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TEMPERATURE EFFECTS ON EGGS AND FRY OF PERCOID FISHES

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ABSTRACT

Temperature effects on the early life history stages of the walleye (*Stizostedion vitreum vitreum* (Mitchill)) and sauger (*Stizostedion canadense* (Smith)) were examined. Walleye eggs and fry were exposed to six temperatures (6-21 C) for effects on fertilization, incubation, and fry survival. Mature sauger were held and eggs were fertilized at four temperatures (9-18 C). Both species were incubated at 6-21 C. Sauger fry survival was also tested at 6-21 C. Optimum fertilization temperatures were 6-12 C for walleye and 9-15 C for sauger. Optimum incubation temperatures were 12-15 C for both walleye and sauger. A sharp drop or rise in temperature had no great effect on walleye fry and juvenile survival except when the upper lethal or lower lethal temperature was approached. Optimum temperature for juvenile walleye and sauger growth was 22 C. Upper lethal temperatures for walleye juveniles were determined for acclimation temperatures at 2 C intervals between 8-26 C. The upper lethal temperature of walleye juveniles was 27.0-31.6 C, depending on acclimation. The upper lethal temperature of sauger acclimated to 10-26 C was 26.6-30.4 C. There was little temperature difference (1-2 C) between 100% survival and no survival.

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CONTENTS

		Page
Abstract		ii
List of Figures		iv
List of Tables		v
Acknowledgments		vii
Sections		
I	Conclusions	1
II	Recommendations	3
III	Introduction	4
IV	Materials and Methods	6
V	Walleye Egg and Fry Survival	17
VI	Growth of Juvenile Walleyes	29
VII	Effect of a Sudden Temperature Change on Walleye	34
VIII	Walleye Upper Lethal Temperature	40
IX	Sauger Egg and Fry Survival	44
X	Growth of Juvenile Saugers	50
XI	Upper Lethal Temperatures for Sauger Juveniles	52
XII	Discussion	57
XIII	References	61
XIV	Appendix A - Statistical Tables	65
XV	Appendix B - Annotated Bibliography	69

FIGURES

No.		Page
1	Diagram of the Experimental Apparatus	8
2	Diagram of the Continuous Flow-Through Incubation Chamber	9
3	Diagram of the Incubation Cylinder	10
4	Schematic Diagram of the Experimental Design for the Egg and Fry Experiments	18
5	The Combined Effect of Fertilization Temperature and Incubation Temperature on the Hatchability of Walleye Eggs	20
6	Growth of Walleye Juveniles Exposed to Temperatures Ranging from 18 C to 28 C	32
7	TL10 and TL90 Levels of Walleye Juveniles Exposed to Upper Lethal Temperatures	43
8	The Combined Effect of Fertilization Temperature and Incubation Temperature on the Hatchability of Sauger Eggs	45
9	TL10 and TL90 Levels of Sauger Juveniles Exposed to Upper Lethal Temperatures	53

TABLES

No.		Page
1	Temperature, pH, Dissolved Oxygen, and Total Alkalinity of Temperature Experiments	2
2	Chemical Analysis of Laboratory Well Water	4
3	Percentage Hatch of Walleye Eggs Fertilized at Six Temperatures	9
4	Time to Median Hatch in Days for Walleye Eggs Incubated and Fertilized at Six Temperatures	23
5	Size of Walleye Fry at Hatch	25
6	Effect of Six Temperatures on Walleye Eggs and Fry	27
7	Growth of Walleye Juveniles for 28 Days at Different Temperatures	30
8	Effects of Temperature Change on Walleye Fry	36
9	Effects of Sudden Temperature Change on Walleye Juveniles Exposed Below Their Acclimation Temperature	38
10	Effects of Sudden Temperature Change on Walleye Juveniles Exposed Above Their Acclimation Temperature	39
11	Percentage Survival of Walleye Juveniles Exposed to Upper Lethal Temperatures	41
12	Percentage Hatch of Sauger Eggs Fertilized at Four Temperatures	46
13	Effect of Six Constant Temperatures on Sauger Eggs and Fry	48
14	Growth of Sauger Juveniles for 36 Days at Different Temperatures	51
15	Percentage Survival of Sauger Juveniles Acclimated to 10-26 C and Exposed to Higher Temperatures	54

No.		Page
16	Median Survival Time of Juvenile Saugers Acclimated to 10-26 C and Exposed to Upper Lethal Temperatures	55

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SECTION I

CONCLUSIONS

The response of walleyes and sauger to temperature are not greatly different except that the optimum range for fertilization is higher in the sauger. The upper lethal temperature is slightly higher for walleyes.

The optimum temperature range for egg survival in walleyes occurs with fertilization at 6-12 C and incubation at 9-15 C. In sauger the optimum range is 9-15 C for fertilization and 12-15 C for incubation. The incubation temperature TL50 on normalized hatch data for walleyes when maximum hatch is greater than 50% for the fertilization temperatures of 6, 9, and 12 C was 19.0, 20.1, and 19.0 C, respectively. Sauger eggs fertilized at 9, 15, and 18 C had a 50% hatch or greater at the incubation temperatures of 6.5-21.0, 10.2-17.5, and 11.0-17.6 C, respectively. Survival of hatched fry through abosrption of the yolk sac is best at the same temperature range (9-21 C) for both species. Survival to the juvenile stage requires a relatively higher temperature (21 C) than through incubation to yolk sac absorption.

Growth rate of juveniles is optimum for both species at 22 C. A sudden temperature change does not appear to be a significant lethal factor for either species until upper lethal temperature is closely approached or very low temperature (6 C) is reached. The amount of temperature change is not important. Upper lethal temperature for walleye is from 27.0-31.6 C and for sauger 26.6-30.4 C, depending on acclimation temperature.

With acclimation to normal summer ambient temperature (22 C) upper lethal temperature is 31 C and 30 C for nonfeeding fish.

Based on tests when walleye juveniles were exposed to a sudden temperature change, the lower lethal temperaure for walleyes accclimated to 25 C is slightly lower than 8 C.

SECTION II
RECOMMENDATIONS

Recommendations for thermal criteria for saugers and walleyes based on the laboratory studies reported here indicate different levels for spawning and incubation and for later stages. For the period of fertilization and incubation temperature should not exceed 15 C. During the period of early fry development temperature should not exceed 18-21 C. Summer temperature should not exceed a weekly average of 24 C or a maximum of 27 C to insure sustained growth and survival of juveniles.

SECTION III

INTRODUCTION

Increased steam power requirements will add to problems of thermal pollution during the immediate future. It is therefore important to define temperature requirements for all life history stages of fish. The effect of temperature is most critical during the early life history stages but is probably most noticeable for its effect on sustained growth and survival.

The determination of temperature effects on the early life history stages of the walleye, Stizostedion vitreum vitreum (Mitchill), and sauger, Stizostedion canadense canadense (Smith), is necessary to establish thermal criteria for these species. To determine temperature influence on early life history stages of walleyes and saugers both optimum and critical temperatures must be defined. Definitive information is scarce on detrimental effects of high temperatures on the Stizostedion species as well as optimum temperatures for different life stages. Many authors have reported that walleye spawning generally takes place in a temperature range of 6-12 C (Bradshaw and Muir[1], Cobb[2], Eddy and Surber[3], Ellis and Giles[4], Eschmeyer[5], Grinstead[6], Johnson[7], Niemuth et al.[8], Payne[9], Priegel[10], Rawson[11], Schumann[12], and Spinner[13]). Others have reported that sauger spawn generally at the same temperature range as the walleye (Carufel[14], Nelson[15], and Priegel[16]). Priegel[17] reported that walleye eggs will hatch in 21 days at temperatures of 10-12 C while saugers will hatch in 13-15 days at that temperature. Various authors have reported thermal effects on egg survival. Steucke[18] concluded that the apparent optimum temperature range for hatching walleye eggs is 16.7-19.4 C. Furthermore it was pointed out by Allbaugh and Manz[19] that temperature fluctuations during incubation of walleye eggs had no great effect on the percentage hatch. Johnson[7] showed that best egg survival in natural conditions occurred in years of warm water temperatures and shorter incubation periods. Therefore, the effect of higher temperature caused by electric generating power plants could have both beneficial and detrimental effects on walleye survival.

The objective of the present investigation was to determine thermal requirements for early life history stages of the walleye and sauger and to provide a basis for the establishment of accurate water quality criteria. These studies include the determination of lethal and sublethal temperature effects on eggs, fry, and juveniles tested in the laboratory at the University of Minnesota. The specific objectives of the study were to determine: 1) optimum temperatures for egg and fry survival; 2) optimum temperatures for juvenile growth; 3) effects of a sudden temperature change on fry and juveniles; and 4) the upper lethal temperatures for juveniles. Optimum temperatures for fertilization, incubation, and fry survival were determined. Juvenile fish were exposed to a series of constant temperatures to determine optimum growth levels. Walleye fry and juveniles were also subjected to a series of test temperatures to determine the effect of a temperature change on survival. To conclude the study, walleye and sauger juveniles were exposed to high temperatures to determine the upper lethal temperatures after acclimation to a series of temperatures.

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SECTION IV

MATERIALS AND METHODS

EXPERIMENTAL FISH STOCK

Adult walleyes were secured from Little Cutfoot Sioux Lake and Upper Red Lake in the spring of 1971 and 1972. The fish were captured with trapnets by the Minnesota Department of Natural Resources during the spawning run. Adult saugers were taken from Lake Winnebago, Wisconsin in 1972 and from the Mississippi River, below Lock and Dam #3 in Red Wing during the spring of 1972 and 1973. The saugers from Lake Winnebago were captured with trapnets by the Wisconcin Department of Natural Resources during the spawning period. Fish from the Mississippi River were collected with a boom shocker by the Minnesota Department of Natural Resources during the spawning run. Adult fish were taken 1 to 2 days prior to full ripeness and transposted to the laboratory at the University of Minnesota in 100 gallon stock tanks aerated with compressed air.

Juvenile walleyes were secured from natural rearing ponds stocked by the Minnesota Department of Natural Resources. These fish were captured in July and August of 1971 and 1972 with seine nets and small-mesh trapnets. Juvenile saugers were collected from Lake Pepin, Minnesota with a seining net during the months of July and August 1973.

EXPERIMENTAL APPARATUS

Apparatus used for thermal tests consisted of six polyethylene head tanks, each with 114 liters capacity. The temperature of the water entering the head tanks was 10 C for experiments conducted above 10 C. Chilled water at 4 C was supplied in head tanks in experiments run at less than 10 C. The water was aerated in each head tank to produce an oxygen concentration of 5 mg/liter or greater.

The temperature in each head tank was controlled with a bimetal thermoregulator wired through a relay to two 1000-watt immersion heaters. They maintained temperatures in the experimental chambers within a range of ± 0.2-0.3 C (SD = 0.26) of the desired temperature of each experiment.

After temperature adjustment water was fed to a set of experimental incubation, fry, and juvenile test chambers. Water from the head tank flowed by gravity through 3/4 inch polyvinyl chloride pipe to each set of chambers and then through tygon tubing to individual chambers (Figure 1).

Eggs were tested in incubation chambers consisting of acrylic tubes 10 cm long, with an inside diameter of 3.8 cm. Inside the cylinder, 5 cm from the top, the eggs lay on #656 Nitex screen where water flowed past at an average rate of 325 ml/min (range, 200-425). The incubation cylinders were submerged in small, 13.5 x 10.5 x 20 cm, cases with three glass sides and one of #656 Nitex screen. These cases were placed in larger aquaria so that the cylinders were submerged but not the top of the cases. This arrangement allowed the fry to swim out of the incubation cylinders and be removed to larger fry chambers. Incubation chambers are shown in Figures 2 and 3.

Fry chambers were set up in a flow-through system consisting of glass aquaria 25 x 25 x 50 cm, constructed of double strength window glass and silicone adhesive (General Electric Silicone Seal). An outlet tube (1/2 inch OD) set 20 cm from the bottom maintained a volume of 25 liters in the chamber. The flow rate through the aquaria was about 1 liter/min (± 100 ml).

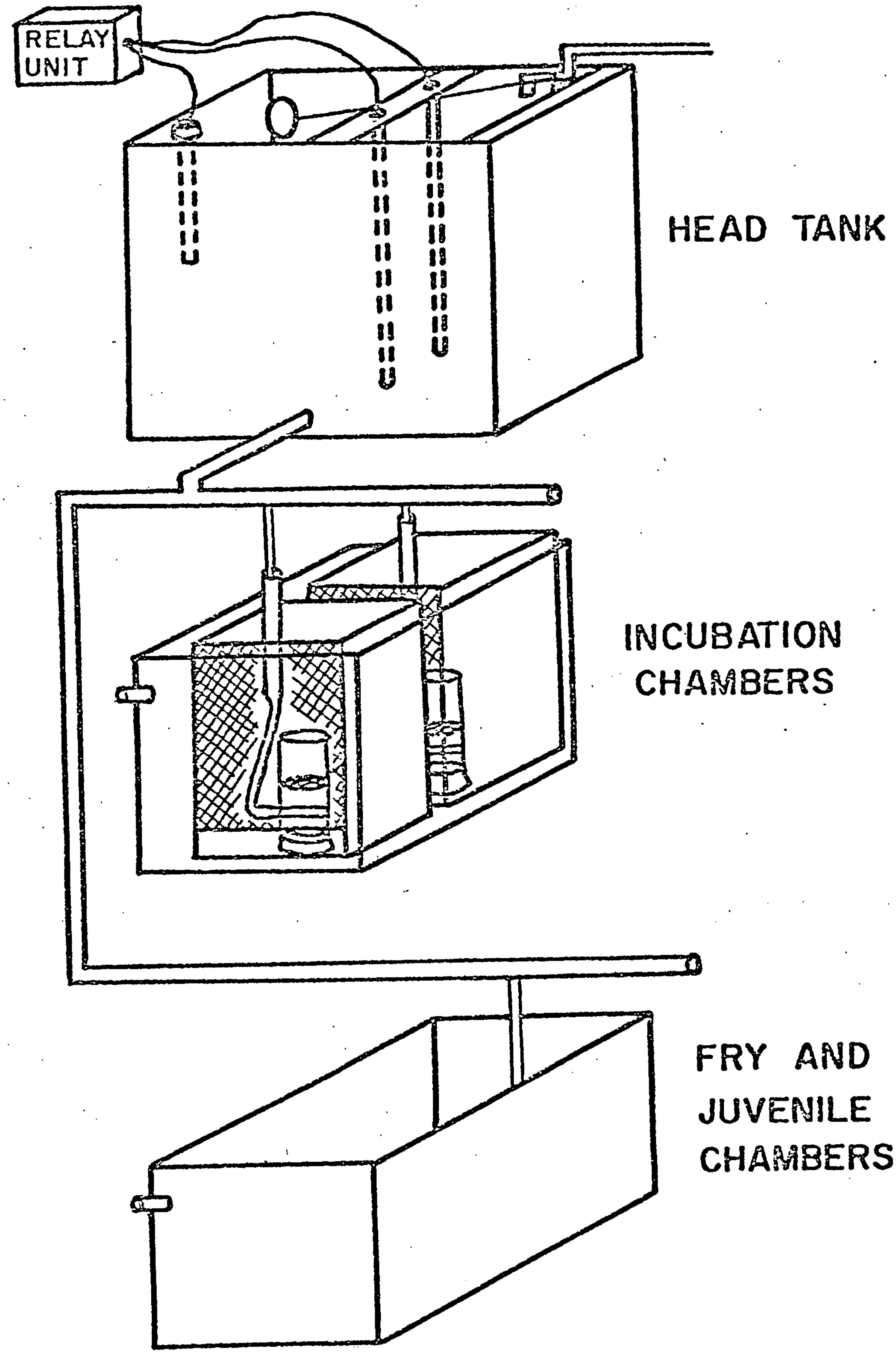

Figure 1. Diagram of the experimental apparatus showing the head tank, incubation chambers, and fry chambers.

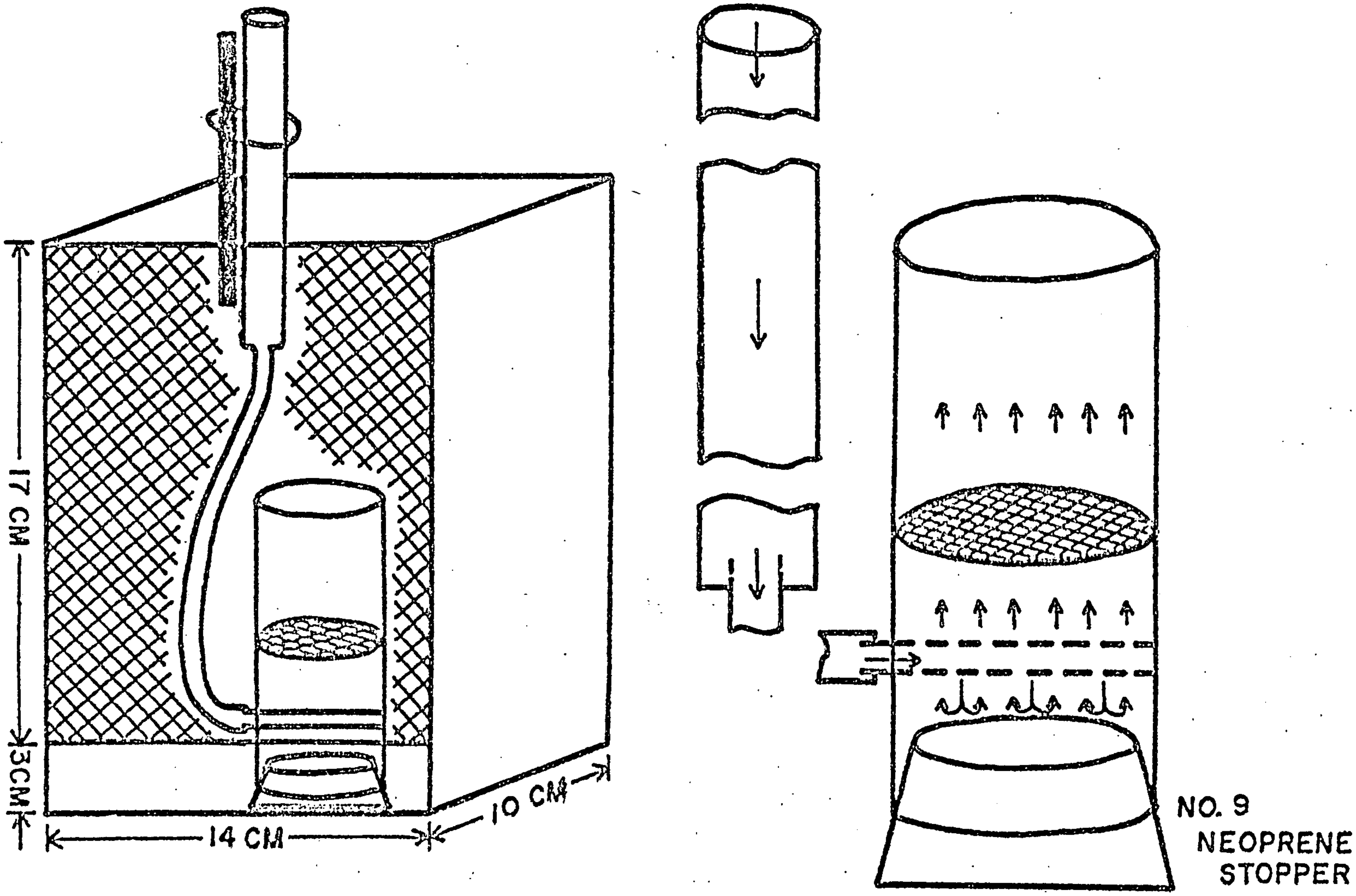

Figure 2. Diagram of the continuous flow-through incubation chamber.

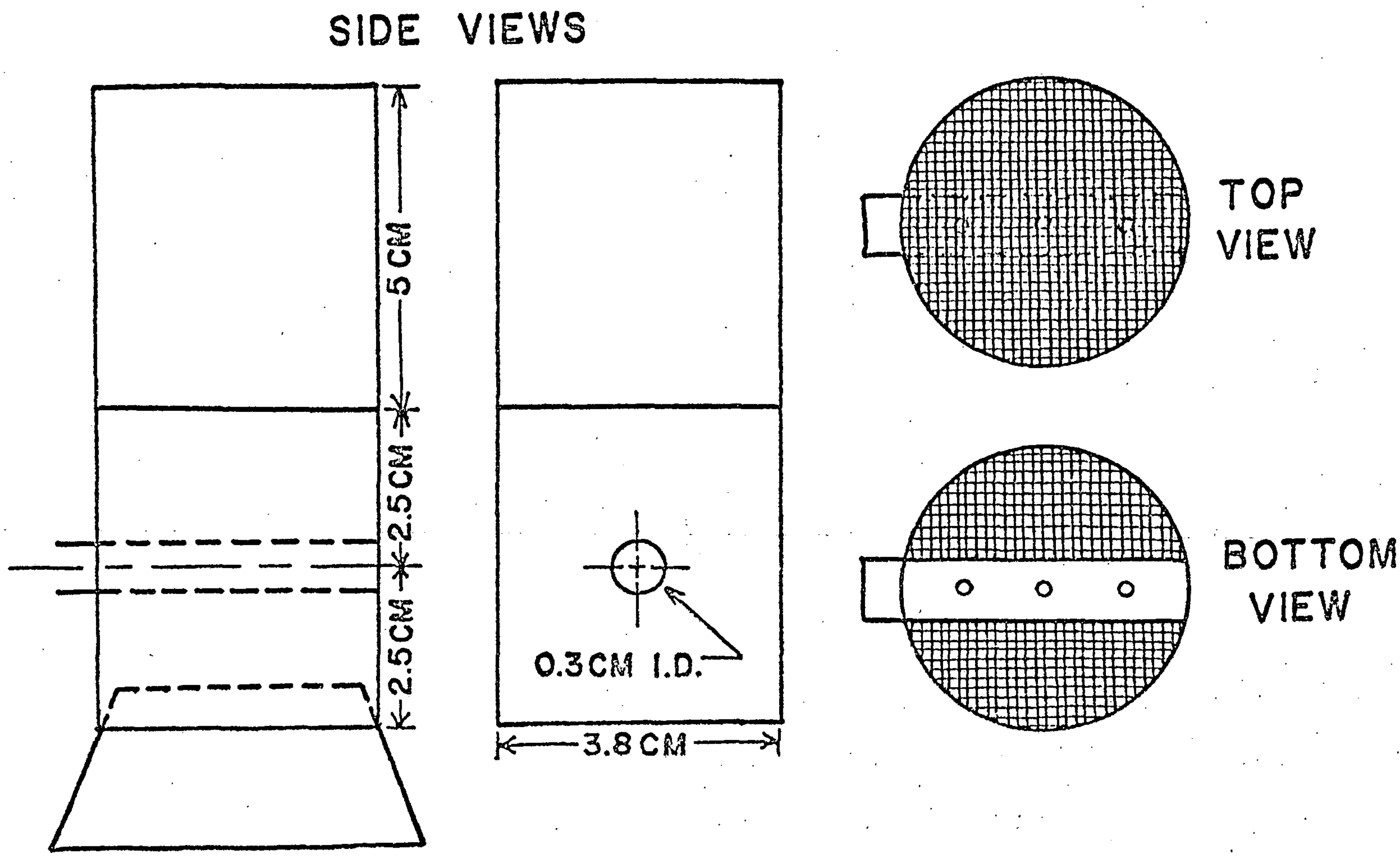

Figure 3. Diagram of the incubation cylinder showing the top, bottom, and side views.

The chambers used for tests on juveniles were identical to the fry chambers except that a higher flow rate was used. Flow rates were controlled with a utility clamp and were adjusted according to the temperature level with flows at higher temperatures of about 2 liters/min. Each chamber was lighted with a 40 watt incandescent light placed approximately 2 feet from the water surface and the photoperiod was adjusted bi-monthly to follow the natural environmental day length cycles.

TEST WATER CONDITIONS

The incubation, fry survival, and growth experiments were conducted at six constant temperatures. The temperature, pH, oxygen concentration, and total alkalinity for the tests are shown in Table 1. The temperature was measured daily with a total immersion thermometer graduated to 0.1 C. A 24 channel temperature recorder was used to monitor temperature variation through the tests. Hydrogen-ion concentration was measured bi-weekly with the azide modification of the Winkler method (APHA[20]). Total alkalinity was determined weekly as mg/liter $CaCO_3$ by the brom-cresol method (Dobie and Moyle[21]). Temperatures fluctuated only slightly, the pH averaged 8.00, the O_2 concentration was 5.8 mg/liter or greater depending on the temperature, and the total alkalinity averaged 225 mg/liter.

Test water was taken from the laboratory well which had a pH at 10 C of 7.5. A complete analysis of water was made by the Minnesota Department of Health, Division of Environmental Sanitation (Table 2).

ACCLIMATION PROCEDURE

The adult fish taken in the field at 5-10 C were acclimated to six test temperatures in the laboratory (6, 9, 12, 15, 18, and 21 C) before they were stripped for eggs. When brought into the laboratory the adults were placed in 335 gallon holding tanks at the temperature of capture. Twelve hours later temperatures were changed in 24 hours

Table 1. TEMPERATURE, pH, DISSOLVED OXYGEN (O_2), AND TOTAL ALKALINITY OF TEMPERATURE EXPERIMENTS

Test	Nominal temperature, C	Observed temperature: Mean, C	Observed temperature: Standard deviation, C	pH	Mean O_2 mg/l	Mean TA mg/l
Walleye	6	6.2	$\pm$0.32	-	8.1	236
adult ac-	9	9.1	$\pm$0.11	-	7.9	232
climation	12	12.0	$\pm$0.14	-	8.0	225
and ferti-	15	15.2	$\pm$0.27	-	7.4	234
lization	18	17.9	$\pm$0.09	-	7.2	237
	21	20.9	$\pm$0.12	-	7.9	215
Sauger						
adult ac-	9	9.2	$\pm$0.16	-	7.8	225
climation	12	11.9	$\pm$0.10	-	7.9	230
and ferti-	15	15.0	$\pm$0.11	-	7.5	215
lization	18	18.2	$\pm$0.21	-	8.0	230
Walleye and sauger	6	6.0	$\pm$0.22	8.0	8.0	232
egg incubation	9	8.9	$\pm$0.26	7.9	7.1	232
and fry	12	12.0	$\pm$0.07	8.0	7.6	227
survival	15	15.0	$\pm$0.19	8.0	7.3	215
	18	18.1	$\pm$0.21	8.0	7.5	230
	21	20.9	$\pm$0.22	8.1	8.4	230
Walleye	16	16.3	$\pm$0.16	8.1	9.4	238
juvenile	21	21.1	$\pm$0.24	8.2	8.3	236
growth I	25	25.2	$\pm$0.26	8.2	8.6	238

Table 1 (continued).

Test	Nominal temperature, C	Observed temperature Mean, C	Observed temperature Standard deviation, C	pH	Mean O_2 mg/l	Mean TA mg/l
Walleye	18	18.1	±0.13	8.1	7.6	232
juvenile	20	20.2	±0.15	8.1	7.0	232
growth II	22	22.1	±0.08	8.2	7.0	225
	24	23.9	±0.08	8.2	6.8	234
	26	26.0	±0.12	8.3	6.1	237
	28	28.0	±0.14	8.2	6.1	215
Sauger	16	16.1	±0.09	8.2	7.9	230
juvenile	18	18.1	±0.08	8.2	6.8	234
growth	20	20.0	±0.12	8.3	7.0	237
	22	22.0	±0.11	8.3	6.1	237
	26	26.0	±0.10	8.3	5.8	232

Table 2. CHEMICAL ANALYSIS OF LABORATORY WELL WATER

Item	Concentration, mg/liter
Total hardness as $CaCO_3$	220
Alkalinity as $CaCO_3$	230
Iron	0.02
Manganese	0.04
Chloride	<1
Sulphate	<5
Fluoride	0.22
Total phosphorus	0.03
Methylene blue active sub. as ABS	0.1
Calcium as $CaCO_3$	140
Sodium	6
Potassium	2
Ammonia nitrogen	0.20
Organic nitrogen	0.20
Phenols	<0.005
Copper	<0.01
Cadmium	<0.01
Zinc	<0.01
Nickel	<0.01
Lead	<0.01

to the test temperatures which ranged from 6 to 21 C. The water temperature was controlled in each tank with a polyethylene heat exchanger. After acclimation temperature was reached the fish were held from 1 to 2 days before being stripped. The fish were stripped when eggs were released by the females when minimum pressure was applied to the lower abdomen.

Juveniles were captured in the field when the water temperature ranged from 18 to 24 C. At the laboratory, they were given a prophylactic treatment of 20 mg/liter neomycin sulfate for 3 days before the acclimation process was started. The holding tanks were then flushed and the temperature was raised with a polyethylene heat exchanger. The fish were acclimated at a rate of 2 C/day and were held at the desired test temperature for at least 2 weeks before testing was initiated. During acclimation fish were fed with fathead minnows. The fish were held in a flow-through system thus requirements for cleaning tanks were minimal. Tanks were siphoned clean every other day. At the time of testing fish were transferred in plastic pails to the test chambers without going through a temperature change.

EGG STRIPPING

Adult fish were stripped and eggs were fertilized at the same water temperature to which the adults were acclimated. Eggs from two females were stripped into a Nalgene beaker, then seconds later milt was stripped from two males and mixed thoroughly with the eggs. At the same time the milt was added, water at the required fertilization temperature was gradually introduced and mixed. Finally bentonite clay was added to the fertilized eggs to prevent clumping. The eggs were then rinsed clean and the beaker was then placed in a water bath to acclimate the eggs to their respective incubation temperatures and allow them to water harden. Within 1 hour after fertilization the eggs were examined under a microscope and 100 to 300 pooled eggs were randomly removed with an eye dropper and placed in the incubation chambers. Eggs that were small and opaque were discarded. The number of opaque eggs varied from 0 to 80% with no relation to temperature of fertilization.

EGG TEST PROCEDURE

Eggs were counted, dead eggs were removed, and mortality counts were recorded daily. Only eggs that had turned white were counted as dead. Live eggs were not handled and remained in the incubation chambers until hatched.

FRY TEST PROCEDURE

Upon hatching fry were removed with a glass tube and gradually transferred to the fry chambers. Fry were sampled for size determinations each day after hatching started. Ten percent of the fry from each day's hatch were randomly removed and preserved in 5% formalin, and 100 fry were placed in each fry chamber for survival tests. All fry were fed twice a day with natural plankton which consisted mostly of copepods and once a day with brine shrimp. Black plastic sheets were taped to the outside walls of all aquaria since it was found that fry in chambers without the black walls did not swim freely but clung to the sides of the chamber without feeding and eventually died. Fry in chambers with black walls swam freely and fed well.

SECTION V

WALLEYE EGG AND FRY SURVIVAL

EXPERIMENTAL DESIGN

Walleye adults were acclimated to six different temperatures, 6, 9, 12, 15, 18, and 21 C. After the adults became ripe, the fish were stripped and the eggs were fertilized at the same six temperatures. To separate the effects of fertilization (parental) temperature and incubation temperature on the hatchability of eggs, the eggs fertilized at each temperature were incubated at six different temperatures, 6, 9, 12, 15, 18, and 21 C. The fry hatched at these temperatures were carried through at the same six temperatures to determine fry survival to yolk sac absorbtion and to the juvenile stage. This design is schematically shown in Figure 4.

HATCHABILITY OF WALLEYE EGGS

Effect of Fertilization Temperature on Hatch

The tests described above on walleye eggs determined the optimum incubation and fertilization temperature range for hatch and permitted separation of effects of incubation temperature, fertilization temperature, or interaction between the two on egg mortality (Table 3, Figure 5).

The lowest fertilization temperature, 6 C, resulted in the highest percentage hatch for each of the incubation temperatures except for the highest, 21 C, where 0.0% of eggs survived. A maximum hatch of 84.0% was obtained at a fertilization temperature of 6 C and an incubation temperature of 6 C. As the fertilization temperature increased the percentage hatch progressively decreased with the highest fertilization temperature resulting in the lowest percentage hatch. At a fertilization temperature of 21 C the percentage hatch ranged from 10.0% at an

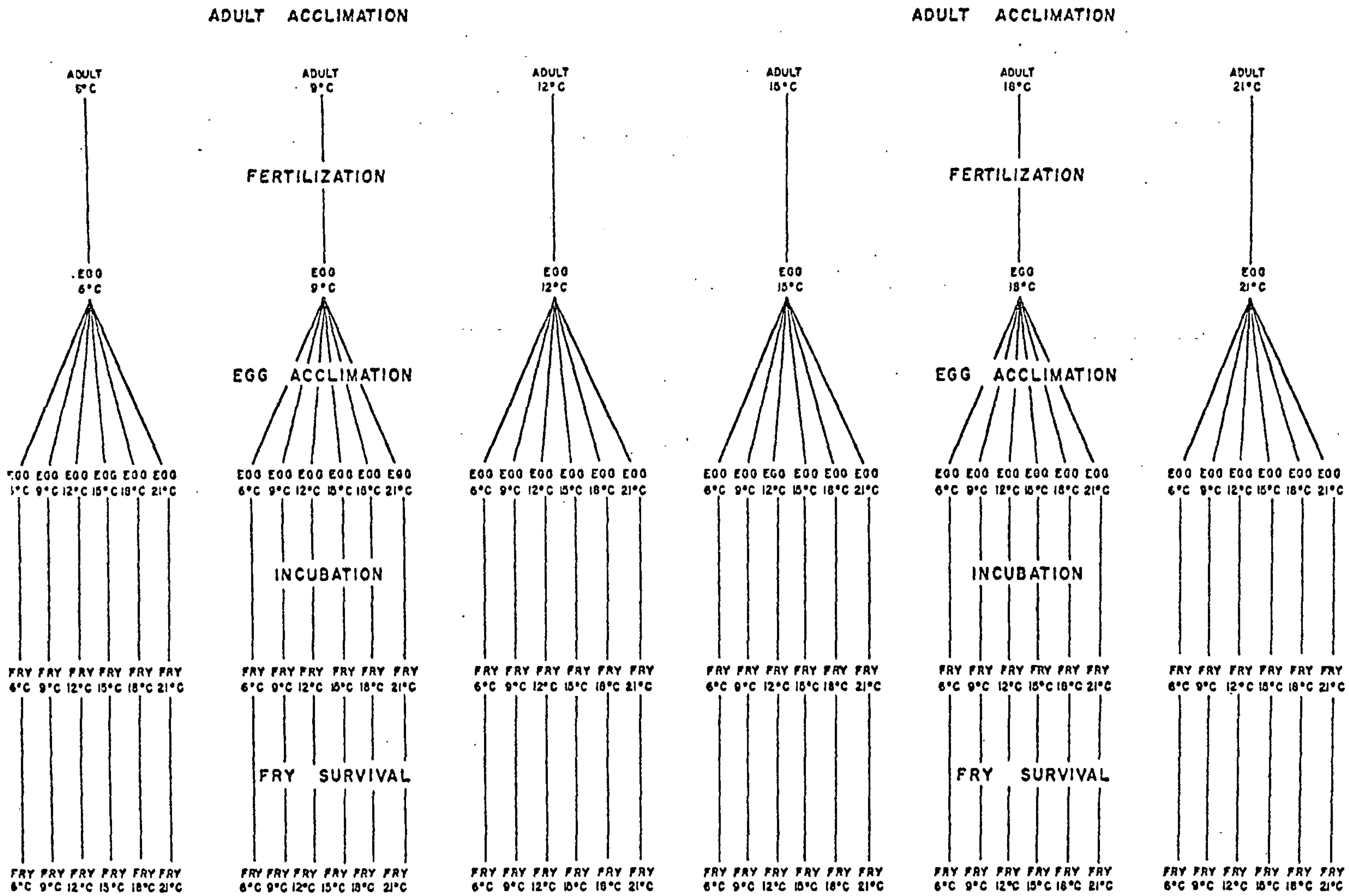

Figure 4. Schematic diagram of the experimental design for the egg and fry experiments.

Table 3. PERCENTAGE HATCH OF WALLEYE EGGS FERTILIZED AT 6 DIFFERENT TEMPERATURES AND INCUBATED AT 6 DIFFERENT TEMPERATURES

Fertilization temperature, C	Incubation temperature, C					
	6.0	8.9	12.0	15.0	18.1	20.9
6.2	84.0	77.0	77.0	80.0	63.0	0.0
9.1	51.0	66.5	67.0	73.0	61.0	23.0
12.0	37.7	59.0	61.5	53.0	38.0	10.0
15.2	5.0	11.0	15.0	15.0	0.0	0.0
17.9	11.0	39.0	27.0	41.0	32.0	1.0
20.9	1.0	5.0	10.0	7.0	0.0	0.0

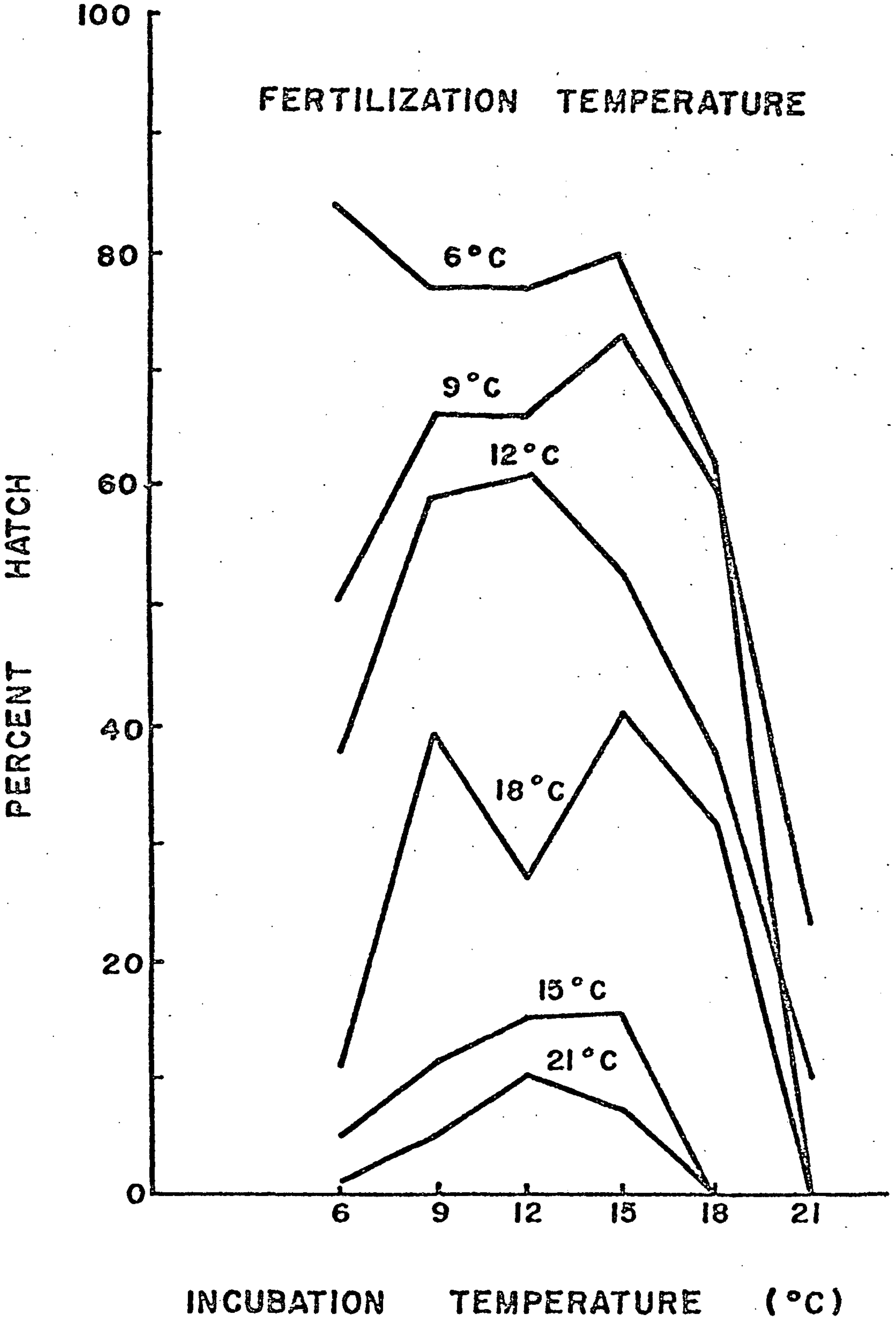

Figure 5. The combined effect of fertilization temperature and incubation temperature on the hatchability of walleye eggs. Each line represents the percentage hatch of eggs fertilized at one of six temperatures and incubated at six temperatures, 6C, 9C, 12C, 15 C, 18C, and 21C.

incubation temperature of 12 C to 0.0% at incubation temperatures of 18 and 21 C. At a fertilization temperature of 18 C the percentage hatch ranged from 41.0% at an incubation temperature of 15 C to 1.0% at an incubation temperature of 21 C. The percentage hatch of eggs fertilized at 15 C ranged from 15.0% at the incubation temperatures of 12 and 15 C to 0.0% at the incubation temperatures of 18 and 21 C. At a fertilization temperature of 12 C the percentage hatch ranged from 61.5% at an incubation temperature of 12 C to 10.0% at an incubation temperature of 21 C. Eggs fertilized at 9 C resulted in a percentage hatch that ranged from 73.0% at an incubation temperature of 15 C to 23.0% at an incubation temperature of 21 C. With fertilization at 6 C the percentage hatch ranged from 84.0% at an incubation temperature of 6 C to 0.0% at an incubation temperature of 21 C.

The effect of incubation temperatures on the hatchability was modified substantially by temperature at fertilization. Independent of the effect of fertilization temperature the greatest percentage hatch was at incubation temperatures of 9-15 C. The lowest percentage hatch was at incubation temperatures of 6 and 21 C. The only exception was at a fertilization temperature of 6 C and an incubation temperature of 6 C, where 84.0% hatch was obtained. The 21 C incubation temperature appears to be lethal for eggs fertilized at all temperatures. At the incubation temperatures of 6 to 18 C there was a mean difference between the highest and lowest percentage hatch of 19.5% (range 10.0-30.0) for all fertilization temperatures. The incubation temperature of 21 C was not included in this analysis for the reasons stated above. The TL50, when maximum hatch is greater than 50%, of the incubation temperature for each fertilization temperature was 19.0 C for the fertilization temperatures of 6 and 12 C and 20.1 C for the fertilization temperature of 9 C.

To determine whether any interaction occurred between the fertilization temperature and the incubation temperature, a statistical analysis was done using a 3-dimensional contingency table (Feinberg[22]). Setting up the data in a 6 x 6 x 2 contingency table and by comparing the Freeman-Tukey Deviations, it was determined that the only place where statistically real interaction occurred was at the 6 C incubation and 6 C fertilization temperatures. At this point there was an unexpected high percentage egg survival. The observed survival was 84.0% while the expected egg survival was 64.29%. Appendix A, Table 1 lists all expected values of egg survival for all incubation and fertilization temperatures.

Effect of Fertilization Temperature on Fry Size

Walleye fry hatched from eggs fertilized at six different temperatures, 6-21 C, were measured from each of the six incubation temperatures.

Time to hatch did not vary between fertilization temperatures within each incubation temperature (Table 4), but the size of the fry showed a significant difference at the .05 level between the fertilization temperatures for each incubation temperature, except at the incubation temperature of 18 C. It was determined from regression analysis that the size of the fry at each fertilization temperature played a significant part in the regression equations calculated for each incubation temperature. The regression equations were determined with the use of dummy variables representing each fertilization temperature. This procedure was done to avoid testing only for a straight line. The dummy variables are presented in Appendix A, Tables 2 and 3. The regression equations determined for each incubation temperature are as follows:

$$6\text{ C}\quad Y = 1.6054 + .0143X_1 + .0124X_2 - .0035X_3 - .0137X_4 - .0088X_5 + .0036X_6 \qquad (1)$$

Table 4. TIME TO MEDIAN HATCH IN DAYS FOR WALLEYE EGGS INCUBATED AND FERTILIZED AT 6 DIFFERENT TEMPERATURES

Nominal incubation temperature, C	Nominal fertilization temperature, C					
	6	9	12	15	18	21
6	34	34	33	33	35	33
9	26	27	25	25	26	25
12	16	17	15	14	14	16
15	10	11	10	10	10	10
18	7	8	7	--	7	--
21	--	6	5	--	--	--

$$9\ C \quad Y = 1.5432 + .0157X_1 + .0130X_2 - .0190X_3 - .0328X_4 + .0288X_5 + .0103X_6 \qquad (2)$$

$$12\ C \quad Y = 1.6645 + .0076X_1 + .0102X_2 + .0137X_3 - .0141X_4 - .0117X_5 + .0121X_6 \qquad (3)$$

$$15\ C \quad Y = 1.6802 + .0025X_1 + .0100X_2 + .0238X_3 - .0130X_4 - .0019X_5 + .0161X_6 \qquad (4)$$

$$18\ C \quad Y = 1.6363 - .0027X_1 - .0069X_2 + .0097X_3 + .0267X_6 \qquad (5)$$

where $Y = \log\frac{(\text{size in mm})}{.1063}$

X_1-X_5 = dummy variables (see Appendix A, Tables 2 and 3)

X_6 = Mean number of days to hatch.

The F-ratios calculated for each incubation temperature were as follows (*significant at .05 level):

6 C F = 2.51*

9 C F = 27.40*

12 C F = 8.25*

15 C F = 8.47*

18 C F = .8151

Table 5 shows the size of the fry at the different temperatures calculated from the regression equations.

With incubation temperatures of 6 C, 9 C, 12 C, and 15 C, the size of the fry at hatch was consistently greater at the lower fertilization temperatures, 6 and 9 C. At the incubation temperature of 18 C there was no significant difference at the .05 level in the size of the fry

Table 5. SIZE OF WALLEYE FRY (MILLIMETERS) AT HATCH CALCULATED FROM THE REGRESSION EQUATIONS

Number of Measurements in Parentheses

Incubation temperature, C	Fertilization temperature, C						Mean number of days to hatch
	6	9	12	15	18	21	
6	6.06(16)	6.03(11)	5.81(12)	5.68(2)	5.75(6)	5.86(1)	37.8
9	7.09(13)	7.05(13)	6.55(11)	6.35(7)	7.29(11)	6.75(4)	25.8
12	7.66(12)	7.72(8)	7.77(12)	7.13(3)	7.33(6)	7.44(5)	15.4
15	7.53(9)	7.65(11)	7.90(9)	7.26(5)	7.45(7)	7.12(1)	10.4
18	7.18(8)	7.11(8)	7.39(5)	-	7.22(6)	-	7.3

between the fertilization temperatures. Due to the low hatch at the incubation temperature of 21 C, the sample size was too small for any type of statistical analysis.

Effect of Constant Temperature on Eggs and Fry

Eggs and fry were held at six constant temperatures through fertilization, incubation, and after hatching. Fry were held to the juvenile stage. Survival of eggs, sac fry, and juveniles as well as time to hatch and size of the fry at hatch were determined (Table 6). Replicates were combined in the final analysis since there was no significant difference found at the .05 level between the replicates.

The lowest temperature, 6 C, resulted in the highest percentage hatch (84.0%) and progressively decreased as the temperature increased, with the highest temperature, 21 C, resulting in 0.0% hatch. As noted above, the high egg survival at 6 C was caused by the interaction of the fertilization temperature and the incubation temperature. If interaction had not occurred, the hatch at 6 C (expected hatch of 64.29%) would have been about the same as the egg survival at 9 C (66.5%) and 12 C (61.5%). Temperatures higher than 12 C had a much lower percentage hatch with 15 C resulting in a 15.0% hatch and 18 C in a 32.0% hatch.

Incidence of abnormalities in fry increased as the temperature increased. The percentage of fry abnormalities was 1.0-3.8% at a temperature range of 6-15 C and increased up to 15-18% at 18 and 21 C, respectively. Percentage of abnormal fry was included in total hatch.

Time to first hatch, to median hatch, and to the completion of hatch was 30, 34, and 49 days at 6 C; 23, 27, and 31 days at 9 C; 12, 15, and 18 days at 12 C; 8, 10, and 11 days at 15 C; 6, 7, and 8 days at

Table 6. THE EFFECT OF 6 DIFFERENT TEMPERATURES ON WALLEYE EGGS AND FRY [a/] HELD AT A CONSTANT TEMPERATURE DURING FERTILIZATION, INCUBATION, AND AFTER HATCHING

Temperature, C	Egg survival[b/] %	Abnormal fry, %	Days to first hatch	Days to median hatch	Days to completion hatch	Mean size at hatch, mm	Survival of sac fry,[c/] %	Survival to juvenile stage,[d/] %
6.0	84.0	1.0	30	34	49	6.0	0	0
8.9	66.5	3.8	23	27	31	7.3	78	0
12.0	61.5	3.3	12	15	18	7.8	88	0
15.0	15.0	1.0	8	10	11	7.2	95	0
18.1	32.0	15.0	6	7	8	7.2	97	1
20.9	0.0	18.0	5[e/]	5[e/]	6[e/]	6.6[e/]	98[e/]	8[e/]

a/ Fry data was determined from 100 hatched fry that were taken at random from the total hatch at each temperature. Abnormal fry were not included.
b/ 200 eggs tested at each temperature.
c/ The sac fry stage was determined to be from hatch to the disappearance of the yolk sac.
d/ Fish were denoted as juveniles when they reached a length of 40 mm.
e/ Data obtained from fry hatched from eggs incubated at 21 C but fertilized at 9 and 12 C.

18 C; and 5, 5, and 6 days at 21 C. Time to first hatch (30 days), median hatch (34 days), and to the completion of hatch (49 days) was longest at the lowest temperature, 6 C, and decreased exponentially to a minimum of 5 days to first hatch, 5 days to median hatch, and 6 days to the completion of hatch at the highest temperature, 21 C.

The mean size of the fry at hatch varied from 6.0 mm at 6 C to 7.8 mm at 12 C. The mean size of the fry at hatch was greatest (7.2-7.8 mm) at the intermediate temperatures, 9-18 C, and least at the temperature extremes, 6 and 21 C, where the mean size of the fry were 6.0 and 6.6 mm, respectively.

The survival of walleye fry from hatch to resorbtion of the yolk sac was high (78-98%) at all temperatures except 6 C. At this temperature the fry never resorbed their yolk sac completely and eventually died about 30 days after hatching.

Total survival of walleye fry from hatch to the juvenile stage was very low. All fry died at the four lowest temperatures and there was only 1% survival at 18 C. At 21 C, 8% of the fry survived to the juvenile stage. The fry at 6, 9, and 12 C never accepted food, but the fry at the higher temperatures, 15, 18, and 21 C, did accept food. A few walleye fry at 15 C accepted food, at 18 C about 50% fed, and at 21 C about 75% of the fry fed on plankton.

SECTION VI

GROWTH OF JUVENILE WALLEYES

EXPERIMENTAL DESIGN

Two experiments were conducted to determine the optimum temperature for growth of walleye juveniles in 1971 and 1972. The growth tests were made in constant-flow chambers of 25-liter capacity. Temperatures from 16-28 C were used and all tests consisted of two replicates with 10 fish in each. The replicates were combined in the final analysis since there was no significant difference at the .05 level found between them. The fish were distributed randomly to the respective chambers and acclimated therein. They were allowed to feed on an excess of small fathead minnows (*Pimephales promelas*). The walleyes were weighed and measured to 0.01 g at the beginning and at the completion of the 28-day test. To facilitate measurement they were anesthetized with tricaine methanesulfonate (MS 222) at a concentration of 100 mg/liter. Total length was measured to the nearest millimeter.

GROWTH AT 16 C, 21 C, AND 25 C (1971)

In 1971 walleye juveniles were grown at three temperatures: 16, 21, and 25 C (Table 7). Mean weights of the fish at the beginning of the test were 2.00, 1.91, and 1.81 g at 16, 21, and 25 C, respectively. The greatest increment in length and weight was at 25 C with an increase in length of 69.7% and in weight of 429.3%. The specific growth rate was 5.950. Growth decreased progressively with a decrease in temperature, with the lowest gain in weight occurring at 16 C where the fish increased 35.5% in length and 156.5% in weight. The corresponding specific growth rate at this temperature was 3.371.

Table 7. GROWTH OF WALLEYE JUVENILES FOR 28 DAYS AT DIFFERENT TEMPERATURES

Temperature, C	Mean length at start of test, mm	Increase in length, mm	Increase in length, %	Mean weight at start of test, g	Increase in weight, g	Increase in weight, %	Specific growth rate, %/day	Survival, %
16.3	65.1	23.1	35.5	2.00	3.13	156.5	3.371	100
21.1	65.0	39.0	60.0	1.91	6.53	341.9	5.325	100
25.2	63.7	44.4	69.7	1.81	7.77	429.3	5.950	100
18.1	84.2	25.8	30.6	4.30	6.48	150.7	3.286	100
20.2	84.6	31.6	37.4	4.59	8.13	177.1	3.639	100
22.1	85.5	36.1	42.2	4.62	9.58	207.4	4.007	100
23.9	85.7	32.6	38.0	4.71	7.79	165.4	3.482	80
26.0	85.2	29.3	34.4	4.42	6.66	150.7	3.286	80
28.0	86.5	23.7	27.4	4.94	5.15	104.3	2.546	60

GROWTH AT 18-28 C (1972)

In 1972 walleye juvenile growth was tested at six temperatures, 18, 20, 22, 24, 26, and 28 C (Table 7). The mean weight of these fish at the beginning of the test was 4.30 g at 18 C, 4.59 g at 20 C, 4.62 g at 22 C, 4.71 g at 24 C, 4.42 g at 26 C, and 4.94 g at 28 C. Maximum growth was at 22 C where the juveniles increased 42.2% in length and 207.4% in weight and had a corresponding specific growth rate of 4.007. Minimum growth was obtained at 28 C. At this temperature the juveniles tained 27.4% in length, 104.3% in weight and had a specific growth rate of 2.546. At 18 and 26 C the growth rate was identical. Although the percentage gain in length at 18 C (30.6%) differed from 26 C (34.4%), the specific growth rate was 3.286 and the percentage gain in weight was 150.7% for both temperatures. The rate of increase in the specific growth rate between 18 and 22 C was the same as the rate of decrease between 22 and 26 C.

A multiple regression analysis was done to determine the temperature where the asymptote of the growth curve occurs. The regression equation describing the growth of walleye juveniles of 1972 at different temperatures was determined to be

$$Y = -50.917 + 5.3740X - .1211X^2 \qquad (6)$$

where Y = weight increase in grams

X = temperature in C.

This equation has an R^2 of 79.3%, which indicates that the resulting binomial curve reduced the variability in the data by 20.7%. Curves for both the actual data and the predicted data are shown in Figure 6.

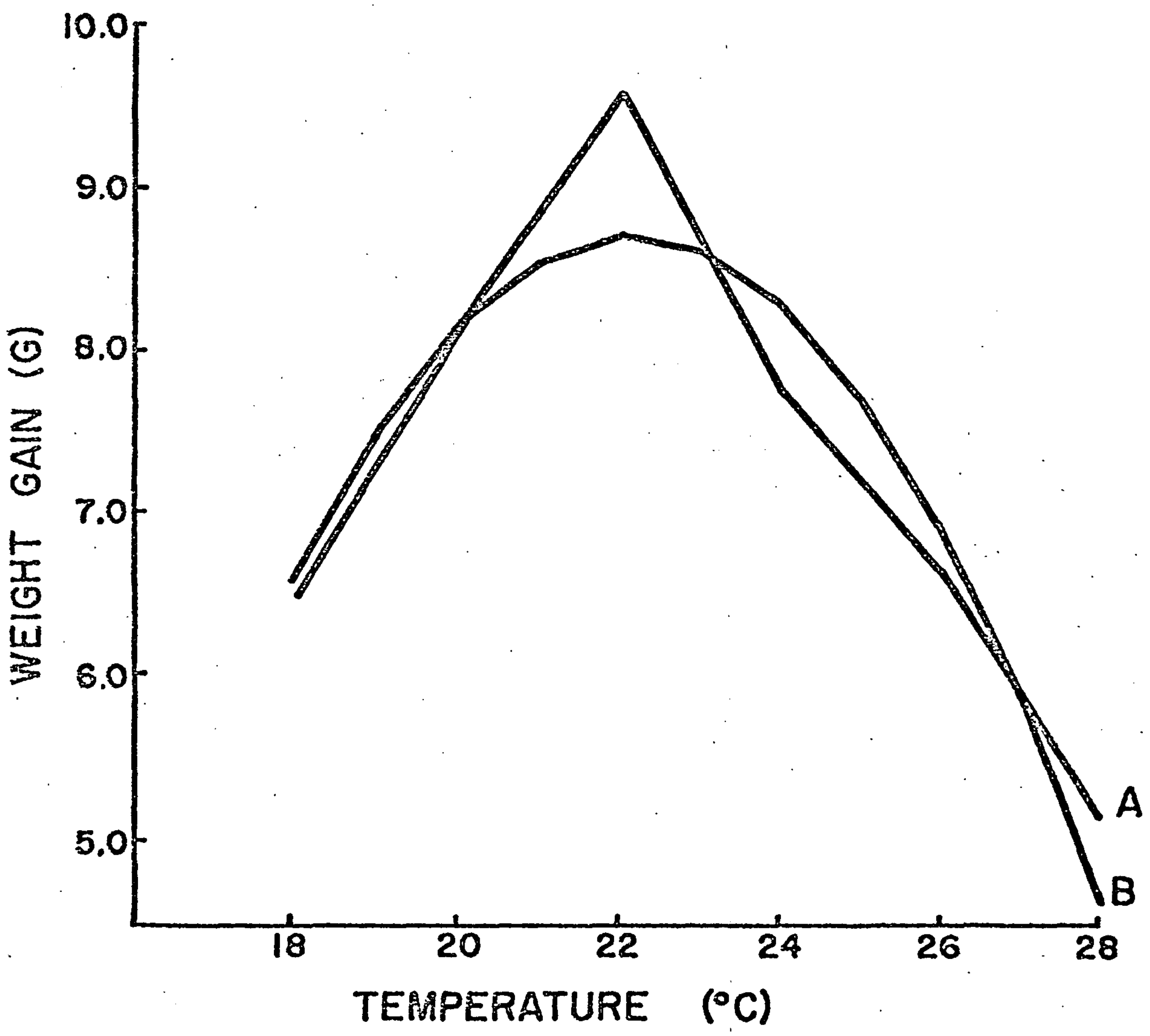

Figure 6. Growth of walleye juveniles exposed to temperatures ranging from 18-28 C. Line A represents the actual data points. Line B represents the predicted points calculated from the equation, $Y = -50.917 + 5.3740X - .1211X^2$.

In both curves 22 C was the optimum temperature for growth of walleye juveniles but the optimum temperature range can be extended to include 19-25 C.

In the 1972 study mortality occurred at the higher temperature levels. At 28 C, 40% of the fish died during the study and at 24 and 26 C, 20% of the fish died.

SECTION VII

EFFECT OF A SUDDEN TEMPERATURE CHANGE ON WALLEYE

EXPERIMENTAL DESIGN

Tests were performed on walleye fry and juveniles to determine the effect of a sudden temperature change on survival. Fry were slowly removed with a glass tube from their respective chambers to a beaker with the same temperature water to which they were acclimated. Then they were transferred to another fry chamber with a higher or lower temperature by lowering the beaker to water level and pouring the fry slowly out into the other chamber. A control was run with each test when the fish went through the same transfer process from one chamber to another but were not exposed to a temperature change. The survival of the control fry was corrected to 100% and the survival in the treatments was corrected accordingly. Walleye juveniles were subjected to a similar transfer process but a net was used for capture and a larger container was used to transfer the fish from the acclimation chamber to the test chamber.

Temperatures did not fluctuate more than ± 0.1 C and the pouring process at the start of the test did not lower or raise the initial test temperature more than 0.1 C.

Tests were done over a 72-hour period for fry and 96-hour period for juveniles. The 72-hour period for fry tests was used to eliminate starvation as a factor of mortality.

FRY TESTS

Sudden temperature changes were performed on walleye fry hatched and acclimated at 6, 11, and 21 C. The fry were subjected to both an upward and downward temperature change over a 72-hour period. A corrected survival rate was determined by comparison to the controls where there was no temperature change.

Five-day old walleye fry reared at 6 C were exposed to test temperatures at 11, 16, and 21 C. Fry mortality was observed only at 21 C, a change of +15 C, where 56% of the fry survived. No mortality was observed at the other temperatures.

Two-day old fry reared at 11 C were tested at 6, 16, and 21 C. The lowest survival, 58%, was at 6 C, a change of -5 C. No mortality occurred at 16 C, a change of +5 C. At a change of +10 C (21 C) 78% of the fry survived.

Seven-day old fry reared at 21 C were exposed to test temperatures at 6, 11, and 16 C. A 100% mortality occurred at 6 C with a change of -15 C. No large mortality was observed at the other temperatures. There was 91% survival at 11 C, a change of -10 C, and no mortality at 16 C, a change of -5 C. Table 8 lists the actual and corrected percentage survival of fry for all tests.

JUVENILE TESTS

Juvenile walleyes (80-100 mm in length) acclimated to various temperatures were exposed to higher and lower temperatures for thermal treatment over a 96-hour period. Both lethal effects and sublethal responses were observed. Sublethal response was recorded in terms of abnormal behavior and food acceptance.

Walleye juveniles acclimated to 16, 21, and 25 C were exposed to temperatures as much as 17 degrees below the acclimation temperature. The only mortality that occurred, 30%, was at a temperature change of -17

Table 8. EFFECTS OF TEMPERATURE CHANGE ON WALLEYE FRY INCUBATED AND REARED AT 6 C, 11 C, AND 21 C - 72 HOURS

Number of fish	Age of fry after hatch, days	Rearing temperature, C	Test temperature, C	Temperature change, C	Survival %	Corrected survival[a/] %
10	5	6.0	6.0	0	90	100
10	5	6.0	11.1	+5.1	90	100
10	5	6.0	15.9	+9.9	100	111
10	5	6.0	21.1	+15.1	50	56
50	2	11.1	11.1	0	98	100
50	2	11.1	6.0	-5.1	56	58
50	2	11.1	15.9	+4.8	100	102
50	2	11.1	21.1	+10.0	76	78
50	7	21.1	21.1	0	66	100
50	7	21.1	6.0	-15.1	0	0
50	7	21.1	11.1	-10.0	60	91
50	7	21.1	15.9	-5.2	72	109

[a/] Control corrected to 100% and other temperature levels adjusted accordingly.

C when juveniles acclimated to 25 C were exposed to 8 C (Table 9). Sublethal response was observed with a change of -17 C. Initially all fish lost their equilibrium and then swam belly up for the first 30 min of the test. Thereafter the survivors (70%) adjusted to the cooler temperature but remained inactive and did not feed. Sublethal effects but no mortality were observed with a temperature change of -13 C when fish acclimated to 21 C were exposed to a temperature of 8 C. Some of the fish lost their equilibrium with this temperature drop. Initially 30% of the juveniles swam belly up but adjusted after 10 min. All the fish were slightly inactive and only a few accepted food. No mortality or abnormal behavior was observed with fish exposed to a -9 to -4 C temperature change. Percentage survival and test temperatures are indicated on Table 9.

Juveniles acclimated to 16 and 21 C were subjected to temperatures as high as 12 C above the acclimation temperature (Table 10). Fish acclimated to 21 C were exposed to temperature changes of +4 and +7 C but no mortality or abnormal behavior was observed.

Table 9. EFFECTS OF SUDDEN TEMPERATURE CHANGE ON WALLEYE JUVENILES EXPOSED BELOW THEIR ACCLIMATION TEMPERATURE - 96 HOURS

Number of fish	Acclimation temperature, C	Test temperature, C	Temperature change, C	Survival %
20	16.0	12.1	- 3.9	100
20	21.0	16.0	- 5.0	100
20	16.0	8.1	- 7.9	100
20	21.0	12.1	- 8.9	100
20	25.0	16.0	- 9.0	100
20	21.0	8.1	-12.9	100
20	25.0	8.1	-16.9	70

Table 10. EFFECTS OF SUDDEN TEMPERATURE CHANGE ON WALLEYE JUVENILES EXPOSED TO A TEMPERATURE ABOVE THEIR ACCLIMATION TEMPERATURE

Number of fish	Acclimation temperature, C	Test temperature, C	Temperature change, C	Survival, %
20	21.0	24.9	+ 3.9	100
20	16.0	21.0	+ 5.0	100
20	21.0	27.8	+ 6.8	100
20	16.0	24.9	+ 8.9	100
20	16.0	27.7	+11.8	100

SECTION VIII

WALLEYE UPPER LETHAL TEMPERATURE

EXPERIMENTAL DESIGN

Upper lethal temperature tests were conducted on juvenile walleyes which had been subjected to a wide range of acclimation temperatures. These fish had a mean length of 115 mm. All fish were acclimated together in a large holding tank for 2 weeks. They were then placed in three 25-liter flow-through chambers at their acclimation temperature in groups of ten for 2 days before each test began. Temperatures were held constant throughout each acclimation period (S.D. = 0.07). According to Brett[23] the rate of temperature change over a period of a few hours will not greatly affect the thermal tolerance limit since the acclimation to changing temperatures requires several days. Therefore for these tests the temperatures were raised to the experimental temperatures at a rate of 3-4 C/hour. The test began at the end of the temperature rise. Test temperatures did not fluctuate greatly (S.D. = 0.11). Fish were not fed for 96 hours prior to testing since feeding could influence the upper lethal temperatures. Javaid and Anderson[24] found that starvation influences the selected temperatures of salmonids.

LETHAL TESTS

Upper lethal temperatures of TL50s were graphically determined for walleye juveniles acclimated to temperatures ranging from 8 to 26 C by 2 C intervals (Table 11). Fish were tested for 96 hours only since mortality occurred mostly within the first 12 hours of the test. The upper lethal temperature is the incipient lethal temperature which is defined by Fry[25] as the temperature at which 50% or more of the fish died.

The upper lethal temperature increased as the acclimation temperature increased. From an acclimation temperature of 8 to 14 C the TL50 in-

Table 11. PERCENTAGE SURVIVAL OF WALLEYE JUVENILES EXPOSED TO UPPER LETHAL TEMPERATURE LEVELS FOR EACH ACCLIMATION TEMPERATURE FOR 96 HOURS

Acclimation temperature, C	Test temperature, C								TL50, C
	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	
8.0	100	50	10	-	-	-	-	-	27.0
10.1	-	100	100	10	-	-	-	-	28.6
12.1	-	-	100	50	0	-	-	-	29.0
13.9	-	-	-	90	10	0	-	-	29.5
16.0	-	-	-	100	100	10	-	-	30.6
18.2	-	-	-	100	100	0	-	-	30.5
20.2	-	-	-	-	100	0	0	-	30.5
22.1	-	-	-	-	100	0	0	-	30.5
24.0	-	-	-	-	-	90	10	-	31.5
25.8	-	-	-	-	-	100	10	0	31.6

creased from 27.0 to 29.5, then at the acclimation temperatures of 16.0 to 22.0 C the upper lethal temperature remained stable at 30.5-30.6 C. The TL50 increased slightly to 31.5 and 31.6 C for the acclimation temperature of 24 and 26 C, respectively. In most cases there was a temperature difference of 1 C between 90-100% survival and 0-10% survival. This effect is shown in Figure 7 where both TL90 and TL10 are plotted.

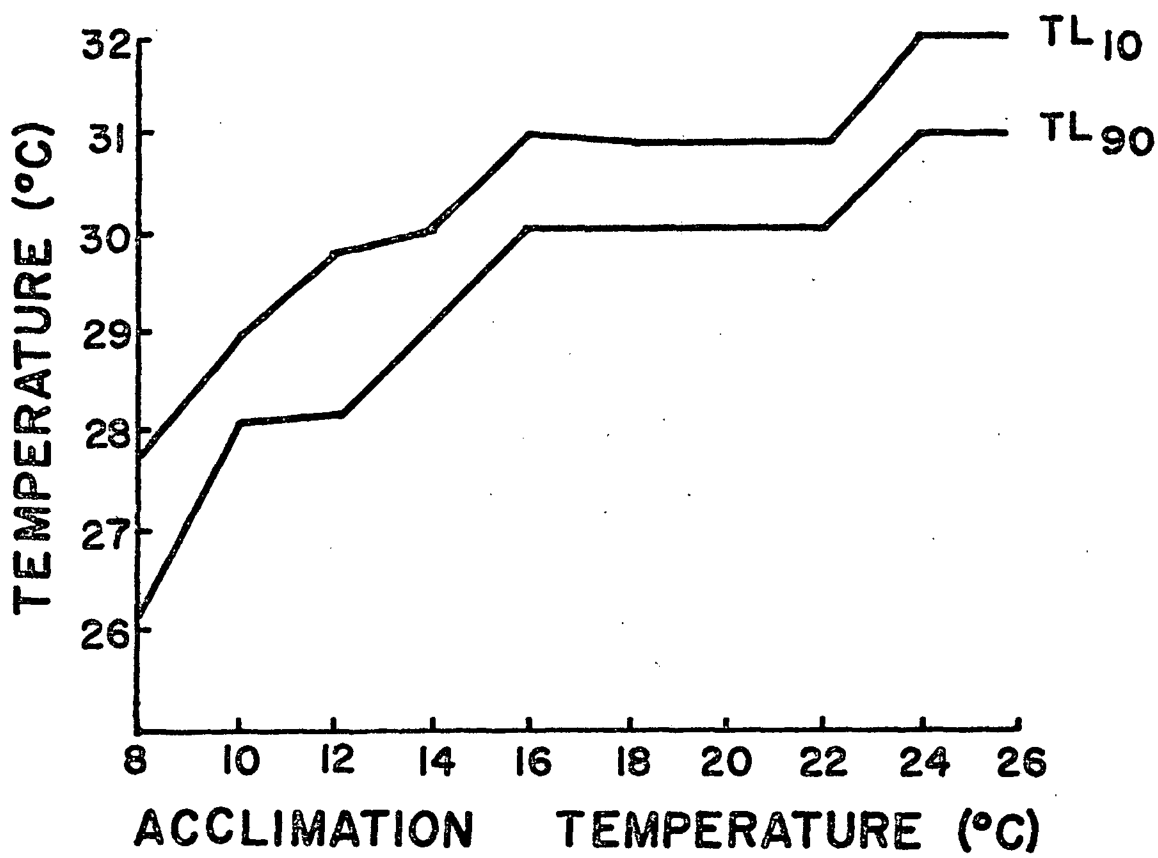

Figure 7. TL10 and TL90 levels of walleye juveniles exposed to upper lethal temperatures. TL10 and TL90 were at 10 and 90% survival plotted on arithmetic paper.

SECTION IX

SAUGER EGG AND FRY SURVIVAL

EXPERIMENTAL DESIGN

Sauger adults were acclimated to four temperatures, 9, 12, 15, and 18 C. After the adults became ripe they were stripped and the eggs were fertilized at the same four temperatures. After fertilization the eggs were incubated in the same manner and at the same six temperatures (6-21 C) as the walleye eggs (Figure 4). The fry hatched at these temperatures were carried through to juveniles at the same temperatures to determine fry survival to yolk sac absorbtion and to the juvenile stage. Replicates were combined in the final analysis since there was no significant difference between replicates at the .05 level.

HATCHABILITY OF SAUGER EGGS

Effect of Fertilization Temperature on Hatch

Sauger eggs were tested to determine the effect of various temperatures on fertilization, incubation, and egg survival (Figure 8, Table 12). Eggs were fertilized at 9, 12, 15, and 18 C and the group of eggs fertilized at each temperature was incubated at six temperatures; 6, 9, 12, 15, 18 and 21 C.

The lowest fertilization temperature (9C) resulted in the highest percentage hatch for each of the incubation temperatures except at 12 C where eggs fertilized at 15 C had a slightly higher percentage hatch (77.0%) than at 9 C (75.7%). The percentage hatch decreased as the fertilization temperature increased. Lowest egg survival resulted from a fertilization temperature of 12 C but these eggs may have had low survival from similar reasons noted for walleye eggs fertilized at 15 C.

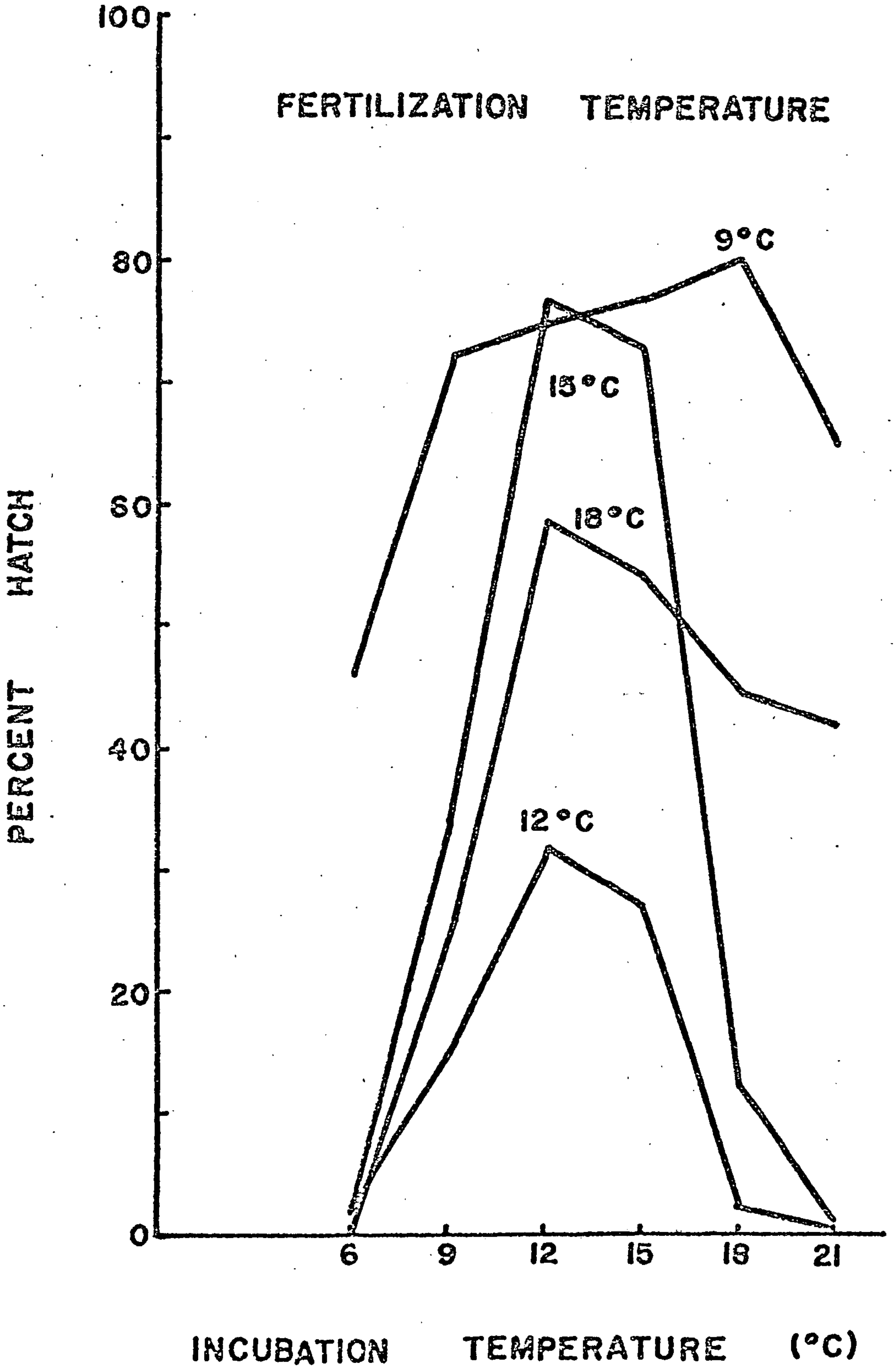

Figure 8. The combined effect of fertilization temperature and incubation temperature on the hatchability of sauger eggs. Each line represents the percentage hatch of eggs fertilized at one of four temperatures and incubated at six temperatures.

Table 12. PERCENTAGE HATCH OF SAUGER EGGS FERTILIZED AT FOUR TEMPERATURES AND INCUBATED AT SIX TEMPERATURES

Fertilization temperature, C	Incubation temperature, C					
	6.0	8.9	12.0	15.0	18.1	20.9
9.2	46.2	72.2	75.7	77.8	80.4	65.7
11.9	1.7	14.8	32.0	27.2	2.2	0.0
15.0	2.0	34.0	77.0	73.5	12.0	1.0
18.2	0.0	25.5	58.6	54.0	44.5	42.0

Eggs fertilized at 9 C had a percentage hatch which varied from 80.4% at an incubation temperature of 18 C to 46.2% at an incubation temperature of 6 C. With fertilization at 12 C the percentage hatch ranged from 32.0% at an incubation temperature of 12 C to 0.0% at 21 C. The percentage hatch of eggs fertilized at 15 C ranged from 77.0% at an incubation temperature of 12 C to 1.0% at 21 C. With fertilization at 18 C the percentage hatch ranged from 58.6% at an incubation temperature of 12 C to 0.0% at 6 C. By separation of the effects of fertilization temperature and incubation temperature on egg survival it was determined that egg survival was greatest at incubation temperatures from 12-15 C regardless of the fertilization temperature. Egg survival was lowest at an incubation temperature of 6 C. Egg survival rates (Table 12) at incubation temperatures of 12-15 C were 75.7-77.8%, 32.0-27.2%, 77.0-73.5% and 58.6-54.0% at fertilization temperatures of 9, 12, 15, and 18 C, respectively. Survival of eggs fertilized at these four temperatures but incubated at 6 C was 46.2%, 1.7%, 2.0%, and 0.0%, respectively.

Effect of Constant Temperature on Eggs and Fry

Sauger eggs and fry were held in six constant temperatures through fertilization, incubation, and after hatching to the juvenile stage. Survival of eggs, sac fry, and juveniles, time to hatch, and size of the fry at hatch were determined (Table 13). Highest egg survival was at 9 and 15 C with 72.2% and 73.5% hatching. At 12 C and 18 C, 32.0% and 44.5% hatched.

Incidence of abnormalities in hatched fry increased as the temperature increased. The percentage of abnormal fry was low at 6, 9, and 12 C where 2.0%, 2.0%, and 3.5% of the total hatch was abnormal. At a temperature of 15 C the percentage of abnormal fry was high (18.0%) but then dropped to 3.3% at 18 C. At 21 C the incidence of abnormalities was highest (23.0%). The percentage abnormal fry were included in the percentage of total hatch.

Table 13. THE EFFECT OF SIX CONSTANT TEMPERATURES ON SAUGER EGGS AND FRY[a/]

Temperature, C	Egg survival,[b/] %	Abnormal fry, %	Time to first hatch, days	Time to median hatch, days	Time to completion hatch, days	Mean size at hatch, mm	Survival of sac fry,[c/] %	Survival to juvenile stage,[d/] %
6.0	-	2.0[e/]	37[e/]	45[e/]	58[e/]	4.77[e/]	0[e/]	0[e/]
8.9	72.2	2.0	22	28	35	5.76	92	0
12.0	32.0	3.5	12	16	21	5.84	86	0
15.0	73.5	18.0	8	10	13	5.58	75	0
18.1	44.5	3.3	7	8	10	5.64	90	1
20.9	-	23.0[e/]	5[e/]	6[e/]	8[e/]	5.59[e/]	85[e/]	8[e/]

a/ Fry data were determined from 100 hatched fry taken at random from the total hatch at each temperature. Abnormal fry were not included.

b/ Two hundred eggs were tested at each temperature.

c/ Sac fry stage was determined to be from hatch to the disappearance of the yolk sac.

d/ Fish were determined to be juveniles when they reached a length of 40 mm.

e/ Data from fry fertilized at 9-18 C but incubated at 6 and 21 C.

Times to first hatch, median hatch, and total hatch were 37, 45, and 58 days at 6 C; 22, 28, and 35 days at 9 C; 12, 16, and 21 days at 12 C; 8, 10, and 13 days at 15 C; 7, 8, and 10 days at 18 C; and 5, 6, and 8 days at 21 C. Time to first hatch, median hatch, and total hatch was longest at the lowest temperature (6 C) and decreased to a minimum of 5 days to first hatch, 6 days to median hatch, and 8 days to total hatch at the highest temperature (21 C).

The mean size of the fry at hatch was 4.77, 5.76, 5.84, 5.58, 5.64, and 5.59 mm at 6, 9, 12, 15, 18, and 21 C, respectively. The size of the fry was least at 6 C (4.77 mm) but did not vary greatly at the other temperatures.

The survival of sauger fry from hatch to the disappearance of the yolk sac was high for all temperatures except 6 C. At 6 C the fry did not lose the yolk sac before dying although they survived about 30 days. The fry survival at the temperature of 9 to 21 C ranged from 75 - 92%.

Total survival of sauger fry from hatch to the juvenile stage was low at all temperatures. At 21 C 8% of the fry survived, at 18 C 1% survived, and at 6-15 C all died before the juvenile stage. All fry were fed large quantities of plankton. Most of the fry at the higher temperatures fed well while fry at the lower temperatures did not accept food. Fry mortality was observed to be caused by starvation, since temperature was the trigger mechanism to feeding for fry held in captivity under laboratory conditions.

SECTION X

GROWTH OF JUVENILE SAUGERS

Optimum temperature for growth of sauger juveniles was determined in a test running 36 days and conducted in the same manner as that described above for walleye growth experiments. Saugers were tested at 2 C intervals ranging from 16 to 26 C (Table 14). A malfunction in the apparatus caused total loss of fish at 24 C. The mean weight of the fish at the beginning of the test was 5.85 g at 16 C, 5.33 g at 18 C, 5.80 g at 20 C, 5.62 g at 22 C, and 6.42 g at 26 C. Maximum growth was at 22 C where the fish increased 22.9% in length and 96.8% in weight, corresponding to a specific growth rate of 1.883. Minimum growth was at 16 C, the lowest temperature, where the juveniles gained 14.0% in length and 52.2% in weight and corresponding to a specific growth rate of 1.164. At 26 C the percentage gains in length and weight and the specific growth rate were 13.6%, 53.9%, and 1.200, respectively. At 18 C the fish gained 20.3% in length, 79.4% in weight, and had a specific growth rate of 1.617. At 20 C the fish increased their length 16.5%, weight 62.9%, and had a specific growth rate of 1.358.

Juvenile mortality occurred at the high temperature (26 C) where the percentage survival was 60%.

Table 14. GROWTH OF SAUGER JUVENILES FOR 36 DAYS AT DIFFERENT TEMPERATURES

Temperature, C	Mean length at start of test, mm	Increase in length, mm	Increase in length, %	Mean weight at start of test, g	Increase in weight, g	Increase in weight, %	Specific growth rate, %/day	Survival, %
16.1	96.0	13.5	14.0	5.85	3.06	52.2	1.164	100
18.1	93.5	19.0	20.3	5.33	4.23	79.4	1.617	100
20.0	95.5	16.5	17.3	5.80	3.65	62.9	1.358	90
22.0	96.0	22.0	22.9	5.62	5.44	96.8	1.883	100
26.0	99.0	13.5	13.6	6.42	3.46	53.9	1.200	60

SECTION XI

UPPER LETHAL TEMPERATURES FOR SAUGER JUVENILES

EXPERIMENTAL DESIGN

Upper lethal temperature (TL50) tests were conducted on juvenile saugers acclimated to temperatures from 10 to 26 C at 2 degree intervals. The fish which had a mean total length of 119 mm were acclimated in 25-liter flow-through chambers in groups of 24 for a period of 2 weeks prior to the test. After acclimation the fish were randomly divided into three groups of eight fish. Each group was then subjected to a sudden temperature change by transferring the fish directly from the acclimation chamber to a higher test temperature. Fish were not fed for 96 hours prior to testing.

LETHAL TEMPERATURE TESTS

After acclimation upper lethal temperature was tested and time of death for each individual fish was recorded. The upper lethal temperature is defined as in the walleye experiments above. Upper lethal temperatures are shown in Table 15 and Figure 9 and median survival times are on Table 16.

Fish acclimated to 10 C and 12 C had an upper lethal temperature of 26.6 C and 26.7 C, respectively. Of the fish acclimated to 10 C and 12 C, 12.5% and 25.0%, respectively, survived at 27 C, while 100% survived at 26 C. The median survival times of the fish exposed to 27 C were 114 minutes for those acclimated at 10 C and 260 minutes for those acclimated at 12 C. The median survival time of fish acclimated to 12 C and exposed to 28 C was 68 minutes. Fish acclimated to 14, 16, and 18 C had an upper lethal temperature of 28.4, 28.6, and 28.7 C, respectively. The percentage survival of the fish acclimated to 14,

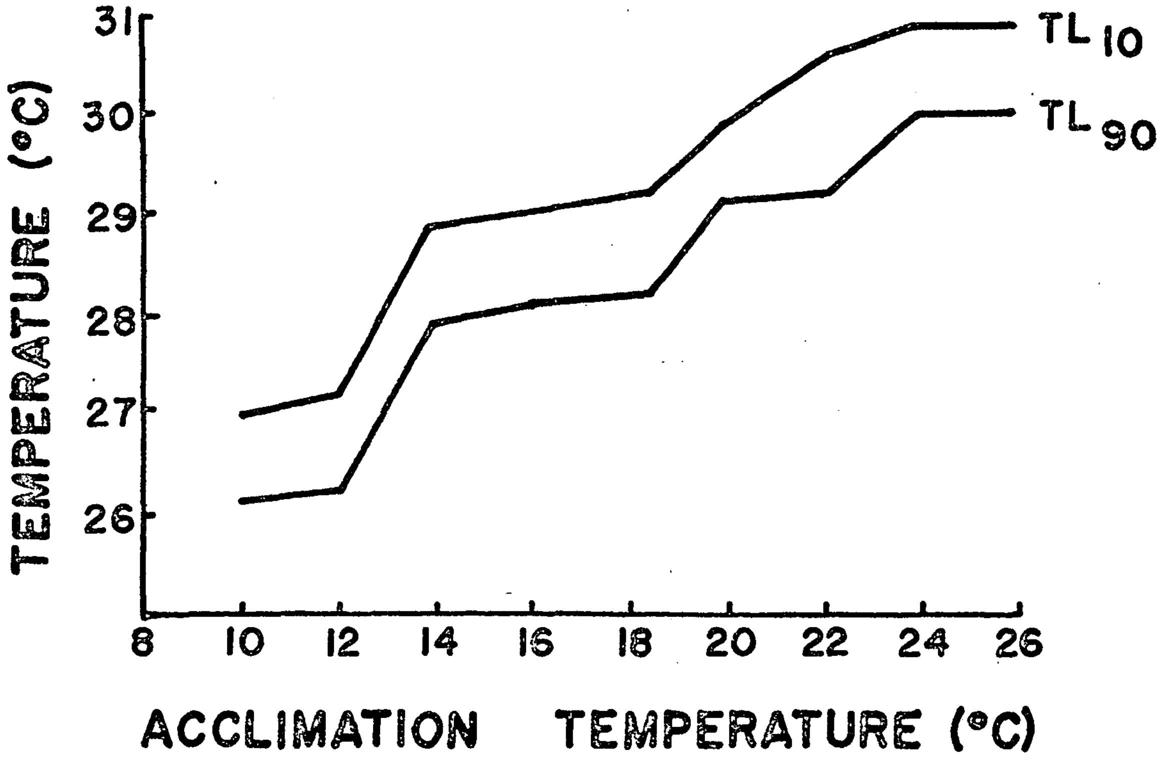

Figure 9. TL10 and TL90 levels of sauger juveniles exposed to upper lethal temperatures. TL10 and TL90 were at 10 and 90% survival plotted on arithmetic paper.

Table 15. PERCENTAGE SURVIVAL OF SAUGER JUVENILES ACCLIMATED TO 10 - 26 C AND EXPOSED TO HIGHER TEMPERATURES FOR 96 HOURS

Acclimation temperature, C	Temperature, C								TL50, C
	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.0	
10.1	100	100	12.5	-	-	-	-	-	26.6
12.0	-	100	25.0	0	-	-	-	-	26.7
13.9	-	-	-	87.5	0	12.5	-	-	28.4
16.0	-	-	-	100	12.5	0	-	-	28.6
18.3	-	-	-	100	25.0	0	-	-	28.7
19.9	-	-	-	-	100	0	12.5	-	29.5
22.0	-	-	-	-	100	25.0	12.5	-	29.9
23.9	-	-	-	-	-	87.5	0	0	30.4
25.8	-	-	-	-	-	87.5	0	0	30.4

Table 16. MEDIAN SURVIVAL TIME (MINUTES) OF JUVENILE SAUGERS ACCLIMATED TO 10 - 26 C AND EXPOSED TO UPPER LETHAL TEMPERATURES

Acclimation temperature, C	Test temperature, C					
	27.0	28.0	29.0	30.0	31.0	32.0
10.1	114	-	-	-	-	-
12.0	260	68	-	-	-	-
13.9	-	-	32	16	-	-
16.0	-	-	29	18	-	-
18.3	-	-	31	19	-	-
19.9	-	-	-	1328	122	-
22.0	-	-	-	1512	545	-
23.9	-	-	-	-	1242	348
25.8	-	-	-	-	690	246

16, and 18 C and exposed to 29 C was 0.0, 12.5, and 25.0%, respectively. The percentage survival at 28 C for the same acclimation temperatures was 87.5, 100, and 100%, respectively. The median survival times for the exposure to 29 C were 32, 29, and 31 minutes for the fish acclimated to 14, 16, and 18 C. The median survival times for the same acclimation temperature and exposure to 30 C was 16, 18, and 19 minutes, respectively. Juvenile fish acclimated to 20 and 22 C had an upper lethal temperature of 29.5 and 29.9 C. Survival was 0% and 25.0% at 30 C and 100% at 29 C for both acclimation temperatures (20 and 22 C). The median survival times for the fish acclimated to 20 and 22 C was 1328 and 1512 minutes for exposure to 30 C and 122 and 545 minutes for exposure to 31 C. Fish acclimated to 24 and 26 C had an upper lethal temperature of 30.4 C. At a temperature of 31 C no fish survived from both acclimation temperatures and 87.5% of the fish survived at a temperature of 30 C for both acclimation temperatures. The median survival times for fish acclimated to 24 and 26 C and exposed to 31 C was 1242 and 690 minutes, respectively. The median survival times for exposure to 32 C was 348 minutes for fish acclimated to 24 C and 246 minutes for fish acclimated to 26 C.

SECTION XII

DISCUSSION

The results of this investigation show that temperature has an important impact on walleye and sauger eggs, fry, and juveniles. The optimum temperatures and lethal temperatures vary significantly for different life history stages with the optima for fertilization, incubation, and fry survival gradually increasing in the successive stages. The optimum temperature ranges for fertilization, incubation, and fry survival of walleyes are 6-9 C, 9-15 C, and 15-21 C, respectively. The optimum temperatures for the same stages in sauger are 9-15 C, 12-15 C, and 15-21 C, respectively. These ranges correspond closely to the temperatures found in nature when the various stages are present. Under normal conditions adult sauger and walleye spawn at temperatures of 6-12 C with the temperature gradually rising to 15 C by the time eggs hatch. Fry development takes place at 15-21 C. On the basis of studies reported here temperature regimes must be considered as an important factor in the establishment of year classes and maintenance of populations in natural water.

If unusually cold weather occurs after fry emergence, fry survival may be inhibited. Conversely strong year class may be dependent on gradual warming of water during egg deposition and incubation, and after fry emergence. Johnson[7] stated that egg mortality, associated with unuaully cold weather during the incubation period, may be an important factor in the limiting of the size of year classes. Feeding of fry may also be reduced when temperatures are low. Fry fed well at the higher temperatures (18-21 C).

One discrepancy in the hatch data (Table 3, Figure 5) suggests that

15 C is more detrimental to egg survival than 18 C. It is believed that eggs fertilized at 15 C were of poor quality and less viable for an undetermined reason, but the egg mortality from this cause was consistent and independent of the incubation temperature or occurred before the incubation temperature had any effect. The shape of the 15 C fertilization curve shown in Figure 5 is the same as that for other temperatures but probably should lie between the 12 and 18 C curves. This descrepancy was also noted with saugers fertilized at 12 C (Table 12, Figure 8). It is believed that these eggs were also less viable for some reason other than temperature.

Incidence of abnormalities was affected by temperature. Both walleyes and saugers showed a substantial increase in abvormalities as the temperature increased.

The size of the walleye fry at hatch was affected by fertilization temperature as well as incubation temperature. The results indicate that lower fertilization temperatures resulted in larger fry. The sauger fry did not show any significant variation in size attributable to the fertilization temperatures.

Optimum temperature for walleye growth was influenced by the size of the juvenile. Smaller fish (mean weight 1.91 g) had a higher optimum temperature (25 C) than the larger fish (mean weight 4.59 g) (22 C). This shift in the optimum temperature could have been caused by differences in dissolved oxygen. Juvenile saugers also had an optimum temperature for growth of 22 C. These fish were uniform in size so no variation due to size difference was noted. The preferred temperature of fish according to Brett[26] is also the optimum temperature for activity and growth, thus the preferred temperature for walleye juveniles is estimated to be 22-25 C. Fry[27], Doudoroff[28], Proffitt[29], and Merriman[30] have noted the tendency for young fish to remain in warm water more than older and larger individuals. Kelso[31] reported 20 C as the optimum temperature for growth of walleyes, age II-VI. Hile and Juday[32] reported the preferred temperature of adult walleyes to be 20.6 C during summer months, and Ferguson[33] reported the preferred temperature of adult walleyes to be 22.7-23.2 C.

Walleye fry and juveniles acclimated to different temperatures were exposed to a sudden temperature change without severe mortality. It is apparent that the extent of temperature change is less important than the absolute test temperature. If the temperature change is within the upper or lower tolerance limits, little or no mortality will occur. Mortality of fry from temperature change occurred only when fry hatched at 11 C were transferred to 6 C, a net change of -5 C, and fry hatched at 21 C were transferred to 6 C, a change of -15 C. It appears that 6 C is a lethal temperature for fry hatched at 11 and 21 C, since fry hatched at 21 C and transferred to a temperature of 11 C, a change of -10 C, did not incur high mortality.

Juvenile walleyes exposed to a sudden temperature change showed a mortality only in fish acclimated to 25 C and dropped to 8 C, a change of -17 C, where loss was 30%. This suggests that 8 C is probably close to the lower lethal temperature of juveniles acclimated to 25 C. Tests done with saugers were upward shifts toward lethal temperatures so the effect of drops in temperature were not assessed. However, the extent of a sudden change in temperature did not harm fish until upper lethal temperature was approached.

The upper lethal temperatures determined for walleye and sauger juveniles can be applied to juveniles only. The upper lethal temperature for larger fish may be slightly lower.

It is apparent from the results of the tests described herein that temperature standards in natural waters must be adjusted for seasonal changes in requirements of the fish and that maximum temperatures not causing death are above the optimum levels for adequate population maintenance. Temperature maxima insuring natural population safety will probably be 3 to 4 degrees below the upper lethal temperature found for unfed fish. Short periods of excess heat could be fatal to the population if permitted levels are too close to the lethal level.

SECTION XIII

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SECTION XIV

APPENDIX A

STATISTICAL TABLES

Appendix A, Table 1

THE EXPECTED VALUES OF PERCENTAGE HATCH OF WALLEYE EGGS FERTILIZED AT SIX DIFFERENT TEMPERATURES AND INCUBATED AT SIX DIFFERENT TEMPERATURES

The Observed Values Are Shown on Table 3 in The Main Text

Nominal fertilization temperature, C	Incubation temperature, C					
	6	9	12	15	18	21
6	64.29	77.27	78.48	79.80	66.83	14.34
9	55.25	69.98	71.43	73.04	58.02	10.30
12	24.71	56.25	57.97	59.90	43.26	5.95
15	5.77	10.37	11.04	11.84	6.42	0.57
18	22.15	34.95	36.56	38.43	48.32	2.58
21	2.82	5.20	5.56	5.99	3.15	0.27

Appendix A, Table 2

DUMMY VARIABLES REPRESENTING FERTILIZATION TEMPERATURE IN THE REGRESSION EQUATIONS FOR DETERMINING THE SIZE OF WALLEYE FRY AT HATCH

Variables Used in Equations for Incubation Temperatures of 6, 9, 12, and 15 C

Nominal fertilization temperature, C	Dummy variables				
	X_1	X_2	X_3	X_4	X_5
6	1	0	0	0	0
9	0	1	0	0	0
12	0	0	1	0	0
15	0	0	0	1	0
18	0	0	0	0	1
21	-1	-1	-1	-1	-1

Appendix A, Table 3

DUMMY VARIABLES REPRESENTING FERTILIZATION TEMPERATURE
IN THE REGRESSION EQUATIONS FOR DETERMINING
THE SIZE OF WALLEYE FRY AT HATCH

Variables Used in Equation for Incubation Temperature of 18 C

Nominal fertilization temperature, C	Dummy variables		
	X_1	X_2	X_3
6	1	0	0
9	0	1	0
12	0	0	1
18	-1	-1	-1

SECTION XV

APPENDIX B

AN ANNOTATED BIBLIOGRAPHY OF THERMAL EFFECTS ON THE NORTH AMERICAN *STIZOSTEDION* SPECIES

INTRODUCTION

The literature on thermal effects on the North American *Stizostedion* species was compiled and presented in annotated form. Only temperature-related literature was reviewed. Temperature data reported in the original literature as Fahrenheit has been changed to Centigrade. The annotated bibliography lists the effects of temperature on the walleye, sauger, and blue pike. The listing of unpublished data is incomplete in university reports as well as unpublished reports of state, provincial, and federal agencies.

Each reference is cross-indexed by species, geographical location, and additional subject headings. Listed numbers in the index refer to the numbers on publications in the main body of the citation list.

ANNOTATED BIBLIOGRAPHY

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1964. Preliminary study of the effects of temperature fluctuations on developing walleye eggs and fry. Prog. Fish-Cult. 26(4): 175-180.

Descriptors
WALLEYE
LAKE ERIE
INCUBATION

A study of the effect of fluctuating temperatures on different stages of embryo development of walleye eggs was done at Put-In-Bay in western Lake Erie. The study was started at 6.7 C and was raised 0.56 C every 48 hours. The rising temperature of the system was called the base temperature or the normal rise in water temperature during incubation of walleye eggs. The temperature fluctuation test was administered by slowly raising the water temperature 4.4 C in 4 hours, and then gradually reducing to the base temperature. The temperature fluctuation was applied at 4 stages of embryo development: cleavage, differentiation, organogenesis, and hatching. 28% of the eggs hatched in the control, 30% of the eggs hatched when the temperature was fluctuated at cleavage, 28% of the eggs hatched when the temperature was fluctuated at differentiation, and 39% of the eggs hatched when the temperature was fluctuated at organogenesis. Due to an accident the water temperature rose to 1.1 C during hatching and no excessive mortalities occurred in 7 out of 8 hatching jars. The author concluded that 399 temperature units are required for normal development and hatching, when 1 temperature unit = 1 degree-day above 32 F.

2. Anonymous
1967. Temperatures for hatching walleye eggs. Prog. Fish-Cult. 29(1): 20.

Descriptors
WALLEYE
WISCONSIN
INCUBATION

At a Wisconsin hatchery, jars containing 1.5 quarts of walleye eggs were set up to test temperatures ranging from 12.8-19.4 C in increments of 1.7 C. Additional tests were set up at 21.7 C and 23.9 C because of the high percentage of hatching success at the higher temperatures. The results of the tests were as follows:

Temperature (C)	Days to eye-up	Days to hatch	Percentage hatch
12.8	7	10	50
14.4	6	10	50
16.1	5	8	51
17.8	4	8.5	65
19.4	3.5	6	60
21.7	3	5	10
23.9	3	4	10

The author concluded that the apparent optimum temperature for hatching walleye eggs is 17.8-19.4 C.

3. Arnold, Dean E.
1969. The ecological decline of Lake Erie. N. Y. Fish Game J. 16(1): 27-45.

Descriptors
BLUE PIKE
LAKE ERIE
DISTRIBUTION

There are five main hypotheses to explain the decline and the extinction of the blue pike (Stizostedion vitreum glaucum) in Lake Erie that have been proposed by various schools of thought. They are: 1) high temperature, 2) O_2 depletion in the central basin; 3) overfishing, 4) pollution, and 5) new predators or competitors. All of these are probably interrelated and mutually responsible. The blue pike have been restricted to the colder waters of the lake, thus being placed at a disadvantage as the waters become warmer.

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1960. The 1960 spawning run of yellow pickerel at Bobcaygeon in relation to water temperature. Ont. Dept. Lands & Forests, Southeastern Region, Spec. Fish. Wildl. Bull. 3: 4-6.

Descriptors
WALLEYE
ONTARIO
SPAWN

In the Bobcaygeon region of the Kawantha Lakes the heavy run of spawning walleyes occurred when river temperatures were at 4.4-7.2 C. The greatest spawning activity occurred at temperatures between 6.1 and 8.3 C. Spawning appeared to be completed when the water temperature reached 10.0 C. In all cases, the heavy spawning run commenced at a temperature 1.7-2.2 C lower than the actual spawning temperature.

5. Butler, G.E.
1937. Artificial propagation of walleyed pike. Trans. Amer. Fish. Soc. 66(1936): 277-278.

Descriptors
WALLEYE
MANITOBA
INCUBATION

It was reported that strong winds stirred up the mud from the creek that fed water to the walleye hatchery and subsequently raised the temperature to 18.3-21.1 C. The combination of mud and high temperatures caused the mortality of a large number of eggs.

6. Carufel, Louis H.
1963. Life history of saugers in Garrison Reservoir. J. Wildl. Manag. 27(3): 450-456.

Descriptors
SAUGER
N. DAKOTA
SPAWN

The 1960 spawning season for saugers in Garrison Reservoir ran from May 2 - June 25, where the height of the season was from May 8-28. Water temperatures ranged from 3.9-11.7 C.

7. Cobb, Eben W.
1923. Pike-perch propagation in northern Minnesota. Trans. Amer. Fish. Soc. 53: 95-105.

Descriptors
WALLEYE
MINNESOTA
SPAWN
INCUBATION

It was decided that the best temperatures for taking walleye eggs range from 7.2-10.0 C, preferably between 7.8-8.9 C. Although eggs were taken at a temperature as high as 17.2 C, they were poor as a rule. Also good hatches have occurred with walleye eggs subjected to as low a temperature as where slush ice had formed in the water.

8. Dendy, Jack S.

1948. Predicting depth distribution of fish in three TVA storage type reservoirs. Trans. Amer. Fish. Soc. 75(1945): 65-71.

Descriptors
WALLEYE
SAUGER
TENNESSEE
DISTRIBUTION

In TVA reservoirs the depth distribution of walleyes and saugers were predictable on a weekly basis based on the relation of temperature and dissolved O_2 to the distribution of fish in gill nets during the years 1943, 1944, and 1945. Thus it can be predicted that in the latter part of July, saugers were most abundant at a depth where the temperature was about 18.3 C and walleyes were most abundant at a depth where the temperature was about 25.0 C.

9. Derback, B.

1947. The adverse effect of cold weather upon the successful reproduction of pickerel, Stizostedion vitreum, at Hemming Lake, Manitoba, in 1942. Can. Fish-Cult. 2(1): 22-23.

Descriptors
WALLEYE
MANITOBA
SPAWN

The author believed that there seemed to be a strong correlation between spawning activity and water temperature. In Hemming Lake, Manitoba, when walleyes ran up the creek to spawn the temperature was 5.6 C. The first walleye eggs were observed 4 days later at 6.1 C. Then a period of cold weather set in to lower the temperature the following week to 5.0 C, and as a result the walleye moved back downstream into the lake. Resulting catches of walleye in late June showed that the females were resorbing their eggs.

10. Doan, Kenneth H.

1942. Some metereological and limnological conditions as factors in the abundance of certain fishes in Lake Erie. Ecol. Monogr. 12(3): 294-314.

<u>Descriptors</u>
WALLEYE
BLUE PIKE
SAUGER
LAKE ERIE
SIZE OF CATCH

Because water temperature has considerable influence over the success of fishing, an attempt was made to correlate the size of the catch of walleyes, blue pike, and saugers in Lake Erie with mean spring air temperatures.

Walleyes: Spring temperatures have shown no relation to sizes of catch. Mean April-May air temperatures at Cleveland, Sandusky, and Toledo had non-significant "r" values with Ohio catches in the same year, and with catches 3 or 4 years later.

Blue Pike: Temperature variations affect the stock of blue pike by affecting the vulnerability of adults to capture and by influencing spawning and fry survival. Over half of the total blue pike catch is taken in May and June, these months also include spawning and early fry stages. However there was no correlation between the mean May-June air temperatures at Cleveland and Erie and the size of the Ohio catches of blue pike the same year. But there was a definite relation between May-June air temperatures and the catch of blue pike 2 years later.

Sauger: There was no significant correlation with catches of sauger and mean spring air temperatures.

It was thought that in Lake Erie the factor to which these fish react most strongly would be temperature since they seek colder waters in the summer by going deeper. To support this view, movements of tagged blue pike and walleyes in Lake Erie were observed. The blue pike inhabited the colder waters, and the walleyes were more tolerant of warmer water but still moved eastward out of the excessively higher temperature waters during the summer in the western section of the lake.

11. Eddy, Samuel | Descriptors

1938. A classification of Minnesota lakes for fish propagation. Prog. Fish-Cult. 41: 9-13.

WALLEYE
MINNESOTA
DISTRIBUTION

Minnesota lakes were classified on the physical, chemical, and biological features. Pike Lake No. 1 has summer temperatures of surface water range between 15.6-23.9 C and bottom waters between 6.7-12.8 C. The difference between the summer surface and bottom temperatures is usually 5.6-11.2 C. Pike Lake No. 2 has summer surface temperature range between 20.0-23.9 C or higher and bottom temperatures range between 18.3-21.1 C. The difference between surface and bottom temperatures is 0.56-2.8 C.

12. Eddy, Samuel, and Thaddeus Surber | Descriptors

1943. Northern fishes with special reference to the upper Mississippi valley. Univ. Minnesota Press, 276 p.

WALLEYE
MINNESOTA
SPAWN

In Minnesota the spawning run of walleyes starts when water temperatures range from 3.3-6.7 C.

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13. Eley, Rex L., Neil E. Carter, and Troy C. Dorris | Descriptors

1967. Physiochemical limnology and related fish distribution of Keystone Reservoir. In Reservoir Fishery Resources Symposium, p. 333-357. Reservoir Comm. Southern Div., Amer. Fish. Soc.

WALLEYE
OKLAHOMA
DISTRIBUTION

Temperature and other limnological parameters were measured at each meter of depth at different stations in Keystone Reservoir, Oklahoma. Depth distribution of fish was determined by suspending a vertical latin-square gill net from the water surface to the bottom for two consecutive 24-hour periods per month at each station. Walleyes were captured within 4 meters of the surface during the summer when temperatures ranged from 26-27 C.

14. Ellis, D. V., and M. A. Giles

1965. The spawning behavior of the walleye, Stizostedion vitreum (Mitchill). Trans. Amer. Fish. Soc. 94(4): 358-362.

Descriptors
WALLEYE
MANITOBA
SPAWN

Spawning activity and courtship was studied in Manitoba. Walleyes have a diel behavioral cycle, low activity in day-time and courtship activity in the evening. The water temperature during the spawning period ranged from 6.7-13.0 C.

15. Eschmeyer, Paul H.

1950. The life history of the walleye Stizostedion vitreum vitreum (Mitchill), in Michigan. Mich. Dept. Conserv., Inst. Fish. Res., Bull. 3, 99 p.

Descriptors
WALLEYE
MICHIGAN
SPAWN

Walleye spawning was observed in Lake Gogebic, Michigan in the years 1941, 1942, 1947, and in the Muskegon River in 1936, 1944, 1947, and 1948. The results were:

Location	Start of spawning run	Peak of spawning run
Lake Gogebic (1941)	3.9 C	8.3 C
Lake Gogebic (1942)	4.4 C	7.8-8.9 C
Lake Gogebic (1947)	1.1 C	--
Muskegon R. (1936)	--	4.4-5.6 C
Muskegon R. (1944)	--	3.3 C
Muskegon R. (1947)	--	4.4 C
Muskegon R. (1948)	--	6.7 C

The peak of the spawning run in Lake Gogebic occurs when shoal temperatures range from 7.2-10.0 C. In the Muskegon River the peak of the spawning run occurs when the temperatures range from 4.4-6.7 C.

16. Ferguson, R. G.

1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada 15(4): 607-624.

Descriptors
WALLEYE
SAUGER
DISTRIBUTION

The preferred temperature for walleyes is 22.7-23.2 C, and the preferred temperature for saugers is 18.6-19.2 C.

17. Forney, John L.

1966. Factors affecting first-year growth of walleyes in Oneida Lake, New York. N.Y. Fish & Game J. 13(2): 146-167.

Descriptors
WALLEYE
NEW YORK
GROWTH

Annual May-June air temperatures suggest that lake temperatures determine the rate of walleye growth in early summer and to some extent may influence the time of hatching of walleye fry.

18. Grinstead, Bobby G.

1971. Reproduction and some aspects of the early life history of walleye, _Stizostedion vitreum_ (Mitchill), in Canton Reservoir, Oklahoma. _In_ Reservoir Fisheries and Limnology, Amer. Fish. Soc., Spec. Pub. No. 8, p. 41-51.

Descriptors
WALLEYE
OKLAHOMA
SPAWN

Walleyes in Canton Reservoir, Oklahoma spawn in March. Water temperatures during peak spawning activities ranged from 5.0-12.8 C in 1966, 7.2-14.4 C in 1967, and 3.9-8.9 C in 1968. It was suggested that these data support the theory that water temperature is the primary controlling influence in determining the time walleyes spawn. In Canton Reservoir they spawn considerably earlier in the year, but within temperature ranges similar to walleyes in other regions.

19. Hassler, William W.

1955. The influence of certain environmental factors on the growth of Norris Reservoir sauger, _Stizostedion canadense canadense_ (Smith). Proc. Southeastern Ass. Game Fish Comm. Mtg., p. 111-119.

Descriptors
SAUGER
TENNESSEE
GROWTH

First year growth rates of sauger during a 13-year span were correlated with:

1. Water temperature data for 13 years. Water temperatures of 15.6 C at a depth of 0.5 feet were used to demarcate the length of the sauger growing season.
2. Time in days between 10.0 C and 15.6 C at a depth of 0.5 feet.
3. Air temperature, both mean monthly and mean annual.

Growth rates were significantly correlated with water temperature with a correlation coefficient of .69. There was an inverse relationship between degree days and growth rates with a correlation coefficient of -.51. There was no correlation between air temperature and growth rates.

It was suggested that there are three possible ways in which sauger growth may be affected inversely during the spring:

1. There is a lower metabolic rate during a prolonged period of time if the water temperature increases slowly.
2. A greater survival of sauger fry and fingerlings may occur during the years when temperature increases slowly. This would result in a greater population density which in turn could be a limiting factor on growth.
3. Because forage fish spawn later than sauger (10.0 C for sauger and 15.6 C for forage fish), there would be a lower rate of growth if the lake warms up slowly. The period of planktonic feeding would be prolonged since forage fish would be available at a later time than usual.

20. Herman, Elmer F. | Descriptors
1947. Notes on tagging walleyes on the Wolf River. Wisc. Conserv. Bull. 12(4): 7-9.
WALLEYE
WISCONSIN
SPAWN

The 1946 spawning run in the Wolf River, Wisconsin, started after the ice left the river when the temperature ranged from 3.3-6.7 C. The actual spawning occurred when the temperature reached 14.4 C.

21. Hile, R., and C. Juday | Descriptors
1941. Bathymetric distribution of fish in lakes of the northeastern highlands, Wisconsin. Trans. Wisc. Acad. Sci., Arts, & Lett. 33: 147-187.
WALLEYE
WISCONSIN
DISTRIBUTION

The average thermal distribution of walleyes during August in Trout Lake, Wisconsin was reported to be 20.6 C.

22. Hurley, Donald A. | Descriptors
1972. Observations on incubating walleye eggs. Prog. Fish-Cult. 34(1): 49-54.
WALLEYE
INCUBATION

In the years 1969 and 1970, walleye eggs were at the eyed stage at 274 and 234 thermal units (TU), median hatch occurred at 440 TU, completion of hatching required 467 TU's, and yolk absorption was completed at 690 TU's. 1 TU = 1 degree-day above 32 F.

23. Johnson, Fritz H. | Descriptors
1961. Walleye egg survival during incubation on several types of bottom in Lake Winnibigoshish, Minnesota, and connecting waters. Trans. Amer. Fish. Soc. 90(3): 312-322.
WALLEYE
MINNESOTA
INCUBATION

Survival of naturally spawned walleye eggs was determined for five types of bottom areas of Lake Winnibigoshish and connecting waters

over a 4-year period. The results were:

Year	Bottom type	Incubation period (days)	Water temperature during in- bation (C)	Daily mean water temperature (C)	Estimated percentage egg survival
1956	Area 1	20-24	5.0-16.1	8.3	0.6
	" 2	20-24	5.0-15.0	8.3	2.7
	" 3	14-16	6.1-13.3	11.1	17.5
	" 4	-	-	-	34.3
1957	Area 1	12-14	7.8-8.9	11.7	4.7
	" 2	12-14	8.9-14.4	11.7	9.9
	" 3	12-16	7.8-14.4	11.7	17.9
	" 4	12-16	7.8-14.4	11.7	17.4
1958	Area 1	16-21	6.1-12.8	10.0	3.6
	" 2 (improved)	16-21	6.1-12.8	9.4	35.7
	" 3	-	-	-	-
	" 4	18-21	6.1-17.8	-	5.2
	" 5	16-21	6.1-12.8	9.4	13.2
1959	Area 1	16-18	7.2-17.2	10.6	1.2
	" 2	12-18	12.8-15.6	10.6	25.9

Area 1 = soft, mucky bottom

Area 2 = firm, fine sand

Area 2 (improved) = former area 2 covered with 6 inches of gravel

Area 3 = gravel and rubble bottom with occasional boulders

Area 4 (1956) = gravel and rubble bottom

Area 4 (1957) = gradually sloping bottom with 60% gravel and 40% sand

Area 4 (1958) = gravel-rubble bar with occasional boulders

Area 5 = bar of firm clean sand

Temperature determinations were made with maximum-minimum thermometers. The author felt that observations on max-min water temperatures do not lend themselves to critical analysis of the effect of water temperature on the rate of embryo development. But he observed that most rapid embryo development and short incubation periods were associated with high daytime water temperatures and high minimum water temperatures. Egg survival was best in years of warmer water temperatures and shorter incubation periods. Also it was stated that egg mortality, especially as associated with unusually cold water during the incubation period, may be an important factor in the establishment of year classes.

24. Johnson, Fritz H. — Descriptors

1966. Environmental and species associations of the walleye in Lake Winnibigoshish and connected waters, including observations on food habits and predator-prey relationships. Minn. Dept. Conserv. Invest. Rep. 301, 34 p.

WALLEYE
MINNESOTA
DISTRIBUTION

Walleye distribution in Lake Winnibigoshish, Minnesota was not influenced by bottom temperatures that ranged between 13.3 C and 20.6 C, but the fish extended their range into deeper, cooler waters when the surface temperatures rose above 21.1 C. Tolerance for water temperatures above 21.1 C appeared to decrease as age and size of the fish increased. When late fall water temperatures on the shoals ranged from 6.7-8.9 C, the fish were no longer in shore. This indicates that there could be a minimum fall temperature threshold below which the fish seek deeper, warmer water.

25. Kelso, John R. M. — Descriptors

1972. Conversion, maintenance, and assimilation for walleye, Stizostedion vitreum vitreum, as affected by size, diet, and temperature. J. Fish. Res. Bd. Canada 29: 1181-1192.

WALLEYE
MANITOBA
GROWTH

Walleyes of age II to VI were tested for growth and food conversion at different temperatures. Greatest walleye weight gain occurred at a temperature of 20 C. K_1, conversion weight gained per unit time to ration size, was 0.143 at 20 C, 0.127 at 16 C, and 0.136 at 12 C. At 4, 8, and 12 C the maintenance requirement varied slightly (33.25-45.70 cal/g/week). At a cycled temperature (16-8 C) for a period of 4 weeks the requirement was 40.2 mg/g/week. Between 20 C and 32 C the amount of energy consumed by the fish was similar.

26. Kennedy, William A.

No date (approx. 1935). Report on the migration of pickerel due to temperature changes. Unpub. MS, 15 p. In Univ. Toronto, Great Lakes Inst. Libr.

Descriptors
WALLEYE
ONTARIO
DISTRIBUTION

It was observed that as the water warmed, walleyes in Lake Nipissing, Ontario moved to deeper waters, the larger fish migrating first. It was found that the walleyes do not penetrate the thermocline which would entail a sudden change of temperature.

27. Nelson, William R.

1968. Reproduction and early life history of sauger, Stizostedion canadense, in Lewis and Clark Lake. Trans. Amer. Fish. Soc. 97(2): 159-166.

Descriptors
SAUGER
S. DAKOTA
SPAWN
INCUBATION

Sauger in Lewis and Clark Lake spawn upstream near the Fort Randall Dam when water temperatures reach 5.6-6.1 C. The incubation period at an average water temperature of 8.3 C was approximately 21 days.

28. Nelson, William R., Norman R. Hines, and Lance G. Beckman

1965. Artificial propagation of saugers and hybridization with walleyes. Prog. Fish-Cult. 24(4): 216-218.

Descriptors
WALLEYE
SAUGER
S. DAKOTA
INCUBATION

Walleye and sauger brood stock were collected in the Missouri River between April 15-29, when the spawning run started. The temperature during the collection period ranged from 3.9 C to 8.3 C. The fish were placed in ponds which had a temperature range from 6.1 C to 12.8 C and were allowed to ripen both normally and with carp pituitary injections. Fertilized eggs were then placed in hatching jars where water temperatures ranged from 10.0 C to 12.2 C when the eggs began hatching. Walleye eggs reached the eyed stage in 8 days and began hatching in 13 days. Sauger eggs began hatching in 9 days and continued through the 14th day.

29. Niemuth, Wallace, Warren Churchill, and Thomas Wirth

1959. The walleye, its life history, ecology, and management. Wisc. Conserv. Dept. Pub. 227, 14 p.

Descriptors
WALLEYE
WISCONSIN
SPAWN
INCUBATION

The walleye spawning migration begins in Wisconsin when the water temperature reaches 3.3-6.7 C. Spawning reaches a peak when temperatures are 8.9-10.0 C, although spawning has been observed between the temperatures of 6.1 and 17.2 C. Walleye eggs hatch in 26 days when the water temperature is 4.4 C, 21 days when the water temperature is from 10.0-12.8 C, and in 7 days with a mean water temperature of 13.9 C.

30. Payne N. R.

1964. The life history of the walleye, *Stizostedion vitreum vitreum* (Mitchill), in the Bay of Quinte. M.A. Thesis, Univ. Toronto, Toronto, Ont. 40 p.

Descriptors
WALLEYE
ONTARIO
YEAR-CLASS
STRENGTH

In lake Ontario walleye spawning commences when the water temperature reaches above 3.3 C and is completed by the time the water temperature is 10.0 C. There is a strong indication that there is a relationship between April air temperatures and the size of year-classes of walleyes in the Bay of Quinte. All strong year-classes occurred in the years when the April mean air temperatures were above normal. Weak year-classes were produced in the two years when the April mean temperatures were subnormal. But also there were weak year-classes produced in 1949, 1953, and 1958 when April mean temperatures were above normal. It was concluded from these facts that 1) above normal temperatures at spawning time are required for the production of a strong year-class, 2) subnormal April mean temperatures result in the development of weak year-classes, and 3) above normal temperatures alone are not sufficient to cause better than average spawning success. It was also suggested that it is feasible that May and June temperatures also are of some importance in enhancing or nullifying the effect of April temperatures.

31. Priegel, Gordon R.

1963. Walleye nursery. Wisc. Conserv. Bull. 28(2): 6-7.

Descriptors
WALLEYE
WISCONSIN
SPAWN

Walleye spawning in Wisconsin occurs in mid-April when the water temperatures approach 5.6 C.

32. Priegel, Gordon R.

1966. Lake Puckaway walleye. Wisc. Conserv. Dept., Res. Rep. 19, 22 p.

Descriptors
WALLEYE
WISCONSIN
SPAWN

Active walleye spawning occurs in the Montello River, Wisconsin when water temperatures reach 5.6 C.

33. Priegel, Gordon R.
1968. Lake Winnebago cousins. Wisc. Conserv. Bull. 33(2): 24-25.

Descriptors
WALLEYE
SAUGER
WISCONSIN
INCUBATION

Walleye eggs will hatch in 21 days at water temperatures of 10.0-12.8 C while sauger eggs will hatch in 13-15 days at the same temperature.

34. Priegel, Gordon R.
1969. The Lake Winnebago sauger. Age, growth, reproduction, food habits and early life history. Wisc. Dept. Nat. Res., Tech. Bull. 43, 63 p.

Descriptors
SAUGER
WISCONSIN
SPAWN
INCUBATION

In 1965 sauger spawning occurred between May 2-9 when the temperature ranged from 6.1-9.4 C. In 1966 the water temperature ranged from 7.2-10.0 C but no spawning activity was observed. In 1967 spawning occurred from April 24 to May 6 when the water temperature ranged from 7.8-11.1 C. In a fish hatchery sauger eggs hatched in 13-15 days at a water temperature of 10.6 C.

35. Priegel, Gordon R.
1970. Reproduction and early life history of the walleye in the Lake Winnebago region. Wisc. Dept. Nat. Res., Tech. Bull. 45, 105 p.

Descriptors
WALLEYE
WISCONSIN
SPAWN
INCUBATION

In the Lake Winnebago region, Wisconsin, walleyes were observed spawning when water temperatures ranged between 2.2-15.6 C. During peak spawning periods water temperatures were 5.6-7.8 C. The following tables show the temperature (C) criteria for spawning and incubation of walleyes and eggs in the Lake Winnebago region:

Year	Range of water temperature (C)					
	Spoehr's Marsh		Fox River Marshes		Lake Winnebago	
	During spawning	During egg development	During spawning	During egg development	During spawning	During egg development
1960	5.6-12.2	7.2-18.9	4.4-12.2	5.6-15.0	-	-
1961	2.2-10.0	2.2-15.6	3.3-10.0	6.7-16.7	-	-
1962	2.2-12.2	2.2-15.6	5.6-10.0	5.0-15.6	-	-
1963	5.6-12.2	2.2-12.8	4.4-11.1	6.7-14.4	-	-
1964	-	-	5.6-10.0	4.4-15.6	5.6-11.1	5.0-12.8
1965	6.1-8.9	5.0-14.4	5.0-14.4	5.6-15.6	5.6-7.8	5.6-10.0
1966	4.4-8.3	4.4-11.1	4.4-13.3	6.7-15.0	6.7-10.6	6.1-10.6
1967	4.4-11.1	6.7-13.3	6.1-15.6	6.1-17.8	3.9-7.8	4.4-10.6

In the Lake Winnebago region, cold weather prolonged the spawning activity over an extended period of time. It was never inhibited. Most rapid embryo development and short incubation periods were associated with daytime temperatures above 10.0 C and high minimum water temperatures that did not fall below 7.2 C for any extended length of time. No correlation between water temperature and embryo survival was found.

36. Rawson, D.S.
1957. The life history and ecology of the yellow walleye, Stizostedion vitreum, in Lac la Ronge, Saskatchewan. Trans. Amer. Fish. Soc. 86(1956): 15-37.

Descriptors
WALLEYE
SASKATCHEWAN
SPAWN
DISTRIBUTION

It was suggested that water temperature appeared to be the controlling influence for the walleye spawning run. No spawning activity was observed in water temperatures below 3.3 C. The main spawning run in Lac la Ronge took place at a temperature of 4.4-5.6 C. Active spawning was observed between 7.2-10.0 C. No evidence was found that walleyes selected, or moved into, water of any particular temperature range during the summer. However, it was found that walleyes were active in the range from 15.0-18.3 C. It was suggested that it was unlikely that temperature preference was the reason for movement into deeper water, since it was found that August water temperatures at 5 to 10 meters were usually between 16.1-18.3 C and the surface temperature rarely exceeded 18.9 C. An alternative reason for movement into deeper water was suggested to be the pursuit of food organisms such as ciscoes.

37. Regier, Henry A., Vernon C. Applegate, and Richard A. Ryder
1969. The ecology and management of the walleye in western Lake Erie. Great Lakes Fish. Comm. Tech. Rep. 15, 101 p.

Descriptors
WALLEYE
SAUGER
LAKE ERIE
DISTRIBUTION

Walleye reportedly prefers a temperature of about 21.1-22.2 C in summer, but some resident populations in rivers (Illinois) tolerate water temperatures as high as 30 C for extended periods. From all available information it appeared to the authors that light intensity is a more important factor in determining depths selected by walleyes in the summer than water temperature. Based on the geographical distribution of saugers and walleyes, it was suspected that saugers are less tolerant to low temperatures and slightly more tolerant to high temperatures than the walleye since saugers occur further southwest and do not occur as far north.

38. Schumann, George C.
1964. The effect of abnormal temperatures on the spawning and developmental success of eggs from the North American walleye. Transl. from Osterreichs Fischerei, May 1964(5): 85-87, by Dieter N. Busch, U.S. Bur. Comm. Fish., Sandusky, Ohio.

Descriptors
WALLEYE
WISCONSIN
SPAWN

In northern Wisconsin it was found that the walleye consistently spawns at water temperatures from 5-10 C with the largest walleyes reaching the spawning grounds first. When temperatures quickly warm up in the spring causing early spawning activity then followed by a cold spell, the walleyes leave the spawning grounds before spawning is completed. It was found that the younger, smaller female walleyes were capable of spawning later when water temperatures warmed up again. Since the complete ripening of eggs is earlier for the larger walleyes, the eggs in the smaller females do not suffer the same delay when unfavorable weather conditions postpone spawning.

39. Smith, Lloyd L., Jr., and Richard L. Pycha
1960. First-year growth of the walleye, _Stizostedion vitreum vitreum_ (Mitchill), and associated factors in the Red Lakes, Minnesota. Limnol. Oceanogr. 5(3): 281-290.

Descriptors
WALLEYE
MINNESOTA
GROWTH

An attempt was made to correlate first-year growth of walleyes in Red Lakes, Minnesota with air degree-days above 45 F and air degree-days above 50 F for the following months: 1) May, June, July; 2) May, June, July, August; 3) July, August; 4) August; 5) August, September; 6) September; and 7) the last two weeks in July, August, and September for a 17-year period, 1940-1956. They all showed a positive correlation with growth of young walleyes, but none were significant below the 15% level.

40. Spinner, John
1968. Environmental effect on the spawning run of northern pike and walleye in the upper Mississippi River. Proc. of North Central Warm-Water Fish Culture Workshop, Iowa Coop. Fish. Unit, 1968: 9-12.

Descriptors
WALLEYE
IOWA
SPAWN

Walleye spawn in the upper Mississippi River when temperatures are 7.8-8.9 C. For management purposes it was suggested that peak of walleye egg taking is when the temperature reaches 8.9-11.1 C. Tests were made on walleye eggs taken from the Mississippi walleyes. Eggs were held at a constant temperature of 12.2 C; by the 10th day eggs are eyed and start hatching in 20 days.

41. Steucke, Erwin W.

1968. Optimum temperatures for hatching northern pike and walleye eggs. Proc. North Central Warm-Water Fish Culture Workshop, Iowa Coop. Fish. Unit, 1968: 32-34.

Descriptors
WALLEYE
WISCONSIN
INCUBATION

Walleye eggs were incubated at different test temperatures ranging from 10.0-23.9 C. The temperature maintenance during the test was $\pm$0.28 C. At 19.4 C, 67% of the eggs hatched. Walleye eggs were then incubated at 21.7 C and 23.9 C. These hatched in 5 days but died immediately after hatching. It was concluded that 16.7-19.4 C was the best temperature for hatching walleye eggs. It was also concluded that based on 32 F, it took an average number of 238 degree-days for walleye eggs to hatch.

42. Walburg, Charles H.

1972. Some factors associated with fluctuation in year-class strength of sauger, Lewis and Clark Lake, South Dakota. Trans. Amer. Fish. Soc. 101(2): 311-316.

Descriptors
SAUGER
S. DAKOTA
INCUBATION
YEAR-CLASS STRENGTH

Saugers spawned in the Missouri River when water temperatures reached 6.1 C. At an average water temperature of 8.7 C the embryo incubation period for saugers is 21 days. It was found that June reservoir water temperature, along with water level fluctuation over the spawning grounds and the reservoir exchange rate account for 86% of the variability in year-class strength. Fewer fish were lost when June water temperatures averaged near 21 C. At cooler temperatures the growth was slower and fry were more subject to current loss in the discharge.

INDEX

WALLEYE (STIZOSTEDION VITREUM VITREUM)

1 2 4 5 7 8
9 10 11 12 13 14
15 16 17 18 20 21
22 23 24 25 26 28
29 30 31 32 33 35
36 37 38 39 40 41

SAUGER (STIZOSTEDION CANADENSE)

6 8 10 16 19 27
28 33 34 37 42

BLUE PIKE (STIZOSTEDION VITREUM GLAUCUM)

3 10