THE EFFECTS OF HEATED WATER ON WARMWATER FISH IN EARTHEN RACEWAYS[a]

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Abstract: Two-year studies were conducted in 3 earthen raceways (160 m x 6 m x 2 m). One raceway was maintained at ambient water temperature, 1 had a heated floating plume over 60% of the surface, and 1 was maintained at near heated water discharge temperature. Average water temperatures ranging up to 36.7 C were not lethal for any fish species tested. With the possible exception of threadfin shad (*Dorosoma petenense*) no difference in long-term survival of any species was detected, but when the entire population was considered as a whole, survival of fishes confined to the highest temperatures was reduced. Growth rates of largemouth (*Micropterus salmoides*) and spotted basses (*M. punctatus*), channel catfish (*Ictaluras punctatus*), redear sunfish (*Lepomis microlophus*, and gizzard shad (*D. cepedianum*) in at least 1 of the heated water treatments exceeded growth in the control. Total standing crop and growth rates of bluegill (*L. macrochirus*) and drum (*Aplodinotus grunniens*) were lowest in the treatment with highest water temperatures. Little difference was seen between the control and the treatment with a floating heated water plume.

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Much work has been done to determine the upper thermal limits of warmwater fishes. Brett (1956) reviewed the principles of thermal tolerances; Raney and Menzel (1969) published a bibliography of the effects of temperature on fish. Recent research was reviewed by Coutant et al. (1972, 1973, 1974, 1975).

Nearly all prior research has been done in aquaria, where fish were subjected to extremely artificial conditions, or in situ studies, where there was little or no control over experimental conditions. Rarely has there been an opportunity to perform field studies of wild fish that were confined to heated waters. The few studies of this nature have reported very high thermal maxima. For instance, in aquaria studies Hart (1952) found that 33.8 C and 36.4 C were the incipient lethal temperatures for bluegill and largemouth bass, respectively. More recent studies showed that bluegill can tolerate temperatures of 35 C to 36 C (Hickman and Dewey 1973; Cherry et al. 1975). However, Holland et al. (1974) found that bluegill confined to Pond C, a heavily loaded thermal lagoon, could resist very high temperatures. Pond C bluegill easily acclimated to 35 C and could tolerate temperatures above 40 C. The critical thermal maximum of these fish was determined to be 42.8 C. Wild largemouth bass have frequently been captured from, or observed in, water with temperatures higher than 36.4 C. Drew and Tilton (1970) captured by hook and line healthy, active largemouth bass that were confined to waters ranging from 36.7 C to 38.4 C in Alcoa Lake, Texas. These temperatures from these field studies are well above the published thermal limits for both bluegill and largemouth bass, indicating that limits derived from laboratory studies fail to show the complete picture of fishes' thermal adaptability.

Our study was conducted in large earthen raceways in which thermal regimes were manipulated to approximate conditions of a heated water discharge canal, a portion of a stream receiving heated water, and an unaffected portion of the same stream.

Investigative emphasis was centered around determining differences in water quality, plankton communities, macroinvertebrate communities, and fish populations confined to 3 different thermal regimes. Results reported in this paper deal with the effects of heated water on the fishes studied.

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MATERIALS AND METHODS

Experimental Channels

Three earthen channels (160.0 m x 6.0 m x 2.0 m) were dug near Alabama Power Company's Greene County Steam Plant located adjacent to the Black Warrior River in Greene County, Alabama. At one end of each channel, a 30.5 cm diameter vertical standpipe was placed to accommodate overflow, and 7.6 cm PVC water supply lines were variously arranged towards the opposite end to produce a constant, undirectional water flow. The newly constructed channels were "V" shaped in cross section with the walls having an approximate 45° slope.

Ambient water was pumped from the intake canal leading from the Black Warrior River to the steam plant cooling water intake and arrived at the channels at approximately the same temperature as the natural river water. Heated water was pumped from the head end of the discharge canal carrying the warmer condensor cooling waters away from the plant to the river. This water arrived at the channels at temperatures varying from 7 to 14 C above ambient when the steam plant was operating normally.

Thermal Regimes

Channel 1 (Ch 1) received only ambient water to simulate natural conditions of the Black Warrior River, and channel 3 (Ch 3) only heated water to simulate the discharge canal and mixing zone in that portion of the river receiving discharge of cooling water. In both, water was introduced approximately 7.6 m above station I and removed through a standpipe drain located at station XI (Fig. 1). Water was drained from the surface of these channels during the warmer months and from a depth of approximately 0.6 m during cooler months.

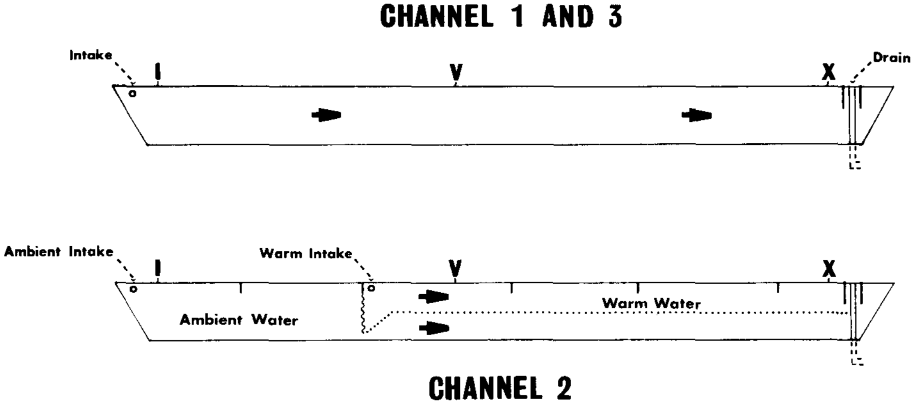

Fig. 1. Longitudinal sections of channels showing locations of stations I, V, and X, direction of flow, the configuration of polyethylene curtain and floating thermal plume in Ch 2.

In channel 2 (Ch 2) ambient river water was introduced approximately 7.6 m above station I. Heated water was released at station IV just downstream of a weighted polyethylene curtain suspended across the channel to within 30 cm of the bottom. This curtain and a series of wooden baffles suspended across the channel to a depth of 15 cm helped prevent wind-produced currents and allowed the water to stratify thermally. The drain in this channel was adjusted to remove water from a depth of 0.75 m. A floating thermal plume formed over the lower end of Ch 2 simulating existing conditions in that reach of the river receiving effluent from the Greene County Steam Plant. This floating plume covered approximately 60 percent of the surface area of Ch 2. Motile organisms in this channel could escape heated water by moving to ambient water areas. All supply lines were equipped with flow meters and gate valves to adjust water supply volume. Care was taken to maintain similar total flows in the 3 channels.

Approximately 30 fish species indigenous to the Black Warrior River were studied. However, many of these fish were stocked for forage only or in such small numbers as to yield little or no useful data. All channels were initially stocked with equivalent numbers and approximately equivalent weights of all species while not exceeding a total standing crop of 225 kg/ha. Thereafter, all stocking was done on a replacement basis in order to maintain approximately equivalent numbers of all species in all channels.

Mortality rates for various species were often much higher in 1 channel than in the other channels. In this case, replacement stocking in that channel raised the total number of stocked fish (of that species) above the totals stocked into the other channels. However, at no time were replacement fish "overstocked" so as to be present in any channel in greater numbers than in the other channels.

Before stocking, all fish were weighed, measured, and marked with a fin-clip. All fish except largemouth bass, fathead minnow (*Pimephales promelas*) and grass carp (*Ctenopharyngodon idella*) were collected by electrofishing from the Black Warrior River and its tributaries in the vicinity of the steam plant. These 3 species were brought from the Fisheries Research Unit, Auburn, Alabama.

In February, May, and November 1975 and April 1976, fishes in each channel were sampled with a 15 m bag seine. Fishes were identified, measured, weighed, and returned to the channels.

At the conclusion of the study in October 1976, the channels were drained and all fishes removed. Fishes were identified, measured, weighed, and examined for evidence of parasites and diseases. Stomachs were removed from a select number of adult fish, preserved and later analyzed for content. Growth and condition (K_n) (Swingle and Shell 1971) were computed for all fish possible after each sampling and at harvest.

Reproductive activity of fishes in the channels was judged from (1) observation of reproductive behavior (courting, nesting or brooding activities) and (2) presence of eggs, fry or fingerlings either observed or seined from the channels with small-mesh minnow seines or larval fish nets. Equal efforts with seines and nets were made in all channels on each sampling date so that results would be comparable. Air and water temperatures, dissolved oxygen, turbidity, and water flow were monitored daily by resident biologists.

RESULTS AND DISCUSSION

Temperature and Water Flow

The ranges in average daily temperatures for Ch 1 and Ch 3 during the 24 month study are presented in Fig. 2. The difference in average temperature between Ch 1 and Ch 3 for any given time and channel location was usually 3-7 C.

Weekly average summer temperatures in Ch 1 seldom exceeded 30 C. From mid-May to mid-September 1975, and from early June through September 1976, the average weekly temperature of Ch 3 exceeded 30 C. For 77 days (33 consecutive) in 1975 and 71 days (36 consecutive) in 1976, the minimum (2 m depth) afternoon temperature in Ch 3 exceeded 32 C. For 19 days (12 consecutive) in 1975 and 23 days (12 consecutive) in 1976, the minimum (2 m depth) afternoon temperature exceeded 34 C while minimum early morning temperatures exceeded 32 C. Highest average weekly temperatures of Ch 1 in 1975 and 1976 were 30.4 C and 30.8 C, respectively. Highest average weekly temperatures in Ch 3 in 1975 and 1976 were 34 C and 35.5 C, respectively. The highest average channel temperature was 36.7 C on 1 August 1976 at 1,500 hours.

The ranges in average daily temperature for the ambient portion of channel 2 (Ch 2A) and the heated plume of channel 2 (Ch 2P) are presented in Fig. 2. Variation in average temperature was more pronounced in Ch 2 than in Ch 1 or Ch 3 due to the relatively small volume of water in Ch 2P. Changes in atmospheric conditions or in the temperature of the heated intake water had a greater impact in Ch 2P than in either of the larger bodies of water. The difference in average temperatures of Ch2A and Ch 2P varied between 0.1 C and 5.0 C.

Weekly average summer temperatures of Ch 2A exceeded 31 C on 2 occasions while the heated plume, Ch 2P, temperature exceeded 21 C on 15 occasions. Beginning the third week of June 1975, some portion of the heated plume exceeded 32 C on 12 of the following 13 weeks. In 1976, the plume temperature exceeded 32 C from June 1 through September 26. Highest average weekly temperatures of Ch 2A in 1975 and 1976 were 31.2 C and 31.1 C, respectively. Highest average weekly temperatures of Ch 2P for 1975 and 1976 were 33.2 C and 34.5 C, respectively. Flow rates averaged 856 m^3/day in Ch 1, 829 m^3/day in Ch 2 and 813 m^3/day in Ch 3. Total exchange time averaged 25.6 hr in Ch 1, 26.3 hr in Ch 2, and 26.7 hr in Ch 3.

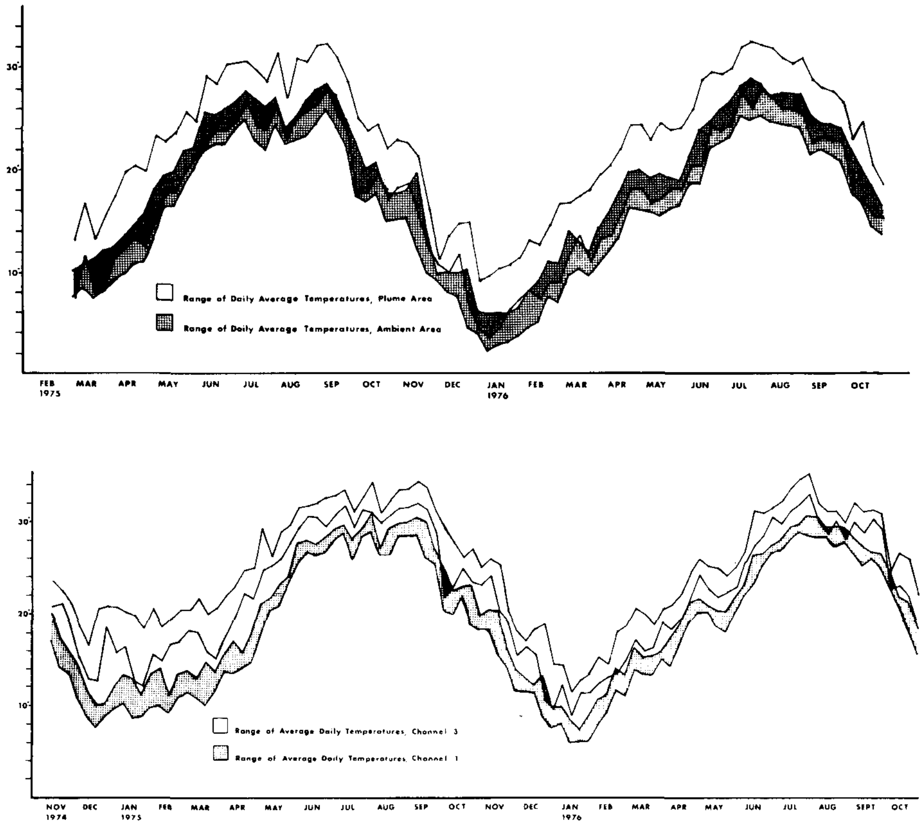

Fig. 2. Range of daily average temperatures in Ch 2 plume area and Ch 2 ambient area (top), and range of average daily temperatures in Ch 1 and Ch 3 (bottom).

Survival

Due to the nature of this research, traditional survival estimates, such as the LD_{50} and the critical thermal maximum (CTM) were not used. Instead, survival was reported as percent survival over the entire study period or a significant portion of it. Survival during critical summer months, when temperatures were highest, was also examined. Large-scale die-offs were noted as they occurred.

The entire study period can be divided into 2 subperiods. There was an initial period, when fish and fish-food organism populations were being established, and a final period, after these populations had become established and relatively stable. In general, growth and survival of all fish species in all channels were much better during the final period than in the initial period. The sampling date, 21 May 1975, is used to separate these 2 periods.

A total of 235, 234, and 235 fish were stocked into Ch 1, Ch 2, and Ch 3, respectively. The channels were drained on 28 October 1976, and a total of 50 stocked fish were recovered from Ch 1, 49 fish from Ch 2, and 29 fish from Ch 3. The survival rates for both Ch 1 and Ch 2 were 21 percent, while the survival rate for Ch 3 was only 12 percent. The mortality rates in the control Ch 1 indicate that lethal temperatures were not responsible for most of this mortality. At least 4 other causative factors were identified: stocking and handling mortality, predation on small species, the lack of a suitable food base during the first winter (1974-1975) of operation and the inability of some species to adapt to the habitat provided in the channels. These factors are discussed where applicable to survival of the following fishes.

During 1974, a total of 12, 18, and 24 largemouth bass were stocked into Ch 1, Ch 2, and Ch 3, respectively. The lack of sufficient forage fish during the first winter resulted in exceptionally high mortality rates for bass in all channels. Mortality was greatest in warmwater Ch 3, where stocking rates and metabolic rates were highest and forage fish populations were lowest. On 21 May 1975 only 2 emaciated bass were alive in Ch 3. Mortality in Ch 1 and Ch 2 was also high. Due to the general lack of food in all raceways, survival and growth before 21 May 1975 were not considered to be relevant to the objectives of this research and were disregarded.

Bass were restocked when forage fish populations were replenished. During the final half of the study period living conditions for bass were improved and mortality rates were low in all channels. The leading cause of death in Ch 3 was fish jumping out of the channel. If these fish are disregarded, the survival of Ch 3 bass was comparable to that of Ch 1 and Ch 2 (Table 1). During the final period 88 percent of

Table 1. Survival and standing crop of stocked fishes from 27 May 1975 to 28 October 1976.

Species	*Channel*	*No. of fish*[a] *stocked/recovered*	*Standing crop (kg)*
Largemouth bass	1	7/4	1.29
	2	8/7	2.49
	3	4/3	1.98
Spotted bass	1	3/1	0.39
	2	4/3	1.38
	3	3/2	0.89
	2	10/4	2.79
	3	7/3	1.20
Bluegill	1	9/5	2.22
	2	10/4	2.74
	3	7/3	1.20
Redear sunfish	1	4/3	0.90
	2	4/3	1.10
	3	4/1	0.22
Channel catfish	1	16/14	4.93
	2	9/7	4.26
	3	8/6	2.61
Freshwater drum	1	3/3	2.76
	2	3/3	1.86
	3	3/2	0.71
Gizzard shad	1	8/(47)	16.10
	2	8/7	6.33
	3	7/5	3.04
Threadfin shad	1	38/(116)	0.39
	2	35/0	—
	3	38/0	—
Totals	1	50/38[b]	28.98
	2	46/34	20.16
	3	36/22	10.65

[a] Fish dying on, or immediately after, 5-21-75 and fish that jumped from raceways are not included in 'number of fish stocked' totals.

[b] Total for CH 1 was calculated using 100% survival of stocked gizzard shad and 0% for stocked threadfin shad.

the fish in Ch 2 survived, 60 percent survived in Ch 3, and 57 precent survived in Ch 1. In Ch 3, 4 of 5 bass survived the summer of 1975; 3 of 4 survived the summer of 1976 (Table 2).

Table 2. Estimated survival of fish during summers of 1975 and 1976.

Species	*Fish present before/after*[a]					
	Summer 1975			*Summer 1976*		
	CH 1	*CH 2*	*CH 3*	*CH 1*	*CH 2*	*CH 3*
Largemouth bass	8/6	6/4	5/4	4/4	7/7	4/3
Spotted bass	3/2	2/2	1/1	2/1	3/3	2/2
Bluegill	4/0	5/0	6/5	5/5	5/4	4/3
Redear sunfish	4/4	5/3	4/3	4/3	3/3	2/1
Channel catfish	16/16	6/6	5/5	15/14	7/7	8/6
Drum	3/3	3/3	3/3	3/3	3/3	3/2
Gizzard shad	4/36	4/3	3/3	39/47	7/7	7/5
Threadfin shad	15/49	15/0	11/0	23/116	20/0	27/0

[a] Totals do not include fish that jumped from raceway.

Both blue catfish (*I. furcatus*) and channel catfish were stocked during September 1974. Within 10 days all of the blue catfish had died from a bacterial infection. During this period, large numbers of channel catfish also died in Ch 2 and Ch 3, but very few died in Ch. 1. On 21 May 1975, 16 channel catfish were alive in Ch 1, while only 5 and 3 fish were alive in Ch 2 and Ch 3, respectively. Smaller numbers of channel catfish were restocked in Ch 2 and Ch 3, and survival of these fish during the final half of the experiment was comparable to catfish survival in Ch 1. In Ch 3, 75 percent of the fish survived, while 88 percent survived in Ch 1 and 78 percent in Ch 2. Survival of channel catfish was not obviously impaired in either heated water treatment.

During the spring of 1975 and 1976, threadfin shad were stocked in all channels. No threadfin shad survived either summer in Ch 2 and Ch 3. Large numbers of threadfin shad survived both summers in Ch 1. Threadfin shad are relatively small and are vulnerable to predation during most of their lives. All channels were stocked heavily with piscivorous species and very few small fish grew larger than 2 inches in Ch 2 or Ch 3. It is possible that all threadfin shad in Ch 2 and Ch 3 were eaten by piscivorous fish, although it is also possible that they succumbed to lethal temperatures. Fingerling threadfin shad were last observed in Ch 3 on 22 July 1976 in water measured at 36.7 C.

Survival of gizzard shad was near 100 percent in all channels until 29 September 1976 when 2 fish died in Ch 3 (Table 1).

In the fall of 1974, a total of 28, 27, and 27 bluegill were stocked into Ch 1, Ch 2, and Ch 3, respectively. Mortality rates for bluegill were exceptionally high during the initial period of the experiment. The reasons for high bluegill mortality are not clear. Invertebrate food organisms were abundant during this period (Alston 1977), bluegill condition values were generally high, and surviving fish appeared to be healthy. Nevertheless, by 21 May 1975 bluegill mortality approached 100 percent in all channels. Bluegill were restocked during the latter part of 1975 and in 1976. Survival of restocked bluegill was approximately equal in all channels. In Ch 3, 83 percent of the restocked fish survived the summer of 1975, and 75 percent survived the summer of 1976. Bluegill were not restocked in Ch 1 and Ch 2 until March 1976; of these fish 100 percent in Ch 1 and 80 percent in Ch 2 survived the summer of 1976.

Freshwater drum were stocked in smaller numbers than most other species (Table 1). In Ch 1 and Ch 2 all drum survived the final half of the experiment. While 2 out of 3 drum survived this period in Ch 3, marked differences in growth rates made it evident that drum did not fare as well in Ch 3 as in the other channels.

Numerous other species were stocked but not in numbers sufficient to yield useful information on survival. Spotted gar (*Lepisosteus oculatus*), spotted bass, and redear sunfish were present in all treatments at harvest. Bowfin (*Amia calva*) and white crappie (*Pomoxis annularis*) were found in Ch 1 and Ch 2, and longear sunfish in Ch

2 and Ch 3 at harvest. One white bass (*Morone chrysops*) and one blue catfish survived to harvest in Ch 1; and warmouth (*L. gulosus*) were found only in Ch 2. Black crappie (*P. nigromaculatus*) survived to harvest only in Ch 3.

With the exception of 100 percent mortality of threadfin shad in Ch 2 and Ch 3 there were no obvious differences in the survival of species in any treatment. However, when considering all fishes, the percent survival in Ch 3 was lower than in other treatments. During the final period (May 1975-October 1976) 43 percent and 42 percent of the fish survived in Ch 1 and Ch 2, respectively. In Ch 3 only 30 percent of the fish survived (Table 1). When threadfin shad and fish that jumped out of the channels were disregarded, the percent survival figures increased to 76 percent in Ch 1, 74 percent for Ch 2, and 61 percent in Ch 3.

Growth and Condition (K_n)

Because of the lack of forage fish, growth and condition of largemouth bass during the initial period of the experiment was very poor. Bass in all channels lost weight and on 21 May 1975 average K_n values were 0.70 in Ch 1, 0.73 in Ch 2, and 0.66 in Ch 3. Because of the abnormal conditions that existed during the initial period of the study, growth, condition, and survival data were disregarded.

During the final period (May 1975-October 1976) the average K_n for bass was 0.84 in Ch 1, 0.84 in Ch 2, and 0.86 in Ch 3. Growth rates were 0.11 kg/yr in Ch 1, 0.10 kg/yr in Ch 2 and 0.21 kg/yr in Ch 3. These figures were all low and were due to a general shortage of forage for piscivorous species throughout the experiment. These poor conditions were also reflected in the Y/C ratio (Swingle, 1950) obtained at harvest. The Y/C ratio when fish were harvested was 0.52 in Ch 1, 0.24 in Ch 2, and 0.19 in Ch 3. All of these indicate overcrowded piscivorous species with forage species disappearing.

During summer months, when temperatures were highest (Fig. 2), bass in Ch 3 made better growth and produced higher K_n values than fish in the other channels. During the cooler winter months Ch 3 bass lost weight and had lower K_n values than fish in the other channels. In Ch 3 fish fed and moved about actively all winter, while bass in Ch 1 and Ch 2 became dormant. In both winters, bass in Ch 3 exhausted their food supply sooner than bass in Ch 1 and Ch 2. This was a critical period for bass in Ch 3, as their elevated metabolic rates demanded more food than bass in Ch 1 and Ch 2 just for maintenance. Consequently bass in Ch 3 were in poor condition at the end of the winter.

Young-of-the-year Ch 3 bass also grew faster than their counterparts in Ch 1. When fish were harvested in October 1976, total length of Year 1 largemouth bass from Ch 3 ranged from 180 mm to 229 mm, whereas Year 1 fish from Ch 1 reached only 111 mm. Although a large bass spawn occurred in Ch 2, none survived to harvest.

Growth and condition data for the few spotted bass stocked were similar to those of largemouth bass, but differences between channels were even more pronounced. Spotted bass in Ch 1 grew little during the course of the study.

Growth and condition of bluegill in Ch 1 and Ch 2 were approximately equal, but fish from Ch 3 grew at a much slower rate (Table 3). Macroinvertebrate studies indicated that in Ch 3 larval insects, an important bluegill food item, were less abundant in both kind and number than in other channels (Alston 1977).

Growth patterns of freshwater drum in Ch 1 and Ch 2 were similar. During the final period, drum in Ch 1 gained an average of 0.29 kg/yr and had an average K_n of 1.23. Drum in Ch 2 gained an average 0.25 kg/yr and had a K of 1.14. Drum in Ch 3 lost an average of 0.03 kg/yr and had an average K_n of only 0.93 (Table 3).

When the fish were harvested the stomach contents of drum were analyzed. Stomachs of drum from Ch 1 and Ch 2 contained an abundance of food-items, notably nymphs of the burrowing mayfly, *Hexagenia,* and various molluscs. Larvae of chironomids and odonates were also common. Alston (1977) found that in Ch 3 these organisms were either rare or absent. No *Hexagenia* or odonate larvae and few molluscs were found in Ch 3 drum stomachs. Larvae of the midge, *Ablabesmyia,* were the most common items in stomachs of Ch 3 drum.

Daiber (1952) found that *Hexagenia* and molluscs were the most important food items of Lake Erie drum. Swedesburg (1968) found that the growth rate of drum correlated with the abundance of *Hexegenia.* In Ch 3 the scarcity of desirable food items greatly reduced the food base of drum.

Growth rates and condition factors of channel catfish were roughly equal through the fall of 1975. K_n values on 19 November 1975 were 0.85 in Ch 1, 0.88 in Ch 2,

Table 3. Average growth and condition (K_n) of stocked fish from 5-21-75 to 10-28-76.

		21 May 75		*19 Nov. 75*		*1 Apr. 75*		*28 Oct. 76*			*Av.*	*Growth*
Species	*Channel*	*No.*	K_n	*No.*	K_n	*No.*	K_n	*No.*	K_n	*(Kg/fish)*	K_n	*kg/yr.*
Largemouth bass	1	10	0.70	5	0.86	4	0.86	4	0.79	0.32	0.84	0.11
	2	5	0.73	4	0.84	4	0.88	7	0.81	0.36	0.84	0.10
	3	2	0.66	6	0.93	6	0.80	3	0.87	0.39	0.86	0.21
Spotted bass	1	3	0.85	2	0.72	1	0.76	1	0.68	0.39	0.78	−0.06
	2	1	0.77	4	0.82	1	1.16	3	0.81	0.46	0.85	0.11
	3	3	0.68	3	0.89	2	0.81	2	0.80	0.45	0.81	0.16
Bluegill	1	4	1.13	0	—	5	1.15	5	1.00	0.13	1.09	0.08
	2	3	1.19	0	—	4	1.06	4	0.98	0.16	1.06	0.07
	3	3	0.90	5	0.96	2	1.09	3	0.89	0.15	0.95	0.02
Redear sunfish	1	4	1.08	4	1.08	4	1.11	3	0.97	0.23	1.07	0.06
	2	5	0.98	2	1.09	2	1.16	3	1.17	0.35	1.08	0.09
	3	3	0.96	3	1.02	2	1.31	1	1.05	0.22	1.08	0.08
Channel catfish	1	11	0.98	14	0.85	14	0.92	14	0.80	0.35	0.87	0.11
	2	5	0.99	7	0.88	6	0.97	7	0.93	0.61	0.92	0.29
	3	2	0.89	8	0.80	8	0.88	6	0.84	0.44	0.87	0.20
Drum	1	3	1.23	3	1.20	3	1.28	3	1.36	0.92	1.23	0.29
	2	3	1.06	3	1.10	3	1.15	3	1.26	0.62	1.14	0.25
	3	3	0.89	3	0.94	3	0.89	2	1.03	0.36	0.93	−0.03

and 0.80 in Ch 3; and growth rates were 0.29 kg/yr in Ch 1, 0.26 kg/yr in Ch 2, and 0.27 kg/yr in Ch 3. From that date until harvest, catfish in Ch 2 grew at a faster rate than catfish in Ch 1 or Ch 3. When harvested, catfish in Ch 2 averaged 0.61 kg, whereas fish from Ch 3 averaged 0.41 kg, and fish from Ch 1 only 0.35 kg. Final averages of growth rates and K_n values were higher in Ch 2 (Table 3). Total standing crop of channel catfish was, however, highest in Ch 1, which yielded 4.95 kg of fish. Ch 2 produced 4.27 kg of fish, and Ch 3 produced 2.86 kg.

Twice as many channel catfish survived in Ch 1 as in either Ch 2 or Ch 3. Because of this, and because Ch 1 yielded the highest standing crop at the lowest average growth rate, it was thought that catfish in Ch 1 might be overcrowded. Therefore, growth and condition of Ch 2 and Ch 3 catfish, which were not overcrowded, should not be compared to the growth and condition of Ch 1 catfish. It appeared, however, that conditions in Ch 2 and Ch 3 were favorable for catfish growth and well-being.

Data on redear sunfish suggested that growth rates in Ch 2 and Ch 3 equalled that of control Ch 1, but not enough fish were involved to provide conclusive data. Incremental growth estimates were not calculated for gizzard shad, but at harvest, gizzard shad in Ch 3 averaged 0.61 kg and gizzard shad in Ch 2 averaged 0.83 kg. In Ch 1, the average weight of stocked gizzard shad could not be calculated because it was impossible to distinguish stocked shad from their offspring. Forty.-seven gizzard shad, ranging from 0.70 to 0.05 kg and weighing a total of 16.10 kg, were harvested from Ch 1.

Standing Crop

Total standing crop at harvest (28 October 1976) was much larger in Ch 1 than in Ch 2, and in Ch 2 than in Ch 3 (Table 1). The difference between Ch 1 and Ch 2 was largely due to the difference in gizzard shad production. Total standing crop with gizzard shad removed was approximately equal in Ch 1 (12.88 kg) and Ch 2 (13.83 kg). Standing crop minus gizzard shad in Ch 3 was only 7.61 kg. The reduction in standing crop of Ch 3 was thought to be due to a shortage of desirable food organisms for some species, the failure to recruit gizzard shad into the population, higher mortality rates, lower stocking rates, and poor food conversion (metabolic inefficiency) during that part of the year when water temperatures exceeded a species' physiological optimum temperature.

Reproduction

Evidence of fish reproduction must be weighed remembering that unfiltered river water was constantly entering all channels. Limited numbers of fish eggs, fry, or fingerlings are known to have survived pumping and entered the channels in this way.

Direct observations of reproductive activities were rare. A successful spawn of redear sunfish was documented for Ch 2 in 1975 and 1976. One nest was found in the heated plume end (1975) and one in the ambient water end (1976). In 1976, eggs were found in a redear sunfish nest in Ch 1, but these eggs failed to hatch. Male longear and bluegill sunfishes were observed guarding nests in Ch 2 in 1976. No nests were ever found in Ch 3. Schools of fry and fingerlings were observed periodically in all channels.

Spawning activity was monitored with a larval fish net and with a small-mesh minnow seine. Larvae of *Micropterus* sp., *Lepomis* sp., and *Dorosoma* sp. (probably threadfin shad) were identified in the fish net collections. These larvae were invariably captured sooner in Ch 2 and Ch 3 than in Ch 1. Advanced spawning in heated waters had been reported (Bennett and Gibbons 1975). This, plus the fact that peaks of abundance of fry and fingerling fish did not coincide for Ch 1 versus Ch 2 and Ch 3, indicates that observed fish were spawned within the channels and were not entering through the water supply lines to any large extent. Larger numbers of young fish, primarily *Lepomis* sp., were captured in Ch 2 and Ch 3 than in the control Ch 1. In 1976, almost twice as many fish were captured in Ch 2 as in the other 2 channels.

A summary of spawning activities in the 3 treatments appears in Table 4. Largemouth bass, bluegill sunfish, and threadfin shad spawned in all treatments during at least 1 year. Redear sunfish spawned in Ch 2 and Ch 3 during 1975 and 1976, but in Ch 1 only 1 light spawn occurred (1976). Threadfin shad were stocked in late spring of 1975 and 1976 and were not subjected to channel conditions throughout egg formation. The lake chubsucker (*Erimyzon sucetta*) spawned only in Ch 1. Gizzard shad adults were present in all treatments at harvest, but fry and fingerlings were seldom captured while sampling. Based on the numbers of adult gizzard shad present at harvest in Ch 1 there probably was a spawn in that channel. It was not known whether gizzard shad failed to spawn in large numbers in the other channels or whether they spawned and failed to reach a size large enough to be distinguished from threadfin shad before perishing.

Table 4. Estimates of fish spawning activities in the treatments during 1975-1976. C = confirmed spawn; Pr = probable spawn; and Po = possible spawn.

	1975			*1976*		
Species	*Ch 1*	*Ch 2*	*Ch 3*	*Ch 1*	*Ch 2*	*Ch 3*
Largemouth bass	C	—	—	C	C	C
Spotted bass	Pr	—	—	—	—	—
Bluegill sunfish	C	C	C	C	C	C
Redear sunfish	Po	C	Pr	Pr	C	C
Longear sunfish	—	—	Pr	—	—	—
Warmouth	—	Pr	—	—	Pr	—
White crappie	—	—	—	Pr	—	—
Threadfin shad	—	Pr	—	C	C	C
Gizzard shad	Pr	—	—	Pr	—	—
Lake chubsucker	C	—	—	—	—	—

SUMMARY AND CONCLUSIONS

No die-offs were observed during the critical summer months in either Ch 2 or Ch 3. Threadfin shad failed to survive through summer months in Ch 2 or Ch 3 after heavy stocking in both 1975 and 1976. No other differences in long-term survival rates were detected for any species, but when the fish population was considered as a whole, the long-term survival of fishes in warm water Ch 3 was less than in Ch 1 and Ch 2. If a larger number of fishes had been employed, it is likely that differences in survival rates could have been detected for some species.

Growth and condition of largemouth and spotted basses in Ch 3 exceeded those in the other channels. Growth and condition of channel catfish in Ch 2 exceeded those in Ch 1 and Ch 3. Growth and condition of bluegill and drum were poorest in Ch 3. Total standing crops in Ch 1 and Ch 2 were approximately equal, but standing crop in Ch 3 was much smaller.

Largemouth bass, bluegill and threadfin shad spawned in all channels. Redear sunfish spawned heavily in Ch 2 and Ch 3, but spawned very lightly in Ch 1. Warmouth spawned only in Ch 2, longear sunfish only in Ch 3, and gizzard shad (probably) only in Ch 1.

At harvest, populations of stocked fish in Ch 1 and Ch 2 were similar. The most significant differences were among (1) growth and condition of largemouth and spotted basses, (2) spawning and recruitment of shad and sunfish, and (3) absence of threadfin shad in Ch 2. Ch 3 was found to roughly equal, or even exceed Ch 1 and Ch 2 for many criteria, but was deficient in a number of others.

The following conclusions were drawn:

(1) Confinement for extended periods to the thermal regimes employed was not directly lethal to any of the fish species tested with the possible exception of threadfin shad.

(2) When confined to heat impacted waters (Ch 3), long-term survival was probably diminished for some of the species tested, notably bluegill, freshwater drum, and threadfin shad.

(3) The health and well-being, as measured by growth rate and condition factor, K_n, of most fish species tested was closely related to their food supply regardless of the thermal regime they were subjected to.

(4) Few fish species were directly affected by long-term exposures to a heated water regime (Ch 3), but many suffered from harmful secondary effects, e.g. habitat degradation in the form of reduced food supplies, increased susceptibility to pathogens, increased predatory pressures, and greater food demand.

(5) The health and well-being of fish was not hampered by access to a heated-water regime, provided that a cool-water refuge was available (Ch 2).

(6) Due to the lack of experimental precision, these results are interpreted as only an indication—rather than a definition—of any given species reaction to similar thermal conditions in a natural setting. Lack of experimental precision was attributed to the relatively small number of fish employed, the absence of experimental replication, and the difficulty in distinguishing between experimental (biothermal) effects and interspecific interactions.

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