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FISH RESPONSES TO TEMPERATURE TO ASSESS EFFECTS OF THERMAL DISCHARGE ON BIOLOGICAL INTEGRITY[1]

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ABSTRACT: The applicability of the U.S. Environmental Protection Agency's (USEPA) water temperature criteria in evaluating the impact of a thermal discharge from the P. H. Glatfelter Paper Company, Spring Grove, Pennsylvania, is analyzed. A review of the literature relative to 11 temperature criteria was conducted for six fish species designated by the USEPA as "representative important species" (RIS) of the West Branch Codorus Creek, Susquehanna River drainage. The species were: *Notemigonus crysoleucas* (golden shiner), *Notropis analostanus* (satinfin shiner), *Rhinichthys atratulus* (blacknose dace), *Catostomus commersoni* (white sucker), *Lepomis gibbosus* (pumpkinseed), and *Micropterous salmoides* (largemouth bass). It was found that by applying only USEPA suggested criteria that a complete evaluation was not satisfactory. Temperature behavior data, specifically preference and avoidance information, coupled with field sampling was needed to properly assess the effects of the thermal effluent. The final analysis indicated that the thermal discharge of the paper company should have minimal effect on the fish community of Codorus Creek.
(KEY TERMS: temperature criteria; thermal behavior; thermal discharges; biological integrity.)

INTRODUCTION

The Federal Water Pollution Control Act (Public Law 92-500) states that the objective of our national water policy is to "restore and maintain the chemical and biological integrity of the Nation's waters." The law also authorizes the U.S. Environmental Protection Agency (USEPA) to establish guidelines limiting industrial discharges, and sets forth a schedule for compliance. Section 316(a) of PL 92-500 allows a variance in regard to thermal effluents if an owner or operator can sufficiently demonstrate that the proposed thermal discharge regulations are more stringent than necessary to assure the protection and propagation of a balanced indigenous population of shellfish, fish, and wildlife in or on the respective waters into which the discharge is made. However, it is the responsibility of the discharger to prove that the modification will indeed protect the biological community.

The Federal Register (1974) indicates three types of demonstrations by which the discharger may submit evidence for a less stringent effluent requirement (i.e., a variance). The three demonstration types are: (I) the use of on-site data to demonstrate absence of prior appreciable harm to the biological community, (II) a demonstration using the USEPA's water temperature criteria that conditions at the site would protect representative important species (RIS), and (III) the use of a combination of biological and engineering data to demonstrate no adverse effects. Generally, a Type II demonstration is recommended (USEPA, 1977), unless extensive on-site data are available for the aquatic communities.

A Type II demonstration in regard to ichthyofauna is facilitated by utilizing the recently finalized protocol and procedures for establishing water temperature criteria (Brungs and Jones, 1977). Generally, these criteria, which were designed specifically for fresh water fishes, are comprised from two principal recommendations. First, the maximum weekly average temperatures (MWAT) should not surpass the following criteria established for RIS: (1) the optimum temperature for growth plus one-third the range between optimum and ultimate upper incipient lethal temperature; (2) the cold shock temperature, that is, a temperature achieved by a rapid drop to ambient temperatures causing mortality; and (3) a temperature that would prevent successful reproduction and development. Secondly, at no time should the MWAT exceed the applicable maximum temperature exposures for short term summer survival and spawning for important species.

The maximum weekly average temperature, which is an integral component of a Type II demonstration, is calculated by at least two methods (Dickson, *et al*, 1976). One approach averages the means of weekly readings (recorded daily every two hours) for at least a one-year period. Thus, there would be 52 temperature values yearly, with each recording representing the mean of four weekly maximum average temperatures for a specific week in the respective time frame. The second method is to select the highest weekly average temperature from the monthly possibilities.

The USEPA (1977) designates RIS by reviewing the existing literature for the respective site and applying a six-fold definition to potential candidates (see USEPA document for assumptions that aid the RIS decision process). Generally,

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qualification specifically includes those species which are: 1) commercially or recreationally available (i.e., within the top ten species landed by dollar value), 2) threatened and endangered, 3) critical to the function of the ecological system, 4) potentially capable of becoming localized nuisance species, 5) necessary in the food chain for the well being of the species determined in 1-4, or 6) representative of the thermal requirements of important species but which themselves may not be important. The word "representative" includes those species which are "representative in the terms of their biological requirements of a balanced, indigenous community of shellfish, fish, and wildlife in the body of water into which the discharge is made" (USEPA, 1977). It should be noted that, although the word indigenous is used in the law, nonnative species can be chosen as RIS (USEPA, 1977). Dickson, *et al.* (1976), indicates that "ideally, water temperature criteria should be applied to important representative organisms for all trophic levels in the aquatic community." However, as they further discuss, this approach is not realistic since data concerning thermal responses of aquatic animals other than fish are lacking. Thus, it is generally acceptable to apply the criteria to only fishes in a Type II demonstration. However, as discussed by Hocutt and Stauffer (e.g., Hocutt, *et al.*, 1978; Stauffer, *et al.*, 1978; Stauffer and Hocutt, 1980; Hendricks, *et al.*, 1980), fish are suitable for biomonitoring since (1) they pass through or occupy a variety of trophic levels above the primary producer level during their development; (2) their presence implies the presence of other phyletic groups, since they occupy the top of the food chain in most aquatic ecosystems; and (3) since they usually represent the top consumer level in an aquatic system, they integrate the responses of the food chain to environmental stress.

The purpose of this paper is to (1) review the literature relative to 11 designated temperature criteria for six RIS, (2) assess the applicability of USEPA water quality criteria to a nonutility thermal discharge, and (3) evaluate the importance of behavioral data in thermal impact assessments.

APPLICABILITY TO A THERMAL DISCHARGE

The P. H. Glatfelter Paper Company (PHGC), Spring Grove, Pennsylvania, in application of a 316(a) variance for their thermal effluent, contracted the Appalachian Environmental Laboratory (AEL), Frostburg, Maryland, to secure data in support of a Type II demonstration. Data compiled and literature reviewed for fish species in this paper are only a partial fulfillment of this demonstration.

The PHGC is located in the West Branch Codorus Creek (Susquehanna River drainage), York County, Pennsylvania (Figure 1). The West Branch is a major tributary (0.85 m^3/s) of the Codorus Creek drainage. Codorus Creek flows in a northeasterly direction through York, Pennsylvania, the largest city within the watershed and situated approximately 16 km upstream of the confluence with the Susquehanna River. The drainage basin encompasses approximately 762 km^2 of the Piedmont, which varies in elevation from 305 m in the headwaters to 70 m at the mouth.

PHGC located 15 temperature monitoring stations on Codorus Creek in order to establish MWAT (Table 1, Figure 1). Station 1, located above Lake Marburg, and Station 14 were designated as reference stations. Station 1 was chosen because it was unaffected by the cold hypolimnial released water of Lake Marburg, built by PHGC for flow augmentation. Station 14, found on the South Branch Codorus, was chosen as the second site, since it was not affected by PHGC discharges. All other stations were downstream of PHGC discharges, except for Station 3 on Oil Creek where a hot water effluent from a sewage treatment plant was known to significantly affect the ambient stream temperatures (Cincotta, *et al.*, 1976). MWAT's were established with the use of maximum/minimum thermometers for a one-year period, employing the temperature extremes approach, which provides a greater margin of safety than the means method (Dickson, *et al.*, 1976).

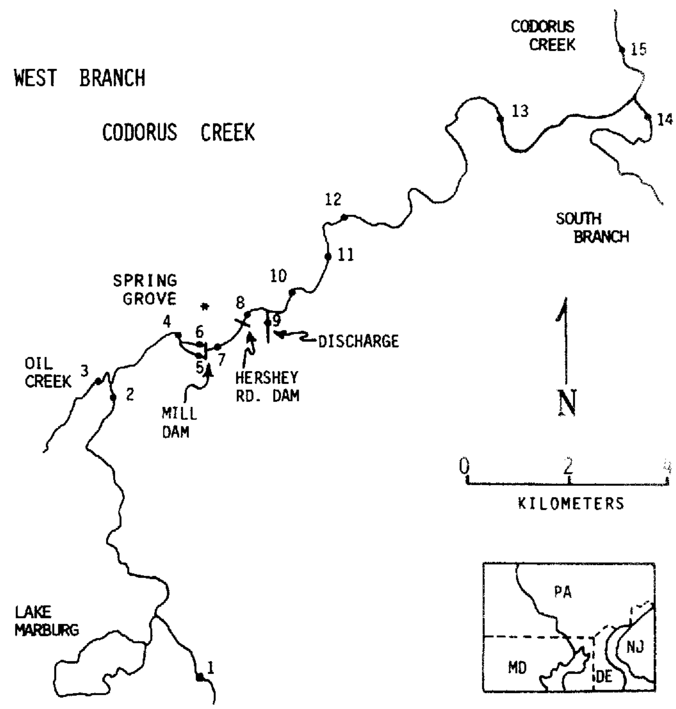

Figure 1. Map of the West Branch Codorus Creek, Susquehanna River Drainage, in the Vicinity of P. H. Glatfelter Co., Spring Grove, Pennsylvania, Indicating Temperature Monitoring Stations (1-15). Station localities are described in Table 1.

An extensive literature review for 11 temperature criteria was conducted on six fish species designated by USEPA as RIS for the West Branch Codorus Creek (Table 2). The species were *Notemigonus crysoleucas* (golden shiner), *Notropis analostanus* (satinfin shiner), *Rhinichthys atratulus* (blacknose dace), *Catostomus commersoni* (white sucker), *Lepomis gibbosus* (pumpkinseed), and *Micropterous salmoides* (largemouth bass). All criteria, except cold shock, were summarized for RIS of fishes according to the format suggested by Dickson, *et al.* (1976), in Table 2; cold shock data are found in Table 3 and Figure 2. Criteria were also superimposed for each species over the MWAT at control Stations 1 and 14, and temperature-affected Stations 10 and 13 (Figures 3-14).

TABLE 1. Temperature Monitoring Stations Location on the Codorus Creek in the Vicinity of the P. H. Glatfelter Company (PHGC), Spring Grove, Pennsylvania (see Figure 1 for graphic identification).

1.	West Branch Codorus at Sinsheim, Pennsylvania
2.	West Branch Codorus at Menges Mills, Pennsylvania, immediately below confluence with Oil Creek
3.	Oil Creek, approximately 0.5 km above confluence with West Branch Codorus Creek
4.	West Branch Codorus at head of Mill Pond, Spring Grove, Pennsylvania
5.	West Branch Codorus at Mill Pond (PHGC Filter Plant), Spring Grove, Pennsylvania
6.	West Branch Codorus at Mill Pond (PHGC Power House), Spring Grove, Pennsylvania
7.	West Branch Codorus at State Rt. 116 bridge
8.	West Branch Codorus at Hershey Road bridge
9.	West Branch Codorus at PHGC Sewage Treatment Plant (secondary effluent)
10.	West Branch Codorus 305 m below PHGC Sewage Treatment Plant
11.	West Branch Codorus at Martins farm, approximately 1 stream km below PHGC Sewage Treatment Plant
12.	West Branch Codorus at Sunnyside Road, Bair, Pennsylvania
13.	West Branch Codorus at junction of York New Salem Road
14.	South Branch Codorus at York Water Company
15.	Main stem Codorus Creek at York County bridge 86

APPLICATION RESULTS AND DISCUSSION BY SPECIES

The MWAT for the West Branch Codorus Creek reported at PHGC monitoring stations (Table 1, Figure 1) are shown in Table 4. Generally, water temperatures were comparable from Stations 1-8, with noticeable increases at Stations 10-12 below the PHGC sewage treatment plant discharge canal (Station 9). The following assessment shall use Station 9 only as a reference point, since screens prevent, for the most part, movement of fishes into the discharge canal. Station 10, immediately below the discharge, revealed differences ranging from 4-10 C (mean 7.2 C) and 3-10 C (mean 6.1 C) when compared to control Stations 1 and 14, respectively. Lastly, it should be noted that stream temperatures begin to return to ambient temperatures at Station 13 (i.e., compare with Stations 1-8).

The fact that the elevated temperatures of the Glatfelter discharge result from an industrial process rather than a cooling process is particularly important to note, since the temperature of the resultant effluent remains relatively constant for at least seven months of the year.

Golden Shiner *Notemigonus crysoleucas*

Critical temperature criteria for the golden shiner in relation to the MWAT found in Codorus Creek are illustrated on Figures 3 and 4. Data for the final field temperature preference (T_3) are not available. The maximum observed *in situ* temperature for this species [T_1, 35.6 C; from Hocutt and Denoncourt (ms)], the estimated UUILT (T_2, 35.0 C), and the short term maximum temperature for survival of juveniles and adults during the summer (T_{11}, 32.5) were not exceeded by the maximum stream temperatures; therefore, golden shiner juveniles and adults, which have a high temperature tolerance (Hart, 1952), should survive anywhere in the vicinity of the PHGC heated effluent. Furthermore, it should be noted that the UUILT might be underestimated based on data generated by Alpaugh (1972). He demonstrated a 40 C lethal temperature for this species, utilizing a methodology which may be capable of predicting UUILT (Fry, 1971). During the summer, the maximum stream temperature surpasses the allowable upper limit for growth (T_{10}, 27.5 C), which is defined as one-third the range between optimum temperature for growth and the UUILT. Thus, during warm weather water temperatures are conducive to good growth of this species in most areas of the West Branch, except in a *ca.* 2 km region immediately below the discharge canal (i.e., between Stations 9-13).

The laboratory preference temperature, which was the only behavior data surpassed by the MWAT, was exceeded at both control and thermally influenced areas of the stream. Preference data (T_4, 23.8 C) suggest that the golden shiner will select waters above the thermal discharge (Station 9) and below Station 12 during summer. Avoidance data also support this prediction, since this species will avoid 30 C when acclimated to 24 C (Cincotta and Stauffer, in review). Moreover, the golden shiner is capable of avoiding temperatures (T_5, 39.0 C) of at least 9 C above the highest MWAT (30 C). Preference data also suggest that the golden shiner will be attracted to the artificially heated winter waters, however cold shock information (T_6, Table 3) imply negligible effects to the population if a thermal shutdown were to occur.

The spawning temperature (T_7, 15.6-21.0 C), the maximum weekly average temperature for spawning (T_8, 18.3 C), and the short term maximum temperature for embryo survival (T_9, 21.0 C), were exceeded by the MWAT at both control and temperature affected areas (Figure 3 and 4). Thus, these data suggest that the golden shiner has a limited amount of suitable water temperatures available anywhere during spawning season (May-June). However, observations by the authors and distributional information (Denoncourt and Stambaugh, 1974; Denoncourt, pers. comm., York College of Pennsylvania, York) appears to contradict expected spawning capabilities and embryo survival. This species was observed as one of the most abundant fishes in the winter months of 1976-78, but became rare during the spring and summer. Most specimens observed in winter were from a spring fed pool between Hershey Road Dam and Mill Dam, located above the discharge canal (Figure 1). Denoncourt and Stambaugh (1974) usually found the golden shiner to be rare in Codorus Creek, with the largest population located near Station 13 below the discharge canal. In summary, these data suggest that the golden shiner is successfully spawning, hatching, and developing in the West Branch Codorus Creek above and below the PHGC heated effluent despite the limited spawning conditions as extrapolated from the literature. Hence, it appears that reported data for this species is not applicable to the Codorus Creek population.

TABLE 2. Critical Temperature Criteria (*) for Representative Important Fish Species of the West Branch Codorus Creek, Susquehanna River Drainage, Pennsylvania. Cold shock data are summarized in Table 3 (**).

Species	Temperature Criteria (C)*										
	T_1	T_2	T_3	T_4[1]	T_5[1]	T_6	T_7	T_8	T_9	T_{10}[2]	T_{11}[2]
Golden Shiner	35.6[3j]	35.0[h]	– – –	23.8	39.0	**	15.6-21.0[f,t]	18.3[5]	21.0[6]	27.5[7]	32.4
Satinfin Shiner	36.7[s]	34.3[4s]	– – –	27.2	39.0	**	18.0-27.0[q]	22.5[5]	25.0[q]	29.6[7]	– –
Blacknose Dace	33.9[p]	29.5[h]	– – –	24.6	34.0	**	15.6-21.1[n,o]	18.4[5]	21.1[6]	26.2[7]	29.6
White Sucker	30.6[p]	29.3[g]	14.1-21.1[d,k]	27.1	30.0	**	6.1-23.2[r]	10.0[c]	20.0[c]	28.0	28.4
Pumpkinseed	38.0[a]	38.9[4s]	27.0-32.0[m]	31.1	39.0	**	20.0-36.1[b,e]	28.5[5]	36.1[6]	33.0[7]	– –
Largemouth Bass	38.0[a]	38.0[4i]	26.5-30.9[m]	32.2	39.0	**	15.6-21.1[b,l]	21.0[c]	27.0[c]	32.0[c]	34.0[c]

*Temperature criteria are:

T_1 = highest temperature at which species was observed *in situ*.
T_2 = ultimate upper incipient lethal temperature.
T_3 = final field temperature preference.
T_4 = final laboratory temperature preference.
T_5 = laboratory upper avoidance temperature at highest acclimation temperature.
T_6 = abrupt cold shock temperature.
T_7 = spawning temperature.
T_8 = maximum weekly average temperature for spawning.
T_9 = short term maximum temperature for embryo survival.
T_{10} = maximum weekly average temperature for growth of juveniles and adults.
T_{11} = short term maximum temperature for survival of juveniles and adults during summer.

NOTES:

[1] On-site data (Cincotta and Stauffer, in review).
[2] Calculated from formulas presented in Brungs and Jones (1977).
[3] 35.6 = bottom water temperature, while surface water temperature = 40 C.
[4] Highest reported upper lethal temperature.
[5] Optimum or mean range of spawning temperatures reported, as suggested by Brungs and Jones (1977).
[6] Upper temperature for successful incubation and hatching reported or upper temperature for spawning, as suggested by Brungs and Jones (1977).
[7] Final laboratory preference temperature and/or highest reported upper lethal temperature substituted in formula when optimum growth temperature and/or ultimate upper incipient lethal temperature were not available.

REFERENCES:

[a]Bailey, 1955; [b]Breder, 1936; [c]Brungs and Jones, 1977; [d]Cooper and Fuller, 1945; [e]Denoncourt and Hocutt (unpublished data); [f]Forney, 1957; [g]Hart, 1947; [h]Hart, 1952; [i]Hathaway, 1927; [j]Hocutt and Denoncourt (unpublished data); [k]Horak and Tanner, 1964; [l]Kramer and Smith, 1960; [m]Neill and Magnuson, 1974; [n]Raney, 1940; [o]Schwartz, 1958; [p]Stauffer, *et al.*, 1976; [q]Stone, 1940; [r]Trautman, 1957; [s]Trembley, 1961; [t]Wojtalik (unpublished data, cited in Natl. Acad. Sci, 1973).

Satinfin Shiner *Notropis analostanus*

Temperature requirements for the satinfin shiner in relation to the MWAT found in Codorus Creek are graphically depicted by Figures 5 and 6. Data on short term maximum temperature for survival of juveniles and adults during summer (T_{11}), and the final field preference temperature (T_3) were not available. The maximum temperature at which this species was observed *in situ* (T_1, 36.7 C) and the highest known lethal temperature (T_2, 34.3 C) are not exceeded by the MWAT. Thus, survival of juvenile and adult satinfin shiners in the vicinity of PHGC thermal effluent should be easily maintained. The MWAT slightly surpasses (i.e., 0.4 C) the highest acceptable temperature for growth of juveniles and adults (T_{10}, 29.6 C) between Stations 9-13 during the month of June. Therefore, the growth potential of this species should be good in most stream areas.

Laboratory preference data (T_4, 27.2 C) shows that this species prefers waters warmer than existing ambient stream conditions; thus, this species, which is capable of avoiding temperatures (T_5, 39.0 C) well above the highest MWAT of 30 C, will probably be found in the thermally influenced regions of the West Branch Codorus. The attraction to heated winter waters can also be predicted from laboratory preference data, however, its cold shock tolerance as indicated in the literature (T_6, Table 3) and by the USEPA nomograph (Figure 2) suggests no shock related mortalities.

The satinfin shiner spawns from May to mid-August when water temperatures approach 18 C (Stone, 1940). Based on the maximum weekly average temperature regime (Figures 5 and 6) all three criteria related to spawning are surpassed by the MWAT. The known spawning temperature range (T_7, 18.0-17.0 C) and the short term maximum temperature of

TABLE 3. Cold Shock Criteria (T_6) for Representative Important Fish Species of the West Branch Codorus Creek, Susquehanna River Drainage, Pennsylvania. Cold Shock Temperature (C) is defined as the temperature at which 50 percent or greater mortality will occur in a specific time period (usually a 5,760, 10,000, or 20,000 min. resistance period).

	Acclimation Temperature (C)													
Species	9	15	15.5	18.5	20	21	24.5	24	25	27	28	30	35	36
Golden Shiner	1.5[e]				4.0[e]	3.4[c]			7.0[e] 7.0[e]			11.2[e] 12.0[a]	12.0[a]	
Satinfin Shiner								6.0[a]				12.0[a]		
Blacknose Dace					2.2[e]			6.0[a]	5.0[d]		6.0[a]			
White Sucker					2.5[d]				6.0[d]					
Pumpkinseed	1.5[g*]	2.7[b]	1.0[g*]		4.5[b]	11.5[f*]	16.0[f*]		9.6[b] 18.0[f*]		12.3[b] 12.0[a]			18.0[a]
Largemouth Bass				3.5[g*] 4.5[g]	5.2[e] 5.5[e]	13.0[f*]	16.0[f*]	7.0[e]	19.5[f*]		10.5[e] 11.8[e] 12.0[a]			12.0[a]

*Fifth percent or greater survival occurred (i.e., information provided for reference).

REFERENCES:

[a]Cincotta, *et. al.*, in review, on site data; [b]Becker, *et al.*, 1977; [c]Brett, 1944; [d]Hart, 1947;[e]Hart, 1952; [f]Peterson and Schutsky, 1976, data selectivity taken from among several acclimation test temperatures; [g]Peterson and Schutsky, 1977.

embryo survival (T_9, 25.0 C), were usually exceeded by the maximum stream temperatures between Stations 9-13 in the warmer months only. The maximum average temperature for spawning (T_8, 22.5 C) was surpassed by the MWAT in both ambient and heated waters. Therefore, data suggest that this species will be found spawning and developing in waters below Station 13 and above the discharge canal. Ichthyofaunal distribution and relative abundance data in Codorus Creek collected by Denocourt and Stambaugh (1974) and Cincotta (personal experience) indicate that the satinfin shiner population is concentrated above Hershey Road dam, as expected. In fact, this species is the most abundant forage fish in the immediate area of Spring Grove, including the thermally affected region below the PHGC discharge. Thus, spawning criteria may be underestimated for the Codorus Creek satinfin shiner population or sufficient spawning areas for this species are located in the vicinity.

Blacknose Dace *Rhinichthys atratulus*

Temperature criteria for the blacknose dace in relation to the MWAT found in Codorus Creek are shown on Figures 7 and 8. Data for final field temperature preference (T_3) are not available. Although this species has a fairly low UUILT (T_2, 29.5 C), it has been reported from 33.9 C (T_1) waters. Terpin, *et al.* (1976), suggested that the UUILT of blacknose dace was underestimated; thus, inference can be made that juveniles and adults should be able to survive in the West Branch Codorus, except for the areas between Stations 9 and 12 during June, where only short term survival (T_{11}, 29.6 C) is probable (i.e., the highest MWAT was only 0.4 C higher than T_{11}). The maximum temperature for growth (T_{10}, 26.2 C) is exceeded by the MWAT in the West Branch during the summer within the *ca.* 2 km heated stream below Station 9. In light of the fact that this species has a pronounced preference to small streams with steep gradients (Starrett, 1950; Trautman, 1957), it is hypothesized that the blacknose dace is spawning and maintaining itself in small tributary streams within the study area (Denoncourt, pers. comm.). Observations by the authors and R. F. Denoncourt during the study period indicate that this species is still present in good numbers and in seemingly good condition inside the heated area at temperatures that approach its UUILT. Furthermore, other work suggests that this species is common throughout the drainage (Cincotta, *et al.*, 1976; Denoncourt and Stambaugh, 1974). Therefore, the blacknose dace has suitable waters for growth within most of the West Branch Codorus, but growth may be hampered in June-August immediately below the PHGC discharge.

Laboratory temperature preference data (T_4, 24.6 C) reveal that the majority of ambient water temperatures are slightly cooler than would be selected by the blacknose dace. Thus, this species would probably move to warmer stream waters, excluding summer water above 24.6 C found immediately below Station 9. Laboratory avoidance data (Cincotta and Stauffer, in review) support this expectation, since this species avoids 27 C when acclimated to 24 C (i.e., equal approximately to T_4). The highest upper avoidance temperature (T_5, 34 C) suggests further that the blacknose dace should not be extirpated from the thermally affected region as long as cooler waters can be eventually reached. These behavioral data also suggest that this species will prefer the artificially elevated stream temperatures created by the PHGC discharge in winter, however cold shock information (T_6, Table 3) and predicted USEPA values (Figure 2) indicate that this species should not be significantly affected by a thermal shutdown.

The highest known spawning temperature (T_7, 21.1 C), the maximum average spawning temperature (T_8, 18.4 C), and the short term maximum temperature for embryo survival (T_9, 21.1 C) were often exceeded by the MWAT in both the ambient stream region and downstream of the effluent. The fact that this species has a known healthy population within all areas of the West Branch Codorus, even though all spawning criteria were surpassed, supports the aforementioned hypothesis of population maintenance in smaller tributary streams. Thus, the blacknose dace appears to have sufficient spawning areas within the Codorus Creek during its May-June spawning period.

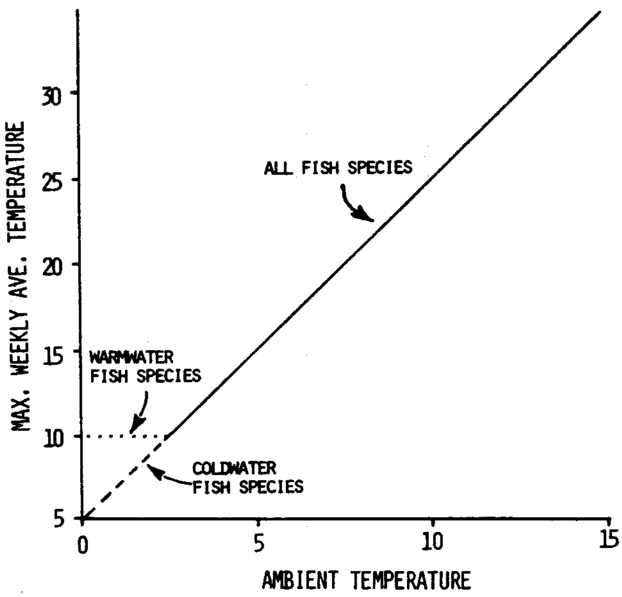

Figure 2. U.S. Environmental Protection Agency Nomograph Indicating the Maximum Weekly Average Temperatures of Plumes at Various Acclimation Temperatures (Brungs and Jones, 1977).

White Sucker *Catostomus commersoni*

Temperature criteria of the white sucker in relation to the MWAT found in Codorus Creek are depicted in Figure 9 and 10. The estimated UUILT for this species (T_2, 29.3 C) and the short term temprature for survival (T_{11}, 28.4 C) appear to be fairly accurate, since this species rarely has been taken in waters above these criteria temperatures. The highest known *in situ* observation (T_1) of 30.6 C was recently recorded by Stauffer, *et al.* (1976). Thus, these criteria (T_1, T_2, T_{11}), which are approximately equal to or below the highest MWAT of 30 C, should not adversely affect this widely distributed and abundant species (Cincotta, *et al.*, 1976; Denoncourt and Stambaugh, 1974) in the West Branch Codorus Creek. The maximum allowable temperature for growth (T_{10}, 28.0 C) was exceeded by MWAT in the *ca.* 2 km stream area below the discharge. Since these data are based on an application to larvae (Brungs and Jones, 1977), conclusions of juvenile and adult growth may be biased. However, distributional data (Cincotta, *et al.*, 1976; Denoncourt and Stambaugh, 1974) and personal observations during the study may support the premise that juvenile and adult segments of the West Branch Codorus white sucker population are successful above and below the PHGC.

Final field and laboratory temperature preference estimations (T_3, 14.1-21.1 and T_4, 27.1 C, respectively) vary considerably. Such discrepancies have been discussed (Richards, *et al.*, 1977), but the validity of either value may be argued on a case-to-case basis. Assuming merit for both estimations, it may be concluded that this species will select a variety of water temperatures. However, the fact that the final field preference is often surpassed at both control Stations 1 and 14 may lend credence to an underestimated field value. Thus,

TABLE 4. Maximum Weekly Average Temperatures (C) for 1976 by Month at all P. H. Glatfelter Company Monitoring Stations on Codorus Creek. Figure 1 and Table 1 indicate station localities (* = control station, ** = thermal discharge canal).

	Month											
Station	J	F	M	A	M	J	J	A	S	O	N	D
1*	3	9	10	19	17	23	20	21	16	14	11	5
2	2	6	8	16	14	18	16	15	14	14	11	5
3	3	9	10	20	17	23	23	24	18	15	13	5
4	3	8	10	19	17	22	18	18	16	15	12	6
5	3	11	12	20	19	23	21	21	18	16	13	8
6	3	11	14	23	20	27	23	23	19	16	15	9
7	4	11	13	23	20	26	23	24	20	17	15	10
8	3	11	12	22	20	25	24	23	20	17	14	8
9**	27	31	31	35	37	38	36	38	36	36	34	29
10	7	16	18	26	24	30	27	29	24	21	17	15
11	7	16	17	26	23	30	26	29	23	21	19	14
12	7	10	17	24	23	29	25	27	22	20	17	13
13	4	13	14	23	20	26	24	26	21	18	16	10
14*	1	8	10	19	18	25	24	24	19	15	13	5
15	2	10	11	20	19	25	24	24	20	16	14	7

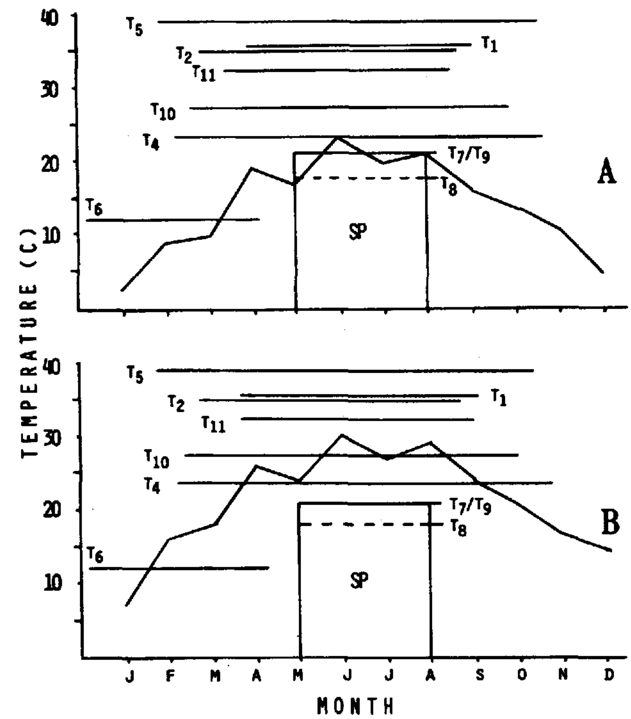

Figure 3. Critical Temperature Criteria (T_{1-2}, T_{4-11}; see Table 2) for the Golden Shiner Superimposed Over the Maximum Weekly Average Temperatures of Codorus Creek at Stations 1 (A) and 10 (B). Spawning period is noted (SP).

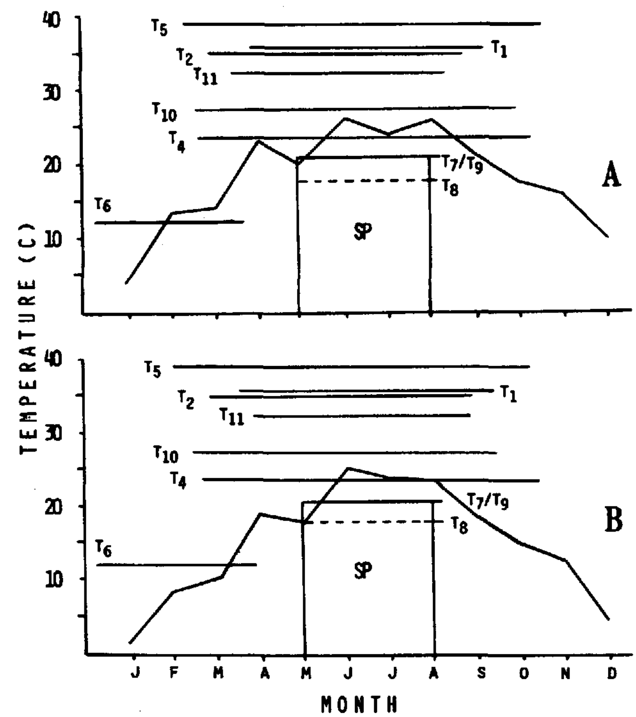

Figure 4. Critical Temperature Criteria (T_{1-2}, T_{4-11}; see Table 2) for the Golden Shiner Superimposed Over the Maximum Weekly Average Temperatures of Codorus Creek at Stations 13 (A) and 14 (B). Spawning period is noted (SP).

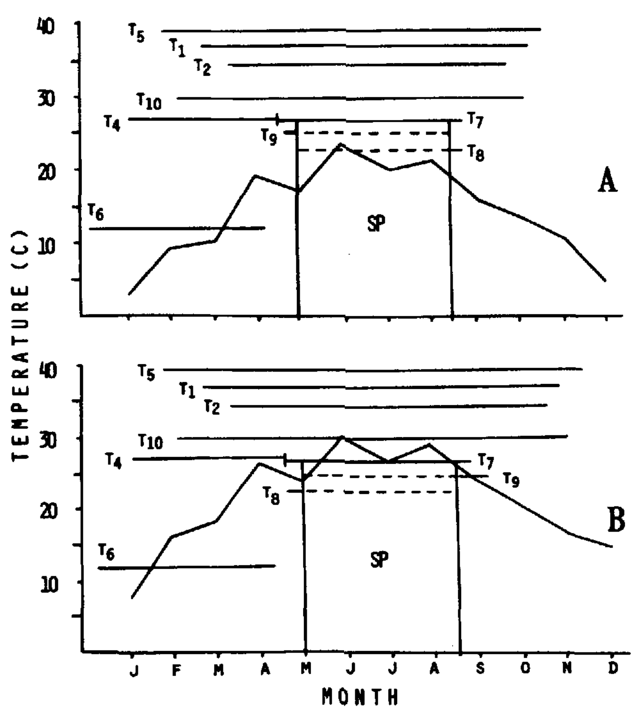

Figure 5. Critical Temperature Criteria (T_{1-2}, T_{4-10}; see Table 2) for the Satinfin Shiner Superimposed Over the Maximum Weekly Average Temperatures of Codorus Creek at Stations 1 (A) and 10 (B). Spawning period is noted (SP).

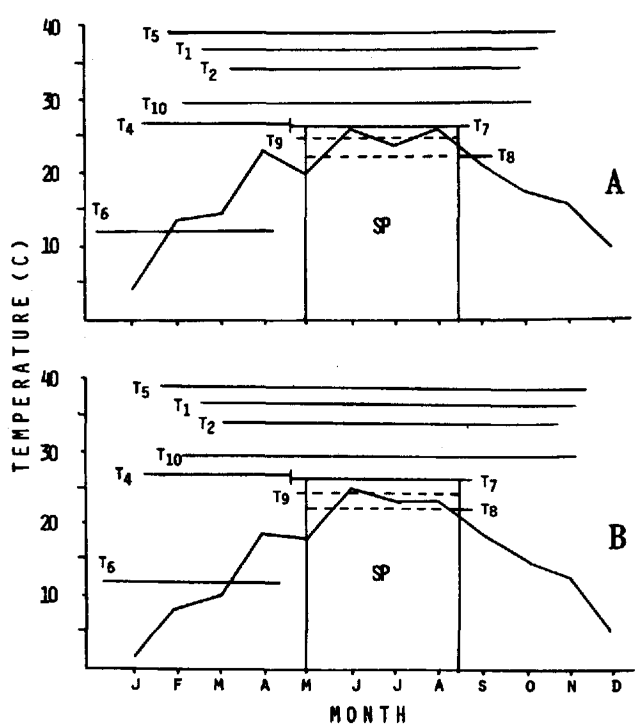

Figure 6. Critical Temperature Criteria (T_{1-2}, T_{4-10}; see Table 2) for the Satinfin Shiner Superimposed Over the Maximum Weekly Average Temperatures of Codorus Creek at Stations 13 (A) and 10 (B). Spawning period is noted (SP).

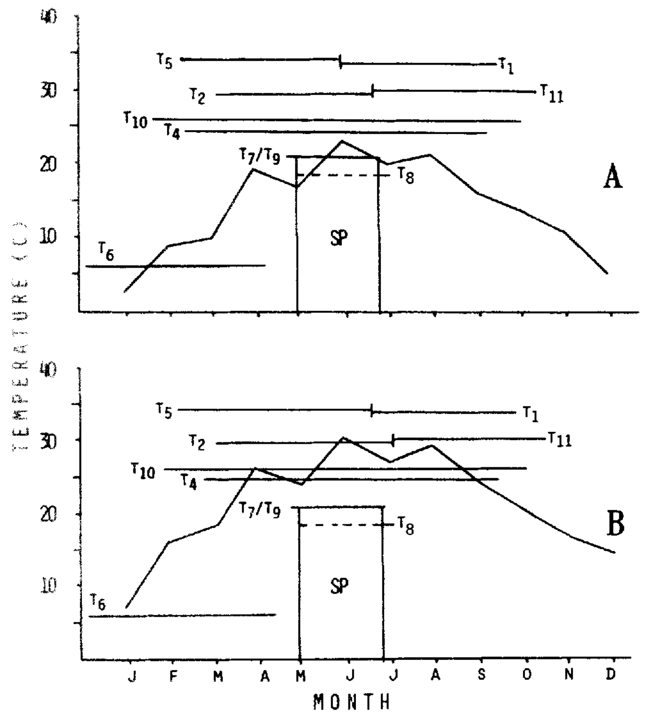

Figure 7. Critical Temperature Criteria (T_{1-2}, T_{4-11}; see Table 2 for the Blacknose Dace Superimposed Over the Maximum Weekly Average Temperatures of Codorus Creek at Stations 1 (A) and 10 (B). Spawning period is noted (SP).

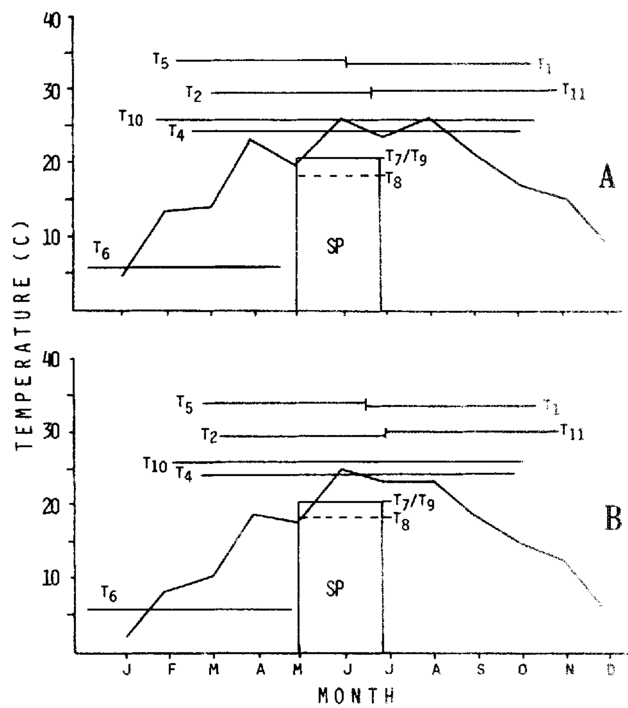

Figure 8. Critical Temperature Criteria (T_{1-2}, T_{4-11}; see Table 2) for the Blacknose Dace Superimposed Over the Maximum Weekly Average Temperatures of Codorus Creek at Stations 13 (A) and 14 (B). Spawning period is noted (SP).

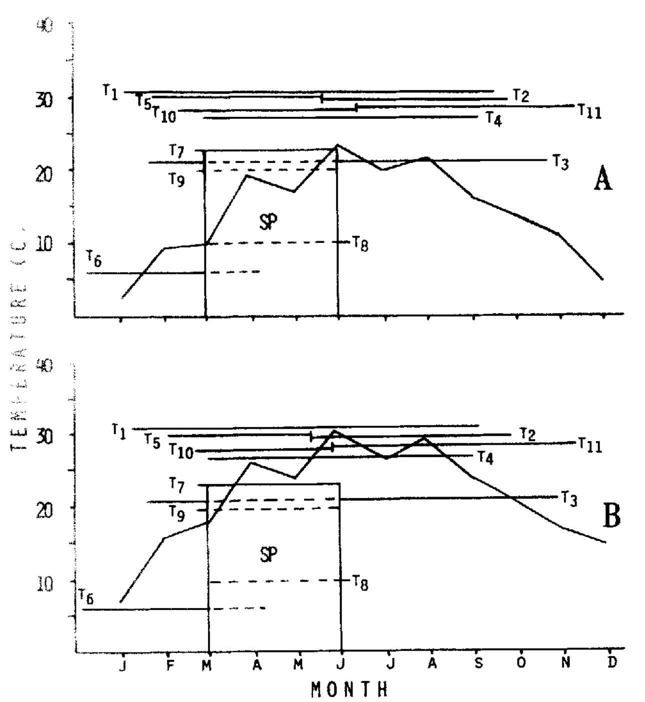

Figure 9. Critical Temperature Criteria (T_{1-11}; see Table 2) for the White Sucker Superimposed Over the Maximum Weekly Average Temperatures of Codorus Creek at Stations 1 (A) and 10 (B). Spawning period is noted (SP).

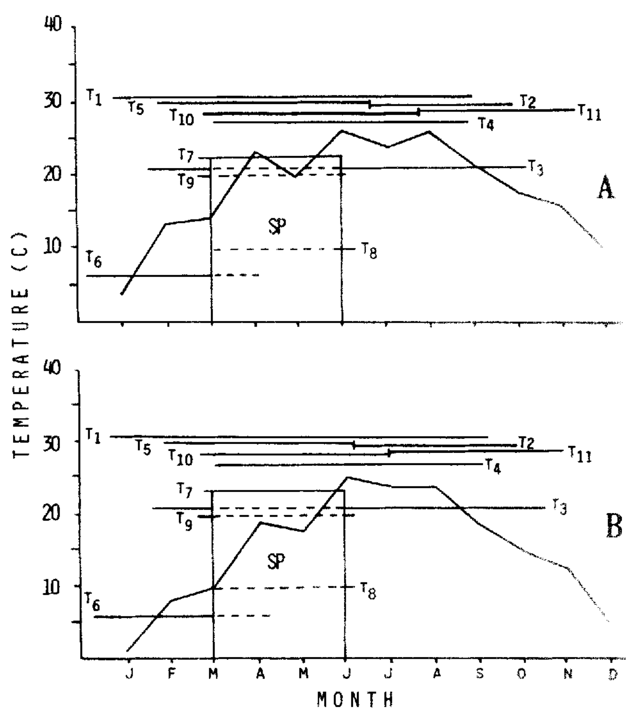

Figure 10. Critical Temperature Criteria (T_{1-11}; see Table 2) for the White Sucker Superimposed Over the Maximum Weekly Average Temperatures of Codorus Creek at Stations 13 (A) and 14 (B). Spawning period is noted (SP).

this species would probably not be found between Stations 9-13 in the warmer months. The upper avoidance temperature (T_5) of 30 C for this species supports this summer distribution prediction. A winter movement into heated stream areas would also be expected from preference data results. This information places the white sucker in an area susceptible to rapid temperature decreases, however, with the aid of data by Hart (1947, Table 3) and the USEPA nomograph (Figure 2), it can be predicted that no appreciable cold shock mortalities should occur.

The white sucker generally spawns in early spring (March-June) in cool shallow areas of small streams (Dickson, *et al*, 1976; Scott and Crossman, 1975). The extremely variable spawning temperature range (T_7, 6.1-23.2 C) allows this species to spawn in most areas of the stream (Figures 9-10, Table 4). Areas for short term embryo survival (T_9, 20.0 C) should also be satisfactory due to the adequate water temperatures (i.e., less than 20.0 C) found in the West Branch Codorus Creek and its smaller thermally unaffected tributaries (Table 4). The theoretical maximum spawning temperature (T_8, 10.0 C) must be severely underestimated, since any conclusions drawn from these data would suggest little or no spawning water available anywhere in the West Branch Codorus (Figures 9 and 10), since ambient stream conditions exceed the requirement in all months, except in March when the maximum of 10.0 C is equaled. The authors, Cincotta, *et al.* (1976), and Denoncourt and Stambaugh (1974) observed a healthy white sucker population (i.e., good numbers and condition) in the study reach, including in the thermal discharge region.

Pumpkinseed *Lepomis gibbosus*

Critical temperature requirements for the pumpkinseed in relation to the MWAT found in Codorus Creek are indicated on Figures 11 and 12; data on the short term maximum temperature for juvenile and adult summer survival (T_{11}) are not available. This species is extremely tolerant of heat as demonstrated by the highest known *in situ* observation of 38.0 C (T_1) and the highest known upper lethal temperature of 38.9 C (T_2), neither of which are surpassed by the MWAT. Therefore, the juvenile and adult sunfish should be able to exist throughout this stream. Furthermore, the highest permissible growth temperature (T_{10}, 33.0 C) for juvenile and adult fishes is 3.0 C above the known optimum temperature for growth (Pessah and Powles, 1974) and the maximum stream temperature which are both equal to 30 C. Thus, the overall growth could be realized in the *ca.* 2 km heated area below the discharge canal, especially in June and August.

The final field temperature preference (T_3, 31.1 C) does not exceed the MWAT. These data suggest that the pumpkinseed would most likely occur in the vicinity of the PHGC thermal effluent in the summer and winter months. Although no adverse effects should be encountered in summer, the possibility of cold shock deaths exist due to the MWAT, which often exceeds the cold shock criteria (T_6) in late winter. However, data (Table 3) for this species predict no significant shock mortalities. The lack of excessively high stream temperatures coupled with the high heat tolerance of this species indicates that this species will not be affected by MWAT (i.e., highest summer stream temperatures was 9.0 below T_5, 39.0 C). Though, it may be worth noting that the indiscernible avoidance data for the young-of-year specimens acclimated to 6 and 12 C may suggest that juveniles of this deme is susceptible to heat shock.

The known spawning temperature range (T_7, 20-36.1 C) and the highest short term temperature for embryo survival (T_9, 36.1 C) are not surpassed by the MWAT, but the theoretical maximum spawning temperature (T_8, 28.5 C) is surpassed in June at Stations 10-13 and 6-7. This information suggests that June water temperatures hinder spawning in the *ca.* 2 km reach below the discharge. However, the 36.1 C observation of the pumpkinseed spawning (Denoncourt and Hocutt, unpublished data) suggests an underestimated maximum spawning temperature (T_8, 28.5 C) and an overestimated short term maximum temperature for embryo survival (T_9, 36.1 C). Although no information are available for the pumpkinseed, the known range for successful incubation and hatching for the closely related bluegill sunfish (*Lepomis macrochirus*) is 22-34 C (Banner and VanArman, 1972). Therefore, a more realistic prediction for the pumpkinseed relative to both criteria would be within the range of 30-34 C. Assuming this range is more accurate, this species will not be adversely affected anywhere in the West Branch Codorus Creek during its May-August spawning season.

Largemouth Bass *Micropterous salmoides*

The thermal criteria for the largemouth bass relative to the MWAT found in Codorus Creek are presented in Figures 13 and 14. Highest known *in situ* temperature (T_1) and lethal temperature (T_2) of 38.0 C for juveniles and adults of this species are not exceeded by ambient or heated temperatures. Other important criteria, the maximum acceptable temperatures for growth (T_{10}, 32.0 C) and short term survival (T_{11}, 34.0 C), were within a margin of safety for juveniles and adults. Hence, the distribution, growth, and survival of juveniles and adults should not be adversely affected by the present stream conditions in any part of the study area.

The final field temperature preference range of 26.5-30.9 C (T_3) and final laboratory value of 32.2 C (T_4) were much higher than summer ambient temperatures, and were slightly higher (0.9 and 2.2 C, respectively) than the highest MWAT. Thus, this species should be attracted to the artificially heated regions of the stream in summer. These data also predict that the largemouth bass will be attracted to heated winter waters. However, cold shock data (T_6, Table 3 and Figure 2) project no appreciable temperature related mortalities. Furthermore, the temperature avoidance capabilities of this species (T_5, 39.0 C) are well beyond the highest existing temperature of this stream (i.e., highest MWAT = 30.0 C).

The northern subspecies of *M. salmoides* spawns between April-July in a relatively narrow water temperature range (T_7, 15.6-21.2 C). The upper level of this range (21.1 C), which is approximately equal to the estimated weekly average spawning temperature (T_8, 21.0 C), is exceeded by ambient and MWAT water temperatures at both control and temperature affected

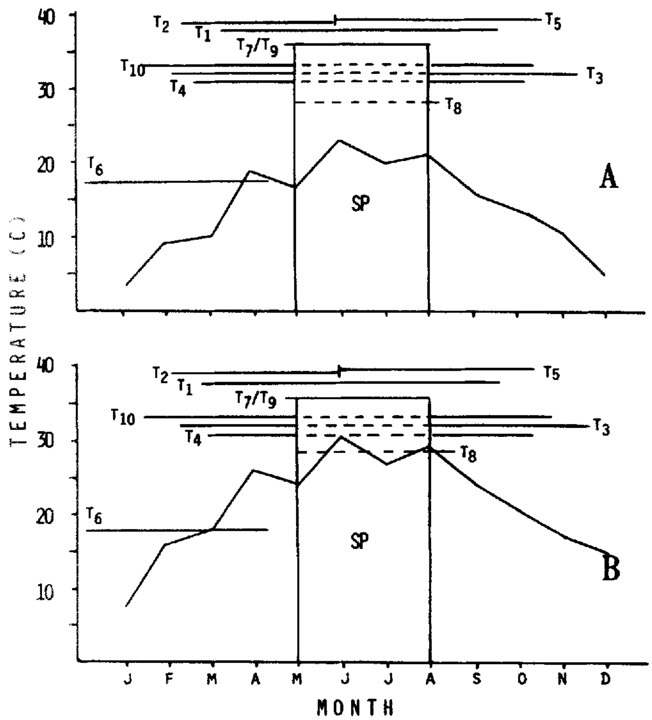

Figure 11. Critical Temperature Criteria (T_{1-10}; see Table 2) for the Pumpkinseed Sunfish Superimposed Over the Maximum Weekly Average Temperatures of Codorus Creek at Stations 1 (A) and 10 (B). Spawning period is noted (SP).

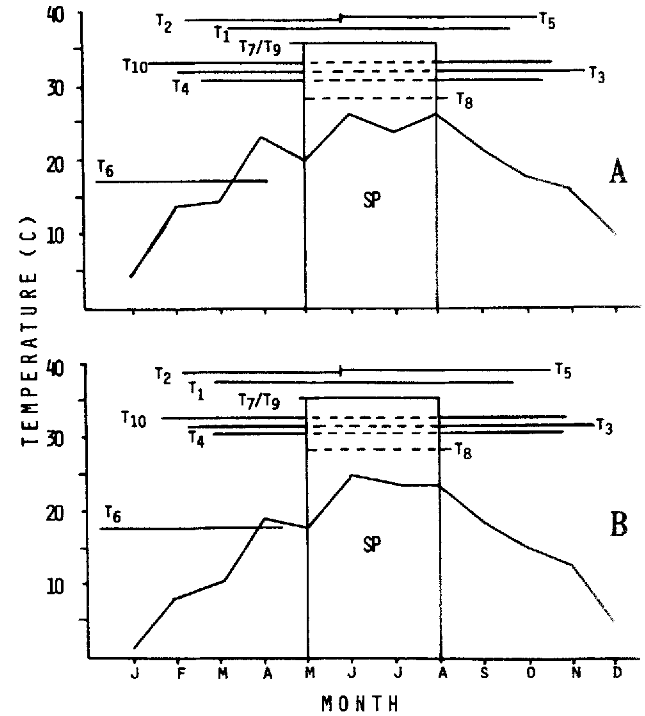

Figure 12. Critical Temperature Criteria (T_{1-10}; see Table 2) for the Pumpkinseed Sunfish Superimposed Over the Maximum Weekly Average Temperatures of Codorus Creek at Stations 13 (A) and 14 (B). Spawning period is noted (SP).

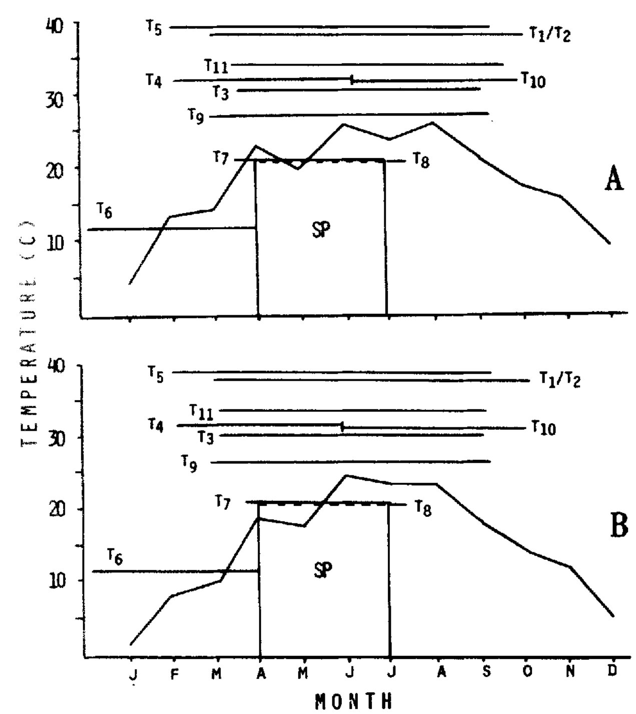

Figure 13. Critical Temperature Criteria (T_{1-11}; see Table 2) for the Largemouth Bass Superimposed Over the Maximum Weekly Average Temperatures of Codorus Creek at Stations 1 (A) and 10 (B). Spawning period is noted (SP).

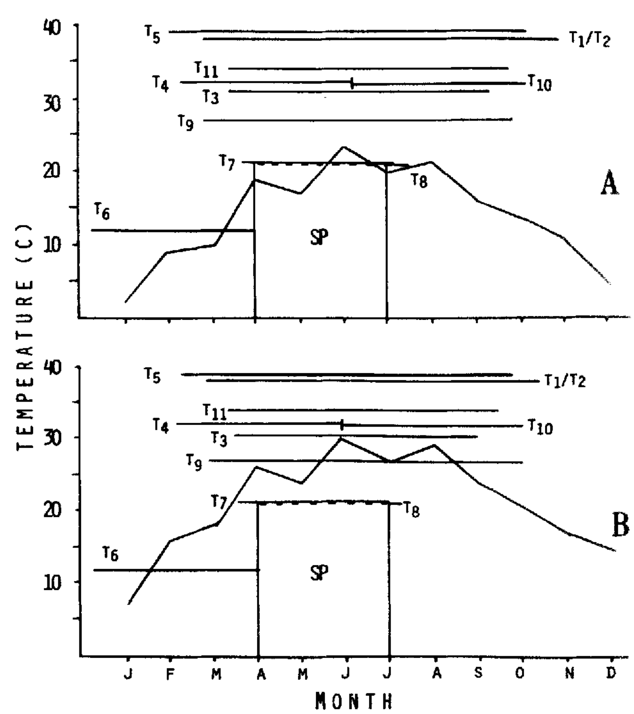

Figure 14. Critical Temperature Criteria (T_{1-11}; see Table 2) for the Largemouth Bass Superimposed Over the Maximum Weekly Average Temperature of Codorus Creek at Stations 13 (A) and 14 (B). Spawning period is noted (SP).

stations (Figures 13 and 14). Thus, due to the erratic occurrence of ideal spawning temperatures, it appears that the water temperature of Codorus Creek is not conducive to the propagation of largemouth bass. Information concerning the limited distribution and numbers of this species within the drainage support this conclusion (Cincotta, *et al*, 1976; Denoncourt and Stambaugh, 1974). Denoncourt (pers. comm.) hypothesizes that the presence of this nonnative species in the vicinity of PHGC is the result of spawning in Mill Pond (Figure 1). He bases this contention on the fact that juveniles dominate the largemouth bass catch in regular collecting surveys of the West Branch Codorus. Criteria regarding embryo survival (T_9, 17.0 C) are surpassed only in the *ca.* 2 km region below the heated effluent during June and August. Hence, embryo survival should not be the limiting factor of the bass population of Codorus Creek.

GENERAL IMPACT ASSESSMENT DISCUSSION

Significance of Behavioral Data

It must be recognized that the temperature effects on aquatic fauna are of a site specific nature, and may vary considerably due to the composition of fauna, unique physical and chemical characteristics of each respective environment, variable climatic regimes, etc. For these reasons, several authors have suggested the adoption of additional information, particularly preference and avoidance data, to facilitate the impact assessments of artificially heated aquatic environments (Coutant, 1975; Dickson, *et al*, 1976; Richards, *et al*, 1977; Stauffer, *et al*, 1975).

Impact assessment decisions may be expedited with preference and avoidance data on RIS in several instances. Stauffer, *et al* (1975), discuss the necessity of preference and avoidance data consideration on a site specific basis, especially in lotic systems where the total heated discharge is small compared to the mean annual flow. They indicate that this approach would be of particular importance in a warm water fishery if it could be demonstrated that: (1) RIS prefer water warmer than ambient conditions or will avoid warmer water during periods when effluent temperatures exceed their UUILT, maximum temperature for optimum growth, reproduction, or short term survival; (2) the avoidance of heated areas by RIS does not significantly decrease the areas needed for reproduction, growth, and maintenance of a viable population; and (3) refuge areas are available for RIS. Another circumstance when behavior information aids an assessment occurs in the northern latitudes where surveys are usually hindered and many times impossible in mid-winter; thus, the knowledge of behavior should help forecast distribution and potential detrimental conditions for species. Temperature information relative to certain variables such as gas supersaturation (Meldrim, unpublished data, *In:* Gift, 1977), feeding (Javid and Anderson, 1967), disease (Reynolds, *et al*, 1976), etc., may elicit fish behavioral responses unexplainable by suggested USEPA criteria alone. An indirect benefit for preference data has been recognized by the USEPA (Brungs and Jones, 1977; USEPA, 1977). Final temperature preferenda are considered to be correlated with growth optima, thus potentially eliminating the generation of the more expensive and time consuming growth data. Behavioral information of fishes may also be utilized by industry during preconstruction assessments of thermal discharges. Gift (1977) discusses several construction designs developed with the partial aid of preference and avoidance data to minimize detrimental impacts on biota.

Thermal addition standards for our nation's waterways should be justifiable and appropriate (Stauffer, 1975; Stauffer, *et al*, 1980). Recognition of the suggestions by Stauffer (1975) may prove to be a sound management philosophy (see previous paragraph). This study indicated the highest summer water temperature of the West Branch Codorus to be 30 C which was still below the final preferenda (i.e., considered by many researchers to be correlated to several physiological optima) of the largemouth bass and pumpkinseed. This temperature, achieved in only one area (Station 10) during the month of June, was a temperature extreme and not an average (see earlier explanation of establishing the MWAT). These data lend credence to the conclusion that all RIS are maintaining viable population numbers (i.e., areas for reproduction and growth are available) in all life history stages, despite the effect of the thermal discharge. Additionally, plenty of refuge areas appear accessible to RIS.

Applicability of USEPA Criteria

Fish usually select the warmest water temperatures available in winter. This response increases their susceptibility to cold shock mortalities. Preference data support this premise; thus, all RIS are potential candidates for this detrimental winter phenomenon. However, it was concluded from past research (Table 3) and the USEPA nomograph (Figure 2) that cold shock deaths would not be appreciable. The data from Table 3 supported this conclusion based on the differential from the maximum water temperature of Station 10 and ambient temperature from Station 1 (i.e., maximum control differential). The largest difference of 10.0 C recorded in December (Table 4) should be considered a conservative shock differential because the 8.0 C water temperature of Station 8 would in reality be the replacing water source (i.e., causing only a 7.0 C temperature change). Data of Cincotta, *et al* (in review) were considered the most accurate when applicable (i.e., depending on acclimation test temperature), since their test specimens were taken from the vicinity of the study area. Their data, however, were only useful for predictions relative to the highest temperature extremes (i.e., their acclimation test temperatures were 24 C or above). In the absence of on-site data, literature sources were utilized. When RIS data were nonexistent or not applicable then the USEPA nomograph was utilized (Figure 3).

Brungs and Jones (1977) indicate that the cold shock nomograph represents a summary of lower incipient lethal temperatures for 20 fresh water fishes (Figure 3). They discuss the logic of a 2.5 C regression line displacement to more accurately predict the shock experience of "cold water or sensitive species" and "warm water species" (none of these terms are defined). This displacement reveals that at no time is it permissible to have greater than 10.0 and 5.0 C differential between ambient and plume temperatures for the former and latter species groups, respectively (Figure 3). Furthermore, the graph has a built-in 2.0 C safety factor, to ensure total survival of shocked RIS. Thus, conservative estimations would be expected for many RIS if no on-site data or past literature are accessible for an application.

Dickson, *et al.* (1976), noted two requirements necessary to effectively apply the USEPA draft water temperature criteria (Brungs, 1974) on New River fishes near Glen Lyn, Virginia: (1) there must be a reasonable basis for the selection of RIS and (2) information on the responses of those species must be available. Little or no difficulty was met in fulfilling the former requirement at Glen Lyn, since much research had been conducted at the site; however, data needed for several USEPA suggested draft water temperature criteria (i.e., Table 9, T_2, $T_{6\text{-}11}$; Brungs, 1974; USEPA, 1974) were lacking to fulfill the latter requirement, especially for nongame fishes.

On the West Branch Codorus Creek, the first requirement of selecting the RIS of fish was accomplished by reviewing the efforts of Cincotta, *et al.* (1976), Denoncourt and Stambaugh (1974), and regular surveys of R. F. Denoncourt (pers. comm., unpublished data collected for PHGC impact evaluations). The second requirement of compiling temperature information was initially problematic, especially for nongame species. However, during the course of the study the USEPA finalized the water temperature criteria (Brungs and Jones, 1977). This document suggested the utilization of related data for the same fish species and/or by "extrapolating" the same or related data from species with similar requirements, when data were not available (i.e., Table 2, footnotes 5-7). Moreover, these other species need not be a close relative to the respective RIS.

The USEPA's procedural recommendations for RIS in regard to unavailable data presents a serious implication that could adversely affect aquatic environments. If permitting the use of alternate (i.e., from other species) behavioral and/or physiological criteria as a replacement for species specific physiological information is legitimate (as suggested by Brungs and Jones, 1977) then this document sets precedent for critical temperature data (i.e., criteria) substitution in impact evaluations.

The use of substituted information (Brungs and Jones, 1977) implies for all practical purposes that RIS are "biological thermal equivalents." Premised on thoughts of Darwin (1859), Stauffer and Hocutt (1980) state "Taxa which are more closely related to one another, occupy more similar niches than those not closely related taxonomically." Although Brungs and Jones (1977) emphasize that extenuating circumstances (e.g., temperature sensitive endangered species or yellow perch's specialized winter chill needed for gamete maturation) must be thoroughly considered in the overall evaluation, it is highly unlikely that most associated species will be totally unaffected. The measure of this effect presents a particular problem, since it may take some time to be realized. This contention is based on the niche concept, that is, species occupy unique positions in their respective multidimensional environment (Hutchinson, 1957; Schoener, 1974). An alteration of temperature, one of the most influential critical environmental factors (Fry, 1947), will surely upset the existing ecosystem equilibrium of many aquatic, and to a lesser degree, terrestrial biota. Thus, it may be said a "thermal equivalent" philosophy may have restricted merit if carefully exercised with taxonomically related species, but if utilized othersise may lead to an overestimation that would be unnecessarily protective to fauna, and would deprive an applicant of a variance justifiably allowed by law. Conversely, underestimation may lead to harm ranging from slight to irrepairable. Brungs and Jones (1977) indicated that the choice of RIS for a demonstration (i.e., usually Type II) is a "socioeconomic decision." The resulting decision, however, may not be biologically justifiable or appropriate.

Generally, in the absence of preference, avoidance and onsite field data, the use of only USEPA parameters (Brungs and jones, 1977; USEPA, 1977) in this application (Table 2, T_2, T_6-T_{11}) would be of limited value. Regardless of the utilization of the questionable "thermal equivalents," predictions concerning spawning, early development, growth, and survival of juvenile and adults could be projected, but only if adequate data were previously known. Moreover, the reliability of these data may be challenged by the fact that a limited amount (if any) of data would have been generated on RIS found at the application site. However, as demonstrated in this report, with the added perspective of preference, avoidance, and onsite field information, an accurate impact evaluation on biological integrity may then be more feasible (Dickson, *et al.*, 1976). This is particularly so, since these data predict and confirm the reactions of the RIS to altered temperature regimes.

From the data presented, it can be said with reasonable assurance that the PHGC discharge is not currently adversely affecting the RIS of fishes from the West Branch Codorus Creek. This conclusion, which is a realistic assessment, is only possible by combining the present USEPA water temperature criteria (Brungs and Jones, 1977) with on-site behavior (i.e., most fishes collected from study area) and field data. Utilization of only USEPA criteria would have resulted in a vague, questionable assessment. In either case, a regular monitoring schedule is needed to ensure that no unforeseen or knowledgeable (i.e., variance granted) alterations to the environment act detrimentally toward the biota of this ecosystem.

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