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Forage Fish Populations and Growth of Muskellunge in a South Dakota Power Plant Cooling Reservoir

James R. Wahl

FORAGE FISH POPULATIONS AND GROWTH OF MUSKELLUNGE IN A SOUTH DAKOTA POWER PLANT COOLING RESERVOIR

BY

JAMES R. WAHL

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FORAGE FISH POPULATIONS AND GROWTH OF MUSKELLUNGE IN A SOUTH DAKOTA POWER PLANT COOLING RESERVOIR

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

Head, Wildlife and
Fisheries Sciences
Department

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FORAGE FISH POPULATIONS AND GROWTH OF MUSKELLUNGE IN A SOUTH DAKOTA POWER PLANT COOLING RESERVOIR

Abstract

James R. Wahl

The standing crop, age, growth, and impingement loss of forage fishes and the growth rate and impingement loss of muskellunge (<u>Esox masquinongy</u>) were studied to evaluate the use of the Big Stone Power Plant cooling reservoir as an area for rearing and holding muskellunge brood stock.

There were 18 species of forage fish present in the reservoir. Sampling indicated that there were 4 major forage fish species. Bluegills (<u>Lepomis macrochirus</u>) made up 68.3% of these species; tadpole madtoms (<u>Noturus gyrinus</u>), 25.8%; orangespotted sunfish (<u>L. humilis</u>), 3.6%; and black bullheads (<u>Ictalurus melas</u>), 2.3%. The estimated total standing crop of the 4 forage species was 28.1 kg/ha.

The 1974 year-class was the oldest present among the forage fishes. Most forage fish populations were dominated by age-groups I and II. The growth rates of forage fishes present in the reservoir were similar to those of natural waters in the northern United States.

Impingement of forage fishes was restricted predominately to young-of-the-year fishes, except during the winter months. An inverse relationship existed between impingement and monthly water temperature for adult bluegills. Higher impingement rates were

noted during evening samples, but only tadpole madtoms were impinged significantly ($P < .05$) more often at night. Muskellunge were most vulnerable to impingement during the first 2 months following their introduction.

Age-group II muskellunge captured in February and March attained a mean TL of 753 mm (700 to 785 mm, range) and age-group I muskellunge captured in February and March attained a mean TL of 465 mm (386 to 575 mm, range). The growth rate of muskellunge in the Big Stone Power Plant cooling reservoir was higher than those reported for populations throughout North America.

INTRODUCTION

This study was conducted to determine the standing crop, age, growth, and impingement loss of forage fishes in a power plant cooling reservoir. The growth rate and impingement loss of stocked muskellunge (*Esox masquinongy*) were also monitored.

In 1973 there were 46 power plants in the United States which utilized cooling ponds, lakes, or reservoirs as a method of power plant cooling (Metz 1977). This total represented 6% of all existing power plants. It has been estimated that by the year 2000 the figure will increase to 20% (Meredith 1973). Through proper power plant siting, cooling ponds, lakes, and reservoirs can assume a multi-purpose function. They can fulfill their primary role of being an artificial, open body of water which dissipates waste heat from power plants as well as serving numerous secondary functions (Metz 1977).

If adequate forage fishes of appropriate size are available, one such secondary function may be to rear and hold muskellunge brood stock. Muskellunge prefer soft-rayed fishes (Oehmcke et al. 1958; Karvelis 1965), but this probably depends on availability. Buss (1960) stated that little preference was shown by adult muskellunge for food; they generally fed on forage fishes that were most available.

The correct size forage at the appropriate time is an important factor. Fry feed on zooplankton initially, but live fish are essential for muskellunge over 38 mm long (Oehmcke et al. 1958). Hourston (1952) found that legal-size muskellunge in Canada ($\geq$ 762 mm fork length) preyed mainly on fish over 150 mm in length.

Rearing muskellunge in heated waters in the northern United States (e.g. thermal effluent from electric generating plants) may also increase the growing season and initiate earlier maturation. Parsons (1959) found that male muskellunge in Tennessee first matured at age III when they were 560 mm long and females at age III-IV when they were 635 mm long. In the cooler waters of Wisconsin muskellunge usually did not mature until age IV to VI (Oehmcke et al. 1958).

The use of a power plant cooling reservoir to rear fish may have drawbacks. Fish kills of muskellunge and forage fishes due to intake screen impingement is a concern. Some investigators have suggested that losses due to impingement may represent a potentially significant impact on existing fisheries (Edsall and Yocom 1972). Others have indicated that impingement does not represent a significant loss to fish populations (Latvaitis et al. 1976; and Mathur et al. 1977).

STUDY AREA

The Big Stone Power Plant and cooling reservoir, owned jointly by Montana-Dakota Utilities Company, Northwestern Public Service Company, and Otter Tail Power Company is located in Grant County, South Dakota. The cooling reservoir was completed in 1972. Water was pumped into the reservoir from nearby Big Stone Lake, located on the South Dakota-Minnesota border. The Big Stone Power Plant, a coal-fired 440 MW steam electric generating facility, became operational in May 1975. The cooling reservoir has a surface area of 145 ha, maximum depth of 10 m, and mean depth of 2.6 m at a water level of 341.1 m above mean sea level (msl) (Fig. 1). The water level fluctuated from a high of 342.0 m to a low of 340.1 m above msl during this study. As water evaporated from the cooling reservoir additional water was pumped from Big Stone Lake.

Cooling water for the power plant is provided by 2 pumps with a total capacity of 8.64 m^3/s. The intake is protected from large debris by vertical steel trash racks. Behind the trash racks are 2 vertical traveling screens of 10 mm mesh. The screens rotate vertically past a jet water spray which dislodges fish and debris into a sluiceway. At the end of the sluiceway the fish are held in a collection basket.

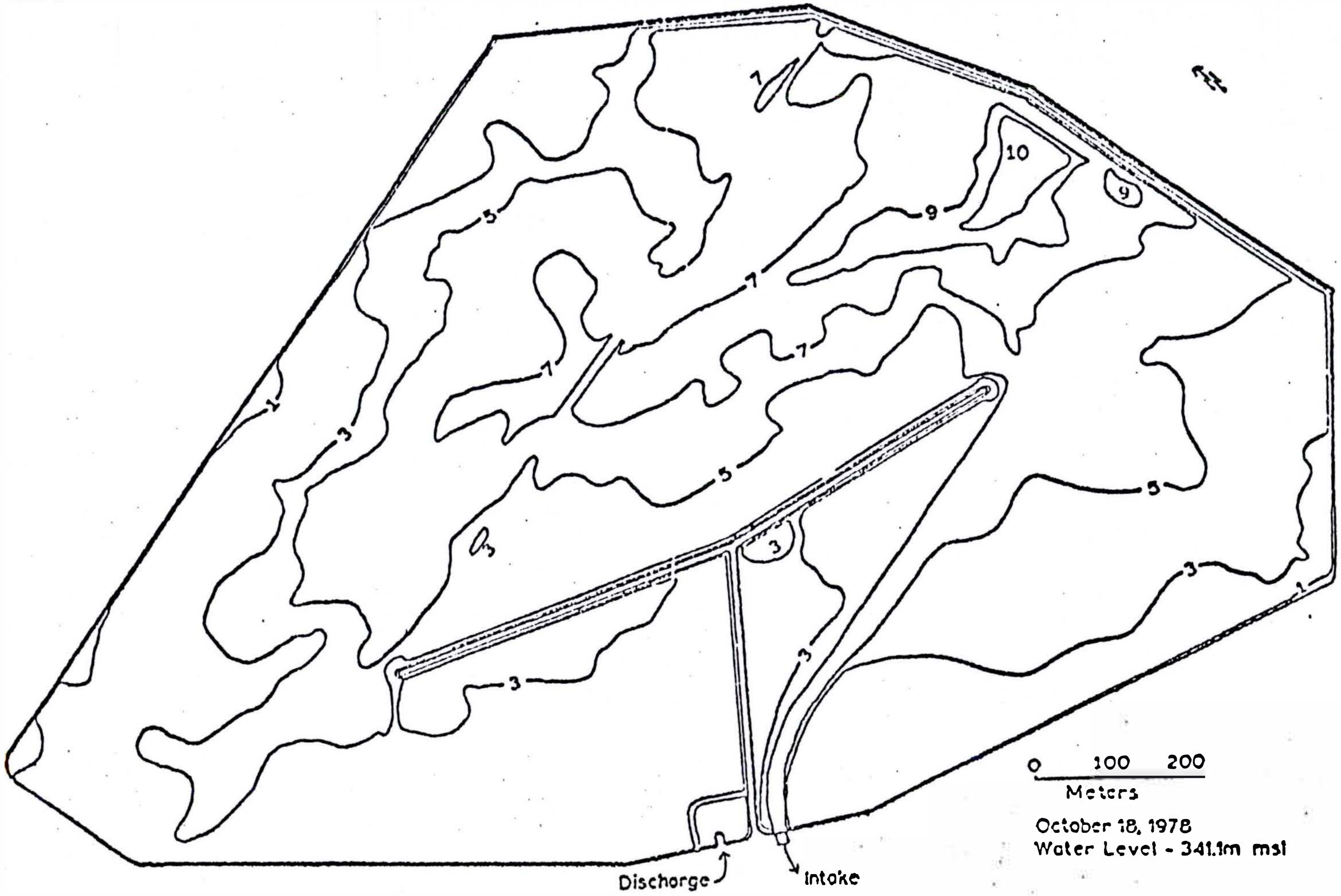

Fig. 1. Big Stone Power Plant cooling reservoir, South Dakota, with depth contours shown at a level of 341.1 m above mean sea level.

MATERIALS AND METHODS

Population Estimate of Forage Fishes

A mark and recapture population estimate of the forage fishes was conducted during a 6 wk period (21 May - 1 July 1979). Fishes were captured with 6 single lead, 1.2 m x 22.9 m, South Dakota trap nets with two 1.2 m x 1.2 m aluminum frames and 2.54 cm stretched mesh. A 240-volt alternating current (A.C.) electrofishing boat was also used.

Six trap nets were placed in the reservoir and examined once every 24 h. The nets were moved to different areas of the reservoir each week to distribute the fishing effort. Electrofishing was conducted 3 times each week along shoreline areas of the reservoir for 40 to 80 min. Age-group I and older fishes were measured, marked by fin clipping one of the pelvic fins and released in the center of the reservoir.

Population estimates were derived using the modified-Schnabel equation, which is a multiple census formula. The equation:

$$\hat{N} = \frac{\Sigma\,(C_t M_t)}{\Sigma\, R + 1}$$

was used, where:

$\hat{N}$ = estimate of population density

C_t = total sample taken on day t

M_t = total marked fish at large at the start of the t^{th} day

R = total recaptures during the experiment (Ricker 1975).

Estimates derived from the equation are asymetrically distributed.

Confidence limits were calculated by treating the number of recaptures as a Poisson variable. Confidence coefficients at the 0.95 level were computed from:

$$1 - P = 0.95 \qquad \Sigma R + 1.92 \pm 1.96 \sqrt{\Sigma R + 1.0} \qquad \text{(Ricker 1975).}$$

Confidence coefficients were substituted for the sum of recaptures in the modified-Schnabel equation to obtain 0.95 confidence limits.

Age and Growth of Forage Fishes

Scale samples were taken from bluegills (*Lepomis macrochirus*), orangespotted sunfish (*L. humilis*), and yellow perch (*Perca flavescens*). Scales were removed from the side of the body below the origin of the dorsal fin and just below the lateral line (Lagler 1956). Scale impressions were made on acetate slides using a roller press (Smith 1954). The impressions were magnified 40X and projected with an Eberbach scale reader. Measurements from the focus to the anterior edge and distances to each annuli were obtained from the projected image.

The right pectoral spine was used for age and growth studies of black bullheads (*Ictalurus melas*) (Sneed 1951; Schoffman 1954; Marzolf 1955). Spines were removed by firmly grasping the articular end of the spine and rotating it in a counter-clockwise direction (Sneed 1951). A 6% solution of sodium hypochlorite (bleach) was used to remove the layer of skin that remained on the spines. Each spine was allowed to soak for approximately 5 min.

A Dremel Moto-tool equipped with a dental separating disc blade and mounted on a slicing device was used to section spines. Spines were sectioned at the distal end of the basal groove to avoid the possibility of omitting growth rings (Sneed 1951). Sections were placed in water on a glass slide and read with an Eberbach projector. Zones of growth appeared as translucent rings alternating with opaque bands. When distinct, the rings were regarded as annular marks. Measurements were made from the center of the lumen along the longest spine radius to each annulus.

The anterior trunk vertebrae were used for age and growth analysis of tadpole madtoms (Noturus gyrinus); madtom pectoral spines were too small and brittle to obtain a consistent spine section. The anterior end of the vertebral column was excised and the excess tissue removed. Growth rings are most sharply defined in the anterior trunk vertebrae (Hooper 1949). The removed vertebral portion was soaked in 6% sodium hypochlorite for approximately 1 h. This cleaned the vertebrae but did not disarticulate them. The first 5 vertebrae were disjointed after drying, which usually left the centrum smooth and clean.

The disjointed vertebrae were placed in a Sedgewick-Rafter cell and read with a 5X magnification compound microscope. Growth during the winter was represented by dark translucent bands alternating with broad white, opaque growth bands that were formed in the summer (Lewis 1949). Measurements were made from the center to the edge of the vertebra with a calibrated Whipple disc.

Body-scale relationships, back calculations of growth rates, condition factor K(TL), and the length-weight relationships were computed with the aid of the SHAD computer program for computation of fish age and growth statistics (Mayhew 1970).

Impingement of Forage Fishes

Fish samples at intake screens were collected 1 day each week from 17 January 1979 through 10 January 1980, except from 22 May to 1 July when impinged fishes were sampled daily. Impinged fishes were collected during 3 successive 8 h periods (night 0200 h; morning 1000 h; day 1800 h) on each of the days sampled. Fishes which accumulated in the basket at the end of 8 h constituted a sample.

Fishes were identified, measured, and weighed. Total number and length were estimated from a random subsample (100 fish) when young-of-the-year bluegills and orangespotted sunfish were impinged (more than 500 fish). The following data were recorded with each sample: intake water temperature, reservoir water level, time of day, and date.

The relationship between the number of fishes impinged and physical factors (intake temperature and water level) was examined by linear correlation. The correlation coefficient provides information on how closely 2 variables are related, but does not imply a cause and effect relationship (Bazigos 1974). The significance of the calculated correlation coefficient (r) was determined by a Student t-test at the 0.95 level (Zar 1974).

One-way analysis of variance was used to evaluate the effect time of collection had on the impingement of several species. Day (1000 h - 1800 h), night (1800 - 0200 h) and morning (0200 - 1000 h) served as treatments.

Impingement and Growth of Stocked Muskellunge

A total of 704 muskellunge (203 mm, mean TL) were stocked in the cooling reservoir on 9 August and 1 September 1978. In 1979 15,500 muskellunge (36 mm, mean TL) were stocked on 10 June, and 290 (137 mm, mean TL) were stocked on 2 August.

Intake screens were checked daily from August 1978 through March 1980 for muskellunge that had been impinged. Impinged muskellunge were measured and weighed, and then preserved in 10% formalin. Muskellunge were also collected on 3 January, 6 February and 7 and 15 March 1980 with a 1.8 m x 91.5 m, 2.54 cm bar mesh gill net. The gill net was used like a seine; it was extended perpendicular to the shore and the outer end moved in a wide arc back to the shore. The free end was then slowly pulled in. Captured muskellunge were weighed, measured, and released.

RESULTS AND DISCUSSION

Population Estimates of Forage Fishes

Sampling indicated that there were 4 major forage fish species (Table 1 and Appendix Tables 1 - 4). Bluegills made up 68.3% of these species; tadpole madtoms, 25.8%; orangespotted sunfish, 3.6%; and black bullheads, 2.3%. The estimated total standing crop of the 4 forage species was 28.1 kg/ha (Table 2). Sampling indicated that there were 14 other forage fishes present in the reservoir (Table 3). No population estimates were calculated for these species because of the low numbers of fish captured.

Bluegill

Bluegill were the dominate forage fish in the cooling reservoir. The population estimate for bluegills was 114,684 (100,777 to 130,985 95% C.I.) (Table 1). The standing crop was estimated at 20.0 kg/ha (17.8 lbs/acre) (Table 2). The estimated standing crop of bluegills in the present study was within the range (1.3 to 55.1 kg/ha) reported for other power plant cooling reservoirs in the United States (Table 4). Carlander (1955) reported an average bluegill standing crop of 33.8 kg/ha for 20 natural lakes in the northern United States. The standing crop in the present study was slightly lower than this, but well within the range that Carlander reported (0.2 to 126.8 kg/ha).

Tadpole Madtom

The second most abundant forage fish in the cooling reservoir was the tadpole madtom. The population estimate for tadpole madtoms

Table 1. Population estimates of the 4 major forage fishes in Big Stone Power Plant cooling reservoir, South Dakota, 1 July 1979.

Species	Total fish marked	Population estimate (N)	95% Confidence limits
Bluegill	6,763	114,684	100,777-130,985
Tadpole madtom	1,774	43,383	31,803-58,952
Orangespotted sunfish	450	6,092	3,924-9,334
Black bullhead	707	3,802	3,019-4,786

Table 2. Standing crop of the 4 major forage fishes in Big Stone Power Plant cooling reservoir, South Dakota, 1 July 1979.

	Standing crop			
Species	Fish/ha	95% Confidence limits	kg/ha	95% Confidence limits
Bluegill	791	695-903	20.0	17.6-22.8
Tadpole madtom	299	219-407	4.3	3.2-5.9
Orangespotted sunfish	42	27-64	0.4	0.3-0.6
Black bullhead	26	21-33	3.4	2.7-4.3
Total	1,158	962-1,407	28.1	23.8-33.6

Table 3. Forage fishes present in addition to the 4 major species found in Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Common name	Scientific name
Carp	(*Cyprinus carpio*)
Emerald shiner	(*Notropis atherinoides*)
Common shiner	(*Notropis cornutus*)
Spottail shiner	(*Notropis hudsonius*)
Fathead minnow	(*Pimephales promelas*)
White sucker	(*Catostomus commersoni*)
Yellow bullhead	(*Ictalurus natalis*)
Channel catfish	(*Ictalurus punctatus*)
Rock bass	(*Ambloplites rupestris*)
Pumpkinseed	(*Lepomis gibbosus*)
Black crappie	(*Pomoxis nigromaculatus*)
Johnny darter	(*Etheostoma nigrum*)
Yellow perch	(*Perca flavescens*)
Freshwater drum	(*Aplodinotus grunniens*)

Table 4. Standing crop of bluegills (Lepomis macrochirus) in Big Stone Power Plant cooling reservoir, South Dakota, and other power plant cooling reservoirs in the United States.

Location	Estimates derived by	Standing crop	
		Fish/ha	kg/ha
North Lake, Texas[a] (Yeh 1971)	mark and recovery	35	1.3
Lake Colorado City, Texas[a] (Follis 1976)	cove rotenone	3,731	31.3
Lake Nasworthy, Texas[a] (Yeh 1971)	mark and recovery	2,282	55.1[b]
Lake Bastrop, Texas[a] (Yeh 1971)	mark and recovery	833	51.7
Eagle Mountain Lake, Texas[a] (Smith 1977)	cove rotenone	-	6.9[b]
Striker Creek Reservoir, Texas[a] (Ryan 1976)	cove rotenone	414	4.4
Thomas Hill Reservoir, Missouri[a] (Hanson 1971)	cove rotenone	-	16.8
Big Stone Reservoir, South Dakota	mark and recovery	791	20.0

[a]Data from Becker et al. (1979).

[b]Mean value of range.

was 43,383 (31,803 to 58,952 95% C.I.) (Table 1). The standing crop was estimated at 4.3 kg/ha (3.8 lbs/acre) (Table 2). Hooper (1949) reported a standing crop of 7.9 kg/ha in a Minnesota lake in which tadpole madtoms were the dominant species.

Orangespotted Sunfish

The population estimate for orangespotted sunfish was 6,092 (3,924 to 9,334 95% C.I.) (Table 1). The standing crop was estimated at 0.42 kg/ha (0.37 lbs/acre) (Table 2). Orangespotted sunfish in 10 midwestern lakes averaged 0.9 kg/ha and ranged from 0.1 to 4.4 kg/ha (Carlander 1955).

Black Bullhead

The population estimate for black bullheads was 3,802 (3,019 to 4,786 95% C.I.) (Table 1). The standing crop was estimated at 3.4 kg/ha (3.0 lbs/acre) (Table 2). The estimated standing crop of black bullheads in the present study was higher than those reported for power plant cooling reservoirs in Texas (Table 5).

Age and Growth of Forage Fishes

Bluegill

A total of 331 bluegills were examined for age and growth. The length-weight relationship was described by the formula $\log W = -5.82 + 3.54 \log L$ ($r = 0.92$; $P < .005$). The condition factor was calculated for 9 length intervals and ranged from 1.56 to 2.60 (Table 6). K values increased as fish length increased. The average K factor was 1.99, which corresponds closely to the typical bluegill condition factor of 2.0 (Carlander 1953).

Table 5. Standing crop of black bullheads (Ictalurus melas) in Big Stone Power Plant cooling reservoir, South Dakota, and other power plant cooling reservoirs in the United States.

Location	Estimates derived by	Standing crop	
		Fish/ha	kg/ha
Lake Colorado City, Texas[a] (Follis 1976)	cove rotenone	66	2.1
Lake Nasworthy, Texas[a] (Yeh 1971)	mark and recovery	2	-
Striker Creek Reservoir, Texas[a] (Ryan 1976)	cove rotenone	1	0.11
Lake Bastrop, Texas[a] (Yeh 1971)	mark and recovery	9	-
Big Stone Reservoir, South Dakota	mark and recovery	26	3.4

[a]Data from Becker et al. (1979).

Table 6. Condition factor for 9 length intervals of bluegills (*Lepomis macrochirus*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Number	Length intervals (mm)	Number of fish	K(TL)
1	51 - 65	17	1.56
2	66 - 80	50	1.62
3	81 - 95	75	1.83
4	96 - 110	44	1.96
5	111 - 125	55	2.06
6	126 - 140	35	2.24
7	141 - 155	37	2.42
8	156 - 170	16	2.60
9	171 - 185	2	2.05

The body-scale relationship was described by the formula $L = 20.73 + 1.17S$ ($r = 0.998$; $P < .005$). Back calculations were made using this linear model. The weighted mean TL for bluegill at annuli I through V was 52, 99, 138, 156 and 174 mm, respectively (Table 7). Growth increments during the first 5 years of life were 52, 49, 30, 20 and 25 mm, respectively (Table 8). These increments indicated that the growth rate was high during the first 2 years of life and low in following years. Bluegills in the present study had a slightly higher growth rate than that reported for populations in 4 other cooling reservoirs in Texas (Table 9). Growth rate of bluegills in Big Stone cooling reservoir was similar to that of bluegills in other waters in the northern United States (Table 10).

The length-frequency of bluegills collected from 21 May to 27 May was plotted at 10 mm length intervals (Fig. 2). Two peaks occurred, one at the 80-89 mm interval and the other at the 120-129 mm interval. These peaks probably represented age-groups I and II and indicated their dominance in the overall population. Everhart et al. (1975) noted that determination of age by length-frequency was often adequate for the younger age-groups, but usually fails in reliable separation of the older age-groups because of increasing overlap in length distribution.

Tadpole Madtom

A total of 51 tadpole madtoms were examined for age and growth. The length-weight relationship was described by the formula $\log W = -4.14 + 2.72 \log L$ ($r = 0.88$; $P < .005$). The condition factor was

Table 7. Back-calculated total lengths (mm) of bluegills (*Lepomis macrochirus*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Year-class	Age-group	Number of fish	Annulus 1	2	3	4	5
1978	I	175	54.2				
1977	II	123	50.6	96.1			
1976	III	28	45.7	108.6	138.5		
1975	IV	3	55.4	110.8	140.1	158.0	
1974	V	1	48.8	99.1	124.9	149.4	174.0
	Weighted mean		52.1	98.7	138.2	155.9	174.0

Table 8. Back-calculated growth increments (mm) of bluegills (*Lepomis macrochirus*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Year-class	Age-group	Number of fish	Annulus 1	2	3	4	5
1978	I	175	54.2				
1977	II	123	50.6	45.2			
1976	III	28	45.7	63.0	29.9		
1975	IV	3	55.4	55.4	29.2	17.9	
1974	V	1	48.8	50.3	25.7	24.6	24.6
	Weighted mean		52.1	48.9	29.7	19.6	24.6

Table 9. Back-calculated total lengths (mm) of bluegills (*Lepomis macrochirus*) in Big Stone Power Plant cooling reservoir, South Dakota, and 4 other cooling reservoirs in Texas.

Location	Number of fish	Annulus 1	2	3	4	5
Lake Bastrop (Serns and Strawn 1975)	196	57	91	116		
Lake Nasworthy (Serns and Strawn 1975)	602	62	97	122	140	
Lake Colorado City (Serns and Strawn 1975)	123	53	91	122	141	166
North Lake (Serns and Strawn 1975)	236	39	77	111	141	159
Big Stone Reservoir, (South Dakota)	330	52	99	138	156	174

Table 10. Back-calculated total lengths (mm) of bluegills (*Lepomis macrochirus*) in Big Stone Power Plant cooling reservoir, South Dakota, and other waters in the northern United States.

Location	Number of fish	Annulus				
		1	2	3	4	5
Battesse Lake, Mich. (Beckman 1950)	195	37	84	130	172	203
Wingra Lake, Wis.[a] (Schloemer 1939)	74	36	102	144	175	189
Ft. Randall Lake, S.D.[a] (Shields 1958)	596	50	122	146	156	188
Oahe Lake, S.D.[a] (Fogle 1963)	12	56	107	147	173	188
Gavins Pt. Lake, S.D.[a] (Nelson 1962)	234	52	99	117	138	158
Clear Lake, Iowa (DiCostanzo 1957)	1,166	61	108	142	159	199
Wyland Lake, Ind. (Gerking 1962)	1,106	43	73	106	125	136
Big Stone Reservoir, South Dakota	330	52	99	138	156	174

[a]Data from Carlander (1977).

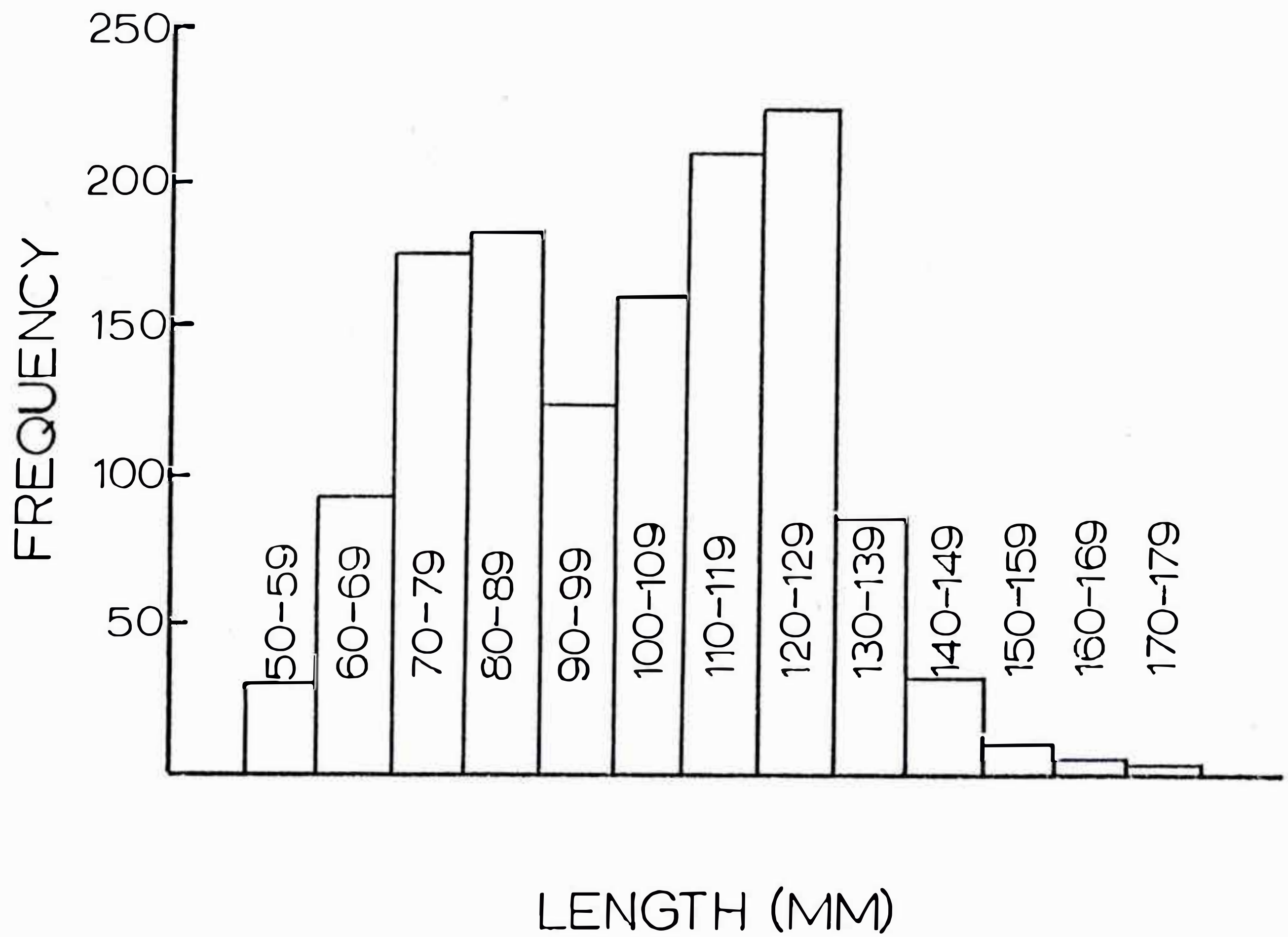

Fig. 2. Length-frequency of 1,361 bluegills (*Lepomis macrochirus*), Big Stone Power Plant cooling reservoir, South Dakota, 21 May to 27 May 1979.

calculated for 3 length intervals and ranged from 2.0 to 2.14 (Table 11). K values decreased as fish length increased. The average K factor was 2.09.

The body-vertebral radius relationship was described by the formula $L = 0.0 + 3.64S - 0.02S^2$ ($r = 0.99$; $P < .005$). Back calculations were made using this quadratic model. The weighted mean TL for tadpole madtoms at annuli I through III was 60, 90 and 104 mm, respectively (Table 12). Growth increments during the first 3 years of life were 60, 33 and 12 mm, respectively (Table 13). The growth rate was high in the first year of life and decreased in the second and third years.

The length-frequency of fish collected from 21 May to 27 May was plotted at 5 mm length intervals (Fig. 3). A single peak at the 90-94 mm interval probably represented age-group II and indicated that the 1977 year-class dominated the population.

Orangespotted Sunfish

A total of 45 orangespotted sunfish were examined for age and growth. The length-weight relationship was described by the formula $\log W = -4.50 + 2.83 \log L$ ($r = 0.59$; $P < .005$). The condition factor was calculated for 3 length intervals and ranged from 1.58 to 1.75 (Table 14). The average K factor was 1.68.

The body-scale relationship was described by the formula $L = 2.75 + 1.49S$ ($r = 0.99$; $P < .05$). Back calculations were made using this linear model. The weighted mean TL for orangespotted sunfish at annuli I and II was 58 and 91 mm, respectively (Table 15). Growth increments during the first 2 years of life were 58 and 36 mm,

Table 11. Condition factor for 3 length intervals of tadpole madtoms (*Noturus gyrinus*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Number	Length intervals (mm)	Number of fish	K(TL)
1	71 - 85	23	2.14
2	86 - 100	23	2.05
3	101 - 115	5	2.00

Table 12. Back-calculated total lengths (mm) of tadpole madtoms (*Noturus gyrinus*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Year-class	Age-group	Number of fish	Annulus 1	Annulus 2	Annulus 3
1978	I	29	62.4		
1977	II	17	57.6	89.1	
1976	III	5	55.7	92.5	104.1
	Weighted mean		60.1	89.9	104.1

Table 13. Back-calculated growth increments (mm) of tadpole madtoms (*Noturus gyrinus*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Year-class	Age-group	Number of fish	Annulus 1	Annulus 2	Annulus 3
1978	I	29	62.4		
1977	II	17	57.6	31.5	
1976	III	5	55.7	36.8	11.6
	Weighted mean		60.1	32.7	11.6

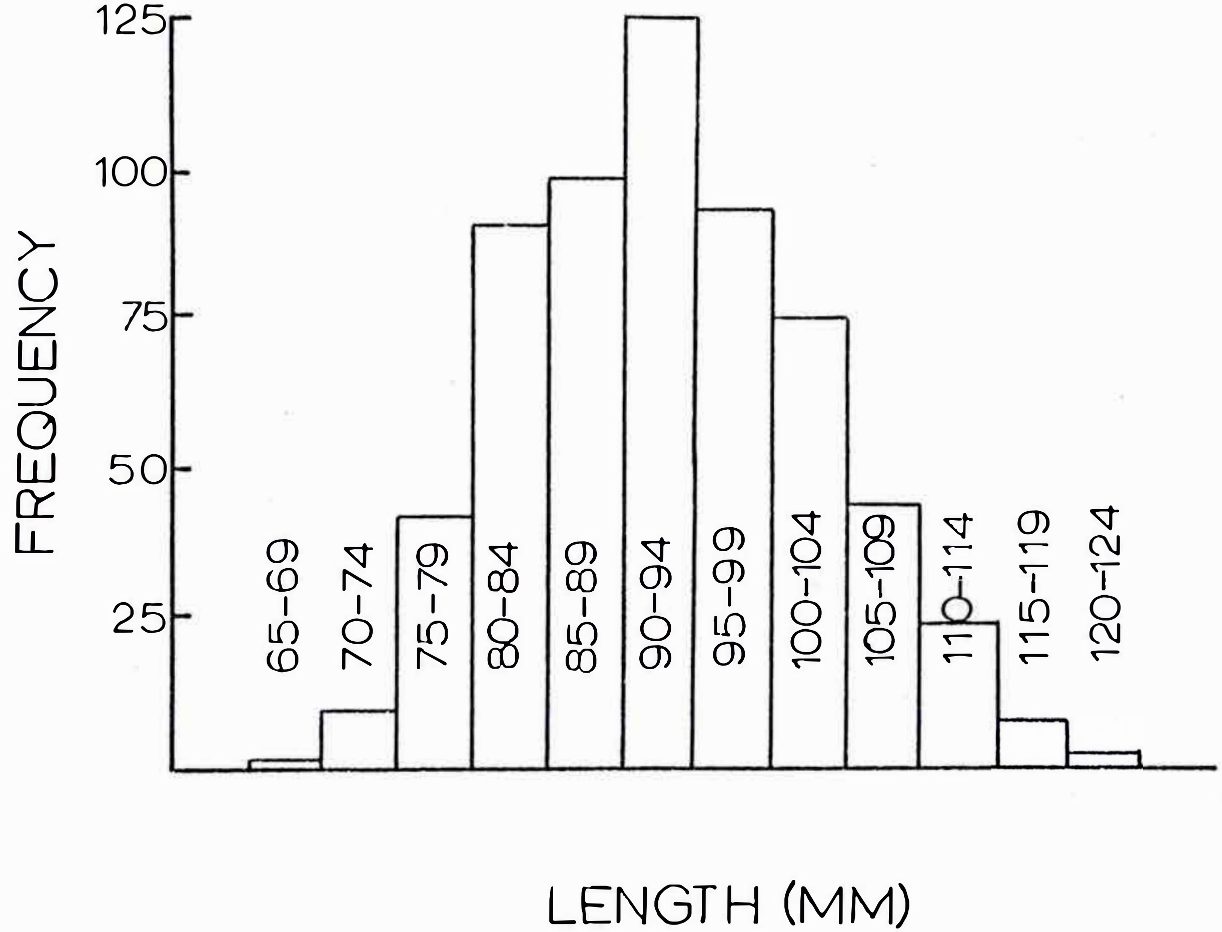

Fig. 3. Length-frequency of 610 tadpole madtoms (*Noturus gyrinus*), Big Stone Power Plant cooling reservoir, South Dakota, 21 May to 27 May 1979.

Table 14. Condition factor for 3 length intervals of orangespotted sunfish (*Lepomis humilis*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Number	Length intervals (mm)	Number of fish	K(TL)
1	66 - 80	17	1.75
2	81 - 95	22	1.66
3	96 - 110	6	1.58

Table 15. Back-calculated total lengths (mm) of orangespotted sunfish (*Lepomis humilis*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Year-class	Age-group	Number of fish	Annulus	
			1	2
1978	I	42	58.6	
1977	II	3	55.0	90.8
	Weighted mean		58.4	90.8

respectively (Table 16). The first year growth rate was higher than that of the second year. The growth rate of orangespotted sunfish in the present study was above average as compared to that reported for populations in other waters in the northern United States (Table 17).

The length-frequency of fish collected from 21 May to 27 May was plotted at 5 mm length intervals (Fig. 4). The 80-84 mm interval occurred with the highest frequency and most likely represented age-group I. A low peak at the 100-104 mm interval suggested the presence of older fish but in low numbers.

Black Bullhead

A total of 157 black bullheads were examined for age and growth. The length-weight relationship was described by the formula $\log W = -4.63 + 2.93 \log L$ ($r = .90$; $P < .005$). The condition factor was calculated for 11 length intervals and ranged from 1.42 to 1.79 (Table 18). K values remained relatively unchanged as fish length increased. The average K factor was 1.66, which is higher than the typical black bullhead condition factor of 1.4 (Carlander 1953).

The body-spine radius relationship was described by the formula $L = 0.0 + 5.50S$ ($r = .93$; $P < .005$). Back calculations were made using this linear model. The weighted mean TL for black bullheads at annuli I through V was 75, 136, 175, 190 and 190 mm, respectively (Table 19). Growth increments during the first 5 years of life were 75, 65, 46, 38 and 50 mm, respectively (Table 20). The growth rate was high during the first year of life and decreased the following

Table 16. Back-calculated growth increments (mm) of orangespotted sunfish (*Lepomis humilis*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Year-class	Age-group	Number of fish	Annulus 1	Annulus 2
1978	I	42	58.6	
1977	II	3	55.0	35.8
	Weighted mean		58.4	35.8

Table 17. Back-calculated total lengths (mm) of orangespotted sunfish (*Lepomis humilis*) in Big Stone Power Plant cooling reservoir, South Dakota, and other waters in the northern United States.

Location	Number of fish	Annulus 1	Annulus 2	Annulus 3
Mississippi River, Minn.[a] (Christenson 1957)	18	28	66	
Crab Orchard Lake, Ill.[a] (Whitacre 1952)	19	45	71	79
Fairport, Iowa[a] (Barney and Anson 1923)	120	37	60	74
Ft. Randall Lake, S.D.[a] (Shields 1955)	22	41	94	
Big Stone Reservoir, South Dakota	45	58	91	

[a]Data from Carlander (1977).

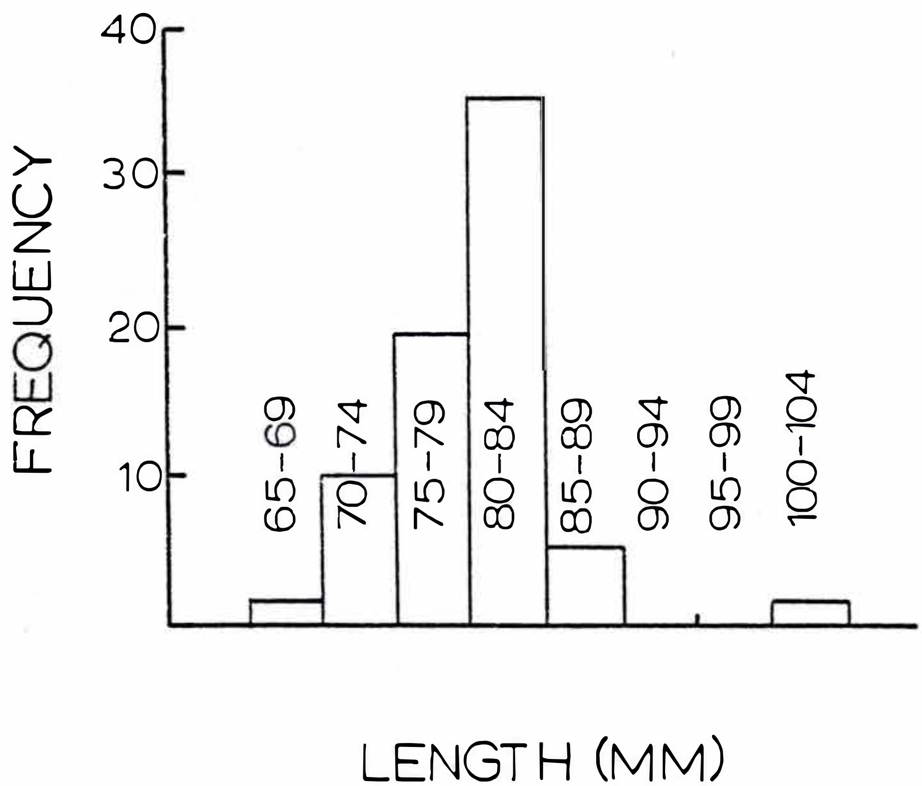

Fig. 4. Length-frequency of 73 orangespotted sunfish (*Lepomis humilis*), Big Stone Power Plant cooling reservoir, South Dakota, 21 May to 27 May 1979.

Table 18. Condition factor for 11 length intervals of black bullheads (*Ictalurus melas*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Number	Length intervals (mm)	Number of fish	K(TL)
1	112 - 126	1	1.42
2	127 - 141	4	1.58
3	142 - 156	6	1.51
4	157 - 171	19	1.79
5	172 - 186	41	1.68
6	187 - 201	26	1.68
7	202 - 216	28	1.64
8	217 - 231	18	1.63
9	232 - 246	9	1.60
10	247 - 261	4	1.63
11	262 - 276	1	1.43

Table 19. Back-calculated total lengths (mm) of black bullheads (Ictalurus melas), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Year-class	Age-group	Number of fish	Annulus 1	2	3	4	5
1978	I	12	123.4				
1977	II	44	74.5	154.0			
1976	III	66	71.4	132.7	186.3		
1975	IV	34	67.8	120.2	153.3	191.9	
1974	V	1	70.0	100.1	125.1	140.1	190.1
	Weighted mean		75.5	136.0	174.6	190.4	190.1

Table 20. Back-calculated growth increments (mm) of black bullheads (Ictalurus melas), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Year-class	Age-group	Number of fish	Annulus 1	2	3	4	5
1978	I	12	123.4				
1977	II	44	74.5	79.5			
1976	III	66	71.4	61.3	53.5		
1975	IV	34	67.8	52.4	33.1	38.6	
1974	V	1	70.0	30.0	25.0	15.0	50.0
	Weighted mean		75.5	64.5	46.4	37.9	50.0

3 years. The growth rate of black bullheads in the present study was low when compared to those reported for populations in other waters in the northern United States (Table 21).

Lee's phenomenon of apparent change in growth rate was characteristic of the black bullhead growth data. The calculated lengths of the older fish in earlier years of life were systematically lower than those of younger fish at the same age. Marzolf (1955) suggested that the structure and manner of growth of the spine is the cause of Lee's phenomenon.

The length-frequency of fish collected from 21 May to 27 May was plotted at 15 mm length intervals (Fig. 5). The single peak at the 170-184 mm interval probably represents age-group III and indicated that the 1976 year-class dominated the population.

Yellow Perch

A total of 34 yellow perch were examined for age and growth. The length-weight relationship was described by the formula $\log W = -6.21 + 3.56 \log L$ ($r = 0.97$; $P < .005$). The condition factor was calculated for 8 length intervals and ranged from 0.84 to 1.31 (Table 22). The average K factor was 1.16, which is lower than the typical yellow perch condition factor of 1.3 (Carlander 1953).

The body-scale relationship was described by the formula $L = 13.18 + 1.72S$ ($r = 0.86$; $P < .005$). Back calculations were made using this linear model. The weighted mean TL for yellow perch at annuli I through IV was 76, 155, 195 and 237 mm, respectively (Table 23). Growth increments during the first 4 years of life were 76, 83, 45 and 36 mm, respectively (Table 24). The growth

Table 21. Back-calculated total lengths (mm) of black bullheads (*Ictalurus melas*) in Big Stone Power Plant cooling reservoir, South Dakota, and other waters in the northern United States.

Location	Number of fish	Annulus				
		1	2	3	4	5
Heart Butte Lake, N.D. (Sprague 1958)	26	53	122	185	226	
Lake Darling, N.D. (Sprague 1958)	43	66	140	201	257	
Clear Lake, Iowa (Forney 1955)	-	97	163	213	201	246
Silver Lake, Iowa[a] (Moen 1959)	-	127	132	201		
Big Stone Reservoir, South Dakota	157	75	136	175	190	190

[a]Data from Carlander (1969)

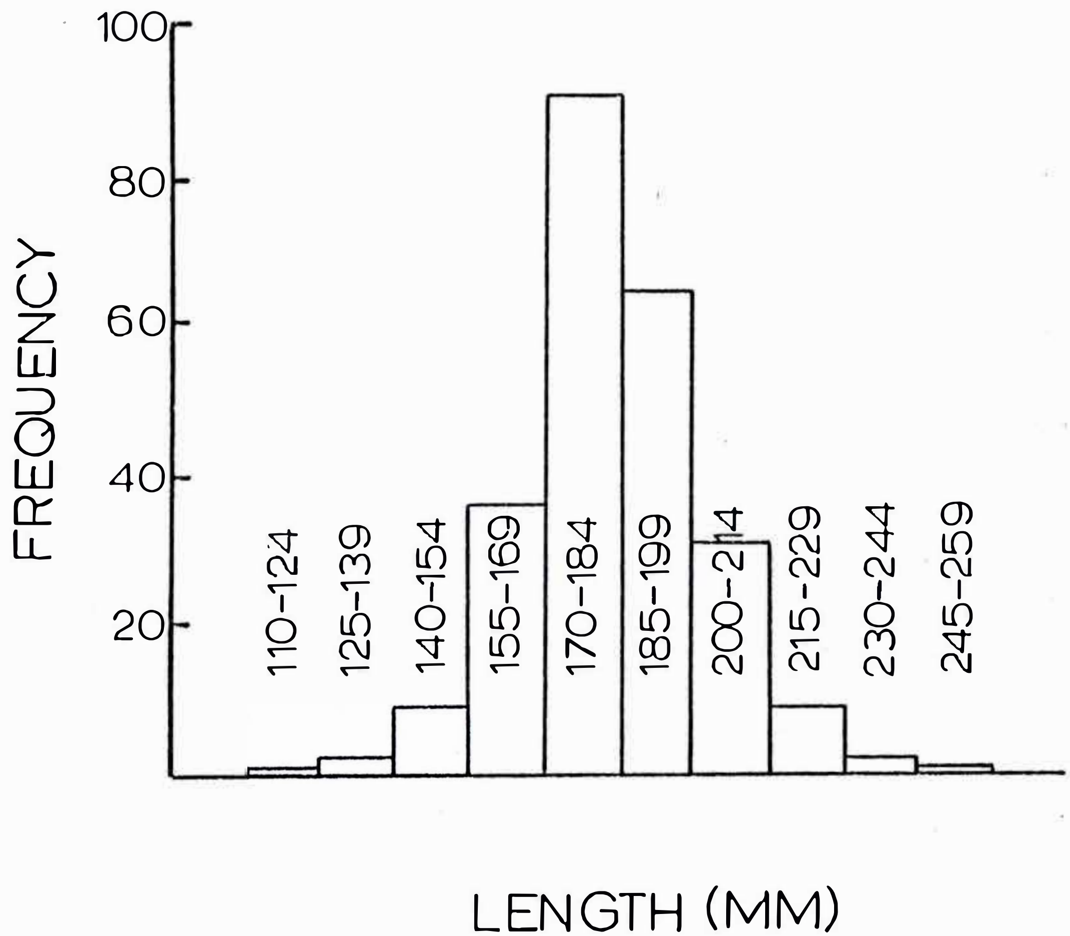

Fig. 5. Length-frequency of 246 black bullheads (Ictalurus melas), Big Stone Power Plant cooling reservoir, South Dakota, 21 May to 27 May 1979.

Table 22. Condition factor for 8 length intervals of yellow perch (Perca flavescens), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Number	Length intervals (mm)	Number of fish	K(TL)
1	100 - 114	5	0.84
2	115 - 129	3	0.84
3	130 - 144	2	1.31
4	175 - 189	6	1.22
5	190 - 204	6	1.25
6	205 - 219	6	1.30
7	220 - 234	4	1.25
8	235 - 249	2	1.18

Table 23. Back-calculated total lengths (mm) of yellow perch (*Perca flavescens*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Year-class	Age-group	Number of fish	Annulus			
			1	2	3	4
1978	I	10	87.8			
1977	II	11	70.7	160.1		
1976	III	11	71.3	148.8	194.1	
1975	IV	1	80.4	158.0	201.1	237.3
	Weighted mean		76.4	154.6	194.7	237.3

Table 24. Back-calculated growth increments (mm) of yellow perch (*Perca flavescens*), Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Year-class	Age-group	Number of fish	Annulus			
			1	2	3	4
1978	I	10	87.8			
1977	II	11	70.7	89.4		
1976	III	11	71.3	77.4	45.3	
1975	IV	1	80.4	77.6	43.1	36.2
	Weighted mean		76.4	83.1	45.1	36.2

rate was high during the first 2 years of life and slowed in the third and fourth year. The growth rate of yellow perch in Big Stone cooling reservoir was comparable to that reported in other lakes in the northern United States (Table 25). The length-frequency of fish collected from 21 May to 5 October was plotted at 15 mm length intervals (Fig. 6).

The Big Stone cooling reservoir was filled in 1972. Initial year-classes of forage fish appeared to have had high growth rates, which is typical of fish in new impoundments (Bennett 1970). The 1974 year-class was the oldest present among the forage fishes and their low densities indicated that most early fast-growing fish had died.

The growth rates of forage fishes present in the reservoir were similar to those of natural waters in the region. Growth was probably limited by available food supply and not by the length of the growing season. Dobie (1956) found that in the production of fishes of above average size, a large source of available food per individual fish exceeded in importance the length of the growing season.

Impingement of Forage Fishes

In 124 samples 108,167 fish (total weight 380.71 kg) of 15 species were impinged between 17 January 1979 and 10 January 1980. Bluegills, tadpole madtoms, black bullheads, and orangespotted sunfish were impinged most frequently (Table 26). These species made up

Table 25. Back-calculated total lengths (mm) of yellow perch (*Perca flavescens*) in Big Stone Power Plant cooling reservoir, South Dakota, and other waters in the northern United States.

Location	Number of fish	Annulus 1	2	3	4
Clear Lake, Ia. (Parsons 1950)	738	69	131	173	249
W. Okoboji Lake, Ia. (Parsons 1951)	85	56	124	187	230
Red Haw Lake, Ia. (Lewis 1950)	87	93	183	260	
Red Lake, Minn.[a] (VanOosten and Deason 1939)	594	53	122	173	213
Weber Lake, Wis.[a] (Schneberger 1935)	1,084	61	110	142	171
Big Stone Reservoir, South Dakota	33	76	155	195	237

[a]Data from Carlander (1953).

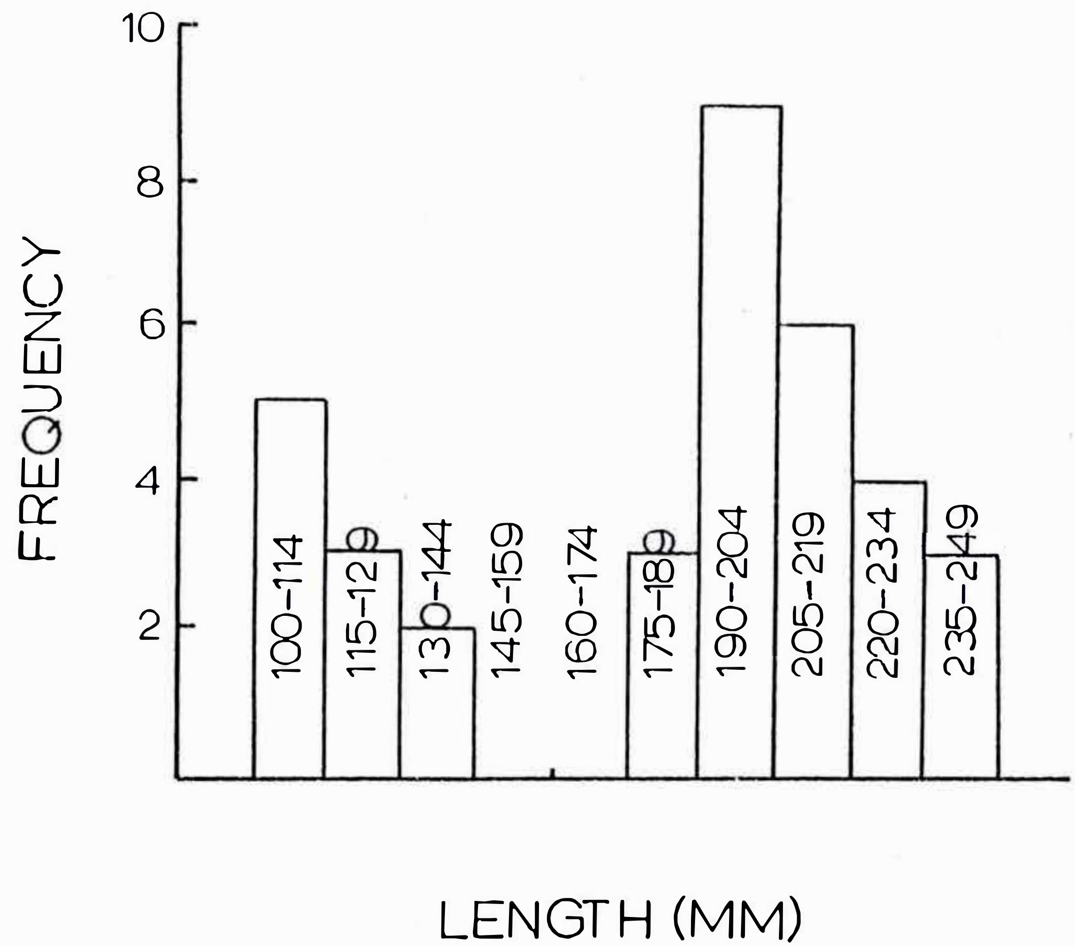

Fig. 6. Length-frequency of 34 yellow perch (*Perca flavescens*), Big Stone Power Plant cooling reservoir, South Dakota, 21 May to 5 October 1979.

Table 26. Frequency of occurrence, mean number, weight, and length of fishes impinged per 8 h, Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980. Number of samples = 124.

Species	Frequency of occurrence (%)	Mean number	Mean weight (g)	Mean total length (mm)
Bluegill adult	81.5	107	1,648.5	101
Orangespotted sunfish adult	24.2	0.7	4.7	75
Bluegill and orange-spotted sunfish young-of-the-year	58.1	743	1,012.2	47
Tadpole madtom	70.2	13	106.4	92
Black bullhead	54.0	6	239.6	90
Yellow perch	37.9	1	8.7	91
Fathead minnow	20.2	0.4	1.9	77
Johnny darter	13.7	0.25	0.5	69
Emerald shiner	14.5	0.4	2.1	101
Spottail shiner	10.5	0.1	0.7	90
Muskellunge	8.9	0.2	2.0	109
Pumpkinseed	7.3	0.1	1.6	88
Carp	8.1	0.1	21.2	161
Freshwater drum	2.4	a	0.3	107
Channel catfish	2.4	0.1	19.7	274
Black crappie	a	a	a	83

[a]Value less than 0.1.

99.6% by number and 98.1% by weight of the total impingement. The remaining 11 species averaged 1.0 fish or less per 8 h sample (Table 26).

The rate of impingement varied considerably among months. A seasonal trend in the impingement of the sunfishes (centrarchids) was noticeable. Large numbers of adult bluegills (101 mm, mean TL) were impinged during the winter months (January - April) when water temperatures were low. Impingement was reduced in May and June as the water temperature increased in the reservoir; fish apparently moved away from the intake area. Adult centrarchids were observed in shallow areas protecting nests during this time.

Impingement of bluegills and orangespotted sunfish young-of-the-year (38 mm, mean TL) was first observed during the last week in June. Impingement of young-of-the-year centrarchids remained high from July through November, while that of adult fish was negligible. An increase in the impingement of adult bluegills and a decrease in impingement of young-of-the-year sunfishes occurred in December and January and coincided with decreasing water temperature. There was an inverse relationship between impingement and water temperature for adult bluegills and all fish totaled (Fig. 7). Impingement of adult bluegills during the winter may have been caused by a cold-induced sluggishness in fishes. Grimes (1975) and Thomas and Miller (1976) noted an increased impingement of organisms at lower temperatures and attributed this to migration and reduced swimming speeds. Lifton and Storr (1977) reported that an inverse relationship existed between number of fish impinged and water temperature and attributed it to in-shore movements during fall and winter months.

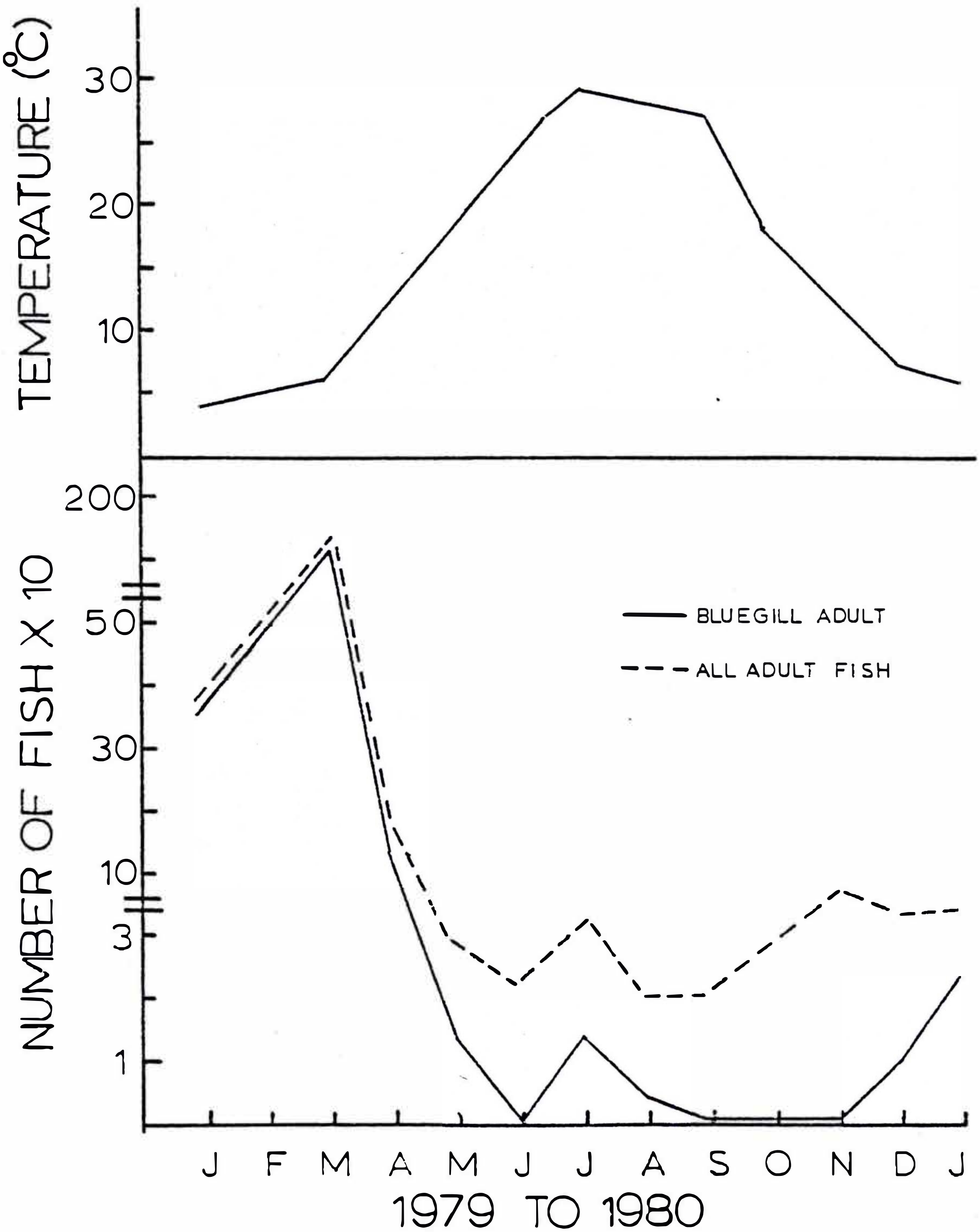

Fig. 7. Relationship between impingement of adult bluegill (*Lepomis macrochirus*) and all adult fish and water temperature, Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980.

Black bullheads and young-of-the-year sunfishes demonstrated a positive relationship between impingement and water temperature (Fig. 8). Correlation between impingement and water temperature was statistically significant ($P < .05$) for black bullheads (Table 27). Fish size probably created this relationship more than water temperature. Black bullheads impinged during the summer months were young-of-the-year fish (75 mm, mean TL).

Literature on the impingement of fishes indicated that impingement is restricted mostly to small fishes. Mathur et al. (1977) noted that larger fishes are better able to avoid or withstand the intake velocities. Young-of-the-year fishes accounted for 85% by number of the total impingement in Big Stone cooling reservoir. The mean TL for all fish impinged in the reservoir was 55 mm.

The relationship between reservoir water level and the number of fishes impinged was also evaluated. Adult bluegills and all species totaled exhibited an inverse relationship to high water levels, but black bullheads and young-of-the-year sunfishes exhibited a positive relationship. Black bullheads again showed the only significant ($P < .05$) correlation (Table 28).

Several investigators (Grimes 1975; Thomas and Miller 1976; Lifton and Storr 1977) have noted higher impingement rates during darkness. Higher impingement rates were observed during evening samples in this study (Figs. 9 and 10), but were not significantly different ($P > .05$) from morning and day samples (Tables 29-32). One exception was the tadpole madtom, which was impinged significantly ($P < .05$) more often at night (Table 33). Scott and Crossman (1973)

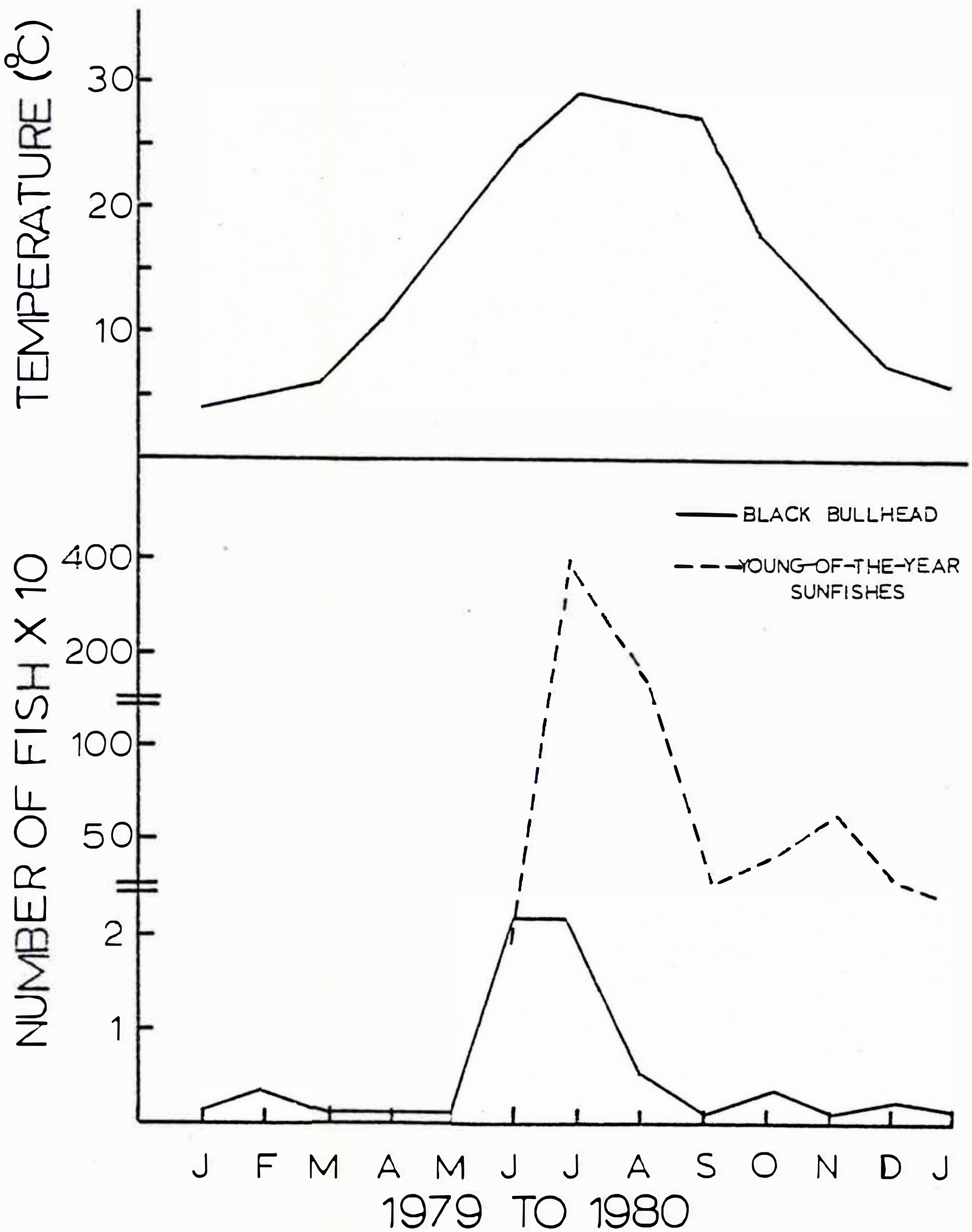

Fig. 8. Relationship between impingement of black bullheads (Ictalurus melas) and young-of-the-year sunfishes and water temperature, Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980.

Table 27. Linear correlation of the relationship between the number of fishes impinged and water intake temperature, Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980.

Species	Correlation coefficient (r)	Degrees of freedom	Calculated t-value
Bluegill adult	-.5119	11	1.788
Black bullhead	+.6045	11	2.217*
Tadpole madtom	+.1204	11	0.381
Bluegill and orangespotted sunfish young-of-the-year	+.6734	5	1.632
All species totaled	-.5062	11	1.762

*Significant at .05 level of probability.

Table 28. Linear correlation of the relationship between the number of fishes impinged and reservoir water level, Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980.

Species	Correlation Coefficient (r)	Degrees of freedom	Calculated t-value
Bluegill adult	-.4398	11	1.493
Black bullhead	+.7269	11	2.917*
Tadpole madtom	+.0232	11	0.073
Bluegill and orangespotted sunfish young-of-the-year	+.8138	5	2.278
All species totaled	-.4363	11	1.478

*Significant at .05 level of probability.

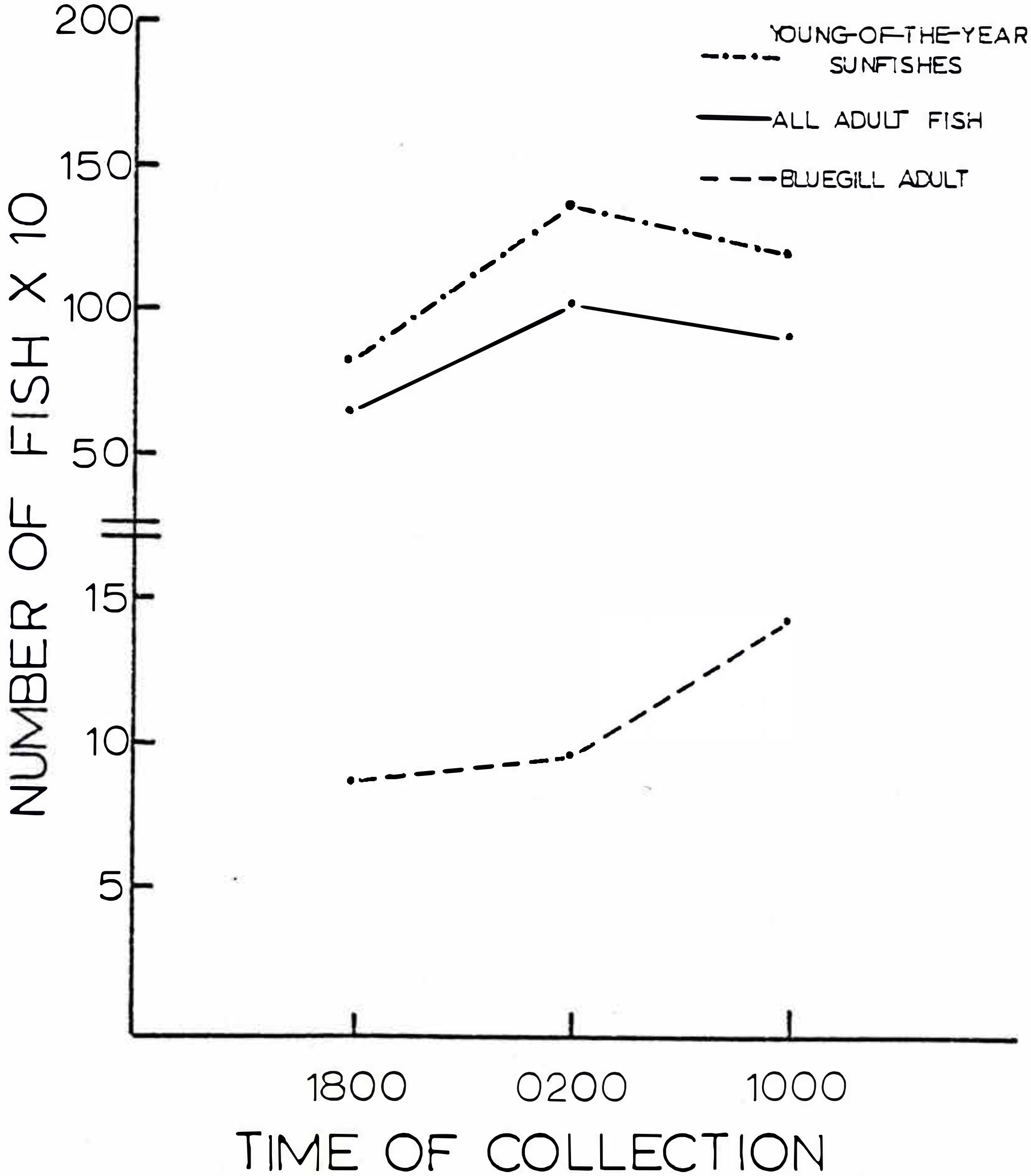

Fig. 9. The effect time of collection (h) had on the impingement of bluegill adult (Lepomis macrochirus), all adult fish and young-of-the-year sunfishes, Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980.

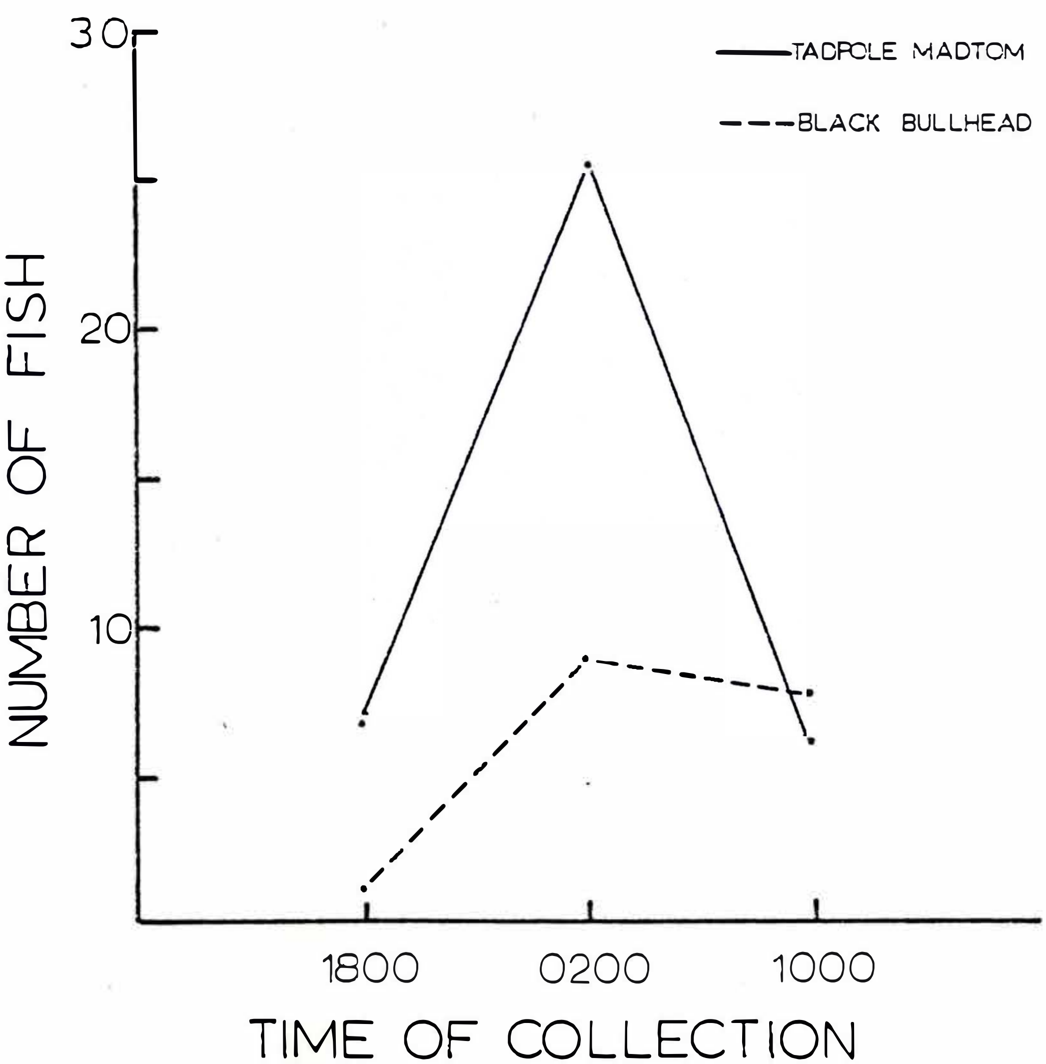

Fig. 10. The effect time of collection (h) had on the impingement of black bullheads (*Ictalurus melas*) and tadpole madtoms (*Noturus gyrinus*), Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980.

Table 29. Analysis of variance of the number of black bullheads (*Ictalurus melas*) impinged during morning, day and evening samples, Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980.

Source of variation	Degrees of freedom	Mean square	F
Treatment	2	139.94	1.51
Within	36	92.65	

Table 30. Analysis of variance of the number of adult bluegills (*Lepomis macrochirus*) impinged during morning, day and evening samples, Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980.

Source of variation	Degrees of freedom	Mean square	F
Treatment	2	71,212.41	0.43
Within	36	164,590.94	

Table 31. Analysis of variance of the number of bluegill (*Lepomis macrochirus*) and orangespotted sunfish (*L. humilis*) young-of-the-year impinged during morning, day and evening samples, Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980.

Source of variation	Degrees of freedom	Mean square	F
Treatment	2	379,536.32	0.20
Within	21	1,909,189.67	

Table 32. Analysis of variance of the number of all adult fish impinged during morning, day and evening samples, Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980.

Source of variation	Degrees of freedom	Mean square	F
Treatment	2	362,914.64	0.27
Within	36	1,323,721.07	

Table 33. Analysis of variance of the number of tadpole madtoms (*Noturus gyrinus*) impinged during morning, day and evening samples, Big Stone Power Plant cooling reservoir, South Dakota, 17 January 1979 to 10 January 1980.

Source of variation	Degrees of freedom	Mean square	F
Treatment	2	1,340.27	3.68*
Within	36	364.46	

*Significant at .05 level of probability.

stated that tadpole madtoms are nocturnally active. The high evening impingement rate was probably associated with this activity peak. Diel cycles appear to be a factor influencing impingement.

Impingement and Growth of Stocked Muskellunge

A total of 151 muskellunge were impinged. Of this total, 65 fish were from muskellunge stocked in 1978 and 86 fish from muskellunge stocked in 1979. In 1978, impingement was highest in September and October; in 1979, impingement losses were greatest from June through August (Fig. 11).

The critical period for impingement appeared to be the first 2 months following stocking. In 1978, 77% of the total number impinged occurred in the first 2 months; in 1979, 83% of the total impingement occurred in the first 2 months. As the fish grew they appeared to be better able to avoid the intake screens.

Muskellunge in both the 1978 and 1979 year-classes increased in length and weight each month (Table 34). There was little difference in first year growth when comparing year-classes. Fish captured in gill nets in February and March 1980 indicated high growth rates for age-groups I and II. The mean TL (mm) and weight (g) of 19 age-group I fish was 465 and 651, respectively. Total length ranged from 386 to 575 mm, and weight from 310 to 1,060 g (Table 34). The mean TL (mm) and weight (g) of 8 age-group II fish was 753 and 2,625 respectively. Total length ranged from 700 to 785 mm and weight from 1,474 to 3,700 g (Table 34).

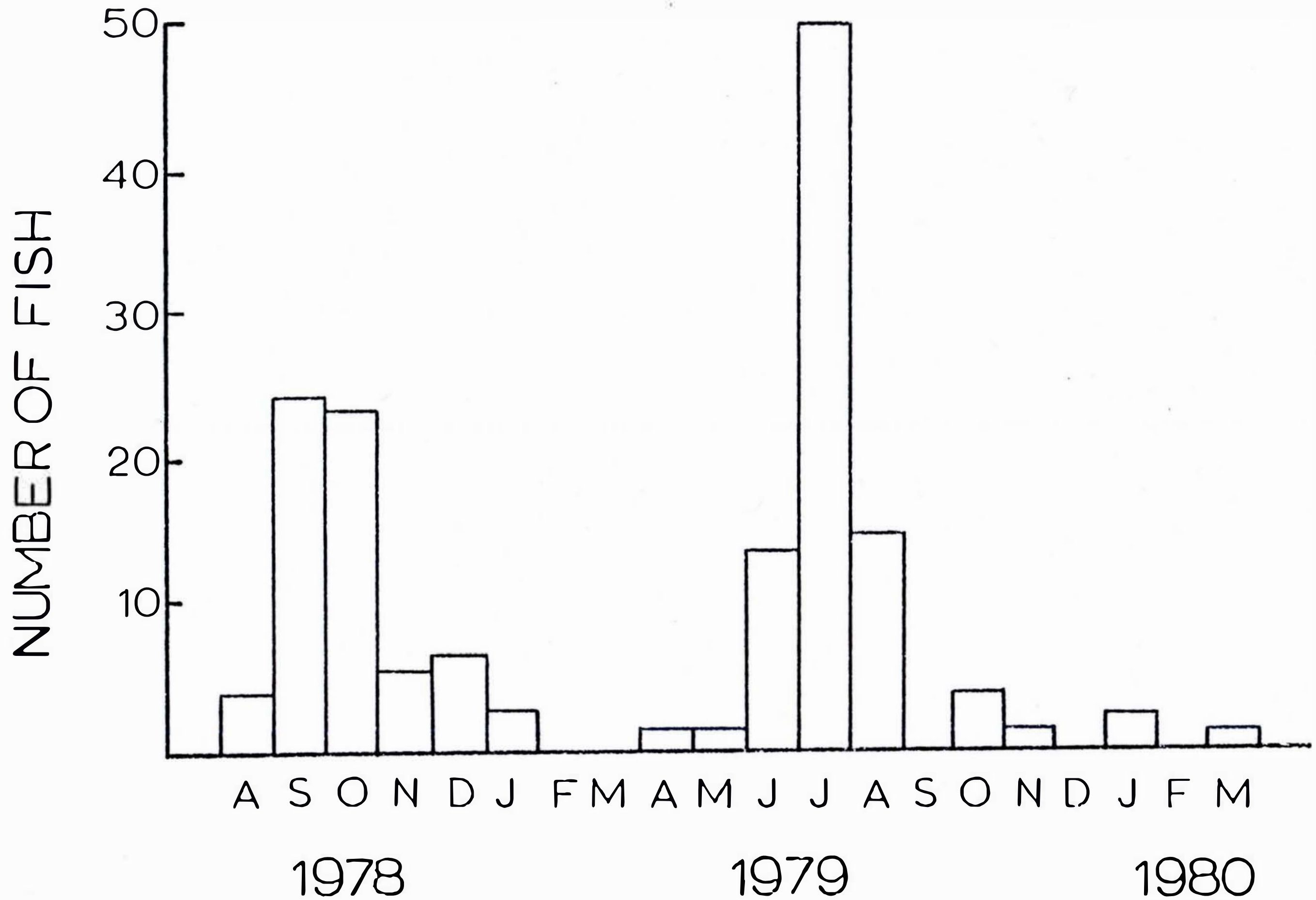

Fig. 11. Impingement of muskellunge (*Esox masquinongy*), Big Stone Power Plant cooling reservoir, South Dakota, August 1978 to March 1980.

Table 34. Age-class, length, and weight of muskellunge (Esox masquinongy) impinged and (in parenthesis) captured with a gill net, Big Stone Power Plant cooling reservoir, South Dakota.

Age-class and date	Number of fish	Mean total length (mm)	Range	Mean weight (g)	Range
0-August 1978	3	166	145-178	21	15-26
0-September	24	201	182-221	39	25-56
0-October	23	243	222-273	71	51-101
0-November	5	285	272-307	112	95-144
0-December	6	338	313-373	238	175-334
I-January 1979	2	349	312-386	249	167-331
I-April	1	285	-	106	-
I-May	1	395	-	330	-
0-June	13	71	60-84	1.5	1-2.5
0-July	50	106	90-141	6	3-14
0-August	14	142	111-165	14	6-23
0-September	2	171	167-174	25	24-26
0-October	3	295	284-306	133	115-150
0-November	1	318	-	170	-
I-January 1980	2	324	303-345	202	147-256
I-March	1	335	-	286	-
I-February-March	(19)	(465)	(386-575)	(651)	(310-1,060)
II-February-March	(8)	(753)	(700-785)	(2,625)	(1,474-3,700)

The high growth rates of muskellunge in the cooling reservoir indicated that the food supply and the length of the growing season was not limiting their growth. Muskellunge in the present study had a higher growth rate than those reported for all other populations in North America (Table 35). The muskellunge in the Big Stone cooling reservoir appeared to be growing throughout the year. I conclude that the power plant cooling reservoir may provide an area for rearing and holding muskellunge brood stock.

Table 35. Mean total length of age I and II muskellunge (Esox masquinongy) in Big Stone Power Plant cooling reservoir, South Dakota, and other waters in North America.

Location	Number of fish		Mean total length (mm)	
	Age I	Age II	Age I	Age II
Wisconsin Lakes[a] (Schloemer 1936)	351	330	198	424
Minnesota Lakes[a] (Eddy and Carlander 1942)	48	48	175	318
Wisconsin Ponds, April[b] (Oehmcke 1951)	599	-	218	-
Ontario, Quebec[b] (Hourston 1952)	-	4	-	508
Tennessee Streams[a] (Parsons 1959)	8	11	216	394
Nogies Creek, Ontario[a] (Muir 1960)	193	625	399	485
Pennsylvania[a,c] (Buss and Miller 1961)	152	152	198	437
Deer Creek Lake, Ohio[a] (Erickson 1961)	84	78	330	645
Cave Run Lake, Kentucky[a] (Axon 1978)	568	568	330	587
Lake Pomme de Terre, Missouri[a] (Belusz 1978)	-	-	310	561
Middle Island Creek, West Virginia[a] (Miles 1978)	15	7	302	500
Big Stone Reservoir, South Dakota[b] February and March	19	8	465	753

[a]Mean back-calculated total length.

[b]Mean total length at capture.

[c]Data from Carlander (1969).

LITERATURE CITED

Axon, J. R. 1978. An evaluation of the muskellunge fishery in Cave Run Lake, Kentucky, p. 328-333. In R. L. Kendall [ed.] Selected coolwater fishes of North America. Lancaster Press, Inc., Lancaster, Pennsylvania.

Barney, R. J. and B. J. Anson. 1923. Life history and ecology of the orangespotted sunfish (*Lepomis humilis*). Rep. U. S. Fish Comm. 16 p.

Bazigos, G. P. 1974. Applied fishery statistics. FAO Fish. Tech. Pap. 135: 164 p.

Becker, D. D., C. E. Cushing, K. L. Gore, K. S. Backer, and D. H. McKenzie. 1979. Synthesis and analysis of ecological information from cooling impoundments. Volume 2: appendix A - study site histories and data synopsis. Electric Power Research Institute, Inc., Palo Alto, California. 283 p.

Beckman, W. C. 1950. Changes in growth rates of fishes following reduction in population densities by winterkill. Trans. Am. Fish. Soc. 78: 82-90.

Belusz, L. C. 1978. An evaluation of the muskellunge fishery of Lake Pomme de Terre and efforts to improve stocking, p. 292-297. In R. L. Kendall [ed.] Selected coolwater fishes of North America. Lancaster Press, Inc., Lancaster, Pennsylvania.

Bennett, G. W. 1970. Management of lakes and ponds. Second Edition. Van Nostrand Reinhold Company, New York, N. Y. 375 p.

Buss, K. 1960. The muskellunge. Pa. Fish. Comm. Sec. Rep. 14 p. mimeo.

_____, and J. G. Miller. 1961. Part VII - The age and growth of the muskellunge in Pennsylvania. Pa. Angler, Apr. 1961.

Carlander, K. D. 1953. Handbook of freshwater fishery biology with the first supplement. Wm. C. Brown Company, Dubuque, Iowa. 429 p.

_____. 1955. The standing crop of fish in lakes. J. Fish. Res. Board Can. 12: 543-570.

_____. 1969. Handbook of freshwater fishery biology. Vol. I. Iowa State University Press, Ames, Iowa. 752 p.

_____. 1977. Handbook of freshwater fishery biology. Vol. II. Iowa State University Press, Ames, Iowa. 431 p.

Christenson, L. M. 1957. Some characteristics of the fish populations in back water areas of the Upper Mississippi River. M. S. thesis, University of Minnesota, Minneapolis, Minn. 125 p.

DiCostanzo, C. J. 1957. Growth of bluegill, Lepomis macrochirus, and pumpkinseed L. gibbosus, of Clear Lake, Iowa. Iowa State J. Sci. 32: 19-34.

Dobie, J. 1956. Walleye pond management in Minnesota. Prog. Fish-Cult 18: 51-57.

Eddy, S., and K. D. Carlander. 1942. Growth rates studies of Minnesota fish. Minn. Dept. Conserv. Fish. Res. Invest. Rep. 28: 64 p. mimeo.

Edsall, T. A. and T. G. Yocom. 1972. Review of recent technical information concerning the adverse effects of once-through cooling on Lake Michigan. Lake Michigan Enforcement Conference. 86 p.

Erickson, J. G. 1961. Muskellunge stocking evaluation in Deer Creek Reservoir, Stark County, Ohio. Ohio Dept. Nat. Resources Tech. Rep. 314: 6 p. mimeo.

Everhart, W. H., A. W. Eipper, and W. D. Youngs. 1975. Principles of fishery science. Cornell University Press, Ithaca, New York. 288 p.

Fogle, N. E. 1963. Report of fisheries investigations during the fourth year of impoundment of Oahe Reservoir, South Dakota. S. D. Dept. of Game, Fish and Parks, D. J. Proj. No. F-1-R-12. 43 p.

Follis, B. J. 1976. Existing reservoir and stream management recommendations: Colorado City Reservoir. Texas Parks and Wildl. Dept., Fed. Aid Proj. F-3-R-2, (unpublished). 19 p.

Forney, J. L. 1955. Life history of the black bullhead, Ameiurus melas (Rafinesque), of Clear Lake, Iowa. Iowa State J. Sci. 30: 145-162.

Gerking, S. D. 1962. Production and food utilization in a population of bluegill sunfish. Ecol. Monogr. 32: 31-78.

Grimes, C. B. 1975. Entrapment of fishes on intake water screens at a steam electric generating station. Chesapeake Sci. 16: 172-177.

Hanson, W. D. 1971. Harvest of fish in Thomas Hill Reservoir. Mo. Dept. of Conserv., D. J. Proj. No. F-1-R-20, (unpublished). 7 p.

Hooper, F. F. 1949. Age analysis of a population of the ameiurid fish, Schilbeodes mollis (Hermann). Copeia 1949: 34-38.

Hourston, A. S. 1952. The food and growth of the maskinonge, Esox masquinongy (Mitchell), in Canadian waters. J. Fish. Res. Board Can. 8: 347-368.

Karvelis, E. G. 1965. The true pikes. Fish. Leafl. Wash. 569: 11 p.

Lagler, K. F. 1956. Freshwater fishery biology. Wm. C. Brown Company, Dubuque, Iowa. 421 p.

Latvaitis, B., H. F. Bernhard, and D. B. McDonald. 1976. Impingement studies at Quad-Cities Station, Mississippi River, p. 269-289. In L. D. Jensen [ed.] Third national workshop on entrainment and impingement. Ecological Analysts, Inc., Melville, New York.

Lewis, W. M. 1949. The use of vertebrae as indicators of the age of the northern black bullhead, Ameiurus m. melas (Rafinesque). Iowa State J. Sci. 23: 209-218.

_____. 1950. Fisheries investigations on two artificial lakes in southern Iowa. Iowa State J. Sci. 24: 287-324.

Lifton, W. S., and J. W. Storr. 1977. The effect of environmental variables on fish impingement, p. 299-311. In L. D. Jensen [ed.] Fourth national workshop on entrainment and impingement. Ecological Analysts, Inc., Melville, New York.

Marzolf, R. C. 1955. Use of pectoral spines and vertebrae for determining age and rate of growth of the channel catfish. J. Wildl. Manage. 19: 243-249.

Mathur, D., P. G. Heisey, and N. C. Magnusson. 1977. Impingement of fishes at Peach Bottom Atomic Power Station, Pennsylvania. Trans. Am. Fish. Soc. 106: 258-267.

Mayhew, J. 1970. SHAD, a computer program for computation of age and growth statistics of fish. Iowa Conserv. Comm. Tech. Ser. 73-1: 13 p.

Meredith, D. L. 1973. Nuclear power plant siting: a handbook for the layman. Mar. Bull. 6: 95 p.

Metz, W. C. 1977. Cooling ponds, lakes and reservoirs - a positive factor in power plant siting. Aware 4: 5-9.

Miles, R. L. 1978. A life history study of the muskellunge in West Virginia, p. 140-145. In R. L. Kendall [ed.] Selected coolwater fishes of North America. Lancaster Press, Inc., Lancaster, Pennsylvania.

Moen, T. E. 1959. Notes on the growth of bullheads. Iowa Conserv. Comm. Quart. Biol. Rep. 11: 29-31.

Muir, B. S. 1960. Comparison of growth rates for native and hatchery stocked populations of Esox masquinongy in Nogies Creek, Ontario. J. Fish. Res. Board Can. 17: 919-927.

Nelson, W. R. 1962. Report of fisheries investigations during the seventh year of impoundment of Gavins Point Reservoir, South Dakota. S. D. Dept. of Game, Fish and Parks, D. J. Proj. No. F-1-R-11. 40 p.

Oehmcke, A. A. 1951. Muskellunge yearling culture and its application to lake management. Prog. Fish-Cult. 13: 63-70.

_____. L. D. Johnson, J. H. Klingbiel, and C. A. Wistrom. 1958. The Wisconsin muskellunge, its life history, ecology, and management. Wis. Conserv. Dep. Publ. 225: 12 p.

Parsons, J. W. 1950. Life history of the yellow perch, Perca flavescens (Mitchell), of Clear Lake, Iowa. Iowa State J. Sci. 25: 83-97.

_____. 1951. Growth studies of yellow perch in three northwestern Iowa lakes. Iowa State J. Sci. 25: 495-500.

_____. 1959. Muskellunge in Tennessee streams. Trans. Am. Fish. Soc. 88: 136-141.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191: 382 p.

Ryan, M. 1976. Existing reservoir and stream management recommendations: Lake O' the Pines and Lake Striker. Texas Parks and Wildl. Dept., Fed. Aid Proj. F-30-R-1, (unpublished). 59 p.

Schloemer, C. L. 1936. The growth of the muskellunge, Esox masquinongy immaculatus (Garrard), in various lakes and drainage areas of northern Wisconsin. Copeia 1936: 185-193.

_____. 1939. The age and rate of growth of the bluegill, Helioperca macrochira (Rafinesque). Ph. D. thesis, University of Wisconsin, Madison, Wisc. 113 p.

Schneberger, E. 1935. Growth of yellow perch, Perca flavescens (Mitchell) in Nebish, Silver, and Weber Lakes, Vilas County, Wisconsin. Trans. Wisc. Acad. Sci., Arts, and Lett. 29: 103-130.

Schoffman, R. J. 1954. Age and rate of growth of the channel catfish in Reelfoot Lake, Tennessee. Tenn. Acad. Sci. 29: 2-8.

Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Board Can. 184: 966 p.

Serns, S. L., and K. Strawn. 1975. Age and growth of bluegill, Lepomis macrochirus, in two heated Texas reservoirs. Trans. Am. Fish. Soc. 104: 506-512.

Shields, J. T. 1955. Report of fisheries investigations during the second year of impoundment of Fort Randall Reservoir, South Dakota. S. D. Dept. of Game, Fish and Parks. 100 p.

_____. 1958. Report of fisheries investigations during the fifth year of impoundment of Fort Randall Reservoir, South Dakota. S. D. Dept. of Game, Fish and Parks, D. J. Proj. No. F-1-R-7. 48 p.

Smith, D. Q. 1976. Existing reservoir and stream management recommendations: Lake Eagle Mountain. Texas Parks and Wildl. Dept., Fed. Aid Proj. F-30-L-2, (unpublished). 48 p.

Smith, S. H. 1954. Method of producing plastic impressions of fish scales without using heat. Prog. Fish-Cult. 16: 75-78.

Sneed, K. E. 1951. A method for calculating the growth of channel catfish, Ictalurus punctatus. Trans. Am. Fish. Soc. 80: 174-183.

Sprague, J. W. 1958. Age and growth determination of the black bullhead from soft fin rays. M. S. thesis, South Dakota State University, Brookings, S. D. 38 p.

Thomas, D. L., and G. J. Miller. 1976. Impingement studies at the Oyster Creek Generating Station, Forked River, New Jersey, from September to December 1975, p. 317-341. In L. D. Jensen [ed.] Third national workshop on entrainment and impingement. Ecological Analysts, Inc., Melville, New York.

VanOosten, J. and H. J. Deason, 1939. Age, growth, and condition of the walleyed pike, yellow perch, and goldeye of Lower Red Lake, Beltrami and Clearwater Counties, Minnesota. Midwest Wildl. Conf., 1939.

Whitacre, M. A. 1952. The fishes of Crab Orchard Lake, Illinois. Midwest Wildl. Conf. 14: 41 p.

Yeh, C. F. 1971. Mark and recovery estimates of fish populations in three heated reservoirs of Texas. M. S. thesis, Texas A & M University, College Station, Tx. 113 p.

Zar, J. H. 1974. Biostatistical analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 620 p.

APPENDIX

Appendix Table 1. Mark and recapture data, population estimate, and confidence intervals for bluegills (*Lepomis macrochirus*) in Big Stone Power Plant cooling reservoir, South Dakota, 21 May to 1 July 1980.

Date	Total caught C_t	Recaptures R	Marked fish at large M_t	C_tM_t	Population estimate N	95% Confidence limits[a]
5-21	217	-	-	-	-	
5-22	238	1	216	51,408	25,704	
5-23	242	6	453	109,626	20,129	
5-24	444	2	689	305,916	46,695	
5-25	217	3	1,129	244,993	54,765	
5-26	302	6	1,342	405,284	58,801	
5-27	152	4	1,637	248,824	59,394	39,827 88,132
5-28	245	5	1,784	437,080	64,398	
5-29	96	1	2,020	193,920	68,864	
5-30	177	2	2,107	372,939	76,451	
5-31	95	1	2,260	214,700	80,772	
6-1	95	3	2,353	223,535	80,235	
6-2	49	0	2,445	119,805	83,658	
6-3	59	2	2,493	147,087	83,111	60,534 113,893
6-4	55	2	2,550	140,250	82,445	
6-5	120	3	2,602	312,240	83,991	
6-6	178	5	2,718	483,804	85,349	
6-7	84	1	2,890	242,760	88,629	
6-8	108	2	2,973	321,084	91,505	
6-9	151	1	3,079	464,929	98,827	
6-10	219	8	3,229	707,151	97,412	75,623 125,214

Appendix Table 1 (cont).

Date	Total caught C_t	Recaptures R	Marked fish at large M_t	C_tM_t	Population estimate N	95% Confidence limits
6-11	173	7	3,436	594,428	96,087	
6-12	389	13	3,602	1,401,178	98,012	
6-13	92	7	3,976	365,792	94,288	
6-14	196	6	4,059	795,564	96,786	
6-15	66	0	4,248	280,368	99,833	
6-16	102	3	4,312	439,824	101,310	
6-17	25	2	4,410	110,250	100,358	82,358 122,296
6-18	14	1	4,432	62,048	99,967	
6-19	235	9	4,445	1,044,575	101,321	
6-20	34	3	4,671	158,814	100,002	
6-21	123	4	4,702	578,346	101,566	
6-22	125	9	4,821	602,625	99,034	
6-23	82	5	4,937	404,834	98,328	
6-24	79	8	5,014	396,106	95,457	80,734 112,790
6-25	120	5	5,085	610,200	96,399	
6-26	123	2	5,200	639,600	99,524	
6-27	589	20	5,321	3,134,069	106,540	
6-28	254	16	5,887	1,495,298	105,370	
6-29	198	7	6,125	1,212,750	107,925	
6-30	467	18	6,315	2,949,105	112,858	
7-1	479	25	6,763	3,239,477	114,684	100,777 130,985

[a]95% confidence limits are listed every 7th day.

Appendix Table 2. Mark and recapture data, population estimate, and confidence intervals for tadpole madtoms (*Noturus gyrinus*) in Big Stone Power Plant cooling reservoir, South Dakota, 21 May to 1 July 1980.

Date	Total caught C_t	Recaptures R	Marked fish at large M_t	C_tM_t	Population estimate N	95% Confidence limits
5-21	54	-	-	-	-	
5-22	89	0	54	4,806	-	
5-23	122	0	143	17,446	-	
5-24	108	0	265	28,620	-	
5-25	114	1	373	42,522	46,697	
5-26	69	1	486	33,534	42,309	
5-27	52	1	554	28,808	38,934	15,891 77,868
5-28	48	0	604	28,992	46,182	
5-29	87	1	652	56,724	48,290	
5-30	61	2	737	44,957	40,916	
5-31	33	1	796	26,268	39,085	
6-1	29	0	828	24,012	42,086	
6-2	36	0	857	30,852	45,943	
6-3	15	0	872	13,080	47,578	24,556 86,505
6-4	13	0	887	11,531	49,019	
6-5	13	0	900	11,700	50,482	
6-6	36	1	913	32,868	48,524	
6-7	37	2	948	35,076	42,891	
6-8	29	1	983	28,507	41,692	
6-9	37	1	1,011	37,407	41,362	
6-10	35	1	1,047	36,645	41,025	24,650 66,785

Appendix Table 2 (cont).

Date	Total caught C_t	Recaptures R	Marked fish at large M_t	C_tM_t	Population estimate N	95% Confidence limits[a]
6-11	17	0	1,081	18,377	42,338	
6-12	24	0	1,098	26,352	44,220	
6-13	27	3	1,122	30,294	38,199	
6-14	25	1	1,146	28,650	37,668	
6-15	35	0	1,170	40,950	39,943	
6-16	44	0	1,205	53,020	42,889	
6-17	41	1	1,248	51,168	43,325	27,904 66,384
6-18	29	2	1,288	37,352	40,977	
6-19	63	0	1,315	82,845	44,922	
6-20	37	2	1,378	50,986	43,233	
6-21	23	1	1,413	32,499	42,785	
6-22	37	2	1,435	53,095	41,536	
6-23	11	0	1,469	16,159	42,158	
6-24	18	1	1,480	26,640	41,583	28,715 60,040
6-25	20	0	1,497	29,940	42,692	
6-26	16	0	1,517	24,272	43,591	
6-27	79	2	1,533	121,107	44,761	
6-28	36	2	1,609	57,924	43,741	
6-29	79	2	1,643	129,797	45,024	
6-30	59	5	1,720	101,480	41,770	
7-1	59	1	1,774	104,666	43,383	31,803 58,952

[a]95% confidence limits are listed every 7th day.

Appendix Table 3. Mark and recapture data, population estimate, and confidence intervals for orangespotted sunfish (Lepomis humilis) in Big Stone Power Plant cooling reservoir, South Dakota, 21 May to 1 July 1980.

Date	Total caught C_t	Recaptures R	Marked fish at large M_t	C_tM_t	Population estimate N	95% Confidence limits
5-21	3	-	-	-	-	
5-22	11	0	3	33	-	
5-23	22	0	14	308	-	
5-24	12	0	36	432	-	
5-25	12	0	48	576	-	
5-26	11	0	60	660	-	
5-27	1	0	71	71	-	-
5-28	12	0	72	864	-	
5-29	10	0	82	820	-	
5-30	5	0	91	455	-	
5-31	1	0	96	96	-	
6-1	2	0	97	194	-	
6-2	5	0	99	495	-	
6-3	0	0	104	0	-	-
6-4	4	0	104	416	-	
6-5	1	0	108	108	-	
6-6	6	0	108	648	-	
6-7	12	0	114	1,368	-	
6-8	11	0	126	1,386	-	
6-9	11	0	137	1,507	-	
6-10	10	1	148	1,480	5,959	1,779 10,363

Appendix Table 3 (cont).

Date	Total caught C_t	Recaptures R	Marked fish at large M_t	C_tM_t	Population estimate N	95% Confidence limits
6-11	7	0	157	1,099	6,508	
6-12	8	0	164	1,312	7,164	
6-13	16	0	172	2,752	8,540	
6-14	8	0	187	1,496	9,288	
6-15	12	0	195	2,340	10,458	
6-16	14	1	206	2,884	7,933	
6-17	4	0	219	876	8,225	2,973 16,451
6-18	4	0	223	892	8,523	
6-19	11	2	227	2,497	5,613	
6-20	5	0	236	1,180	5,849	
6-21	10	0	241	2,410	6,331	
6-22	7	0	251	1,757	6,682	
6-23	10	0	257	2,570	7,196	
6-24	26	3	267	6,942	5,366	2,769 9,755
6-25	13	0	290	3,770	5,837	
6-26	8	0	303	2,424	6,140	
6-27	33	1	311	10,263	6,598	
6-28	7	1	342	2,394	6,178	
6-29	44	4	348	15,312	5,506	
6-30	66	4	388	25,608	5,705	
7-1	29	1	450	13,050	6,092	3,924 9,334

[a]95% confidence limits are listed every 7th day.

Appendix Table 4. Mark and recapture data, population estimate, and confidence intervals for black bullheads (*Ictalurus melas*) in Big Stone Power Plant cooling reservoir, South Dakota, 21 May to 1 July 1980.

Date	Total caught C_t	Recaptures R	Marked fish at large M_t	C_tM_t	Population estimate N	95% Confidence limits[a]
5-21	17	-	-	-	-	
5-22	13	0	17	221	-	
5-23	48	1	30	1,440	831	
5-24	46	3	77	3,542	1,041	
5-25	51	4	120	6,120	1,258	
5-26	31	4	167	5,177	1,269	
5-27	40	4	194	7,760	1,427	899 2,246
5-28	55	5	230	12,650	1,678	
5-29	28	2	280	7,840	1,865	
5-30	37	4	306	11,322	2,003	
6-1	37	0	360	13,320	2,650	
6-2	36	2	397	14,292	2,940	
6-3	24	4	431	10,344	2,900	2,092 4,011
6-4	10	2	451	4,510	2,865	
6-5	22	1	459	10,098	3,055	
6-6	25	6	480	12,000	2,911	
6-7	24	4	499	11,976	2,918	
6-8	15	0	519	7,785	3,080	
6-9	8	2	534	4,272	3,042	
6-10	11	1	540	5,940	3,099	2,363 4,063

Appendix Table 4 (cont).

Date	Total caught C_t	Recaptures R	Marked fish at large M_t	C_tM_t	Population estimate N	95% Confidence limits
6-11	27	2	550	14,850	3,263	
6-12	11	1	575	6,325	3,319	
6-13	19	2	585	11,115	3,399	
6-14	16	1	602	9,632	3,509	
6-15	12	2	617	7,404	3,515	
6-16	8	0	627	5,016	3,600	
6-17	5	1	635	3,175	3,593	2,796 4,616
6-18	4	1	639	2,556	3,576	
6-19	2	0	642	1,284	3,597	
6-20	3	0	644	1,932	3,629	
6-21	10	2	647	6,470	3,616	
6-22	8	1	655	5,240	3,642	
6-23	2	0	662	1,324	3,662	
6-24	4	1	664	2,656	3,647	2,866 4,639
6-25	0	0	667	0	3,647	
6-26	3	0	667	2,001	3,678	
6-27	8	0	670	5,360	3,760	
6-28	12	1	678	8,136	3,826	
6-29	13	3	689	8,957	3,790	
6-30	9	1	699	6,291	3,826	
7-1	3	1	707	2,121	3,802	3,019 4,786

[a]95% confidence limits are listed every 7th day.