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An Analysis of Factors Influencing the Impingement of Threadfin Shad (Dorosoma pretenense) at Power Plants in the Southeastern United States*

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ABSTRACT

Data on intake design and location, plant operating procedures, water quality, numbers of fish impinged, and sampling procedures were analyzed for 27 fossil-fueled and 5 nuclear power plants located on inland waters in the southeastern United States. Small (less than 9 cm) clupeids, especially threadfin shad (Dorosoma pretenense), comprised the majority of the fish impinged at these facilities. The parameter that was most strongly associated with shad impingement was water temperature. Maximum impingement rates occurred during the winter when intake temperatures dropped below 10°C.

Analyses of differences in impingement rates between plants failed to adequately demonstrate that the magnitude of impingement at a particular plant was the result of any site-specific characteristics

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associated with intake design or location. High approach velocities at the traveling screens did not necessarily result in high levels of impingement. Results obtained from inter-unit comparisons at several plants indicate that unit and screen differences do exist, but it is unclear from existing data whether or not such inter-unit differences determine the magnitude of impingement losses or merely affect the distribution of impinged fish at a given intake structure.

Recommendations for monitoring fish impingement include the (1) identification of impinged fish by species, (2) collection of data on water temperatures and various plant operational parameters, (3) periodic analyses of localized velocity regimes near the intake, and (4) frequent estimates of the relative density of the fish population in the vicinity of the intake. Implementation of these recommendations will help not only to provide reliable estimates of total annual impingement, but also to assure that sufficient information exists for identifying the causal factors influencing impingement at a given power plant.

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INTRODUCTION

Although a number of biological, physical, and hydraulic parameters, including cooling water intake design and location, have been postulated as factors influencing fish impingement, relatively few studies have examined the effect of any given parameter on impingement for a wide range of intake designs and locations. Without a knowledge of the parameters influencing impingement at power plants now in operation, we will not be able to successfully mitigate impingement at existing plants nor accurately evaluate and minimize impingement at future plants.

This paper presents the results of a study which attempted to identify the factors influencing the impingement of threadfin shad (Dorosoma petenense) at inland power plants in the southeastern United States.

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To accomplish this objective, we contacted all utilities which own and operate power plants in this region to seek their cooperation and participation in the project. Many of the utilities had collected impingement data over the past several years in order to comply either with Section 316(b) of Public Law 92-500 or with the Environmental Technical Specifications promulgated by the Nuclear Regulatory Commission. We requested data on fish impingement, sampling methodologies, water quality and fish standing crops of the cooling water source, plant operational parameters, and general information on the design and location of intake structures. Impingement data were received for 27 fossil-fueled and five nuclear plants located in the southeastern region, which was broadly defined to include 15 states and the District of Columbia (Fig. 1). At most plants, data on water quality (e.g., dissolved oxygen, turbidity) and plant operation (e.g., volume of water pumped, identification of pumps and/or units not operating) were not collected concurrently with the impingement counts (or not collected at all), thus limiting the scope of the analyses that could be performed. Finally, impingement monitoring programs had only recently been initiated at eight of the 32 sites. Since data were not available for an entire year, these sites are not included in the analyses which follow.

RESULTS

Species Composition, Size, and Seasonal Patterns

Approximately 98%, by number, of the fish impinged at the 24 power plants where sampling was conducted for a period of at least one year

were members of the family Clupeidae. The relative abundance of clupeids in the impingement collection exceeded 75% at 15 sites. The average relative abundance of threadfin shad was 79.7% for 11 of the 15 sites where clupeid species were identified. In addition, this species accounted for more than 90% of the total impingement for all the plants included in this study. Because the majority of the fish impinged at inland power plants in the southeastern United States are threadfin shad, our analyses focused on identification of factors which influence the impingement of this particular species.

Data on both length and weight of impinged fish were available for only three of the plants included in this study. At most plants, impinged fish were either weighed or measured, and these data are presented in Table 2. Those plants which (1) impinged relatively low numbers of threadfin shad, (2) failed to distinguish between clupeid species, and/or (3) only presented summarized data on size for the entire impingement sampling period are not listed. Most of the threadfin shad that were collected during the peak impingement period were small (less than 9 cm) and probably represented young-of-the-year or yearling fish.

Threadfin shad impingement exhibited a distinct seasonal pattern throughout most of the southeastern region (Table 2). In those water bodies with presumably large populations of threadfin shad, the peak impingement period usually occurred during the winter. Although this pattern was most commonly observed at plants located on large reservoirs, several of the river sites (e.g., Green River and Wateree) also

exhibited peak periods of impingement during the colder months of the year.

Effects of Temperature on Impingement

At many plants in the Southeast, maximum impingement rates occurred during the winter when intake temperatures dropped below 10°C. The percent of the impingement samples collected when intake temperatures were 10°C or less and also 15°C or less was compared with the percentage of the total numbers of threadfin shad collected during these periods (Table 3). A greater proportion of fish were impinged during both periods than would have been expected if the fish were impinged randomly throughout the year. However, at the Greene County power plant, which is located on the Black Warrior River in western Alabama, water temperatures were below 15°C on 31% of the sampling dates, yet only 4% of the annual impingement occurred at this time. The low impingement in the winter has been attributed to the fact that fish can avoid low temperatures by overwintering in the discharge from the plant (Alabama Power Company 1975).

Inter-plant Comparisons

To determine the influence on fish impingement due to differences of intake design and location, data from the 24 plants where sampling had been conducted for an entire year were compared. All species of Clupeidae were included in this analysis so that a broad spectrum of intake designs and locations could be utilized. Clupeids other than

threadfin shad were primarily gizzard shad (Dorosoma cepedianum). Inter-plant comparisons were made on the basis of the number of clupeids impinged per unit volume of cooling water pumped. The unit volume of water employed in this analysis was $10^6 m^3$. This volume corresponds to the daily flow for a plant pumping at the rate of 11.6 m^3/sec, approximately that of a small (300-400 MWe) fossil-fuel plant. Since the number of pumps actually operating per plant or per unit was usually not available, all pumps were assumed to be operating at full capacity for half of the year (spring-summer) and half of the pumps were assumed to be operating for the remaining six months of the year (fall-winter). Because it does not take into consideration the occasional shutdown of pumps for maintenance and repair, this method probably represents an overestimation of the amount of cooling water actually pumped and therefore an underestimation of the number of fish impinged per unit volume of water.

Those plants having similar values for the number of fish impinged per unit volume of water were grouped into one of five categories (< 1, 1-10, 11-100, 101-1000, and > 1000 fish/$10^6 m^3$), and the intake velocities and site characteristics were compared within and between categories to assess similarities and differences. The velocities listed in Table 4 were calculated by dividing the design flow by the screen area and represent the theoretical maximum velocities approaching the traveling screens. Data on actual velocities measured near the intake screens were available at only two of the plants included in this analysis. Finally, it should be noted that the velocities existing

during the winter when most clupeids are impinged were not available for all the plants, so maximum summer velocities, which would be greater than winter velocities at many intake structures, were used.

Five of the 24 plants included in this analysis impinged less than one clupeid per $10^6 m^3$ of water and at none of these plants did clupeids comprise more than 16% of the total impingement. All of these plants had shoreline intake designs and, with the exception of Robinson, were located on relatively small, swift-flowing rivers. Although intake velocities ranged from 14 cm/sec at the Dan River plant to 88 cm/sec at the Lee plant, clupeid impingement per unit volume of water was similar at both plants.

Intake canals and approach velocities near the intake screens of approximately 30 cm sec^{-1} (1 fps) were characteristic of three of the five plants that impinged 1-10 and 11-100 clupeids/$10^6 m^3$ of water. With the exception of the Handley plant which is located on Lake Arlington, a small cooling reservoir near Ft. Worth, Texas, plants in these categories are situated on large rivers. In comparison, the majority of the plants that impinged more than 1000 clupeids/$10^6 m^3$ of water also had intake structures which were either located on a cove or situated near the end of an intake canal, but were located on large reservoirs. The relative abundance of threadfin shad in the impingement samples exceeded 95% at five of the seven plants included in this category.

Intra-plant Comparisons

Since impingement counts taken at individual screens or grouped by individual units were available at several plants, possible differences between the units or screens could be evaluated. Data collected at the other plants either did not differentiate between screens, or if samples were taken from several screens, they were not taken concurrently and, therefore, were not used in the analysis. Only the impingement counts for units or screens of an individual plant which were sampled at the same time were used in the analysis.

Differences Between Units

Data collected at individual units of the Allen and Marshall fossil-fuel plants in North Carolina were analyzed and relevant information on the design, location, and impingement for the various units of each plant is shown in Fig. 2. Many fish were identified only as *Dorosoma sp*., but threadfin shad probably comprised the majority of the fish impinged at both plants.

The Allen plant consists of five units which are located on a small embayment of Lake Wylie (Fig. 2). Most of the shad were impinged on 10 sampling dates between December and February and these data are presented in Fig. 2. The maximum condenser cooling water flow and the maximum approach velocity were approximately 1.5 times higher at Units 3-5 compared with Units 1-2, but total impingement at Units 3-5 was 4.7 times that observed at Units 1-2. The lower impingement at Unit 4 compared with Units 3 and 5 was not a consistent trend observed throughout the sampling period.

Differences in impingement between units were even more pronounced at the Marshall Steam Station which is located in a relatively large cove on Lake Norman. A skimmer wall blocks off the cove and the four units, with fixed screens, are located along the shoreline. Impingement data are presented for the 9 sampling dates from late November to mid-March when most of the shad were impinged (Fig. 2). Even though all units were operating on these dates, information on the number of pumps in operation at each unit was not available. Intake velocities and condenser circulating water flows were similar for all four units, yet the unit adjacent to the blind end of the cove (Unit 4) collected approximately 80% of the fish. Although the flows and velocities at Units 3 and 4 were identical, impingement at Unit 4 exceeded that observed at Unit 3 by a factor of 8.

Differences Between Screens

In the preceding analysis of differences in impingement between individual units, only one of several intake screens at each unit was sampled. For example, there were three traveling screens at each of the five units of the Allen Steam Station, and only the middle screen at each unit was sampled. At the Browns Ferry Nuclear Plant, however, counts of the number of fish impinged at a few test screens are expanded to give a total count using expansion factors that are periodically derived by counting the fish impinged at each screen. These periodic counts of all screens were analyzed in order to determine differences between screens.

The Browns Ferry Nuclear Plant is located on Wheeler Reservoir in northern Alabama. This facility utilizes a small intake cove with a return channel for closed-cycle cooling systems on the upstream side. Three units (with three pumps per unit) are present, but only Units 1 and/or 2 were operating when the data used in this analysis were collected. A total of 18 traveling screens (two screens per pump) extend across the end of the intake cove. The majority of the fish are impinged from December to March and consist primarily of threadfin shad (Table 2).

Using Friedman's non-parametric two-way layout analysis (Hollander and Wolfe 1973), impingement during the period February-June, 1974, was found to be significantly higher ($p < 0.05$) at screen 1AA compared with the other screens (Table 5). For this period, approximately half of the total impingement occurred at this screen and on one day alone, 22,431 fish were impinged. Screen 1AB, which is adjacent to 1AA, had the highest impingement on four of the five sampling dates and the second highest on the other date. A multiple comparison test based on Friedman's rank sums indicated that the impingement rate for this screen was significantly greater ($p < 0.05$) than that for screens 1BB, 1CA, or 1CB. During the second test period in July, 1974, screen 1AB had the highest level of impingement on each of the five sampling dates, and the number of fish impinged on this screen was significantly higher ($p < 0.05$) than on screens 1BB, 2BA, and 2CB. During the third sampling period, screen 1AB again exhibited the highest level of impingement although none of the differences between screens was significant ($p > 0.05$).

The same general impingement pattern was observed during all three sampling periods. Impingement was relatively high on the screens associated with pump A at the edge of the intake cove but gradually declined at the screens located near the center of the cove. Other than the increased number of fish on screen 1AB over screen 1AA as noted previously, the trend in decreasing impingement from the edge to the center screens was, with few exceptions, linear. In this regard, the operation (or non-operation) of pump 2A could be postulated as having had some effect on the level of impingement at the Unit 1 screens. For example, when pump 2A was off-line during the July, 1974 sampling period, screens 1BB and 1CB exhibited extremely low levels of impingement. When pump 2A was operating, however, screens 1BB and 1CB exhibited the fourth and sixth highest impingement levels, respectively.

DISCUSSION

The parameter that was most highly associated with threadfin shad impingement at the power plants included in this study was water temperature. Maximum impingement rates occurred during the winter when intake temperatures dropped below 10°C. Previous studies have demonstrated that threadfin shad may be susceptible to stress from cold temperatures (Parsons and Kimsey 1954; Strawn 1961). Recent laboratory experiments on the swimming ability of threadfin shad have shown that individuals were sluggish and displayed reduced swimming abilities at temperatures below approximately 13°C (Griffith and Tomljanovich 1976). Their lower lethal temperature is approximately 5°C (Griffith 1978).

In general, those plants exhibiting a peak period of threadfin shad impingement in the winter are located within a zone that extends across the Southeast between 33° and 37°N latitude (Table 3). Below 33°N latitude, water temperatures rarely fall below 10°C and periods of peak threadfin shad impingement in the winter would not be expected. Above 37°N latitude, on the other hand, water temperatures during the winter are generally too low for the successful establishment of threadfin shad populations. Although plants located within this zone appear to have the greatest potential for impinging threadfin shad during the winter months, the actual level of impingement will be influenced by local meterological conditions, plant design, and the distribution and abundance of threadfin shad in the cooling water source.

The temperature regimes to which threadfin shad populations are exposed as well as the distribution and abundance of shad in the cooling water source, may be the dominant factors influencing impingement at southeastern power plants and may override any effects due to intake velocity. Rates of impingement have been regarded as being directly related to velocities at or around cooling water intake structures and to numerous other physical and biological parameters (Boreman 1977). No direct relationship was found between clupeid impingement and the theoretical maximum intake velocity calculated for the power plants included in this study.

Two reasons may account for the absence of such a relationship. First, he theoretical maximum approach velocities used in this analysis may not have represented the actual velocities that existed near the

intake structures. The localized velocity regime and flow patterns near the intake could be important. Results of this study have shown that the level of impingement may vary between the units of a power plant and between the screens that span an intake channel. These unit and screen differences are site-specific and apparently depend on the hydraulics unique to each intake configuration. As Edwards et al. (1976) have pointed out, the existnece of a large eddy adjacent to Unit 4 of the Marshall Steam Station may be responsible for the differential impingement between the four units (Fig. 2). It is unclear from existing data, however, whether or not such intra-plant variability in impingement results in increased levels of impingement or merely determines the distribution of impinged fish across the screens of a given intake structure.

Second, the temperature regimes during the winter and/or the abundance and distribution of clupeids in the cooling water source may override the effects due to high intake velocities. For example, clupeid impingement was similar at two plants (Dan River and Lee) which had a fivefold difference in the estimated maximum intake velocity. Both have shoreline intakes that are located on small, swift-flowing rivers. Water temperatures probably fall below 10°C in the winter and, although no data are available on the standing crop of clupeids at these sites, it is probable that the threadfin populations are relatively low. These and other river sites probably provide a less than optimal habitat for this species, thus possibly explaining the general trend of lower impingement at plants located on rivers compared with those on reservoirs (Table 4).

That shad abundance on the cooling water source is an important parameter influencing shad impingement also was shown in the comparison of plants that impinged 1-100 clupeids/$10^6 m^3$ of water with those that impinged more than 1000 clupeids/$10^6 m^3$. The majority of the plants in the latter category are located on large reservoirs with presumably large threadfin shad populations and had intake structures which either were located on a cove or were situated at the end of an intake canal. Plants that impinged 1-10 and 11-100 clupeids/$10^6 m^3$ of water were primarily situated on large rivers where clupeids populations could have been low, especially during the colder months of the year. Also, since these plants also obtain cooling water via a canal or channel, the presence of these structures per se, cannot account for the differences in the magnitude of impingement observed at the various plants.

CONCLUSIONS AND RECOMMENDATIONS

Members of the family Clupeidae and primarily young-of-the-year and yearling threadfin shad comprised the majority of the fish impinged at the southeastern power plants included in this study. Important parameters influencing shad impingement are water temperature and the distribution and abundance of shad in the cooling water source. The magnitude of impingement at a given plant could not be related to plant operational parameters such as flow rates and velocities near the intake screens. The effects of intake velocity may possibly be overriden by the effects of the temperature regimes to which the fish are exposed and also by differences in shad abundance and distribution. However,

information on the density of clupeids in the vicinity of the plant as well as data on plant flow rates and velocities measured near the intake structure were generally unavailable.

The presumably higher standing crop of clupeids, especially threadfin shad, in reservoir habitats may account for the higher impingement observed at reservoir compared with river sites. Although the majority of the plants located on lakes or reservoirs had intake structures which were located on coves or at the end of a canal or channel, the influence on fish impingement due to the presence of this type of structure could not be firmly established. Several plants with canals impinged relatively low numbers of shad.

These conclusions, which are based on an analysis of impingement data collected at 32 inland power plants in the southeastern United States, suggest that several factors should be considered in designing impingement monitoring programs. The recommendations that follow are based on the assumption that most, if not all, of these programs are designed to provide (1) an accurate estimate of the total annual losses due to impingement, and (2) a basis for assessing the significance of these losses.

Efforts should be made to identify the species of all impinged fish. When large numbers of fish are impinged, identification to species of a representative subsample may be sufficient. In any case, identification only to genus or family should be avoided. Since threadfin shad impingement at most of the power plants included in this study exhibited distinct seasonal patterns, intake temperatures should be

recorded on each sampling date. Further, detailed information on (1) the screens sampled, (2) total flows for each pump in operation, and (3) identification of all units and/or pumps which are not operating should be routinely collected on each sampling date. Selection of the units or screens to be sampled is an important consideration in any impingement monitoring program. It will directly affect the reliability of estimates of total annual impingement which are based on extrapolations of the actual screen counts. If only a few test screens rather than all screens are sampled, then frequent tests should be conducted throughout the duration of the monitoring program in order to assure that the extrapolation technique is valud.

If the purpose of the monitoring program also includes the identification of causal factors, then additional information will usually be required. Velocities near the intake and flows past and entering the plant should be obtained at various times (e.g. periods of maximum and minimum water levels or flows in the cooling water source) during the course of the impingement monitoring program. Frequent estimates of the relative density of the fish populations in the vicinity of the plant may also be necessary, and these could be obtained using some standard gill net unit.

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Titles of Figures

Figure 1. Map of the Southeast region showing the general location of the 32 power plants included in the study. More specific information on the location of each of these plants is presented in Table 1.

Figure 2. Unit locations, operating parameters, and observed impingement levels at the Allen and Marshall Steam Stations. Winter CCW=maximum condenser circulating water flow ($x10^6 m^3 day^{-1}$).

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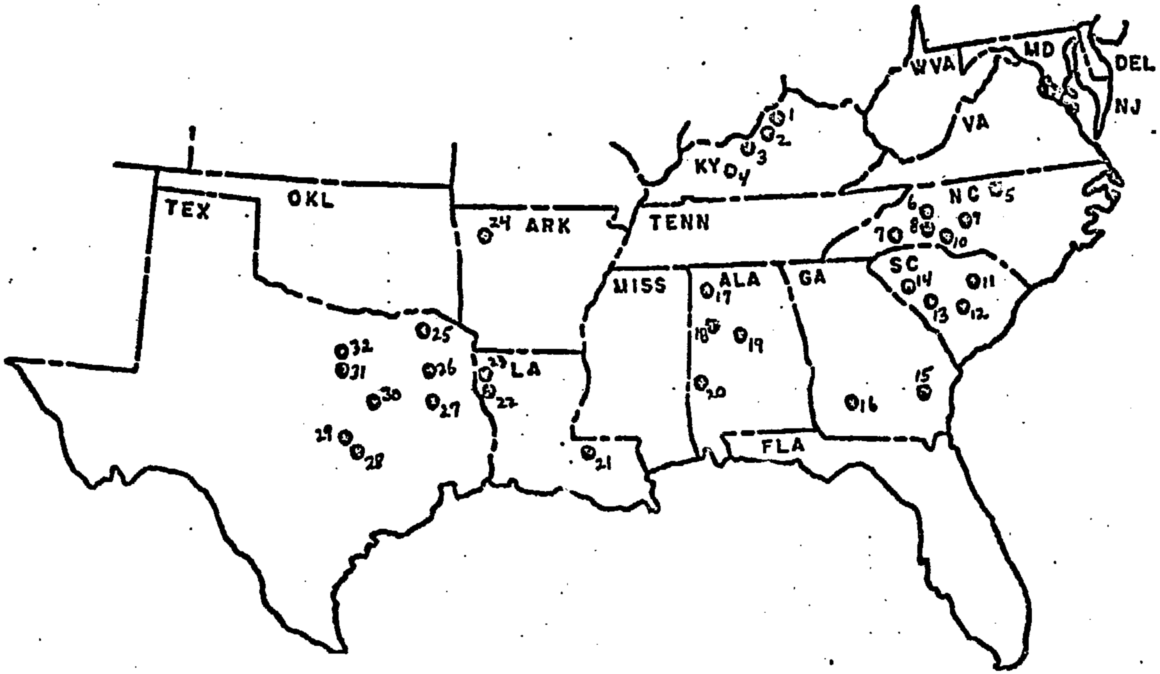
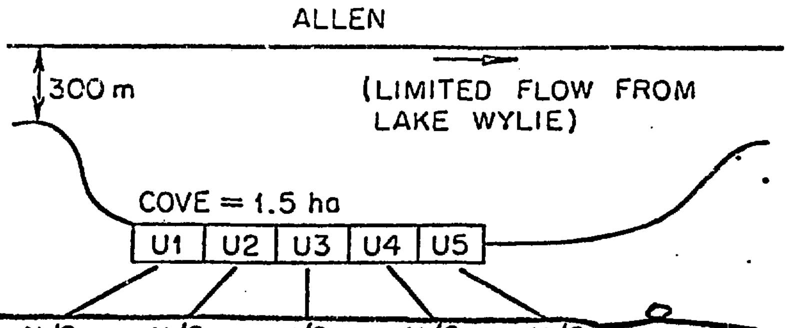
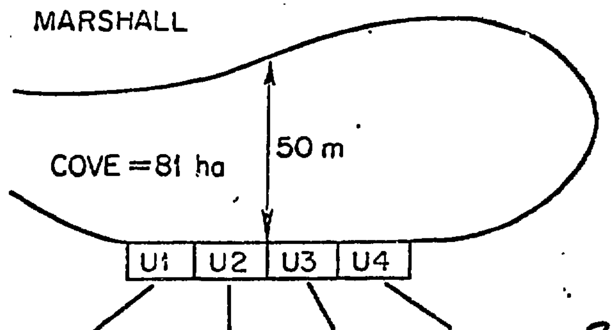




	U1	U2	U3	U4	U5
SUMMER CCW	N/S	N/S	N/S	N/S	N/S
WINTER CCW	3.51	3.51	5.24	5.24	5.24
MAXIMUM VELOCITY (cm/sec)	12	12	19	19	19
TOTAL ~~FISH~~ SHAD	~~364~~ 347	~~397~~ 393	~~1,282~~ 1,284	~~819~~ 819	~~1,398~~ 1,388



	U1	U2	U3	U4
SUMMER CCW	7.84	7.84	9.53	9.53
WINTER CCW	5.60	5.60	6.85	6.85
MAXIMUM VELOCITY (cm/sec)	19	19	21	21
TOTAL ~~FISH~~ SHAD	~~14,321~~ 11,954	~~124,834~~ 85,529	~~106,175~~ 94,190	~~823,069~~ 765,022

Table 1

Descriptions of the locations of the 32 power plants included in the study. The numbers of the individual plants correspond with the locations shown in Fig. 1.

				Location		
Plant No.	Name	Type	Cooling System[a]	County	State	Cooling Water Source
1	Ghent	Fossil	CT	Carroll	Kentucky	Ohio River
2	Cane Run	Fossil	OT	Jefferson	Kentucky	Ohio River
3	Mill Creek	Fossil	OT	Jefferson	Kentucky	Ohio River
4	Green River	Fossil	OT	Muhlenberg	Kentucky	Green River
5	Dan River	Fossil	OT	Rockingham	North Carolina	Dan River
6	Marshall	Fossil	OT	Catawba	North Carolina	Lake Norman
7	Cliffside	Fossil	OT/CT	Rutherford	North Carolina	Broad River
8	Riverbend	Fossil	OT	Gaston	North Carolina	Catawba River
9	Buck	Fossil	OT	Rowan	North Carolina	Yadkin River
10	Allen	Fossil	OT	Gaston	North Carolina	Lake Wylie
11	Robinson	Fossil (Unit 1) Nuclear (Unit 2)	OT OT	Darlington	South Carolina	Lake Robinson
12	Wateree	Fossil	OT	Richland	South Carolina	Wateree River
13	Lee	Fossil	OT/CT	Anderson	South Carolina	Saluda River
14	Oconee	Nuclear	OT	Oconee	South Carolina	Lake Keowee
15	Hatch	Nuclear	CT	Appling	Georgia	Altamaha River
16	Mitchell	Fossil	OT	Dougherty	Georgia	Flint River
17	Browns Ferry	Nuclear	OT/CT	Limestone	Alabama	Wheeler Reservoir

Table 1 (Continued)

Plant No.	Name	Type	Cooling System[a]	Location: County	Location: State	Location: Cooling Water Source
18	Gorgas	Fossil	OT	Walker	Alabama	Mulberry Fork of Black Warrior River
19	Gaston	Fossil	OT	Shelby	Alabama	Coosa River
20	Green County	Fossil	OT	Greene	Alabama	Black Warrior River
21	Willow Glen	Fossil	OT	Iberville	Louisiana	Mississippi River
22	Arsenal Hill	Fossil	CP	Caddo	Louisiana	Arsenal Hill Cooling Pond
23	Lieberman	Fossil	OT	Caddo	Louisiana	Caddo Lake
24	Arkansas	Nuclear (Unit 1)	OT	Pope	Arkansas	Dardenelle Reservoir
25	River Crest	Fossil	CP	Red River	Texas	Sulphur River
26	Wilkes	Fossil	CP	Marion	Texas	Johnson Creek Reservoir
27	Knox Lee	Fossil	OT	Gregg	Texas	Lake Cherokee
28	Tradinghouse	Fossil	CP	McLennan	Texas	Tradinghouse Creek Reservoir
29	Lake Creek	Fossil	CP	McLennan	Texas	Brazos River
30	Trinidad	Fossil	CP	Henderson	Texas	Trinity River
31	Handley	Fossil	CP	Tarrant	Texas	Lake Arlington
32	Eagle Mountain	Fossil	CP	Tarrant	Texas	Eagle Mountain

[a]OT = once-through; CT = cooling towers; CP = cooling ponds.

Table 2

Seasonal impingement patterns and size of threadfin shad collected during peak impingement periods. The percentage of fish impinged during the peak period as calculated from $I_t/I_T \times 100$, where I_t = number impinged during time t and I_T = total annual impingement.

	PERIOD OF PEAK IMPINGEMENT (t)	$I_t/I_T \times 100$	MEAN SIZE LENGTH (cm)	MEAN SIZE WEIGHT (g)	COMMENTS
Allen (North Carolina)	December-February	32	6.3		98.8% of the Dorosoma sp. were impinged from December to February
Arkansas One (Arkansas)	December-March	98		8.0	
Browns Ferry (Alabama)	December-March	89	8.8		
Green River (Kentucky)	December-January	89	5.8	1.6	
Marshall (North Carolina)	December-February	86	5.2		90.1% of Dorosoma sp. were impinged from December to February with mean length of 4.4 cm (range was 2-6 cm)
Riverbend (North Carolina)	December-February	96	5.0		Range was 2-10 cm; 91.5% were < 6 cm
Wateree (South Carolina)	January-February	86	< 7.6	2.0	
Willow Glen (Louisiana)	December	61		1.7	Peak impingement of Dorosoma sp. was September to November and the average weight was 1.7 g

Table 3

Impingement of threadfin shad expressed as the percentage of the total annual impingement (by number) that occurred during periods when intake temperatures at 12 power plants were less than 15°C.

PLANT	LATITUDE N (APPROXIMATE)	MINIMUM INTAKE TEMPERATURE (C°) DURING ANY SAMPLING DATE	TEMPERATURE < 10°C		TEMPERATURE < 15°C	
			% SAMPLING TIME	% OF ANNUAL IMPINGEMENT	% SAMPLING TIME	% OF ANNUAL IMPINGEMENT
Kentucky						
Green River	37° 18'	5.6	26	90	35	90
North Carolina						
Allen	35° 20'	9.0	17	70	46	98
Marshall[a]	35° 12'	7.8	31	88	50	> 99
Riverbend	35° 12'	7.8	28	95	42	95
Arkansas						
Arkansas One	35° 16'	5.5	46	> 99	50	> 99
South Carolina						
Oconee	34° 47'	8.0	6	26[b]	45	> 99
Wateree	34° 00'	8.9	8	46	35	99
Alabama						
Browns Ferry[a]	34° 42'	4.5	21	46	41	85
Greene County[a]	32° 55'	8.9	2	< 1	31	4
Texas						
Eagle Mountain	32° 57'	7.8	13	80	21	94
Handley	32° 50'	7.2	7	72	21	82
Tradinghouse[a]	31° 28'	11.0	0	0	14	32

[a]Some gizzard shad probably included.

[b]An underestimate, since many unidentified fish were probably threadfin shad.

Table 4

Comparison of the number of clupeids impinged per unit volume of water withdrawn and various intake design parameters. Impingement categories are based on the values shown in Column 8. Approach velocities in feet per sec are given in parentheses.

IMPINGEMENT CATEGORY	PLANT	PLANT CAPACITY (MWe)	SITE DESCRIPTION: COOLING WATER SOURCE	SITE DESCRIPTION: TYPE/LOCATION OF INTAKE STRUCTURE	CALCULATED MAXIMUM APPROACH VELOCITY, cm/sec	% ABUNDANCE OF CLUPEIDS IN IMPINGEMENT SAMPLES	NUMBER OF CLUPEIDS IMPINGED PER $10^6 m^3$
< 1	Dan River (NC)	284	River	Shoreline	14 (0.46)	16	0.1
	Cliffside (NC)	770	River	Shoreline	24 (0.79)	0	0.0
	Hatch (GA)	786	River	Shoreline	26 (0.85)	3	0.4
	Robinson (SC)	975	Reservoir	Shoreline	6, 64 (0.02, 2.10)[a]	0	0.0
	Lee (SC)	323	River	Shoreline	88 (2.89)	11	0.1
				Mean	37 (1.21)	6	0.1
1-10	Ghent (KY)	511	River	Canal	25 (0.82)	33	2
11-100	Handley (TX)	523	Reservoir	Slough	31 (1.02)[b]	77	16
	Greene Co. (AL)	568	River	Canal	33 (1.08)	86	74
	Riverbend (NC)	730	River/Reservoir[c]	Canal	35 (1.15)	89	16
	Buck (NC)	519	River/Reservoir[c]	Shoreline	82 (2.69)	98	45
				Mean	45 (1.48)	88	38

Table 4 (Continued)

IMPINGEMENT CATEGORY	PLANT	PLANT CAPACITY (MWe)	SITE DESCRIPTION: COOLING WATER SOURCE	SITE DESCRIPTION: TYPE/LOCATION OF INTAKE STRUCTURE	CALCULATED MAXIMUM APPROACH VELOCITY, cm/sec	% ABUNDANCE OF CLUPEIDS IN IMPINGEMENT SAMPLES	NUMBER OF CLUPEIDS IMPINGED PER $10^6 m^3$
101-1000	Allen (NC)	1140	Reservoir	Cove	19 (0.62)	99 (97)[d]	892 (17)
	Gaston (AL)	1061	River/Reservoir[c]	Canal	19 (0.62)[b]	97	114
	Green River (KY)	263	River	Shoreline	28 (0.92)	94	414
	Gorgas (AL)	1546	River/Reservoir[c]	Canal	31 (1.02)	99	325
	Cane Run (KY)	1017	River	Shoreline	46 (1.51)	40	332
	Oconee (SC)	2658	Reservoir	Canal	51 (1.67)	44	386[e]
	Willow Glen (LA)	1586	River	Offshore	N/A	39	112
				Mean	32 (1.05)	73	316
> 1000	Wateree (SC)	772	River	Canal	15 (0.49)	99	5,988
	Marshall (NC)	2025	Reservoir	Cove	21 (0.69)	99	1,052
	Browns Ferry (AL)	3456	Reservoir	Canal	27 (0.89)	96	2,544
	Eagle Mountain (TX)	706	Reservoir	Canal	46 (1.51)[b]	97	1,703
	Mill Creek (KY)	330	River	Shoreline	47 (1.54)	22	1,161
	Tradinghouse (TX)	1380	Reservoir	Shoreline	56, 82 (1.84, 2.69)[a]	86	2,327
	Arkansas (ARK)	820	Reservoir	Canal	90 (2.95)[f]	99	25,921
				Mean	45 (1.48)	85	5,814

[a]Unit 1, Unit 2

[b]Actual observed approach velocity

[c]River with reservoir influence

[d]Values are for 1973, with 1974 data in parentheses

[e]Based on identifiable fish only

[f]Value represents the maximum velocity in the intake canal

Table 5

Impingement of fish on individual intake screens at the Browns Ferry Nuclear Plant, Units 1 and 2. Data are presented as the percent of the total fish impinged on each screen during the sampling period. Values in parentheses represent the average rank based on Friedman's test. N/A = no data available because pumps were not operating.

SAMPLING PERIOD	NO. OF SAMPLING DATES	UNIT 1						UNIT 2					
		PUMP A		PUMP B		PUMP C		PUMP A		PUMP B		PUMP C	
		1AA	1AB	1BA	1BB	1CA	1CB	2AA	2AB	2BA	2BB	2CA	2CB
February -	5	49.1	18.8	14.2	5.7	8.3	3.9	N/A		N/A		N/A	
June, 1974		(5.2)	(5.8)	(4.0)	(2.6)	(2.4)	(0.8)						
July, 1974	5	16.3	39.4	12.4	3.5	5.9	4.2	N/A		5.4	5.4	4.2	3.3
		(8.6)	(10.0)	(8.4)	(2.0)	(6.2)	(3.6)			(5.6)	(5.8)	(2.4)	(1.4)
August, 1974 -	7	12.5	20.3	12.5	11.1	10.6	7.5	7.0	5.0	4.3	3.8	2.8	2.5
February, 1975		(10.0)	(11.4)	(9.0)	(8.0)	(7.9)	(6.9)	(6.6)	(5.4)	(4.9)	(3.6)	(2.6)	(1.9)