EVALUATION OF AN AIR-BUBBLE CURTAIN TO REDUCE IMPINGEMENT AT AN ELECTRIC GENERATING STATION

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Abstract: A biological testing program was conducted during 1974-75 to determine the efficiency of an air-bubble curtain in reducing fish impingement at Arkansas Nuclear-One Unit 1, on Dardanelle Reservoir, AR. Air curtain operation did not effectively deter fish from entering the intake canal or substantially reduce impingement. Seasonal variations in species composition and length-frequency distribution of impinged fish were independent of air curtain operation. There was a significant inverse correlation between water temperature and impingement levels during fall 1974 and spring 1975. Highest impingement rates occurred during late fall, winter, and early spring, regardless of air curtain status. Impinged individuals were predominantly young-of-the-year-fish, especially threadfin (*Dorosoma petenense*) and gizzard shad (*D. cepedianum*), assumed to be thermally stressed by low ($<$ 15.5 C) water temperatures.

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A major environmental concern involved with the withdrawal of once-through cooling water has been the impingement of aquatic organisms, especially fish, on plant intake screens. To avoid or mitigate this problem, Arkansas Power & Light Company (AP&L) contracted Texas Instruments Incorporated (TI) to design and implement a program to determine the efficiency of an air-bubble curtain in reducing fish impingement at their Arkansas Nuclear-One Unit-1 generating facility on Dardanelle Reservoir. For a chronological overview of behavioral screening techniques in general and air curtain development in particular, the authors suggest a review of publications by Sharma (1974) and U.S. E.P.A. (1973).

Study objectives included a characterization of the species composition and abundances, biomasses, and length-frequency distributions of fishes impinged during 4 seasonal air curtain test periods and an examination of causal relationships between impingement, air-bubble curtain status, and selected biological and physicochemical parameters measured during air curtain testing. The authors wish to thank Arkansas Power & Light Company for financial support of this and other related projects, to: B. Keith, Arkansas Game and Fish Commission for supplying Dardanelle Reservoir fisheries data; D. Dubose and I. Savage of Texas Instruments Incorporated, Ecological Services, for assisting with statistical design and analysis.

MATERIALS AND METHODS

Description of Dardanelle Reservoir

Dardanelle Reservoir is part of the McClellan-Kerr Arkansas River navigation system which extends from the confluence of the Arkansas and Mississippi Rivers to Catoosa, Oklahoma, on the Verdigris River. The reservoir surface coverage varies between 13,892 and 14,013 ha with a shoreline length of 506.8 km at normal pool elevation of 10.30 m (Arkansas Power & Light Company 1974).

Arkansas Nuclear-One Cooling Water System

Cooling water is taken from Dardanelle Reservoir through a 1.2 km long intake canal to 8 forebays at Unit 1 (Fig. 1). The average approach velocity at the mouth of the intake canal is 0.12 m/sec. Water velocity increases to 0.9 m/sec at one point within the canal due to reduced canal depth and width. Velocities then reduce to approximately 0.46 m/sec along the remainder of the canal up to the Unit-1 intake screens. Cooling water passes through Unit-1 condensers and is returned to Dardanelle Reservoir via an effluent canal and discharge bay.

Air Curtain System

The air curtain structure is located in approximately 4.6 m of water, across the mouth of the intake canal, which is approximately 121.9 m wide at the juncture with Dardanelle Reservoir (Fig. 1). Four fiberglass pipes 10.2 cm in diameter lie side by side

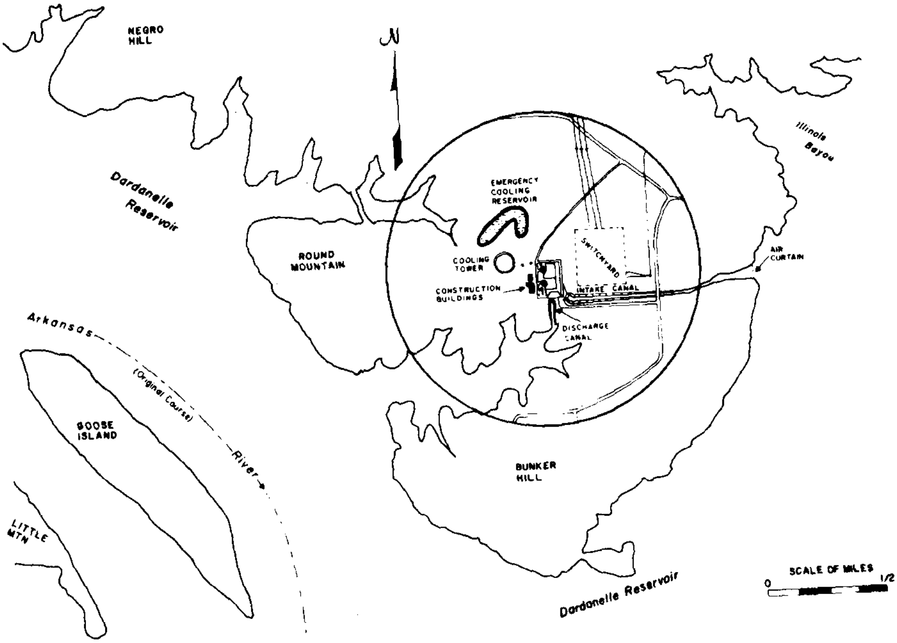

Fig. 1. Plant arrangement for Arkansas Nuclear One on Dardanelle Reservoir, Arkansas.

(25.4 cm apart, center to center) on the canal bottom for distances of 121.9 m (completely across), 91.4 m, 54.9 m, and 24.4 m, respectively (Fig. 2). Each pipe is drilled along the upper surface with 0.2-cm air holes, spaced 2.5 cm center-to-center, apart. These air holes are located only in the last section of each pipe. A series of control valves provides approximately equal amounts of air pressure at each hole, thus forming one uniform 121.9-m long air curtain across the mouth of the intake canal. Compressed air for the curtain is provided by 6 air compressors, each with a capacity 19.5 m^3/min at 517.1 cm of Hg.

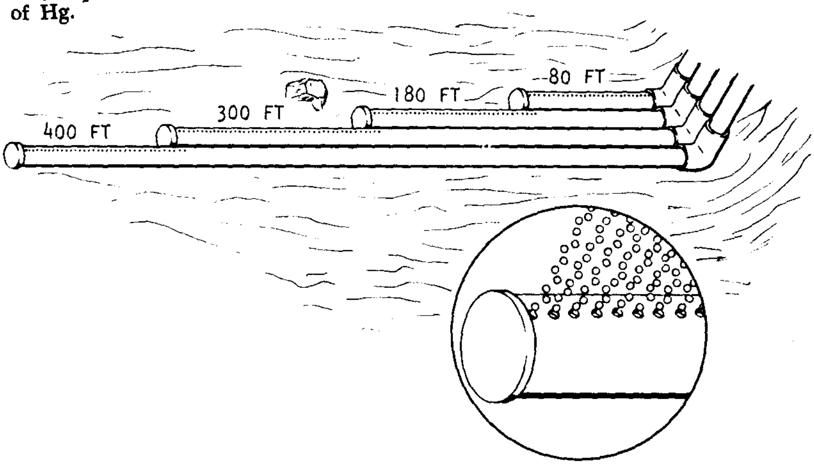

Fig. 2. Schematic of air curtain in intake canal to Arkansas Nuclear One.

Test Design and Analysis Methodology

Seasonal tests were conducted during the following months:

Fall: October, November
Winter: January, February
Spring: April, May
Summer: July, August

Seasonal testing of the air curtain consisted of 6 consecutive weekly periods of 3 days "on" and 3 days "off" operation over 6 consecutive days, with 1 off day between periods. The seventh day impingement results were not used in the analysis.

All screens were washed and all fish removed at 0800 on the first day of the 6 wk seasonal test period and disregarded; shortly thereafter, the air curtain was put in operation. At 0800 on the 2 succeeding consecutive days (first and second day of "on" test) the screens were washed and the fish processed. At 0800 on the third consecutive day (end of third day of "on" test) the fish were processed, the air curtain shut down and 3 consecutive days of "off" testing performed, with fishes removed and processed at 0800 on each of the 3 days. This process of turning the air curtain on or off (depending on the test) shortly after the 0800 washing on the third day continued throughout the 6 runs. Fish collections at 0800 following each seventh day (the day between runs) were not processed. This overall procedure provided clean screens at the beginning of each "on" or "off" test and each run.

For the 24 hr impingement determination, the 0.9-cm wire mesh vertical traveling screens on each forebay were rotated until all fish were removed. These fish were separated by species, weighed to the nearest 0.05 kg and enumerated. If the total catch was large, the entire sample was weighed, and a representative subsample taken.

Each species was then separated into size groups to determine length-frequency and biomass composition. Total length (cm) and weight (to the nearest 0.05 kg were recorded for all fish, or in the case of large numbers a representative subsample.

To avoid selecting against size classes with few individuals in the subsample, all large individuals in the group were measured before a subsample was taken. Percent length-frequency distributions were calculated for the 7 most heavily impinged species.

It was proposed that fish passing through the air curtain when it was in operation might have remained in the 1.2-km long intake canal and were not impinged until the air curtain "off" test period, and vice versa. The actual lag time between a fish's entering the intake canal and its subsequent impingement on the plant intake screens is presently unknown.

We assumed that:

(1) once a fish is past the air curtain and canal entrance, the lag time is indepedent of air curtain status (ON-OFF); and is short in relation to the sampling period.
(2) once a fish is within the canal, only the strongest and/or largest individuals can surpass the 0.9 m/s velocity.

Therefore, all fish collected at 0800 at the end of a test day were recorded as having passed through the air curtain during the previous 24 hours.

Air and water temperature, percentage cloud cover, wind direction and intensity, and rainfall were recorded daily during all 4 seasonal air curtain test periods.

Statistical Analyses

The statistical analyses for the air curtain test was a 2 x 4 layout with 2 treatments (on-off) in 6 blocks for each of the 4 seasonal periods.

Three analysis techniques were used to test for differences between the 2 treatments: the paired t-test (exactly equivalent to a randomized complete block analysis of variance F-test with 2 treatments), the Wilcoxon signed-ranks test and the Sign test. To test for a possible relationship between impingement during air curtain testing and physical parameters (i.e., water temperature), 3 measures of association (Pearson's r, Spearman's rho and Kendall's tau) were applied. The nonparametric test procedures utilized in the analysis of air curtain test data followed Conover (1971). The parametric analysis methods are described in Snedecor and Cochran (1967).

RESULTS AND DISCUSSION

General

Thirty-eight species of fish representing 14 families were identified from intake screen samples taken from October 1974 through August 1975 (Table 1). These numbers

Table 1. Taxonomic list and percent frequency of occurence of fish species impinged during air curtain testing at Arkansas Nuclear One, Unit 1, 1974-1975.

		Fall 1974 Air Curtain		Winter 1974 Air Curtain		Spring 1975 Air Curtain		Summer 1975 Air Curtain	
Scientific Classification	Common Name	On	Off	On	Off	On	Off	On	Off
Lampreys-Petromyzontidae									
Ichthyomyzon castaneus (Girard)	Chestnut lamprey			0	5	47	47		
Paddlefishes-Polyodontidae									
Polyodon spathula (Walbaum)	Paddlefish			5	0				
Gars-Lepisosteidae									
Lepisosteus osseus (Linnaeus)	Longnose gar			5	0			0	6
Lepisosteus platostomus (Rafinesque)	Shortnose gar							0	6
Herrings-Clupeidae									
Dorosoma cepedianum (Lesueur)	Gizzard shad	100	100	100	100	100	100	83	100
Dorosoma petenense (Gunther)	Threadfin shad	100	100	100	100	100	100	100	100
Alosa chrysochloris (Rafinesque)	Skipjack herring	33	11	5	11			17	22
Mooneyes-Hiodontidae									
Hiodon alosoides (Rafinesque)	Goldeye					7	7		
Minnows and Shiners-Cyprinidae									
Cyprinus carpio (Linnaeus)	European carp	22	11	5	0	73	73		
Carassius auratus (Linnaeus)	Goldfish	5	0						
Notemigonus crysoleucas (Mitchill)	Golden shiner	17	33	5	5	67	67	28	56
Pimephales notatus (Rafinesque)	Bluntnose minnow	0	11						
Notropis girardi (Hubbs & Ortenburger)	Arkansas river shiner					20	7	6	6
Notropis cornutus (Mitchill)	Common shiner	0	5						
Notropis simus (Cope)	Bluntnose shiner	17	5						
Suckers-Catostomidae									
Carpoides carpio (Rafinesque)	River carpsucker	33	5			53	27	17	0
Ictiobus cyprinellus (Valenciennes)	Largemouth buffalofish					7	0		
Ictiobus bubalus (Rafinesque)	Smallmouth buffalofish	33	28			60	40	11	0
Freshwater Catfish-Ictaluridae									
Ictalurus furcatus (Lesueur)	Blue catfish	100	100	83	67	100	100	100	100
Ictalurus punctatus (Rafinesque)	Channel catfish	100	94	89	78	100	100	100	100
Pylodictis olivaris (Rafinesque)	Flathead catfish					27	40	39	33
Ictalurus melas (Rafinesque)	Black bullhead	22	0	0	11	53	40		
Silversides-Atherinidae									
Labidesthes sicculus (Cope)	Brook silverside	0	11						
Menidia audens (Hay)	Mississippi silverside	83	89	67	61	33	7	28	17
Temperate Waterbasses-Percichthyidae									
Morone chrysops (Rafinesque)	White bass	94	100	5	17	87	80	89	78
Morone saxatilis (Walbaum)	Striped bass	0	5			0	7	28	22
Sunfishes-Centrarchidae									
Micropterus salmoides (Lacepede)	Largemouth bass	0	5			13	7	33	11
Pomoxis nigromaculatus (Lesueur)	Black crappie	11	17	5	0			11	6
Pomoxis annularis (Rafinesque)	White crappie	94	100	33	22	100	100	100	100
Chaenobryttus gulosus (Cuvier)	Warmouth	11	17			33	27	6	22
Lepomis cyanellus (Rafinesque)	Green sunfish	50	28	5	5	40	20	11	28
Lepomis megalotis (Rafinesque)	Longear sunfish	28	28	5	5	47	47	56	39
Lepomis macrochirus (Rafinesque)	Bluegill sunfish	72	61	0	0	93	100	100	94
Lepomis humilis (Girard)	Orange spotted sunfish	22	5	5	0	20	20	22	0
Lepomis microlophus (Gunther)	Redear sunfish	0	5					6	0
Percidae-Perches									
Percina caprodes (Rafinesque)	Logperch					7	7	6	0
Drums-Sciaenidae									
Aplodinotus grunniens (Rafinesque)	Freshwater drum	100	100	50	67	100	100	100	100
Cichlids-Cichlidae									
Tilapia sp.	Tilapia	33	5						

*Percentage determined by dividing the number of 24-hr samples in which a species occurred by the total number of 24-hr on/off tests run during a given season.

compare with a combined total of 53 species representing 18 families collected in Dardanelle Reservoir by all previous investigators between 1968 and 1974. Of the species previously reported but not impinged during this study, the majority were taken rarely by other researchers.

Total Numbers and Biomass Impinged

A total of 9,571,922 fish comprising a biomass of 78,762 kg was impinged over the entire 4 season (24 wk) test cycle (October 1974-August 1975). Of these totals, 4,930,127 fish weighing 41,218 kg were collected during air curtain operation and 4,41,795 fish weighing 37,544 kg were impinged when the air curtain was off.

Impingement rates rose during late October 1974, when testing began, through the end of the fall test period (30 November 1974) (Fig. 3). An increase in impingement rates during week 3 of fall testing raised numerical and biomass impingement levels from less than 10,000 fish and 45 kg per 3 day period to more than 20,000 fish and 68 kg

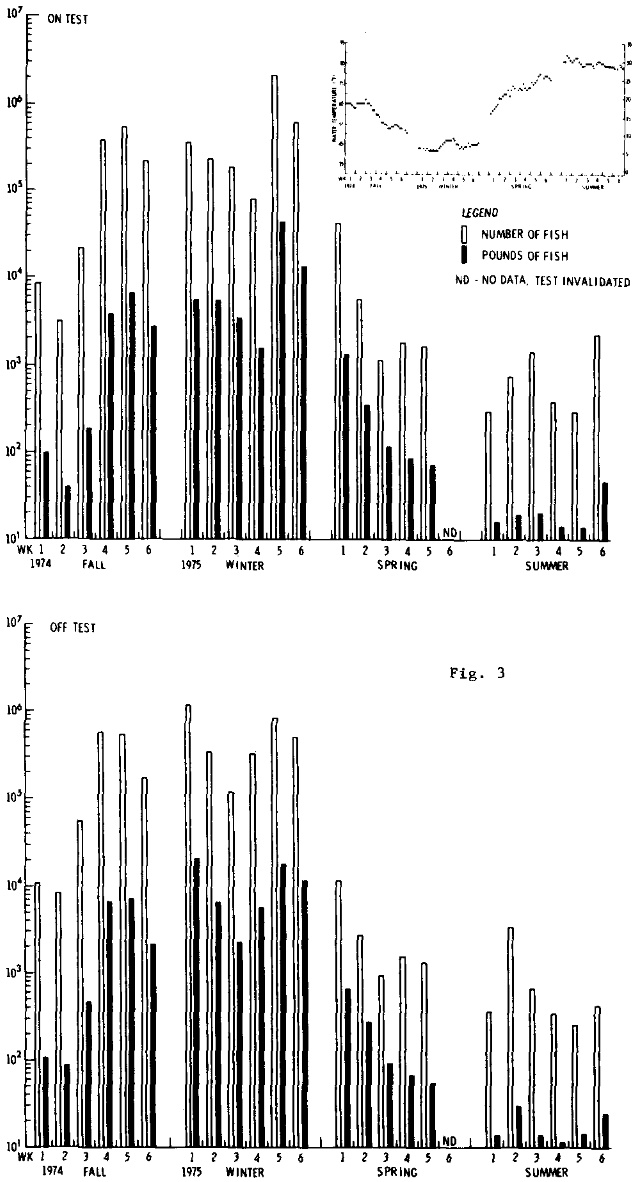

Fig. 3. Total numbers and biomass [(lbs) cumulative for 3-day test period] and length-frequency distribution (seasonal collapse) of all fish species impinged during air curtain testing at Arkansas Nuclear One, October 1974-August 1975.

per 3 day period. During this week, water temperatures in Dardanelle Reservoir declined below 18.3 C (Fig. 3). High impingement levels (> 200,000 fish and 454 kg per 3 day period) persisted through the remainder of the fall and winter. As water temperatures in Dardanelle Reservoir increased during the spring, both the numbers and biomass impinged decreased to generally < 1,000 fish and 23 kg per 3 day test period.

A comparison of air curtain ON and OFF test data for fall 1974, winter 1974-75, and summer 1975 revealed no statistically significant differences in the levels of fish impinged. Both the Wilcoxon test (α = 0.10) and Sign test (α = 0.05) Table 2), however, revealed consistently greater numbers of fish impinged during air curtain operation in the spring. Examination of fall, winter, and summer test data revealed no significant differences in the biomass of fish impinged with the air curtain on or off. Spring data, also revealed a significantly greater biomass impinged with the air curtain on (Sign Test α = 0.05 (Table 3).

Table 2. Statistical tests for difference in fish numbers impinged during On and Off air curtain testing at Arkansas Nuclear One-Unit 1.

Species	Fall P	Fall W	Fall S	Winter P	Winter W	Winter S	Spring P	Spring W	Spring S	Summer P	Summer W	Summer S
All species	-0.803	8	4	0.254	10	3	1.151	0†	5*	-0.016	9	4
Threadfin shad	-0.975	5	5*	0.258	10	3	1.019	1.5	4†	0.581	10	3
Gizzard shad	-0.248	10	3	0.091	10	3	1.694	2	4†	-1.163	3	4
Blue catfish	0.879	10	3	-1.020	6	3	1.682	0†	5*	-0.803	6.5	4
Channel catfish	1.653	3	5*	1.020	6	4	1.555	0†	5*	0.845	6	3
Freshwater drum	0.139	8	4	-0.970	6	3	1.105	3	3	-0.261	9	4
White crappie	-1.264	8	3	-0.550	4	3	0.970	4	4†	-1.745	1.5	4
White bass	0.759	9.5	3	-1.442	IC	2	1.262	2.5	4†	0.497	7	4

P - Paired t test
W - Wilcoxon test
S - Sign test

*Significant at α = 0.05 level
†Significant at α = 0.10 level

IC - Insufficient nonzero catches to detect any difference between on and off tests

Table 3. Statistical tests for differences in fish biomass impinged during On and Off air curtain testing at Arkansas Nuclear One-Unit 1.

Species	Fall P	Fall W	Fall S	Winter P	Winter W	Winter S	Spring P	Spring W	Spring S	Summer P	Summer W	Summer S
All species	-0.990	5	5	0.285	10	3	1.268	0†	5*	0.887	6	4
Threadfin shad	-1.323	4	5*	0.307	10	3	1.024	3	3	0.718	9	4
Gizzard shad	-0.010	10	3	-0.504	10	3	1.848	0*	5*	-0.115	10	3
Blue catfish	0.703	10	4	0.070	9	4	0.529	5	4†	1.022	8	3
Channel catfish	0.068	10	3	-0.276	10	3	1.720	1	4†	-0.057	10	3
Freshwater drum	0.246	9	3	-1.286	6	3	1.199	3	3	0.026	9	4
White crappie	1.517	5	4	-1.038	1	3	-0.389	5	4†	-0.802	8	3
White bass	0.376	10	3	-1.277	IC	2	0.141	7	3	-0.914	7	4

P : Paired t test
W · Wilcoxon test
S · Sign test

*Significant at α = 0.05 level
†Significant at α = 0.10 level

IC = Insufficient nonzero catches to detect any difference between on and off tests

Species Composition

The species occurring most frequently during seasonal tests were threadfin shad, gizzard shad, blue catfish, channel catfish, white bass, and freshwater drum. Occurrences were evenly distributed between ON and OFF tests, and no overall seasonal trends could be discerned (Table 1). White crappie, white bass, and bluegill sunfish were collected in the great majority of test runs during fall, spring, and summer testing, but were infrequently impinged during the winter tests.

Threadfin shad, gizzard shad, blue catfish, channel catfish, freshwater drum, white crappie, and white bass accounted for the greatest numbers and biomass impinged throughout the study (Fig. 4). Threadfin and gizzard shads contributed the greatest proportion (> 95%) of impinged numbers and biomass during the fall and winter test periods. Of these 2 species, the threadfin shad clearly dominated both numbers (> 91%) and biomass (> 88%) impinged during these seasons.

No distinct differences in total species composition were discerned between ON and OFF air curtain status during the fall or winter tests. A shift in species composition was observed in both spring and summer tests, reflecting a noticeable decline in the numbers and biomass of threadfin shad impinged, as well as increased impingement of gizzard shad during the spring and freshwater drum in the spring and summer.

Threadfin Shad

Overall, more threadfin shad were impinged during air curtain operation (4,560,419 fish; 37,980 kg) than when the air curtain was off (4,290,325 fish; 34,435 kg (Fig. 5). However, the differences in impinged numbers and biomass when collapsed over the 4 season test cycle were found to be nonsignificant at the $\alpha = 0.10$ level (Paired t-test, Wilcoxon test, Sign test).

A comparison of total numbers and biomass of threadfin shad impinged during and without air curtain operation indicated significantly (Sign test, α = 0.05 level) greater numbers and biomass of threadfin shad impinged in the fall when the air curtain was not in operation (Tables 2 and 3).

No significant differences were observed in threadfin shad impingement rates during the winter 1974-1975 and summer 1975 air curtain tests. Spring test results, however, indicated that more threadfin shad were impinged during air curtain operation (Sign test, α = 0.05 level) (Table 2).

The predominant threadfin shad size class impinged during the fall 1974 test period was the 60-90 mm length group. These young-of-the-year fish were recruited into the 90-120 mm sie range as yearlings by January and February 1975 when they appeared as the dominant size class in winter tests (Fig. 6). A relatively low number of 121-150 mm theadfin shad, possibly a mixture of yearling and older fish (based on the data of McConnell and Gerdes 1964), were also impinged during the winter test period (Fig. 6).

The predominance of 91-120 mm yearling threadfin shad impinged continued during spring 1975 tests. Young-of-the-year (1975 year class) threadfin shad, recruited into an impingeable size range (> 30 mm), appeared in summer test samples. The 0+ year fish were represented by both the 30-60 mm and 60-90 mm size ranges, during summer testing (Fig. 6). Yearling and older threadfin shad contributed only a small percentage to impinged numbers during this season.

Comparisons of threadfin shad impinged during the 4 seasonal air curtain ON/OFF test periods revealed no discernible differences in the size ranges of fish impinged with or without air curtain operation (Fig. 6).

Gizzard Shad

More gizzard shad were impinged during air curtain operation (327,320) than when the air curtain was not in operation (321,862). A greater biomass (2,595 kg was impinged, however, during off tests than during on tests in this same time period (Fig. 7).

The only statistically significant difference in the numbers of gizzard shad impinged over the 4 seasons occurred during spring when more gizzard shad were impinged during air curtain operation than with the air curtain not functioning (Table 2). A comparison of gizzard shad biomass impinged during these same weeks indicated statistically greater biomass levels during air curtain ON than during air curtain OFF tests (Table 3).

No differences between ON/OFF modes could be discerned for the length-frequency distribution during the fall, winter, and spring seasons. Summer test data, however, indicated that a greater percentage of young-of-the-year gizzard shad (30-90 mm) were

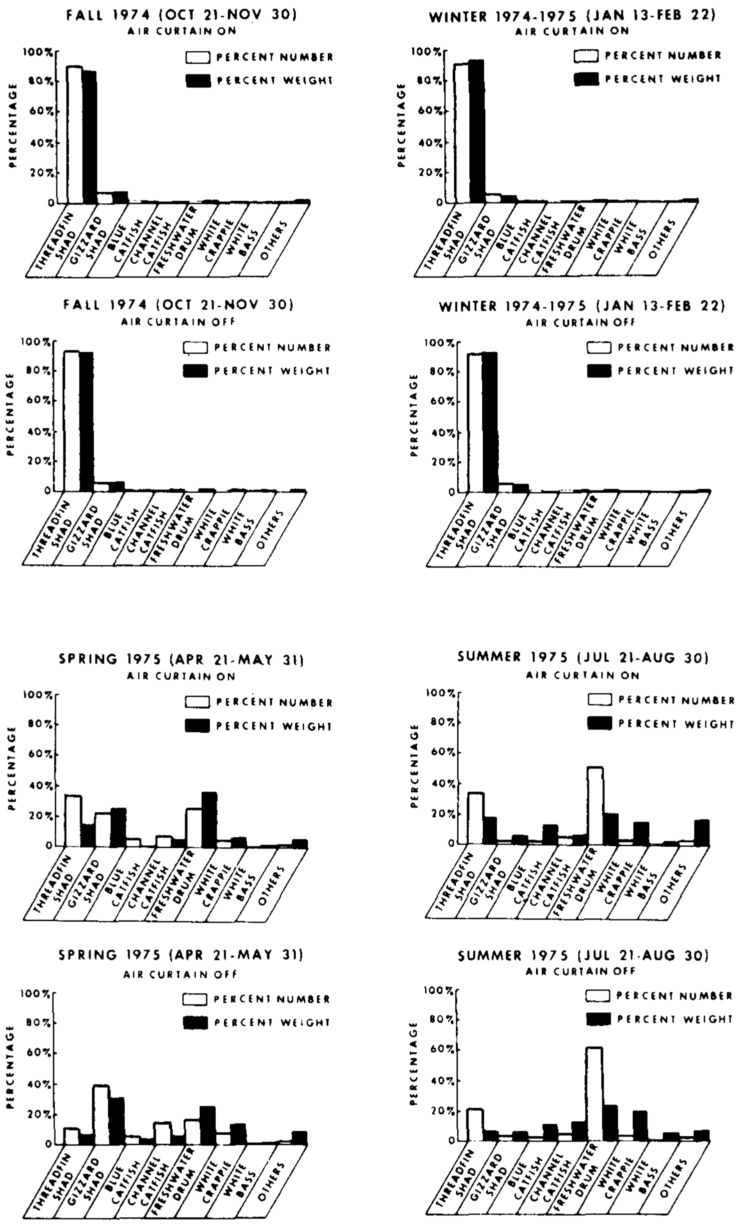

Fig. 4. Percent composition of fish species impinged during ON/OFF air curtain testing at Arkansas Nuclear One, October 1974-August 1975.

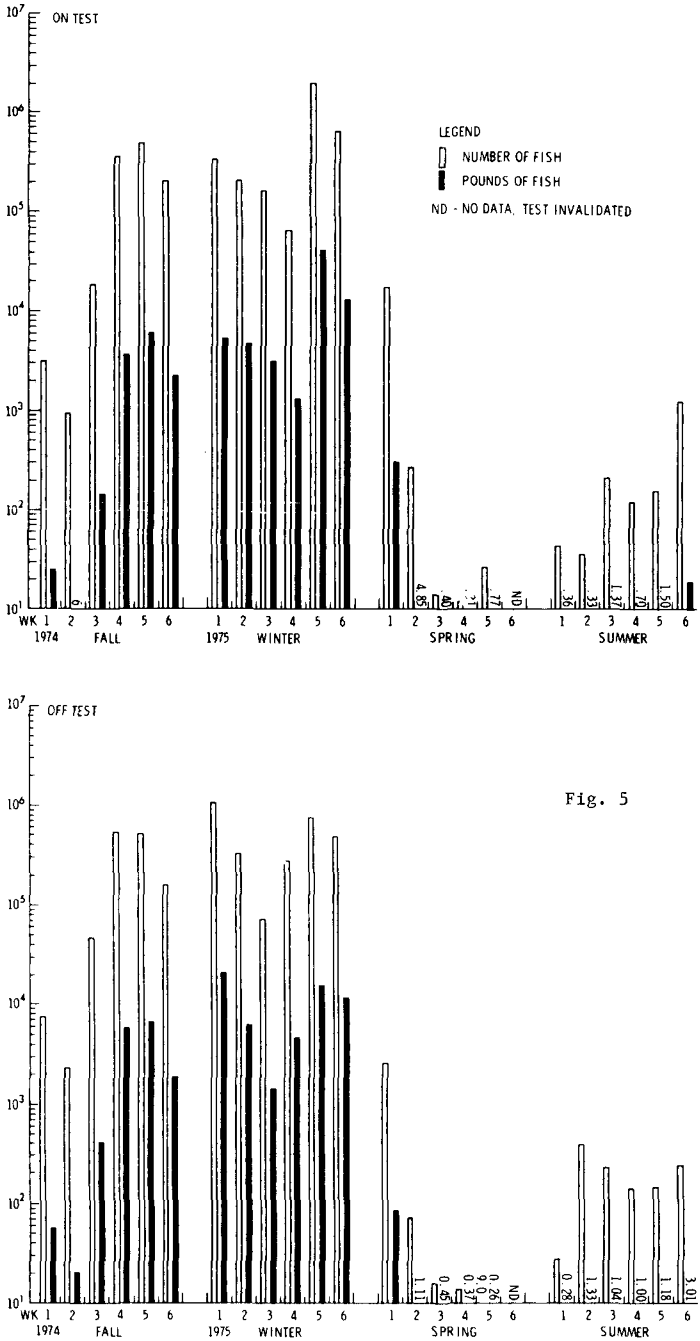

Fig. 5. Total numbers and biomass [(lbs) cumulative for 3-day test period] and length-frequency distribution (seasonal collapse) of threadfin shad impinged during air curtain testing at Arkansas Nuclear One, October 1974-August 1975.

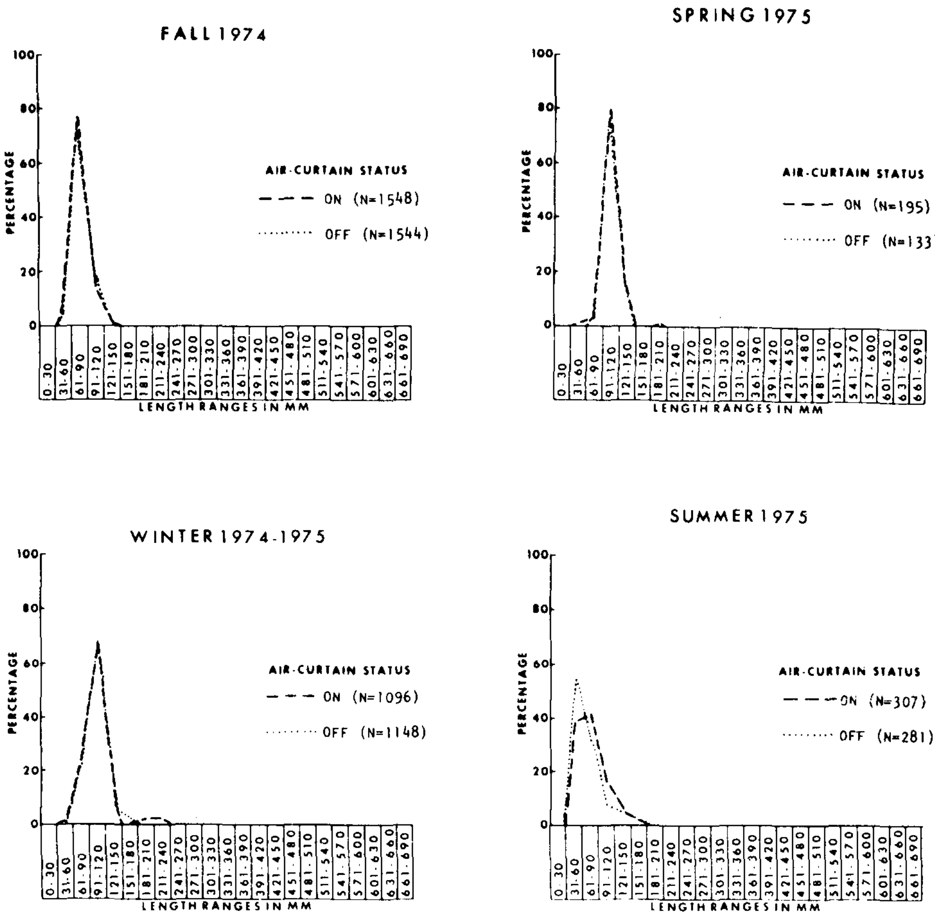

Fig. 6. Seasonal length-frequency distribution of threadfin shad impinged during air curtain testing at Arkansas Nuclear One.

impinged with the air curtain off, while a greater number of larger shad (151-240 mm) were impinged during air curtain operation (Fig. 8).

Impingement During Air Curtain Testing in Relation to Water Temperature

Within certain limits, the higher the water temperature, the more active the fish, and vice versa. However, ambient water temperatures approaching either high or low extremes may result in loss of equilibrium, muscular incoordination, and feeding cessation, leading to excessive damage or death. Data from a number of researchers including Miller 1960, Domrose 1963, Strawn 1963, Coward 1963, Bodola 1966, Henley 1967, Griffith and Tomljanovich 1976, Texas Instruments 1974 and 1975, indicate that in waterbodies with temperature regimes similar to Dardanelle Reservoir, threadfin and gizzard shad are living close to their lower lethal limit during late fall, winter, and early spring. A comparison of impingement rates at 13 Tennessee Valley Authority steam electric generating stations using sample periods when minimum intake water temperatures were below 10 C and above 10 C showed that 90-99 percent of threadfin shad impingement occurred during the $<$ 10 C periods at 5 of these plants (Griffith and Tomljanovich 1976). At 3 others, approximately half of the impingement occurred during $<$ 10 C periods and about half either immediately preceding or following these periods. Related laboratory studies indicated that water temperatures below approximately 14 C produced

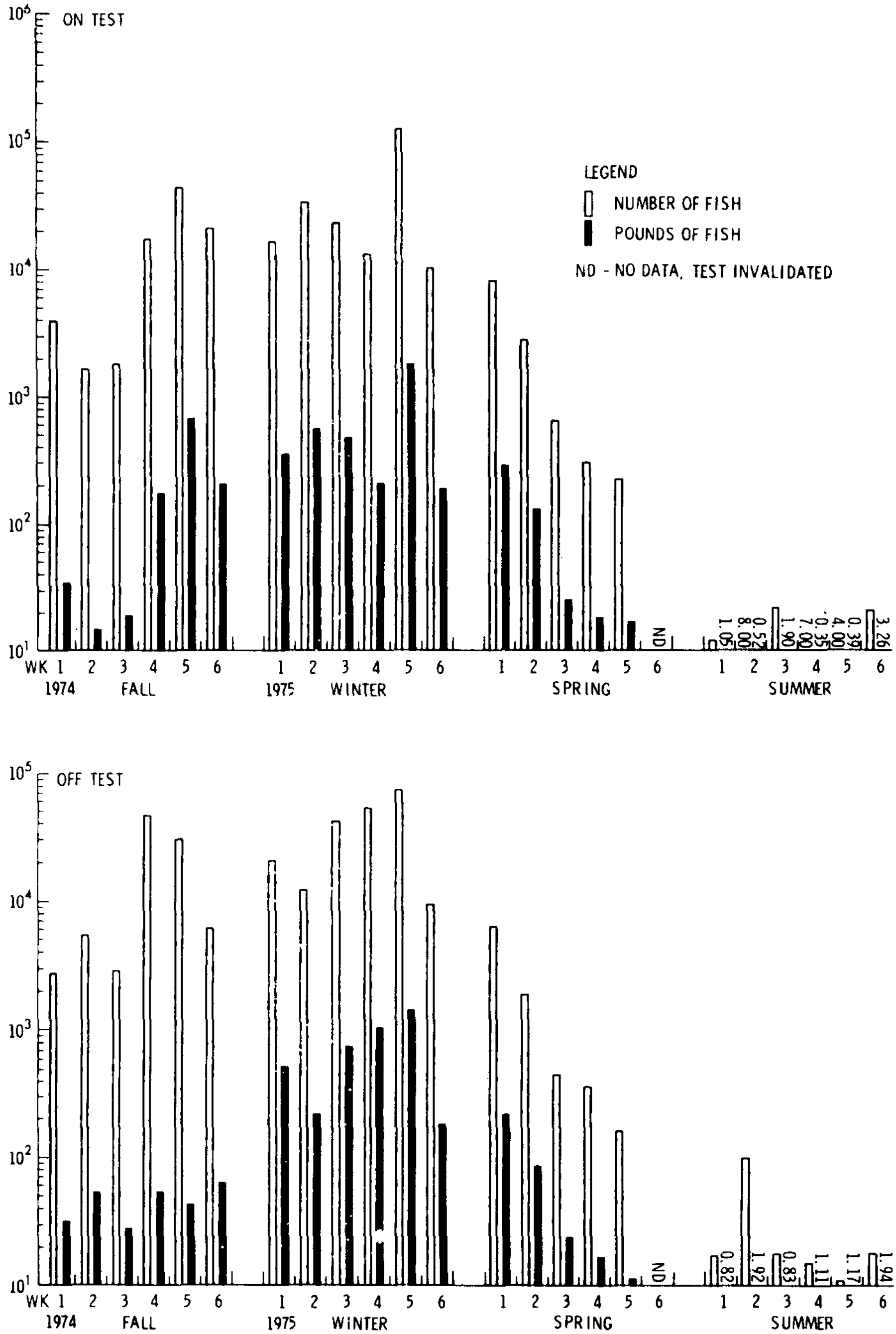

Fig. 7. Total numbers and biomass [lbs) cumulative for 3-day testing period] and length-frequency distribution (seasonal collapse) of gizzard shad impinged during air curtain testing at Arkansas Nuclear One, October 1974-August 1975.

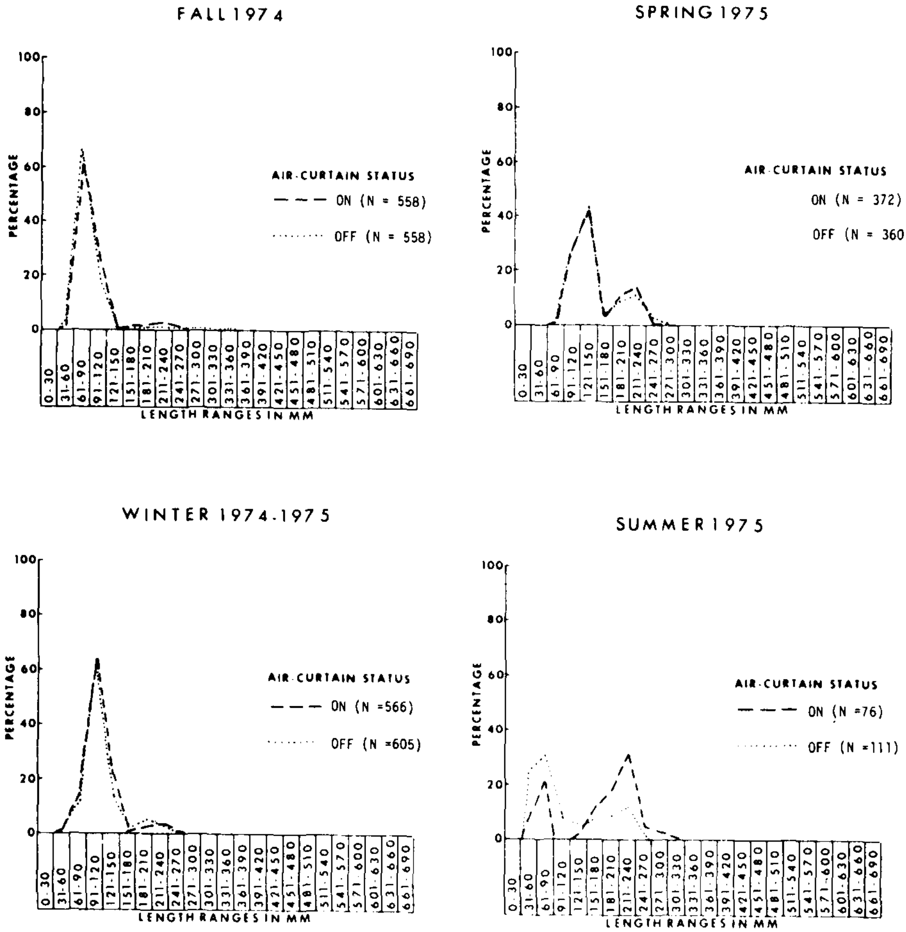

Fig. 8. Seasonal length-frequency distribution of gizzard shad impinged during air curtain testing at Arkansas Nuclear One.

stress in adult threadfin shad resulting in loss of coordination and swimming efficiency, and leading to increased impingement and consequent mortality. The ability of threadfin shad to resist impingement in a test flume was even more severely impaired below 8 C. It was also noted that this laboratory induced cold stress behavior; subsequent mortality closely paralleled that observed under natural conditions in reservoir populations of threadfin shad during the coldest period of the year (Griffith and Tomljanovich 1976).

Impingement rates for all species combined, including threadfin and gizzard shad, were found to be significantly correlated with water temperatures in Dardanelle Reservoir during fall 1974 and spring 1975. In the great majority of cases, these significant correlations were negative; i.e., increasing impingement was associated with decreasing temperatures and vice versa. However, a small number of positive correlations were observed for blue catfish, channel catfish, and freshwater drum during the winter and white crappie during the spring (Tables 4 and 5). In most instances, correlations with temperature were observed during both ON and OFF tests.

We suggest that the significant inverse correlations between impingement and water temperatures were the result of the adverse effects of decreasing water temperatures in

Table 4. Statistical tests for correlation between numbers of fish impinged and water temperatures during On/Off air curtain testing at Arkansas Nuclear One.

Species	Air-Curtain Status	Fall P	Fall S	Fall K	Winter P	Winter S	Winter K	Spring P	Spring S	Spring K	Summer P	Summer S	Summer K
All species	On	-0.854*	-0.883*	-0.733*	-0.253	-0.314	-0.200	-0.929*	-0.700	-0.600†	-0.518	-0.294	-0.200
	Off	-0.681	-0.771†	-0.600†	-0.507	-0.657	-0.600†	-0.694	-0.700	-0.600†	-0.009	-0.203	-0.133
Threadfin shad	On	-0.846*	-0.883†	-0.733*	-0.248	-0.314	-0.200	-0.899*	-0.700	-0.600†	-0.687	-0.899*	-0.800*
	Off	-0.691	-0.771†	-0.600†	-0.542	-0.657	-0.600†	-0.758	-1.000*	-1.000*	-0.508	-0.551	-0.533
Gizzard shad	On	-0.896*	-0.883*	-0.733*	-0.325	-0.657	-0.467	-0.982*	-1.000*	-1.000*	-0.333	-0.029	-0.000
	Off	-0.502	-0.657	-0.467	0.454	0.314	0.200	-0.848†	-1.000*	-1.000*	0.021	0.456	0.333
Blue catfish	On	-0.788†	-0.795†	-0.600†	0.484	0.657	0.467	-0.948*	-0.900*	-0.800*	0.427	0.551	0.400
	Off	-0.884*	-0.886*	-0.733*	0.740 ⊕	0.714†	0.467	-0.783	-1.000*	-1.000*	0.089	0.015	-0.067
Channel catfish	On	-0.642	-0.618	-0.333	0.750 ⊕	0.600	0.600 ⊕	-0.968*	-0.700	-0.600†	-0.153	-0.058	0.000
	Off	-0.318	-0.029	0.067	0.803 ⊕	0.771 ⊕	0.600 ⊕	-0.782	-0.600	-0.400	-0.663	-0.812†	-0.667†
Freshwater drum	On	-0.829*	-0.883*	-0.733*	0.774 ⊕	0.522	0.400	-0.924*	-0.700	-0.600†	-0.184	-0.058	0.000
	Off	-0.548	-0.829*	-0.733*	0.477	0.429	0.200	-0.790	-0.700	-0.600†	0.072	0.696	0.533
White crappie	On	-0.767†	-0.795†	-0.600†	0.513	0.213	0.133	0.669	0.800 ⊕	0.600 ⊕	0.399	0.464	0.400
	Off	-0.951*	-0.886*	-0.733*	-0.011	0.030	0.000	0.869 ⊕	0.900 ⊕	0.800 ⊕	-0.369	-0.279	-0.200
White bass	On	-0.745†	-0.795†	-0.600†	IC	IC	IC	-0.944*	-1.000*	1.000*	-0.884*	-0.841*	-0.667†
	Off	-0.933*	-0.943*	-0.867*				-0.654	-0.700	-0.600†	-0.095	-0.224	-0.133

* Significant at α = 0.05 level
† Significant at α = 0.10 level

P = Pearson's r test
S = Spearman's ρ (rho) test
K = Kendall's T (tau) test

IC = Insufficient nonzero catches to detect any correlation with water temperature.
⊕ = Circled significant correlations are positive; all other significant correlations are negative.

Table 5. Statistical tests for correlation between biomass of fish impinged and water temperature during On/Off air curtain testing at Arkansas Nuclear One.

Species	Air Curtain Status	Fall P	Fall S	Fall K	Winter P	Winter S	Winter K	Spring P	Spring S	Spring K	Summer P	Summer S	Summer K
All species	On	-0.864*	-0.883*	-0.733*	-0.243	-0.314	-0.200	-0.963*	-1.000*	-1.00 *	-0.506	-0.116	0.0
	Off	-0.253	-0.829*	-0.733*	-0.462	-0.657	-0.600†	-0.8631	-1.000*	-1.000*	-0.306	-0.579	-0.400
Threadfin shad	On	-0.849*	-0.883*	-0.733*	-0.237	-0.314	-0.200	-0.899*	-0.700	-0.600†	-0.683	-0.899*	-0.800*
	Off	-0.692	-0.829*	-0.867*	-0.492	-0.657	-0.600†	-0.752	-1.000*	-1.000*	-0.081	-0.203	-0.133
Gizzard shad	On	-.0792†	-0.8827*	-0.7333*	-0.365	-0.657	-0.467	-0.985*	-1.00 *	-1.00 *	-0.525	-0.261	-0.267
	Off	-0.525	-0.543	-0.200	0.412	0.314	0.200	-0.861*	-1.00 *	-1.00 *	-0.489	-0.667	-0.533
Blue catfish	On	-0.737†	-0.647	-0.467	-0.069	-0.314	-0.200	-0.987*	-0.900*	-0.800*	-0.360	-0.058	0.0
	Off	-0.854*	-0.943	-0.867*	0.779 ⊕	0.771 ⊕	0.600 ⊕	-0.842†	-1.00 *	-1.00 *	-0.212	-0.579	-0.333
Channel catfish	On	0.745 ⊕	0.529	0.333	0.687	0.600	0.467	-0.978*	-1.00 *	-1.00 *	-0.005	-0.058	0.0
	Off	0.127	0.429	0.333	-0.269	0.371	0.333	-0.837*	-1.00 *	-1.00 *	-0.688	-0.812†	-0.667†
Freshwater drum	On	-0.906*	-0.883*	-0.733*	0.206	0.058	0.133	-0.944*	-0.700	-0.600†	-0.020	-0.029	-0.133
	Off	-0.499	-0.714	-0.467	0.257	0.200	0.200	-0.802	-0.900*	-0.800*	0.061	0.522	0.400
White crappie	On	0.159	0.471	0.333	-0.179	0.213	0.133	0.663	0.0	-0.20	-0.414	-0.232	-0.133
	Off	0.032	0.429	0.200	-0.472	0.030	0.0	0.058	0.100	0.0	-0.479	-0.696	-0.533
White bass	On	-0.641	-0.412	-0.333	IC	IC	IC	-0.897*	-0.700	-0.600†	-0.532	-0.638	-0.533
	Off	-0.818*	-0.600	-.0467				-0.168	-0.600	-0.400	-0.475	-0.551	-0.533

*Significant at α = 0.05 level
†Significant at α = 0.10 level

P = Pearson's r test
S = Spearman's ρ (rho) test
K = Kendall's T (tau) test

IC = Insufficient nonzero catches to detect any correlation with water temperature.
⊕ = Circled significant correlations are positive, all other significant correlations are negative correlations.

Dardanelle Reservoir. The relatively low current velocities observed in the vicinity of the air curtain (generally 0.18 m/sec are within the range of (0.15-0.3 m/s) recommended for most power plants (U.S. EPA 1973, Bibko et al 1974), and within the swimming capabilities of all except the smaller or weaker fish of impingeable size at water-temperature conditions approximating late spring, summer, and early fall in Dardanelle Reservoir (Texas Instruments 1972, U.S. EPA 1973, Bibko et al. 1974). Length-frequency data for the 7 most impinged species over the 4 seasonal test periods show the heaviest impingement pressure to be on young-of-the-year fish. Consequently, the high impingement rates observed during late fall and winter may have represented impingement of passive, and/or moribund, smaller fish which were thermally stressed by decreasing water temperatures.

CONCLUSIONS

The air curtain did not effectively deter fish from entering the intake canal, or substantially reduce fish impingement at Arkansas Nuclear-One Unit-I. Although seasonal variations in species composition of impinged fish occurred, these variations were independent of air curtain operation. Air curtain operation did not alter the length-frequency distribution of the species impinged.

Impingement was significantly correlated with water temperature. Increasing impingement rates were associated with declining temperatures in the fall, while decreasing impingements were associated with rising temperatures in the spring. High impingement rates during the late fall, winter and early spring may have represented collection of incapacitated and/or moribund small fish thermally stressed by low (< 15.5 C) reservoir water temperatures.

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