FISHERIES STUDIES IN RELATION

TO A LONG HEATED DISCHARGE CHANNEL

(COLBERT STEAM PLANT, TENNESSEE RIVER)

by

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I. INTRODUCTION

The potential of significant damage to fish populations resulting from heated waste-water discharges is generally recognized. However, only minimal effects on warm water fish populations have been demonstrated at existing fossil-fueled electric stations, particularly at those plants that discharge into a lotic environment. Six years of study of the effects of a heated discharge into the White River (Indiana) has revealed little or no effect on growth, reproduction, or movement (Benda and Proffitt, 1974). On the basis of the cluster analysis of data on occurrence and distribution of fish in the upper Potomac River, Cairns and Kaesler (1971) reported no changes in the environment which could be ascribed to operation of a power plant. Based on the ability of the fish to either seek out or avoid heated segments of the Wabash River (Indiana), Gammon (1971 and 1973) reported no significant alteration of the fish population of that river. Similar observations on the fishery of the upper Delaware River were made by Trembley (1960); he reported that all the species found in adjacent portions of this river were present in the heated discharge zone at least part of the year. Trembley also noted an overall increase of some species in relation to the discharge, but an almost complete elimination of most species from the maximum heated zone during summer months.

Although the effect of heated water discharges has been negligible, site studies (including those cited above) have usually involved only adult fish populations in discharge canals or mixing zones. Coutant (1970) has listed five primary areas of the condenser cooling system where fish could be affected: (1) intake, (2) condenser and outlet piping, (3) discharge canal (if used), (4) mixing zones, and (5) mixed body of water. For example, Marcy (1973) observed significant mechanical and heat damage to young fish passed through a condenser-cooling system. Also, site studies have usually, either by design or possibly species involved, lacked predicative capabilities; however, various authors have indicated that both field and laboratory studies are necessary for adequate evaluation of power plant effects (Cairns, 1970 and 1972; Coutant, 1970 and 1971; and Langford, 1972).

The scientific literature on the effects of temperature on fish and other aquatic organisms is voluminous (Cairns, 1972; Kennedy and Mihursky, 1967; and Raney and Menzel, 1969); however, the amount devoted to site studies involving warm water fish populations is limited. This amount is further reduced if one wishes to compare particular species in similar types of receiving water (e.g., smallmouth bass in rivers). The lack of information (both laboratory and field data) for some species is especially notable since most water temperature standards have been based on the preferred species concept (Mount, 1969). Coutant (1972) has tabulated the species for which data are available on the resistance to extreme temperatures (upper and lower lethal). These data are based upon the quantitative study of lethal temperature effects first established by Fry, Hart, and Walker (1946).

Fishery studies at fossil-fueled electric generating stations on mainstream reservoirs of the Tennessee River have been limited to intermittent surveys to determine species composition, relative abundance, and sport fishing in discharge canals and basins (Dryer and Benson, 1956; Tennessee Valley Authority, 1969 and 1973). Results from these studies have indicated a seasonal concentration of various species, intensive seasonal fishing pressure, and no direct mortalities from the effects of temperature differences.

This study was designed to evaluate conditions in two areas of the condenser cooling water system, condenser passage and discharge canal, of a fossil-fueled electric generating plant located on a mainstream reservoir of the Tennessee River. Major objectives were to determine: (1) the effect of temperature on species composition, relative abundance, diversity, and movement of the adult fish population in the discharge canal, (2) temperature preference and avoidance of selected species that frequent the discharge canal, and (3) species composition and density of entrained larval fish.

Description of Study Area

Colbert Steam Plant, constructed and operated by the Tennessee Valley Authority (TVA), is located on Pickwick Reservoir in northwest Alabama. This reservoir, a mainstream impoundment of the Tennessee River, covers parts of Alabama, Mississippi, and Tennessee (Fig. 1). The reservoir, formed by Pickwick Landing Dam (closed 1939) and bounded upstream by Wilson Dam (closed 1925), is a part of the 650-mile (1,046 km) navigation system of the Tennessee River (Tennessee Valley Authority, 1954a). It is 85 km long, and maximum width is 2.4 km. Width is 0.7 km at the plant site which is 24 km downstream from Wilson Dam. The site is located at Tennessee River Mile 245 or 394 km upstream from the mouth where the Tennessee River joins the Ohio River. The habitat at the plant site is essentially riverine.

Surface area of Pickwick Reservoir is 17,449 ha at normal full pool. Volume at this elevation (126 above msl) is 1.35×10^9 m^3. Under conditions of normal winter drawdown (124 m above msl), volume is 8.4×10^8 m^3. Flushing rates at these volumes are approximately ten and six days, respectively. Length of shoreline is 798 km.

Ambient water temperature ranges from 4.0 to 31.0 C, depending on seasonal climatic conditions. Thermal stratification does not occur. Mean total alkalinity is 57 mg/l ($CaCO_3$), and mean total hardness is 71 mg/l ($CaCO_3$) (Water Quality Branch, TVA unpublished data).

The fish fauna of Pickwick Reservoir is composed primarily of typical warm water species (Lagler, 1956). However, some of the species, such as sauger (Stizostedion canadense), have recently been considered cool water or "lukewarm" species in relation to thermal requirements (K. E. F. Hokanson, personal communication). Cove rotenone samples in 1971 yielded a mean standing stock biomass of 502 kg/ha, consisting of 48 species (Tennessee Valley Authority, 1972).

Dominant species by weight were: Gizzard shad (Dorosoma cepedianum) 58 percent, threadfin shad (Dorosoma petenense) 13 percent, smallmouth buffalo (Ictiobus bubalus) 7 percent, carp (Cyprinus carpio) 6 percent, freshwater drum (Aplodinotus grunniens) and channel catfish (Ictalurus punctatus) each 4 percent. Combined weight of sauger, largemouth bass (Micropterus salmoides), and smallmouth bass (Micropterus dolomieui) was 2.5 percent.

Colbert Steam Plant has five units with a total capacity of 1396 MW. Four units were in commercial operation in 1955, and the fifth unit was put on the line in 1963 (Tennessee Valley Authority, 1955; 1963). At peak load, water for condenser cooling is pumped from Pickwick Reservoir at a rate of 56 m^3/sec. The plant generally uses less than five percent of the river flow; normal flow at the plant site is 1,513 m^3/sec. Water passed through the condenser is heated about 7.5 C above the ambient water temperature.

The intake structure is approximately 50 m from the main channel of the Tennessee River. Connection to the river is via an excavated channel or basin that is approximately 3.5 m deep where it intersects the river channel and 8.0 m at the intake structure. Depth of the reservoir at this location is 9.0 to 10.0 m at normal full pool. Since the edge of the excavated area does not extend to the bottom of the river channel, it appears that the condenser cooling water is drawn from the upper 3.5 m of the water column passing the plant.

Water for condenser cooling passes through (1) six concrete conduits, one each for units 1-4 (2.4 m ID); two for unit 5 (1 @ 2.4 m ID and 1 @ 3.4 m ID), (2) 1-cm mesh traveling screens, (3) mixed-flow circulating pumps, (4) 1.5 m piping, (5) twin, single pass divided water boxes, (6) 1.5 m piping from the condensers to another series of concrete conduits (five) which discharge into an oblong basin (approximately 700 m in circumference) that was dredged to join an existing creek channel. Velocities approach 2.2 m/sec, and travel time from the intake to the basin ranges from 174 sec (units 1-4) to 193 sec (unit 5).

The heated effluent then passes from the discharge basin down the lower 4.5 km of Cane Creek before returning to the Tennessee River 1.6 km below the plant intake (Fig. 1). Time of travel down the creek has been calculated as approximately 2.5 to 3 hours, depending on plant load and reservoir elevation. Although mean velocity is estimated as 0.4 m/sec, velocity is quite variable due to variations in depth, width, substrate material, and upstream run-off; it approaches 2.5 m/sec in some areas.

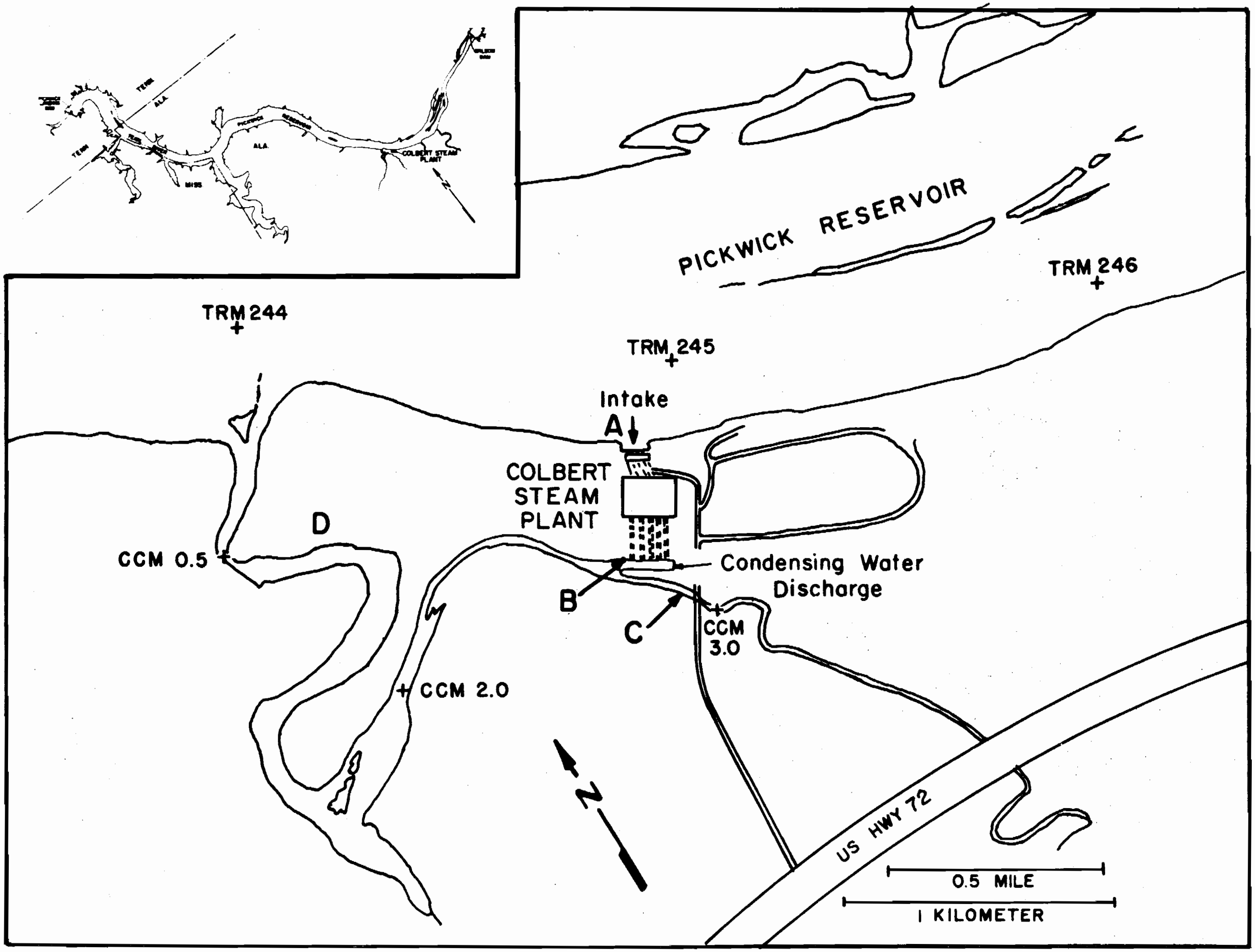
The mixing zone where the heated effluent returns to the river (TRM 244) varies according to reservoir elevation. At elevations above 125 m msl, the major portion of the heated water follows the shallow overbank area on the left side of the river and is only gradually diffused into the mainstream (Tennessee Valley Authority, 1967). At lower elevations this overbank is exposed, and the effluent is contained in the creek channel until it reaches the main river channel where it mixes rapidly.

With the exception of larval fish sampling near the intake, the study area was confined to the lower 5.1 km of Cane Creek, the lower 4.5 km receiving the heated effluent and the upper 0.6 km having essentially ambient temperature conditions. The entire study area is in the backwater of Pickwick Reservoir; therefore, water depth in both heated zone and the ambient zone is affected by reservoir elevations. Water depth in the heated zone is primarily a function of reservoir elevation and plant discharge, whereas in the ambient zone it is primarily a function of reservoir elevation. Natural stream flow has a minor effect, e.g., mean daily volume calculated from an upstream gauging station for March-June 1973, was less than 1 percent of the heated effluent.

Lower Cane Creek is essentially a complex discharge canal; at the upper end of which, the discharge basin and the ambient section of the creek form a y-maze with reference to water temperature and those fish swimming up the creek or seeking the heated effluent whichever the case may be. A steep thermal gradient is created at the junction of the discharge basin and the creek. Temperature of the heated effluent normally ranges from 5.0 to 8.0 C above the ambient water temperature of Pickwick Reservoir, and it reaches the mouth of the creek. Water temperature in the upper section of the study area (extending 0.6 km upstream from the discharge basin) is similar to that for the reservoir.

The substrate, submerged objects, and bank vegetation are similar in both the heated and ambient sections of the creek. Maximum flow rates, depth, width and emergent plants are variable. The substrate ranges from fine sediment to boulders; submerged stumps and fallen trees are common. Willow (Salix sp.) and river birch (Betula nigra) are dominant along the lower banks; the upland areas, formed by limestone bluffs, are covered by various hardwoods. In the ambient section the width ranges from 6 to 8 m, and it is less than 10 m to more than 50 m in the heated section. Mid-stream water depth ranges from 1 to 3 m in the ambient section and from 1 to 7 m in the heated section. Dense patches of alligator grass (Alternanthera philoxeroides) are common in the shallow water along the banks in the heated section during the spring and summer. Reservoir drawdown and colder temperatures crop it back during fall and winter. Alligator grass is not present in the ambient section.

Figure 1. A map of lower Cane Creek which receives the heated effluent from Colbert Steam Plant (CCM - Cane Creek Mile; TRM - Tennessee River Mile).


PICKWICK RESERVOIR
TRM 244
TRM 245
TRM 246
Intake
A
COLBERT
STEAM
PLANT
Condensing Water
Discharge
B
C
D
CCM 0.5
CCM 2.0
CCM
3.0
N
US HWY 72
0.5 MILE
1 KILOMETER
COLBERT STEAM PLANT
ALA.
MISS.

II. SPECIES COMPOSITION, RELATIVE ABUNDANCE, DIVERSITY, AND MOVEMENT OF THE ADULT FISH POPULATION

Materials and Methods

Sampling gear included gill nets and a boat-mounted electrofishing unit. Gill nets (3.8 cm bar-mesh) were 30.4 m long and 2.4 m deep. The electrofishing unit consisted of a 2500-W portable gasoline generator, a Coffelt model 2C variable voltage pulsator designed to supply pulsating voltage (half-wave 60 cps) or A. C., an electrode assembly of stainless steel wire rope (0.6 cm x 3.0 m) that was suspended from three fiberglass pole booms which were mounted on the bow of an aluminum boat (4.8 m long). The boat was also equipped with a safety rail on the bow, two tredle safety switches, and dual livewells which were supplied with a continuous flow of fresh water. Electrofishing was the primary method of sampling since it was more versatile for sampling shallow and swift reaches in both the heated and ambient zones of lower Cane Creek. Also, previous experience with both gill nets and electrofishing in the discharge basin indicated that electrofishing yielded a better overall estimate of species composition and relative abundance, but that gill nets were more effective for channel catfish and sauger.

Night electrofishing (pulsed D. C.) samples were collected at approximately two-week intervals at two stations (B and D) within the heated effluent and at an upstream control (C) from January 1972 - October 1973 (Fig. 1).

Station B included the discharge basin and had a shoreline distance of about 0.7 km. Station D extended from approximately CCM 0.5 to CCM 0.8 and had a shoreline distance of 1.7 km. Station C extended from CCM 2.8 upstream to approximately CCM 3.2; shoreline distance was 1.0 km. Relative abundance was based upon the catch per 300 m of shoreline electrofished. Samples were not collected during periods of high turbidity which were generally of short duration. Night electrofishing, generally more effective in this area, also reduced interference with sport fishermen.

Captured fish (except shad) were held in live-wells, processed after each station, and then released. Number of each species and total length (nearest mm) were recorded. Gizzard and threadfin shad, usually present in great numbers, were estimated to the nearest hundred specimens that were turned up in the electrical field.

To determine movement in relation to the heated effluent, selected game and food species were tagged with numbered and addressed Floy-type anchor tags (Dell, 1968) and released at the midpoint of the station in which they were captured. Notices of the tagging program and postpaid tag return forms were distributed to sport and bait centers in the area.

Three gill nets were fished overnight at Station B at approximately two-week intervals from January 1972 - November 1973. The catch by species was recorded as number per net-night and total length (mm) was measured. Gonad condition and stomach contents of fish captured by gill netting were routinely checked. Spawning condition of specimens collected by electrofishing was also checked (externally), but only those fish that were ripe were noted.

To summarize the numerical structure of the fish population in lower Cane Creek, two diversity indicies were computed for the 36 electrofishing samples from each station:

(1) Shannon index (Shannon and Weaver, 1963)

$$\overline{H} = \Sigma P_i \log P_i$$

where P_i is the proportion of individuals in the i-th species,

(2) "Species richness" as used by Margalef (1958)

$$D = S - 1/\log N$$

where S is the number of species and N the number of individuals. All calculations were based on natural logarithms ($\log_e$).

Water temperature was taken with a calibrated electric thermometer at the mid-point of each sampling station (surface and bottom) during each electrofishing or gill net cruise. Continuous temperature monitors were installed at five locations within lower Cane Creek in April 1972 (Hydraulic Data Branch, TVA). Also, a water quality monitor for the heated effluent was installed in a standard instrumentation trailer to measure pH, dissolved oxygen, temperature, and conductivity. Data from these monitors as well as additional water chemistry analyses of the heated effluent and ambient river water were processed and conducted by the Water Quality Branch of TVA.

Results

Species Composition and Relative Abundance

A total of 34 species, consisting primarily of adult and larger subadult specimens, were collected by electrofishing and gill netting in lower Cane Creek (Table 1). Selectivity of the collecting gear generally excluded small forage species, e.g., minnows and darters. Thirty species were captured by electrofishing which was used in both the heated zone (Station B and D) and ambient zone (Station C). Gill netting, used only at B, yielded 27 species. Species collected only by electrofishing were: American eel, threadfin shad, longear sunfish, warmouth, and green sunfish. Those collected only by gill netting were: northern hog sucker, mooneye, blue catfish, and striped bass. Species collected by only one type of gear, with the exception of threadfin shad and longear sunfish, appeared in only one sample. Excluding these seven uncommon species, species composition between stations was similar. The median number of species per electorfishing sample (36 samples per station) at Station B, D, and C was eight, ten, and eight, respectively. The median number collected by gill netting (36 samples) at B was nine.

Gizzard shad was the dominant species with regard to frequency of occurrence and numbers collected by electrofishing at each of the three sampling stations. Substantial numbers were collected at water temperatures that ranged from 4.2 C to 36.0 C (Tables 2, 3, and 4). Gizzard shad made up approximately 70 percent of the catch at each of the stations (B and D) in the heated zone and 55 percent of the catch in the control (C). Peak abundance, exceeding 400 per 300 m of shoreline sampled, occurred during April in the discharge basin when the effluent temperature ranged from 18.0 C to 21.0 C. This concentration consisted primarily of fish in spawning condition.

Threadfin shad were also abundant in all three sampling areas; frequency of occurrence was more variable and somewhat more temperature dependent than that for gizzard shad. Threadfin shad were not collected from the ambient zone during January through March at water temperatures of 4.2 C to 13.5 C, but did appear in a fall sample at a temperature of 13.0 C. This species occurred frequently in the heated zone at the maximum water temperatures (34.0 - 36.0 C). The combined number of threadfin and gizzard shad made up approximately 90 percent of the fish collected from each station by electrofishing.

The frequency of occurrence of selected game and food species in relation to the annual temperature regime for each station is presented in Figures 2-5. This group represents the dominant predatory species that were collected in this study. Channel catfish, which occurred in 92 percent of the gill net samples (Table 5), demonstrated a wide range of thermal tolerance (Fig. 5). This species was also present in 45 percent of the electrofishing samples from the heated zone (both stations combined) and in 28 percent of the electrofishing samples from the control.

Largemouth bass, which occurred in approximately 90 percent of the electrofishing samples at each sampling station, also showed a eurythermal response to the heated effluent. Peak abundance in the discharge zone occurred in the winter and spring months (Tables 2 and 3). Although there was an increase in the relative abundance of largemouth bass in the control (C) when the effluent temperature approached 35.0 C, the greatest concentration at this station appeared to be in relation to a heavy fall concentration of gizzard and threadfin shad (Table 4).

Although smallmouth bass did not occur as frequently as largemouth bass, this species did show a preference for conditions in the heated zone. Smallmouth bass were collected in 53 percent of the electrofishing samples from Station B and in 42 percent of the samples from Station D; but in the control, this species was collected only once. In the heated discharge, this species was collected at temperatures that ranged from 11.2 C to 35.1 C. Those specimens collected at the highest effluent temperatures were usually less than 200 mm long. Size distribution of the dominant predatory species is presented in Tables 6 and 7.

Spotted bass had a pattern of occurrence similar to that for smallmouth bass; in the electrofishing samples at Station B and D it was present in 47 percent and 36 percent of the samples, respectively, but occurred only twice (5.5 percent) at Station C. This species was vulnerable to gill netting, as it occurred in 44 percent of these samples (Fig. 5). Although spotted bass were not as abundant as largemouth bass, maximum temperature tolerance (35.0), as determined by presence or absence, was similar.

Of the dominant predatory species that frequented the heated effluent, sauger and walleye were the only species whose presence or absence appeared to be consistently related to temperature (Fig. 5). Gill netting was more effective for collecting both species at Station B. Walleye were collected only at this station; however, to get to Station B an adult fish had to come through either Station C or D. The largest concentration of both species occurred in the heated zone. Sauger were collected from late November through early June in the discharge basin (Station B) at water temperatures ranging from 11.2 C to 29.0 C. At Station D, this species was collected at temperatures of 7.2 C to 29.0 C. The presence of sauger in the control station was generally coincidental with the peak abundance in the discharge basin; however, single specimens were collected in the ambient zone on two occasions (late August and September) when this species was not observed in the heated discharge. Walleye, although fewer in number, were present in the heated discharge at similar temperatures and seasonal periods as sauger (Fig. 5 and Table 5). In the gill net catch at B, walleye and sauger occurred in 31 percent and 44 percent of the samples, respectively.

Frequency of occurrence of white bass as determined by electrofishing was essentially the same at all stations. Also, this species occurred in 36 percent of the gill net samples at Station B. In the heated effluent white bass were captured at temperatures which ranged from 12.2 C to 34.0 C and in the control at temperatures that ranged from 7.2 C to 28.1 C. Peak abundance in the discharge zone was January through April; relative abundance was less in the control with no evidence of a peak concentration.

White crappie, another important game fish of the Tennessee River system, was collected infrequently at all three stations. Occurrence was generally associated with cooler effluent temperatures in the winter and spring, but on one occasion two specimens were collected at temperatures exceeding 34.0 C (Table 3).

Skipjack herring, a non-game predatory species, was common in the heated zone of Cane Creek from October to June at temperatures below 30 C; however, on two occasions this species was captured in Station B when the effluent temperature exceeded 34 C (Table 2). This species was collected only once from the control station, but occurred in 70 percent of the gill net samples from the discharge basin.

Other species collected frequently at all stations by electrofishing were: carp, bluegill, and longear sunfish. These species demonstrated a eurythermal response as they were consistently present at both the minimum and maximum temperatures for each station (Tables 2, 3, and 4). The more or less constant numbers of bluegill and longear sunfish indicated that resident populations of both species existed within each sampling area. Whereas, the number of carp increased dramatically in April and May at Station B (Table 2). This concentration was apparently due to an upstream spawning migration that terminated in the discharge basin.

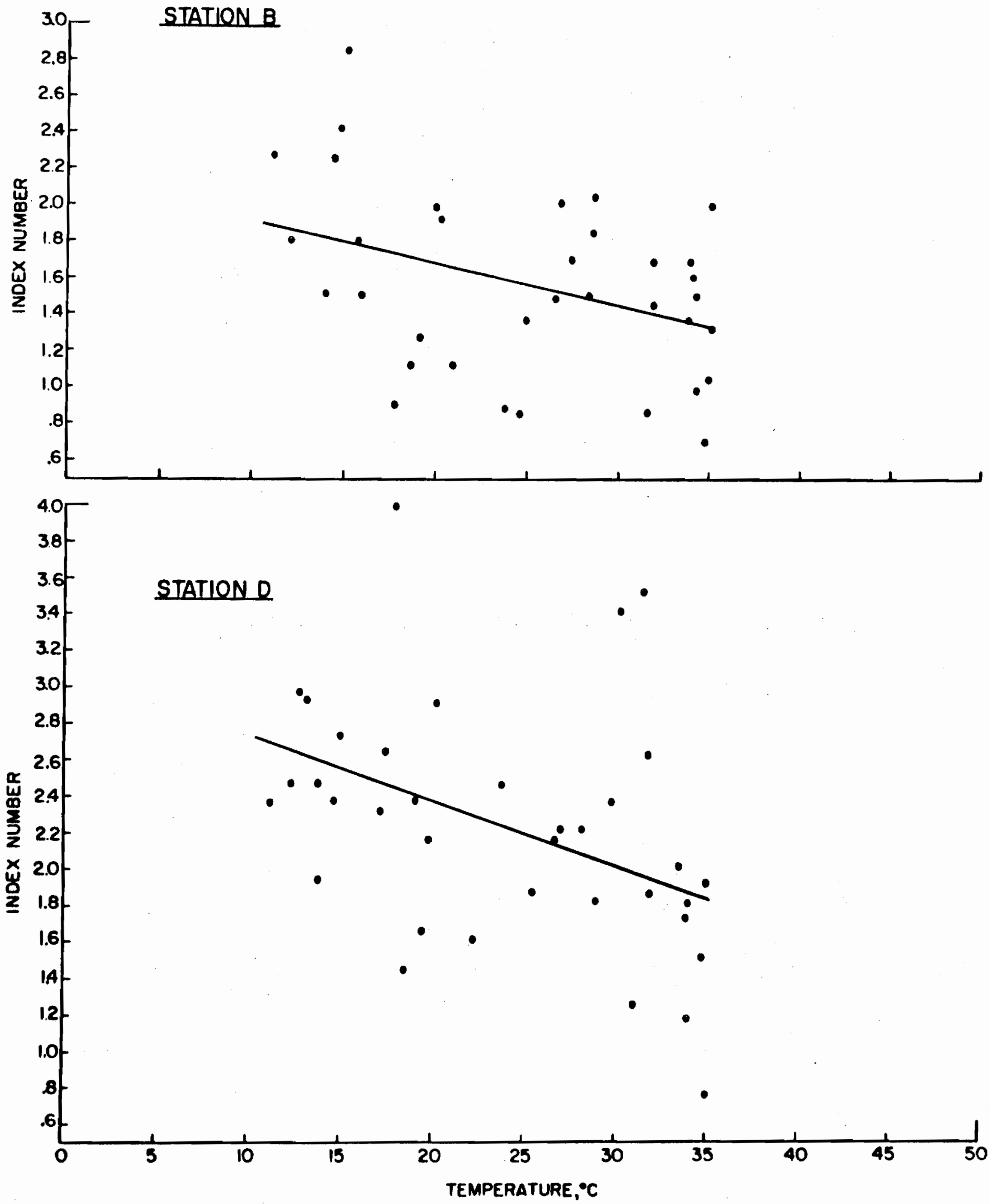
Based on concentrations of ripe adults and periodic gonad inspection of various species collected by electrofishing and gill netting, the following species apparently spawned within the 4.5 km heated discharge zone of Cane Creek: gizzard shad, carp, spotted sucker, white bass, yellow bass, bluegill, and longear sunfish. Additional observations on reproduction is presented in relation to larval fish entrainment (Section IV).

Periodic analysis of the stomach contents of predatory species indicated that gizzard and threadfin shad, skipjack herring, and logperch (*Percina caprodes*) were eaten most frequently. Crayfish were common in the stomach contents of spotted bass. Based on the number present in the stomach samples, the bottom dwelling logperch (seldom collected by electrofishing) was common in the heated zone of Cane Creek.

Diversity

Comparison of the diversity indices, D and $\overline{H}$, between stations indicated that overall species diversity and relative abundance (equitability) were greater in the heated zone than in the ambient zone of lower Cane Creek (Table 8). Also, species diversity was significantly different between stations within the thermal effluent. Regression analysis of both indices in relation to water temperature at each station revealed that only species diversity (D) at Stations B and D was temperature dependent (Fig. 6). Species diversity was inversely related to increased effleunt temperatures at both Station B

Figure 6. Species diversity (D) of the electrofishing catch at two stations within the heated discharge from Colbert Steam Plant, 1972-73.


STATION B
STATION D
INDEX NUMBER
INDEX NUMBER
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
0
5
10
15
20
25
30
35
40
45
50
TEMPERATURE,°C

($r = -0.36$; $0.01 < P < 0.05$) and Station D ($r = -0.42$; $P < 0.01$). The regression equation for Station B is:

$$D = 2.153 - .0237\ T,$$

and for Station D:

$$D = 3.096 - .0356\ T,$$

where D = "species richness" in index units ($\log_e$) and T = temperature (°C). Species diversity, lowest in the control station, did not show a corresponding increase as the species diversity declined in relation to higher effluent temperatures in the heated zone. Index units of $\bar{H}$ for the control station ranged from 0.2 to 1.2, and in the heated zone values ranged from 0.3 to 1.7.

Movement

A total of 300 fish, including seven species, were tagged to determine movement in relation to the heated effluent (Table 9). Sport fishermen accounted for 68 percent of the recaptures, and the remainder was recaptured by electrofishing or gill net. Movement between sampling stations was limited; 88 percent of all recaptures were within the station in which the fish was released. Equal numbers were not released at each station since the number tagged was dependent on the electrofishing catch within a given station, e.g. walleye were captured only at Station B (discharge basin). Six fish were recaptured in Pickwick Reservoir. This included three largemouth bass, two white bass, and one sauger; all of these fish had been released at the mid-point of Station D which is approximately 0.7 km upstream in the heated effluent.

Movements of those fish returning to the reservoir were extensive. A largemouth bass, recaptured in the navigation canal below Wilson Dam, had moved approximately 25 km in 23 days. Another largemouth, caught 18 days after release, had moved 16 km downstream. Two white bass, at large 42 and 70 days, were recaptured upstream 16 and 25 km, respectively. The sauger was also recaptured (89 days at large) in the tailwater of Wilson Dam, 25 km from the point of release. These five fish were released prior to the known spawning periods for these species in the Tennessee River. It could not be determined that their movements were associated with spawning, but these fish had apparently moved out of the heated discharge at temperatures well below upper tolerance levels.

Although those fish which moved out of Cane Creek were at large for extended periods, fish recaptured within the same area of release were also at large for similar periods. Two largemouth bass released in Station C (control) were recaptured 86 and 132 days later; recaptures for this species within Station D ranged from 14 to 74 days. Smallmouth bass released and recaptured within Station D were at large for 14 to 81 days, and the only sauger recaptured within the heated discharge was out 17 days. The only channel catfish that was returned was at large for 93 days before it was recaptured approximately 0.5 km from the point of release (Station D).

Discussion

Although regression analysis showed that species diversity ("species richness") declined significantly in relation to increased effluent temperatures, the Shannon index ($\bar{H}$) was not significantly related to temperature. The highest value of species diversity, at Station D in the heated zone of lower Cane Creek, may have been due to the proximity of this station to Pickwick Reservoir. Harrel and Dorris (1967) noted that species diversity (D) increased in relation to stream order.

Diversity, as determined by the Shannon index, is primarily a function of the proportions of the more common species (equitability), and only secondarily by the length of the species list (Sager and Hasler, 1969). The lack of a significant relation between $\bar{H}$ and temperature indicated that several species remained in the heated effluent in similar numbers throughout the year. Moss (1973) indicated that diversity, though variously and precisely defined in several different formulae, is a concept to which it is difficult to give concrete meaning. Presumably it is generally a reliable index of environmental health (Dahlberg and Odum, 1970). Gammon (1973) reported that diversity ($\bar{H}$) of the fish population was not significantly altered by the heated effluent from a new power plant on the Wabash River (Indiana) and that in the absence of a dramatic change in the overall fish community, it was necessary to examine seperate species populations for signs of change.

Occurrence of most of the common species collected from three stations in Cane Creek, with the exception of threadfin shad, skipjack herring, sauger, and walleye, was not well correllated with temperature.

Threadfin shad, a highly desirable forage species that has been abundant in mainstream reservoirs of the Tennessee River since about 1948 (Tennessee Valley Authority, 1954b), avoided temperatures below 13 C in the control station. Strawn (1963) reported that a winter (field) temperature of 5 C was lethal for this species and that chronic exposure below 9 C was detrimental. Various authors have reported winter concentrations of threadfin shad in heated effluents (Adair and DeMont, 1971; Barkley and Perrin, 1971; and Dryer and Benson, 1956).

Gizzard shad, also an important forage species but not as desirable as threadfin shad (Houser and Netsch, 1971), did not appear to avoid the extreme upper temperatures (34 - 36 C) in the heated zone nor the lowest temperatures (4 - 5 C) in the ambient zone. The tendency for shad to invade warm-water effluents (Miller, 1960) has been documented in other studies (Adair and DeMont, 1971; Proffitt, 1969; Benda and Proffitt, 1974; and Gammon, 1971).

Skipjack herring, sauger, and walleye were not captured in the heated zone at temperatures above 30 C; however, when these species were present in lower Cane Creek (about November to June) they had a distinct preference for the heated discharge zone. Apparently food supply and increased water flow in the effluent also attracted these highly predaceous species. Dryer and Benson (1956) reported that the abundance of sauger and skipjack in the heated discharge from New Johnsonville Steam Plant on Kentucky

Reservoir (Tennessee River) was directly related to numbers of threadfin shad during the winter months. Gammon (1971) reported that skipjack herring avoided effluent temperatures above 29 C, but that turbidity and food supply may have also been limiting. Following start-up of a power plant on the Wabash River, sauger avoided heated zones above 29 C (Gammon, 1973). Trembley (1960) reported that walleye were attracted to a heated effluent on the Delaware River, but that maximum body temperature for specimens caught in the effluent was 28.9 C. He also observed walleye undergoing heat death at approximately 30.6 C. Dendy (1948) reported that the summer temperature preference for sauger and walleye in Norris Reservoir was approximately 20 and 25 C, respectively.

Apparently summer avoidance of the heated discharge from Colbert Steam Plant by sauger and walleye was ultimately determined by thermal intolerance; however, the departure from the effluent by these migratory species coincides with their seasonal migration from the tailwaters of dams on both the mainstream and major tributaries of the Tennessee River (Eschmeyer and Manges, 1945; Tennessee Valley Authority, 1960). Walburg, Kaiser, and Hudson (1971) have also reported a fall-to-spring concentration of sauger and walleye in the Lewis and Clark Lake tailwater on the Missouri River; the fewest numbers occurred from June to September when the maximum temperature was 20 C. Rawson (1957) reported that walleye in Lac La Rouge were widely scattered in the deeper waters during August and September;

he suggested that pursuit of some food organism was the cause of this movement rather than thermal preference (surface water of this lake rarely exceeded 19 C).

Smallmouth bass, although not excluded from the heated discharge zone at maximum effluent temperatures, did demonstrate a size/age dependency in relation to upper extreme temperatures (34 - 36 C). Few specimens that exceeded 200 mm were collected in water above 33 C. When present, this species also preferred water conditions in the effluent as it was collected only once from the ambient zone. Trembley (1960) did not indicate a size/age dependence for smallmouth bass frequenting a heated effluent in the Delaware River; he reported that body temperatures of smallmouth bass collected in the heated effluent ranged up to 34.5 C. Maximum summer preference of both adult and underyearling smallmouth bass tested in a horizontal gradient was 31 C (Barans and Tubb, 1973).

Although Gammon (1971) indicated that spotted bass had a field preferendum of 27 C and avoided heated zones, this species in the present study tolerated temperatures above 34 C. Benda and Proffitt (1974) captured spotted bass in a heated discharge canal when temperatures ranged between 35 and 37 C.

White bass also tolerated effluent temperatures up to 34 C. Gammon (1973) reported that this species showed some attraction to heated zones in the Wabash River, but preferred temperatures 28 to 29.5 C. Barans and Tubb (1973) reported that the summer thermal preferendum was 30 C for this species.

Tolerance of maximum effluent temperatures from this plant (seldom exceeding 35 C for any extended period) by other common species collected in this study (largemouth bass, bluegill, longear sunfish, channel catfish, and carp) was similar to that reported for these species in various studies (Benda and Proffitt, 1974); Clugston, 1973; Gammon, 1971 and 1973; Neill, Strawn, and Dunn, 1966; Neill, 1972; and Smith, 1971).

Results of tag returns from seven game and food species tagged with conventional tags indicated that some fish remained in the heated discharge zone for extended periods: Channel catfish - 93 days, largemouth bass - 74 days, smallmouth bass - 81 days, and sauger - 17 days. However, these data provided only circumstantial evidence concerning temperature preference, tolerance, or duration of exposure to given temperatures. Recaptures of fish that returned to Pickwick Reservoir did indicate that some species probably move into and out of the heated discharge zone of lower Cane Creek somewhat at random, at least during part of the year. Rates of return and extent of movement for those species tagged in this study (Table 9) were quite similar to previous movement studies on these species in the Tennessee River (Haslbauer and Manges, 1947; Hulse and Miller, 1958; and Miller, 1950).

Although primary emphasis in this study was on the response of fish to the elevated temperature in the discharge canal, it is recognized that winter fish concentrations in such a discharge canal are subject to lethal cold shock if the plant shuts down.

Such a kill was reported on the Susquehanna River when fish in a heated zone were subjected to a sudden 24.5 C temperature drop (Sport Fishing Institute Bull. No. 223, April 1971). Based on the midwinter temperature differential (7.0 - 8.0 C) in the discharge canal of Colbert Steam Plant, plus the unlikelihood of all five of its units being down, it does not appear that cold shock would occur at this plant. Also, in the 20-year operation of this plant this problem has not been experienced. Laboratory studies on the lower lethal threshold for smallmouth bass (Horning and Pearson, 1973), largemouth bass, channel catfish, and bluegill (Hart, 1952) indicated that these species can withstand an instantaneous drop of about 15 C.

Other water quality parameters of the heated effluent which could limit the presence of fish were essentially the same as those of the ambient river water (e.g., dissolved oxygen ranged from 5.4 to 11.3 mg/l and pH ranged from 7.0 to 8.0). Also, chlorination for slime control in the condenser tubes is not used at this plant.

Table 1. Species composition of adult fish collected in relation to the heated discharge from Colbert Steam Plant into lower Cane Creek.

Common Name[1]	Scientific Name	Sampling Station[2]		
		B	D	C
Spotted gar	Lepisosteus oculatus	X	X	X
Longnose gar	Lepisosteus osseus	X	X	X
American eel	Anguilla rostrata	X		
Skipjack herring	Alosa chrysochloris	X	X	X
Gizzard shad	Dorosoma cepedianum	X	X	X
Threadfin shad	Dorosoma petenense	X	X	X
Mooneye	Hiodon tergisus	X		
Carp	Cyprinus carpio	X	X	X
River carpsucker	Carpiodes carpio	X	X	X
Northern hog sucker	Hypentelium nigricans	X		
Smallmouth buffalo	Ictiobus bubalus	X	X	X
Spotted sucker	Minytrema melanops	X	X	X
River redhorse	Moxostoma carinatum	X		X
Golden redhorse	Moxostoma erythrurum	X	X	X
Blue catfish	Ictalurus furcatus	X		
Black bullhead	Ictalurus melas	X		
Yellow bullhead	Ictalurus natalis	X	X	X
Channel catfish	Ictalurus punctatus	X	X	X
Flathead catfish	Pylodictis olivaris	X		
White bass	Morone chrysops	X	X	X
Yellow bass	Morone mississippiensis	X	X	X
Striped bass	Morone saxatalis	X		
Green sunfish	Lepomis cyanellus	X		X
Warmouth	Lepomis gulosus			X
Bluegill	Lepomis macrochirus	X	X	X
Longear sunfish	Lepomis megalotis	X	X	X
Redear sunfish	Lepomis microlophus	X	X	X
Smallmouth bass	Micropterus dolomieui	X	X	X
Spotted bass	Micropterus punctulatus	X	X	X
Largemouth bass	Micropterus salmoides	X	X	X
White crappie	Pomoxis annularis	X	X	X
Sauger	Stizostedion canadense	X	X	X
Walleye	Stizostedion vitreum	X		
Freshwater drum	Alpodinotus grunniens	X	X	X

[1] American Fisheries Society, Spec. publ. No. 6, A List of Common and Scientific Names of Fishes from the United States and Canada-

[2] Stations B and D in the heated discharge zone; Station C, upstream control.

Figure 2. Frequency of occurrence of selected game and food species in the heated effluent from Colbert Steam Plant, collected by electrofishing, Station B (discharge basin).

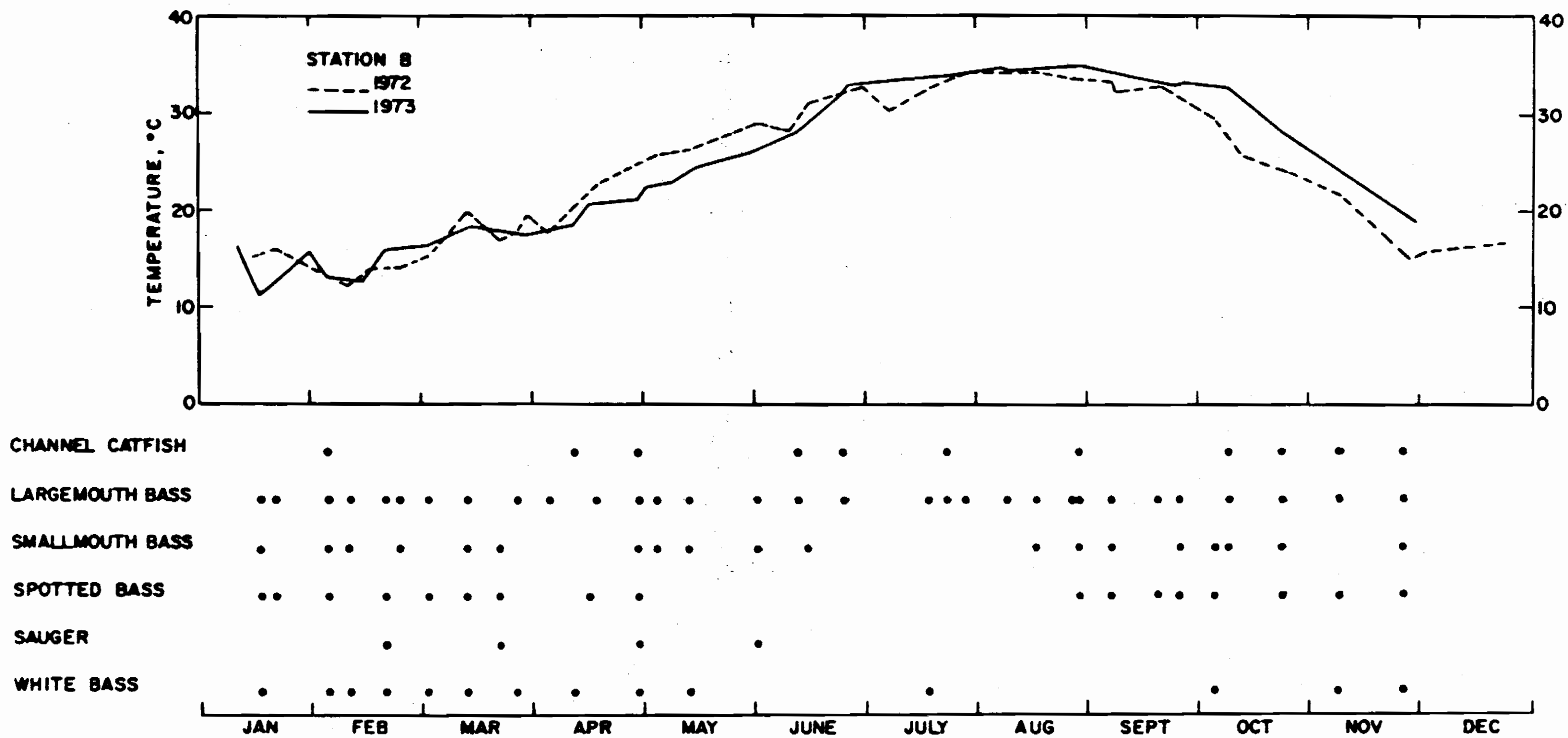
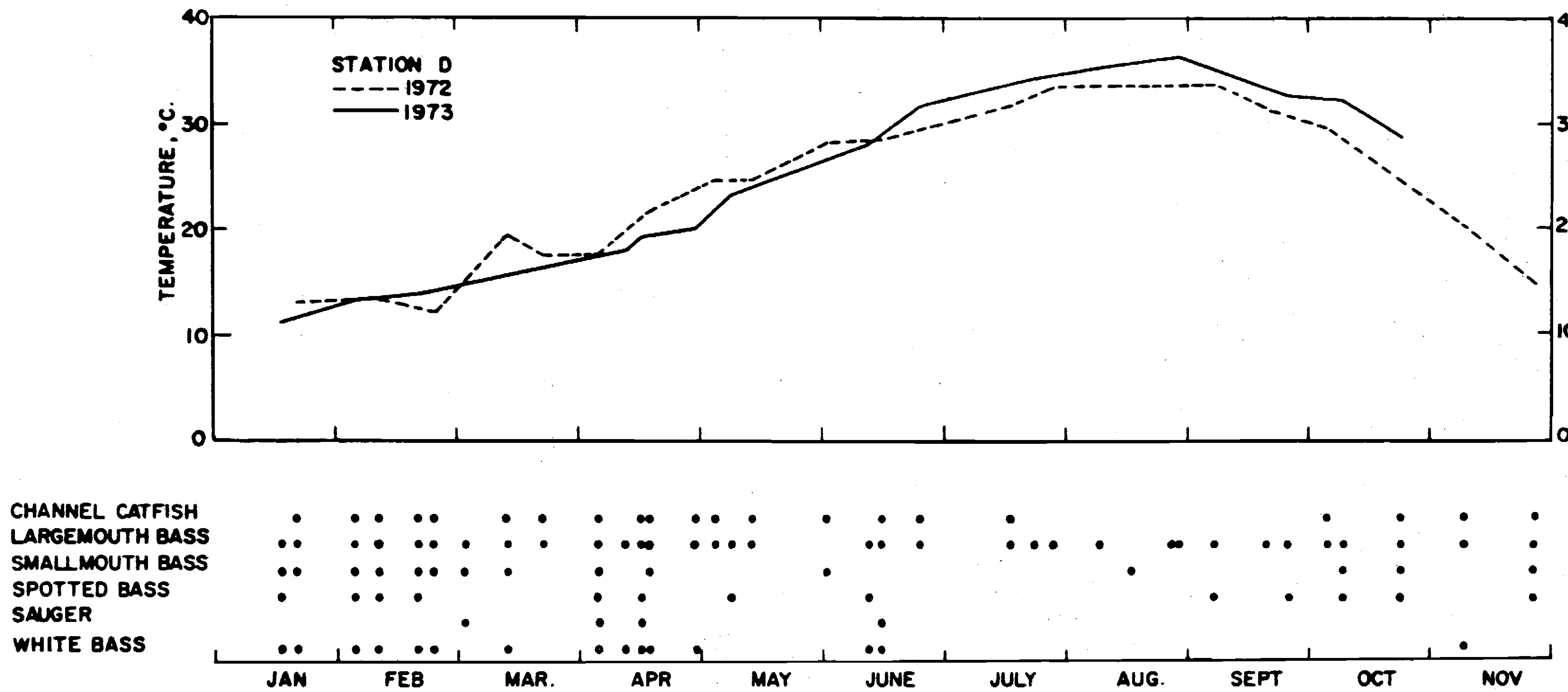
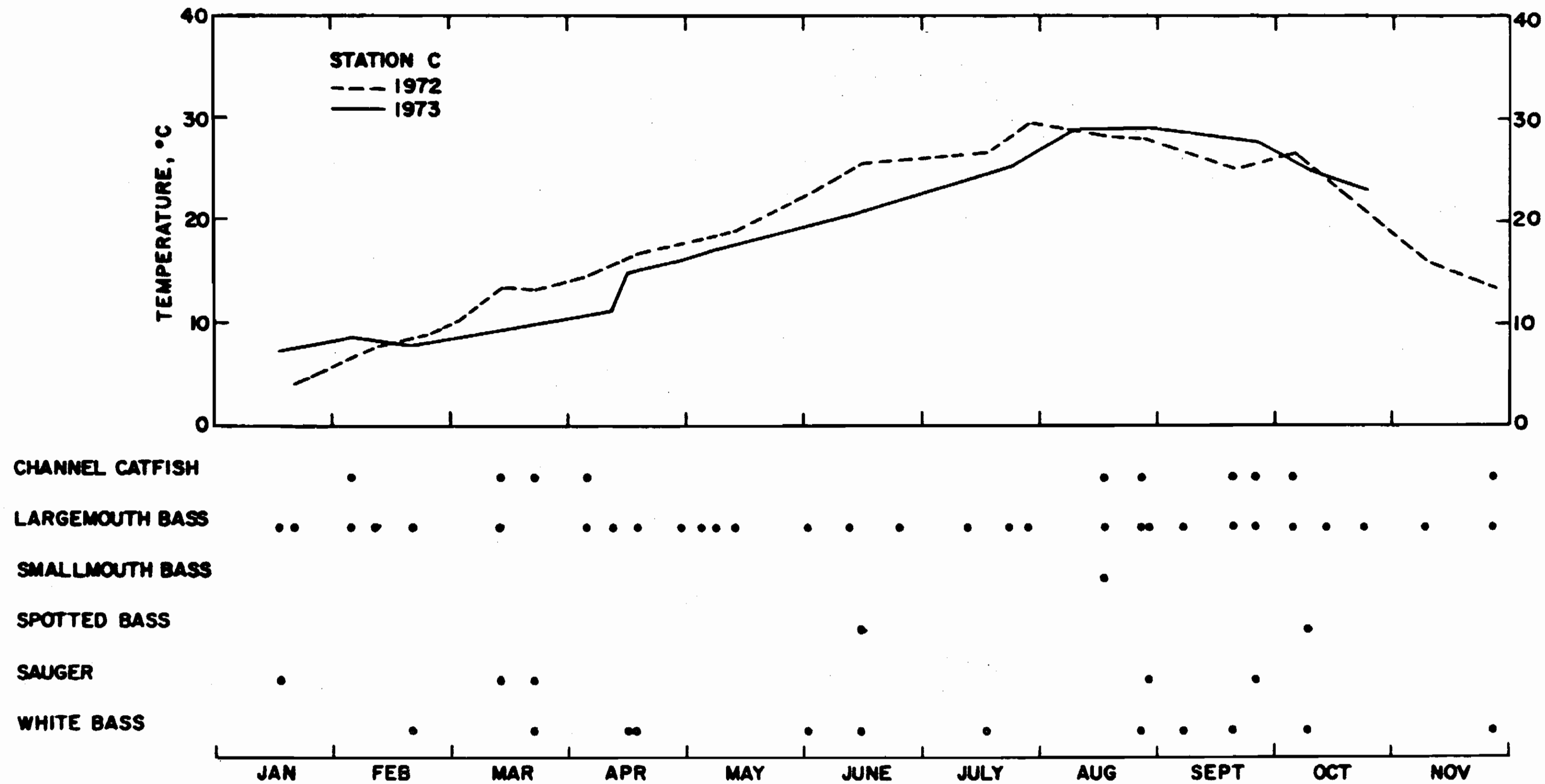

STATION B
1972
1973
TEMPERATURE, °C
0
10
20
30
40
CHANNEL CATFISH
LARGEMOUTH BASS
SMALLMOUTH BASS
SPOTTED BASS
SAUGER
WHITE BASS
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC

Figure 3. Frequency of occurrence of selected game and food species in the heated effluent from Colbert Steam Plant, collected by electrofishing, Station D (lower discharge zone).



STATION D
1972
1973
TEMPERATURE, °C.
0
10
20
30
40
CHANNEL CATFISH
LARGEMOUTH BASS
SMALLMOUTH BASS
SPOTTED BASS
SAUGER
WHITE BASS
JAN
FEB
MAR.
APR
MAY
JUNE
JULY
AUG.
SEPT
OCT
NOV

Figure 4. Frequency of occurrence of selected game and food species in Cane Creek (Station C, upstream control) as determined by electrofishing.



STATION C
1972
1973
TEMPERATURE, °C
40
30
20
10
0
CHANNEL CATFISH
LARGEMOUTH BASS
SMALLMOUTH BASS
SPOTTED BASS
SAUGER
WHITE BASS
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV

Figure 5. Frequency of occurrence of selected game and food species in the heated effluent from Colbert Steam Plant, comparing electrofishing (EF) and gill netting (GN).

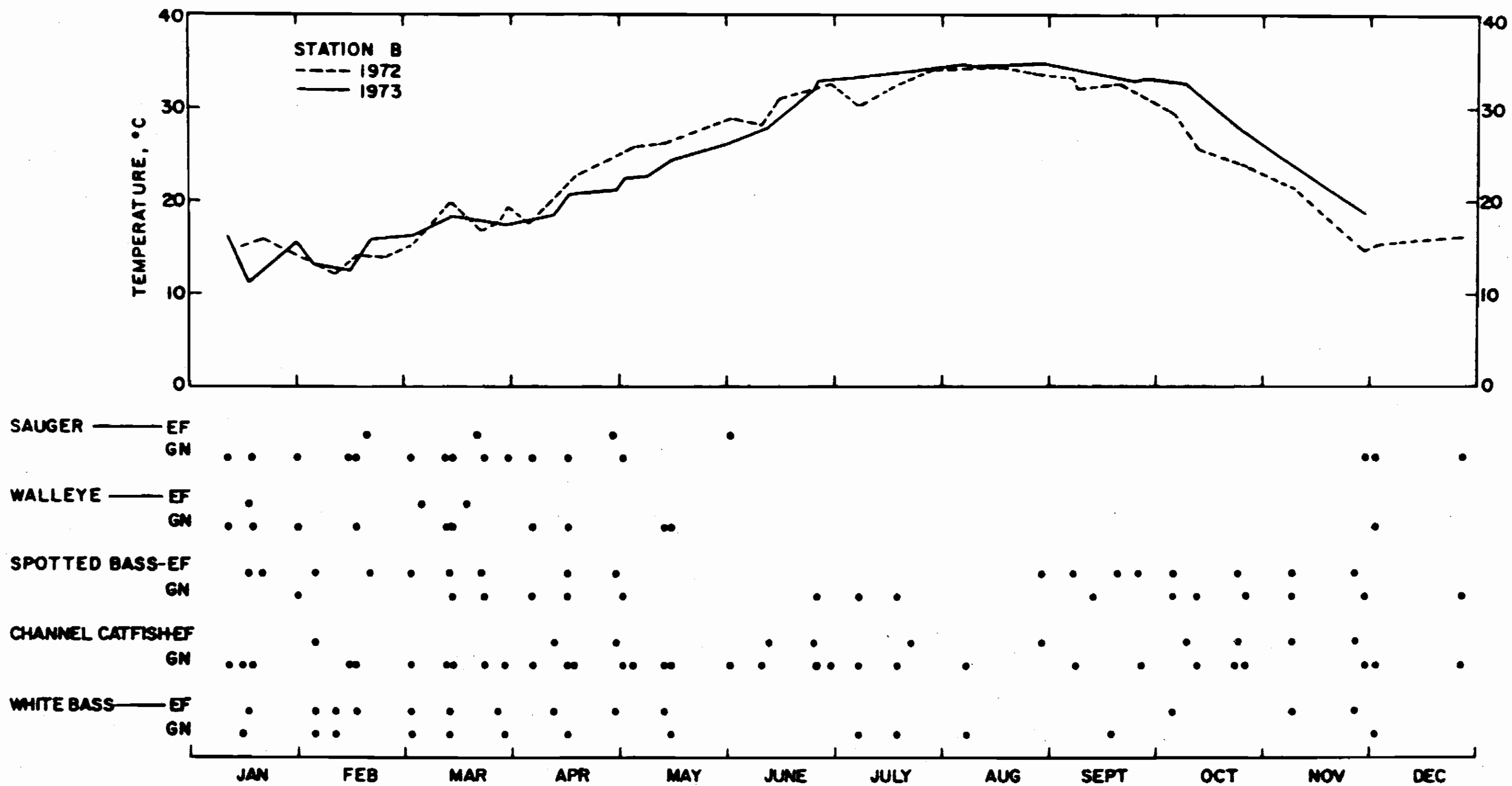

STATION B
1972
1973
TEMPERATURE, °C
40
30
20
10
0
SAUGER — EF
GN
WALLEYE — EF
GN
SPOTTED BASS-EF
GN
CHANNEL CATFISH-EF
GN
WHITE BASS — EF
GN
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC

Table 2. Relative abundance (NO./300 m) of fish collected by electrofishing at Station B (discharge basin), Colbert Steam Plant.

	January		February				March			April					May		
Species	1972	1973	1972		1973		1972			1972		1973			1972		1973
Gizzard shad	45.9	27.5	68.9	45.9	45.9	229.5	45.9	45.9	91.8	91.8	137.7	229.5	459.0	459.0	68.9	45.9	183.6
Threadfin shad	0.5	0.5	-	-	4.6	-	-	-	91.9	91.8	45.9	229.5	137.7	-	-	-	6.9
Skipjack herring	-	-	-	-	-	-	0.9	-	-	0.5	-	-	-	-	-	-	-
Carp	1.4	3.7	4.6	0.5	1.8	2.3	4.6	2.8	11.5	45.9	23.0	0.9	2.3	4.6	29.8	5.5	57.4
Spotted sucker	1.8	2.8	0.5	-	2.8	2.8	3.2	0.5	2.3	-	-	-	-	0.5	-	-	-
Golden redhorse	-	0.5	0.5	-	-	0.5	0.9	0.9	2.3	-	-	-	-	-	-	-	0.5
River carpsucker	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	-
Channel catfish	-	-	-	-	0.5	-	-	-	-	-	-	0.9	-	0.5	-	-	-
Freshwater drum	-	-	-	-	-	0.5	-	-	-	-	-	-	-	0.9	-	-	-
Longnose gar	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spotted gar	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.7
Smallmouth buffalo	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	-	-	-
White bass	0.5	-	0.5	0.5	0.5	-	1.8	1.4	3.7	-	-	0.9	0.5	-	-	1.4	-
Yellow bass	-	-	-	-	-	-	0.5	-	4.1	-	-	-	-	-	-	-	-
Bluegill	-	4.1	0.5	1.4	0.9	0.9	1.4	-	-	-	-	1.8	0.9	0.9	-	-	2.8
Longear sunfish	-	2.3	1.4	0.5	1.4	1.4	3.7	0.5	-	-	-	2.8	0.9	2.3	-	-	-
Redear sunfish	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.6	-
Smallmouth bass	-	0.9	0.5	0.5	0.5	-	-	0.5	1.4	-	-	-	-	0.5	-	0.9	-
Spotted bass	0.5	2.3	-	-	0.9	0.5	0.5	0.5	1.4	-	-	-	0.9	0.9	-	-	-
Largemouth bass	1.8	3.7	3.2	0.9	0.9	1.4	1.4	1.4	4.6	0.5	0.5	2.3	-	0.5	-	1.8	-
White crappie	-	-	-	-	-	-	0.5	-	0.5	-	-	-	-	-	-	-	-
Sauger	-	-	-	-	-	0.9	-	-	0.9	-	-	-	-	0.5	-	-	-
Walleye	-	0.5	-	-	-	-	-	-	-	1.4	0.5	-	-	-	-	-	-
Miscellaneous	-	0.5	-	-	-	0.5	0.5	-	-	-	0.5	-	-	0.5	-	-	-
Total	52.4	49.3	80.6	50.2	60.7	241.2	65.8	54.4	216.3	231.9	208.1	468.6	602.7	471.6	99.2	60.1	254.9
Temperature °C																	
Instantaneous	16.0	11.2	12.2	14.0	14.8	15.0	15.2	20.0	17.0	17.8	20.3	18.6	21.0	21.3	24.6	26.6	23.8
$\bar{X}$ Daily	-	11.6	-	-	13.1	15.9	-	-	-	-	22.8	18.6	20.6	-	25.9	26.4	22.8

Table 2. (Continued)

Species	June				July			August				September			October			November	
	1972		1973		1972		1973	1972		1973		1972		1973	1972	1973		1973	
Gizzard shad	68.9	114.8	91.8	45.9	91.8	45.9	4.6	23.0	13.8	45.9	137.7	20.7	45.9	91.8	91.8	183.6	137.7	91.8	114.8
Threadfin shad	-	-	-	-	-	-	91.8	-	-	-	45.9	45.9	23.0	23.0	23.0	137.7	45.9	-	0.5
Skipjack herring	0.5	-	-	-	-	-	-	1.8	0.9	-	-	-	-	-	0.5	-	-	0.5	0.5
Carp	7.3	3.2	4.6	1.4	3.2	0.9	1.4	-	-	-	-	-	2.3	-	1.8	0.9	3.7	6.9	-
Spotted sucker	-	-	0.9	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5
Golden redhorse	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5
River carpsucker	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Channel catfish	-	-	0.9	1.4	0.5	-	-	-	-	-	0.5	-	-	-	-	0.9	0.5	0.5	0.9
Freshwater drum	-	0.5	-	-	-	-	0.5	0.5	-	-	-	-	-	-	-	-	0.5	-	-
Longnose gar	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	0.9	-	-	-
Spotted gar	-	1.4	1.4	0.9	-	-	2.8	-	-	-	0.5	-	-	-	0.5	-	-	-	-
Smallmouth buffalo	-	-	-	-	-	-	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-
White bass	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-	1.4	-	-	-	-
Yellow bass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bluegill	1.4	0.9	3.7	4.6	-	3.7	-	3.2	1.4	13.8	2.8	1.4	1.8	1.4	0.9	1.4	-	-	4.6
Longear sunfish	0.9	6.0	3.2	2.8	-	2.3	0.9	2.3	-	4.6	1.4	2.3	-	1.8	4.6	2.3	1.4	0.9	2.8
Redear sunfish	-	-	-	-	-	-	-	-	-	-	-	-	1.4	-	-	-	-	-	-
Smallmouth bass	0.9	0.5	-	-	-	-	-	0.5	-	-	0.5	0.9	-	0.9	1.4	0.5	1.4	-	0.5
Spotted bass	-	-	-	-	-	-	-	-	-	-	1.4	0.5	0.9	0.5	0.5	-	1.4	0.9	0.9
Largemouth bass	0.5	-	1.4	1.8	0.5	0.5	1.4	0.5	-	0.5	0.9	1.4	1.8	1.4	-	1.4	2.8	2.8	3.7
White crappie	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sauger	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Walleye	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Miscellaneous	-	-	-	-	-	-	-	-	-	-	-	0.5	-	-	-	-	0.5	-	0.5
Total	80.9	128.3	107.9	59.7	96.5	53.3	103.9	32.3	16.1	64.8	192.5	73.6	77.1	121.3	126.4	329.6	195.8	104.3	130.7
Temperature																			
Instantaneous	26.8	28.7	28.4	32.0	31.7	34.4	34.4	35.1	35.0	34.8	34.0	34.2	33.9	32.0	28.6	25.0	27.5	19.2	14.5
$\overline{X}$ Daily	29.2	31.1	28.3	32.2	32.5	34.2	34.2	34.5	33.9	34.7	35.0	33.4	32.8	33.0	29.7	32.8	28.0	21.7	15.0

Table 3. Relative abundance (No./300m) of fish collected by electrofishing at Station D (lower discharge canal), Colbert Steam Plant.

Species	January		February				March			April					May			June			
	1972	1973	1972		1973		1972			1972			1973		1972		1973	1972		1973	
Gizzard shad	25.5	34.0	34.0	17.0	51.0	102.0	34.0	34.0	17.0	34.0	51.0	85.0	51.0	51.0	68.0	34.0	34.0	34.0	34.0	51.0	25.5
Threadfin fish	21.3	-	34.0	17.0	8.5	170.0	12.8	8.5	0.2	0.2	2.0	34.0	8.5	8.5	-	-	0.3	-	-	0.7	-
Skipjack herring	0.2	0.2	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carp	0.2	0.7	0.7	0.7	1.0	0.5	0.7	0.9	0.2	1.2	2.9	1.4	0.9	1.0	1.0	1.4	0.3	1.2	0.7	0.9	0.7
Spotted sucker	0.5	0.2	-	0.2	0.9	0.3	0.3	0.3	0.9	1.0	1.2	-	0.5	0.3	0.7	1.4	0.9	1.0	2.6	0.5	0.5
Golden redhorse	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	0.3
River carpsucker	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	-	-
Channel catfish	1.5	-	0.2	0.9	0.3	0.2	-	0.3	0.2	0.2	1.0	-	0.7	0.5	0.9	0.7	-	0.9	0.5	-	0.2
Freshwater drum	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	0.7	-	-
Longnose gar	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spotted gar	-	-	-	-	-	-	-	-	-	0.7	0.7	0.7	-	-	1.5	1.0	1.0	0.9	0.3	0.7	0.2
Smallmouth buffalo	0.5	-	0.3	-	-	-	0.9	-	-	-	-	-	-	-	-	-	-	-	0.7	-	0.2
White bass	2.6	0.2	2.0	0.7	0.3	1.4	-	0.3	-	0.2	0.2	0.7	0.3	0.3	-	-	-	-	0.2	0.3	-
Yellow bass	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-
Bluegill	1.7	0.9	6.1	-	1.4	1.7	1.7	1.4	0.9	2.7	0.5	0.7	1.2	0.5	0.9	1.7	0.7	1.4	2.9	1.4	1.4
Longear sunfish	0.2	-	0.9	-	0.3	0.9	0.2	0.3	0.3	0.2	0.3	0.3	0.9	0.5	0.2	0.7	-	0.3	1.5	0.7	1.0
Redear sunfish	0.9	0.2	0.9	-	-	0.2	0.3	-	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-
Smallmouth bass	0.7	0.5	0.7	0.2	0.7	0.5	0.7	0.3	-	0.3	0.3	-	-	-	-	-	-	0.9	0.2	-	-
Spotted bass	-	0.3	0.7	-	0.2	1.0	-	-	-	0.2	-	-	0.3	-	-	-	0.3	-	-	0.5	-
Largemouth bass	3.6	1.7	3.7	1.0	0.5	0.3	2.2	1.4	0.9	0.9	1.4	0.7	1.2	1.5	1.4	0.9	0.3	-	0.3	0.9	0.2
White crappie	-	0.2	0.7	0.2	-	-	-	-	-	-	-	-	0.3	0.2	-	-	0.2	-	-	-	-
Sauger	-	-	-	-	-	-	0.7	-	-	0.2	0.3	-	-	-	-	-	-	-	0.3	-	-
Miscellaneous	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-
Total	59.4	39.1	85.1	37.9	65.1	279.0	54.8	47.7	20.8	42.7	62.0	123.5	65.8	64.3	74.6	41.8	38.2	40.8	45.1	57.6	30.2
Temperature °C																					
Instantaneous	13.2	11.2	13.5	12.3	14.7	13.9	15.2	19.5	17.5	17.8	20.3	18.5	19.2	20.0	22.5	25.5	23.8	26.8	28.5	28.1	31.8
$\bar{X}$ Daily	-	11.6	13.4	13.9	13.4	13.9	-	-	-	-	21.7	18.0	19.1	20.3	24.7	24.7	23.4	28.1	28.4	28.1	31.7

Table 3. (Continued)

Species	July			August				September			October			November	
	1972		1973	1972		1973		1972		1973	1972		1973	1972	
Gizzard shad	-	-	25.5	51.0	-	25.5	17.0	34.0	34.0	51.0	170.0	85.0	17.0	34.0	51.0
Threadfish shad	5.1	12.8	34.0	17.0	8.5	-	8.5	17.0	17.0	17.0	51.0	-	-	-	-
Skipjack herring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carp	0.3	0.2	0.2	-	-	0.3	0.2	0.5	-	0.7	0.5	0.9	0.3	0.7	0.7
Spotted sucker	1.2	-	-	0.2	0.5	-	-	-	-	-	0.3	-	0.3	-	0.2
Golden redhorse	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
River carpsucker	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Channel catfish	0.2	-	-	-	-	-	-	-	-	-	-	0.2	0.2	0.2	0.2
Freshwater drum	0.5	-	-	-	-	-	0.2	-	-	-	-	-	-	0.2	-
Longnose gar	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-
Spotted gar	0.2	-	0.7	-	-	0.3	-	0.7	0.5	0.2	0.3	0.2	0.5	-	0.2
Smallmouth buffalo	-	-	0.5	-	-	-	-	-	-	0.3	0.2	-	0.2	-	-
White bass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5
Yellow bass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bluegill	3.6	0.9	1.7	0.7	-	0.5	0.7	1.4	0.9	1.7	2.7	0.2	0.2	-	1.4
Longear sunfish	1.2	0.3	-	-	-	0.2	0.2	0.9	-	0.5	0.7	0.3	-	-	0.2
Redear sunfish	-	-	0.2	0.2	-	-	-	-	-	-	-	0.2	-	-	-
Smallmouth bass	-	-	-	0.3	-	-	-	-	-	-	0.2	0.3	-	0.7	0.2
Spotted bass	-	-	-	-	-	-	-	0.3	-	0.7	0.3	1.0	-	0.2	0.9
Largemouth bass	0.5	0.5	0.5	-	0.3	0.3	0.2	1.2	0.9	0.9	0.7	1.2	0.5	-	1.2
White crappie	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-
Sauger	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Miscellaneous	-	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-
Total	12.9	14.7	63.6	69.4	9.3	27.1	27.0	56.0	53.5	73.0	226.9	89.7	19.2	36.0	56.7
Temperature °C															
Instantaneous	31.7	33.5	36.0	34.0	35.0	35.0	34.0	33.8	31.0	31.8	29.0	27.0	29.8	19.5	14.0
$\bar{X}$ Daily	-	33.4	34.2	33.4	33.4	35.3	36.1	33.6	31.4	32.5	32.2	28.9	29.5	20.0	14.5

Table 4. Relative abundance (No./300 m) of fish collected by electrofishing at Station C (control, CCM 3.0). Colbert Steam Plant.

Species	January 1972	January 1973	February 1972		February 1973		March 1972			April 1972			April 1973		May 1972		May 1973
Gizzard shad	15.7	31.4	33.0	31.4	62.8	94.2	31.4	31.4	31.4	62.8	23.6	47.1	94.2	47.1	94.2	94.2	4.2
Threadfin shad	-	-	-	-	-	-	-	-	-	62.8	6.3	-	1.6	-	-	-	0.6
Skipjack herring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carp	-	2.2	1.9	0.9	3.1	1.6	0.9	3.1	0.3	0.3	1.6	-	0.9	1.2	1.3	1.9	0.3
Spotted sucker	0.6	0.6	1.6	0.3	1.9	1.3	0.9	1.9	1.6	1.3	1.3	0.3	1.9	-	-	0.6	1.3
Golden redhorse	0.6	0.3	0.3	0.6	-	0.3	-	0.9	0.3	0.9	0.6	0.3	-	0.6	0.3	0.3	0.6
River carpsucker	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Channel catfish	-	-	-	-	0.6	-	-	0.6	0.3	0.3	-	-	-	-	-	-	-
Freshwater drum	-	-	0.3	-	-	-	-	-	-	0.3	0.3	-	0.3	-	-	-	-
Longnose gar	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spotted gar	-	0.3	-	-	0.3	0.3	-	-	0.9	0.6	0.3	-	0.6	0.6	0.9	0.9	-
Smallmouth buffalo	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-
White bass	-	-	-	-	-	0.3	-	-	0.3	-	0.3	-	0.3	-	-	-	-
Yellow bass	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-
Bluegill	0.6	1.9	1.6	0.3	2.2	0.9	-	0.3	0.6	1.3	0.9	1.3	1.3	1.2	0.6	2.2	-
Longear sunfish	-	1.6	0.9	0.3	1.3	0.6	0.6	-	0.6	1.6	-	1.3	-	1.6	0.3	0.6	-
Redear sunfish	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6
Smallmouth bass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spotted bass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Largemouth bass	0.3	0.6	0.6	-	0.3	0.3	-	0.3	-	0.3	0.3	1.6	0.9	0.9	1.3	1.3	-
White crappie	-	-	0.3	-	-	-	-	-	-	-	0.3	-	0.3	-	-	-	-
Sauger	-	0.6	-	-	-	-	-	0.9	0.6	-	-	-	-	-	-	-	-
Miscellaneous	-	-	-	-	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-
Total	17.8	40.1	40.8	33.8	72.8	100.1	34.1	39.4	36.9	132.5	36.1	51.9	102.3	53.2	98.9	102.0	7.6
Temperature °C Instantaneous	4.2	7.2	7.6	8.7	10.2	7.5	10.2	13.5	13.4	14.6	16.8	12.0	16.2	16.1	18.3	19.0	17.4

Table 4. (Continued)

Species	June				July			August				September			October			November	
	1972		1973		1972		1973	1972		1973		1972		1973	1972	1973		1972	
Gizzard shad	94.2	157.0	62.8	94.2	314.0	23.6	47.1	62.8	15.7	31.4	125.6	314.0	314.0	94.2	314.0	314.0	314.0	23.6	94.2
Threadfin shad	0.3	0.6	-	-	0.6	-	314.0	-	0.3	314.0	314.0	314.0	314.0	94.2	314.0	314.0	314.0	-	23.6
Skipjack herring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-
Carp	1.6	0.9	0.9	0.9	0.3	0.3	1.9	0.9	0.9	0.6	-	0.6	1.3	2.2	2.8	1.3	3.1	0.9	1.6
Spotted sucker	0.3	0.6	0.6	1.3	0.9	-	0.3	-	-	-	-	0.6	1.6	0.3	2.2	0.6	-	0.9	0.6
Golden redhorse	-	0.6	0.9	-	1.6	1.3	-	-	0.6	0.3	0.6	0.9	0.6	0.6	0.3	0.3	1.3	0.3	1.3
River carpsucker	-	-	-	0.3	-	0.3	-	-	-	-	0.6	-	-	-	-	-	-	-	-
Channel catfish	-	-	-	-	-	-	-	0.3	0.6	-	-	-	0.6	0.3	0.3	-	-	-	0.3
Freshwater drum	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.3	-	-
Longnose gar	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	-	-	-
Spotted gar	-	0.6	0.3	1.3	-	0.3	0.3	0.3	-	0.3	0.3	0.3	-	-	0.3	0.3	2.5	0.3	0.6
Smallmouth buffalo	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-
Yellow bullhead	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
White bass	0.3	0.9	-	-	0.3	-	-	-	0.9	-	-	1.3	0.9	-	-	0.3	-	-	0.3
Yellow bass	-	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3
Bluegill	1.9	2.8	0.9	1.3	-	0.3	0.3	3.1	0.3	1.3	1.6	0.3	0.6	0.3	0.3	0.9	1.9	2.5	-
Longear sunfish	0.3	-	-	-	-	1.6	-	1.9	-	2.5	-	-	-	-	0.3	0.3	0.9	-	-
Redear sunfish	-	0.3	-	-	-	-	-	-	-	-	0.3	-	-	0.3	-	-	-	-	0.3
Smallmouth bass	-	-	-	-	-	-	-	0.9	-	-	-	-	-	-	-	-	-	-	-
Spotted bass	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	-	-	-
Largemouth bass	1.6	-	0.6	0.3	0.3	1.3	0.3	0.9	5.0	-	1.9	2.8	3.1	2.2	2.8	3.1	2.5	1.9	1.6
White crappie	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	0.3	-
Sauger	-	-	-	-	-	-	-	-	-	-	0.3	-	-	0.3	-	-	-	-	-
Miscellaneous	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	100.5	165.8	67.0	99.6	318.0	29.0	364.2	71.1	24.3	350.7	445.2	635.1	636.7	194.9	637.6	636.6	640.5	30.7	124.7
Temperature °C																			
Instantaneous	22.6	25.8	20.7	22.2	26.8	29.8	25.4	28.3	28.1	29.0	29.0	26.8	25.2	27.8	19.0	25.0	23.0	16.0	13.0

Table 5. Relative abundance (No./net-night) of fish collected by gill net at Station B (discharge basin), Colbert Steam Plant.

	January		February		March		April		May		June	
Species	1972	1973	1972	1973	1972	1973	1972	1973	1972	1973	1972	1973
Gizzard shad	2.3	4.0	3.3	1.3	4.0	16.3	0.8	1.7	-	2.7	0.2	0.7
Skipjack herring	2.7	6.3	2.0	3.3	3.6	8.7	4.5	2.7	1.0	2.0	0.2	0.3
Carp	0.7	0.3	0.7	-	1.2	2.3	0.8	-	-	2.0	0.3	1.3
Spotted sucker	0.3	11.7	1.0	18.0	1.8	34.0	0.5	0.7	-	-	-	0.3
Golden redhorse	-	-	0.3	-	0.8	0.3	-	-	-	-	-	-
Channel catfish	4.0	3.3	3.0	1.3	5.6	4.3	4.0	1.3	3.0	2.0	0.5	5.0
Flathead catfish	-	-	-	-	-	-	-	-	-	-	-	-
Freshwater drum	-	-	-	-	-	-	-	-	0.3	0.7	0.2	2.7
Longnose gar	-	-	-	-	-	-	0.3	-	1.5	4.3	-	0.3
Spotted gar	-	-	-	-	-	2.3	-	0.3	-	-	-	1.0
Black bullhead	-	0.3	-	1.0	-	0.3	-	-	-	-	-	-
White bass	0.3	-	0.7	0.7	0.8	3.0	-	1.0	-	1.3	-	-
Bluegill	-	-	-	-	0.2	0.3	-	-	-	-	-	0.7
Spotted bass	-	0.3	-	-	0.2	0.3	0.2	0.3	-	0.3	-	0.3
Largemouth bass	-	-	-	-	-	-	-	-	0.5	-	-	-
White crappie	-	0.3	-	0.3	0.2	0.7	-	0.3	-	-	-	-
Sauger	1.3	6.7	1.7	0.7	0.6	5.0	0.2	0.7	-	0.3	-	-
Walleye	0.3	0.7	0.7	-	0.8	1.0	0.3	0.3	0.5	0.3	-	-
Miscellaneous	-	-	-	0.3	0.4	-	0.4	-	-	3.9	-	0.3
Total	11.9	33.9	13.4	26.9	20.2	78.8	12.0	9.3	6.8	19.8	1.4	12.9
Total Net-Nights	3	6	3	3	5	9	6	3	4	6	6	6

Table 5. (Continued)

Species	July 1972	July 1973	August 1972	August 1973	September 1972	September 1973	October 1972	October 1973	November 1972	November 1973	December 1972
Gizzard shad	0.7	0.3	0.3	0.7	-	9.0	-	6.3	0.3	-	-
Skipjack herring	-	-	-	-	-	-	0.2	0.3	2.3	1.7	5.2
Carp	0.2	-	0.7	-	-	-	0.2	-	0.3	0.3	0.2
Spotted sucker	-	-	-	-	-	-	-	-	-	0.7	4.0
Golden redhorse	-	-	-	-	-	-	-	-	.3	-	-
Channel catfish	1.0	0.7	0.7	7.7	2.0	1.0	1.3	1.0	1.7	4.7	2.7
Flathead catfish	-	-	-	-	-	0.3	0.2	0.3	-	-	0.2
Freshwater drum	-	0.3	-	1.0	-	2,3	-	-	-	0.7	-
Longnose gar	0.3	-	-	-	-	0.7	-	1.3	-	0.3	-
Spotted gar	-	0.3	0.7	0.3	0.3	0.3	0.2	0.7	-	-	-
Black bullhead	-	-	-	-	-	-	-	-	-	-	-
White bass	0.2	1.0	-	0.3	-	0.3	-	-	0.3	0.3	0.3
Bluegill	0.5	0.7	0.3	1.0	-	1.3	-	-	-	-	-
Spotted bass	0.2	0.3	-	-	-	0.3	0.5	-	0.7	-	0.3
Largemouth bass	-	-	-	-	-	-	-	0.3	-	-	0.2
White crappie	-	-	-	-	-	-	-	-	-	0.7	-
Sauger	-	-	-	-	-	-	-	-	0.7	1.7	2.0
Walleye	-	-	-	-	-	-	-	-	-	-	0.3
Miscellaneous	-	-	-	-	-	-	-	-	-	0.7	0.2
Total	3.1	3.6	2.7	11.0	2.3	15.5	2.6	10.2	6.6	11.8	15.6
Total Net-Nights	6	3	6	3	3	6	6	6	3	3	6

Table 6. Size distribution of selected game and food species collected by electrofishing at three stations* in lower Cane Creek.

Species	Station B			Station D			Station C		
	No.	Total Length (mm) Range	x	No.	Total Length Range	x	No.	Total Length Range	x
Channel catfish	17	206-615	358	58	195-697	433	12	290-540	401
White bass	29	190-378	246	59	155-358	232	20	135-356	225
Smallmouth bass	30	110-388	217	41	41-401	211	3	147-392	229
Spotted bass	34	85-357	214	40	114-348	225	3	105-437	271
Largemouth bass	112	130-562	316	201	107-600	259	134	100-560	277
White crappie	1	230- -	230	10	152-237	195	5	178-275	226
Sauger	6	254-330	304	9	251-350	297	9	261-363	298
Walleye	5	410-615	525	-	-	-	-	-	-

*Stations B and D in the heated discharge from Colbert Steam Plant. Station C, upstream control.

Table 7. Size distribution of selected game and food species collected by gill netting in the discharge basin (Station B) of Colbert Steam Plant.

Species	Number	Total Length (mm)	
		Range	$\bar{x}$
Channel catfish	221	215-665	397
White bass	37	225-310	276
Smallmouth bass	1	333- -	333
Spotted bass	18	231-409	385
Largemouth bass	4	285-360	325
White crappie	9	235-285	260
Sauger	70	270-467	376
Walleye	21	335-666	463

Table 8. Comparison (t-test) of the diversity indices D and $\bar{H}$ by sampling station, as determined by electrofishing.

Sampling Station*	Diversity Index	n	t-value (.05)
B vs. C	D	36	-1.19
	$\bar{H}$	36	2.11**
B vs. D	D	36	-4.96**
	$\bar{H}$	36	-0.68
C vs. D	D	36	-4.26**
	$\bar{H}$	36	-2.72**

*Station B and D in the heated discharge from Colbert Steam Plant. Station C, upstream control.

**Significant.

Table 9. Movement of fish tagged (Floy-type) within the heated discharge canal (lower Cane Creek) of Colbert Steam Plant, January 1972-August 1973.

Species	Number Tagged	Percent Recaptured	Days at Large ($\bar{x}$)	Mean Distance (km)
Largemouth bass	151	12.6	28	2.4
Smallmouth bass	18	22.2	58	0.3
Spotted bass	24	12.5	3	0.4
White bass	36	5.6	56	20.9
Sauger	15	13.3	53	12.2
Walleye	5	-	-	-
Channel catfish	51	1.9	93	0.5

III. THERMAL PREFERENCE AND AVOIDANCE AS DETERMINED BY ULTRASONIC TELEMETRY

Materials and Methods

To monitor specific preference and avoidance responses of unrestrained fish in relation to the heated effluent, 10 fish (four species) were tagged with temperature sensing ultrasonic transmitters (Rochelle and Coutant, 1973). Two sizes of transmitters (sonic fish tags) were used in this study: eight of the tags were 40 mm long (excluding thermistor), 17 mm in diameter, and weighed approximately 23 g in air; and two were 32 mm long, 17 mm in diameter, and weighed approximately 19 g in air. The thermistor was located at the end of a flexible polyvinyl appendage which extended 100 mm from the tag body. The entire assembly was covered with medical grade silicone rubber to insure biological compatibility, as the tag was designed to be implanted in the body cavity. The carrier frequencies of the 10 tags ranged from 60 to 110 kHz, and tag life ranged from 2.5 to 11 months (Table 10). Tag numbers were assigned by the developer. With this tag design, temperature information was extracted from the ultrasonic signal by pulse interval modulation. Each tag was individually calibrated; calibration accuracy was within $\pm$ 0.2 C over a + 5 to 35 C range.

The receiving system consisted of a directional hydrophone (Smith Root, model SR-70-H) which had a conical beam pattern of 8^{o}, tuneable receiver (60 to 180 kHz, Smith Root, model TA-60) which was

Table 10. Performance of temperature sensing ultrasonic transmitters (fish tags) used in this study.

Tag Number	Design Frequency (KH_z)	Field Frequency (KH_z)	Expected Tag Life* (months)	Field Life (days)	Accurate Field Temperature
24	60	65	4.5	17	yes
25	65	68	4.5	2	yes
26	70	70	4.5	14	yes
27	75	75	6.5	180	no
28	80	85	6.0	30	yes
29	80	80	11.0	33	yes
30	90	90	6.5	36	yes
31	90	90	2.5	3	no
32	100	105	2.5	30	yes
33	110	110	4.5	10	yes

*Based on advertised capacity of fresh cells.

modified to produce a digital output signal suitable for time interval measurement (temperature extraction), headphones, frequency counter (Hewlett Packard, model 5221B), and a digital recorder (Hewlett Packard, model 526A). This system was portable; it was set on the bow (wash-out deck) of the electrofishing boat which served as the tracking boat. The hydrophone handle was mounted in a bracket on the safety rail for support. Headphones improved signal detection while the boat was in motion as well as increasing the range of detection. The generator in the electrofishing boat provided a power source for the frequency counter and digital recorder. The electrofishing boat also served as the field surgical station.

Species that were tagged included six smallmouth bass, two flathead catfish, a largemouth bass, and a walleye. Initially the objective was to tag only fish that could be captured within or immediately adjacent to the heated effluent; however, it was soon apparent that specimens of a particular species and of an adequate size were not always available at the proper time. Large specimens were selected to avoid possible behavioral changes resulting from negative buoyance (Gallepp and Magnuson, 1972). Weights ranged as follows: smallmouth bass - 1.1 to 2.7 kg, flathead catfish - 3.8 to 5.4 kg, largemouth bass - 1.3 kg, and walleye - 1.5 kg. The tailwater area just below Wilson Dam, 24 km upstream from Colbert Steam Plant, served as the source of supply for all the specimens except the largemouth bass and walleye which were captured in the study area. All of the fish were captured by electrofishing. In most cases the fish were collected, transported in an aerated live-tank if necessary, tagged, and released on the same day; otherwise they were held overnight in a temperature-controlled aquarium and then tagged and released on the following day. Fish captured within or near the heated zone were tagged and released at point of capture. Those specimens collected from the dam tailwater were released at approximately CCM 2.9 in the control station, upstream from the heated discharge into Cane Creek (Fig. 1).

The transmitters (tags) were implanted in the body cavity via a midventral incision in the abdomen. For smallmouth and largemouth bass, the incision was made about 2 cm anterior of the anus, and for walleye and flathead catfish it was about 4 cm anterior of the anus. The incision was sutured with 2-0 surgical gut, and the thermistor was left protruding through the sutured incision. Smallmouth bass were by far the hardest to tag; the thick abdominal musculature and skin of this species made suturing difficult (particularly for the largest specimens). For surgery, the fish were anesthetized with 10--12 ppm quinaldine (Muench, 1958), and then positioned, ventral side up, in a redwood box (43 x 20 x 25 cm deep) by a canvas sling such that the head and gills remained submerged in the anesthetic solution while exposing the mid-ventral region for surgery. While the transmitter was being implanted, the anesthetic solution in the redwood box was aerated by a small aquarium air pump. Prior to implantation the transmitter and surgical instruments were washed with an antiseptic and rinsed with physiological saline (Wolf, 1963), also during surgery the incision was bathed periodically with saline solution. As soon as the fish recovered from the anesthetic, it was released.

After release, a fish was tracked continuously for at least four to five hours to check for any immediate ill-effects from tagging and to insure that the transmitter was functioning properly. Subsequent intervals of tracking varied from periods of continuous observation to intermittent checks of 15 minutes. Continuous tracking was generally initiated if the fish was apparently on the move. Although an attempt was made to locate each fish at least five days per week at different periods of the day, randomized observation periods were not established since the fish could not always be found and the time in the field for a single two-man tracking crew was limited.

After receiving the signal from a given fish and establishing (by manipulating the direction of the hydrophone and sensitivity of the receiver) a fix on its location, the generator was started to power the frequency counter so that a temperature reading (pulse interval) could be obtained. The fish was not approached such that the operation of the outboard motor or generator would likely frighten it. Water temperature in the vicinity of the fish was checked by a portable electric thermometer. Also, the five permanent temperature monitors (noted in section II) provided additional reference temperatures. Time of day, stream location, water temperature, and fish movement were recorded on a field form. Transmitted temperatures were derived back in the laboratory from the calibration curve for each tag.

Results

A summary of the results of eight experiments using temperature sensing ultrasonic transmitters is presented in Table 11. Detailed results for each species are described below.

Largemouth bass

The first fish tagged was a largemouth bass (453 mm TL and 1.3 kg) that was captured in the control station upstream from the heated effluent. This fish (Number 28) was released at CCM 2.9, approximately 50 m upstream from the point of capture (Fig. 7). Except for one foray into the edge of the heated effluent, this fish was always located in the lower half of the control station from 2 August through 24 August. Transmitted temperatures indicated that this fish was most frequently found at 27.0 to 29.0 C during this 15-day period; however, on one occasion, it moved into the steep thermal gradient at the conflunce of the discharge basin and creek. It remained four hours in water that ranged from 31.0 to 32.2 C. Maximum effluent temperatures (15-day interval) ranged from 33.5 to 35.0 C. Daily movement during this interval ranged from less than 20 m to 150 m.

On 25 August this fish could not be located. Although extensive searches of the control station and most of the heated zone were made at various periods of the day for a week, this fish was not found until 30 August. It was relocated in a swift turbulent stretch of the heated effluent approximately 200 m downstream from the discharge basin. At the time of relocation (0930) the temperature reading was 34.1 C. This section had been neglected since it had been assumed that tracking would be impossible because of the water turbulence and that a largemouth bass would not frequent this habitat. It was discovered that tracking could be done in the swift and turbulent zones by keeping the hydrophone directed downstream while the boat was in motion. Headphones also enhanced signal detection under these conditions.

For about an hour this fish remained stationary in the current, but then began moving upstream to the discharge basin. Enroute to the discharge basin transmitted water temperature ranged from 34.0 to 35.0 C. Shortly after the fish arrived in the basin the transmitted temperature dropped to 33.5 C. It remained at this temperature for approximately 15 minutes then moved (less than 10 m) into a cooler zone (30.5 C) where it remained for the next three hours then tracking for that day was terminated. Although the thermometer probe was not dropped right over the fish in order to avoid spooking it, the cooler zone could not be detected from the boat. The surrounding effluent temperature was 35.0 C.

On the following day tracking was not begun until 1400 hours, but the fish was found in the same location. The transmitted temperature was 28.7 C, but the measured effluent temperature was 34.5 C. After tracking the fish at this spot for two hours, tracking was terminated to search downstream for the second fish which had been released on 25 August. Resuming the track for the largemouth bass at 1930, it was relocated in the control station at a temperature of 28.5 C. The fish had moved approximately 150 m, downstream out of the discharge basin and upstream into the ambient zone. Tracking was terminated for that day (31 August) at 2030, and as it turned out, this was the last signal received from this fish.

Based on the actual time (33 hours) of known location, the largemouth bass was found predominately at temperatures ranging from 27.0 to 30.0 C. Total time in the extreme effluent temperatures may have been longer if the fish could have been located. The possibility of a cool pocket in the effluent (28.7 - 30.5 C), which this fish apparently occupied while in the discharge basin, was substantiated after a check of the plant operating records showed that although Unit 3 was off during this period, one of the two condenser circulating pumps for this unit remained in operation (pumping ambient river water). Stationary temperature monitors located in the discharge basin but upstream and downstream of Unit 3 revealed a mean daily temperature of 34.5 C for this period.

On 5 October 1972, this largemouth bass was caught (on a minnow) by a fisherman in the upper end of the discharge basin. The tag was recovered, and the battery was dead. Effluent temperature at point of capture was 29.7 C. The incision for the tag was apparently well healed. There was some irritation around the extruding thermistor appendage, but the fish had been dashed around on a stringer for three to four hours before it was examined.

Flathead catfish

Transmitters were implanted in two flathead catfish that were displaced from the Wilson Dam tailwater. The first one (711 mm and 5.4 kg; Number 29) was released at CCM 2.9 on 25 August 1972. After release (1400 hours), it moved downstream approximately 20 m and stayed at this point (28.0 C) for the remainder of the tracking period for the first day. On the following day it was located downstream 150 m in the edge of the thermal gradient. Transmitted temperature was 30.3 C.

During the following week this fish made extensive movements up and down the heated zone of Cane Creek (Fig. 8). On the third day after release, it was located in the heated effluent (33.0 C), 1.6 km downstream from its previous location. It remained here (approximately CCM 1.8) for two days then returned to the gradient zone just above the confluence of the discharge basin and creek (CCM 2.8). After remaining one day at this location (29.5 C), it returned to CCM 1.8 where it was located during the next seven days. During this interval it apparently remained in water which ranged from 33.7 to 34.2 C.

On 9 September this fish could not be located. It was relocated two days later in a side channel at CCM 1.8. This small side channel apparently received some spring flow and surface run-off; water temperature at this location was 29.5 C. On 13 September it again returned to the main channel at CCM 1.8; transmitted temperature was 33.6 C.

During the next 15 days this fish was always located either in the main channel at CCM 1.8 or 350 m downstream in the main channel at approximately CCM 1.5. The transmitted temperature, the same as the recorded effluent temperature, ranged from 31.0 to 33.0 C. The last signal was received on 28 September; but it was weak and out of phase with the effluent temperature. Premature battery failure was suspected; expected tag life for Number 29 was 11 months (Table 10). Hoop nets were set in the channel at CCM 1.5 and 1.8 in an attempt to recapture this specimen. Although not successful, eight other flathead catfish, over 500 mm total length, were caught during a three-week period. Water depth at the two locations was 7 m and 4 m, respectively.

With the exception of being present on one occasion when Number 29 moved approximately 100 m, this fish was never tracked during an extensive move. Since most of the tracking effort was expended between 0830 and 2000, most of its movements probably occurred between 2100 hours and dawn. Maximum rate of movement occurred on two occasions when it moved at least 1.6 km in 10 hours or less.

A summation of the actual hours tracked indicated that this fish spent half its time in the heated zone and half in ambient temperatures; however, based on probable locations between tracking intervals it was in the heated zone 24 days and in the cooler areas for nine days. The temperature differential, for the three times this fish moved into the heated effluent from ambient, ranged from 4.0 to 5.5 C.

The second flathead catfish, smaller than the first (600 mm TL and 3.8 kg), was released at the same location (CCM 2.9) but a year later. This fish (Number 33) was tracked daily from 3 September 1973 until 18 September when it was suspected that the tag was no longer in the fish. The suspicion was correct as the tag (still operating) was recovered by scuba diving. After rechecking the field data, specifically the record of movement, it was determined that the tag probably was lost from the fish 9 or 10 days after tagging. During the 9-day interval prior to tag loss, the specimen remained in what was essentially the lower half of the control station (Fig. 9). On three occasions it moved into the edge of thermal gradient just above the discharge basin, maximum transmitted temperature was 30.7 C. Most of the time it was located in water 28.0 to 29.0 C. Maximum daily movement was at least 250 m. Mean daily effluent temperatures while this fish was at large ranged from 34.5 to 35.6 C.

Walleye

After obtaining the ultrasonic fish tags, only one walleye was captured that was suitable for tagging. This specimen (575 mm TL and 1.5 kg) was collected by another fisheries crew while electro-fishing for ripe white and yellow bass at approximately CCM 2.2. This fish (Number 32) was released the following day (27 April 1973) in the vicinity where it was captured (Fig. 10). It was tracked for 30 days and was always located in the heated effluent. The transmitted temperature during this interval ranged from 19.2 to 27.2 C, which agreed with instantaneous and recorded measurements of the effleunt temperature. During the last 16 days of this period, the effluent temperature was above 25.0 C. The last signal was received on 26 May; this fish was tracked approximately one half of the expected tag life. However, since tracking was not resumed until 28 May, the fish may have merely eluded the trackers. Although its mean daily range was 50 m or less, it did have a maximum daily range of approximately 450 m. It apparently moved mostly during the late night.

Smallmouth bass

The first smallmouth bass (495 mm TL and 2.2 kg; Number 24) was released at CCM 2.9 on 13 September 1972 (Fig. 11). During the first day, at least until 1730, it remained in the ambient zone upstream from the heated effluent. On the following day, beginning at 0730, this fish could not be located. The entire length of the discharge zone and a portion of the upstream section (approximately 1.5 km) of Cane Creek was searched thoroughly. The same route was tracked again during the next two days, but to no avail. On the fourth day after release, it was located in Pickwick Reservoir across and upstream from the mouth of Cane Creek. Apparently during the first night after release this fish moved from the ambient zone of Cane Creek (27.5 C), through the heated effluent (32.8 C), and back to the ambient conditions (26.6 C) in the reservoir. Estimated rate of travel was 4.6 km in 12 hours.

Until this fish was lost or the tag battery failed (29 September), it ranged up and down the river channel between the intake of Colbert Steam Plant and the mouth of Cane Creek. During periodic diurnal checks this fish moved very little; however, on two occasions unobserved overnight movement approached 2.0 km. It appeared to prefer a depth of 4 to 5 m; transmitted temperature ranged from 25.8 to 27.0 C.

Behavior and movement of the second smallmouth bass (Number 30) was essentially opposite from that of the first. The second one (565 mm TL and 2.7 kg), released on 2 November at CCM 2.9, moved very little and spent most of the time in the lower half of the control station above the confluence of the heated discharge (Fig. 12). During the 34 days in which it remained in the ambient zone, it was located at temperatures which ranged from 15.3 C at the time of release to 7.8 C on other occasions.

Sometime between 1400 hours on 5 December and 1500 hours on 6 December, it moved downstream approximately 50 m and into the heated discharge. Water temperature in the ambient zone was 11.5 C, and the effluent temperature was 19.5 C. This fish was moving around in the lower part of the discharge basin when tracking was terminated at 1800 hours. On 7 December this fish was to be found nowhere. Additional searches during the next two weeks were also fruitless. Expected tag life for Number 30 was 6.5 months.

A third smallmouth bass (Number 28, battery replaced after recovery from the largemouth bass) was released at CCM 2.9 on 19 April 1973. This was the only smallmouth (520 mm TL and 2.5 kg) that moved upstream initially (Fig. 13). On the second day it was located approximately 150 m upstream from the point of release. At this location, the transmitted water temperature was 16.9 C. On the third day it was not tracked. By the fourth day it had moved 1.5 km downstream and into the heated discharge. After it was located (1730), it continued to move downstream (about 50 m) during the next two hours. Apparently it remained in the heated zone overnight since it was found at about the same location at 0900 the next morning. During the day it moved upstream approximately 25 m. Transmitted water temperature, the same as the day before, was 19.3 C, which corresponded to the measured effluent temperature. Tracking was continued the next day, but this fish was never located again. Although tag failure was suspected (expected life was six months), this specimen had begun to make extensive moves similar to the first smallmouth bass.

The fourth smallmouth bass (Number 25) tagged, as well as the sixth (Number 31), was lost after only two days of tracking. Both fish were apparently moving out of the ambient zone downstream into the heated effluent. Premature battery failure was suspected for both tags. Number 25 (518 mm TL and 2.3 kg) was released on 8 July 1973, and Number 31 (465 mm TL and 1.9 kg) was released on 4 September.

The fifth specimen (419 mm TL and 1.1 kg; Number 26) was released at CCM 2.9 at 1300 hours on 24 August. When tracking was terminated at 1700, it was still in the ambient zone, transmitted temperature was 29.8 C. When tracking was resumed at 1900, this smallmouth had moved downstream out of the ambient zone and upstream into the upper end of the discharge basin (Fig. 14). Water temperature at this location was 31.8 C, but the maximum effluent temperature was

33.5. Unit 1, which discharges into the upper end of the basin, was apparently operating at a reduced load. Shortly after it was relocated, this fish began to move downstream through the discharge basin. It moved in a stop-and-go fashion for approximately 300 m before stopping. It held this position until tracking was terminated at 2300. Transmitted temperature at this location was 33.4 C.

On the succeeding day it was again located in the heated discharge, but it had moved 150 m upstream and was located near the confluence of the discharge basin and creek. Temperature at this location was 31.7 C. On the following day (26 August), it had moved upstream approximately 25 m into the gradient zone between the creek and discharge basin; it was still located in water 31.7 C.

From 27 August until about 6 September, this fish was always located in the ambient zone at temperatures that ranged from 28.0 to 29.0 C. Maximum effluent temperatures during this interval ranged from 32.4 to 33.6 C. This fish was tracked until 18 September, but no movement was recorded after 6 September. The tag was recovered by scuba diving on the same day that Number 33 from a flathead catfish was found.

Discussion

Temperature selection of the single largemouth bass tagged with an ultrasonic transmitter in this study was very similar to that for this species in the Par Pond reservoir system, South Carolina (Clugston, 1973). Clugston, using the same temperature sensing ultrasonic fish tag but with the thermistor appendage implanted inside the body cavity, reported that the most common body temperature of largemouth bass tracked during summer was 27 to 30 C. He also reported that the body temperature of one specimen reached 35.6 C before this fish returned to a cool spring (25 C) entirely surrounded by heated water, and that on other occasions largemouth bass were tracked while moving through water 33 C. Clugston noted that this species was attracted to flowing water, but that the largemouth bass population within the heated effluent apparently changed more or less continuously. The largemouth bass tracked in the present study was also able to seek out a cool zone (28.7 - 30.5 C) surrounded by a turbulent effleunt (35 C). This fish selected water 27 to 30 C most frequently, but it also made several forays into water above 33 C.

Apparently it is not uncommon for largemouth bass to venture into zones in which the temperature is near or above the reported upper incipient lethal temperature for this species (36.4; Hart, 1952). The ability of the largemouth bass (and possibly for any given fish species) to frequent abnormally high temperatures associated with heated discharges may be determined by exposure to cyclic temperatures near or exceeding upper lethal values. Otto (1974) reported that the heat tolerance of western mosquito fish (Gambusia affinis affinis) subjected to brief daily exposure to temperatures approximating or exceeding the upper lethal limit was increased over that obtained with constant temperature acclimation in proportion to the peak temperature of the cycle. Brett (1944) also reported that field temperature tolerance by the brown bullhead (Ictalurus nebulosus) exceeded the lethal temperature derived in the laboratory after acclimating this species to a constant mean field temperature.

Movement of the largemouth bass in this study, although not extensive, was also similar to that reported by Clugston (Ibid). He observed that specimens tracked in the summer were less active and moved shorter distances than those in the autumn and winter. Warden (1973), using non-temperature sensing sonic tags, tracked largemouth bass in a 600-acre impoundment in Mississippi and noted that the distances traveled between new locations and activity within a home area were reduced at temperatures above 26.7 C. Warden also reported that nocturnal movement increased when the water temperature was above 26.7 C. Nocturnal tracking in the present study was limited.

Although the response to the heated effluent by the two flathead catfish tracked in this study was different, results for the second specimen were somewhat incomplete since the transmitter was lost from this fish and it was not tracked as long as the first. The first one (Number 29) appeared to be quite tolerant of the maximum effluent temperatures (34 - 35 C). This specimen made rather rapid and extensive movements within the heated zone of Cane Creek and then apparently established a home range in the creek channel of the heated zone. Gammon (1971 and 1973) reported that this species was relatively immobile in the Wabash River, but that it did concentrate in zones receiving heated discharges; optimum temperature ranged from 31.5 to 33.5 C. Summerfelt, Hart, and Turner (1972) tracked flathead catfish in Lake Carl Blackwell (Oklahoma) with non-temperature sensing transmitters and reported that this species was highly mobile (home range was approximately nine times greater than that determined by conventional mark and recapture methods). Summerfelt et al. also reported that movement immediately (1.5 days) after release was often rapid and expansive and that this species frequently sought out the old river channel in this reservoir.

The occurrence of flathead catfish in Cane Creek, as determined by electrofishing and gill netting, was too infrequent to relate to temperature. However, as indicated by a limited number of hoop net sets, this species was probably common in Cane Creek. Laboratory studies on the temperature tolerance and preference of this species apparently have not been done.

The walleye tagged in this study remained in the heated effluent for an extended period (30 days), but the maximum temperature (27.4 C) during this interval was similar to temperatures at which this species had been captured in Cane Creek and in other waters. Walleye, which are relatively uncommon in the mainstream reservoirs on the Tennessee River, were collected in small numbers from the heated discharge zone in Cane Creek from December to mid-May at temperatures of 16 C to 25 C, respectively. Trembley (1960) reported that the maximum body temperature of walleye (apparently not undergoing heat stress) collected in a heated effluent was 28.9 C. Dendy (1948) reported that the mid-summer temperature preference (based on the catch in vertical gill nets in Norris Reservoir) was 25 C for this species. Report of any attempt to tag walleye with ultrasonic transmitters was not found in the literature.

As indicated above, walleye reappeared in the heated effluent in the fall at temperatures approximately nine degrees (C) cooler than those which it tolerated or selected in the spring. Although acclimation temperature probably has the major effect on thermal preferences (Fry and Hochachker, 1970), seasonal temperature selections somewhat independent of acclimation temperature have been determined from laboratory studies with other species. The preferred temperature of brook trout (Salvelinus fontinalis) (Sullivan and Fisher, 1953) and white perch (Morone americana) (Meldrim and Gift, 1971) dropped more rapidly than the acclimation temperature in late fall and rose more rapidly than the acclimation temperature in spring. Temperature selection of four species from Western Lake Erie tested in a thermal gradient appeared to be determined by acclimation temperature and a seasonal factor, which may have included photoperiod and physiological condition of the fish (Barans and Tubb, 1973). Some species, such as the estuarine goby (DeVlaming, 1971), do not display seasonal differences in temperature preferences. Since the normal seasonal migration of walleye to the tailwaters of dams on the mainstream of the Tennessee River coincides with its appearance in the heated effluent in Cane Creek, the seasonal effect on temperature selection was not clearly deomonstrated.

The six smallmouth bass, displaced from Pickwick Reservoir and released in the upstream control station, demonstrated a variation of behavoir in relation to the heated effluent, although three fish were lost shortly after release. The four specimens released in conjunction with the maximum effluent temperatures (July, August, and September) moved downstream into the heated effluent within 24 hours after release. The fish released under fall-winter conditions (November) apparently remained in the ambient zone for about a month before moving downstream into the heated zone, and the one released in April remained in the ambient zone for approximately three days before it too moved downstream into the heated zone. Two of the fish tracked under summer conditions and the one tracked in the spring were lost within two to four days after release. Battery failure in these transmitters was suspected. The possibility of premature battery failure may have been reduced if the transmitters had been activated and checked for two to three weeks prior to implanting in a fish (Rochelle and Coutant, 1973).

The other two specimens tracked under summer effluent conditions moved into the heated zone at 33 C, which is greater than the reported maximum summer preference (31 C) for this species (Barans and Tubb, 1973) but less than the upper incipient lethal temperature (about 38 C; Larimore and Duever, 1968). Both fish returned to ambient conditions within at least 48 hours, but one moved downstream (4.5 km) to Pickwick Reservoir and the other returned upstream to the control station. Temperature conditions in the heated zone of Cane Creek, that exceed summer preference but are less than lethal for smallmouth bass, generally occur from mid-June through mid-September. Results from those specimens tagged with temperature sensing ultrasonic transmitters, as well as the occurrence of this species at temperatures above 34 C (collected by electrofishing), indicated that thermal conditions in lower Cane Creek, although not necessarily preferred, would not be a barrier to movement of smallmouth bass.

The smallmouth bass released in November remained in the ambient zone for over 30 days at temperatures (7.8 to 15.3 C) somewhat below the winter preference temperature (18 C modal) reported for this species (Barans and Tubb, 1973). This fish moved into the heated zone when the temperature was 19.5 C. Temperature selection demonstrated by this fish was similar to that discussed in relation to the walleye, i.e. some species select lower temperatures somewhat independent of acclimation temperature when the temperature is declining in the fall.

Although thermal preference of fish may change in response to a variety of environmental factors (Gammon, 1971, and Barans and Tubb, 1973), abnormal temperature selection or behavior resulting from implanting ultrasonic fish tags has not been reported (Rochelle and Coutant, 1973, and Clugston, 1973). Clugston reported that although there is not a control method to evaluate how wild fish behave, he felt that the transmitters had little influence on behavior of largemouth bass which moved freely and fed while carrying transmitters for periods of 37 to 175 days. Similar observations applied to the four species tagged in the present study.

Apparently one of the most important considerations regarding the use of ultrasonic transmitters is the effect of negative buoyancy. Gallepp and Magnuson (1972) suggested that the transmitter should be neutrally buoyant or if not, its excess mass should be small enough to permit buoyancy adjustment by gas secretion. They indicated that possible problems that would result from negative buoyancy were changes in behavior, depth distribution, and metabolic requirements. Transmitters used in the present study were not neutrally buoyant but apparently their mass was not excessive. Weight of the transmitters in relation to fish weight in this study ranged from a maximum of 1.7 percent for the smallest smallmouth bass to 0.4 percent in the largest flathead catfish.

Table 11. Summary of the results of thermal preference-avoidance experiments using temperature sensing ultrasonic fish tags.

Tag Number	Species	Released	Terminated	Actual Hours Tracked	°C Temperature Encountered (range)	Movement	
						Total Distance (km)	$\bar{x}$ Daily (m)
28	Largemouth bass	1400 8/2/72	2030 8/31/72	33.2	27.0-35.0 C	1.5	50
29	Flathead catfish	1415 8/25/72	1500 9/28/72	48.2	28.0-34.5 C	6.9	209
24	Smallmouth bass	1230 9/13/72	1430 9/29/72	28.2	25.8-32.8 C	10.5	618
30	Smallmouth bass	1545 11/2/72	1700 12/6/72	83.6	7.8-17.4 C	0.8	23
28	Smallmouth bass	1130 4/19/73	1700 4/23/73	14.2	14.5-19.3 C	1.7	340
32	Walleye	1130 4/27/73	1030 5/26/73	37.5	19.2-27.4 C	1.5	50
26	Smallmouth bass	1300 8/24/73	1800 9/6/73	38.7	28.0-33.4 C	1.4	108
33	Flathead catfish	1020 9/3/73	2010 9/12/73	30.6	28.2-30.7 C	1.3	130

Figure 7. Movement of a non-displaced largemouth bass (Number 28) in relation to the heated discharge from Colbert Steam Plant as determined by temperature sensing ultrasonic transmitters (width of Cane Creek not to scale, enlarged for illustration).

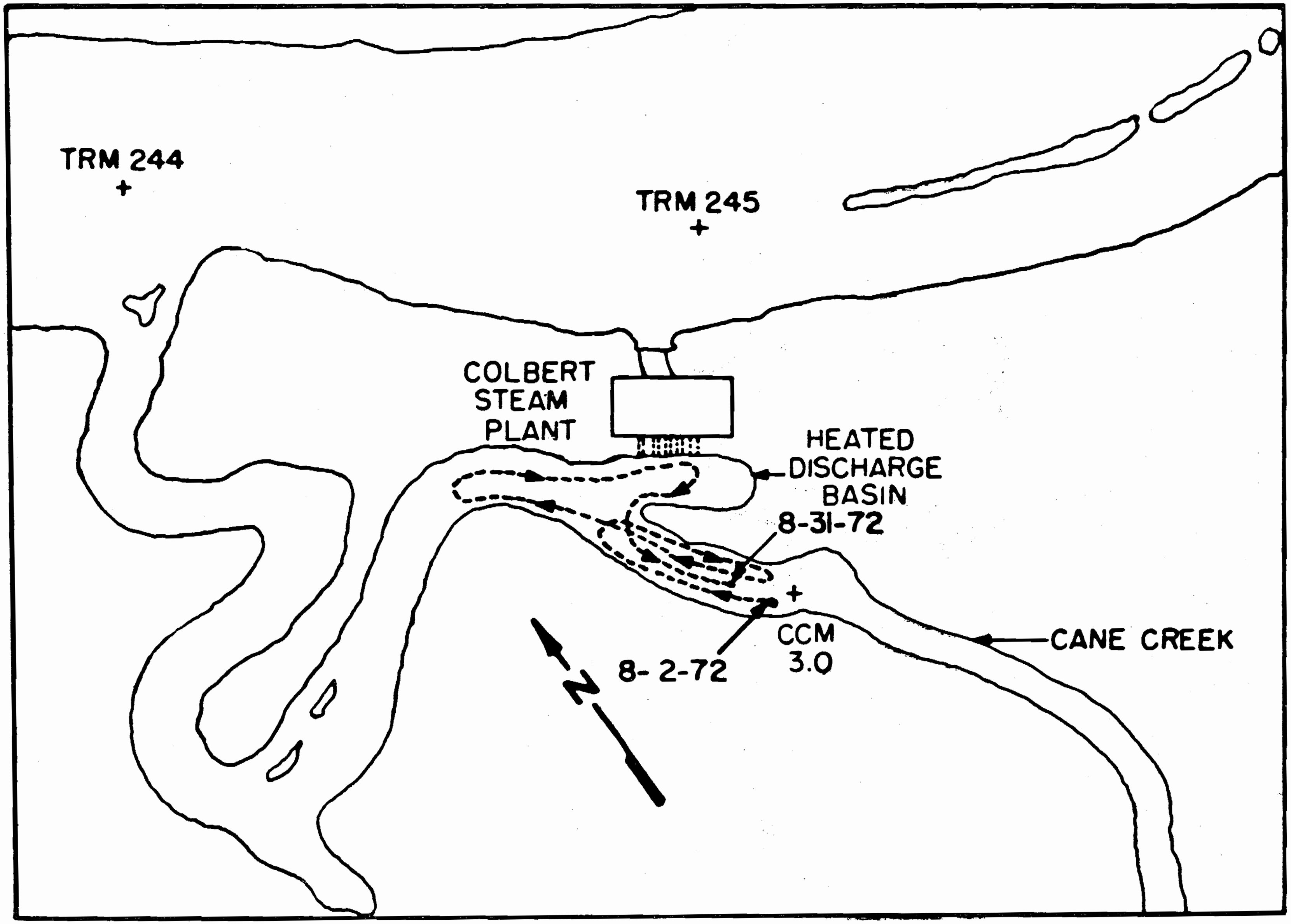

TRM 244
TRM 245
COLBERT
STEAM
PLANT
HEATED
DISCHARGE
BASIN
8-31-72
CCM
3.0
8- 2-72
CANE CREEK
N

Figure 8. Movement of a displaced flathead catfish (Number 29) in relation to the heated discharge from Colbert Steam Plant as determined by temperature sensing ultrasonic transmitters (width of Cane Creek not to scale, enlarged for illustration).

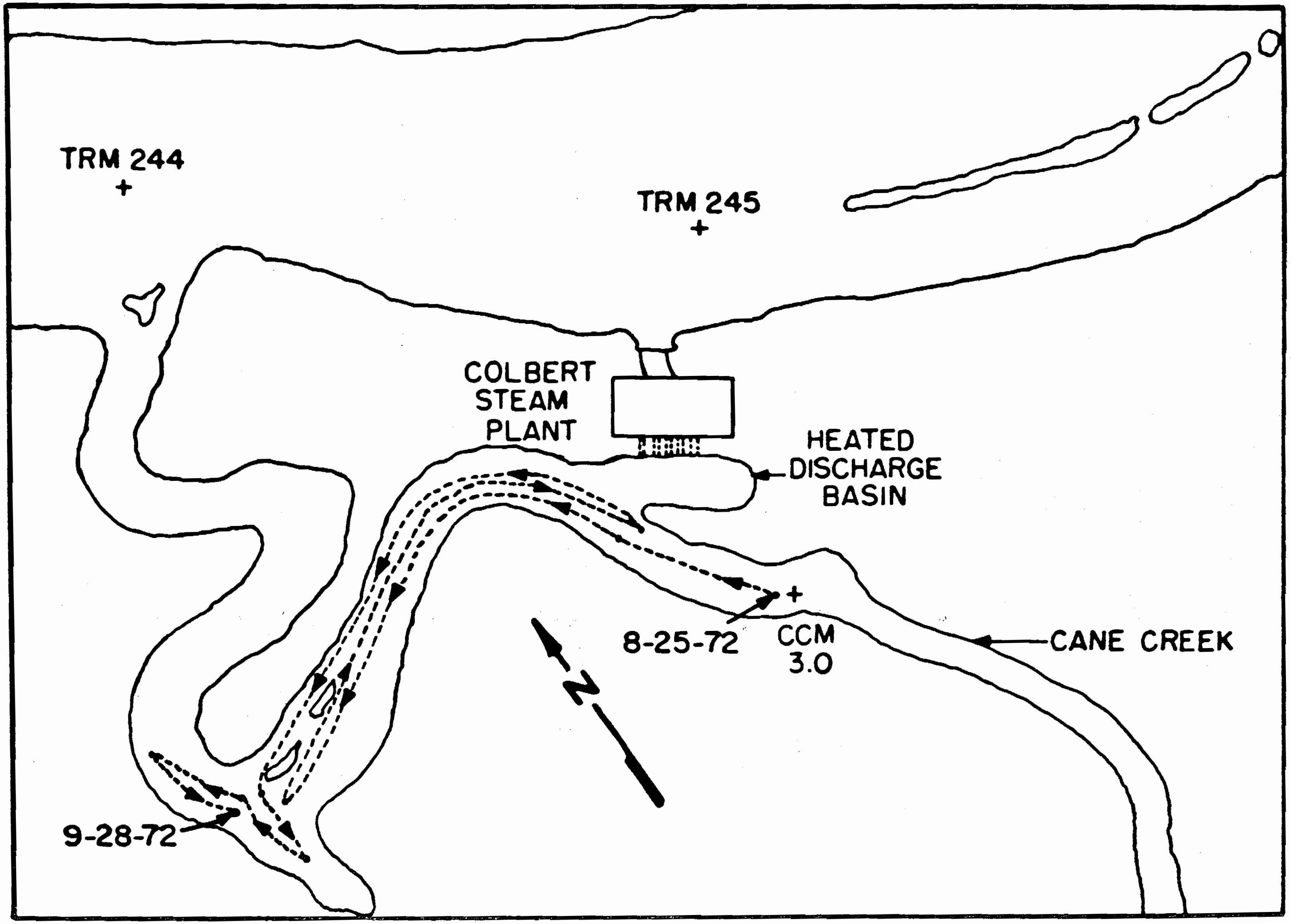

TRM 244
TRM 245
COLBERT
STEAM
PLANT
HEATED
DISCHARGE
BASIN
8-25-72
CCM
3.0
CANE CREEK
N
9-28-72

Figure 9. Movement of a displaced flathead catfish (Number 33) in relation to the heated discharge from Colbert Steam Plant as determined by temperature sensing ultrasonic transmitters (width of Cane Creek not to scale, enlarged for illustration).

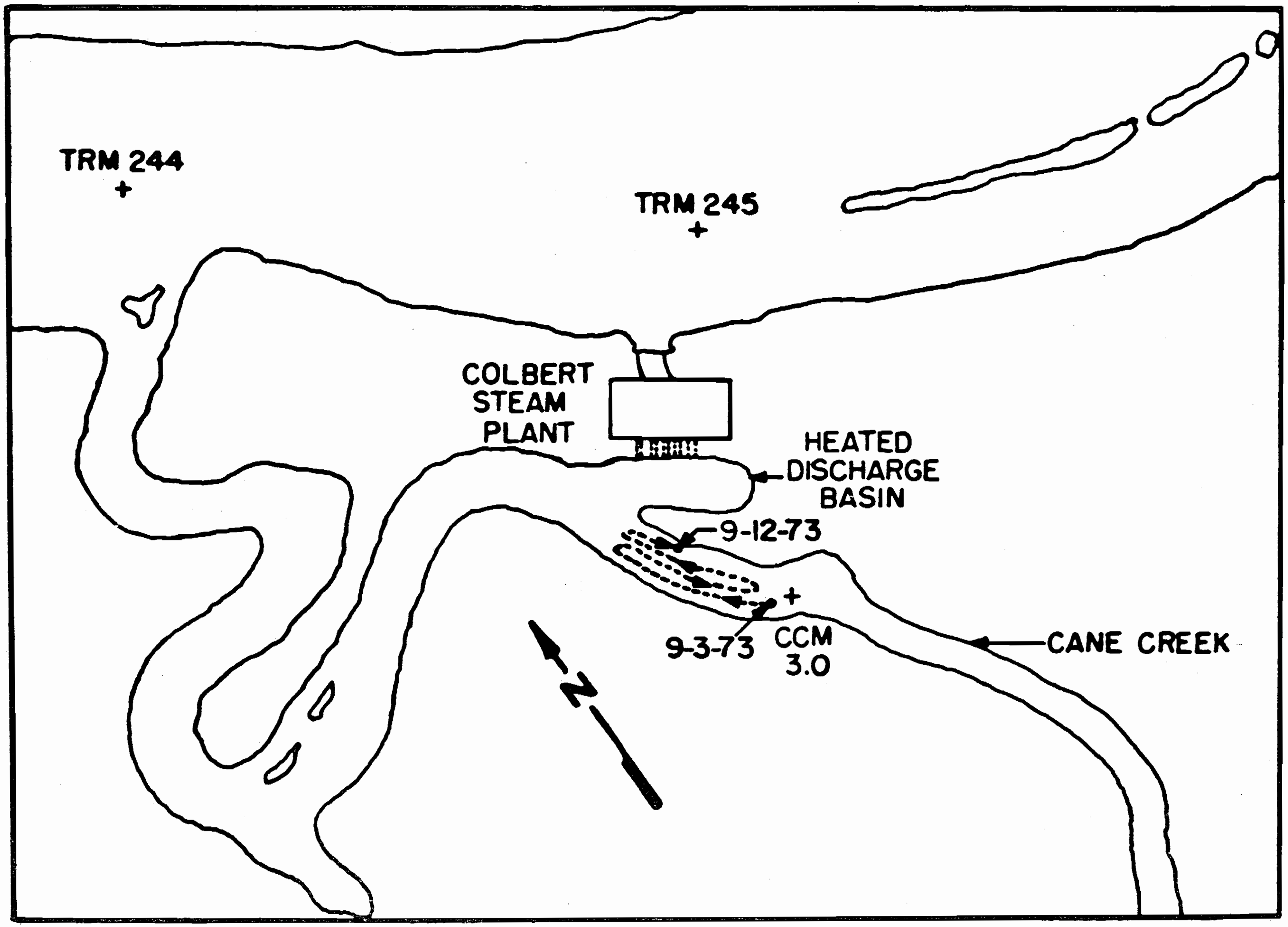

TRM 244
TRM 245
COLBERT STEAM PLANT
HEATED DISCHARGE BASIN
9-12-73
9-3-73
CCM 3.0
CANE CREEK
N

Figure 10. Movement of a non-displaced walleye (Number 32) in relation to the heated discharge from Colbert Steam Plant as determined by temperature sensing ultrasonic transmitters (width of Cane Creek not to scale, enlarged for illustration).

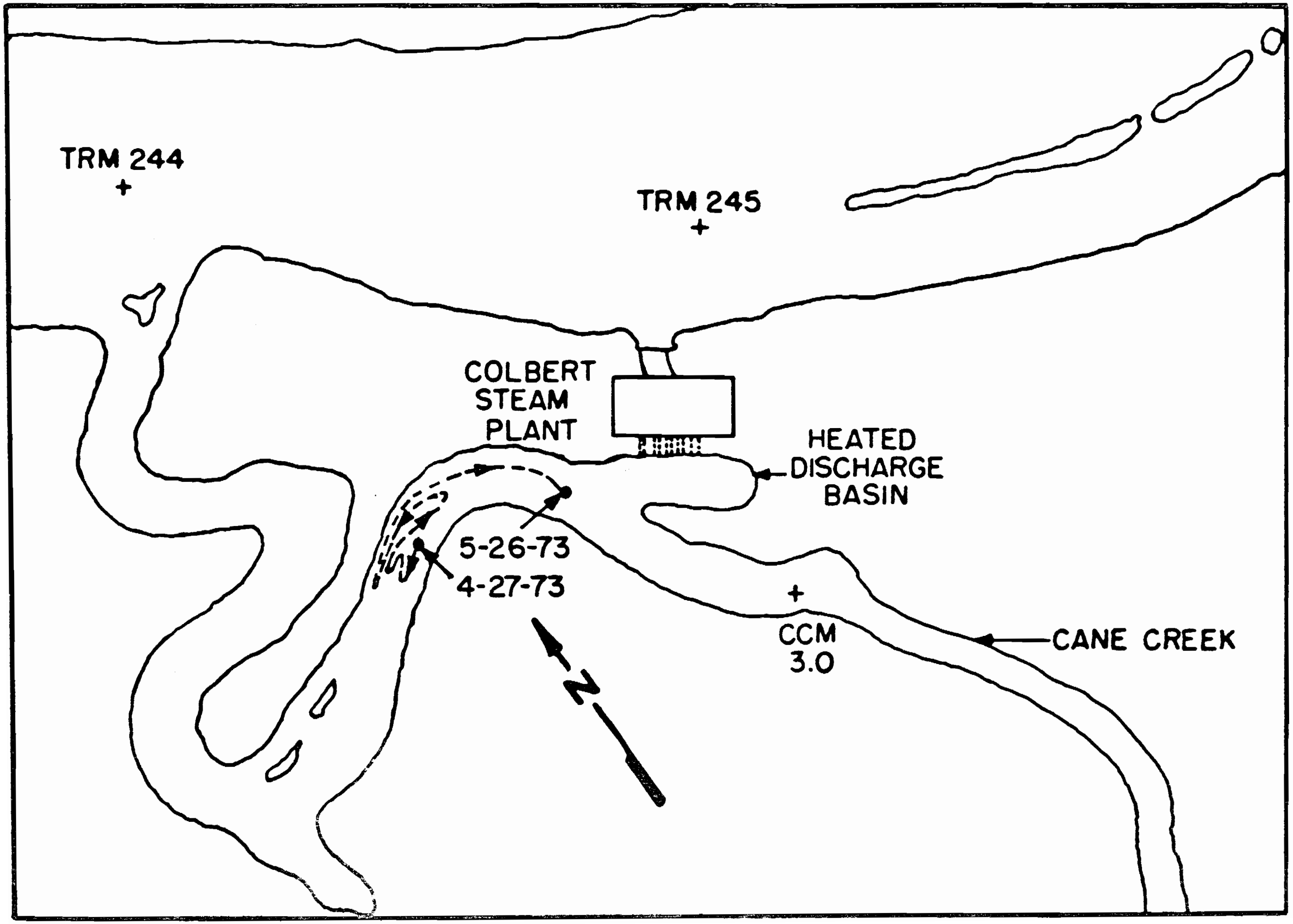

TRM 244
TRM 245
COLBERT
STEAM
PLANT
HEATED
DISCHARGE
BASIN
5-26-73
4-27-73
CCM
3.0
CANE CREEK
N

Figure 11. Movement of a displaced smallmouth bass (Number 24) in relation to the heated discharge from Colbert Steam Plant as determined by temperature sensing ultrasonic transmitters (width of Cane Creek not to scale, enlarged for illustration).

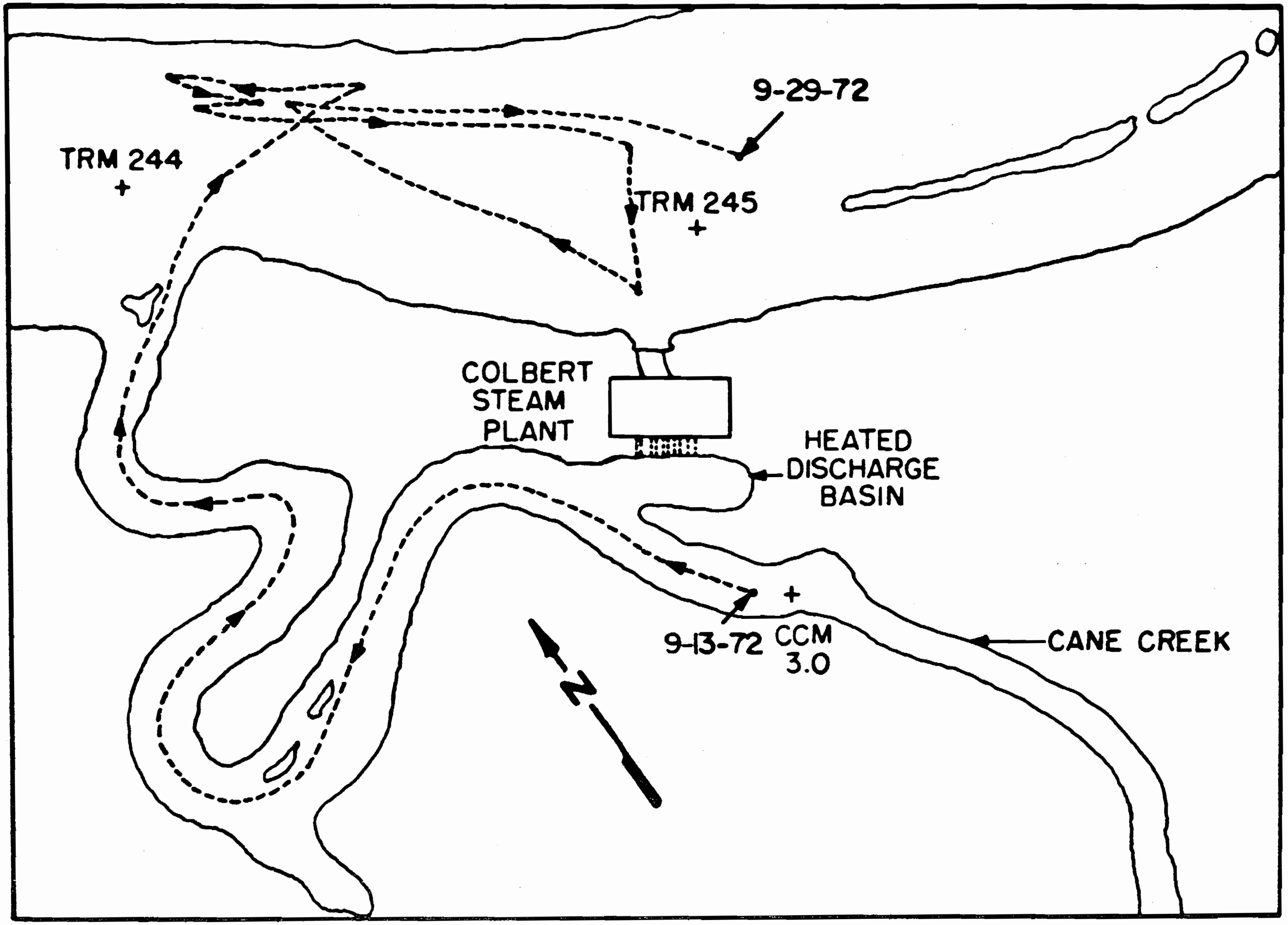
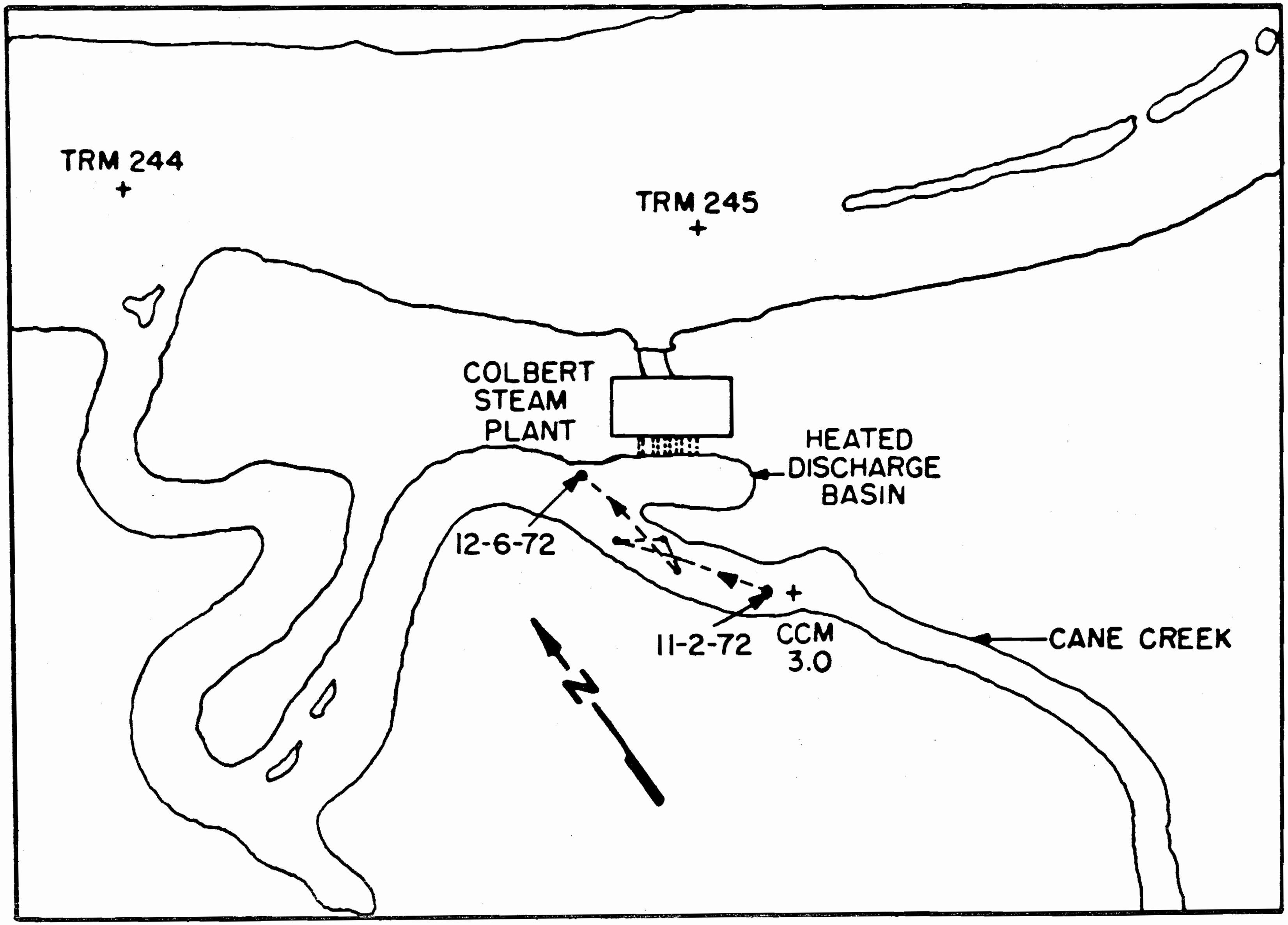

9-29-72
TRM 244
TRM 245
COLBERT
STEAM
PLANT
HEATED
DISCHARGE
BASIN
9-13-72
CCM
3.0
CANE CREEK
N

Figure 12. Movement of a displaced smallmouth bass (Number 30) in relation to the heated discharge from Colbert Steam Plant as determined by temperature sensing ultrasonic transmitters (width of Cane Creek not to scale, enlarged for illustration).



TRM 244
TRM 245
COLBERT
STEAM
PLANT
HEATED
DISCHARGE
BASIN
12-6-72
11-2-72
CCM
3.0
CANE CREEK
N

Figure 13. Movement of a displaced smallmouth bass (Number 28) in relation to the heated discharge from Colbert Steam Plant as determined by temperature sensing ultrasonic transmitters (width of Cane Creek not to scale, enlarged for illustration).

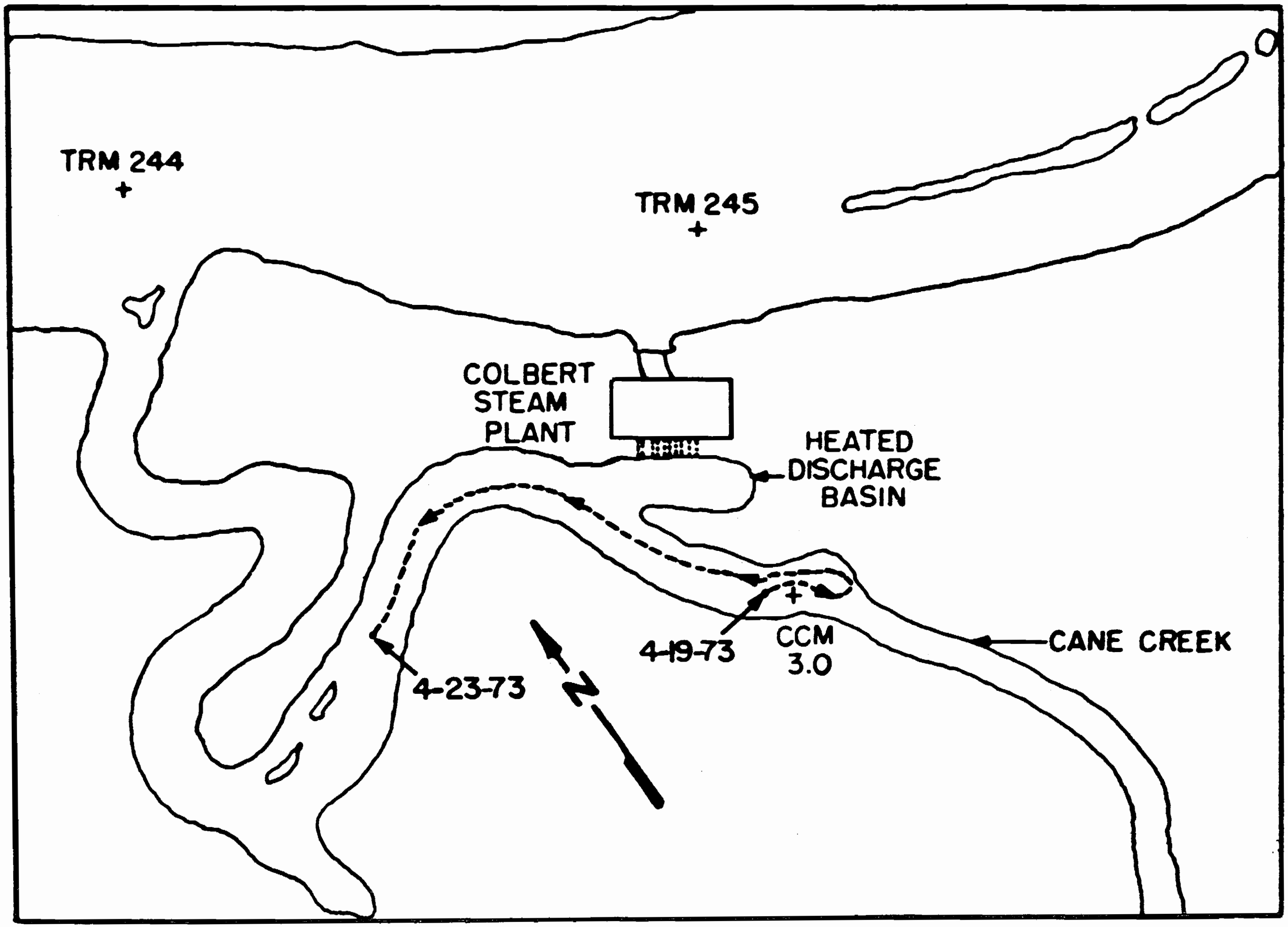
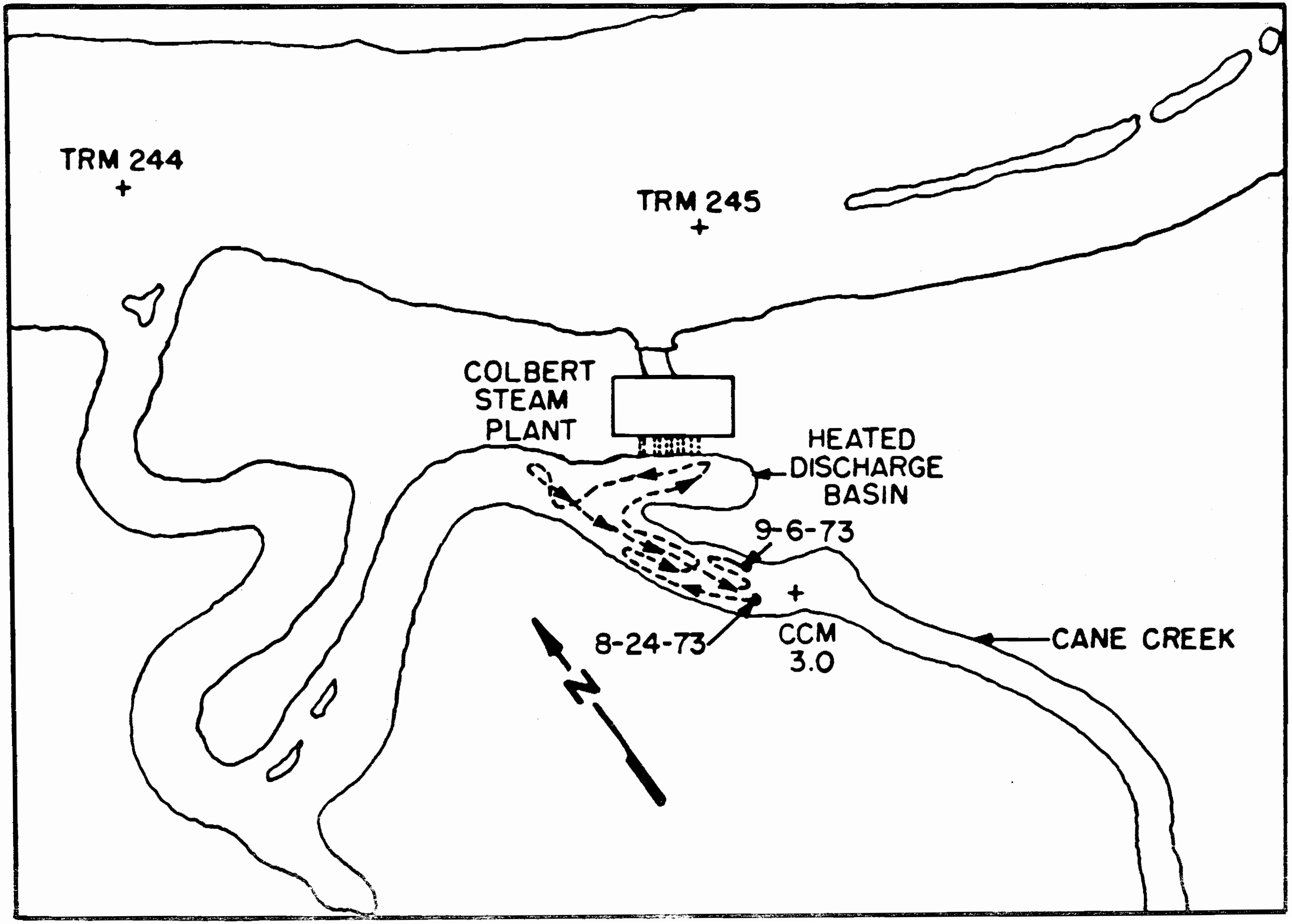

TRM 244
TRM 245
COLBERT
STEAM
PLANT
HEATED
DISCHARGE
BASIN
CANE CREEK
CCM
3.0
4-19-73
4-23-73
N

Figure 14. Movement of a displaced smallmouth bass (Number 26) in relation to the heated discharge from Colbert Steam Plant as determined by temperature sensing ultrasonic transmitters (width of Cane Creek not to scale, enlarged for illustration).


TRM 244
TRM 245
COLBERT
STEAM
PLANT
HEATED
DISCHARGE
BASIN
9-6-73
8-24-73
CCM
3.0
CANE CREEK
N

IV. LARVAL FISH ENTRAINMENT

Materials and Methods

Two modified plankton nets were used for the collection of larval fish: (1) a framed stationary net for filtering larvae from the condenser cooling water system within the plant and (2) a towed net for sampling near the intake forebay and in the heated discharge channel. The stationary net (0.79-mm mesh) was cone shaped, 0.5 m in diameter and 1.0 m long. The collecting bucket was a 15-cm section of 7.6-cm diameter PVC pipe that was threaded on the posterior end and fitted with a cap. The net was suspended in a cylindrical frame (flat-steel strips). The frame and net were suspended vertically in a 0.75 m^3 galvanized tank that was mounted on a wheeled platform. Attachment to the frame prevented the net from collapsing in the tank while the condenser water flowed through the net and out over the top of the tank. The tank served as a retention reservoir for the collected specimens, and it also provided a means of estimating total volume sampled (time of filling/tank volume : : total time sampled/total volume). The platform facilitated positioning the tank and net under a 10-cm valved drain from which the water was filtered. One of these drains, approximately 1 m from floor-level, was located on the condenser inlet and outlet pipes for each unit.

Gear for towed net collections, modified slightly after that described by Netsch, Houser, and Vogele (1971), included an enlarged cone-shaped plankton net (0.79-mm mesh) 1.0 m in diameter and 3.1 m long, planing type depressor and wire angle indicator for deep tows, stachion and winch assembly mounted in a 6.1 m aluminum boat, and a #313 TSK-flowmeter. The flowmeter was mounted on a retractable bracket that was lowered prior to each tow. The boat was powered by a 65-hp outboard and was equipped with a tachometer and timer to standardize speed and duration of tow.

Stationary net collections were initiated on an exploratory basis on 10 and 26 May, 1972. Samples were collected weekly from June through early August. Duplicate two-hour samples were collected each time. Total volume was approximately 150 m^3 for each sample, but it varied somewhat since the valve opening was not exactly the same for each sample. Water pressure was too great to open the 10-cm valve completely. All samples were collected from the condenser cooling water for Unit 1. Samples were preserved in five percent formalin; counting and identification were completed in the laboratory. Mean number of fish larvae per cubic meter was calculated and then extrapolated to number per 1000 m^3.

Stationary net collections were discontinued in 1973 in order to sample in the discharge channel and in the reservoir adjacent to the intake forebay. Preliminary towed net samples collected from these areas in 1972 indicated that the in-plant samples may not have been indicative of the species and numbers entrained. Unfortunately there was not enough manpower available in 1973 to make both types of collections.

In 1973 samples were collected weekly at three locations from 28 March to 29 June. At Station A (river channel adjacent to the intake forebay), duplicate five-minute tows were made at the surface and at 5 m (the approximate depth at which the intake forebay connects to the river channel) (Fig. 1). At Stations B and D in the heated discharge, only duplicate surface tows were made since submerged objects and limited distance prevented deeper tows. Duration of tows at Stations B and D was based on pre-set distances. Towing speed (3000 rpm) was the same for all stations. Preservation and counting of the samples were the same as that described for the stationary net samples. The following sources were consulted for larval fish identification: May and Gasaway (1967), Meyer (1970), Nelson (1968), Purkett (1961), Taber (1969), Shelton (1972), Wrenn and Grinstead (1971), and J. P. Buchanan and J. J. Hogue (Fish and Waterfowl Branch TVA, unpublished data).

To estimate the number of fish larvae entrained in relation to total riverflow, volume of riverflow and volume of the condensing water used were calculated for monthly intervals during the period samples were collected. Volume of riverflow past the plant site was computed by the Hydraulic Data Branch of TVA. Volume of condensing water was computed from the pumping capacity for each of the five units and the plant operating records for each unit during that interval.

Results

A total of 887 postlarval fish (yolk sac absorbed) was collected from the condenser cooling water system within the plant from 10 May to 9 August 1972. The number included at least six species and six families (Table 12). Entrained species were: channel catfish, Dorosoma spp. (gizzard and threadfin shad), freshwater drum, Lepomis sp., Morone spp. (white and yellow bass), and Notropis sp. Although there appeared to be only one species of Lepomis and Notropis represented, both species of shad as well as white and yellow bass were probably present. Shelton (1972) reported that it was practically impossible to separate postlarval (approximately 6-18 mm TL) gizzard and threadfin shad. He also noted that the spawning periods and habitat of these species overlap. A similar problem has been encountered in separating white and yellow bass, particularly for the prolarval and early postlarval stages (J. P. Buchanan, personal communication).

Towed meter net samples, collected from three stations in 1973, yielded 22,185 young fish. Prolarvae and postlarvae comprised 98 percent of the specimens. At least 19 species (10 families) were identified from Station A, 13 from Station B, and 15 from Station D (Table 13). All species collected in the heated discharge (Stations B and D) were represented in the river samples near the intake; however, the reverse was not true. Species that were collected only from the river channel included: paddlefish (Polyodon spathula), smallmouth bass and walleye. The occurrence of the larvae of these three species was considered rare since only two paddlefish (11 April and 4 May), one smallmouth bass (16 May), and one walleye (11 April) were captured. A single specimen of three other species was present only once in samples from the heated discharge: sauger, Station D, 18 April;

yellow bullhead (Ictalurus natalis), Station B, 6 June; and channel catfish, Station D, 29 June.

Species or taxa that occurred most frequently near the intake and from the discharge channel were: shad, carp, cyprinids, catostomids (tentatively identified as Ictiobus sp.), white and/or yellow bass, logperch, and freshwater drum. Other less common species were: mooneye (Hiodon tergisus), largemouth bass, redhorse (Moxostoma spp.), crappie (Pomoxis spp.), sunfish (Lepomis spp.), and darters (Etheostoma spp.).

Shad (6-18 mm TL) made up 92 percent of the total catch in 1972, and freshwater drum (5-12 mm TL) comprised approximately six percent. The remaining two percent included Lepomis sp., Morone spp., Notropis sp., and one channel catfish. Percent occurrence of the dominant species or taxa in the total catch in 1973 was as follows: shad 87 percent, freshwater drum 6 percent, catostomids 2 percent, and carp 1 percent. Cyprinids (excluding carp), logperch, and Morone spp. had a combined occurrence of 2.4 percent.

Comparison of mean relative densities of the seven dominant taxa at each sampling station is presented in Table 14. Mean densities of Dorosoma spp. and cyprinids were significantly greater in the discharge channel than those near the intake. Carp, logperch, and Morone spp. also were apparently more abundant in the heated effluent. Mean relative densities of freshwater drum were significantly higher at Station A and Station B than those at the lower end of the discharge channel.

Estimated relative numbers of larvae entrained during 1972 and 1973 in relation to total riverflow are presented in Table 15. Relative densities in June (only period with almost equal sampling effort) were similar for both years, and Dorosoma spp. were dominant both years. Ambient intake temperatures and the temperature rise across the condensers during June were also similar between years (Table 16). The percentage of cooling water used declined during the sampling period for 1973 due to above average riverflow. Mean daily riverflow during the larval fish sampling period for 1972 was 1.07 x 10^8 m^3, and that for the 1973 sampling period was 1.95 x 10^8 m^3.

Discussion

Although the primary concern for entrained organisms has been in regard to lethal or sublethal effects resulting from thermal shock, entrained organisms (in this case fish) also experience pressure changes, possible mechanical disruption, and possible chemical toxicity from chemicals used for slime and corrosion control (Coutant, 1971). Fish entrainment studies at operating power plants, quite limited in general, have dealt primarily with short-term thermal effects on anadromous species such as salmon and striped bass (Kerr, 1953). However, Marcy (1973) did a more detailed study on the biocidal, mechanical, and thermal effects on young fish entrained at the Connecticut Yankee Nuclear Plant (Connecticut River); he reported that mechanical damage accounted for 80 percent of the total mortality while 20 percent was attributed to heat shock and prolonged exposure at temperatures above 28 C in a 1.83-km discharge canal. There was no measurable mortality due to the injection of sodium hypochlorite into the system as a biocide.

The condenser cooling water at Colbet Steam Plant is not chlorinated, but mortality from mechanical and possibly thermal effects probably occurred. An attempt to measure mortality in this study was made; but apparently due to impingement in the collecting nets (both within the plant and the towed nets), a mortality differential after condenser passage could not be established. Also, in the towed net samples it was often impossible in a field inspection to even locate the larval fish due to heavy concentrations of zooplankton (primarily *Leptodora*) and detritus. Coutant (1970) has emphasized that long discharge canals compound the effect of temperature (a function of exposure time as well as temperature above the incipient lethal level) on entrained organisms, but it would appear that if the magnitude of mechanical damage at a given power plant was similar to that reported by Marcy (*Ibid*) the importance of thermal effects would be greatly reduced. Unfortunately it would appear almost impossible to eliminate mechanical effects, whereas elimination of a discharge canal would likely reduce thermal damage.

Thermal effects on larval fish entrained at the Colbert plant would not necessarily occur at 28 C since thermal resistance often varies between species and since the thermal regime (ambient and temperature rise) would likely differ, particularly in relation to peak larval fish concentrations. In relation to the dominant species and peak concentration, shad (Dorosoma spp.) would appear to be the most suseptible during May and June (Table 15). However, based on the thermal regime for this period (Table 16) and thermal-resistance data for gizzard shad (Dorosoma cepedianum, Hart, 1952), it would appear that even when considering an additional 180-minute exposure in the discharge canal (heated zone of Cane Creek) shad would not be exposed to lethal thermal effects. Hart's data indicated that gizzard shad (acclimated at 25 C) could withstand 34 C for approximately 300 minutes. Although similar data are not available for threadfin shad (Dorosoma petenense), a study of the maximum incubation temperature (34 C) for this species indicated that the upper temperature tolerance of larval threadfin shad would be very similar to that for gizzard shad (Hubbs and Bryan, 1974). Thermal resistance data for freshwater drum, the second most abundant species entrained, is not available.

Regardless of the mortality rate experienced by entrained larval fish, the overall ecological impact will depend on the proportion of the total volume of the receiving water to the volume diverted through the condensers (Coutant, 1971). Also, any estimate of the effect of mortality from entrainment should take into account the natural mortalities during specific life stages (Marcy, 1973). Marcy (Ibid) noted that the natural mortality rate for prolific species, such as shad and freshwater drum in this study, is high (survival rate approximately 0.001 percent). On the basis of these observations, even assuming a 100 percent mortality rate, overall effects of entrainment at the Colbert Steam Plant was considered insignificant since this plant uses only approximately three percent of the total riverflow. This study also indicated that few important game and food species, such as sauger, smallmouth bass, and walleye, were entrained at this plant.

Assessment of entrainment effects at this plant, particularly in reference to the long (4.5 km) discharge zone of Cane Creek, was further complicated by the fact that several species spawned in this section of Cane Creek. On the basis of the differences in larval fish concentrations between intake samples and samples from the heated discharge (Table 14), the following species spawned in the heated zone; gizzard and threadfin shad, carp, white and yellow bass, and unidentified cyprinids. Also, incidental collections in the discharge zone, with an insect sweep-net, produced several largemouth bass larvae. Although sample size and the inherent variability of the distribution of larval fish may have produced these differences (see Carlson and McCann, 1969), collection of ripe adults in the heated zone substantiated these observations. Based on the occurrence of the larvae of the above species in the control samples (Station A, Table 13), spawning in lower Cane Creek was not out of phase with that in the ambient temperatures of Pickwick Reservoir. Based on the occurrence of prolarvae or early postlarvae, approximate temperatures at which various species spawned intitally in the heated zone of Cane Creek and in upper Pickwick Reservoir are presented in Table 17.

Table 12. Species composition and relative density (No./1000 m^3) of larval fish collected from the condenser water system within the plant, Colbert Steam Plant, 1972.

Family by Species	May 10	May 26	June 6	June 13	June 22	July 5	July 13	July 20	July 28	August 9
Clupeidae										
Dorosoma spp.	210	150	290	1,120	1,970	50	30	40	-	30
Cyprinidae										
Cyprinid spp.	-	-	-	10	-	-	10	-	-	-
Ictaluridae										
Ictalurus punctatus	-	-	-	-	-	-	-	10	-	-
Percicthyidae										
Morone spp.	-	10	4	5	-	-	-	-	-	-
Centrarchidae										
Lepomis spp.	-	20	-	10	-	-	-	-	-	-
Sciaenidae										
Aplodinotus grunniens	20	30	50	30	10	30	60	-	30	-
Total	230	210	344	1,175	1,980	80	100	50	30	30

Table 13. Species composition and relative density (no./1000 m^3) of larval fish collected from the river channel near the condenser water intake and from two locations within the discharge channel, Colbert Steam Plant, Pickwick Reservoir, 1973.

Family and Species	March 28 Station*			April 4 Station			April 11 Station		
	A	B	D	A	B	D	A	B	D
Clupeidae									
<u>Dorosoma</u> spp.	-	-	-	-	-	-	-	-	-
Hiodontidae									
<u>Hiodon</u> <u>tergisus</u>	-	-	-	4.5	0.6	-	0.9	1.0	-
Cyprinidae									
<u>Cyprinus</u> <u>carpio</u>	-	-	-	-	-	-	-	-	-
Cyprinid spp.	0.8	-	2.0	-	-	-	-	-	-
Catostomidae									
Catostomid spp.	15.6	21.3	40.5	69.3	22.8	5.8	141.0	38.0	4.3
<u>Moxostoma</u> spp.	-	-	-	-	-	-	-	-	-
Percicthyidae									
<u>Morone</u> spp.	0.9	2.5	5.5	0.9	3.6	14.2	1.5	5.0	21.3
Centrarchidae									
<u>Lepomis</u> spp.	-	-	-	-	-	-	-	-	-
<u>Micropterus</u> <u>salmoides</u>	-	-	-	-	-	-	-	-	-
<u>Pomoxis</u> spp.	-	-	-	-	-	-	-	-	-
Percidae									
<u>Percina</u> <u>caprodes</u>	2.7	1.3	2.0	4.5	3.0	-	-	8.0	4.4
<u>Stizostedion</u> <u>canadense</u>	-	-	-	10.8	-	-	6.0	-	-
Sciaenidae									
<u>Aplodinotus</u> <u>grunniens</u>	-	-	-	-	-	-	-	-	-
Miscellaneous	-	-	-	-	-	-	0.6	-	-
Total	20.0	25.0	50.0	90.0	30.0	20.0	150.0	52.0	30.0

*Station A - Pickwick Reservoir, near the intake; Station B - Discharge basin; Station D - Lower discharge channel.

Table 13. Continued.

Family and Species	May 9 Station* A	B	D	May 16 Station A	B	D	May 24 Station A	B	D
Clupeidae									
Dorosoma spp.	126.0	117	303.4	1254	2929	2189	273	315	327.6
Hiodontidae									
Hiodon tergisus	0.7	-	-	1.3	-	-	-	-	-
Cyprinidae									
Cyprinus carpio	-	-	82.0	2.5	9.1	123.0	-	-	14.4
Cyprinid spp.	-	-	-	-	6.0	17.2	0.6	-	3.6
Catostomidae									
Catostomid spp.	1.4	-	12.3	-	-	24.6	-	-	-
Moxostoma spp.	-	-	-	-	-	-	-	-	-
Percicthyidae									
Morone spp.	1.4	-	-	5.1	15.1	98.4	1.2	-	-
Centrarchidae									
Lepomis spp.	-	-	-	-	-	-	-	-	-
Micropterus salmoides	-	-	1.4	-	-	-	-	-	7.2
Pomoxis spp.	0.7	3.0	4.1	1.3	6.0	-	0.6	7.0	-
Percidae									
Percina caprodes	7.0	30.0	8.2	12.8	30.2	15.5	3.0	7.0	3.6
Stizostedion canadense	-	-	-	-	-	-	-	-	-
Sciaenidae									
Aplodinotus grunniens	-	-	-	5.1	30.2	-	21.0	17.5	3.6
Miscellaneous	-	-	-	2.6	3.0	-	0.6	3.5	-
Total	137.0	150.0	410.0	1285	3029	2468	300.0	350.0	360.0

*Station A - Pickwick Reservoir, near the intake; Station B - Discharge basin; Station D - Lower discharge channel.

Table 13. Continued.

Family and Species	April 18 Station* A	B	D	April 25 Station A	B	D	May 4 Station A	B	D
Clupeidae									
Dorosoma spp.	-	-	79.2	17.2	-	8.0	187.2	174.0	712.5
Hiodontidae									
Hiodon tergisus	11.7	6.6	-	0.8	6.5	-	-	-	-
Cyprinidae									
Cyprinus carpio	2.7	3.3	3.6	-	10.0	67.2	-	-	7.5
Cyprinid spp.	-	-	-	-	-	-	-	2.0	7.5
Catostomidae									
Catostomid spp.	27.0	6.9	6.0	10.8	20.0	-	36.0	10.0	7.5
Moxostoma spp.	0.6	-	14.4	1.6	-	2.4	-	-	-
Percicthyidae									
Morone spp.	0.9	6.6	3.6	0.8	3.5	1.6	7.2	6.0	7.5
Centrarchidae									
Lepomis spp.	-	-	-	-	-	-	-	-	-
Micropterus salmoides	-	-	-	-	-	0.2	-	-	2.5
Pomoxis spp.	-	-	1.2	-	-	-	4.8	2.0	-
Percidae									
Percina caprodes	4.5	6.6	10.8	8.8	10.0	0.8	4.8	6.0	7.5
Stizostedion canadense	33.3	-	1.2	-	-	-	-	-	-
Sciaenidae									
Aplodinotus grunniens	-	-	-	-	-	-	0.5	-	-
Miscellaneous	-	-	-	-	-	-	0.5	-	-
Total	81.0	30.0	120.0	40.0	50.0	80.0	241.0	200.0	753.0

*Station A - Pickwick Reservoir, near the intake; Station B - Discharge basin; Station D - Lower discharge channel.

Table 13. Continued.

Family and Species	May 30 Station* A	B	D	June 6 Station A	B	D	June 13 Station A	B	D
Clupeidae									
Dorosoma spp.	3014	3628	1463	105	383.4	124.2	168	1629	492.8
Hiodontidae									
Hiodon tergisus	-	-	-	-	-	-	-	-	-
Cyprinidae									
Cyprinus carpio	0.6	3.9	2.8	37.5	21.6	7.2	9.6	-	11.2
Cyprinid spp.	2.6	7.7	4.3	10.0	48.6	3.6	3.8	38.8	11.2
Catostomidae									
Catostomid spp.	1.3	-	15.4	2.5	-	-	-	-	5.6
Moxostoma spp.	-	-	-	-	-	-	-	-	-
Percicthyidae									
Morone spp.	13.2	11.6	15.4	2.5	-	19.8	-	3.9	-
Centrarchidae									
Lepomis spp.	-	-	-	0.8	-	5.4	1.4	3.9	-
Micropterus salmoides	0.6	-	-	-	-	1.8	-	-	1.7
Pomoxis spp.	3.3	3.9	1.5	-	-	-	-	3.9	-
Percidae									
Percina caprodes	1.3	3.9	7.7	1.6	2.7	3.6	3.8	3.9	-
Stizostedion canadense	-	-	-	-	-	-	-	-	-
Sciaenidae									
Aplodinotus grunniens	264.0	193.0	30.8	97.5	81.0	12.6	297.6	252.2	39.2
Miscellaneous	-	3.9	-	-	2.7	1.8	-	-	-
Total	3300	3856	1540	257.0	540.0	180.0	484.0	1936	560.0

*Station A - Pickwick Reservoir, near the intake; Station B - Discharge basin; Station D - Lower discharge channel.

Table 13. Continued.

Family and Species	June 22 Station* A	B	D	June 29 Station A	B	D
Clupeidae						
Dorosoma spp.	1024	2530	3353	31.2	513	423.5
Hiodontidae						
Hiodon tergisus	-	-	-	-	-	-
Cyprinidae						
Cyprinus carpio	1.3	-	3.5	0.6	5.7	1.7
Cyprinid spp.	12.8	8.3	35.3	0.6	11.4	7.2
Catostomidae						
Catostomid spp.	-	-	24.7	-	-	1.7
Moxostoma spp.	-	-	-	-	-	-
Percicthyidae						
Morone spp.	-	-	-	-	-	-
Centrarchidae						
Lepomis spp.	-	2.8	7.1	-	-	55.0
Micropterus salmoides	-	-	-	-	-	-
Pomoxis spp.	-	-	-	-	-	-
Percidae						
Percina caprodes	-	-	3.5	-	-	-
Stizostedion canadense	-	-	-	-	-	-
Sciaenidae						
Aplodinotus grunniens	230.4	192.5	70.6	27.0	39.9	49.5
Miscellaneous	27.5	-	7.1	0.6	-	11.0
Total	1296	2733	3505	60.0	570.0	550.0

*Station A - Pickwick Reservoir, near the intake; Station B - Discharge basin; Station D - Lower discharge channel.

Table 14. Comparison (t-test) of mean densities of the dominant fish larvae collected near the intake and from two locations in the heated discharge of Colbert Steam Plant, March 28 - June 30, 1973.

Species	Sampling Station*	Sample Size (n-1)	t-value (.05)
Dorosoma spp.	A vs. B	9	-2.90**
	A vs. D	10	-1.06
	B vs. D	9	1.03
Cyprinus carpio	A vs. B	11	0.05
	A vs. D	11	-1.80
	B vs. D	11	-1.98
Cyprinid spp.	A vs. B	9	-1.96
	A vs. D	9	-2.33**
	B vs. D	9	0.48
Catostomid spp.	A vs. B	13	1.68
	A vs. D	13	0.96
	B vs. D	13	0.46
Morone spp.	A vs. B	12	-1.73
	A vs. D	12	-1.66
	B vs. D	12	-1.55
Percina caprodes	A vs. B	13	-2.14
	A vs. D	13	-0.83
	B vs. D	13	1.61
Aplodinotus grunniens	A vs. B	8	1.50
	A vs. D	8	2.34**
	B vs. D	8	2.58**

*Station A - Pickwick Reservoir, near intake; Station B - discharge basin; Station D - lower discharge channel.
**Significant

Table 15. Estimates of the numbers of larval fish entrained in relation to volume of river flow and volume of condenser cooling water, Colbert Steam Plant, 1972-73.

	Larvae/ 1000 m^3	Dominant Species (%)	Volume of Condensing Water (m^3)	Percent of River Flow
1972*				
May 10-26	200	*Dorosoma* spp. - 83 *Aplodinotus grunniens* - 10	5.9×10^7	2.0
June 1-30	1,100	*Dorosoma* spp. - 97	9.1×10^7	3.3
July 1-Aug. 9	61	*Dorosoma* spp. - 53 *Aplodinotus grunniens* - 43	14.5×10^7	3.5
1973				
March 28-April 30	40	Catostomids - 57 *Percina caprodes* - 16 *Morone* spp. - 11	11.4×10^7	1.7
May 1-31	1,390	*Dorosoma* spp. - 95 *Aplodinotus grunniens* - 3	12.4×10^7	2.0
June 1-30	1,530	*Dorosoma* spp. - 88 *Aplodinotus grunniens* - 10	9.8×10^7	1.6

*Based on samples collected from cooling system within the plant in 1972 and on samples from the discharge basin in 1973.

Table 16. Temperature of the condenser cooling water during larval fish sampling, Colbert Power Plant, 1972-73.

Date	Intake[a] °C	Discharge[b] °C	ΔT
1972			
May 10	20.0	26.1	6.1
May 26	22.2	29.5	7.3
June 6	24.4	31.1	6.7
June 13	25.3	31.4	6.1
June 22	25.5	30.3	4.8
July 5	26.1	31.4	5.3
July 13	26.7	33.1	6.4
July 20	27.8	34.2	6.4
July 28	28.8	34.2	5.4
August 9	28.4	34.2	5.8
1973			
March 28	12.2	16.7	4.5
April 4	13.2	18.6	5.4
April 11	12.2	19.5	7.3
April 18	14.0	20.0	6.0
April 25	16.2	21.4	5.2
May 4	18.0	22.8	4.8
May 9	18.4	22.5	4.1
May 16	19.6	24.6	5.0
May 24	20.5	26.0	5.5
May 30	21.4	27.0	5.6
June 6	23.0	27.0	4.0
June 13	24.2	29.0	4.8
June 22	25.4	32.0	6.6
June 29	26.8	32.2	5.4

[a]Instantaneous - Recorded during larval sampling

[b]Daily mean - From temperature recorder

Table 17. Approximate temperatures at which selected species spawned initially in the heated zone of Cane Creek or in upper Pickwick Reservoir in 1973, as determined by the occurrence of their larvae.

Species	Cane Creek		Pickwick Reservoir	
	°C	Date	°C	Date
Dorosoma spp.	20.0	4/18	16.2	4/25
Cyprinus carpio	19.5	4/25	13.9	4/18
Morone spp.	19.4	4/4	12.2	3/28
Micropterus salmoides	19.5	4/25	-	-
Micropterus dolomieui	-	-	18.4	5/9
Stizostedion canadense	-	-	13.0	4/4
Aplodinotus grunniens	-	-	18.0	5/4

V. CONCLUSIONS

1. Although there was a reduction in the number of species in the heated zone during the summer months (July - September), the effect of the heated discharge in the lower 4.5 km of Cane Creek was considered minimal since several species frequented the heated zone throughout the year while others reappeared more or less on a seasonal basis.
2. No direct mortalities resulting from temperature differences (heat stress or cold shock) were observed.
3. The dominant fish population of lower Cane Creek was primarily an extension of the Pickwick Reservoir population rather than an isolated stream population. Apparently a combination of factors attract fish from the reservoir to this area: increased water flow, food supply, spawning habitat, and optimum seasonal temperatures.
4. The presence or absence of only three species (sauger, skipjack herring, and walleye) appeared to be temperature dependent. Temperatures above 30 C were apparently limiting for these species; however, sauger and walleye underwent a seasonal migration into and out of Cane Creek that may not have been totally temperature dependent.
5. Smallmouth bass and spotted bass demonstrated a temperature tolerance very similar to that for largemouth bass (33 - 35 C). Also, as determined by tagging specimens with temperature

sensitive ultrasonic transmitters, the normal maximum effluent temperatures (33 - 35 C) from this plant would not create a thermal barrier to the movement of largemouth and smallmouth bass in lower Cane Creek.

6. Based on the small volume of condenser cooling water used in proportion to total river flow (approximately three percent), the numbers of larval fish entrained were considered insignificant even if it was assumed that total mortality occurred. Also, any entrainment effects would be somewhat nullified since apparently four to six species spawned in the heated zone of Cane Creek in phase with the spawning of these species in Pickwick Reservoir.

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increased from 19.2 to 27.4 C.

Dorosoma spp. and *Aplodinotus grunniens* comprised approximately 90 percent and six percent, respectively, of the larval fish entrained by this plant which normally uses about three percent of the total riverflow for condenser cooling. Peak density ($1.5/m^3$) occurred during June. Assessment of entrainment effects were further complicated since four to six species apparently spawned in the discharge channel in phase with the spawning of these species in the Tennessee River.