NUREG-0601

Impingement Dynamics and Age and Growth of Selected Species at Lake Dardanelle, A Southcentral Reservoir

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Division of Site Safety and Environmental Analysis
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
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Abstract

Impingement data collected between 1974 and 1979 was analyzed and compared with four years of data from Arkansas Nuclear One located on Lake Dardanelle, a southcentral run-of-the-river reservoir. Dorosoma petenense, D. cepedianum, Ictalurus punctatus, Lepomis macrochirus, and several other recreationally or ecologically important species commonly found on the intake screen were chosen for comparison. Weekly natural log transformed impingement estimates were plotted, and yearly impingement estimates were determined over the five year period. An analysis of variance on the transformed weekly estimates of eight species of fish indicated the significance ($F < .002$) of temperature on impingement for seven species. Yearly impingement of D. petenense was found to be correlated ($R^2 = .965$) with the weekly average minimum water temperature of the reservoir for all years except 1978. Based on impingement monitoring results and weekly average water temperatures, the lower lethal temperature threshold (recorded at the intake) was determined to be between 3.3 and 5.5 °C for D. petenense and 0 and 0.5°C for D. cepedianum. Impingement of D. petenense decreased significantly when the water temperatures dropped below the lower threshold temperature. Results of the impingement analysis were compared and contrasted with age and growth studies in the reservoir.

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Acknowledgements

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INTRODUCTION

Studies indicate (Edsall, 1976; Freeman and Sharma, 1977) that the numbers of fish impinged on power plant cooling water intake screens may be significant and may have a major impact on aquatic ecosystems. Impinged fish suffer nearly 100 percent delayed mortality unless early escape is possible. The amount of fish impinged on traveling screens can be considerable. Edsall (1976) cites losses of 92,000 pounds of gizzard shad (Dorosoma cepedianum) killed in six weeks (Ontario Hydro-Lanton Plant), 1.2 million fish (June 1972 to July 1973, Commonwealth Edisons Waukegan Plant, Illinois) and 5 million fish (Nine Mile Point, January to December 1973). Generally one or two species comprise the majority of fish impinged at a particular station. Loar et al. (1977) cites that since their introduction and subsequent proliferation in 16 southeastern states, the threadfin shad (D. petenense) comprises 98 percent of the impinged fish. Physical factors such as temperature, biological factors such as fish behavior and population size, and engineered design factors such as intake configuration have all been suggested to affect impingement losses.

One of the largest impingement losses to be recorded in the southcentral U.S. occurred at Arkansas Nuclear One (ANO), a nuclear power plant located on Lake Dardanelle, a run of the river reservoir on the Arkansas River. ANO began operation in the fall of 1974. Between the years of 1974 and 1979 approximately 64 million fish were impinged on the traveling screens. An estimated 1.6 million fish were impinged within a single 24 hour period on February 9, 1979. An average of 95 percent of the total number of fish impinged at ANO have been threadfin and gizzard shad. The number of threadfin shad impinged within each calendar year may range over 6 orders of magnitude. Year to year impingement of threadfin shad at ANO has not been consistent, and has decreased in past years (16 million in 1975, versus only 99,000 in 1979). The number of gizzard shad impinged has increased from 207,000 in 1976 to 22.7 million in 1979.

This study in part examines the effect of temperature on impingement for certain species, Dorosoma petenense, D. cepedianum, and six other species (see Table I) that were consistantly impinged were considered in the analysis using natural log transformed estimates of the data. An analysis of variance (ANOVA) was used to identify trends and show whether they were statistically significant. Since temperature has been shown to be the critical factor affecting threadfin shad biology, (Loar et al, 1977; Griffith, 1978; Strawn, 1965) and since threadfin shad is the most numerous species impinged at ANO, temperature was used as a covariate in the ANOVA. As an aid in the interpretation of ANOVA results, the natural log transformed impingement estimates (numbers of fish) were graphed as a function of time.

Because of the large number of threadfin shad and other prey species impinged, far field data were examined to determine whether noticable changes had occurred in the growth rates of predators. Using data collected by Tatum (1975a, 1975b, 1976a, 1976b, 1977a, 1977b, 1978a) on age growth relationships, changes in the age class length were examined for four species of fish: Pomoxis annularis, Aplodinotus grunniens, Morone chrysops, and Micropterus salmoides. The analysis uses data from 1965 to 1976, and therefore spans both preoperational and operational phases of the station.

TABLE I

COMMON AND SCIENTIFIC NAMES OF DISCUSSED SPECIES

SCIENTIFIC NAME	COMMON NAME
Dorosoma petenense	Threadfin shad
Dorosoma cepedianum	Gizzard shad
Lepomis macrochirus	Bluegill
Ictalurus punctatus	Channel catfish
Ictalurus furcatus	Blue catfish
Aplodinotus grunniens	Freshwater drum
Pomoxis annularis	White crappie
Morone chrysops	White bass
Micropterus salmoides	Largemouth bass

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Data used in this report were collected at the ANO plant located on a penninsula on the Illinois Bayou arm of the run-of-the-river reservoir Lake Dardanelle. Condenser cooling water is withdrawn from a shallow intake canal approximately 1340 meters (4400 feet) long (area B, figure 1). Water velocity in the canal is between 0.37 and 0.46 m/sec resulting in a velocity of 0.61 m/sec (2.0 ft/sec) to 0.76 m/sec (2.5 ft/sec) through the intake screen, (USNRC, 1977). Water is used for cooling at a rate of 48 m^3/sec (1703 ft^3/sec) during maximum power output. An additional unit (Unit 2) utilizing closed cycle cooling is scheduled to begin operation in September 1979. The small increase in water usage (0.87 m^3/sec, 31 ft^3/sec) due to the operation of Unit 2 is not expected to result in an observable increase in impingement losses (USNRC, 1977).

Threadfin shad, (Dorosoma petenense), and Gizzard shad, (D. cepedianum) comprise over 95 percent of the fish impinged at ANO. Understanding of some inherent differences between these two species is necessary for data interpretation. Gizzard shad are native to the Arkansas River and Lake Dardanelle; threadfin shad was introduced in the reservoir in 1965 by the State of Arkansas as prey species. The threadfin shad population had become established by 1967, and the species was abundant throughout the lake by the middle of the 1970's (pers. comm. Keith, 1975). Threadfin shad is preferred over the larger gizzard shad by resources managers because it provides a better forage food for desirable game fish. The two species differ slightly in their feeding habits; adult gizzard shad are primarily bottom feeders, whereas adult threadfin shad, are primarily limnetic feeders (Baker and Schmitz, 1971).

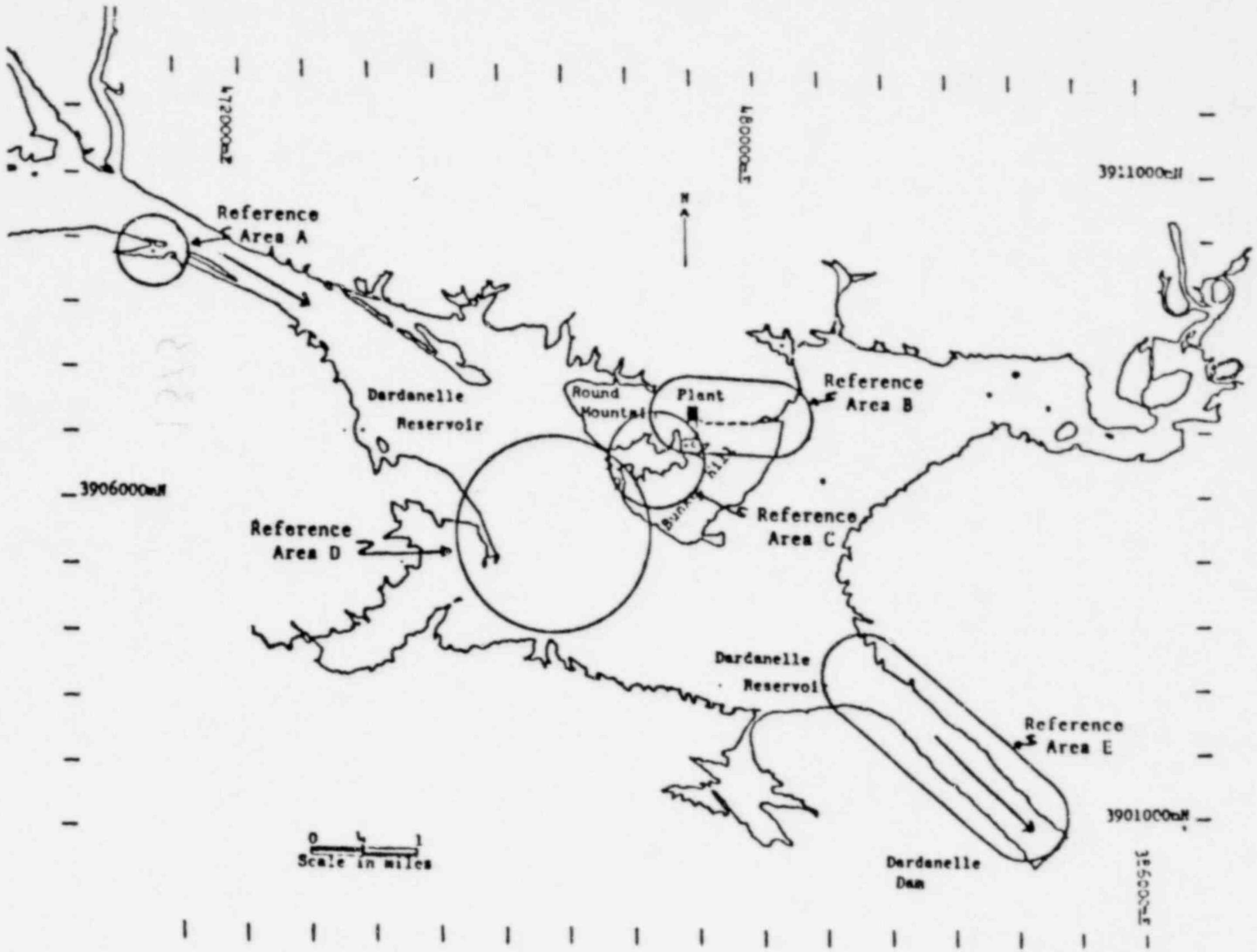

FIGURE 1 Aquatic Sampling Sites

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Studies by Strawn (1965), Griffith (1978), Loar et al. (1977) and others have documented that mortality occurs in threadfin shad at moderately low temperatures.

They are sensitive to cold stress which can cause loss of equilibrium and eventual death. Griffith and Tomljanovich (1975) found that no mortality was observed above 12°C (54°F) in test fish exposed to temperature drop of 1-4°C (1.8 to 7.2°F) per hour. However it was found that below 12°C (54°F) mortality rates to threadfin shad increased with the magnitude of the drop

Griffith (1978) found that threadfin shad acclimated to 15°C, (59°F) when exposed to a temperature drop of 1°C per 72 hours, schooled less compactly and decreased feeding activity at 9°C (48°F), ceased feeding at 7°C (45°F), and experienced 100 percent mortality below 5°C (40°F).

Cox and Coutant (1976) found in acute cold shock studies that gizzard shad acclimated to temperatures of 15 to 20°C (59 to 68°F) maintained equilibrium at temperatures above 6 to 7°C (43 to 45°F) and experienced only a 10 percent mortality at lower temperatures. Although these studies are not directly comparable it may be inferred that threadfin shad is more sensitive to cold shock than gizzard shad.

METHODS

All numerical calculations, manipulations and graphing procedures were computerized. The different data sets used for the impingement and for the far field studies were analyzed using different computer programs. The methods used in each analysis are discussed below.

Impingement Analysis

Impingement sampling is conducted by ANC in accordance with procedures outlined in the USNRC Environmental Technical Specifications. Twice a week during the period April 1 to September 30, and three times a week the rest of the year impinged fish were sampled from the intake screens throughout a 24-hour period. If the weight exceeded more than 68 kgs (150 lbs) during any 24 hour period sample, two replicate subsamples of 34 kgs (75 lbs) each were used to determine daily estimates of weight and numbers of fish impinged. Data were provided monthly to the NRC by species, by date collected, on the number of fish impinged, the weight impinged, range in length, modal length, range in weight, modal weight and the temperature of the intake water. Impingement data received from the utility was placed with other data from the utility in a computer storage file referred to as a data base. Once stored any portion of data entered could be retrieved with a minimum of effort using a data base management language.

Since the data base management system can only recall data in its original form, programs to restructure the data into a uniform matrix were developed. In addition, a natural log transformation was performed on each data point to facilitate statistical treatment.

By grouping the log transformed data points, uniform data essential for an ANOVA was obtained. Several grouping sizes or clump intervals for a yearly data matrix were examined to choose an optimum interval size. Because of the sampling interval and the known annual variation in impingement levels, time intervals ranging from three days to one year were appropriate. To estimate impingement within a specified time interval, the 24 hour impingement estimates within the interval were averaged and multiplied by the number of days within the time interval. Interval sizes were compared in terms of the effect on ANOVA significance. Regardless of the interval choosen--days, weeks, months, or seasons--the results of the ANOVA were of similar significance. Since choosing a weekly interval maximized the number of data points while minimizing the amount of missing data, a clump interval of seven days or one week was chosen as the optimum, resulting in 52 points for each year of data collection.

Once the data had been restructured into an ordered matrix of impingement by weeks and years, the transformed natural log estimates were used in an ANOVA. A commercially available statistical programming package (SPSS) was used to perform a two way ANOVA. The program used only data submitted; if the resultant matrix structure was non-orthogonal because of missing values, the missing points in the matrix were not replaced by interpolated results. The program, however, adjusted the non-orthogonalized matrix to reflect the ANOVA effects of these missing values. The missing data points were due to plant shut-down for maintainance and refueling at various times throughout the study period. The results indicated whether or not the years were significantly different data sets. Since cold stress was exhibited by at least two species, temperature was used as a covariate in the ANOVA to partially explain why impingement varied from year to year. This indicated whether temperature was an important consideration for the species being impinged, and whether the yearly trends was still significant after temperature effects had been evaluated.

To assist in identifying trends, a graphical package (DISSPLA) was used to graph the natural log transformed weekly estimates for all years. Each year of data was subjected to a smoothing subroutine to print a curve. The amount of response of the smoothed line to data fluctuation was set to an arbitrary value before execution, and was constant for all curves printed on each graph. Each symbol used represents separate data for each year; the hierarchy of symbols is presented in the attached Appendix. The zero point of the time axis represents the 26th week of the year (July). Each curve represents the latter half of the indicated year, and the first half of the following year. For convenience, it is referred to as an impingement year. This was done to facilitate visual comparison of the various years particularly during the high impingement winter months.

Far Field Data

Annual and Semiannual Environmental Reports by consultants to the utility (Tatum, 1975a, 1975b, 1976a, 1976b, 1977a, 1977b, 1978a) contained data on the average year class lengths for selected species from fish collected in Lake Dardanelle. Four species were examined for age-growth analysis: *Pomoxis annularis*, *Aplodinotus grunniens*, *Morone chrysops*, and *Micropterus salmoides*. Size and incremented growth of the calculated fish caught in the lake were back calculated using scale annuli (much as the growth in trees can be calculated from the thickness of its rings). This allowed reasonable estimations of the amount of growth in each year (age-class) of the fish's life.

The average amount of growth (in centimeters) of a n year old fish was determined for each species, where n varied between one and eight years. The average amount of growth for a n year old fish was plotted as a function of years between 1967 and 1977, for all n age classes. Although these points were discrete data, they were connected to form a line. This line was used to indicate fish growth patterns before and during operation of Arkansas Nuclear One. Horizontal lines demonstrated that no discernable changes have occurred in growth patterns for that age class, while an upward slope showed increased growth and a downward slope showed decreased growth.

RESULTS

Impingement

Impingement estimates by calendar year for the 8 species of fish studied are presented in Table II, and impingement estimates by impingement year are presented in Table III. The listed species accounted for 97.9 to 99.8 percent of the total number of fish impinged each year. Since threadfin and gizzard shad comprised greater than 96.5 percent of yearly impingement estimates in each year except 1978, or approximately 98 percent of the six year total of 64 million fish impinged, overall impingement trends can be explained through analysis of these two species.

Prior to 1978, threadfin shad consistantly accounted for the greatest number of impinged specimens. In 1975 an estimated 15.6 million threadfin shad were impinged on the ANO traveling screens; an estimated 13.1 million fish were impinged during the last quarter of 1974, or about 84 percent the number impinged in 1975 during one third the time. Subsequent to 1977, gizzard shad replaced threadfin as the dominant impinged species. In 1977 and 1978 threadfin shad comprised 30.0 and 0.43 percent of the yearly estimates, and gizzard shad comprised 56.4 and 97.8 percent of the yearly estimates respectively. Prior to 1977, gizzard shad comprised approximately 4 percent of the yearly impinged numbers. The shift in relative impingement levels of these two species by at least two orders of magnitude suggests a change in the community structure of the lake.

TABLE II

Estimates of the Number of Fish Impinged During Each Calendar Year
At Arkansas Nuclear One For Selected Species

Name	1974*	1975	1976	1977	1978	1979.
% Operation	100.	75.	79.	81.	79.	100.
All Species	13,000,000	16,500,000	5,020,000	4,930,000	1,160,000	23,200,000
T. Shad	12,300,000	15,600,000	4,760,000	4,130,000	348,000	99,000
%	94.62	94.55	94.82	83.77	30.00	.43
G. Shad	559,000	777,000	207,000	622,000	654,000	22,700,000
%	4.30	4.71	4.12	12.62	56.38	97.84
Bluegill	340	1,100	1,900	4,370	1,900	21,400
%	0.01	0.01	0.04	0.09	0.16	0 .09
C. Catfish	4,400	17,100	3,400	8,700	2,200	1,300
%	0.03	0.10	0.07	0.18	0.19	0.01
B. Catfish	8,400	10,000	2,000	1,800	1,800	3,400
%	0.06	0.06	0.04	0.04	0.16	0.01
F. Drum	10,000	34,900	28,900	111,000	119,000	40,300
%	0.08	0.21	0.58	2.25	10.26	0.17
W. Crappie	2,500	10,000	2,500	7,300	3,500	1,500
%	0.02	0.06	0.05	0.15	0.30	0.01
W. Bass	2,700	2,100	4,200	13,000	6,800	6,400
%	0.02	0.01	0.08	0.26	0.59	0.03
% acc:	99.13	99.71	99.80	99.36	97.96	98.59

*Represents data for the months of September through December only.
.Represents data for the months of January through March only.

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TABLE III

Estimates of the Number of Fish Impinged During
Each Impingement Year at Arkansas Nuclear One
For Selected Species

Species	1974-75	1975-76	1976-77	1977-78	1978-79
All Species	26,600,000	5,700,000	3,090,000	4,790,000	23,500,000
T. Shad	25,200,000	5,580,000	2,370,000	4,010,000	124,000
%	94.44	97.89	76.70	83.72	0.53
G. Shad	1,330,000	79,600	577,000	591,000	23,000,000
%	5.00	1.40	18.67	12.34	97.87
Bluegill	680	1,460	4,550	1,980	22,400
%	0.01	0.03	0.15	0.04	0.10
C. Catfish	19,000	3,590	5,440	6,580	2,400
%	0.07	0.06	0.18	0.14	0.01
B. Catfish	16,000	3,720	650	2,240	4,520
%	0.06	0.07	0.02	0.05	0.02
F. Drum	40,500	10,600	86,100	140,000	67,300
%	0.15	0.19	2.79	2.92	0.03
W. Crappie	11,500	1,550	5,940	5,940	2,480
%	0.04	0.03	0.19	0.12	0.01
W. Bass	3,670	1,210	8,420	9,670	12,100
%	0.01	0.02	0.27	0.20	0.05
% acc:	99.97	99.69	98.97	99.53	98.62

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Results of the ANOVA for the impinged species listed in Table I are presented in Table IV. The second column shows that the impingement of all species was significantly different throughout each year (by weeks) at a .02 significance level. The third column indicated that the number of fish impinged by species was significantly different for the years 1974 to 1979 at the .001 level of significance.

Table V presents the results of the ANOVA for selected species with temperature as a covariate by weeks and years. Temperature effects were significant ($F < .002$) for all species except the blue catfish. The ANOVA between weeks and years with temperature effects removed (columns 2 and 3) still indicated significance ($F < .05$) in most cases.

A comparison of the F statistic in table IV to table V for variation of impingement estimates by week for gizzard shad indicated that variation in impingement estimates were almost fully explainable by variation in temperature and not explainable by weeks. After temperature effects had been considered the threadfin still showed a significant F statistic of .001. This does not mean that temperature did not affect the threadfin impingement by weeks (the significance of column 1 shows this to be contrary to the case), but it implies that merely comparing the temperature and impingement data over the entire year does not fully explain the observed impingement trends. Yearly effects of temperature--while important in the majority of the species--also cannot fully explain trends in impingement data as evidenced by the persistance of significance in the last two columns of Table IV. The F value of .887 for the category of "all species" was a result of the impingement trends of the two shad species

TABLE IV

Two Way Analysis of Variance of Impingement Estimates for Selected Species by Weeks and Years

Species Name	Significance of F	
	Weeks	Years
All species	.001	.001
Threadfin shad	.001	.001
Gizzard shad	.001	.001
Bluegill	.001	.001
Channel catfish	.002	.001
Blue catfish	.021	.001
Freshwater drum	.001	.001
White crappie	.001	.001
White bass	.001	.001

TABLE V

Two Way Analysis of Variance of Impingement Estimates for Selected Species with Temperature as a Covariate By Weeks and Years

Species Name	Significance of F Temp	Weeks	Years
All species	.001	.887	.001
Threadfin shad	.001	.001	.001
Gizzard shad	.001	.770	.001
Bluegill	.001	.001	.001
Channel catfish	.002	.005	.001
Blue catfish	.128	.020	.001
Freshwater drum	.001	.001	.001
White crappie	.001	.005	.009
White bass	.001	.001	.001

which together accounted for 98 percent of the total numbers of fish impinged. Weekly impingement variations for the category of "all species" were not significant after temperature fluctuations were removed.

Figures 2 through 9 present the graphed data and resulting regressed data curves for each species. Since the natural log of zero is undefined the plotting routine arbitrarily assigned a value of ln 1 to all zero weekly impingement estimates. A value of ln 1 on any graph indicates that no specimens of that species were collected in the impingement monitoring program during that week. Figure 10 shows average temperatures of each week for all the weeks there were impingement data.

For all winters except the 1978-1979 season, threadfin shad impingement trends (Figure 2) have been similar in magnitude through approximately the first 20 weeks of the impingement year (July through November). After the 20th week, there was a trend towards decreasing numbers of fish as a function of successive years. The 1978-1979 season curve is inconsistent with prior years, and indicates substantial decrease in the number of threadfin shad being impinged.

During the three winters of 1974-75, 1976-77, and 1977-78 impingement of gizzard shad appears very similar (Figure 3). The 1975-76 season shows an impingement trend similar to that found during these three years but at reduced impingement levels. The data for the 1978-79 season (indicated by x's) shows a different trend for this species than in previous years, and appears similar to the pre-1978-79 impingement curves of threadfin shad.

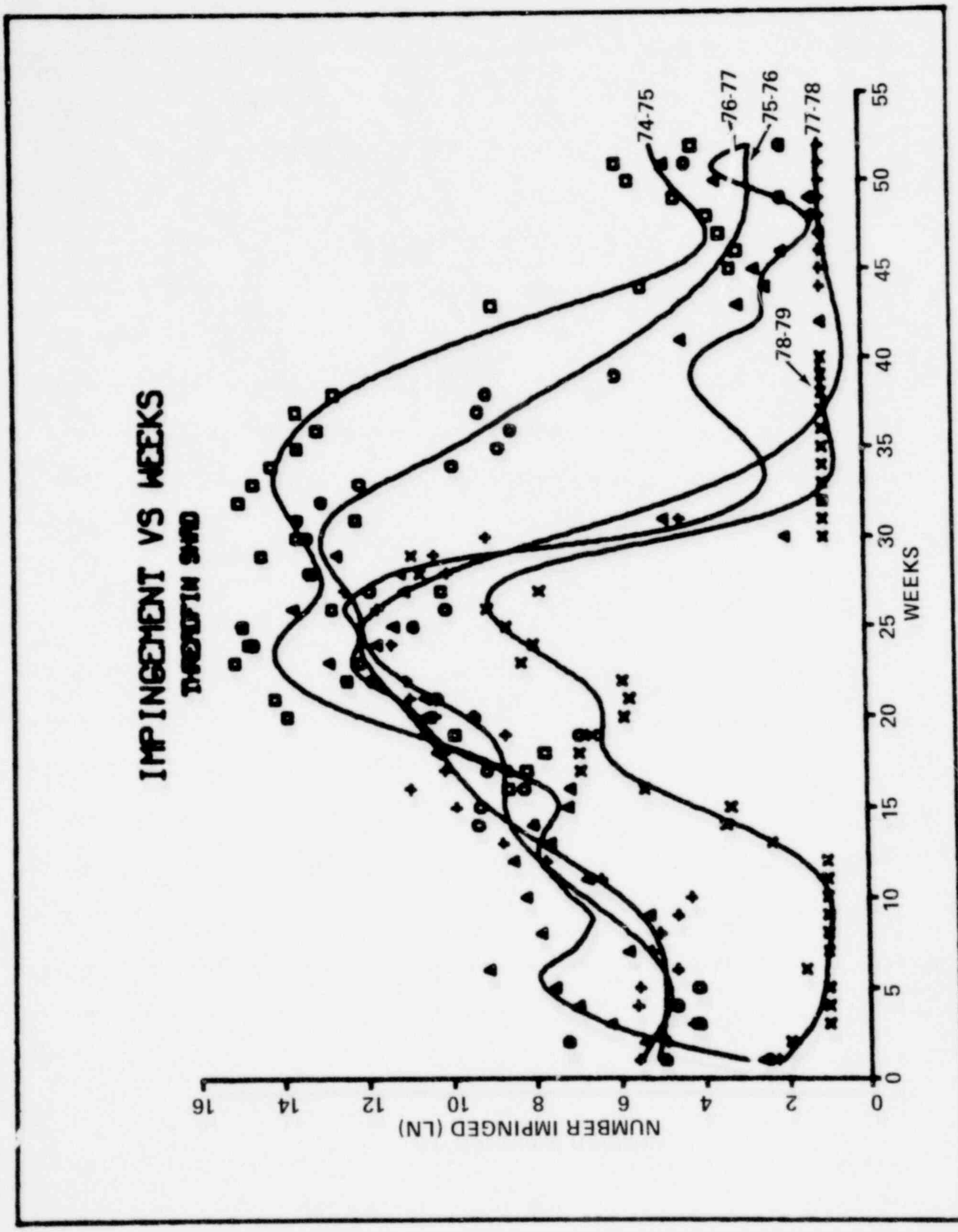
IMPINGEMENT VS WEEKS
NUMBER IMPINGED (LN)
WEEKS
74-75
76-77
75-76
77-78
78-79
0
2
4
6
8
10
12
14
16
5
10
15
20
25
30
35
40
45
50
55

FIGURE 2

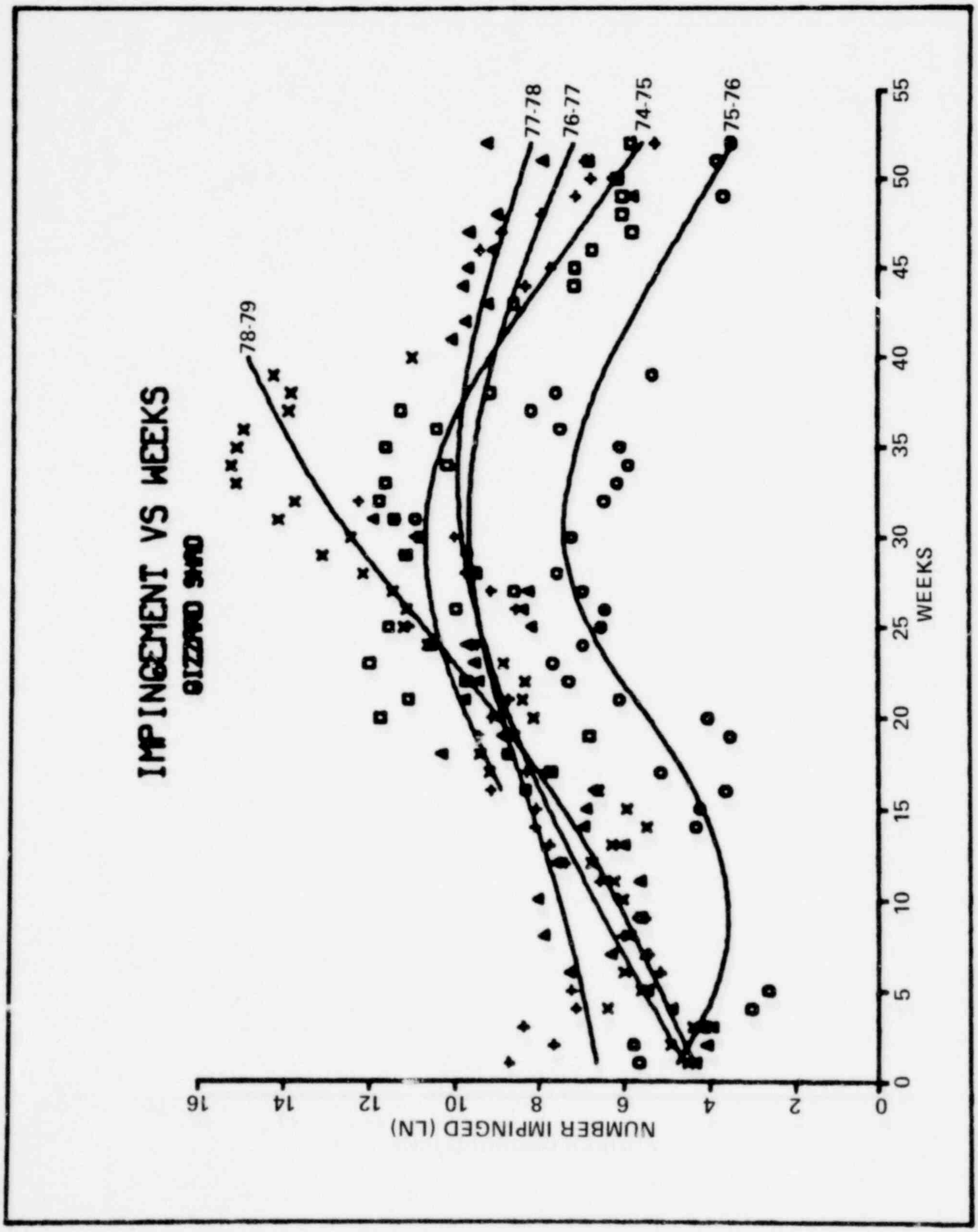

FIGURE 3

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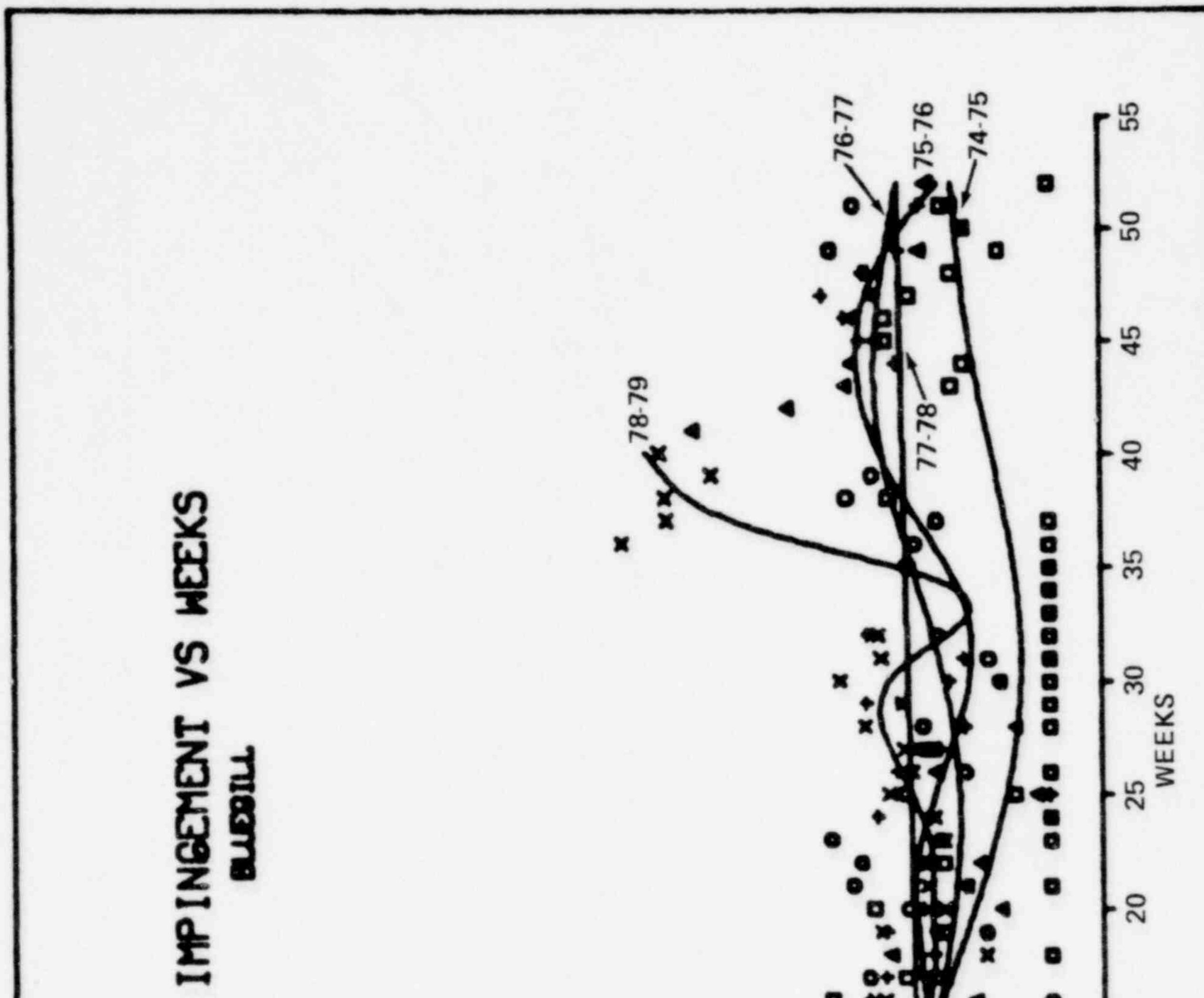
IMPINGEMENT VS WEEKS
BLUEGILL
NUMBER IMPINGED (LN)
WEEKS
78-79
77-78
76-77
75-76
74-75
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
45
50
55

FIGURE 4

Figure 4 (bluegill, Lepomis macrochirus,) shows consistent impingement curves until 1979, when impingement of this species increased by an order of magnitude (see Table VII). There was also a significant number of zero estimates during the 1974-75 winter coinciding with the largest recorded rates for impingement of threadfin shad. These zero estimates are frequently seen for species normally impinged at low levels during a time period of high impingement of one species, and may therefore be an artifact in the data due to subsampling error. The number of fish impinged by species was different for the years 1974 to 1979 at a significance level of <.001 in all cases. It is impossible to determine if in fact there were as few bluegills impinged the winter of 74-75, as the data seems to indicate, or if there were some impinged but that the occurrence of these individuals were masked by the volume of threadfin shad impinged concurrently. Caution should be used when interpreting data from subsamples taken during large impingement episodes dominated by one or two species.

The channel catfish experienced higher impingement rates in 1975 than in subsequent years (Figure 5).

The blue catfish (Figure 6), shows an order of magnitude larger impingement numbers during the first winter (1974-75 winter), than in subsequent years.

The graph of freshwater drum impingement in Figure 7 shows a general increase in impingement through the years, with the highest impingement rate occuring during late 1977 and 1978 (also see Table III).

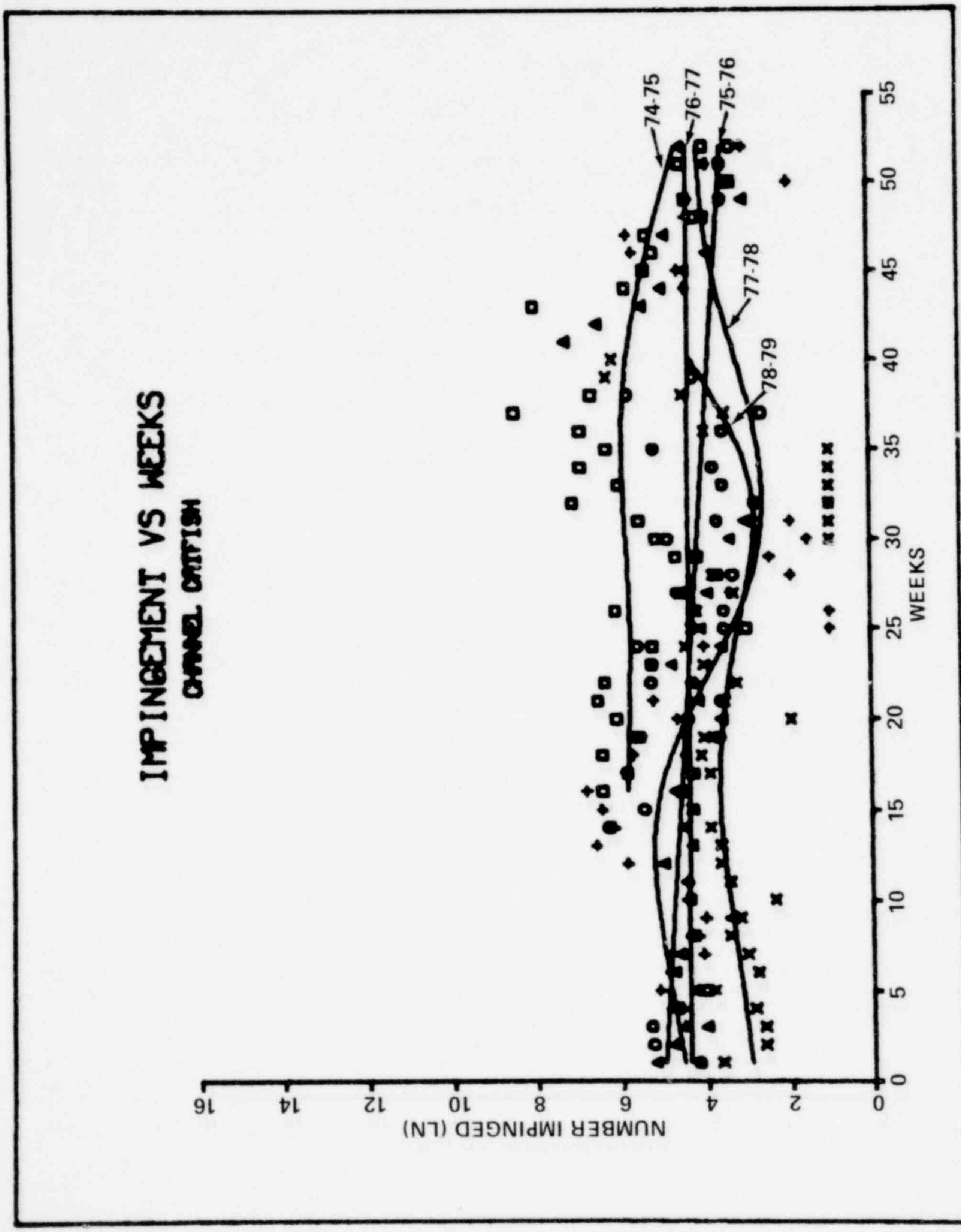

FIGURE 5

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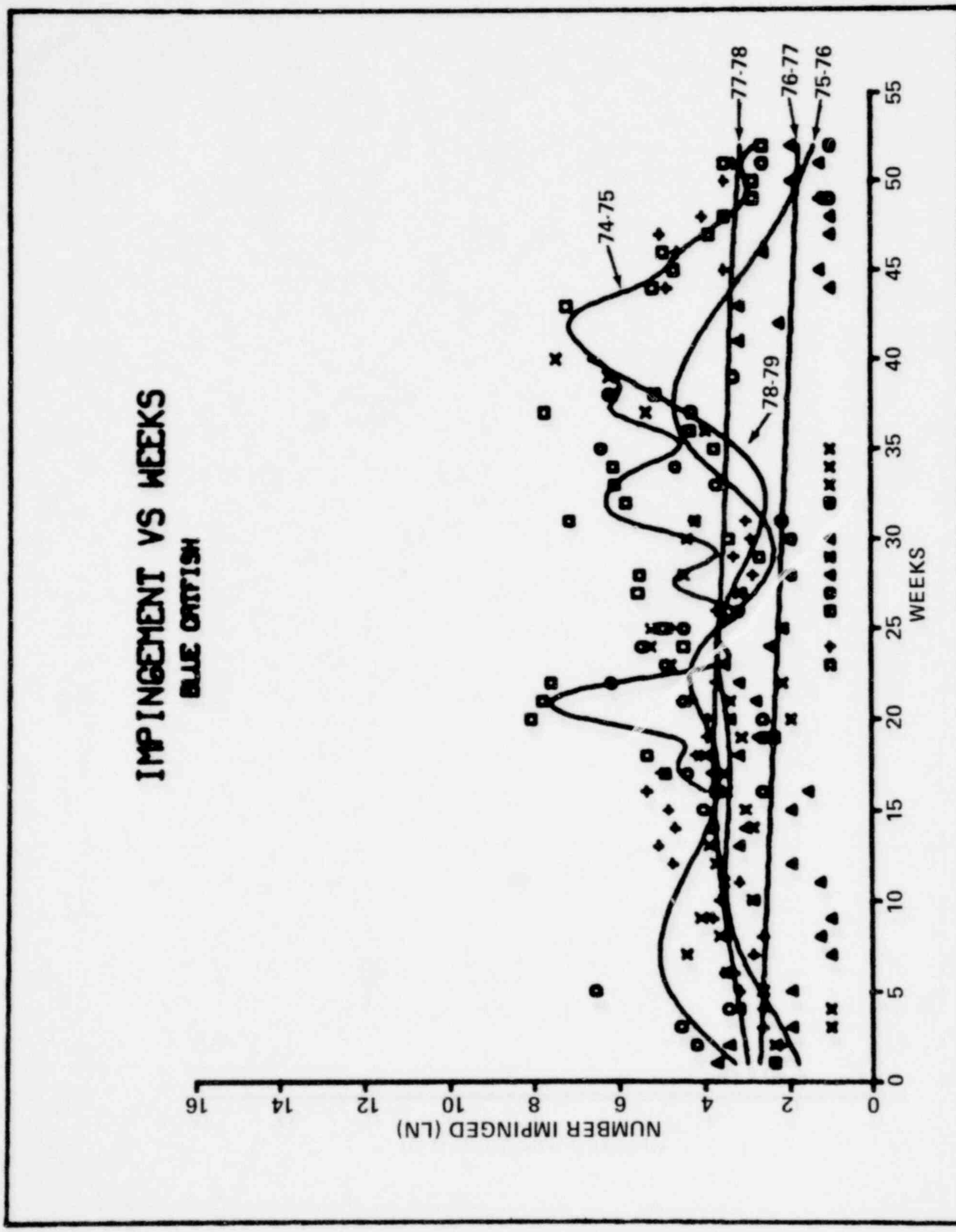

FIGURE 6

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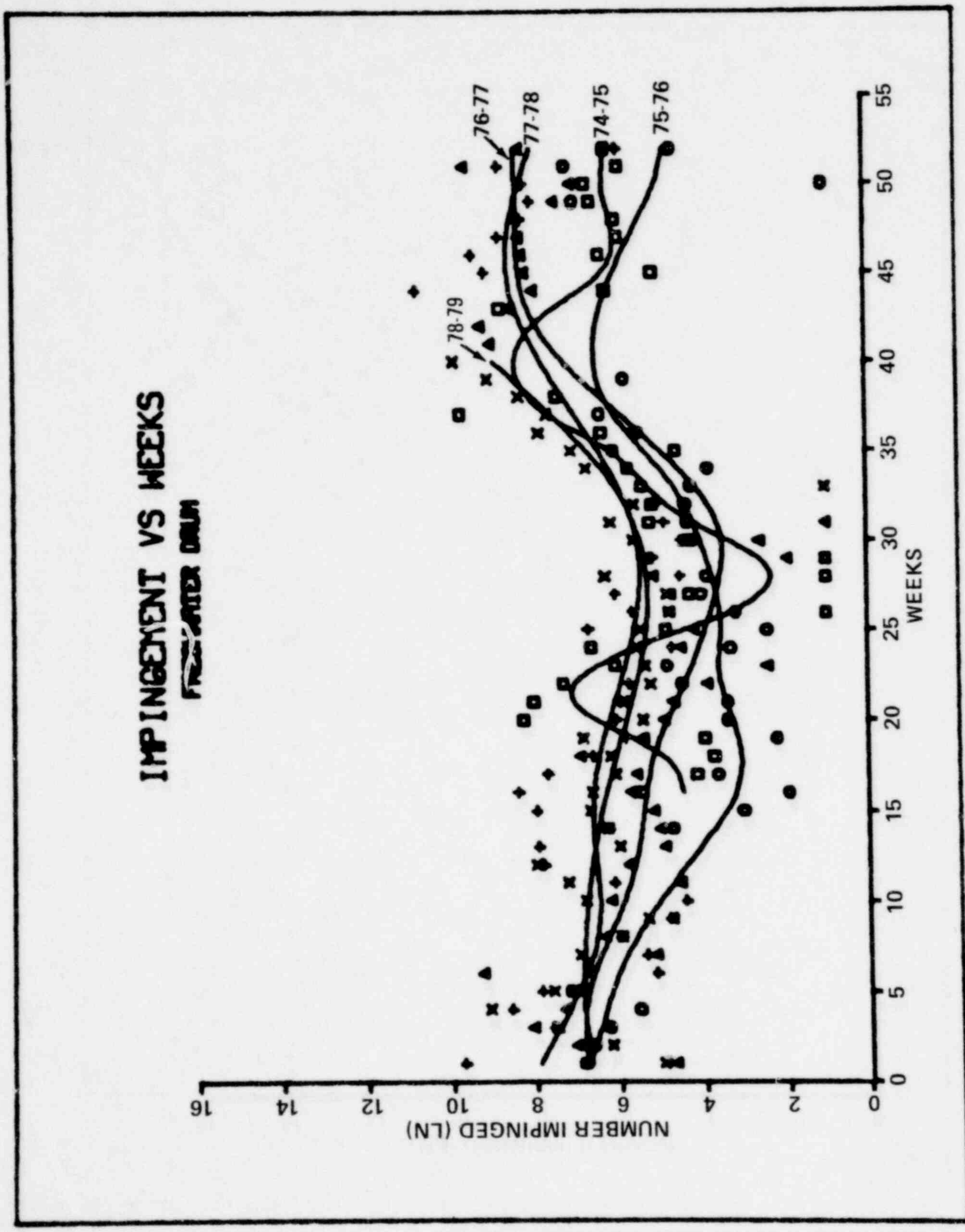

FIGURE 7

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In Figures 8 and 9, no significant trends were noted for the white crappie or white bass impingement, although more white bass appears to have been impinged in the later years.

Far Field Data

The far field results provide an indication of the growth patterns of white crappie, largemouth bass, freshwater drum, and white bass. The data were collected during 1976 and 1977 and span the first through the eighth age classes from years 1967 to 1976. Data for over 1000 fish were used to prepare the graphs with an average of 12 fish per data point.

The white crappie (Figure 11) shows a significant change in its growth rate. Age groups I through III ha ; shown a marked and consistent upward trend and have grown 2.5 to 5 cms more in 1976 than in 1974. Adult age group IV and above display either no change or a slight downward trend in growth rate.

The largemouth bass (Figure 12) displayed large deviations in age class growth rates; the two year old fish grew only 5 cms during 1973, but in 1976 a two year old bass grew nearly 15 cms in one year--a 300 percent increase over 1973. The youngest age class appears to have an overall upward trend since 1967; this may be due to the introduction and establishment of threadfin shad.

The first two age classes of the white bass (Figure 13) followed each other very closely each year until a sharp division in growth occurred in 1975 to 1976, with the first age class increasing by 5 cms, and the second age class decreasing by 5 cms. The reasons for this divergence is unknown. Older classes essentially remain unchanged.

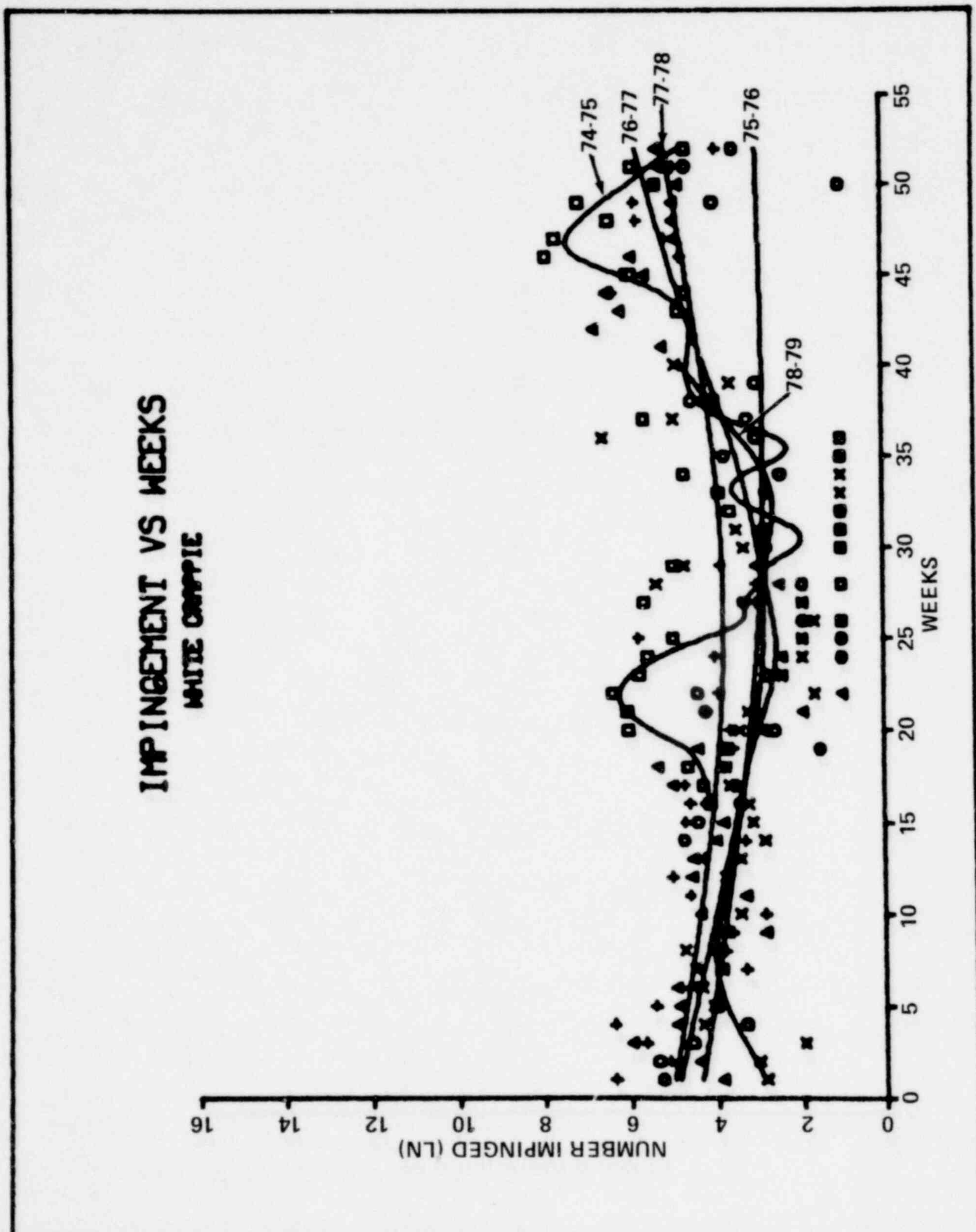

FIGURE 8

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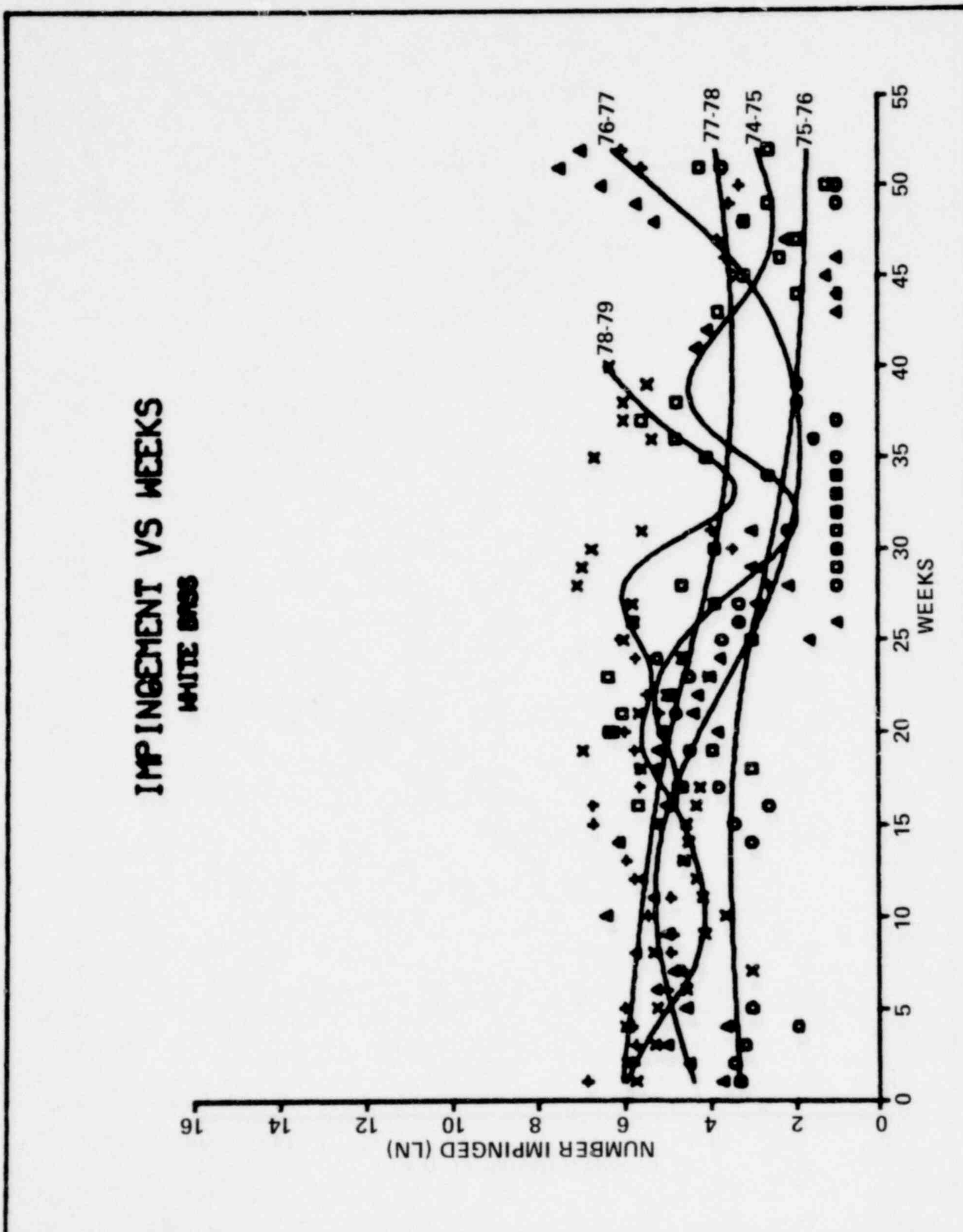
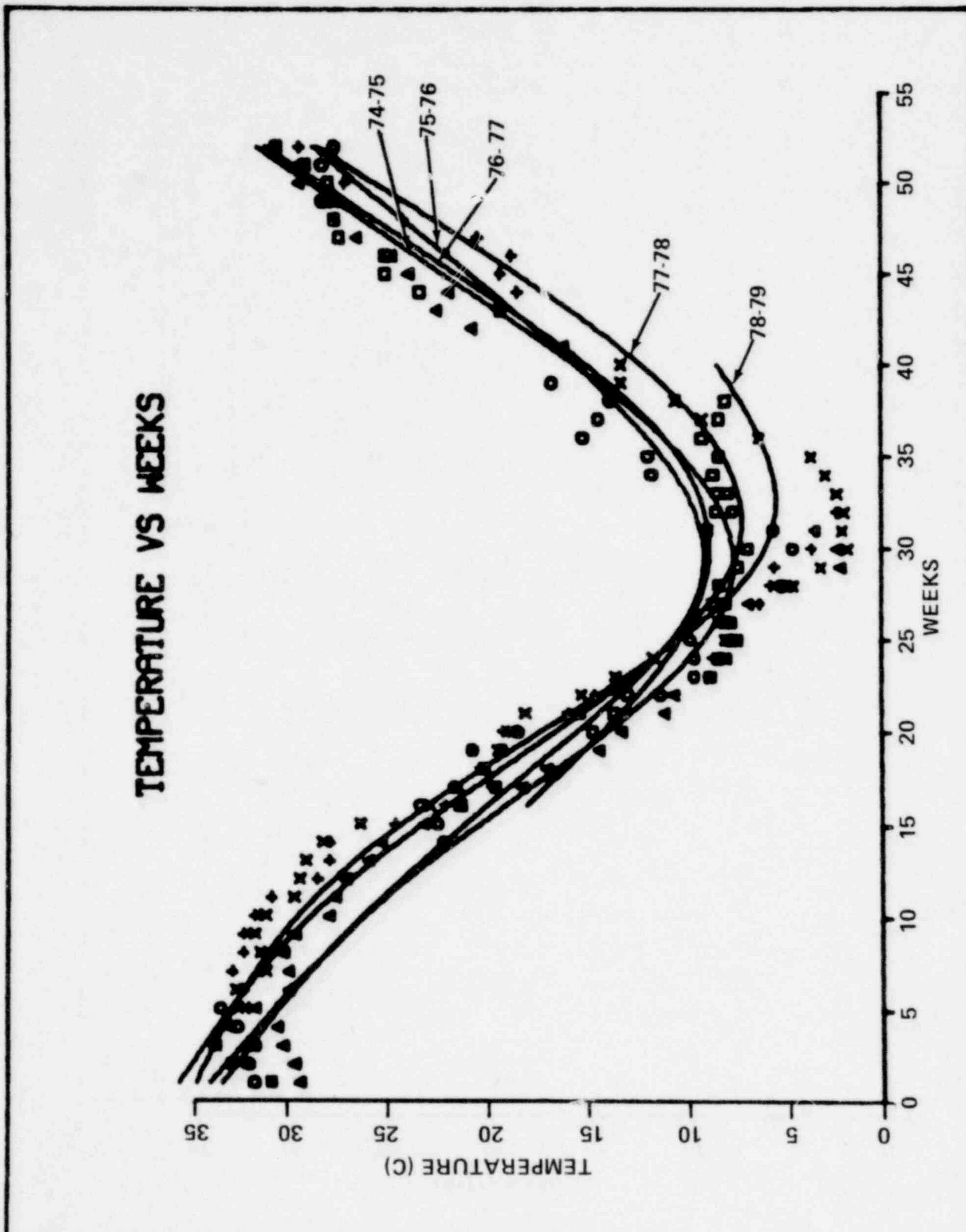


IMPINGEMENT VS WEEKS
WHITE BASS
NUMBER IMPINGED (LN)
WEEKS
76-77
77-78
74-75
75-76
78-79

FIGURE 9



TEMPERATURE VS WEEKS
TEMPERATURE (C)
WEEKS
74-75
75-76
76-77
77-78
78-79
0
5
10
15
20
25
30
35
40
45
50
55

FIGURE 10

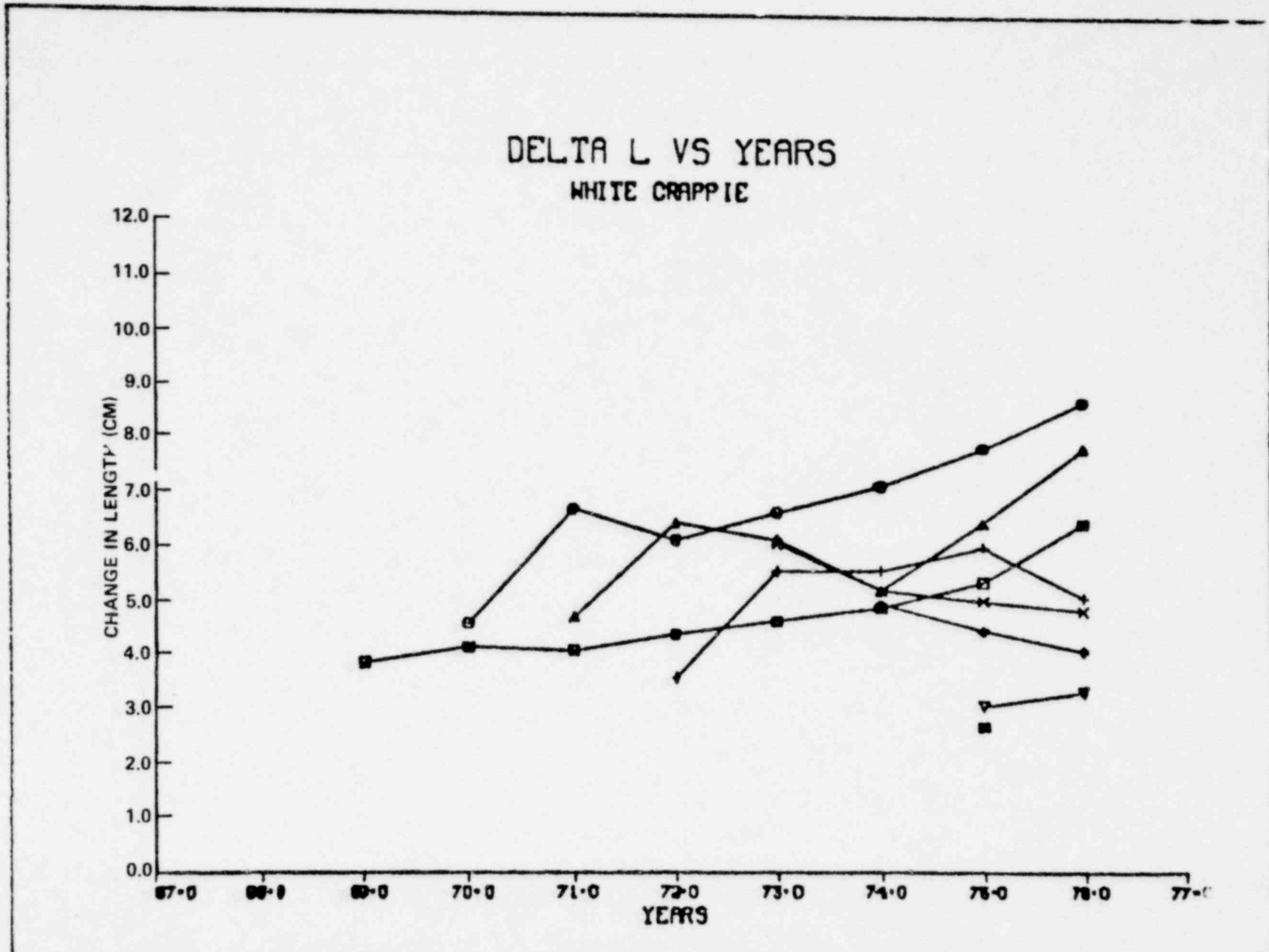


FIGURE 11

1373 247

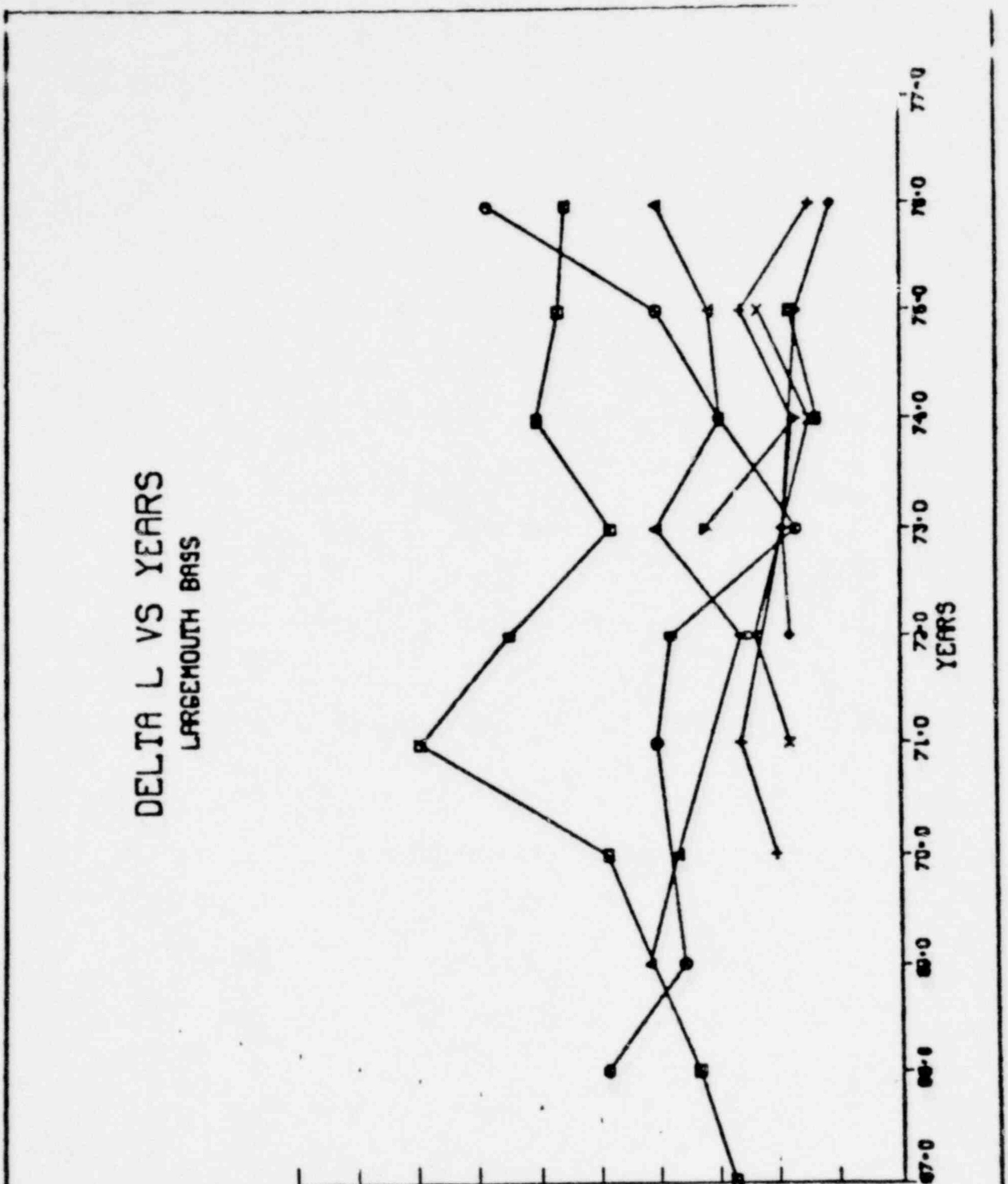

DELTA L VS YEARS
LARGEMOUTH BASS
CHANGE IN LENGTH (CM)
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
67.0
69.0
70.0
71.0
72.0
73.0
74.0
75.0
76.0
77.0
YEARS

FIGURE 12

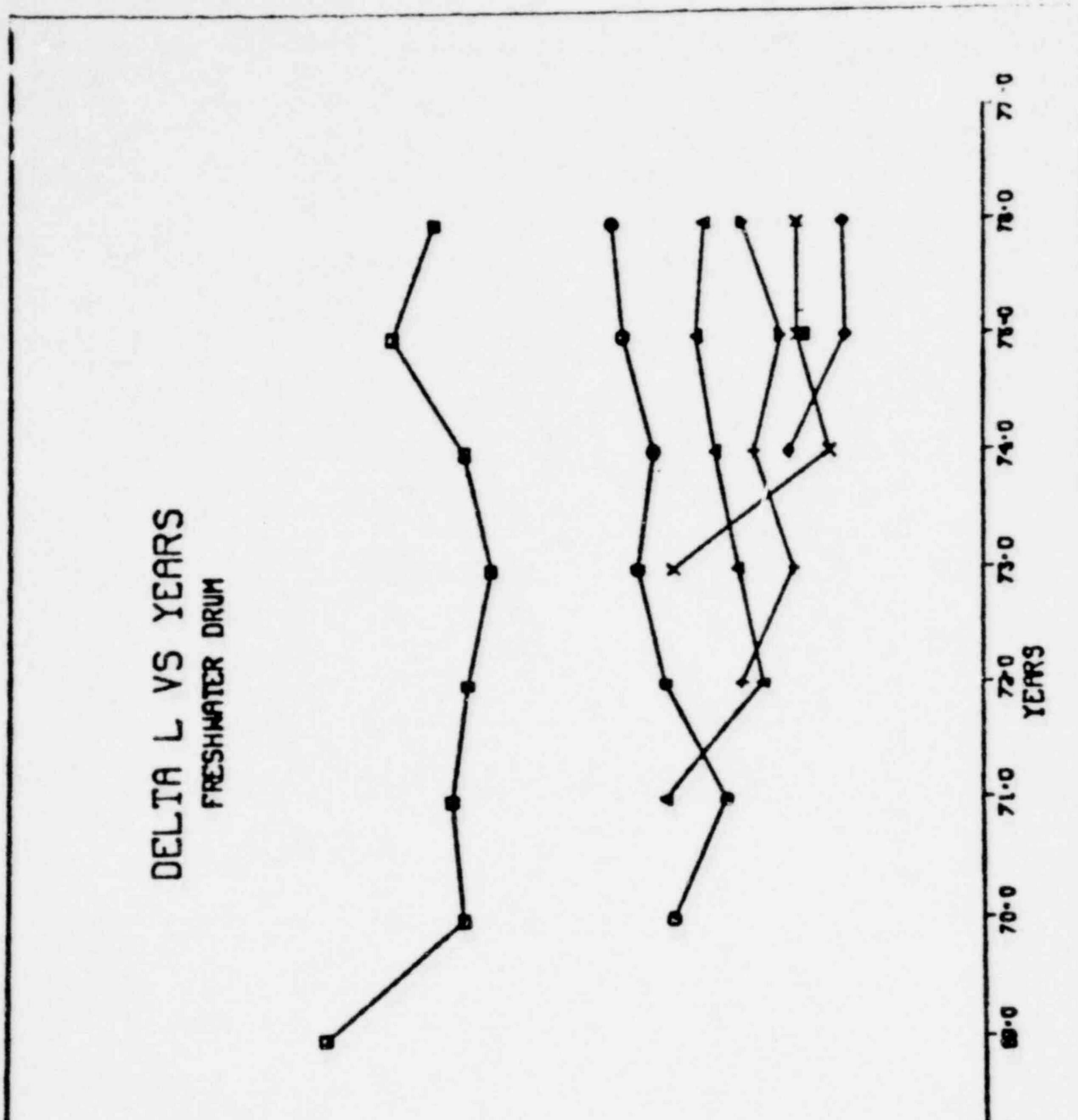

DELTA L VS YEARS
FRESHWATER DRUM
CHANGE IN LENGTH (CM)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
YEARS
67.0
70.0
71.0
72.0
73.0
74.0
75.0
76.0
77.0

FIGURE 13

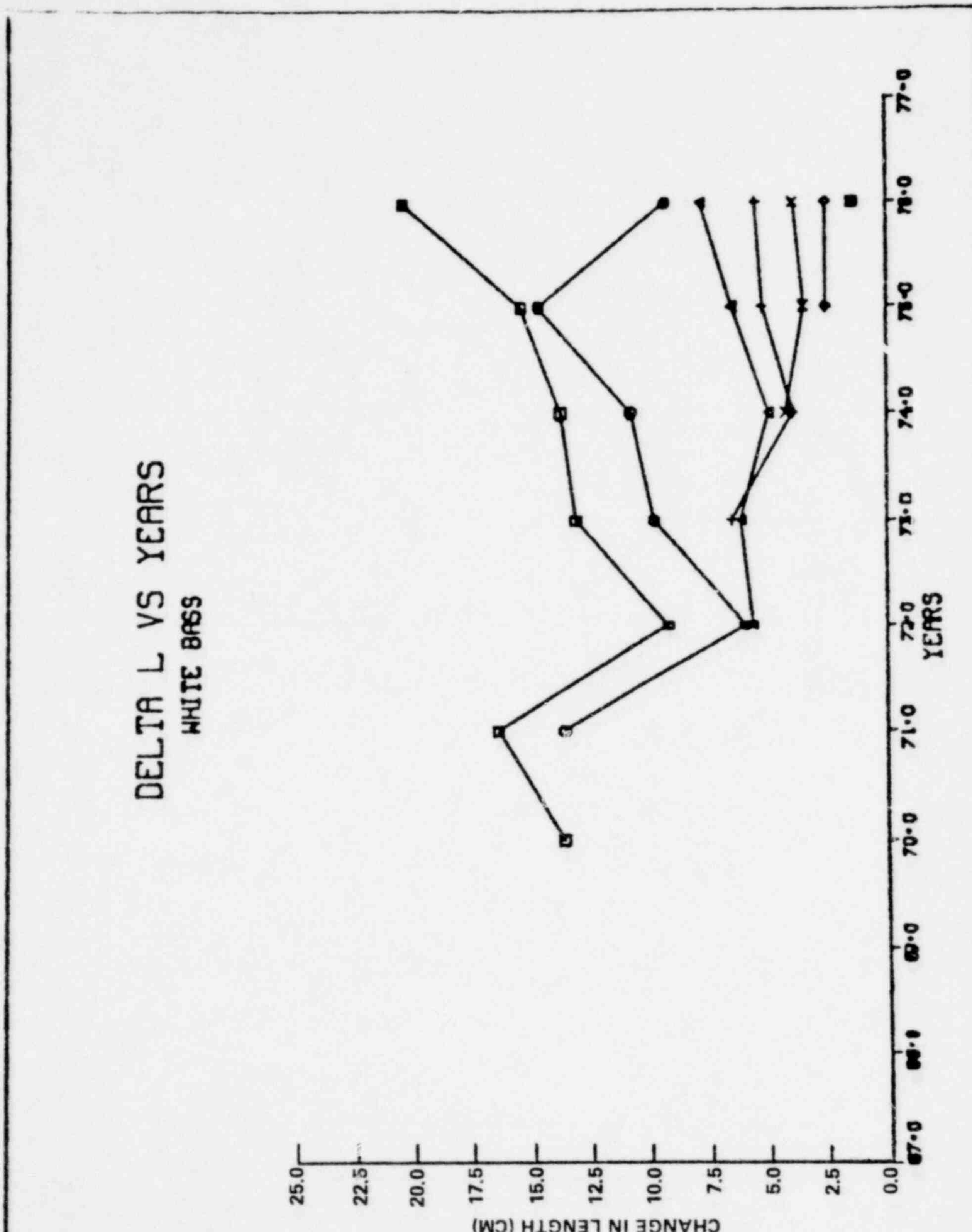

DELTA L VS YEARS
WHITE BASS
CHANGE IN LENGTH (CM)
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
YEARS
70.0
71.0
72.0
73.0
74.0
75.0
76.0
77.0

FIGURE 14

DISCUSSION

Between September 1974 and March 1979, 98 percent of the 64 million fish impinged on the cooling water screens at ANO were gizzard and threadfin shad. The overall impingement trends at ANO were due to the dominance of these two species in the impingement samples. Cold stress effects on these species have been documented in the literature. Since an ANOVA only established the significance of temperature on impingement rates, the effects of cold stress on both the threadfin and gizzard shad were re-examined. Griffith (1978) stated that it was the final low temperature, not the magnitude of the drop or the past thermal history of the fish, that is responsible for the death of threadfin. Results of examination of the severity of a winter as indicated by the minimum temperature attained in that winter are listed in Table V. The temperatures used were the weekly average inlet temperature to the condenser system. The week in which the temperature first averaged below 16°C (60°F) was used as the beginning of the analysis. The choice of the 16°C (60°F) temperature as a starting point is arbitrary; no significantly different results were obtained in a sensitivity study (Hoelzer, 1978) performed using alternate temperature choices. The number of weeks in which the average weekly intake water temperature was less than 12°C (54°F) before either plant shutdown for refueling in the early spring or intake temperature returned to 16°C (60°F) is presented in the second to last column of table Vi. This temperature of 12°C (54°F) was that point at which threadfin began to experience stress in the results reported by Griffith and Tomljanovich (1975). The last column lists the number of weeks that the temperature dropped below 5°C (41°F), the temperature at which threadfin shad exhibited 100 percent mortality in laboratory studies (Griffith

TABLE VI

NUMBER OF "DEGREE WEEKS" BELOW SELECTED CRUCIAL TEMPERATURES BY WINTERS FOR THREADFIN SHAD

Winter	Weeks Span*	<16C (<60F)	<12C (<54F)	<5C (<40F)
74 - 75	46 → 12	19	18	0
75 - 76	47 → 13	19	14	4
76 - 77	44 → 5	14	12	4
77 - 78	47 → 6	12	10	4
78 - 79	48 → 14	19	18	8

*Weeks are numbered sequentially starting from the beginning of the year. 46 denotes the 46th week of 1974. The time period begins at the week where temperatures averaged less than 16°C (60°F) and ends when the plant either shuts down for maintenance, or the water temperature returns to 16°C.

and Tomljanovich, 1975). Relating the last column of Table VI back to Table III, we note that the 1974-75 impingement year showed the highest impingement of threadfin shad. The winter of 1974, was also the least severe winter of those studied. The winters of 1975 through 1978 were all colder and intake water temperature was below the reported lethal temperature threshold.

In a study by Cox and Coutant (1976) only a 10% mortality was indicated for gizzard shad when cold shocked at temperatures of 6 to 7°C (43 to 45°F). In the 1978-79 winter however, temperatures at the ANO intake reached 0°C (32°F), and subsequent impingement of gizzard shad occurred at levels equivalent to those of threadfin shad in the 1974-75 winter. On February 9, 1975, 1.5 million threadfin shad were impinged at a mean water temperature of 6.7°C (44°F); on February 29, 1979, 1.1 million gizzard shad were impinged after exposure to sustained mean water temperatures of 0°C (32°F), and no threadfin were impinged. Until plant shutdown at the end of March, 1979, gizzard shad continued to be impinged at levels similar to those of threadfin impingement in 1975.

These similar impingement trends at specific temperatures suggests that impingement of each of these species is directly related to a cold-stress temperature threshold. Assuming a similar population sizes from year to year, when the temperature drops below this species-specific threshold impingement increases by orders of magnitude. The graph of the number of gizzard shad impinged each year (Table VII) versus the minimum temperature is shown in Figure 15. Above .5°C (33°F), gizzard shad were impinged at similar levels each year; below

.5°C (33°F), impingement increased by an order of magnitude, indicating a possible temperature threshold between .5 and 0°C (33 and 32°F) as measured at the intake. Impingement levels of gizzard shad prior to 1978-79 were only 4-10% of the 1978-79 level; this supports Cox and Coutant's research suggesting small percentage mortality above a lethal cold-stress threshold.

The threadfin shad suffers cold stress at higher temperatures. For all years of study, minimum temperatures were below the threshold stress temperatures suggested by Griffith and Tomljanovich (1975) for threadfin shad, and in some cases dropped below the suggested threadfin shad lower lethal temperature of 5.0°C (41°F). As speculated by Houser (pers. comm. 1975) the mild 1974 winter at ANO resulted in water temperatures that were never quite cold enough to produce mass mortality, so rather than massive kills the threadfin remained in the disequilibrated state for some time providing a large available disoriented population for extended periods of time unable to resist the intake current flow, and thereby causing extremely high impingement. In the next three winters however, as water temperatures dropped down below the suspected lethal temperature of 4.5°C (40.1°F) the threadfin rapidly suffered cold stress, died, and probably sank to the bottom where they decomposed. The ultimate fate of threadfin shad that died in TVA reservoirs due to cold stress was investigated by McLean et al. (1979). Significantly fewer threadfin were impinged probably because there were fewer left alive early in the season in the reservoir because of cold stress mortalities. Imp ngement increases as temperature decreases but the total number of threadfin impinged is dependent on the number of weeks threadfin shad are cold stressed while temperatures

TABLE VII

COMPARISON OF MINIMUM AVERAGE WINTER WATER TEMPERATURES AND TOTAL IMPINGEMENT ESTIMATES FOR GIZZARD SHAD DURING THE INDICATED WEEKS

Winter	Weeks Span T<16°C	# Impinged	Minimum Temperature
1974 - 75	46 - 12	1,300,000	5.5°C (42°F)
1975 - 76	47 - 13	76,000	3.3°C (38°F)
1976 - 77	44 - 5	420,000	.5°C (33°F)
1977 - 78	47 - 6	485,000	1.1°C (34°F)
1978 - 79	48 - 14	23,000,000	0.0°C (32°F)

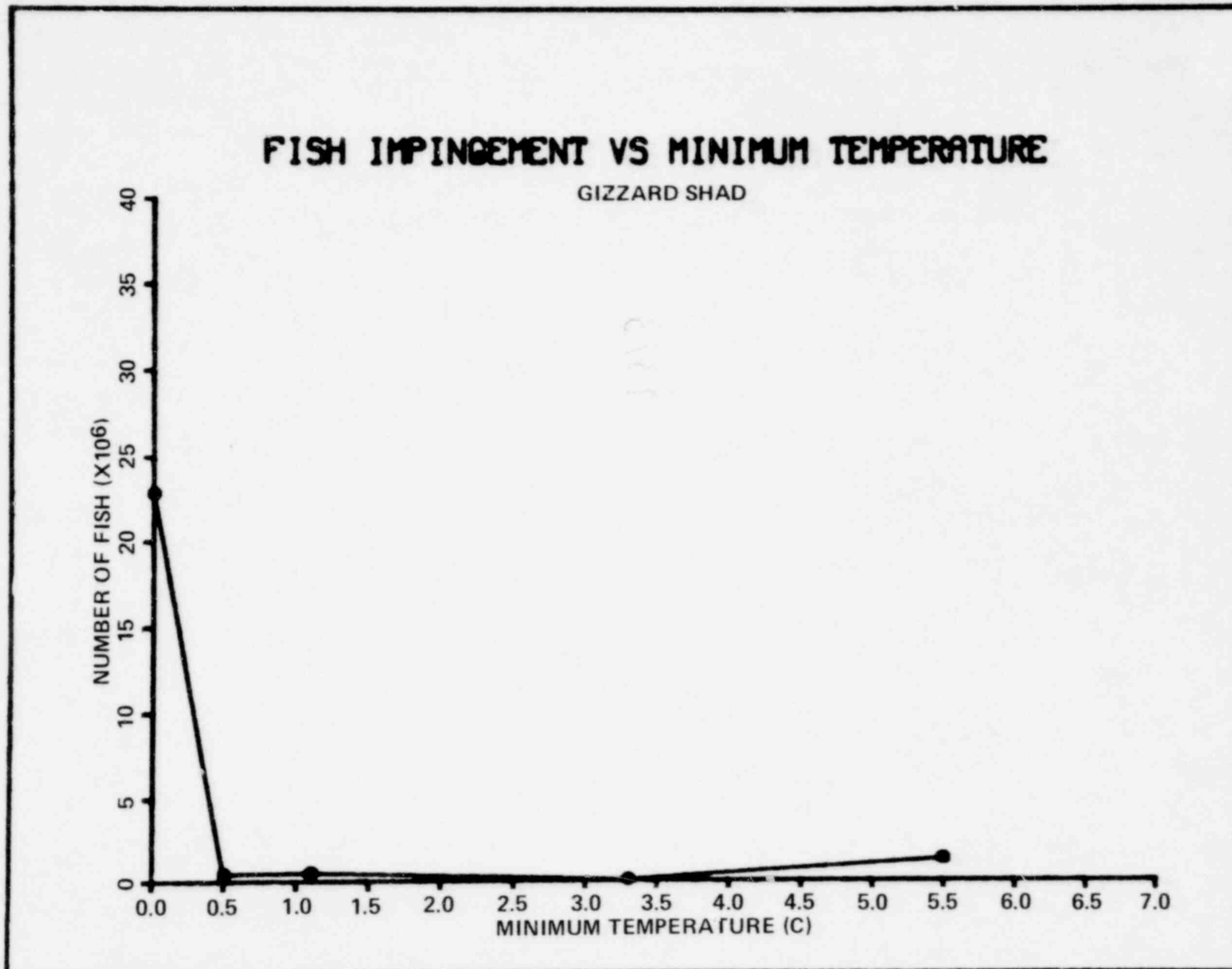

FISH IMPINGEMENT VS MINIMUM TEMPERATURE
GIZZARD SHAD
NUMBER OF FISH (X10^6)
0
5
10
15
20
25
30
35
40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
MINIMUM TEMPERATURE (C)

FIGURE 15

remained above the lethal threshold temperature. Findings of this study indicate the lower lethal threshold temperature for of Dorosoma petenense is between 3.3 - 5.5°C (38-42°F) as measured at the station intake.

Attempts were made to correlate yearly impingement losses with the number of weeks in which the weekly intake water temperature averaged below the cold-stress temperature threshold and above the lower lethal temperature. The use of an unweighted average weekly water temperature, the imprecision as to the actual cold-stress and lower lethal temperature values, and the difficulties associated with the inclusion of data from periods below the cold-stress temperature and above the lower lethal temperature once the lower lethal temperature had been reached or exceeded made the decision to include or reject specific weeks of impingement data arbitrary. It became apparent that meaningful conclusion drawn from such an analysis would be extremely suspect. Because of Griffith's (1978) study suggesting that the extent of mortality sustained by the threadfin shad population is dependent on the final low temperature and the observed similarity of the reservoir yearly water temperature curves, an attempt was made to correlate average minimum weekly water temperature that occurred in an impingement year with the number of threadfin shad impinged during that year.

Table VIII lists the number of threadfin impinged for the winters 1975 through 1978 as a function of minimum average weekly water temperatures. These data were plotted in Figure 16, and show an exponential relationship. This impingement-temperature relationship was graphed in Figure 17, with the natural log of the minimum temperature as a function of the number of threadfin impinged.

TABLE VIII

COMPARISON OF MINIMUM AVERAGE WINTER WATER TEMPERATURES AND TOTAL IMPINGEMENT ESTIMATES FOR THE THREADFIN SHAD DURING THE INDICATED WEEKS

Winter	Weeks Span T<16°C	# Impinged	(Minimum) Temperature
1974 - 75	46 - 12	25.2×10^6	5.5°C (42°F)
1975 - 76	47 - 13	5.55×10^6	3.3°C (38°F)
1976 - 77	44 - 5	2.33×10^6	.5°C (33°F)
1977 - 78	47 - 6	3.83×10^6	1.1°C (34°F)
1978 - 79	48 - 14	$.12 \times 10^6$	0.0°C (32°F)

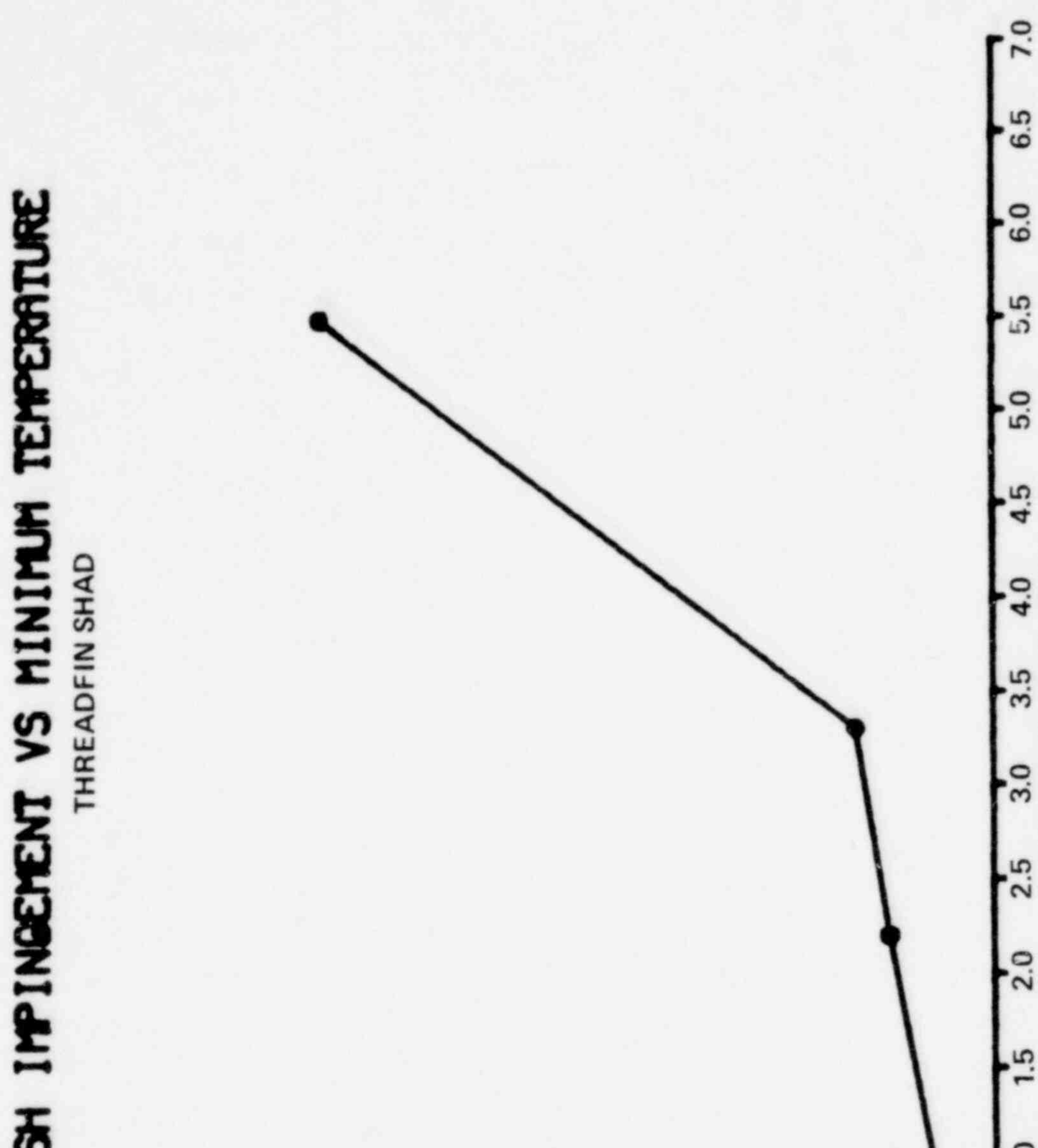

FISH IMPINGEMENT VS MINIMUM TEMPERATURE
THREADFIN SHAD
NUMBER OF FISH (X106)
0
5
10
15
20
25
30
35
40
MINIMUM TEMPERATURE (C)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0

FIGURE 16

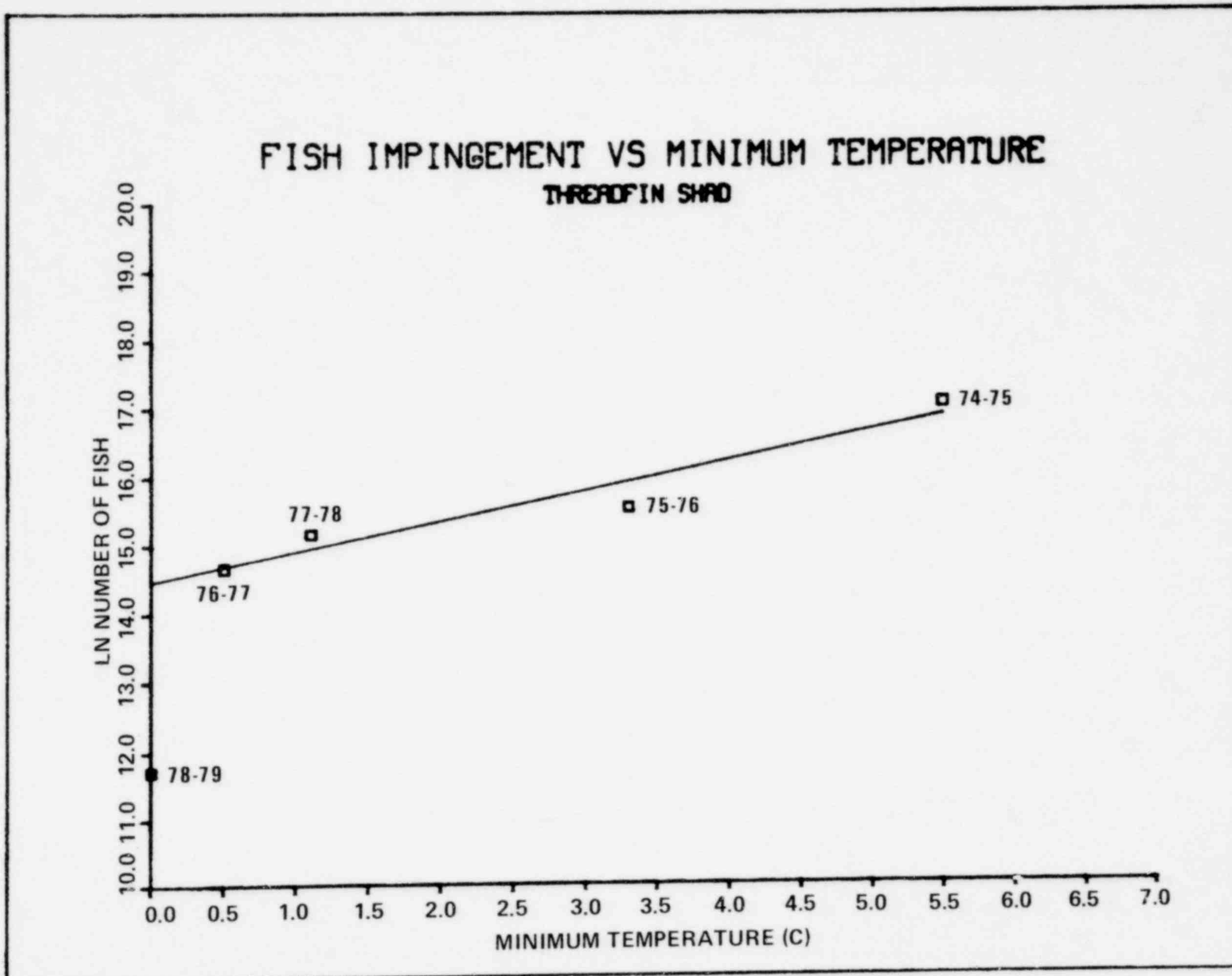

FISH IMPINGEMENT VS MINIMUM TEMPERATURE
THREADFIN SHAD
LN NUMBER OF FISH
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
78-79
76-77
77-78
75-76
74-75
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
MINIMUM TEMPERATURE (C)

FIGURE 17

The resultant relationship depicts the effect of low temperatures on impingement and establishes a firm basis for the belief that the relationship was exponential.

From this line, an equation relating temperature and impingement has been developed using impingement data prior to the 1978-79 winter:

$$N = 1.92 \times 10^6 e^{.43T}$$

Where: N = No. of fish impinged

T = Minimum Temperature (°C)

for $0.5 \leq T \leq 5.5$

A linear least squares regression analysis provide a R^2 correlation of .965. This relationship is believed to be valid for years when (1) the minimum temperature is below approximately 5.5°C (42°F), (2) ANO does not stop operation before the threadfin impingement has reached a minimum after high winter impingement, and (3) the population of threadfin in the reservoir is abundant from year to year. It is suspected that the true curve is S shaped, providing an upper and lower value to changes in impingement regardless of the minimum temperature attained; there will be fish impinged even as the water cools to 0°C (32°F), and it is intuitive if the minimum temperature is above 5.5°C (42°F) impingement would not continue to increase exponentially since the population is finite, and the fish are not stressed above 12°C (54°F).

The data for 1978-1979 is not included because the hypothesis for the relationship is based on the condition that threadfin exist in the lake in abundance.

Impingement of threadfin shad in the fall of 1978 was at least two orders of magnitude less than impingement in previous years. Although large fluctations in rotenone samples (used for population estimates by the Arkansas Fish and Game Commission) were observed during the years 1974 to 1977, only a total of only 13 threadfin shad were found in 1978 samples versus an average of 23,905 (range 978-48,616) based on samples from 1974 to 1977 (Tatum, 1979a).

Bluegill were impinged in significantly larger numbers in early 1979 coincident with the lowest water temperatures recorded at the intake. An estimated 21,400 bluegill were impinged in 1979 versus an average of 2,500 for the previous years (Table IIA). The causes of the increased impingement are presently unclear, although temperature effects and population size are suspect.

The analyses of impingement trends in the other species of fish were also inconclusive. Temperature effects were significant in the examination of all species ($F < 0.002$) except the channel catfish ($F = 0.128$). The inability to explain variation may be due to masking by threadfin shad. Although changes in impingement levels were discernable and were noted, it is unclear at this time why these changes have occurred.

Far field analysis was used to examine fish growth for possible trends in predator species growth patterns caused by changing impingement patterns of the prey shad species. Far field data did not indicate a significant change in age growth relationships--with a possible exception in the white crappie, <u>Pomoxis annularis</u>, which showed increased growth in age classes 1 to 3, and decreased growth in older age classes. It is concluded from the age and growth data that the four predator species studied here have not experienced any detectable deleterious effects as a result of the initially observed high shad impingement rates.

From the results of the impingement data, we can speculate on the past history and relative fate of the fisheries for threadfin and gizzard shad. These two species occupy similar ecological niches. Since the introduction of threadfin, the population of the native gizzard shad appears to have initially declined (Tatum, 1979b) perhaps because of the success of threadfin shad in the reservoir. Recent successive unusually cold winters have severely affected both species of shad, and probably selected for gizzard shad, the more cold resistant species. The decline of threadfin in Lake Dardanelle is typical of the threadfin populations in surrounding waterbodies (Tatum, 1979b) and is reflected in impingement estimates. During the years 1977 to 1979, the impingement of threadfin declined from 94 to 0.43 percent of the yearly estimates (Table II). Impingement estimates of gizzard shad have increased from an average of 4 percent of the total number impinged during 1974-76 to 98 percent in 1979 (Table II). The two orders-of-magnitude increase in the number impinged is disproportionate to a much smaller increase in population size exhibited in rotenone studies. The average number of gizzard shad collected in the rotenone samples in 1974-1977 was 9,250 with a range of 3,236 to 15,417. In 1978 a total of 24,847 gizzard shad were collected in the rotenone samples indicating an increase in the lake population. As discussed earlier, the rotenone survey data also indicated a reduction in the lake population of threadfin shad.

It appears that the size of the threadfin shad population in Lake Dardanelle is partially controlled by the density-independent factor of minimum water temperature attained in the lake and that the size of the threadfin population is in some way controlling the population size of gizzard shad. However, in the 1978-79 impingement year, the minimum water temperature attained in the lake was low enough to induce widespread cold shock mortality among the gizzard shad as well. Therefore, high impingement rates for gizzard shad were also observed.

Even though it is suggested that the population size of gizzard shad has increased primarily because of the succession of unusually cold winters and the resulting reduction of the threadfin population, the increase in impingement mortality to gizzard shad is much greater than would be expected due to the minor increase in the lake population that was indicated in the rotenone study. In 1979 during the late fall when lake water temperatures were dropping, the weekly rate of impingement of gizzard shad began to increase. This increase was comparable to the typical late fall increase in weekly impingement rate for gizzard shad (Figure 3). Once the lower threshold temperature was reached (between .5 and 0°C) the rate of impingement increased significantly. The weekly rate prior to reaching the threshold temperature was approximately 10% of the weekly rate after reaching and dropping below the threshold. This supports the 10% mortality figures determined in the laboratory by Cox and Coutant (1976).

It is concluded that the large impingement estimates of gizzard shad in 1979 was caused by cold stress mortalities induced by the extremely low temperatures.

It is suggested that the populations of the two species will continue to fluctuate, the threadfin shad in response to the density-independent factor of minimum water temperature attained in the lake, and the gizzard shad additionally to the density of threadfin.

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APPENDIX

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Hierarchy of Symbols used in Graphs

1 - □

2 - ○

3 - △

4 - +

5 - ×

6 - ◇

7 - ⊠

8 - ✳

9 - ◈

10 - ⊕

NRC FORM 335 (7-77) U.S. NUCLEAR REGULATORY COMMISSION **BIBLIOGRAPHIC DATA SHEET**	1. REPORT NUMBER (Assigned by DDC) NUREG-0601
4. TITLE AND SUBTITLE (Add Volume No., if appropriate) Impingement Dynamics and Age and Growth of Selected Species at Lake Dardanelle, a Southcentral Reservoir	2. (Leave blank)
	3. RECIPIENT'S ACCESSION NO.
7. AUTHOR(S) Bruce E. Logan and Michael T. Masnik	5. DATE REPORT COMPLETED MONTH September YEAR 1979
9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) Environmental Specialists Branch, P-234 Division of Site Safety and Environmental Analysis U.S. Nuclear Regulatory Commission Washington, D. C. 20555	DATE REPORT ISSUED MONTH October YEAR 1979
	6. (Leave blank)
	8. (Leave blank)
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	11. CONTRACT NO.
13. TYPE OF REPORT Technical Report	PERIOD COVERED (Inclusive dates) 1974-1979
15. SUPPLEMENTARY NOTES	14. (Leave blank)

16. ABSTRACT (200 words or less)

Impingement data collected between 1974 and 1979 was analyzed and compared with four years of data from Arkansas Nuclear One located on Lake Dardanelle, a southcentral run-of-the-river reservoir. Dorosoma petenense, D. cepedianum, Ictalurus punctatus, Lepomis macrochirus, and several other recreationally or ecologically important species commonly found on the intake screen were chosen for comparison. Weekly natural log transformed impingement estimates were plotted, and yearly impingement estimates were determined over the five year period. An analysis of variance on the transformed weekly estimates of eight species of fish indicated the significance ($F < .002$) of temperature on impingement for seven species. Yearly impingement of D. petenense was found to be correlated ($R^2 = .965$) with the average minimum water temperature of the reservoir. The lethal temperature threshold (as recorded at the intake) was determined to be between 3.3 and 5.5 $^{\circ}C$ for D. petenense and 0.5 and $0^{\circ}C$ for D. cepedianum. Results of the impingement analysis were compared and contrasted with age and growth studies in the reservoir.

17. KEY WORDS AND DOCUMENT ANALYSIS — 17a. DESCRIPTORS

Dorosoma petenense
Dorosoma cepedianum
Impingement
Age-and-growth
Lake Dardanelle

1373 272

17b. IDENTIFIERS/OPEN-ENDED TERMS

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