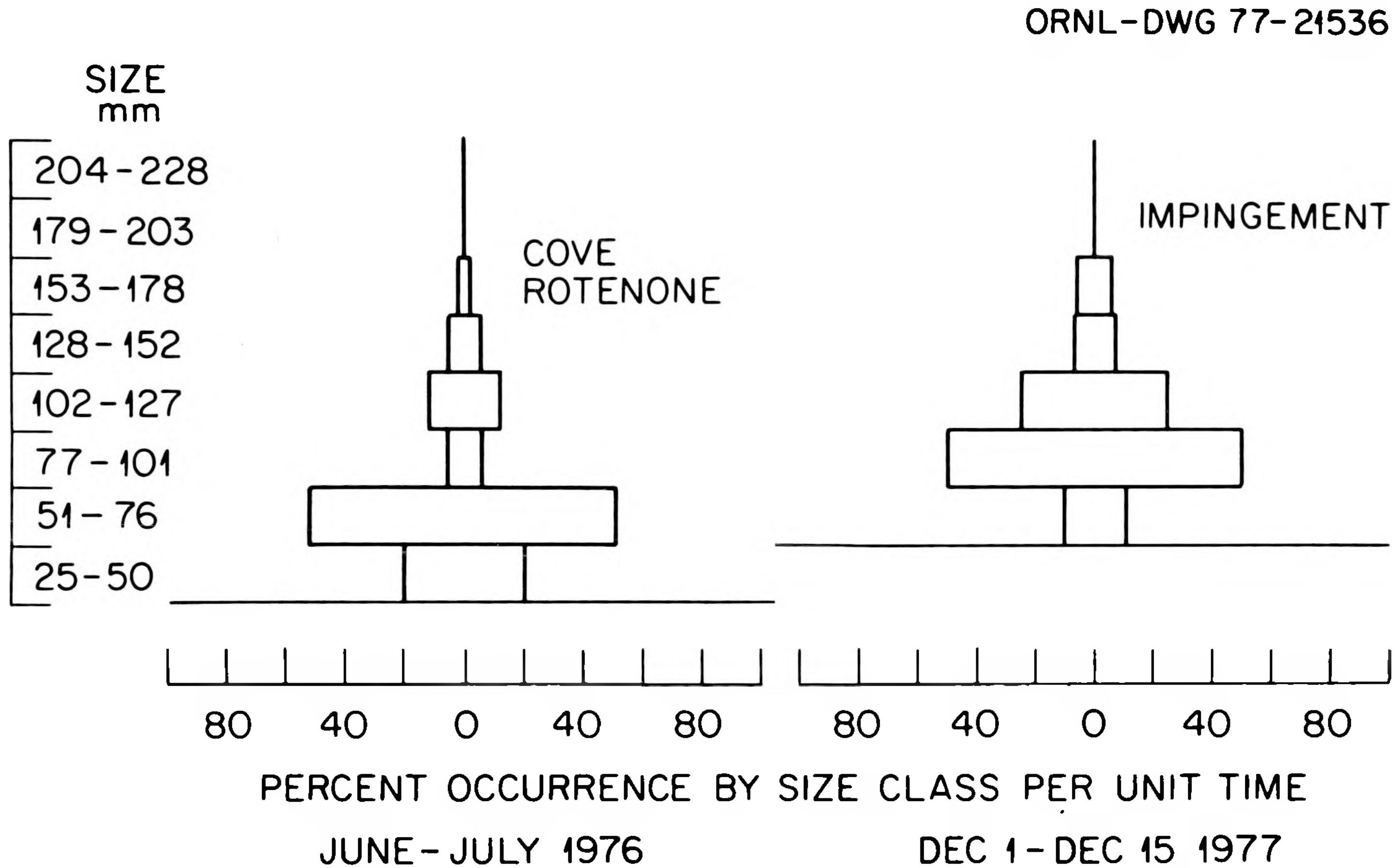

Fig. 23. Percent distribution of size classes of threadfin shad found in eight coves in June and July 1976 in the Clinch and Tennessee Rivers in the vicinity of the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, compared to those collected on the screens during peak impingement (December 1-15, 1977).

equally affect all size classes and given that no major differential mortality of size classes occurred between summer rotenoning and winter impingement.

CONCLUSION

There are eight main conclusions resulting from this two-year study.

1. Temperature greatly influences impingement of threadfin shad, gizzard shad, and probably skipjack herring. Temperature also greatly influences any potential effects that loss of these prey may have on predators.
2. Natural cold kills of threadfin shad masked any ecological effects due to impingement.
3. Most of the shad, had they not been impinged, would have died due to cold stress, and they would have decomposed rather than been eaten by scavengers.
4. Reservoir-wide mortality of threadfin and gizzard shad did have a measurable short-term effect on sauger as determined by changes in condition factor, and this mortality contributed to the higher percentage of empty stomachs in late winter of skipjack herring, striped bass, and white bass.
5. The population of threadfin shad rebounded after the winter kill of 1976-1977, resulting in a dominant 0+ year class.
6. Thermal refuges were identified for gizzard shad and hybrid shad, including the thermal discharge of the Kingston Steam Plant.

7. Hybrid shad made up 11.2% of the total threadfin populations sampled both years, and they may provide a gene pool for the cold-sensitive threadfin if hybrids are reproductively viable and are able to survive colder temperatures than threadfin.

8. Blood serum electrolytes (Na^+, K^+, Cl^-) were not found to be good predictable indicators of cold stress of young-of-the-year gizzard shad.

In summary, the results of this study have provided an understanding of the causes of impingement of threadfin shad and young-of-the-year gizzard shad and effects of threadfin impingement on threadfin population and trophic dynamics. These results have also indicated the value of a comprehensive approach to monitoring physical and biological parameters associated with impingement. The information derived to date provides a sounder base on which decisions can be made concerning the value of technical specification monitoring programs, monitoring data in environmental reports, and analysis of those data as presented in environmental statements. In addition, these data provide a better knowledge of the potential for impingement at southeastern power plants, the significance of impingement, and a guidance for future research in the area of impingement. The data give promise to the development of a methodology which can be used to monitor any predator-prey population and translate indices of predator condition into the significance that prey fluctuations have on game fish in reservoir communities.

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APPENDICES

APPENDIX A

Number, total weight [wt (g)], and mean weight [$\bar{X}$ wt (g)] by size class of threadfin shad (*Dorosoma petenense*) impinged at the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, between November 18, 1976, and April 27, 1977. Numbers of fish impinged on dates between November 22 and December 27, 1976 were estimated from subsamples.

	Size class (mm)																						Totals[a]		
	50-76			77-101			102-127			128-152			153-178			179-203			204-228					
Date	No.	Wt	$\bar{X}$ wt	No.	Wt	$\bar{X}$ wt	No.	Wt	$\bar{X}$ wt	No.	Wt	$\bar{X}$ wt	No.	Wt	$\bar{X}$ wt	No.	Wt	$\bar{X}$ wt	No.	Wt	$\bar{X}$ wt	No.	Wt	$\bar{X}$ wt
(1976)																								
11/18	168	359	2.1	291	1502	5.2	69	693	10.0				3	95	31.7	4	155	38.8				535	2804	5.2
11/19	462	1022	2.2	969	5045	5.2	97	960	9.9				10	380	38.0	3	120	40.0				1541	7527	4.9
11/22	646	1982	3.1	1413	8520	6.0	62	827	13.3													2121	11329	5.3
11/24	498	996	2.0	1694	10216	6.0	249	2491	10.0	50	1620	32.5										2491	15323	6.2
11/26	186	405	2.2	510	2875	5.6	81	809	10.0				4	145	37.5							781	4234	5.4
11/29	365	987	2.7	543	3256	6.0	89	987	11.1													997	5230	5.3
12/1	548	1219	2.2	4390	22863	5.2	610	6097	10.0				488	18290	37.5							6036	48469	8.0
12/3	936	2924	3.1	4502	24561	5.5	468	4678	10.0	117	3801	32.5										6023	35964	6.0
12/6	1434	3894	2.7	2416	15488	6.4	407	4602	11.3	62	1682	27.1	133	5000	37.7	80	3629	45.6				4532	34296	7.6
12/8	3652	8452	2.3	22226	137216	6.2	13148	127303	9.7	1669	44869	26.9	939	37043	39.4	104	5217	50.0				41738	360100	8.6
12/10	1202	4673	3.9	6782	35939	5.3	7369	73427	10.0	1655	51800	31.3	694	28837	41.5	80	4539	56.7				17782	199215	11.2
12/13	159	358	2.3	3697	25541	6.9	4194	48497	11.6	1292	38262	29.6	676	27926	41.3	20	994	50.0				10038	141578	14.1
12/15				268	2098	7.8	408	5245	12.9	256	8042	31.4	210	8450	40.3							1142	23835	20.9
12/17				338	2531	7.5	526	6752	12.8	496	14993	30.2	139	5858	20.7							1499	30134	20.1
12/20				99	1219	12.3	267	3048	11.4	152	4228	27.8	114	4343	38.0	8	381	47.6				640	13219	20.7
12/22	74	368	5.0	202	1657	8.2	644	7547	11.7	331	10676	32.2	110	3681	33.3	18	920	51.1				1379	24849	18.0
12/27	165	368	2.2	368	2577	7.0	295	3866	13.1	37	920	25.0	37	1381	37.5							902	9112	10.1
12/30				13	90	6.9	31	420	13.5	1	10	10.0	1	25	25.0							46	545	11.9
(1977)																								
1/3	3	10	3.3	12	92	7.7	38	490	12.9	33	1080	32.7	16	667	44.5							102	2339	22.9
1/5				3	20	6.7	7	90	12.9	2	70	35.0	2	90	45.0				1	115	115.0	15	385	25.7
1/7				4	50	12.5	11	200	18.0	3	110	36.7	7	310	44.3	1	80	80.0				26	750	28.9
1/10							3	40	13.3	4	120	30.0										7	160	22.9
1/12																						0	0	0
1/14										14	490	35.0	5	220	44.0	1	85	85.0	1	130	130.0	21	925	44.1
1/25							3	58	19.3	14	390	27.9	1	50	50.0							18	498	27.7
1/28										9	200	22.2	3	65	21.7				1	85	85.0	13	350	26.9
2/2										5	120	24.2	1	40	40.0	1	80	80.0	1	110	110.0	8	350	43.8
2/4										2	65	32.5	2	85	42.0							4	150	37.5
2/9							16	345	21.6	44	1250	28.5	2	105	52.3							62	1700	22.4
2/11							10	243	24.3	4	120	30.0										14	363	25.9
2/14				1	17	17.0	7	164	23.4	1	47	47.0										9	228	25.3
2/16							6	155	25.8													6	155	25.8
2/18							8	215	26.8							1	104	104.0				9	316	35.1
2/23							3	78	26.0													3	78	26.0
2/25																						0	0	0
2/26							1	35	35.0													1	35	35.0
3/2							1	40	40.0													1	40	40.0
3/4																						0	0	0
3/7																						0	0	0
3/9																						0	0	0
3/11										2	76	38.0				1	85	35.0				3	161	53.6
3/14										1	20	20.0							1	34	34.0	2	104	52.0
3/16																			1	117	117.0	1	117	117.0
3/18																						0	0	0
3/21																						0	0	0
3/25																						0	0	0
3/28																						0	0	0
3/30																						0	0	0
4/1																						0	0	0
4/4																						0	0	0
4/6							1	10	10.0	1	25	25.0										2	35	17.5
4/8																						0	0	0
4/11																						0	0	0
4/13																						0	0	0
4/27																						0	0	0
Total number and weight[b]	10498		28134	50741		303373	29728		300412	6257		185086	3597		143086	322		16389	6		641			
Mean number and weight[c]	190.9		2.7	922.6		6.0	540.5		10.1	113.8		29.6	65.4		39.8	5.9		50.9	0.1		106.8			

Total fish impinged on sampling days: 101,141

[a]Total number, total weight, and mean weight by date over all size classes.

[b]Total number and weight of each size class impinged on all sampling dates.

[c]Mean number = $\frac{\text{Total number of each size class}}{\text{Total number of sampling days}}$; mean weight = $\frac{\text{Total weight of each size class}}{\text{Total number of each size class}}$.

APPENDIX B

Threadfin shad (Dorosoma petenense) caught in gill nets between October 29, 1976, and April 27, 1977, at sample stations upstream of the thermal discharge and in the discharge of the Kingston Steam Plant. Data are normalized for a standard net length of 7.6 m (No. of fish caught in a 15.2-m net, divided by 2 to acquire catch per standard net length). Fish were caught in three mesh sizes: 13, 15, and 25 mm.

	Sample station (Number designation)																
	Discharge (6)			Intake (3)		Clinch (4 & 5)			Emory (1 & 2)			Totals[a]			Mean[b]		
	Mesh sizes (mm)			Mesh sizes (mm)		Mesh sizes (mm)			Mesh sizes (mm)			Mesh sizes (mm)			Mesh sizes (mm)		
Date	13	15	25	13	25	13	15	25	13	15	25	13	15	25	13	15	25
(1976)																	
10/29	2.5	-	0	-	-	30.0	0	3.0	13.0	0	1.5	45.5	0	4.5	15.1	0	0.8
11/10	0.5	-	0	-	-	3.5	0	0	1.0	0	0	5.0	0	0	1.7	0	0
11/17	-	-	-	125.0	42	22.0	0	0.3	0	0	0	49.0	0	42.3	16.3	0	14.1
11/24	50.0	-	0	-	-	1.0	0	0	0	0	0	51.0	0	0	17.0	0	0
12/1	-	-	-	406.0	61	42.0	-	4.0	0	0	0	448.0	0	65.0	149.3	0	21.7
12/8	0	-	0.5	-	-	10.3	0	0	2.3	0	0	12.6	0	0.5	4.2	0	0.1
12/15	-	-	-	1.0	0	0.7	3.0	2.0	0	0	0	1.7	3.0	2.0	0.6	1.5	0.7
12/21	0.5	-	20.0	-	-	5.3	2.0	0.4	0	0	0	5.8	2.0	20.4	1.9	1.0	6.8
12/29	-	-	-	-	-	3.3	30.0	4.0	0	0	0	3.3	30.0	4.0	1.7	15.0	2.0
(1977)																	
1/5	-	-	-	0	0	2.5	46.0	0.4	0	0	0	2.5	46.0	0.4	0.8	23.0	0.1
1/12	53.0	188.0	543.0	-	-		Ice			Ice		53.0	188.0	543.0	53.0	188.0	543.0
1/18	-	-	-	-	-		Ice			Ice		0	0	0	-	-	-
1/25	12.5	-	23.5	-	-	3.7	0	0.8		Ice		16.2	0	24.3	8.1	0	12.2
2/2	-	-	-	0	0	0	1.0	0.5		Ice		0	1.0	0.5	0	1.0	0.3
2/9	1.5	-	1.5	-	-	0	0	0.2		Ice		1.5	0	1.7	0.8	0	0.9
2/16	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2/24	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
2/23	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3/2	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
3/9	0	100.0	6.0	0	0	0	0	0	0	0	0	0	100.0	6.0	0	33.3	1.5
3/17	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
3/30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4/13	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
4/27	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total[c]	120.5	288.0	594.5	532.0	103	124.3	82.0	15.6	16.3	0	1.5						
Mean[d]	11.0	96.0	59.5	53.2	10.3	5.7	3.9	0.71	0.9	0	0.1						
Total[e]		1003.0		635.0			221.9			17.8							
Mean[f]		43.6		31.8			3.4			0.3							

[a]Total number of fish caught in each mesh size, at all stations, for a given date.

[b]Mean number of fish caught in each mesh size, at all stations, for a given date = $\frac{\text{Total fish caught in each mesh}}{\text{Total number of stations}}$.

[c]Total fish caught in each mesh size for all dates.

[d]Mean number = $\frac{\text{Total number fish caught in each mesh size}}{\text{Total number of sampling dates}}$.

[e]Total fish caught in all mesh sizes at each station, for all dates.

[f]Mean number of fish caught for each station = $\frac{\text{Total fish caught in all meshes}}{\text{Total number of sampling dates}}$.

APPENDIX C

Threadfin shad (Dorosoma petenense) caught in gill nets at sample stations downstream of the thermal discharge of the Kingston Steam Plant, Watts Bar Reservoir, Tennessee, between October 24, 1976, and April 26, 1977. Data are normalized for a standard net length of 7.6 m (No. of fish caught in a 15.2-m net, divided by 2 to acquire catch per standard net length). Fish were caught in three mesh sizes: 13, 15, and 25 mm.

	Sample station (Number designation)																												
	I-40 (7)			Kingston Park (8)			58 Bridge (9)			FRS (10)			FRN (11)			562S (12)			562N (13)			Total[a]			Mean[b]			Total[c]	Mean[d]
	Mesh sizes (mm)			Mesh sizes (mm)			Mesh sizes (mm)			Mesh sizes (mm)			Mesh sizes (mm)			Mesh sizes (mm)			Mesh sizes (mm)			Mesh sizes (mm)			Mesh sizes (mm)				
Date	13	15	25	13	15	25	13	15	25	13	15	25	13	15	25	13	15	25	13	15	25	13	15	25	13	15	25		
(1976)																													
11/24	0	29	0	16	2	0	2	0	0	6	0	0	0	6	0	0	0	0	6	14	1	30	51	1	4.3	7.3	0.1	82	3.9
12/8	-	-	-	12	9	0	0	0	0	0	1	0	1	1	0	5	3	0	1	1	0	19	15	0	3.2	2.5	0	34	1.8
12/23	5	39	1	0	27	2	0	0	0	4	0	0	1	2	1	0	1	2	10	4	0	20	73	6	2.9	10.4	0.9	99	4.7
(1977)																													
1/5	9	53	2	8	50	109	2	1	0	0	0	1	0	16	4	0	0	0		Ice		19	120	116	3.2	20.0	19.3	255	13.4
1/20	0	29	2	0	161	17	0	0	0	0	1	1	0	0	0	0	0	0	1	0	3	1	191	24	0.1	27.3	3.4	216	10.3
2/3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2/24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3/9	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0.3	0	2	0.1
3/22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4/12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4/26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total[e]	14	150	5	36	250	128	4	1	0	10	3	2	2	25	5	5	4	2	19	19	4								
Mean[f]	1.4	15	0.5	3.3	22.7	11.6	0.4	0.1	0	0.9	0.3	0.2	0.2	2.3	0.5	0.5	0.4	0.2	1.7	1.9	0.4								
Total[g]		169			414			5			15			32			11			42									
Mean[h]		15.4			37.6			0.5			1.4			3.3			1.0			3.8									

[a]Total number of fish caught in each mesh size, at all stations, for a given date.

[b]Mean number of fish caught in each mesh size, at all stations, for a given date = $\frac{\text{Total fish caught in each mesh}}{\text{Total number of stations}}$.

[c]Total number of fish caught in all mesh sizes for a given date.

[d] Mean number of fish caught in all mesh sizes for a given date = $\frac{\text{Total fish caught in all meshes}}{\text{Total number of meshes}}$.

[e]Total fish caught in each mesh size for all dates.

[f]Mean number = $\frac{\text{Total number fish caught in each mesh size}}{\text{Total number of sampling dates}}$.

[g]Total fish caught in all mesh sizes at each station, for all dates.

[h]Mean number of fish caught for each station = $\frac{\text{Total fish caught in all meshes}}{\text{Total number of sampling dates}}$.

APPENDIX D

Stomach contents of 449 sauger collected from November 1976 through April 1977 in gill nets at 13 stations in the vicinity of Kingston Steam Plant, Watts Bar Reservoir, Tennessee

	Sauger		No. of prey[a] eaten by sauger									Length (cm) of threadfin prey	
Date	Size (cm)	No.	TFS	UIDS	DR	CE	LP	Mayfly	UID	R[b] No.	Empty stomachs No.	Min.	Max.
November	20.3 - 30.5	2	0	0	0	0	0	0	0	0	2	-	-
	30.6 - 40.6	20	17	4	0	0	0	0	4	2	4	8	8
	40.7 - 50.8	17	2	8	0	0	0	0	0	7	3	13	13
December	20.3 - 30.5	9	7	0	0	0	0	0	4	1	2	8.5	8.5
	30.6 - 40.6	96	80	11	0	0	0	0	87	3	10	7.5	14.0
	40.7 - 50.8	32	41	10	0	0	0	0	12	2	5	7.0	15.8
January	20.3 - 30.5	9	0	0	0	0	0	0	1	0	8	-	-
	30.6 - 40.6	14	0	1	0	0	0	0	11	1	3	11.5	11.5
	40.7 - 50.8	8	0	4	0	0	0	0	18	0	0	10.5	13.5
February	20.3 - 30.5	8	0	0	0	0	0	0	0	0	8	-	-
	30.6 - 40.6	35	0	1	4	0	0	0	7	5	21	10.7	10.7
	40.7 - 50.8	10	0	4	1	0	0	0	6	1	4	-	-
March	20.3 - 30.5	51	0	0	2	3	0	0	7	2	42	2.7	4.0
	30.6 - 40.6	85	0	0	3	0	3	6	7	2	68	4.0	12.5
	40.7 - 50.8	17	0	0	2	0	0	0	1	0	14	-	-
April	20.3 - 30.5	6	0	0	0	1	1	1	2	1	2	-	-
	30.6 - 40.6	26	0	0	1	1	1	0	0	0	21	8.7	12
	40.7 - 50.8	6	0	0	0	0	0	0	0	0	6	-	-
TOTALS		449	147	43	13	5	5	7	167	27	224		

[a]TFS - threadfin shad, UIDS - unidentified shad, DR - freshwater drum, CE - centrarchids, LP - log perch, UID - unidentified fish.

[b]R - regurgitated.

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